PROCEEDINGS OF THE SECOND INTERNATIONAL SYMPOSIUM ON THE MANAGEMENT OF LARGE RIVERS FOR FISHERIES

Sustaining Livelihoods and Biodiversity in the New Millennium

11th - 14th February 2003 in Phnom Penh, Kingdom of Cambodia

Edited by Robin L. Welcomme and T. Petr

Volume I

RAP Publication 2004/16

PROCEEDINGS OF THE SECOND INTERNATIONAL SYMPOSIUM ON THE MANAGEMENT OF LARGE RIVERS FOR FISHERIES

VOLUME I

Sustaining Livelihoods and Biodiversity in the New Millennium

11–14 February 2003, Phnom Penh, Kingdom of Cambodia

Edited by Robin L. Welcomme and T. Petr

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
& THE MEKONG RIVER COMMISSION, 2004

Copies of FAO publications can be requested from:
Food and Agriculture Organization
of the United Nations
Regional Office for Asia and the Pacific
Bangkok
FAO-RAP@fao.org

Production by:
Red Plough International Co., Ltd.
Udon Thani, Thailand
clayton@loxinfo.co.th

Cover:
Dararuang Yutthakitjamnong
PenPrapa Graphic, Thailand
Tel: 06-6300366
E-mail: thaichaba@yahoo.com

Fishing Gear Illustrations from:
Fishing Gears of the Cambodian Mekong
Compiled by: Deap Loeung, Peter Degen and Nicolaas van Zalinge
Illustrations and Layout by: Arijan Jansonius

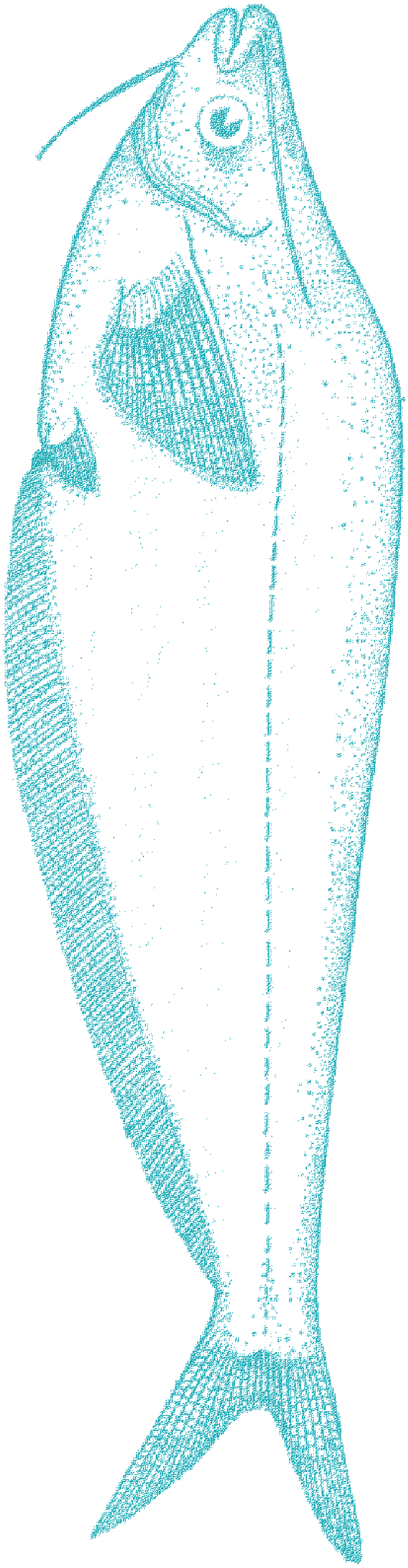
For bibliographic purposes, please reference this publication as in the examples below:

For Volume I

Cowx I.G., Almeida O., Bene C., Brummett R., Bush S., Darwall W., Pittock J. & van Brakel M. (2004). Value of river fisheries. In: *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume I.* Welcomme R. and T. Petr, Eds., FAO Regional Office for Asia and the Pacific, Bangkok, Thailand. RAP Publication 2004/16, pp. 1-20.

For Volume II

Abell R., Thieme M. & Brenner B.L. (2004). Ecoregion conservation for freshwater systems, with a focus on large rivers. In: *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume II.* Welcomme R. and T. Petr, Eds., FAO Regional Office for Asia and the Pacific, Bangkok, Thailand. RAP Publication 2004/17, pp. 1-14.



DISCLAIMER

The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Food and Agriculture Organization of the United Nations (FAO) and the Mekong River Commission (MRC) concerning the legal or constitutional status of any country, territory or sea area or concerning the delimitation of frontiers or boundaries.

NOTICE OF COPYRIGHT

Images courtesy of the Mekong River Commission Fisheries Programme

ORIGINS of the SYMPOSIUM

The Second International Symposium on the Management of Large Rivers for Fisheries was held on 11 – 14 February 2003 in Phnom Penh, Kingdom of Cambodia. It had three primary objectives:

- to provide a forum to review and synthesise the latest information on large rivers;
- to raise the political, public and scientific awareness of the importance of river systems, the living aquatic resources they support and the people that depend on them; and
- to contribute to better management, conservation and restoration of the living aquatic resources of large rivers.

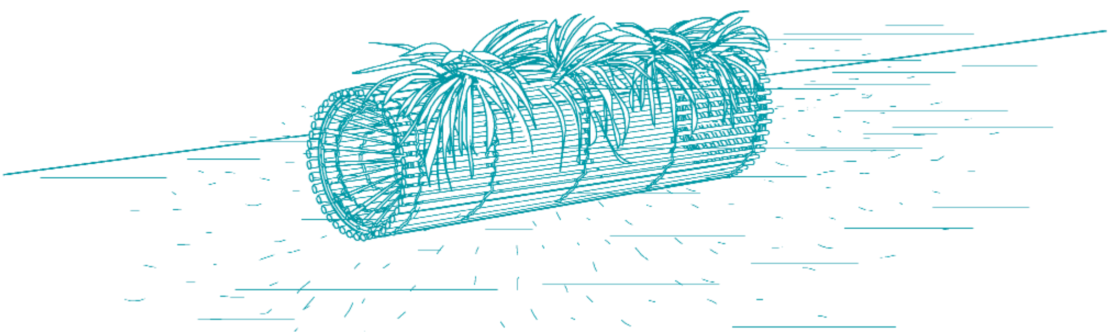
The Symposium was organised in six sessions:

Session 1 Status of rivers
Session 2 Value of river fisheries
Session 3 Fisheries ecology and conservation
Session 4 Management of river fisheries
Session 5 Statistics and information
Session 6 Synthesis

Over 220 river scientists and managers from around the world attended the Symposium. Contributed papers represented 96 rivers from 61 river basins from all continents and climatic zones.

Selected papers submitted to the Symposium appear in these proceedings, which consist of:
Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries: Volume 1
Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries: Volume 2

Papers appearing in these proceedings have been subject to the regular academic refereeing process. Additional selected papers will appear in the journal Fisheries Management and Ecology.



RECOMMENDATIONS for ACTION

1) Improve the valuation of living river resources in order to contribute to equitable and sustainable management of fishery resources and properly place the fishery in the context of the other uses of rivers.

2) Direct greater effort to better understanding the social and economic aspects of fisheries to support policy and management priorities; livelihood approaches will be a valuable tool.

3) Communicate and engage with environment and water resources managers within the context of multi-use of water in order to accurately assess impacts and to sustain the benefits of river fisheries in an equitable manner.

4) Develop processes that facilitate the users and beneficiaries of the fishery resource to assume greater control of its management.

5) Establish appropriate mechanisms at national and basin level to enable negotiation for the needs of communities dependent upon the living aquatic resources. In particular further regulations need to be elaborated to protect general ecosystem function and provide for environmental flows.

6) Use instruments such as the freshwater eco-regions approach, the Ramsar Convention and the guidelines for water allocation suggested by the World Commission on Dams, to enhance planning for conservation and sustainable use of river habitats.

7) Incorporate ecological flow requirements of river-floodplain systems into development plans and impact assessments that affect river flows, taking into account the seasonality of the system and the environmental cues needed by the fish for migration and reproduction.

8) Rehabilitate degraded ecosystems wherever possible. Prioritize schemes that ensure connectivity and protection of critical habitats.

SUMMARY CONCLUSIONS

IMPORTANCE OF RIVER FISHERIES AND BIODIVERSITY

Large rivers harbour a disproportionate share of the world's aquatic biodiversity, including over 50 percent of all freshwater fish species. Riverine biota are also among the most threatened components of biological diversity, with a much higher proportion of organisms classed as endangered or threatened than in most other ecosystems.

A significant proportion of the world's people use the living aquatic resources of rivers for food and recreation. Recent evidence indicates that the number of people dependent on these resources is far larger than previously thought. Studies further show fish to be particularly important in the livelihoods and diets of the poor, providing an inexpensive source of animal protein and essential nutrients not available from other sources.

VALUATION OF RIVER FISHERIES

Inland fisheries are generally undervalued in terms of their contribution to food security, income generation and ecosystem functioning. Conventional economic approaches aim to provide detailed quantification using a cost-benefit framework, which may not sufficiently value the role and function of rivers. Socio-economic approaches and livelihood analysis can help to highlight the complex contributions of fisheries to rural livelihoods. Better valuation of living river resources is necessary to ensure the equitable sharing of benefits and for proper placing of the fishery in the context of the many other uses of rivers. It is important to recognise that fishers themselves have largely been excluded from valuation exercises.

STATE OF KNOWLEDGE

The first systematic expression of how rivers function dates from the first LARS in 1986 and many of the concepts arising from that meeting have proved extremely robust. The flood-pulse concept, the integral nature of the river-floodplain system, relationships between flood strength and catch, and the fishing down process in complex fisheries all continue to apply in many areas and conditions around the World. The general understanding of how river fish communities function is now sufficiently refined to permit broad management decisions concerning the river environment for fish and fisheries.

Despite a sound general understanding, detailed knowledge of the biology and ecology of individual species and ecosystems remains poor. Further studies on individual species, communities and ecosystems are urgently needed. However, in view of the large number of species living in most rivers, management based on requirements for individual species is often impractical (except for flagship endangered species). General concepts of migration and food web structure are now emerging to allow for a better understanding of the impact of human interventions.

Research on flow-ecological relationships in large rivers is an urgent priority. However, sufficient knowledge exists to set interim conservation measures including environmental flow prescriptions, and the need for further research should not be used as an excuse to delay much needed action. Adaptive management will often be the most effective means of improving outcomes and knowledge.

Conventional methods for studying large rivers are generally inadequate and new approaches are being developed to gain understanding of the processes underlying fish ecology and fisheries. In particular, local knowledge held by traditional fishing communities has provided a wealth of information.

The effort put into the study and collection of data from rivers depends on national perceptions as to the value of rivers and their fisheries. Given the high cost of collecting data, programmes should concentrate on variables that are carefully selected to support desired research and management objectives.

SOCIAL, ECONOMIC AND INSTITUTIONAL ASPECTS

Study of the social, economic and institutional aspects of fisheries is a relatively recent development. However, the current global emphasis on rural poverty and sustainable livelihoods, together with deeper understanding of fisheries, has shown that knowledge of the human dimension of fisheries is essential for proper management. Understanding of the social organization of the fishery and the relationships between fisheries and other livelihood strategies is poor in most cases. However, the recent establishment of co-management arrangements for fisheries in some river basins and the involvement of users and other stakeholders in decision-making are forming the basis for better recognition of the relationship between people's livelihoods and their aquatic resources.

MANAGEMENT OF RIVER FISHERIES

A number of issues have emerged as particular concerns at this stage in our attempts to manage river fish, fisheries and their environment. A tension continues to exist between use and conservation. It is impossible to catch fish without influencing the composition of the fish community. However, the goal of fishery management should be to maintain or establish conditions consistent with the continued survival of all species.

It has become increasingly clear that most river fisheries are not managed effectively. This is largely due to the old pattern of centralized Government agencies applying a one-size-fits-all approach. This pattern has failed worldwide, largely due to inflexibility, insufficient funding for agencies, and lack of stakeholder collaboration. In some cases this failure has led to a laissez faire approach to policy and enforcement. Sometimes state-owned river resources are in practice treated as open access systems and are vulnerable to overexploitation. Where systems of limiting access are being contemplated they have to take into consideration the needs of community members who might be excluded.

Management alternatives are being developed that attempt to bridge the gap between centralized government and traditional, locally enduring participatory management systems. Such strategies are being tried in most climatic zones and continents and are compatible with a livelihoods focused approach that considers other stakeholder activities. Participatory approaches depend strongly on cultural, social and political environments. After more than a decade of innovative schemes and experiments, there are many international examples of how to enable users and other beneficiaries of resources to assume more significant control. It would be appropriate to make greater use of these experiences in policy formulation.

Major conflicts between the various users of river systems can only be resolved if there are appropriate mechanisms at national and basin levels to enable negotiation for the needs of the living aquatic resources. River basin organizations are an essential instrument for managing such conflicts, especially for rivers flowing through more than one nation or province.

Appropriate legislation must be formulated to encourage more equitable treatment of living aquatic resources and the fisheries that depend on them. In some areas water quality, quantity and mechanisms for fish passage around obstacles are already the subject of legislation. But further regulations are needed to protect general ecosystem diversity and provide for environmental flows. In addition, the involvement of user groups in management decision-making should be legally supported and/or mandated.

GENERAL DEGRADATION OF THE RESOURCE

Most river basins support intensive fisheries and yields in some basins are still increasing. River fisheries continue to provide large catches, even in the face of intensive exploitation, although changes in species composition and size are occurring and some large and late-in-life maturing species have become rare as a result of fishing pressure. In contrast to marine and lake fisheries, there are no proven cases of a river fishery as a whole having collapsed from fishing pressure alone. Where collapses have occurred, they have always been linked to degradation in environmental quality.

Indicators on all continents show that there is a general decline in the physical, chemical and ecological quality of rivers from source to mouth. This decline is typically associated with rising population pressures. The form and function of rivers have changed in response to dams and channelization, and changing land use practices and marginal agriculture have resulted in deforestation leading to increased siltation.

The increasing demand for water is altering the timing and magnitude of flow regimes in many rivers. There is a need for improved understanding of the ecological flow requirements of river-floodplain systems, taking into account the seasonality of the system and the environmental cues needed by fishes for migration and reproduction. This will allow definition of the timing and amount of water that should be reserved for fish in the context of other developments in the river basin.

Strategic assessments, such as the ecosystems-based approaches, freshwater eco-regions approach, and the guidelines for water allocation suggested by the World Commission on Dams provide some possible mechanisms for the conservation of river habitats. A number of conventions provide additional supporting frameworks including, in particular, the Ramsar Convention and the Convention on Biological Diversity. Frameworks for making decisions on water management should include assessment of options and environmental and social impacts, and involve full public participation.

MITIGATION, REHABILITATION AND ENHANCEMENT

There is an urgent need to rehabilitate degraded ecosystems. Technical options do exist for amelioration and mitigation of adverse impacts. Several examples of successful rehabilitation are already emerging, but they are often expensive and time consuming. The eventual cost of rehabilitating a resource is likely to far exceed the benefit derived from its destruction and it is clear that conservation is better than rehabilitation.

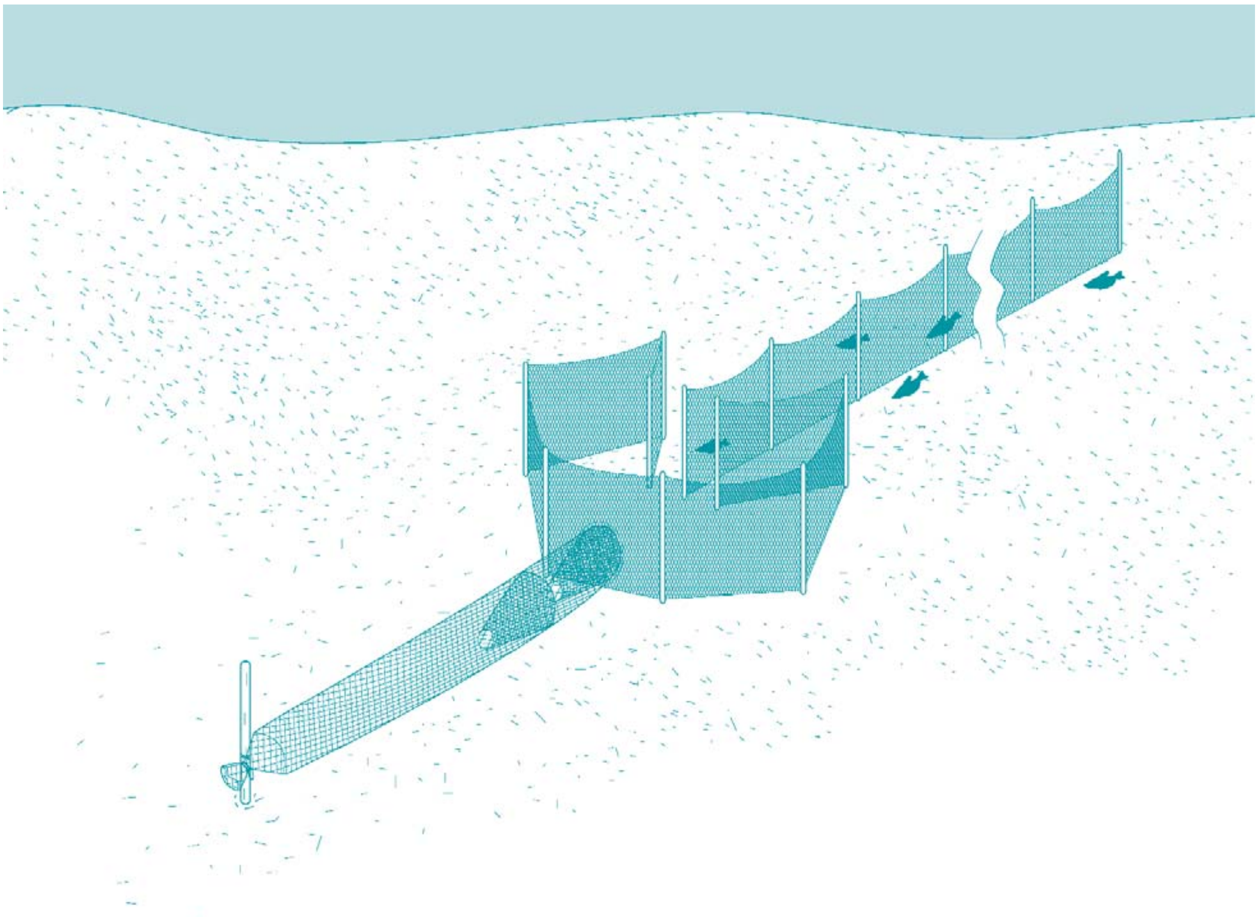
There have been attempts on all continents to mitigate problems caused by dams, levees and polders which bar fish migrations. The success of these mitigating structures is extremely variable since they cannot cope with the numbers of fish migrating or be used by all fish species, and they generally focus only on facilitating upstream movements, ignoring the downstream drifting of fry and juveniles. Research is needed to develop ways to allow less obstruction to fish movement that are significantly broader in their application.

Aquaculture is frequently seen as mitigation for declines in wild fisheries or as providing an alternate activity. Although stocking of juvenile fish and fish farming have shown promise in some areas, there is often a policy conflict where the benefits of enhancement do not accrue to those formerly dependent on wild fisheries, and their access to land, water and feed resources may be jeopardized by enhancements.

PROSPECTS

Maintenance of healthy rivers and restoration of degraded rivers and their fisheries will only be achieved if there is political will at all levels of society to do so. Those responsible for managing riverine resources need a collective approach that is sensitive to the needs of resource users and society at large. Adequate and accurate information on the value and the functioning of rivers, as well as on the impacts of other users on the resource, is required. The fisheries sector must not continue in isolation but must communicate clearly with the public and other users of inland water resources in order to arrive at equitable solutions for sustaining the fishery.

There are some encouraging developments. The international community is slowly becoming aware of the value of living inland aquatic resources as evidenced by the European Union Water Directive, the World Water Forum, the high priority awarded to it by the Convention on Biodiversity, the decommissioning of dams in North America and Europe, and the reestablishment of keystone species such as salmon through large scale rehabilitation of some damaged rivers. It is unfortunate that inland fisheries received such a low profile from the World Summit on Sustainable Development and this situation needs urgent redress.



CONTENTS VOLUME I

SESSION 2 REVIEW
VALUE OF RIVER FISHERIES

Ian G. Cowx[1] O. Almeida[2] C. Bene[3] R. Brummett[4] S. Bush[5] W. Darwall[6] J. Pittock[7] & M. van Brakel[8]

1 University of Hull International Fisheries Institute, Hull HU6 7RX, UK E-mail: i.g.cowx@hull.ac.uk

2 Instituto de Pesquisa Ambiental da Amazonia-IPAM, Av. Nazare 669, Centro 66035-170 Belem, PA, Brasil

3 CGIAR, The World Fish Centre, 1st Floor, 15 G Radwan Ibn El Tabib Street, Giza, 11511 Eygpt

4 The WorldFish Centre, BP 2008, Yaoundé, Cameroon

5 Australian Mekong Resource Centre (AMRC), Division of Geography, School of Geosciences, University of Sydney, NSW, Australia

6 IUCN – The World Conservation Union, 219c Huntingdon Road, Cambridge, CB3 ODL, UK

7 World Wildlife Fund, 1250 24th St. NW, Washington, DC, USA

8 Institute of Aquaculture, University of Stirling, Scotland, UK

INTRODUCTION

Fishing always has been, and for the foreseeable future will remain, a major source of food and income for society (Cowx 2002c). However, its importance relative to other food production systems has evolved, especially over the last half century, as a result of the way fisheries are exploited (FAO 1997). This is especially true of fishery activities in inland waters with different scenarios being enacted in the densely populated and highly industrialised countries of the northern temperate world and tropical developing countries (Arlinghaus, Mehner and Cowx 2002). These differences are largely the result of contrast-ing social and economic objectives for inland fisheries and the different ways they are managed (Table 1, after Welcomme 2001). Fisheries management in industrialised countries focuses almost exclusively on recreation and conservation, whereas the objective in developing countries remains largely on food security, although a shifting emphasis towards recreational fisheries (Cowx 2002c) and conservation (Collares-Pereira, Cowx and Coelho 2002) is occurring as a result of globalisation and the influence of international protocols such as the Convention for Biological Diversity.

In addition, multi-purpose use patterns in industrialised countries have created a very distinct climate for the development of inland fisheries (FAO 1997). Activities such as agriculture, damming, flood control, deforestation, navigation, wetland reclamation, urbanisation, hydropower generation, water abstraction and transfer and waste disposal (Cowx 2002a) have altered freshwater ecosystems profoundly, probably more than terrestrial ecosystems (Vitousek *et al*. 1997; Cowx 2000). As a result, the majority of freshwater ecosystems in industrialised countries are considered impacted (Dynesius and Nilsson 1994; Vitousek *et al.* 1997). Similar diversification of aquatic resource use is prevalent in developing countries (Nguyen Khoa, Lorenzen and Garaway 2003; Nguyen Khoa *et al.* 2003), but the impact is less dramatic and fishing for food has remained a sustainable activity, although fisheries are also under threat from development and shifts in fishery management activities to support production from culture based fisheries (Araujo-Lima *et al.* 2003; Pusey 2003) and aquaculture are occurring (van Brakel, Muir and Ross, 2003). In this context, capture and culture fisheries must be seen as complimentary and not alternatives (van Brakel *et al.* 2003), as this could potentially lead to reduced production from a particular water body. Conventional aquaculture is also not necessarily an

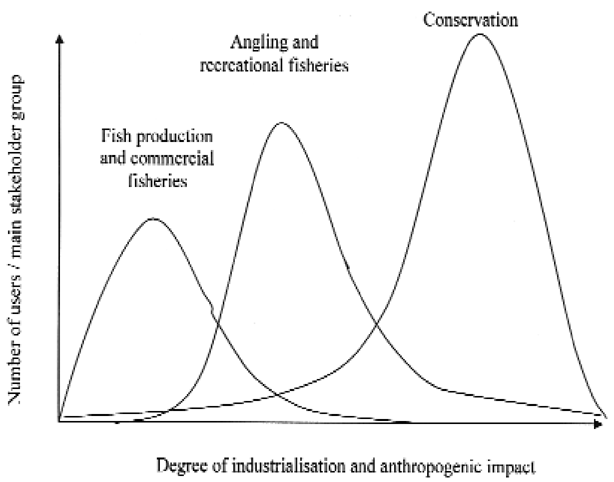
Table 1: Different strategies for management of inland waters for fisheries in developed and developing countries (from Welcomme 2000, 2001, slightly modified)

Industrial (temperate)	Emerging economies (tropical)
Objectives	
Conservation/Preservation	Provision of food
Recreation	Income
Mechanism	
Recreational fisheries	(Commercial) Food fisheries
Habitat rehabilitation	Habitat modification
Environmentally sound stocking	Enhancement, e.g. through intense stocking
Intensive aquaculture	Extensive, integrated, rural aquaculture
Economic	
Capital intensive	Labour intensive

This diversification of objectives arises because increasing exploitation of inland fishery resources, both in terms of effort and fishing efficiency, tends to reduce opportunities for production of fish as food and shifts resource use towards recreational needs (Smith 1986; Radonski 1995). Consequently, in most temperate countries recreational, leisure or “sport” fisheries are the dominant components of inland fisheries systems that evolved from a simple food production focus (FAO 1999; Welcomme 2001; Cowx 2002c). In developing countries food security and employment remain the primary focus (FAO 1997) despite major changes in aquatic resource use in these countries.

option for the rural poor and diversion of resources from capture fisheries could contribute to food insecurity. Aquaculture in these circumstances should be focussed on enhancement of natural production of resources accessible to the rural poor.

Basically, inland fisheries can be viewed as evolving organisms (Figure 1), with the major stages in the life cycle of an inland fishery comprising an initial phase on food production, then a growing interest in recreation, with aesthetic and nature conservation interests emerging last (Smith 1986). Although this process is a continuum, industrialised countries can be envisaged at one end of the spectrum and developing countries towards the other, depending of the scale of industrialisation that has taken place. This is, however, a simplification because the need for food security has triggered activities such as aquaculture and fish stock enhancement strategies (culture based fisheries), which replace or support fish production, especially in developing countries (see Petr 1998 for review). Thus, in most areas of the world the principal impacts on inland fisheries do not originate from the fishery itself but outside the fishery (e.g. FAO 1997; Garcia, Cochrane *et al.* 1999; Welcomme 2001). The need for concerted effort to prevent and reduce degradation, as well as conserving freshwater fish and fisheries as renewable common pool resources or entities in their own right, are the greatest challenges facing sustainable development of inland waters (FAO, 1999).



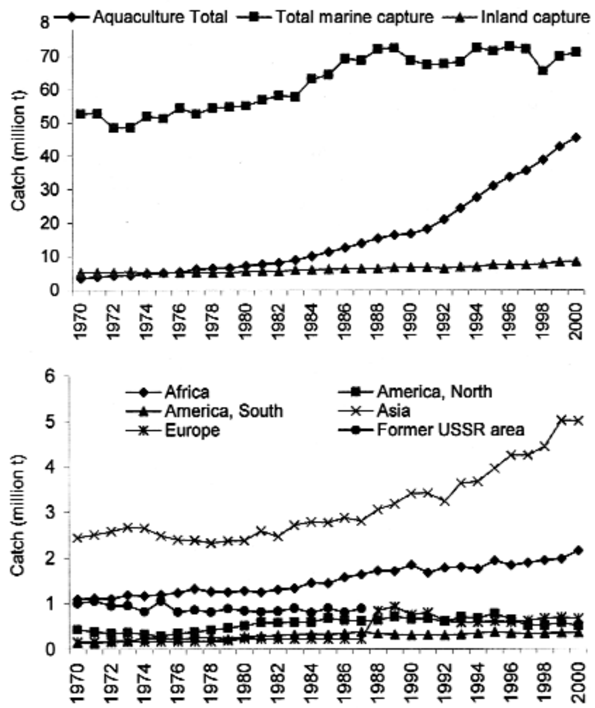
■ Figure 1. Generalised evolution of inland fisheries along an industrialisation gradient (modified from Smith 1986).

One of the underlying aspects relating to these changes that has received little attention is the value of the fisheries and aquatic resources, including the importance of ecosystem services and biodiversity. Fisheries are poorly or undervalued in multiple aquatic resource-user scenarios and this has undoubtedly contributed to the changes described (Cowx 2002c). However, it must be recognised that in some rural communities, fisheries are considered of little importance and thus of minimal value and it is important to understand why fisheries are valued differently between these locales (Bene and Neiland 2003). This paper examines the importance of accurately valuing the fisheries of large rivers (and in all ecosystems) and how such information can be used to maintain, improve and develop inland fisheries and ecosystem services, from both the exploitation and conservation perspectives, for future generations.

TRENDS IN INLAND FISHERIES

Although the net contribution of inland fisheries to total world fish production is small in comparison to marine capture fisheries and aquaculture (Figure 2a), it has sustained a growing trend of about 2 percent per annum, worldwide (FAO 2002). However, this growth belies the true picture elucidated from a regional review (Figure 2b). Net declines in catches are prevalent in Europe, much of which occurred post decentralisation of the eastern European economies and North America. The main increases have been in Asia and Africa, the latter being mainly due to increased yield from lakes, especially by Nile perch, *Lates niloticus* (L.), from Lake Victoria. Production figures in Asia have increased for a number of reasons, notably the proliferation of culture-based fisheries in China and Bangladesh, but also because more reliable catch statistics data from, for example, the Mekong countries, show the true extent of exploitation. Notwithstanding these trends the overall picture for natural river fisheries is unfavourable. Throughout the world, there is no doubt a river fishery makes valuable contributions to leisure activities and food security, but their performance is generally on the wane or shifting in character.

Throughout the literature and electronic statistical databases, commercial/artisanal/subsistence



■ **Figure 2. a)** Trends in production from aquaculture and marine and inland fisheries between 1970 and 2000 and b) catches from inland waters by continental region (European data for 1988 onwards include former USSR data) (Source: FAO 2002). Note, that underreporting of catch by countries and incomplete data on recreational fisheries suggest that catches in inland waters may be at least twice as high as shown in the figure (FAO 1999).

catches from the major river fisheries generally indicate declining trends, which have direct implications for rural livelihoods (Bene and Neiland 2003; Hand 2003). By contrast, improvements in recreational/sport catches are evident in Western Europe and North America as a result of rehabilitation and restocking activities, e.g. River Rhine (Brenner, Buijse, Lauff *et al.* 2003). However, in both scenarios the fisheries and fish community structures are changing. Increasing fishing pressure usually results in a decline in yield but also fishing down of the food web whereby a marked shift in catch composition toward individuals and species that mature at a small size and/or age is observed (e.g. Oueme Delta fishery, Welcomme 2001). These early maturing, small-sized fishes tend to be economically less valuable and less desirable than the large predatory species that are removed from the fishery first. Notwithstanding this argument, these small-sized fish are nutritionally important and often contribute greatly to food security in rural areas. Similarly, enhancement of recreational fisheries through stocking and introductions has altered fish community structures markedly toward species considered desirable by anglers, often to the detriment of the indigenous species (Cowx 2002c). These changes in the fisheries structure and function not only have marked impact on the economic value of the fisheries, but also have considerable environmental cost (Arlinghaus *et al.* 2002).

WHY VALUE ENVIRONMENTAL GOODS?

Despite recent developments in inland fisheries, they undoubtedly have high socio-economic and socio-cultural importance and provide “a myriad of benefits to society” (Weithman 1999; Welcomme and Naeve 2001; Pitcher and Hollingworth 2002). However, benefits created by inland fisheries are difficult to group, quantify and evaluate (e.g. Talhelm and Libby 1987; Kearney 1999, 2002). There are a number of reasons for this, including the fact that it is difficult to assign value to such factors as the value to artisanal and subsistence fisheries of reducing risk and vulnerability to poverty or the high social and cultural value, often in terms of community solidarity, festivals and spiritual links, especially in agrarian countries. This problem, however, should not be used as an argument for not valuing the benefits of inland fisheries. Three main arguments exist for pricing environmental goods like river quality and protecting aquatic ecosystem function and biodiversity, including river fisheries (after Navrud 2001).

First, some socially optimal quantity/quality of an environmental good exists where the marginal cost of supplying the good is equal to or less than its marginal benefit, expressed as the public’s demand for the good. This argument stems from the increasing awareness among policy makers that a non-zero goal of environmental degradation has to be accepted and that trade-offs can be viewed in economic terms as costs and benefits. Although the costs of supplying environmental quality (usually the costs of protection and rehabilitation) is relatively easily to determine, the demand for environmental quality in terms of corresponding benefits is more difficult to value. For example, improving the quality of effluent discharge into rivers will reduce pollution and increase the diversity and potential for exploitation of fish stocks. The same result can be achieved by stocking. While the social costs of pollution control programmes are relatively well known, the social benefits in terms of improved fish stocks are not. To calculate the optimal level of pollution control or optimal stocking regime there is a need to know the social benefits. To conduct a complete cost-benefit analysis of pollution control, the social benefits from all environmental improvements have to be calculated. Thus, not only increased fish stocks, but also reduced costs of treating water supplies for agricultural and human uses, reduced health impacts, increased uses for recreational purposes and other damage to estuarine or marine ecosystems etc., have to be valued.

Environmental goods have significant public good characteristics since individuals generally cannot be excluded from enjoying environmental improvements nor can they avoid environmental degradation. Thus, these goods are generally not bought and sold in markets and have no market prices or have market prices that do not reflect the full, marginal social costs of providing them. However, there is a need to know the marginal values or prices of environmental goods to be able to compare marginal costs and benefits and set an economic efficient level for the provision of these goods and corresponding environmental policy goals. Environmental prices are also needed to decide upon which regulations and projects are socially most desirable. Monetary values enable alternatives to be ranked and, by reference to other uses of the resource being valued, enable the opportunity cost (the value of opportunities foregone in order to derive a benefit) of each option to be compared.

Second, if environmental goods are not valued explicitly, policy decisions will value them implicitly, which often produces an arbitrary and inconsistent set of prices, because decision makers are often unaware they make these valuations. To illustrate this argument, consider a hydropower development project. This could pose environmental impacts on recreational and/or commercial fisheries, outdoor recreational activities, agriculture, forestry, water quality and supply, cultural and historical objects, landscape aesthetics and the ecosystem in general, which are usually only defined in a qualitative manner. Rarely is any attempt made to value these environmental impacts. Cost-benefit analyses (CBA), taking into account all social benefits and costs except the environmental costs, tend to be based on the net present value. If the net present value of a dam designed to be operational for 50 years is $10 million, with a discount rate of 5 percent pa, the annual net benefits are about $700 000. If the construction of the dam has consequences only for a local community of 20 000 persons, policy makers have implicitly valued the damage such that each person is willing to pay less than $35 each year to avoid the environmental damage. This value is much less if the river is of national or international significance and many people are affected. However, people have not been asked about their preferences and might be willing to pay more than this amount to avoid the negative environmental effects and preserve rivers (Navrud 1994). Consequently, the total social costs of the hydropower project will most likely exceed the benefits. Thus, from an economic point of view the dam should not be constructed. Care must be paid when adopting this type of valuation as there is a great deal of uncertainty when transferring benefits or costs from a study site to the policy site (i.e. the site for which values are needed). However, this uncertainty is judged to be acceptable in cost-benefit analysis, as other benefit and cost factors could easily be equally or more uncertain (Navrud 1994).

Third, there is the need to promote inland fisheries and aquatic biodiversity in environmental impact assessment and conflict resolution situations. This need largely falls out of the previous argument about decision makers making implicit valuations. When decisions are made on major development schemes the fish and fisheries must present a strong economic argument, otherwise they are overridden and suffer in the face of economically strong sectors such as hydropower production, water supply and agricultural development (e.g. Halls, Shankar and Barr 2003; Kaunda and Chapotk 2003). In many respects this argument is the most important because of the recognition that inland fisheries is just one element of a multi-user environment and the sector often promotes a weak argument for sustainability because it is undervalued in real terms. This issue is discussed in more detail later.

Despite the arguments presented above, there are some objections to assigning values to natural systems. The first objects to the role of market prices, implying the consumers are the best judges of the value of a system and that community considerations are irrelevant. This may be countered by noting the purpose of valuation is to provide more information to the political process of resource management, rather than leaving the process to be influenced wholly by political considerations. The second problem is the assumption that consumers understand the value of the ecological services provide by biological resources. The objection revolves around the complexity of ecological process and, therefore, the need to treat the system as a whole. One implication is that if there is a case for the protection of a system, great care has to be taken in an even moderate level of use because of the frequent lack of knowledge about what species or parts of the system are necessary for ecosystem maintenance and what are redundant. For example, the ecological processes associated with aquatic vegetation are necessary to provide the appropriate conditions for favourable fish habitats. It is frequently difficult to assess, however, what extent of vegetation cover is necessary to provide for this favourable status. The third problem is that the techniques used to assess economic value tend to ignore many equity and moral considerations. The economic argument is that the techniques are quite distinct from the political recognition that inequities exist and of the need for the necessary policy instruments to reduce or remove them.

BENEFITS VALUES AND IMPACTS

Generally, three domains can be distinguished where benefits associated with river fisheries are accrued, *viz.*: economic, social and ecological benefits (Table 2). Furthermore, when reviewing impacts additional components need to be taken into account: (a) negative impact of fisheries on aquatic ecosystems; and (b) impacts, threats and constraints on river fisheries.

Table 2: Socio-economic benefits of inland fisheries and impacts on inland fisheries (modified from Weithman 1999)

Values	Impacts
Economic benefits	
Direct use: Consumptive, non-consumptive, indirect option Non-use: Existence, bequest	Direct, indirect, induced
Social benefits	
Cultural, societal, psychological, physiological	Quality of life, social well-being
Ecological benefits	
- Species diversity - ecosystem goods and services - maintenance of habitat	Mitigation, rehabilitation, management, negative “benefits” (impacts) Other impacts environmental degradation, low societal priority, user conflicts, cost-effectiveness, constraints

Economic benefits

Total economic value (TEV) of river fisheries can be divided into two main components: a) direct use value; and b) non-use/preservation value. TEV is the sum of all use and non-use values, no matter how derived.

The direct use value of a fish stock can be divided into consumptive, non-consumptive and indirect values (Randall 1987; Bishop, Boyle and Welsh 1987; Table 2). Consumptive use includes the net income from commercial fisheries (i.e. income from fish sales minus the cost of input factors), harvest by an angler, or the economic value of recreational fisheries. This is the main criteria used to value fisheries in both industrial and developing countries, see for example Almeida, Lorenzen and McGrath (2003). Non-consumptive use (value that individuals derive that is not conditional on consumption of, or physical change in, natural resources) includes research or sightseeing, for example salmon jumping up a waterfall, fresh air and other public goods that do not deplete the fishery resources. Indirect use (also referred to as ecological function values) comprise all the ecological functions within a system, or may include activities away from the site (i.e. not fish used directly for food or sport), including trade, reading about or special activities at the fishery location (Riechers and Fedler 1996). A derivation of direct use and indirect use values are option values (value to an individual of maintaining the option to use a resource some time in the future). These may be seen as extra insurance against the risk of losing goods and services that are important in the life of the community. As such, they are also part of preservation values (see below).

Non-use values are the values which can be attributed to systems as a result of certain people deriving satisfaction from simply knowing that certain systems exist, although they do not obtain any direct or indirect goods and services from it. Non-use value is partitioned into bequest (value to an individual knowing that a resource is available for future generations to use) and existence value (value derived by an individual from knowing that a resource exists and that others have the opportunity to use it) (e.g. Riechers and Fedler 1996; Weithman 1999; Peirson, Tingley, Spurgeon *et al*. 2001). Existence values are, perhaps, more widespread among industrialised countries (in the UK, for example, the Royal Society for the Protection of Birds is the top income generating charity based on donations and directs its income to habitat protection), but not entirely. There also exist preservation values that are similar to option values. These are values attached by those who benefit directly or indirectly from preserving and natural system. This is a value to communities that fishing accords (e.g. McGrath, Castro, Futemma *et al.* 1993; McGrath, Silva and Crossa 1998). In this situation it is possible to create a market for environmental services, such as carbon sinking, reduction of erosion and control of fire.

Additionally, if a project could lead to irreversible impacts such as the extinction of a fish species, a quasi-option value may be assessed and used as a correction factor to the total economic value. This is equivalent to the precautionary principle and relates to the value of increased information about the value of fish species gained from not implementing the project with irreversible impacts. Another related concept is the Safe Minimum Standard (Bishop *et al*. 1978), which says preserve unless the costs are intolerable. The challenge is to define how high the costs can be before they become intolerable.

There are two main approaches to valuing non-market goods: i) methods based on individual preferences; and ii) methods based on preferences of experts and decision makers. The latter includes methods like multi-criteria decision analysis, Delphi techniques and implicit valuation elicited from political decisions (see above). These methods can be viewed as complementary decision tools to cost-benefit analysis (CBA) and will not be discussed further. Valuation techniques based on individual preferences can be broken down into two approaches: revealed preference and stated preference methods (Table 3).

Table 3: Classification of environmental valuation techniques based on individual preferences (modified from Navrud 2001)

	Indirect	Direct
Revealed Preferences	Household Production Function (HPF) Approach - Travel Cost (TC) method - Averting Costs (AC) Hedonic Price (HP) analysis	Simulated markets Market prices Replacement Costs (RC)
Stated Preferences (SP)	Contingent Ranking (CR) Choice Experiments (CE) - Conjoint Analysis	Contingent Valuation (CV)

Revealed preference methods use data from observed behaviour of respondents in markets related to the non-use value. The Travel Cost method assumes that the costs incurred travelling to the recreational site (including direct travel costs, accommodation and expenditure on food etc.) are a complementary good to recreational activities. The basic premise of the method is that the number of trips to a recreation site will decrease with increasing distance travelled (and travel costs), other things remaining equal and thus provides an indirect measure of net willingness-to-pay (i.e. consumer surplus). In the Hedonic Price method the environmental good is assumed to be one of several characteristics that affects property price, e.g. noise, air and water quality and aesthetic landscapes (including river views) and is of little relevance for valuing inland fish stocks.

Stated Preference methods value the environmental good in question by constructing a hypothetical market for the good and this is the major criticism of the approach. However, stated preference methods are useful because they provide a mechanism for estimating both use and non-use value of a future change in environmental goods.

Stated Preference methods can be divided into direct and indirect approaches. The direct Contingent Valuation (CV) method is the most commonly used, but mostly for recreational fisheries. Amongst the papers presented to LARS2, only Alam (2003) attempted to value commercial fisheries based on this approach, during a study in Bangladesh. Over the past few years indirect approaches of Contingent Ranking (CR) and Choice Experiments (CE) have also gained popularity. The main difference between these two approaches is that while the CR method typically is a two-options (referendum) approach, CE employs a series of questions with more than two options that are designed to elicit responses allowing for estimation of preferences over attributes of an environmental state.

A Contingent Valuation (CV) survey constructs scenarios that offer different possible future government actions. Under the simplest and most commonly used CV question format (binary discrete choice or closed-ended method), the respondent is offered a choice between an action that maintains the status quo policy and one having a greater cost (e.g. increased taxes, higher prices associated with regulation, or user fees). Basically the respondent provides an in favour/not in favour answer with respect to the alternative policy (versus the status quo). Factors such as what the alternative policy will provide, how it will be provided and how much it will cost and how it will be charged for (i.e. payment vehicle), are specified.

An alternative elicitation method is open-ended questions where respondents are asked directly about either: (a) how much they are willing to pay (WTP) for a service or the increase they are willing to pay to maintain access to that service; or (b) how much they are willing to accept (WTA) as compensation for a loss of the service or a change not occurring. Since it is often improvements in the quantity or quality of fish stocks that are being assessed, the appropriate measure is either compensation surplus (WTP for improvement) or equivalent surplus (WTA for the change not occurring). The choice of WTP or WTA depends on assumptions about entitlements and whether the change is an improvement or deterioration in environmental quality. Generally, WTA is only used where there are clear property rights to the *status quo* and changes are a deterioration (Peirson *et al.* 2001). WTP, which includes actual expenditures and excess value (benefits that exceed monetary cost, net economic value or consumer surplus) to users, is an appropriate measure of economic value of a recreational fishery (see Pollock, Jones and Brown 1994; Riechers and Fedler 1996; Weithman 1999; Navrud 2001 for reviews) and of part-time or artisanal commercial or subsistence fisheries, which are comparable to "leisure" activities. In addition, the value that non-users place on fisheries has to be considered if total economic value of the fishery is to be evaluated.

Whilst the benefits of using CV methods to value resources where no direct market value is available, such as maintaining a pristine habitat or conserving species with no economic value, are important for influencing politicians and decision makers, the methods are also open to criticism. For example, individuals with pro-environmental tendencies are willing to pay more than the general public, thus increasing the WTP estimate (e.g. Kotchen and Reiling 2000). Similarly, when financial outlay becomes a reality, individuals tend to be less willing to pay than when it is only a query. They are also difficult to use in developing country situations where rural people have no perception of the economic value of environmental goods and services.

These WTP or consumer surplus estimates can, however, be used in benefit-cost analysis to evaluate the benefits of improvements of environmental quality in relation to the economic losses (costs) for other water uses such as irrigation or hydropower generation. Willis and Garrod (1999), for example, investigated the benefits to anglers and other recreation users (e.g. swimming, wildlife viewing) of increasing flows along low-flow rivers in England and demonstrated that the benefits to anglers alone outweighed the costs of low-flow alleviation programmes in two of seven rivers evaluated. The value to other recreational and non-users justified the low-flow alleviation in another three rivers. Only where the costs of low-flow alleviation were extremely high did recreational benefits fail to exceed the costs of implementing an environmentally acceptable flow regime in the investigated rivers. Other studies also demonstrated that marginal increases in stream flow can generate benefits to recreational fishing that exceed the marginal value of water in agriculture (Hansen and Hallam 1991). However, there might be also net losses associated with a change in management regimes, which benefit recreation including fishing, but constrain commercial enterprises such as hydropower generation.

Profit through the provision of animal protein to society is a useful measure of economic value of a commercial fishery because, like consumer surplus, profit is value in excess of costs (Edwards 1991). However, commercial fishers experience certain value components not embraced by profit alone (Lackey 1979; Hart and Pitcher 1998), e.g. producer surplus (Edwards 1991). Irrespective, without profit a commercial enterprise would leave the fishery, unless it is subsidised. Net economic value of commercial fishing comprises consumer surplus and producer surplus, the latter of which is not quite equivalent to profit (Edwards 1991). Because there are market prices in commercial fisheries, demand and supply functions allow determination of economic value of commercial fishing. Care has to be taken when comparing revenues or profits of commercial fisheries with economic value of recreational fisheries to allocate fishery resources because these "economic arguments" derive from fundamentally different economic concepts (see Edwards 1991 for critique). Instead net economic value or consumer surplus of recreational fisheries and net economic value of commercial fisheries, which are consumer surplus and producer surplus, should be compared and allocation be based on the basis of incremental tradeoffs in net economic value (see Edwards 1991 for details).

Expenditures by anglers or commercial fishers represent revenues and jobs generated in local economies. There are three types of economic impacts: (1) direct impacts, which are the purchases made by fishers, including travel, accommodation and food costs; (2) indirect impacts, which are the purchases made by businesses to produce goods or services demanded by fishers; and (3) induced impacts, which are the purchases of goods and services by households receiving wages from businesses producing direct or indirect goods. The summation of these three levels of impact is the total economic impact (TEI). TEI divided by the direct impact is called the multiplier and reflects the number of times the initial expenditure circulates through the local economy. This can add considerable value to the fishery activities. For example, an impact analysis on fishing expenditure (US$25.6 million in 1990) on the regional economy bordering Lake Texoma (USA) found the direct, indirect and induced impacts of this expenditure was directly associated with US$57.4 million in total business sales, US$23.3 million in value added and 718 jobs (Schorr *et al*. 1995).

Social benefits

Four categories of social value relate to river fisheries: cultural, societal, psychological and physiological (Table 2). The former two pertain more to nations and regional communities, whereas the latter two relate to individuals (Weithman 1999).

Cultural values represent a collective feeling toward fishes and fishing. Fishing in rivers is an important societal asset and is valued by the community as a whole. Societal values are based on relationships among people as part of a family or community (e.g. family fishing). Psychological values are those that relate to satisfaction, motives or attitudes associated with the use, or knowledge of the existence, of a fishery. Physiological values relate to improvements in human health (e.g. reduction of stress) related to fishing (Weithman 1999). Data on the incidence of human illness can be obtained from the local health office or hospital.

Social impacts are very elusive (Vanderpool 1987). They relate to quality of life and social well-being caused by fishing (Gregory 1987), including improvements in rural livelihoods (Bene and Neiland 2003; Hand 2003). For example, attracting lots of recreational anglers to a river would generate income to the commercial fishing community and increase social well-being, which can be measured through improved quality of life.

Ecological benefits

Ecological benefits of river fisheries are, typically, difficult to quantify (Kearney 1999, 2002; Table 2). Because most rivers are impaired in some way, there is an increasing trend towards intervening either to improve the functioning of degraded systems or to restore them (Cowx 1994; Cowx and Welcomme 1998). Thus, much river fisheries management aims to mitigate or rehabilitate the adverse human-induced changes by manipulating the ecosystems in an attempt to gain positive benefits (Brown 2003). Kearney

(1999) suggested that the conservation-conscious fishing community represents one of the greatest potential forces for the conservation of aquatic biodiversity. Kearney (2002) further stressed that fishery users have different potential positive ecological impacts such as education, promotion of environmental responsibility, aid in environmental monitoring, engendering support for restoration and aid of surveillance of environmental vandalism. Indirectly, in some northern temperate countries, fishery stakeholders, especially recreational fishing societies, have pushed governments to formulate environmental legislation and were the driving forces behind improvements to river quality.

However, not all measures adopted under traditional inland fisheries management are considered positive. For example, common management measures such as stocking and introductions (Araujo-Lima *et al.* 2003) are serious threats to biodiversity of fish (Cowx 2002a; Freyhof 2002). Regardless of these potential negative impacts, a relatively high proportion of society keeps in contact with nature through linkages with inland fisheries and consequently tends to be more sensitive to environmental issues than the majority of an increasing urban population (Lyons, Hickley and Gledhill 2002). This awareness of environmental issues and diversity of ecosystems by fishery protagonists (e.g. Kearney 1999; Connelly, Brown and Knuth 2000) is paramount for ecosystem based management (e.g. Olsson and Folke 2001) and sustainability, assuming that ecological responsibility is achieved. Furthermore, indigenous knowledge of the fishing communities and informal (local) institutions can play an important role in the sustainable management of fishery resources (e.g. Mackinson and Nøttestad 1998; Berkes, Colding and Folke 2000; Johannes, Freeman and Hamilton 2000).

A NOTE ON THE VALUATION OF BIODIVERSITY

It remains the exception for values to be put on diversity in aquatic resource management planning. Some part of this may be due to difficulties in understanding the concept of diversity while another factor may be the quite considerable difficulties in collecting and analysing the required information. Diversity, however, underpins our existence on this planet; it should not be ignored. When it is not, decisions that might otherwise by made solely on political grounds, should be further refined by an economic and ecological examination of the issue.

Biodiversity is a concept that describes the way in which the different goods (or components) and services (or functions) of an ecosystem are organised. It has three parts - genetic diversity, species diversity and ecosystem diversity. Essentially, for all three parts, it is the degree of variety in the natural resources - measures of the richness and distribution within the system; it should not be confused with the biological resources themselves. For example, genetic diversity describes the variation within a particular pool - the number of genes and their distribution, not the pool itself or the characteristics of individual genes. Likewise, species diversity is a measure of species richness and their distribution, but it is not a description of individual organisms. The diversity of ecosystems indicates the number and range of the types of ecosystems that exist in a given area but does not describe the ecosystems themselves. Thus, the valuation of biological diversity is not to be equated with the valuation of resources, although the two sets of values are closely related.

As do biological resources, biological diversity is recognised to have direct and indirect use values. The essence of the difference in the measurement of the value of resources and the value of diversity is that whereas in the former the analyst is concerned with the identification of the gross use values, in the measurement of diversity values, attention is directed towards measuring marginal changes in output that result from marginal changes in relevant factor inputs. Measuring the change in economic activity that results from a specified decline in diversity is one way of estimating the direct and indirect use values of diversity. For example, in the measurement of the direct use values of the species diversity of a coral reef, changes in both the diversity of coral species and the gross amount of coral cover affect fish biomass. The resulting elasticities could be used in calculating the value of coral diversity by estimating the change in the revenues earned from fishing on the reef. An example of a direct use value of ecosystem diversity is the tourist revenues derived from the viewing of coral reefs.

In the case of direct use values, ecological substitutes are often more elusive than economic ones. For example, if favoured firewood for smoking fish becomes unobtainable because of over exploitation but the substitute, which is readily available, is almost as satisfactory in terms of heat output, smoking quality and ease of collection, the economic costs of switching to the alternative will be small. It follows that in this case the direct value of species diversity will be small, although the ecological cost will be high. By contrast, if a favoured firewood can only be replaced by people who collect it having to travel much longer distances, then the economic costs will be high, making also high the direct value of species diversity.

Indirect use values of biodiversity may also have economic or ecological substitutes. Again the benefits gained from degrading a diverse range of valued environmental services should be weighed against the availability and usefulness of substitutes, e.g. the value of marginal wetland may be high because the relatively low availability of ecological substitutes and the high costs of economic substitutes (e.g. water purification plants, water transport, relocation of fishing communities dependent on the wetlands).

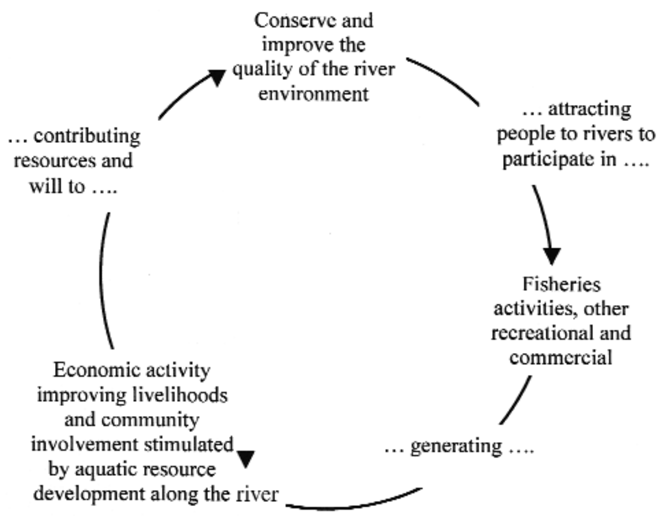
In the calculation of direct and indirect use values of diversity, there is room for double counting of resource use values and diversity values and for trade-offs. Care has to be taken to ensure that diversity values are used separately from resources values to evaluate the impacts on biodiversity of current pressures or threats.

ROLE OF VALUATION IN RIVER FISHERIES MANAGEMENT

The value of maintaining and supporting river ecosystem function is illustrated in Figure 3. A healthy ecosystem generates wealth for the local and regional economies, which implicitly supports rural livelihoods. In this cycle, fisheries plays three important roles:

- As a public good for all to use and enjoy;
- Generating revenue for local economies;
- As a catalyst for ecosystem regeneration and community engagement.

These three elements must be interdependent to succeed. Without the landscape, biodiversity and aquatic resource value people are not drawn to use rivers. These qualities depend on good management and environmental control of the entire river ecosystem, including the river catchment and its biodiversity. If the river corridor does not attract participation in resource use there is no catalyst for economic development or stimulus for community engagement and there is no reason to maintain or enhance the river environment.

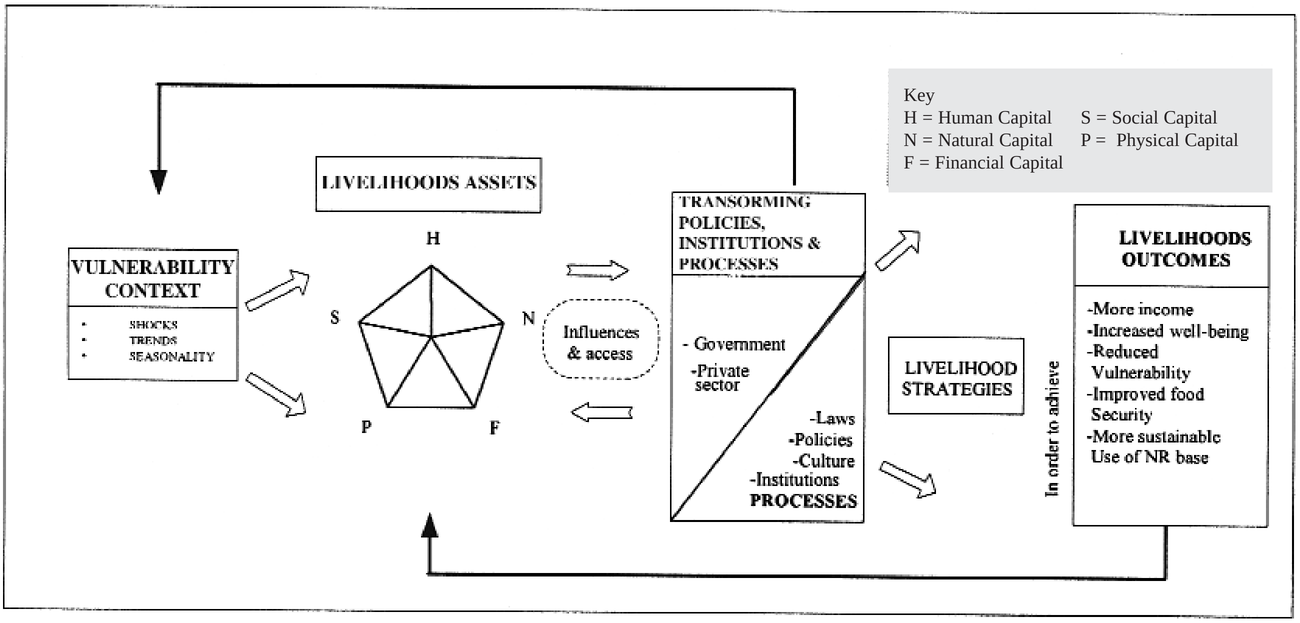


■ **Figure 3.** The river cycle illustrating the importance of participation in maintaining ecosystem function and supporting rural livelihoods.

The underlying tenet of these arguments is to recognise the value of river fisheries and the ecosystem for sustaining rural livelihoods. This is highlighted in DFID's sustainable livelihoods framework (Figure 4) that shows how the values of various assets are the focal point for influencing policy to improve the well-being of riparian communities. The livelihoods approach addresses issues related to vulnerability and reduction of risk associated with resource exploitation patterns. These are values that are difficult to assess but low risk and reduced vulnerability to poverty are very important features of sustainable livelihood strategies and maintaining food security.

Unfortunately, river fisheries are threatened by a wide array of factors and therefore communities are highly vulnerable to change, but anthropogenic disturbance seems to underlie the decline and extinction of many fish species (see Cowx, 2002b for review). The main perturbations can be broken down into five key problems, viz: species introductions and translocations, impoundment of rivers (dams and weirs, water abstraction and water transfer schemes), water quality deterioration (pollution, eutrophication, acidification), habitat degradation and fragmentation (channelisation and land use change, mineral extraction) and overexploitation. These problems seem to be universal. Although many of the issues are being addressed in developed countries through environmental legislation, the rate of progress in reversing the impacts is pathetically slow. Furthermore, the cost of implementing rehabilitation programmes or seeking alternative solutions to the demands on water resources, which underlies many of the issues, is prohibitive and at best only a *status quo* is being achieved with respect to habitat quality and at worst, as is still commonly found throughout the developing world where financial resources are limited, progressive deterioration is rife.

One of the key reasons for the problems facing fisheries is that the value of the fisheries resource is usually ill defined and poorly represented from an economic and social perspective (Cowx 2002a and 2002b). Fisheries are traditionally managed based on the quality of the fishing experience or volume of catch and few are managed from an economic perspective



■ **Figure 4.** DFID sustainable livelihoods framework

(Cowx 2002a), an issue born out by the paucity of information on the economic value of fisheries (e.g. Baker and Pierce 1997; Peirson *et al.* 2001). A large number of recent works underline the high potential of small scale fishing activities for economic development (both at local and national levels) but systematically highlight how poorly the true (economic) value of this sector is reflected in official statistics and discussions of food security and livelihoods (e.g. European Commission 2000; Kaczynski and Looney 2000; Anon 2001). As a consequence, fish and fisheries are generally not considered of sufficiently high priority or value and thus suffer in the face of economically and socially higher priorities, e.g. agriculture, hydroelectric power production or other water sports. It is also usually presented as the main constraint for the design of appropriate policy for aquatic resource management, both at the national and regional levels. If fisheries are to be promoted in the future, there is an urgent need to provide robust, defensible, social and economic valuation of aquatic biodiversity and fisheries (Cowx 2002a). Once this information is available, value will be a powerful tool for arguing the case of fisheries. However, it must be recognised that it is not the only tool to be used because the economic value of, for example, a major water resource scheme may far outweigh fisheries value. This is primarily because the methods used for valuation are often fisheries specific and do not consider the upstream economic value in terms of aesthetic and conservation value and the provision of goods and services, or the downstream value associated with the service sectors. To reverse these philosophies is going to be a major challenge to fisheries and conservation managers, but neither will be achieved if the true economic value of preserving fisheries is not enunciated (Cowx 2002b). As mentioned earlier, accurate valuation of the fisheries should be a major thrust of fisheries development activities in the immediate future.

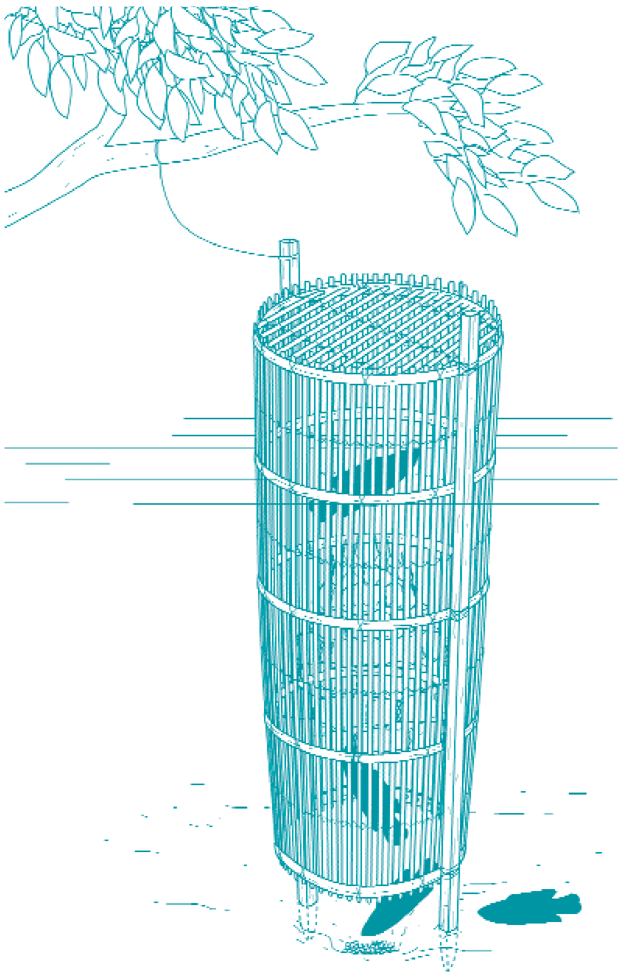
In the past, management of fisheries resources has been based on interpreting information on the fish stocks and reacting to shifts in availability (Cowx 1996). Integral within this approach are adequate stock assessment procedures that provide the baseline information on which to manage the fisheries resources. However, when reviewing the problems relating to river fisheries it is clear that this approach is inadequate. Increasing pressures on aquatic resources dictate that fisheries exploitation and conservation can no longer be treated in isolation and an integrated approach to aquatic resource management is required (Cowx 1998). Similarly, fish biodiversity is being constantly eroded, not only by exploitation of fish directly but mainly through degradation of their habitat. Fortunately, the demands for sustainability that grew out of the World Summit on Sustainable Development (WSSD) in 1992 have put emphasis on the need not only to manage exploited resources but also promote biodiversity. Unfortunately the WSSD did not endorse fisheries, but this was rectified in the 2002 WSSD in Johannesburg. Consequently, conflicts between various user interests must be resolved by involving all stakeholders in the management process and defining priority areas for conservation and preservation of biodiversity (Brummett and Teugels 2003; Darwall and Vié 2003). This can be achieved through integrated aquatic resource planning and management. River basin management plans, at both the national and multi-national scale, which for example will be obligatory under the new European Union Water Framework Directive, will support this process, but the profile of fisheries exploitation in the widest sense and fish conservation need to be raised and be better integrated into the planning process. Without this involvement the future of river fish and fisheries remains uncertain.

Aquatic resource planning and management, as suggested above, must be a multi-disciplinary, interactive approach dealing with all the existing and potential user groups, including adjacent land use. It should allow wider issues than those related to a single activity, in this case river fisheries, to be taken into account during the process of decision-making about an activity and its likely effect upon the environment and other activities, or conversely the likely affect of other activities on fisheries. For this process to be effective, data on the social and economic importance of each resource are needed, without it, economically strong activities such as hydropower development will override.

Many of the sources of conflicts between aquatic resource users lie in the difficulties of communication between user groups, the lack of a mechanism for dialogue or in a failure to understand common objectives. However, the failure of dialogue between user groups frequently arises through a lack of willingness on the part of the stronger group to discuss resource allocation with the minority group. One solution might be the better co-operation of players within, for example, a co-management framework (Sen and Raakjaer Nielsen 1996), challenging the present routines. An essential element in co-management is continuous shared responsibility and decision-making between government, fishers and other stakeholders. Co-management is one possible mechanism that could ensure that the human element is accounted for. Inclusion of all stakeholders in co-management systems ensures that decisions better reflect local, social, economic and environmental conditions. In developing countries co-management is being promoted on many fisheries with the devolvement of responsibility to the riparian communities. In Europe and North America, less participatory co-management approaches are likely to apply, with many inland fisheries being jointly managed by fishers and government officials. In both cases, however, the objective remains the same, sustainability of the exploitable resources and biodiversity for future generations.

Similarly, there is a need to develop partnerships with stakeholders in affected ecosystems to strengthen and implement fish and fisheries related activities and develop mechanisms to influence other players. To achieve this, scientists must expand their range of activities from monitoring and reporting the status of stocks and species to more influential and preventative work. They must use the best available data to educate other stakeholders and the wider public. They need to be involved in accurate environmental impact assessments and rehabilitation programmes to argue the case for fish and fisheries, i.e. there is a need to develop a risk based approach to fisheries management. There is also a need to develop fiscal measures, such as the ‘polluter-pays principle’ and enforce legislation through the appropriate channels and institutions. This will only be achieved through valuation of fisheries resources, an issue that is acting against the fisheries lobby and will be essential for integration into river basin management plans. As previously stressed, there is an urgent need to adapt environmental economic evaluation tools to value the social and economic importance of freshwater fisheries and biodiversity. Until this is undertaken fish and fisheries will continue to be given low priority in any consultation process and it will remain difficult to attract investment or credit for protection of the fisheries.

Irrespective of the mechanism of implementation, the managers and resource users need a true economic value of their resources to defend their position in conflict and development scenarios. This will increase the capacity of beneficiaries of river (inland) fisheries to communicate and influence at all levels of society. In this context it is important that information on values is conveyed to politicians, planners and stakeholders in simple language. It is therefore important to understand how value is interpreted within communities, i.e. between rich and poor and fisher and non-fisher. This can only be achieved if stakeholders in the fishery sector understand the motives, modes of operation and reward systems of other spheres of society and engage in cooperative interchange. More effective management of fisheries resources also requires scientists to learn new skills to interact in complex, disorderly and confusing arenas and not producing scientific information in the vain hope that managers and policy makers will use it. Finally, the methods to value aquatic resources and environmental goods and services do exist. The lack in progress in this field is largely because the fisheries scientists and managers do not have active dialogue with experts in environmental and ecological economics. This needs to be promoted in the drive towards sustainable use of aquatic resources in general and river fisheries in particular.



REFERENCES

Alam M.K. 2003. Estimating the benefits of water quality improvement of the Buriganga river. Abstract submitted to the *Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Almeida O., Lorenzen K. & McGrath D. 2003. The Commercial Fishing Sector in the Regional Economy of the Brazilian Amazon. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 2.* Food and Agriculture Organization of the United Nations & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/17. pp. 15-24.

Anon. 2001. Report of the Seminar on Contribution of fisheries to poverty reduction in West Africa, 14-15 February 2001, Dakar.

Arlinghaus R., Mehner T. & Cowx I.G. 2002. Reconciling traditional inland fisheries management and sustainability in industrialised countries, with emphasis on Europe. *Fish and Fisheries*, 3: 261-316.

Araujo-Lima C.A.R.M., Martins H. Jr., Roubach R., Gomes L.C. Malta J.C.O., Lorenzen K. & Almeida-Val V. 2003. Testing the effectivness of stock-enhancement in the Amazon floodplain to increase *Colossoma* yield. Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.

Baker D.L. & Pierce B.E. 1997. Does fisheries management reflect societal values? Contingent valuation evidence for the River Murray. *Fisheries Management and Ecology,* 4: 1-15.

Berkes F., Colding J. & Folke C. 2000. Rediscovery of traditional ecological knowledge as adaptive management. *Ecological Applications*, 10: 1251-1262.

Béné C. & Neiland A.E. 2003. Traditional management systems of Inland African fisheries. The case of Lake Chad Basin's riverine and floodplain fisheries. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 2*. Food and Agriculture Organization of the United Nations & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/17. pp. 67-78.

Bishop R.C., Boyle K.J. & Welsh M.P. 1987. Towards total economic valuation of Great Lakes fishery resources. *Transactions of the American Fisheries Society,*. 116: 339-345.

Brenner T., Buijse A.D., Lauff M., Luquet J.F. & Staub E. 2003. The present status of the river Rhine with special emphasis to the fisheries development. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 1*. Food and Agriculture Organization of the United Nations & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/17. pp. 121-148.

Brown J.J. 2003. Restoration of the fisheries of the Susquehanna and Delaware rivers, USA. Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.

Brummett R.E. & Teugels G.G. 2003. Rivers of the Lower Guinean rainforest: Biogeography and sustainable exploitation. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 1*. Food and Agriculture Organization of the United Nations & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/17. pp. 149-172.

Collares-Pereira M.J., Cowx I.G. & Coelho, M.M. 2002. *Conservation of freshwater fish: Options for the future*. Oxford, UK, Fishing News Books, Blackwell Science. 472 pp.

Connelly N.A., Brown T.L. & Knuth B.A. 2000. Do anglers and fishery professionals think alike? *Fisheries*, 252: 21-25.

Cowx I.G. 1994. *Rehabilitation of freshwater fisheries*. Oxford, UK, Fishing News Books, Blackwell Science. 484 pp.

Cowx I.G. 1996. *Stock Assessment in inland fisheries*. Oxford, UK, Fishing News Books, Blackwell Science. 513 pp.

Cowx I.G. 1998. Aquatic resource planning for resolution of fisheries management issues. *In* P. Hickley & H. Tompkins, eds. *Social, economic and management aspects of recreational fisheries.* Oxford, UK, Fishing News Books, Blackwell Science. pp. 97-105.

Cowx I.G. 2000. *Management and ecology of river fisheries*. Oxford, UK, Fishing News Books, Blackwell Science. 444 pp.

Cowx I.G. 2002a. Analysis of threats to freshwater fish conservation: Past and present challenges. *In* M.J. Collares-Pereira, I.G. Cowx & M.M. Coelho, eds. *Conservation of freshwater fish: Options for the future.* Oxford, UK, Fishing News Books, Blackwell Science. pp. 201-220.

Cowx I.G. 2002b. *Management and ecology of lake and reservoir fisheries*. Oxford, UK, Fishing News Books, Blackwell Science. 396 pp.

Cowx I.G. 2002c. Recreational fishing. *In* P.J.B. Hart and J.S. Reynolds, eds. *Handbook of fish biology and fisheries, Volume II.* Oxford, UK, Fishing News Books, Blackwell Science. (forthcoming)

Cowx I.G. and Welcomme R.L. 1998. *Rehabilitation of rivers for fish*. Oxford, UK, Fishing News Books, Blackwell Science. 260 pp.

Darwall W.R.T. & Vié J.C. 2003. Identifying important sites for conservation of freshwater biodiversity: Extending the species-based approach. Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.

Dynesius M. and Nilsson C. 1994. Fragmentation and flow regulation of river systems in the northern third of the world. *Science,* 266: 753-761.

Edwards S.F. 1991. A critique of three economics arguments commonly used to influence fishery allocations. *North American Journal of Fisheries Management*, 11: 121-130.

European Commission. 2000. *Communication from the commission to the council and the European parliament. Fisheries and poverty reduction.* COM2000 724 Final. Commission of the European Communities, Brussels, 20 pp.

FAO. 1997. Inland fisheries: *FAO technical guidelines for responsible fisheries 6.* 36 pp.

FAO. 1999. Review of the state of world fisheries resources: Inland fisheries. *FAO Fisheries Circular No. 942*. 53 pp.

FAO. 2002. *FISHSTAT Plus*. Universal software for fishery statistical time series. Version 2.3. Data set: Capture Production 1970-2000. Rome, Fisheries Department, Fishery Information, Data and Statistics Unit, FAO.

Freyhof J. 2002. Freshwater fish diversity in Germany, threats and species extinction. *In* M.J. Collares-Pereira, I.G. Cowx & M.M. Coelho, eds. *Conservation of Freshwater Fish: Options for the Future*. Oxford, UK, Fishing News Books, Blackwell Science. pp. 3-23.

Garcia S.M., Cochrane, K., van Santen, G. & Christy F. 1999. Towards sustainable fisheries: A strategy for FAO and the World Bank. *Ocean and Coastal Management*, 42: 369-398.

Gregory R. 1987. Nonmonetary measures of nonmarket fishery resource benefits. *Transactions of the American Fisheries Society.* 116: 374-380.

Hand R.T. 2003. Protein, fat and carbohydrate food security maintenance in the Mekong Basin: Racing for rice while fumbling with fish. Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.

Halls A.S., Shankar B. & Barr J. 2003. Fish out of water: Modelling some tradeoffs between fisheries and agriculture in the floodplains of Bangladesh. Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.

Hansen L.T. & Hallam A. 1991. National estimates of the recreational value of streamflow. *Water Resources Research*, 27: 167-175.

Hart P.J.B. & Pitcher T.J. 1998. Conflict, consent and cooperation: An evolutionary perspective on individual human behaviour in fisheries management. *In* T.J. Pitcher, P.J.B. Hart & D. Pauly, eds. *Reinventing Fisheries Management*. London, Chapman & Hall. pp. 215-225.

Johannes R.E., Freeman M.M.R. & Hamilton R.J. 2000. Ignore fishers´ knowledge and miss the boat. *Fish and Fisheries*, 1: 257-271.

Kaczynski V.M. and Looney S.W. 2000. Coastal resources as an engine of economic growth and reduction of poverty in West Africa: Policy considerations. *Coastal Management,* 28: 235-248.

Kaunda E. and Chapotoka O. 2003. The conflict between poverty and river system management: The case of Malawi, Southern Africa. Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.

Kearney R.E. 1999. Evaluating recreational fishing: Managing perceptions and/or reality. *In* T.J. Pitcher ed. *Evaluating the benefits of recreational fisheries*. Vancouver, Canada, The Fisheries Centre. pp. 9-14.

Kearney R.E. 2002. Recreational fishing: Value is in the eye of the beholder. *In* T.J. Pitcher and C.E. Hollingworth, eds. *Recreational fisheries: Ecological, economic and social evaluation*. Oxford, UK, Blackwell Science. pp. 17-33.

Kotchin M.J. & Reiling S.D. 2000. Environmental attitudes, motivations and contingent valuation of non-use values: A case study involving endangered species. *Ecological Economics*, 32: 93-107.

Lackey R.T. 1979. Options and limitations in fisheries management. *Environmental Management*, 3: 109-112.

Lyons J., Hickley P. & Gledhill S. 2002. An evaluation of recreational fishing in England and Wales. *In* T.J. Pitcher and C.E. Hollingworth, eds. *Recreational fisheries: Ecological, economic and social evaluation*. Oxford, UK, Blackwell Science. pp. 144-155.

Mackinson S. & Nøttestad L. 1998. Combining local and scientific knowledge. *Reviews in Fish Biology and Fisheries*, 8: 481-490.

Navrud S. 1994. Economic valuation of the external costs of fuel cycles. Testing the benefit transfer approach. *In* A.T. Almeida ed. *Models for integrated electricity resource planning*. Dordrecht, The Netherlands, Kluwer Academic Publishers. pp. 49-66.

McGrath D.G., Castro F., Futemma C., Amaral B.D. & Calabria J. 1993. Fisheries and evolution of resource management on the Lower Amazon floodplain. *Human Ecology*, 21: 167-195.

McGrath D., Silva U. & Crossa M. 1998. A traditional floodplain fishery of the lower Amazon River, Brazil. *NAGA*, Jan-Mar: 4-11.

Navrud S. 2001. Economic valuation of inland recreational fisheries: Empirical studies and their policy use in Norway. *Fisheries Management and Ecology*, 8: 369-382.

Nguyen Khoa S., Smith L., Lorenzen K. & Garaway C. 2003. Assessment and management of irrigation impacts on tropical inland fisheries: A case study from Sri Lanka. Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.

Nguyen Khoa S., Lorenzen K. & Garaway C. 2003. Impacts of irrigation development on capture fisheries in the rice-based farming systems of southern Laos. Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.

Olsson P. & Folke C. 2001. Local ecological knowledge and institutional dynamics for ecosystem management: A study of Lake Racken watershed, Schweden. *Ecosystems*, 4: 85-104.

Peirson G., Tingley D., Spurgeon J. and Radford A. 2001. Economic evaluation of inland fisheries in England and Wales. *Fisheries Management and Ecology*, 8: 415-424.

Petr T. ed. 1998. Inland fishery enhancements. *FAO Fisheries Technical Paper* 374. 463 pp.

Pitcher T.J. and Hollingworth C.E. 2002. Recreational fisheries: Ecological, economic and social evaluation. *Fish and Aquatic Resources Series 8*. Oxford, UK, Blackwell Science. 271 pp.

Pollock K.H., Jones C.M. and Brown T.L. 1994. *Angler surveys methods and their applications in fisheries management*. Bethesda, Maryland, American Fisheries Society. 371 pp.

Pusey B.J. 2003. The translocation of recreationally satisfying fishes is detrimental to the maintenance of local biodiversity: Sleepy cod and other translocated species in the Burdekin River. Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.

Radonski G. 1995. Issues and attitudes impacting fisheries now and into the twenty-first century. *Fisheries*, 205: 10-12.

Randall A. 1987. Total economic value as a basis for policy. *Transactions of the American Fisheries Society*, 116: 325-335.

Riechers R.K. & Fedler A.J. 1996. An overview of economic impact and value of recreational fisheries. *In* L.E. Miranda & D.R. de Vries, eds. *Multidimensional approaches to reservoir fisheries management*. Bethesda, Maryland, American Fisheries Society. pp. 245-250.

Schorr M.S., Sah J., Schreiner D.F., Meador M.R. & Hill L.G. 1995. Regional economic impact of the Lake Texoma Oklahoma-Texas striped bass fishery. *Fisheries*, 205: 14-18.

Sen S. & Raakjaer Nielsen J. 1996. Fisheries co-management: A comparative analysis. *Marine Policy*, 20: 405-418.

Smith C.L. 1986. The life cycle of fisheries. *Fisheries*, 114: 20-25.

Talhelm D.R. & Libby L.W. 1987. In search of a total value assessment framework: SAFR symposium overview and synthesis. *Transactions of the American Fisheries Society*, 116: 293-301.

Van Brakel M.L. Muir J.F. & Ross L.G. 2003. Modelling for aquaculture related development, poverty and needs in the Mekong Basin. Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.

Vanderpool C.K. 1987. Social impact assessment and fisheries. *Transactions of the American Fisheries Society*, 116: 479-485.

Vitousek P.M., Mooney H.A., Lubchenco J. & Melillo J.M. 1997. Human domination of earth´s ecosystems. *Science*, 277: 494-499.

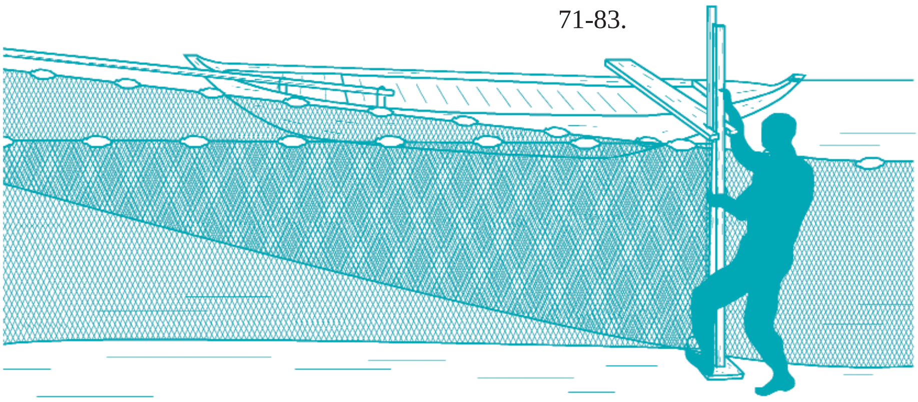
Weithman A.S. 1999. Socioeconomic benefits of fisheries. *In* C.C. Kohler & W.A. Hubert, eds. *Inland Fisheries Management in North America*, 2nd edition, Bethesda, Maryland, American Fisheries Society. pp. 193-213.

Welcomme R.L. 2000. Principles and approaches to river fisheries management. *In* I.G. Cowx, ed. *Management and ecology of river fisheries*. Oxford, UK, Fishing News Books, Blackwell Science. pp. 331-345.

Welcomme R.L. 2001. *Inland fisheries: Ecology and management*. Oxford, UK, Fishing News Books, Blackwell Science. 358 pp.

Welcomme R. & Naeve H., eds. 2001. An international symposium on fisheries and society Budapest, Hungary, 01-03 June, 2000, *Fisheries Management and Ecology*, 84-5: 283-462.

Willis K.G. & Garrod G.D. 1999. Angling and recreation values of low-flow alleviation in rivers. *Journal of Environmental Management*, 57: 71-83.



SESSION 3 REVIEW

RIVER FISHERIES: ECOLOGICAL BASIS FOR MANAGEMENT AND CONSERVATION

A.H. Arthington[1,2] K. Lorenzen[3] B.J. Pusey[1,2] R. Abell[4] A.S. Halls[5] K.O. Winemiller[6] D.A. Arrington[7] E. Baran[8]

[1] Co-operative Research Centre for Freshwater Ecology, Centre for Riverine Landscapes, Griffith University, Nathan, Brisbane, Queensland 4111, Australia

[2] Co-operative Research Centre for Tropical Rainforest Ecology and Management, Centre for Riverine Landscapes, Griffith University, Nathan, Brisbane, Queensland 4111, Australia

[3] Department of Environmental Science and Technology, Imperial College, London SW7 2BP, UK

[4] WWF-United States, 1250 24th St. NW, Washington, DC 20037, UK

[5] Renewable Resources Assessment Group, Department of Environmental Science and Technology, Imperial College of Science, Technology and Medicine, Prince Consort Road, London SW7 2AZ, UK

[6] Department of Wildlife and Fisheries Sciences, Texas A&M University, College Station, TX 77843-2258, USA

[7] Department of Biological Sciences, University of Alabama, Tuscaloosa, AL 35487-0206, USA

[8] WorldFish Center (formerly ICLARM), P.O. Box 500 GPO, Penang 10670, Malaysia

Abstract

Large rivers and their floodplains support a significant proportion of the world's biodiversity and provide important goods and ecological services to society, including fisheries. Riverine ecosystems and fisheries are subject to intense pressure from a wide range of anthropogenic disturbances, the main ones being impacts from altered land use, modifications to river flow regimes, riparian and physical habitat loss, water pollution, exotic species invasions and intensive exploitation of fish stocks. As a consequence, a far greater proportion of freshwater species are threat-

ened or endangered than terrestrial or marine species in the same taxonomic groups. In this paper we review ecological processes sustaining river and floodplain biodiversity and productivity. We also outline the status of knowledge of fundamental issues in fish ecology, including fish habitat requirements, trophic ecology, life history strategies, migration, the population biology of riverine fish and modelling of fish populations and assemblages. We evaluate threats to the productivity and diversity of large river systems, as well as conservation and rehabilitation measures and discuss ecological approaches and tools for management decision support. The final summary highlights knowledge gaps and research priorities and new research frontiers that demand more attention in river ecosystem studies, conservation efforts and fisheries management.

INTRODUCTION

Large rivers and floodplain ecosystems support a significant proportion of the world's aquatic biodiversity. Species richness within some tropical systems surpasses that of marine ecosystems, including coral reefs. The Mekong River, for example, contains 500 known fish species, with several hundred more species lacking formal definition (Dudgeon 2000). The floodplains of large rivers are also amongst the most productive landscapes on earth (Bayley 1988a; Welcomme 2001). Fisheries in large rivers and their associated wetlands and floodplains provide a major source of food, employment and/or income that is crucial to sustaining the livelihoods of multitudes of people, particularly the rural poor in large areas of the world. For example, fisheries are the single most important source of income for floodplain dwellers in the Amazon (Almeida, Lorenzen and McGrath 2002) and match income from rice farming in rural households in Cambodia and Laos (Lorenzen *et al.* 2000). However, due to their diffuse and inconspicuous nature, inland fisheries are often grossly underreported and undervalued.

Freshwater species are, on average worldwide, more imperilled than their terrestrial and marine counterparts (McAllister, Hamilton and Harvey 1997; Stein, Kutner and Adams 2000). Of those species considered in the 2000 IUCN (The World Conservation Union) Red List, approximately 30 percent of fishes (mostly freshwater) are threatened (IUCN Species Survival Commission 2000). At a regional scale, the projected mean future extinction rate for North American freshwater fauna is about five times greater than that for terrestrial fauna and three times that for coastal marine mammals. This rate is comparable to the range of estimates predicted for tropical rainforest communities (Ricciardi and Rasmussen 1999). Such inventories can account only for described forms and even within well-known groups such as fish, species could be going extinct before they can be classified (McAllister, Parker and McKee 1985).

Rarely is a given species imperilled as a result of a single threat and it is often impossible to tease out the intertwined effects of the many disturbances occurring within a given watershed (Malmqvist and Rundle 2002). Only seven of forty recent extinctions of North American fishes were judged to have a single cause (Miller, Williams and Williams 1989). In a more recent global analysis of fishes, Harrison and Stiassny (1999) estimated that 71 percent of extinctions were related to habitat alteration, 54 percent to exotic species, 26 percent to pollution and the rest to hybridization, parasites and diseases, or intentional eradication. On the Iberian Peninsula, habitat alteration and water pollution were identified as the most important causes of degradation of native fish communities (Aparicio, Vargas, Olmo and de Sostoa 2000), a pattern that may be typical of developed countries. Exploitation, however, may be more important as a threat to freshwater fish diversity in some developing countries (Welcomme 1979; 1985). In analyses of threats, the categories themselves often overlap, signalling the difficulty of isolating proximate causes. As any conservation planner knows, mitigating threats to freshwater biodiversity requires understanding of a complex set of biophysical interactions operating over a range of spatial and temporal scales.

Fisheries production and ecosystem conservation interests are often, but not necessarily, identical. Certainly, intensive exploitation can be detrimental to ecological integrity. A somewhat more insidious conflict arises when habitat modifications or species introductions impair ecological integrity but result in increased fisheries production. For example, reservoirs in the Sri Lanka dry zone retain significant amounts of water in the upper basin for much longer than would naturally be the case and support productive fisheries based largely on introduced tilapias. Overall, this type of modification of habitats and biota in small river basins is likely to increase basin-wide fish production (Lévêque1995; Lorenzen *et al.* 2002). However, impacts on native biodiversity and ecological integrity, although rarely quantified, are likely to be negative (World Commission on Dams 2000; Bunn and Arthington 2002; Naiman *et al.* 2002). As a result, conflicts may arise between fisheries production and related livelihood issues *versus* the maintenance or restoration of habitats and river flow patterns that are critically important from a conservation perspective.

Similar examples of divergence between fisheries and biodiversity conservation interests have been reported from North American and European rivers (Walters 1997; Arlinghaus, Mehner and Cowx 2002), in particular where modified systems favour certain species of particular fisheries or conservation interest. Hence it is important to distinguish clearly between fisheries production and conservation aspects of rivers where the former are important, particularly in a developing country context.

To provide effective support for management, river fisheries ecologists must analyse and predict processes and impacts at the level of species, assemblages and ecosystem processes, in systems of high spatial and temporal heterogeneity. This paper reviews aspects of fish biology and ecology of importance to biodiversity conservation and sustainable fisheries and provides a perspective on the role of ecological knowledge in river and fisheries management. We identify key areas where ecological information is demanded by managers and/or where scientists believe it should be taken into account. The global water crisis and the threat to riverine biota increase the necessity to deliver models that serve science, management and policy. We review the need to understand and predict river fish population and assemblage dynamics, particularly in relation to forecasting and mitigating the impacts of human activities (such as flow regulation) and sustaining fishery yields. Theoretical concepts describing river ecosystems and ecological processes sustaining biodiversity and productivity in large rivers must also progress if we are to protect and restore damaged ecosystems and sustain their fisheries production.

After reviewing recent developments, we discuss ecological approaches and tools for management decision support, methods for integrating information and novel approaches to resolving uncertainty. We conclude with a summary of major points arising from this review and the discussions held during LARS 2, beginning with general statements to emphasize the importance of rivers and fisheries and ending with a perspective on conspicuous gaps in the science discussed at LARS. Throughout this summary we highlight research priorities and new research frontiers that demand more attention in river ecosystem studies, conservation efforts and fisheries management.

THE ECOLOGICAL BASIS OF RIVER FISHERIES AND BIODIVERSITY

River hydrology and geomorphology

A fluvial hydrosystem comprises the whole river corridor - the river channel, riparian zone, floodplain and alluvial aquifer. This hydrosystem can be considered as four-dimensional, being influenced not only by longitudinal processes, but also by lateral and vertical fluxes and by strong temporal changes (Ward 1989; Arthington and Welcomme 1995). Rivers and their floodplains are disturbance-dominated ecosystems characterised by a high level of habitat heterogeneity and spatial-temporal fluxes of materials, energy and organisms are driven largely by fluvial dynamics (Tockner and Standford 2002). Fluvial hydrosystems provide corridors through the landscape (Gregory *et al.* 1991) and the marginal zones (ecotones) provide buffers between the watercourse and the variety of land uses within the catchment (Cowx and Welcomme 1998).

A river basin can be characterised in a variety of ways (Frissell *et al.* 1986). A useful broad categorisation breaks the basin into three longitudinal sections (upper/headwater, middle and lower) and two lateral sections (upland and floodplain). Floodwaters and their silt load are dispersed laterally within the middle and lower catchment, extending over the floodplain and carrying with them nutrients, organic matter and organisms. The annual (or more erratic) cycles of flooding and flow pulses ensure the connectivity of river channels and their floodplains and the silt, nutrients and organic load carried in the floodwaters form and maintain the floodplain ecosystems (Ward and Stanford 1995; Tockner and Stanford 2002).

The habitat components of the fluvial hydrosystem include the main channel with its different habitats: backwaters, side arms; floodplain lakes and wetlands; estuaries and intermittent coastal lagoons, man-made reservoirs and canals land subject to seasonal flooding and non-floodable land that nonetheless influences the quantity and quality of runoff received (Cowx and Welcomme 1998). Temporal variation in discharge and habitat heterogeneity are closely linked and such linkages span a wide range of time frames, from that of daily changes associated with short-term floods or spates, to seasonal and decadal changes (e.g. creation of oxbows and wetlands).

Hydrological variations associated with longer time frames are also important. For example, drought associated with El Nino events has been reported to greatly influence riverine and estuarine fishes in Suriname (Mol *et al.* 2000). Processes occurring over historical time spans may continue to influence contemporary riverine ecology. The Mary River of south-eastern Queensland, Australia, has cut down over 70 m into its bed in response to sea level lowering during the Pleistocene. Subsequent aggradation in the middle reaches has raised the bed by 40 m but the river remains deeply incised into the landscape (Bridges, Ross and Thompson 1990). Such conformation has consequences for the dissipation of flows during floods and may influence in-stream production by limiting light penetration. Long-term changes in discharge, channel morphology and habitat and their interrelationship, need to be carefully considered in light of projected changes in global climate.

River ecosystems and processes sustaining biodiversity and productivity

River ecologists have investigated various functional linkages among riparian, floodplain and river ecosystem components since the earliest studies on large European rivers, but it is only relatively recently that integrative frameworks have been proposed for lotic ecosystems. The initial conceptual frameworks were linear, particularly the River Continuum Concept (Vannote *et al.* 1980), modified for large rivers by Sedell, Ritchie and Swanson (1989), the idea of nutrient “spiralling” (Elwood *et al.* 1983) and the Serial Discontinuity Concept (Ward and Stanford 1983).

Junk, Bayley and Sparks (1989) formalised the “flood pulse concept” (FPC) at the first LARS meeting, distinguishing lateral processes from concepts of ecological continua along the length of rivers. According to this model, flood conditions should be associated with greater nutrient availability, aquatic primary production (dominated by macrophytes), allochthonous inputs and secondary production (especially among juvenile fishes) in floodplain habitats. The degree to which flooding occurs in phase with warm temperatures and enhanced system productivity influences selection for alternative life history strategies of fish and other biota (Winemiller 2003). In strongly seasonal floodplain systems, reproductive cycles and associated migrations of fish have evolved to exploit relatively predictable habitats and resources on the floodplain (Welcomme 1985; Lowe-McConnell 1987; Junk *et al.* 1989; Winemiller and Rose 1992). Physiological adaptation is also possible in response to seasonal fluctuations in habitat condition and patterns of distribution may be influenced by tolerance to naturally fluctuating water quality (Hickley and Bailey 1987). In aseasonal flood-pulse regimes, fish are "more challenged to respond appropriately to relatively unpredictable patterns of resource variation" (Winemiller 2003). One strategy shared by many species in highly variable systems is to spawn and recruit in main channels and backwaters under relatively low flow conditions (Humphries, King and Koehn 1999).

While the FPC has undoubtedly provided an integrating paradigm for highly diverse and complex ecological processes in river-floodplain-systems, new perspectives have emerged from studies on floodplain processes in different latitudes and continents (Junk and Wantzen 2003). Walker, Sheldon and Puckridge (1995); Dettmers *et al.* (2001) and Ward *et al.* (2001) suggest that energy flow in large river systems might best be viewed as an interaction of three concepts, the RCC (downstream transport), the FPC (lateral transport to and from floodplains) and the "riverine productivity model" of Thorpe and Delong (1994), which describes the role of autochthonous production. Some of the major new developments in floodplain theory and management include the importance of hydrological connectivity (Ward, Tockner and Schiemer 1999; Robinson, Tockner and Ward 2002; Winemiller 2003); alternatives to the "highway analogy" with respect to the ecological functions of the main river channel (Galat and Zweimuller 2001); the ecological consequences of erratic flow pulses (Puckridge *et al.* 1995); and the Multiple Use Concept developed for the central Amazon River floodplain (Junk and Wantzen 2003).

A pervasive theme in river ecology and management is the importance of hydrological variability, perceived by Walker *et al.* (1995) to operate at three temporal scales: the flood pulse (days to weeks), flow history (weeks to years) and the long-term statistical pattern of flows, or flow regime (decades or longer). Many ecologists perceive that the ecological integrity and long-term evolutionary potential of rivers and their floodplains depends upon the spatial and temporal variability of the natural flow regime (e.g. Arthington *et al.* 1992; Sparks 1992; Poff *et al.* 1997; Richter *et al.* 1997; Ward *et al.* 2001; Olden and Poff 2003). Poff *et al.* (1997) proposed the "natural flows paradigm" as a blueprint for management of river flows and river corridor restoration and several methods for determining flow regimes intended to protect or restore river ecosystems (i.e. by providing environmental flows) are founded upon it (Arthington and Pusey 2003; Arthington *et al.* 2003; Brizga *et al.* 2002; Arthington and Pusey 2003; King, Brown and Sabet 2003). Likewise, the UNESCO conceptual tool "ecohydrology" (Zalewski 2003) suggests that the sustainable development of water resources is dependent on our ability to maintain established evolutionary processes of water and nutrient circulation and energy flow at the basin scale.

The ecological roles of littoral and riparian ecotones have received much attention in the recent literature on river-floodplain studies (Naiman and Decamps 1997; Naiman *et al.* 2002). Riparian zone processes influence river fish communities by way of effects on individual fitness and species diversity, mediated by changes in light and shade, water quality, habitat quality and heterogeneity and trophic dynamics (Pusey and Arthington 2003). Sustaining the processes linking riparian and river systems is crucial to the management, rehabilitation and conservation of river landscapes (Cummins 1992; Bunn, Pusey and Price 1993;

Wissmar and Beschta 1998; Naiman, Bilb and Bisson 2000).

Riverine fish assemblages: Diversity, habitats and trophic ecology

Biodiversity

Species richness in relation to area of habitat is extremely high in many freshwater groups with an estimated 10 000 fish, 5 000 amphibians and 6 000 mollusc species dependant on freshwater habitats which account for only 0.01 percent of the earth's total aquatic habitat. Other major groups dependent upon freshwaters include bacteria, fungi, plants, additional invertebrate taxa, reptiles, birds and mammals. River conservation and management activities in most countries suffer from an inadequate knowledge of the constituent biota, especially in large, poorly investigated tropical river systems (e.g. the Amazon, Saint-Paul 2003), many Asian and southern African rivers (e.g. Dudgeon 2000; Shrestha 2003) and tropical Australian rivers (Pusey 1998).

Rivers are islands of freshwater aquatic habitat isolated from one another by terrestrial and marine ecosystems. Studies of geographic variation in riverine fish diversity have established significant relationships between species richness and catchment area or discharge (Welcomme 1985; Hugueny 1989; Oberdorff, Guegan and Hugueny 1995; Oberdorff, Huegeny and Guegan 1997; Guegan, Lek and Oberdorff 1998; Pusey and Kennard 1996). In lowland rivers of the southern llanos of Venezuela, interactions among seasonal hydrology, variability in habitat structural complexity and landscape heterogeneity appear to maintain high aquatic species richness (Arrington and Winemiller 2003). Likewise, multivariate models of fish assemblage structure in Australian rivers demonstrate the importance of catchment and local scale habitat structure and hydrological variability (Pusey, Arthington and Read 1995; Pusey, Arthington and Read 1998; Pusey, Kennard and Arthington 2000). Diversity of hydrological pattern appears to be central to the maintenance of habitat heterogeneity and species diversity (Ward *et al.* 2001; Tockner and Stanford 2002).

Alteration of water quantity, seasonal flows and patterns of flow variability (e.g. by damming and abstraction, or inter-basin transfers - IBTs) have substantial and negative consequences for the maintenance of biodiversity in many rivers (Arrington and Winemiller 2003; Pusey *et al.* 2000; Bunn and Arthington 2002). The disconnection of river channels from their floodplains also affects biodiversity (Halls, Hoggarth and Debnath 1998; Toth *et al.* 1998; Galat and Zweimuller 2001; Robinson *et al.* 2002), with the magnitude of effect likely to be greater in tropical and temperate seasonal rivers than for temperate aseasonal rivers (Winemiller 2003). The further development of macro-ecological models predicting regional variation in freshwater fish diversity remains a task of major importance, given that conservation plans to protect species from current and impending threats (such as water use and global environmental change) often seek to identify areas of highest biological importance (Oberdorff *et al.* 1995).

Genetic analysis of the major populations of fish species can reveal the geographic location, extent and connectivity of genetically distinct stocks (Hogan 2003; So and Volckaert 2003) and thus inform fisheries management and environmental impact assessments. For example, dams and barriers to fish migration may disconnect populations that now intermingle and breed freely thus leading to depression of genetic diversity (Jager *et al.* 2001; Matsubara, Sakai and Iwata 2001). IBTs may connect distinct stocks with a long history of separation, undermining their genetic integrity and long-term evolutionary potential (Davies, Thoms and Meador 1992; Bunn and Hughes 1997). Dams often reduce the extent of downstream flooding and thereby reduce the extent of connectivity between adjacent river systems, with consequences for the genetic structure of regional fish populations.

Genetic studies can assist in the identification of unique assemblages of species and genetic strains and in the management of rare, endangered, “flagship” or indicator species. Genetic analysis may also aid the identification of processes threatening the genetic integrity of metapopulations (e.g. unidirectional gene flow) and mechanisms to minimise such impacts (Jager *et al.* 2001; Matsubara *et al.* 2001). Resolution of the systematics of many groups of fishes is needed also to identify evolutionary significant units (ESUs) and to identify at what scale conservation and fisheries management strategies should be aimed (i.e. ESUs, species or species complexes) (Mayden and Wood 1995). Neglect of such fundamental investigations will inevitably result in management strategies lacking an adequate biological foundation, with loss of biodiversity and ecosystem services in the long term.

Distribution and habitat requirements

River networks have provided many opportunities for allopatric speciation of aquatic taxa and also serve as reservoirs that accumulate species over evolutionary time (Winemiller 2003). To assess the habitats, populations and communities being managed and opportunities for biodiversity conservation (Abell 2002), detailed surveys of the fish faunal composition of individual river basins are needed, including major tributary systems as well as main channels (Shrestha 2003). Ideally, such surveys should be undertaken within a rigorous quantitative framework, in order to provide meaningful and useful information on as many aspects of organism biology as possible (density, micro and macrohabitat use, population size structure) in addition to distribution at the macrohabitat scale. This type of information is proving immensely useful in devising strategies to mitigate the impacts of flow regime change in regulated rivers. Pusey (1998) and Arthington, Rall, Kennard and Pusey (2003a) have recommended fish data sets considered essential for the determination of the flow requirements of river fishes.

Specific habitat requirements of aquatic organisms may be characterized by many factors, including water depth, flow velocity, temperature and substrate. Habitat preferences of different life stages of many temperate fish species have been established and expressed in the form of preference curves. Data on habitat preferences are the crux of the earliest and most widely applied methods to predict the ecological consequences of flow regulation and water abstraction, most notably the Instream Flow Incremental Methodology (IFIM) and its physical habitat component, PHABSIM (Bovee 1982; Stalnaker, Lamb, Henriksen *et al.* 1994). As well as physical attributes, water quality factors, in-stream and bank cover (Crook and Robertson 1999; Pusey 1998; Pusey *et al.* 2000) and biotic features/processes merit more investigation to ensure suitable conditions of space, shelter and food supplies for each life history stage (Power 1992; King 2002). For example, the distribution of some species may be better predicted from knowledge of the factors that determine the distribution of food items than it is by habitat preferences defined by depth, flow and substrate composition (Petty and Grossman 1996). Habitat-centred methods for the assessment of minimal and optimal stream flow requirements are discussed in more detail below.

Trophic ecology and food web structure

Sustaining river ecosystems and productive fisheries depends upon understanding the energetic basis of their productivity, linked to the trophic ecology of fish and to food web structure. In many habitats, algae seem to provide the most important source of primary production entering the grazer web (Lewis *et al.* 2001; Winemiller 2003), even in the highly turbid rivers of Australia’s arid-zone (Bunn, Davies and Winning 2003). In contrast, fine suspended organic matter apparently fuels the food web of the constricted -channel region of the Ohio River (Thorp *et al.* 1998). Even in species-rich tropical rivers, most material transfer in food webs involves relatively few species and short food chains (3-4 levels, 2-3 links), i.e.

remarkable "trophic compression" (Lewis *et al.* 2001). Although longer food chains that involve small or rare species are common and increase ecological complexity, they probably have minor effects on total primary and secondary production (Winemiller 2003).

Seasonal rivers in nutrient-rich landscapes can sustain greater harvest than aseasonal rivers or seasonal rivers in nutrient-poor landscapes (e.g. Carvalho de Lima and Araujo-Lima 2003). However, the productivity of oligotrophic ecosystems can be enhanced by "spatial food web subsidies" (Polis, Anderson and Holt 1997; Winemiller 2003). For example, fishes that migrate out of tributaries draining the floodplain during the falling water period subsidize the food web of the flowing channel by providing an abundant food source for resident piscivores (Winemiller and Jepsen 2002). Food web subsidies can have major effects on food web dynamics, even inducing trophic cascades (Polis *et al.* 1997; Winemiller and Jepsen 1998, 2002) and stabilising complex systems (Huxel and McCann 1998; Jefferies 2000).

The food web paradigm provides an approach that allows us to model complex communities and ecosystems with the ultimate aim of understanding relationships and predicting dynamics (Woodward and Hildrew 2002). To inform management, multispecies fisheries in large rivers require a food web perspective because stock dynamics are influenced by both bottom-up factors related to ecosystem productivity and by top-down factors influenced by relative densities of predator and prey populations (Winemiller 2003). Water resource infrastructure can modify aquatic food webs by regulating downstream transport of organic carbon, modifying water transparency and changing the extent of movement of fishes throughout the riverine landscape (Jordan and Arrington 2001), such changes impacting river fisheries (Barbarino Duque, Taphorn and Winemiller 1998). Empirical models relating fish diversity to discharge (e.g. Guegan *et al.* 1998) suggest that reductions in discharge will necessarily result in reductions in diversity and this effect is, at least in part, likely to be due to changes in food web complexity (Livingston 1997).

Population Biology of Riverine Fish

Life histories

Most fish (and other exploited aquatic organisms such as crustaceans and molluscs) have complex life cycles involving several morphologically distinct, free-living stages such as eggs, larvae, juveniles and adults. In the course of their lives, many organisms will grow by several orders of magnitude in mass and their resource and other ecological requirements may change drastically. As a consequence, many aquatic organisms undergo ontogenetic shifts in habitat requirements. Even so, habitat requirements and even life cycles are not necessarily set in stone. Some species, such as tilapias (Arthington and Bluhdorn 1994; Lorenzen 2000), display considerable plasticity in their life histories and can cope well (or even benefit from) changes in habitat availability. Others show very little plasticity and may become locally extinct as a result of even small environmental changes. For example, the introduction of novel predators caused the local extinction of the Lake Eacham rainbowfish, *Melanotaenia eachamensis*, in Australia (Barlow, Hogan and Rogers 1987).

Life history characteristics of fish, including maximum size, growth rate, size at maturity, fecundity and migratory behaviour, have important implications for populations as well as their risk of extinction (Winemiller and Rose 1992; Parent and Schriml 1995; Denney, Jennings and Reynolds 2002). While life history theory has been increasingly used to assess exploitation threats to marine fish stocks arising from fishing pressure, there has been far less work on freshwater populations that face a far wider set of threats.

In the following sections we review key aspects of fish life histories and population ecology.

Habitat use and migrations

To meet the different requirements of different life history stages, most aquatic organisms require access to a variety of habitats in the course of their life cycle. This requirement has two implications: (1) a variety of habitats must exist and (2) organisms must be able to migrate between them (actively or passively). Migration requires some degree of connectivity between aquatic habitats, which can be highly fragmented and separated spatially.

Migration has evolved as an adaptive response to natural environmental variation on a daily, seasonal and multi-annual basis, with biomes and habitats visited during the life cycle and distance travelled being essential characteristics of fish migration. Migrants must respond to the right cues, travel at the right pace and arrive at their destination within a certain time interval. Embryos, larvae and juveniles must find appropriate shelter and feeding grounds in order to reach the size threshold at which they maximize their survivorship. Migration also acts as a mechanism of energy transfer ("subsidy") between biomes and ecosystems (Winemiller 2003) as discussed above. Gross, Coleman and McDowall (1988) suggest that various forms of diadromy (i.e. catadromy, anadromy) have evolved in response to differences in marine and freshwater productivity and it seems likely that the evolution of potamodromy may also reflect spatial differences in aquatic production within river networks.

Many fisheries in large rivers are based mainly on migratory species. For example, medium to large-sized characiforms with wide distribution on the floodplains of the Amazon/Solimões and other rivers migrate by descending the nutrient-poor, clear and black-water rivers to spawn in the nutrient-rich, white-water rivers that originate in the Andean ridge. The high abundance attained by these species may be a consequence of their tactic of migrating towards nutrient-rich habitats to spawn and using floodplain habitats as nursery grounds (Carvalho de Lima and Araujo-Lima 2003). The study of fish migrations has emerged as a key area of fisheries research in the Mekong River Basin (Warren, Chapman and Singhanouvong 1998; Baird, Flaherty and Phylavanh 2000). Preliminary evidence suggests that changes in fishing activities in Cambodia may have resulted in changes in fish catches in southern Laos (Baird and Flaherty 2003), highlighting the need for fish management strategies that transcend national jurisdictions.

Similarly, in rivers where diadromous fishes are an important component of the overall riverine fishery, management strategies (and river fisheries valuation studies) need to transcend the distinction between freshwater, estuarine and marine habitats and to more properly consider critical chains of habitats. Over-exploitation of piscivorous migratory species in marine or estuarine systems may potentially affect far-removed populations of fishes in freshwaters by altering top-down processes of regulation (Winemiller and Jepsen 2002). Fully integrated (freshwater/estuary/coastal) biological monitoring programs would address these dependencies but appear to be lacking in most large river systems, even though the close relationship between discharge and coastal fish production has been documented in both temperate and tropical rivers (e.g. Loneragan and Bunn 1999 and references therein).

Determination and regulation of abundance

Management for both exploitative and conservation purposes requires an understanding of the dynamics of populations as a whole. Losses, through emigration and death and gains, through immigration and birth, are integral to an understanding of population dynamics and have received much attention in the ecological literature (Humphries *et al.* 1999).

The abundance of fish populations is determined by a combination of density-dependent and density-independent factors. Compensatory density dependence regulates the abundance of populations and its magnitude has important implications for the population dynamics of exploitation and disturbances (Rose *et al.* 2001). The sustainable exploitation of populations is possible only because populations compensate for the removal of animals by density-dependent improvements in natural mortality, growth and reproductive rates. Likewise, populations can compensate for the loss of individuals as a result of pollution and other environmental catastrophes. Density-dependence has been detected in mortality, growth and reproductive traits of fish populations (Bayley 1988b; Rose *et al.* 2001). While traditional age-structured models of fish population dynamics assume that regulation occurs predominantly through density-dependent mortality at the juvenile stage, recent studies have pointed to the importance of density-dependent growth and reproductive parameters in the recruited population (Post, Parkinson and Johnston 1999; Lorenzen and Enberg 2002). Regulation in the late juvenile and adult population implies a greater potential to compensation for increased mortality rates in juveniles (e.g. as a result of juvenile habitat loss, or losses due to entrainment), but also lower potential benefits of increasing juvenile survival or abundance (e.g. by stocking of hatchery fish) as compared to populations regulated only at the juvenile stage. A good quantitative understanding of regulatory mechanisms is therefore important to management and conservation decisions, but our knowledge base in this respect remains relatively poor.

The relative importance of density-dependent and density-independent processes in determining population abundance is difficult to assess and model. This is particularly so in river systems characterized by extreme environmental variability, where disturbance can be a major factor (Reeves *et al.* 1995). Recovery from disturbance is typically rapid in temperate fish populations, although rates of recovery vary according to the types of disturbance (i.e. pulse or press) (Detenbeck *et al.* 1992; Winemiller 1989b, 1996; Winemiller and Rose 1992).

Population processes

Reproduction and recruitment

Various recruitment models or hypotheses have been put forward, attempting to explain how fish in early life history stages encounter sufficient quantities of food of the right size, while avoiding predation. One of the pre-eminent hypotheses is the “match/mismatch” hypothesis of Cushing (1990), which recognizes that fish spawn at approximately the same time each year, but that prey abundance is less predictable and more responsive to the vagaries of oceanic conditions. Thus, in years when larvae and prey coincide or ‘match’, there will be strong recruitment, whereas in years when larvae and prey do not coincide (‘mismatch’), there will be poor recruitment. Under experimental conditions in dry season waterbodies in Bangladesh, Halls *et al.* (2000) found the recruitment of a typical floodplain fish to be strongly dependent upon both spawning stock biomass (egg density) and biolimiting nutrient concentrations. These responses were believed to reflect cannibalism by adult fish on larvae and juveniles, competition for shelter from predators and the abundance of food organisms for developing larvae.

Harris and Gehrke (1994) proposed a ‘flood recruitment model’ similar to the flood pulse concept (Junk *et al.* 1989), to explain how some species of fish in the Murray-Darling Basin, Australia, respond to rises in flow and flooding. Humphries *et al.* (1999) questioned the generality of this model, based mainly on the fact that flooding in large areas of the Murray-Darling Basin does not coincide with peak spawning times for many species and there are no published accounts of larvae being found on the floodplain. Whilst not dismissing the potential importance of the floodplain, Humphries *et al.* (1999) proposed the ‘low flow recruitment hypothesis’, which describes how some fish species spawn in the main channel and backwaters during periods of low flow and rising water temperatures. Ironically, only the introduced carp

(*Cyprinus carpio*) seemed to respond to flood events in the Murray-Darling system with a renewed bout of spawning. More recently, King (2002) proposed five reproductive strategies among fishes of Australian floodplain rivers (generalists, flood opportunists, low flow specialists, main channel specialists and floodplain specialists).

Establishment and defence of territories, feeding, cues for reproduction and rearing of young are all critical for the production of the next generation. Yet our ignorance of these processes and how they are affected by environmental disturbances caused by the actions of humans is profound.

Mortality

Numerous and often interacting factors affect natural mortality rates in fish (including predation, disease, starvation, abiotic factors, spawning stress and senescence), yet our understanding of the importance of different sources of mortality remains poor, particularly for riverine fish. Mortality is strongly dependent on body size in fish (Lorenzen 1996). It is greatest in early life history stages, where variation in mortality rates plays a major role in determining the strength of cohorts. Whereas predation and starvation are assumed to be the primary reasons for high mortality, information on the links between these processes and alteration to the natural environment is virtually non-existent. Overall mortality rates decline as juveniles grow, but mortality at the juvenile stage is generally believed to be most strongly density-dependent. Moreover, juveniles may also disperse considerable distances and thus are vulnerable to artificial barriers and other anthropogenic as well as natural threats (Gallagher 1999).

The juvenile stage in fishes is often the most difficult to study and hence knowledge of this stage (including mortality rates and the factors influencing them) remain particularly poor. In seasonal river-floodplain systems, extremely high density-dependent and density-independent mortality rates may be associated with the period of receding water levels, when fish may become stranded and densities in remnant water bodies can increase by several orders of magnitude relative to flood conditions (Welcomme 1985; Halls 1998). This seasonal mortality pattern has major fisheries management implications. Intensive harvesting during receding floods may replace rather than add to the high natural mortality at this stage and consequently, floodplain fisheries may be able to sustain very high levels of exploitation during the recession phase. Conversely, however, these fisheries may be very vulnerable to exploitation of the remnant dry season stocks that form the basis for future recruitment.

Growth

Body growth is an important population process in fish, because it has a major impact on population biomass development as well as reproduction. Growth in river and floodplain fish is strongly influenced by environmental conditions, including hydrology (Bayley 1988a and b; De Graf *et al.* 2001), food resources and population density (Halls 1998; Jenkins *et al.* 1999). In at least one highly channelized river (Kissimmee River, Florida, USA), the restoration of a more natural hydrologic regime has resulted in increased growth rate and maximum size of a target game fish, *Micropterus salmoides* (Arrington and Jepsen 2001).

Population dynamics

There are two aspects that set the dynamics of river-floodplain fish populations apart from those of fish populations in other habitats: the strong influence of hydrological variation and the dendritic structure of riverine metapopulations (Dunham and Rieman 1999).

The influence of hydrology on population dynamics is most striking in seasonal floodplain systems where aquatic habitat may expand and contract by over three orders of magnitude and populations may respond with extreme cycles of production and mortality (Welcomme and Hagborg 1977; Halls, Kirkwood and Payne 2001; Halls and Welcomme 2003). As a direct consequence of this response, floodplain fish stocks can withstand very high levels of harvesting during the period of receding waters. Indeed, simulation studies described by Welcomme and Hagborg (1977) and Halls *et al.* (2001) both indicate that yields from floodplain fisheries can be maximized by removing a significant proportion (up to 85 percent) of the population just prior to the draw-down period. Perhaps not surprisingly, this corresponds to the period of maximum fishing activity in most floodplain fisheries (de Graaf *et al.* 2001).

Overall, quantitative modelling of population dynamics in relation to habitat factors, such as hydrological variables and land use change, is a relatively recent development (Welcomme and Hagborg 1977; Peterson and Kwak 1989; van Winkle *et al.* 1998; Jager, van Winkle, Holcomb 1999; Gouraud *et al.* 2001; Halls *et al.* 2001; Lorenzen, de Graf and Halls 2003a; Halls and Welcomme 2003; Minte-Vera 2003). Whilst validation of the models is required, good fits have been achieved using long time-series data sets from Bangladesh. Individual-based simulation models provide a powerful means of exploring any effects of different hydrological conditions on the dynamics and production of riverine fish, providing valuable insights to improve water use management at local and basin-wide scales. More work is required, in particular with respect to systems where large-scale hydrological modifications are likely in the future and/or restoration of natural hydrological regimes is but a distant possibility (i.e. in many areas of the developing world). However, even in pristine or restored river systems, climate change is likely to lead to significant hydrological change within the next few decades and understanding population responses to such changes will become increasingly central to fisheries management and conservation.

Most river fish populations have a metapopulation structure, i.e. they are comprised of local-scale sub-populations that are subject to relatively frequent extinction and re-colonization (Schmutz and Jungwirth 1999; Matsubara, Sakai and Iwata 2001). Gotelli and Taylor (1999) show that conventional metapopulation models that do not account for gradients may poorly describe the behaviour of riverine metapopulations. Connectivity patterns in river systems differ from those found in terrestrial habitats. The dendritic structure of the river habitat implies that fragmentation of rivers results in smaller and more variable fragment sizes than in two-dimensional landscapes and a possible mismatch on the geometries of dispersal and disturbance (Fagan 2002). As a result, fragmentation of riverine habitats can have more severe consequences for population persistence than would be predicted from models for two-dimensional landscapes.

Anthropogenic Impacts on River Ecology and Fisheries

Many types of river ecosystem have been lost and populations of many riverine species have become highly fragmented due to human intervention (Dynesius and Nilsson 1994; Bunn and Arthington 2002). Over three quarters of the 139 major river systems in North America, Mexico, Europe and Republics of the former Soviet Union are affected by dams, reservoir operation for different purposes, interbasin diversions and irrigation (Dynesius and Nilsson 1994). The range of human activities known to damage and degrade river systems includes: (1) supra-catchment effects such as inter-basin transfers of water, acid deposition, climate change, (2) catchment land-use change, (3) river corridor ‘engineering’ and (4) in-stream impacts (Boon, Calow and Petts 1992; Arthington and Welcomme 1995; Junk 2002). Increasingly, aquatic ecosystems are being impacted by recreation and tourism (Mosisch and Arthington 1998). The following sections briefly review anthropogenic impacts on river ecosystems and fisheries and measures for the mitigation of impacts.

Supra-catchment effects

Supra-catchment effects such as acid deposition, inter-basin transfers and climate change increasingly affect river ecosystems and fisheries in multiple catchments and bioregions simultaneously. Acidification of surface waters has caused a suite of new pollution problems in industrialized areas, with massive impacts on aquatic habitats and fisheries (Brocksen and Wisniewski 1988). The general effects of toxic pollution and acidification are first, the elimination of the most sensitive aquatic species and, as the loading increases, the production of large tracts of river that do not support fish. Climate change affects temperature, but most importantly the spatial and temporal distribution of rainfall and consequently river hydrology and ultimately geomorphology, habitat and biotic processes. Climatic or man-made changes to the environment may compromise finely adapted fish reproductive and migratory strategies, to an extent largely depending on the intensity and recurrence of the perturbation and on the adaptability of the species.

Catchment land-use and river corridor engineering

Changes in catchment land-use affecting rivers include afforestation and deforestation, urbanisation, agricultural development, land drainage and flood protection. Corridor engineering includes flow and flood transformation by dams, weirs and levees, channelization and dredging, water abstraction and the removal or deterioration of riparian vegetation.

In many river systems land use change and corridor engineering are the most important factors affecting fish ecology and fisheries. These impacts arise primarily from changes in habitat availability (both quantity and quality) and habitat connectivity (Trexler 1995; Toth *et al*. 1995; Toth, *et al*. 1998; Bunn and Arthington 2002; FAO 2000). Loss of habitat connectivity has resulted in the local extinction of many migratory species including shads, salmonids and sturgeons (Boisneau and Mennesson-Boisneau 2003; Faisal 2003; Fashchevsky 2003; Gopal 2003) and the diminished abundance of floodplain migrant species (Halls *et al.* 1998). Many rivers still face the threat of loss of connectivity and its ecological consequences. For example, the largest dam in the world, the Three Gorges Dam in the Yangtze River basin of China, will create a reservoir 600 km in length, reaching from Sangliping to Chongqing. Closure of this dam will cause blockage of fish migrations, extensive loss of riverine habitat and profound ecological changes that will threaten fish biodiversity in the river (Fu Cuizhang *et al.* 2003).

The impacts of hydrological change (e.g. by damming of rivers) may affect individual fish in any history stage, biotic assemblage structure and ecosystem processes. These impacts have been observed at multiple spatial and temporal scales (World Commission on Dams 2000; Bunn and Arthington 2002). Only a brief review of key issues can be provided here. Pulsed reservoir discharges associated with on-demand hydroelectric power generation limit the quality and quantity of habitat available (Valentin *et al.* 1994), causing fish to become stranded on gravel bars or trapped in off-channel habitats during rapid decreases in flow. The timing of rising flows serves as a cue to the spawning of certain fish species and loss of these cues may inhibit reproduction (King, Cambray and Dean Impson 1998), whereas cold-water releases from dams have been found to delay spawning by up to 30 days in some fish species (Zhong and Power 1996) or even inhibit spawning entirely. Larval development can be inhibited by cold-water releases. Furthermore, anoxic waters are often released from reservoirs in which the vegetation has not been removed prior to filling (e.g. Petit Saut Dam, Sinnamary River, French Guyana), causing mortality in many river species. Changes in river hydrology that are not in natural harmony with seasonal cycles of temperature and daylength may influence many critical life history events and have negative impacts on fish and other biota (Bunn and Arthington 2002). Natural flood regimes (and other aspects of the natural flow regime) are critical for maintaining biodiversity and fisheries, especially in strongly seasonal systems (Welcomme 1985; Junk *et al.* 1989; Winemiller 2003), but also in rivers with less predictable flooding regimes (Puckridge *et al.* 1998; Pusey *et al.* 2000). Ecological restoration of hydrologically degraded river floodplain systems should pay careful attention to restoration of the historical hydrologic regime including natural periods of low and high flow and periodic extreme flood and drought events (Toth *et al.* 1997).

In-stream impacts

Exploitation

Many fisheries, particularly in the tropics, exploit a wide range of species. In such multi-species fisheries, the relationship between total effort and long-term total yield (obtained from a range of different species) tends to be asymptotic, i.e. yield increases initially with effort but approaches a constant maximum over a wide range of higher effort levels (Welcomme 1985, 1999; Lae 1997). This is because, as exploitation increases, large and slow-growing species are depleted and replaced by smaller, fast-growing species that can produce high yields even at very high levels of exploitation. Even though multi-species yields can be maintained at very high levels of fishing effort, it is neither economically nor ecologically desirable to operate at very high effort. Economically, the returns to individual fishers tend to diminish with increasing effort (albeit not linearly) and at the level of the overall fishery, unnecessarily high levels of resources are expended to achieve the same fish catch that would be achieved at much lower effort levels. However, where access is open and opportunity costs are low, fisheries tend to be over-exploited in this way. The small fast-growing species that dominate catches at high effort levels are usually less valuable in monetary terms than the large species they have replaced, but the nutritional value of small fish eaten whole is extremely high (Larsen *et al. 2000;* Roos *et al.* 2002). Ecologically the overexploitation of larger species - “fishing down” the food web (Pauly *et al.* 1998) is obviously undesirable because it may threaten the very existence of some of these species. Of course, even multi-species yield must decline at very high levels of fishing effort (when even the most productive species are overexploited), but whether this point has been reached in many fisheries is questionable.

Recreational fisheries tend to have less drastic impacts than food fisheries in that the target species are generally limited and when these species are overexploited there are rarely shifts to smaller elements of the community. It is also likely that loss of much genetic variability occurs before a species is eliminated from the fishery or the community. Total disappearance of species through this process is comparatively rare, although in some cases such as the Oueme River in Benin, Africa, species (e.g. Nile perch, *Lates niloticus*) have become commercially and ecologically extinct at the local scale (Welcomme 1999). Where biological extinctions follow, this is usually the result of combined environmental and fishing pressures.

Introduced species

With progressive deterioration of native fish stocks as a result of over-exploitation and other environmental impacts, many countries have turned to exotic species as substitutes, rather than addressing the underlying causes of fisheries degradation (Welcomme 1988). In many instances fish have been introduced to satisfy local anglers with strong preferences for exotic angling species of international repute (e.g. salmonids and bass). Fish have also been introduced deliberately for pest and disease control (especially the mosquito fishes), as ornamental species for aquariums, parks and botanic gardens (Lobon-Cervia, Elvira and Rincon 1989; Arthington 1991) and as a source of protein for human populations (e.g. tilapias, carps). Fish introduced for fish-farming have also escaped and colonised local waterbodies and even most of some large drainage basins (e.g. carp in the Murray-Darling Basin, Australia).

The major modes of impact associated with introduced fishes (both exotic and translocated) are genetic effects via hybridisation, alterations of habitat and water quality, consequences to native populations of competition for space and food and from predation and impaired health from imported parasites and diseases (Moyle and Light 1986; Arthington 1991; Pusey *et al.* 2003). Environmental impacts due to introduced fishes frequently exacerbate the effects of over-fishing, river regulation, habitat destruction and water pollution and these disturbances themselves often provide ideal conditions for introduced species (Arthington, Hamlet and Bluhdorn 1990; Bunn and Arthington 2002). However, despite decades of empirical studies and some experimental work, our capacity to predict the species most likely to become established, spread and impact of introduced species is still very limited (Moyle and Light 1996; Williamson and Fitter 1996). Many countries have used risk assessments to identify potentially invasive species (see Arthington *et al.* 1999; Leung *et al.* 2002) and then placed restrictions on the range of species imported from other continents. The translocation of native fish species that are not endemic to particular basins should also be restricted (Pusey *et al.* 2003).

Fisheries enhancement and supplementation

Aquaculture-based fisheries enhancement and supplementation programs are frequently used in river and floodplain systems. Such programmes may serve a variety of purposes, from supplementation of indigenous populations for conservation to culture-based fisheries of exotic species exclusively for fisheries production (Cowx 1994; Welcomme and Bartley 1998). Particularly common are programmes to maintain populations of large migratory species threatened by loss of habitat connectivity (e.g. salmonids, sturgeons, major carps) and/or to enhance fisheries production in storage reservoirs and floodplain habitats. There are good examples where the stocking of hatchery fish has contributed to the conservation or restoration of populations (Philippart 1995), or led to substantial increases in fisheries production with little environmental cost (Lorenzen *et al.* 1998). However, many aquaculture-based enhancements have proved ineffective and/or ecologically and genetically problematic (Meffe 1992; Lorenzen in press). Compensatory density-dependent mechanisms imply that stocking into naturally reproducing populations tends to reduce vital rates (growth, survival, reproduction) of wild fish unless their density is far below the environmental carrying capacity. Stocking of hatchery fish may also increase the transmission of infectious diseases or introduce new diseases into wild stocks. Genetic risks to natural populations arise from low effective population size of hatchery-reared fish (leading to inbreeding depression) and from loss of local genetic distinctiveness and adaptation if hatchery fish are not derived from local populations (leading to outbreeding depression). Where exotic species are used for enhancement, this may give rise to strong and sometimes unexpected ecological interactions with native species, as well as to hybridization between the exotic and related native species (Arthington and Bluhdorn 1996). However, there is little evidence for the common assumption that ecological and genetic risks of stocking native species are necessarily lower than those of stocking exotics (see also Pusey *et al.* 2003). Potential and actual benefits and risks of any stocking programme should be assessed carefully and there are now several frameworks to assist in this task (Cowx 1994; Lorenzen and Garaway 1988).

Aquaculture

Aquaculture is the farming of aquatic organisms, usually confined in facilities such as ponds or cages. Where cultured organisms escape into natural systems in significant numbers, this may raise ecological and genetic concerns similar to those encountered in fisheries enhancement and supplementation (Arthington and Bluhdorn 1996). Most aquaculture systems rely on external inputs of feeds and/or fertilizers and large-scale aquaculture can be a significant source of nutrient pollution (Baird *et al.* 1996).

Conservation, Mitigation and Rehabilitation Priorities

The global assessments of the World Resources Institute (Revenga *et al.* 2000), the IUCN (Darwall and Vié 2003) and others (Miller *et al.* 1989) all indicate the serious vulnerability and degradation of inland water habitats world-wide. To address these issues, three levels of intervention - preservation/protection, mitigation and rehabilitation/restoration - are appropriate for the protection of lotic systems, depending upon the degree and type of modification and the level of investment society chooses to make. Here we review methods, opportunities and progress with river conservation, mitigation and rehabilitation.

Identifying conservation areas

There is widespread agreement that it is far cheaper for society to prevent degradation of rivers and their floodplains in the first place than it is to restore degraded aquatic ecosystems. The first challenge for managers and policy makers is therefore to review the legislative and institutional background to biodiversity conservation and river protection and then to identify and protect relatively undisturbed large rivers and river basins that are representative of the world's lotic biodiversity (Arthington *et al.* 2003a). Apart from their heritage values, conserved rivers and wetlands will serve in the future as the major sources of propagules and colonists for degraded rivers and wetlands that have already lost much of their biological diversity (Frissell 1997; Arthington and Pusey 2003). Clearly a method is needed for prioritising inland water sites for conservation at both local and regional scales.

Several major conservation organisations, including WWF and The Nature Conservancy, identify priority areas and strategies through ecoregion planning (Groves *et al.* 2002; Abell *et al.* 2002). Conservation strategies formulated at the ecoregional scale have the potential to address the fundamental goals of biodiversity conservation: (1) representation of all distinct natural communities within conservation landscapes and protected-area networks; (2) maintenance of ecological and evolutionary processes that create and sustain biodiversity; (3) maintenance of viable populations of species; and (4) conservation of blocks of natural habitat that are large enough to be resilient to large-scale stochastic and deterministic disturbances as well as to long-term changes. Freshwater ecoregions have been delineated largely on the basis of fish distributions and planning approaches incorporating the broader dynamics of freshwater systems are evolving (Abell *et al.* 2003). Areas of future work include, but are not limited to, designing strategies to address threats posed by supra-catchment stresses and by catchment land uses. While supra-catchment impacts cannot be mitigated through the designation of traditional protected areas, there is largely untapped potential to develop protected areas to address terrestrial impacts.

Based on a review of existing site prioritisation schemes such as the ecoregion approach, as well as on consultations with experts, the IUCN Species Programme has developed an integrative method for terrestrial, marine and freshwater ecosystems (Darwall and Vié 2003). Similar approaches are being instituted in Australia (Dunn 2003), the UK (Boon 2000) and elsewhere.

Focal species protection

Species-focused conservation measures are particularly important where threatened species cannot be conserved through protected areas. This is the case for many of the large migratory species spending much of their life cycle outside protected areas and those that may also be heavily exploited. Species-focused strategies will typically involve multiple measures like protection of key habitats and provision of passage facilities (Galat and Zweimuller 2001), as well as restrictions on fisheries exploitation. Chang *et al.* (2003) used an adaptive learning algorithm, the self-organizing map (SOM) to pattern the distribution of endemic fish species found in the Upper Yangtze and to identify alternative reserve areas for their conservation.

Mitigation

Attempts to mitigate, rather than remove, existing threats are probably the most common approach to conservation of river resources. Most mitigation measures aim to retain something of the original diversity of the ecosystem.

Only very limited mitigation or compensation for supra-catchment effects can be carried out at the level of aquatic ecosystems, such as liming of water bodies affected by acid deposition, or management of regulated rivers to compensate for hydrological effects of climate change.

A range of mitigation measures is available for effects of catchment land use and river corridor engineering. These include buffer strips to protect rivers from direct agricultural runoff, agricultural land and waste management to minimize erosion and pollution (Large and Petts 1996). A wide range of habitat protection and creation techniques have been described (Cowx and Welcomme 1998), although their effectiveness in achieving biological conservation objectives requires further investigation. Details in the design and operation of dams, weirs and flood control embankments can make a great deal of difference to the integrity of riverine ecosystems Larinier, Trevade and Porcher 2002; de Graaf 2002). Much experience is available now in the design of fishways (Larinier *et al.* 2002, FAO/DVWK 2002), although this is focused on temperate climates and the common designs may not be appropriate for tropical systems. Other measures include creation of spawning substrate for focal fish species (e.g. salmonids), instituting fish stocking programs, providing simulated flood discharges and flushing flows for particular ecological and water quality objectives (Reiser, Ramey and Lambert 1989) and implementing more comprehensive flow prescriptions to protect river ecosystems (for method see Arthington *et al.* 2003a and b; King *et al.* 2003). Maintenance or restoration of key hydrological patterns is crucial to conservation and methods for assessing such patterns are discussed in section 5. Large rivers can be protected from further deterioration by limiting development on the floodplains, prohibiting mainstream dams and limiting activities designed to constrain the main channel, such as dredging, straightening and hardening of banks.

Exploitation impacts are addressed by regulating fishing activities through restrictions on total effort, gear types and seasonal or spatial closures. In multi-species fisheries, determining appropriate exploitation levels is difficult even in principle because vulnerability to fishing differs greatly between species that may be harvested fairly indiscriminately by fishing gear. Even moderate levels of overall effort may be too high for the most vulnerable (usually long-lived) species, while aggregated yields may be maximized at much higher effort levels. The inherent problem of deciding what level of exploitation is sustainable or desirable (Rochet and Trenkel 2003) is further confounded by the practical difficulties of assessing exploitation status and options in often data-poor inland fisheries. Methods for assessing exploitation are reviewed in section 5, while the human aspects of managing fisheries are dealt with in other chapters of this volume.

Worldwide, fish introductions and translocations are strongly restricted by national and international laws and codes of conduct. Where such measures are considered, a risk assessment should be conducted following established frameworks such as those reviewed by Coates (1998).

Rehabilitation and restoration

Rehabilitation and restoration are assuming a high profile in many countries as an extension of soil conservation programs and initiatives to improve water quality. Interventions focused on the morphology of river systems are also increasing (Brookes 1992; Clifford 2001), for instance by restoring portions of the floodplains by local piercing of dykes, setting back levees from the main channel and removing revetments and wing dykes from river banks. Many of these strategies are based on the recognition of the importance of connected side-arm channels and their role in sustaining the fish biodiversity of large rivers (Humphries *et al.* 1999; Brosse *et al.* 2003). Adequate protection and management of riparian zones, based on sound ecological principles, is another effective strategy for addressing many existing problems of river ecosystem degradation (Bunn *et al.* 1993; Kauffman *et al.* 1997) and is essential to the maintenance and management of freshwater fishes (Pusey and Arthington 2003). However, various studies have produced conflicting results regarding the relative impacts to aquatic ecological integrity of land uses in the riparian zone versus activities in the wider catchment (Hughes and Hunsaker 2002).

Numerous examples of how these and other restorative measures have been implemented exist, principally from developed countries. Among the most famous is the ongoing restoration of the channelled Kissimmee River in Florida, which involves integration of hydrological, hydraulic and water quality principles with concepts of ecological integrity (Koebel, Harris and Arrington 1998). The primary goal of the project is to re-establish the river's historical flow characteristics and its connectivity to the floodplain (Toth *et al.* 1993). A method for rehabilitating smaller rivers has been articulated in the stepwise ("Building Block") approach (Petersen *et al.* 1992) and there is a growing literature on principles and guidelines for river corridor restoration (e.g. Ward *et al.* 2001).

Ecological Approaches and Tools for Management Decision Support

The conservation of river ecosystems and the sustainable exploitation of their fisheries require integrating ecological knowledge into river and fisheries management. In this section we review approaches and tools for making such ecological knowledge available to management and decision processes.

The challenge of providing ecological decision support

There are four important requirements for effective decision-support tools: (1) tools must be relevant, i.e. they must address the specific issues encountered by decision makers; (2) tools must be scientifically and ecologically sound, i.e. they must reflect current knowledge including uncertainties/ ignorance; (3) tools must be practical, i.e. they must be easily parameterised and understood; and (4) tools must be appropriate in the context of the decision-making process, i.e. they must be usable by some of the stakeholders involved and should be transparent to most. Failure of any management approach or tool to satisfy these criteria will render it ineffective. This implies that factors such as the degree of stakeholder participation in management and the extent of local ecological knowledge are just as important to consider in the design of decision-support tools as the underlying ecology.

Habitat-centered assessment

Many approaches for assessing ecological impacts of corridor engineering and other disturbances focus on habitat availability and suitability rather than aquatic population abundance or assemblage structure as such (e.g. Clifford 2001). This reflects the reasonable (but not always accurate) assumption that populations are likely to persist as long as habitats are maintained. Predicting population or assemblage dynamics is a complex task and will introduce additional uncertainty, without necessarily producing additional insight into the problem at hand. However, it is unlikely that any single assessment of habitat will encompass the myriad different ways or scales at which habitat is perceived or used by aquatic organisms. There is always the potential for a habitat-based approach to define a reach as suitable for one taxon but completely unsuitable or less suitable for another and in the case where the former taxon is critically dependent on the latter, it is unlikely that a good conservation outcome will be achieved. The maintenance of a desired proportion of "optimum habitat" at a series of river reaches may result in the situation where it is impossible to simultaneously accommodate each reach because of spatial variation in the overarching factor determining habitat suitability (i.e. discharge). Habitat-centred assessments may not be sufficiently holistic in outlook to advise managers strategically.

Nonetheless, habitat approaches have value in identifying critical elements for individual species. For example, discharge-based modelling of habitat structure may be used to identify the magnitude of critical flow events necessary to allow the passage of migratory species. In addition, time series of habitat suitability based on the flow duration curve may be useful (Tharme 1996) in assessing the importance (defined by the frequency of occurrence) of particular conditions or the desirability of maintaining such conditions. In her discussion of physical habitat/discharge modelling, Tharme (1996) recommended that a wide array of trophic levels be included so as to improve the generality of habitat-based assessments.

Some larger-scale habitats, such as floodplains, are accepted as being important to a wide range of riverine biota. In this case, assessments of habitat availability, for example through combinations of hydrologic and terrain topographic modelling, may present a useful approach.

Modeling fish populations and assemblages

Empirical models

Empirical models are statistical representations of variables or relationships of interest, without reference to underlying processes. Average fisheries yield per area estimates (e.g. from different habitat types) may be regarded as the simplest of empirical models, but can be extremely useful in decision-making about habitat protection or creation (Jackson and Marmulla 2001; Lorenzen *et al.* 2003b).

Most empirical models are regression models that relate parameters such as yield, abundance, or diversity to one or more factors of interest, usually exploitation intensity (effort) and/or environmental characteristics. Regression models are appropriate for comparative studies involving independent observations, while time-series models are appropriate where data are auto-correlated (i.e. time series of observations from a single system). Fishing intensity tends to be the single most important factor determining yields in comparative studies of floodplain rivers (Bayley 1989) and lagoons (Joyeux and Ward 1998). However, hydrological factors may be dominant in system-specific models, particularly where fishing effort is either stable or itself related to hydrology (as in the floodplains of Banglasdesh). Empirical models relating river or estuarine fisheries yields to hydrological variables such as discharge have been derived for many systems (e.g. Welcomme 1985; Loneragan and Bunn 1999; de Graaf *et al.* 2001).

Rule-based and Bayesian network models

Rule-based and Bayesian network models are logical representations of the relationships between cause and effect variables, hence they occupy an intermediate position between purely empirical models and mechanistic (e.g. population dynamics) models. In the case of Bayesian networks, probability distributions are attached to all variables and the distributions of response variables are modified by applying Bayes theorem (Jensen 1996). Bayesian network models for predicting (co)-management performance are described by Halls *et al.* (2001b). These models use multidisciplinary explanatory variables to predict a range of performance measures or outcomes, including sustainability, equity and compliance and are designed to support adaptive management approaches. Baran, Makin and Baird (2003) present a Bayesian network model to assess impacts of environmental factors, migration patterns and land use options on fisheries production in the Mekong River. The natural production levels that can be expected for each fish group (black fishes, white fishes and opportunists and three geographic sectors (Upper Mekong, Tonle Sap system and the Mekong Delta), are qualitatively expressed by a percentage between “bad” and “good”. Such a result can be converted into tons of fish when statistical time series are available.

Bayesian network models are increasingly being incorporated into decision support systems for the determination of river flow regimes that will sustain river ecosystems and their fish populations (Arthington *et al.* 2003a and b).

Population dynamics models

Population dynamics models have been central to decision analysis in marine fisheries management for a long time, but they have not been widely used in rivers. This is likely to reflect differences in management requirements (annual setting of exploitation targets in marine fisheries versus more focus on environmental factors and a longer term perspective in freshwater systems) and the fact that models developed for marine fisheries are largely unsuitable for addressing the river fisheries issues.

The development of models addressing the linkages between fish populations and abiotic processes central to the management of rivers for fisheries began with Welcomme and Hagborg’s (1977) model. Over the past few years, there has been an upsurge of interest in population models for river and floodplain fish stocks. Halls *et al.* (2001a) and Halls and Welcomme (2003) present an age-structured model incorporating sub-models describing density-dependent growth, mortality and recruitment to explore how various hydrographical parameters affect the dynamics of a common floodplain river fishes. The results of the simulations offer insights into hydrological criteria for the maintenance of floodplain-river fish faunas and can be used to design appropriate flooding regimes that maximise benefits from the water available. Minte-Vera (2003) developed a lagged recruitment, survival and growth model (LRSG - Hilborn and Mangel 1997) for the migratory curimba *Prochilodus lineatus* (Valenciennes 1847) in the high Paraná River Basin (Brazil), with recruitment as a function of flood and stock size. Distributions obtained were used to evaluate the risk to the population from various fisheries and dam-operation management decisions. Lorenzen *et al.* (2003a) developed a biomass dynamics model for fisheries and hydrological management of floodplain lakes and reservoirs. The model accounts explicitly for production and catchability effects of water area fluctuations. Models of population dynamics in relation to flow in non-floodplain rivers have been developed by van Winkle *et al.* (1998); Jager *et al.* (1999); Peterson and Kwak (1989) and Gouraud *et al.* (2001).

Model development and testing are still at a relatively early stage; more validation is required and the relative importance of compensatory processes remains largely uncertain. However, initial results appear promising, particularly with respect to biomass dynamics and dynamic pool models. Certainly, density-independent effects on fish populations require further investigation, particularly the effect of different flooding patterns on primary and secondary production per unit area or volume flooded. Other factors such as the influence of hydrology on processes such as spawning success need further evaluation and consideration in models of this type.

Many tropical river-floodplain fisheries are inherently multi-species and multi-gear fisheries. In such systems it is difficult to manage species in isolation, due to technical and biological interactions. Technical interactions arise because a range of species are harvested by the same fishing gear and it is not therefore possible to optimize exploitation for individual species independently. Biological interactions arise from predation and competition. The assessment of multi-species fisheries remains a major challenge, but several tools are now available to aid their analysis. Technical interactions can be analyzed using BEAM4 (Sparre and Willmann 1991) for river fisheries applications see Hoggarth and Kirkwood (1995). The ECO-

PATH family of models has emerged as a widely used tool for assessing biological interactions. Often, however, data available for river fisheries will be too limited to allow even simple applications of such models. Simple and robust indicators for assessing such fisheries based on aggregated catch/effort and possibly size structure or species composition data should receive more attention. All of the models discussed above focus on the dynamics of populations at relatively high abundance, where populations are subject to compensatory density dependence and demographic stochasticity can be ignored. Such models are important to decision-making in fisheries management contexts, but the dynamics of populations at risk of extinction are not captured well. Methods of population viability analysis have been used to prioritize salmon stocks for conservation (Allendorf *et al.* 1997), but further development of these approaches for freshwater fish populations is highly desirable.

Integrating information

The integration of biological and environmental data in models (conceptual, rule-based, statistical, predictive) is increasingly being used to underpin audits of aquatic ecosystem health (Bunn, Davies and Mosisch 1999), in environmental impact assessments and in river restoration activities (e.g. the restoration of important characteristics of river flow regimes; Toth *et al.* 1995; Toth *et al.* 1997). The quantification of modified flow regimes that will maintain or restore biodiversity and key ecological functions in river systems is increasingly concerned with the integration of information on river hydrology, geomorphology, sediment dynamics and ecology, all linked to the social consequences of changing river flows (Arthington *et al.* 2003a and b; King *et al.* 2003). The so-called holistic environmental flow methods that make use of many types of information, including local ecological knowledge, models and professional judgement, are the most suitable for large river systems. Examples include the environmental flow methodology DRIFT (Downstream Response to Imposed Flow Transformations) originating in South Africa (King *et al.* 2003) and similar Australian approaches (Cottingham, Thoms and Quinn 2002; Arthington and Pusey 2003). For reviews of such methods and recent innovations see Arthington *et al.* (2003a and b) and Tharme (1996, 2003).

Resolving uncertainty

Major theoretical advances have been made in understanding how large rivers and their fisheries function, yet the science underlying river and fisheries management is still beset by fundamental problems of uncertain knowledge and limited predictive capability (Poff *et al.* 2003). Uncertainly arises both from irreducible ecosystem complexity and from uncertain transferability of general ecological understanding to specific situations. Uncertainty is such a pervasive factor in ecological management that it must be dealt with explicitly and constructively by, we suggest, process research and tools such as adaptive management, strategic assessment and meta-analysis.

Process research

More research on many of the key ecological processes discussed above is clearly warranted (see priorities discussed below), but this will take time and may not reduce uncertainty enough to allow reliable predictions at the scale required for management decision-making.

Adaptive management

In the long term we may reduce uncertainty and increase the effectiveness of management measures, if their consequences are monitored and management measures adapted accordingly. Adaptive management is a process of systematic “learning by doing” (Walters 1997). It involves three main aspects: (1) uncertainty is made explicit, (2) management measures are considered as experiments, designed to yield information as well as material benefits and (3) management measures and procedures are modified in light of results from management experiments. Adaptive management may be implemented within just a single site, but it is often advantageous to work across a number of similar sites in order to increase replication and, possibly, test a range of management options in parallel, thus achieving results more quickly than through sequential experimentation. The costs of adequate monitoring can be considerable and therefore experimental management should be considered only where the costs of the intervention or the anticipated benefits warrant this expenditure.

Strategic assessment and meta-analysis

Strategic assessments of impacts or mitigation measures synthesize results from individual projects as well as wider relevant knowledge. Strategic assessments carried out on a national or regional basis are likely to improve the effectiveness of future assessments and management interventions substantially. Meta-analysis is an approach increasingly used to synthesize and integrate ecological research conducted in separate experiments and holds great promise for identifying key factors affecting river ecosystems and effective conservation measures (Arnqvist and Wooster 1995; Halls *et al.* 2001b). Fuzzy Cognitive Mapping (Hobbs *et al.* 2002) is a promising new technique for integrating disconnected case studies to guide ecosystem management. Bayesian networks, which express complex system behaviour probabilistically, can facilitate predictive modelling based on knowledge and judgement, thereby enhancing basic understanding without the requirement of excessive detail (e.g. Reckhow 1999).

Summary and Recommendations

Although major advances have been achieved across the broad field of river ecology and fisheries, substantial information gaps characterize every fundamental aspect of fish biology and the ecological processes sustaining fisheries in large river systems. Here we summarize the major points and conclusions arising from our review and the discussions held during LARS 2, beginning with general statements intended to emphasize the importance of healthy rivers and their fisheries. The main research priorities identified in this review are given emphasis (see also Dugan *et al.* 2002).

Large rivers and their floodplains provide a wide range of ecosystem goods and services to society. Many of these services, fisheries production in particular, depend upon the biodiversity and ecological integrity of aquatic ecosystems. The harnessing, development and management of rivers and their natural resources have contributed to economic development for some segments of society, but usually such development is accompanied by severe degradation of ecological integrity. There is evidence that the true value of fisheries has often been underestimated compared to the value of river development.

Biodiversity of large rivers are threatened by climate change, deforestation, agricultural and urban land use, pollution, channel modifications, inter-basin transfers of water and modified flow regimes, loss of habitat and habitat connectivity, introduced species and fishing pressure. These impacts are of particular concern in tropical floodplain rivers, which are home to over 50 percent of the world’s freshwater fish species. There is a critical need to define the factors and processes that maintain biodiversity and ecosystem services at river basin and regional scales.

Tropical floodplain rivers present a rare opportunity to conserve important areas of biological diversity and aquatic resources before they deteriorate under pressure from development. The conservation of important genetic stocks, species and species complexes is a priority. Methods are evolving to define conservation and restoration priorities in large rivers but theoretical and methodological considerations merit more attention (Abell 2002). Major data gaps for species distributions prevent identification of hotspots for richness, endemism and other conservation targets, hindering effective conservation planning. Further, planners are challenged to design strategies that will maintain the often large-scale abiotic and biotic processes that shape habitats and support the persistence of biodiversity.

In many cases, the maintenance of healthy river ecosystems and all components of biodiversity (species, genetic stocks, ecological and evolutionary processes) are synonymous with maintaining healthy productive fisheries and sustaining livelihoods. Occasionally, however, modified systems can provide high levels of fishery production (e.g. via stock enhancement programs in modified habitats, particularly water storage reservoirs) even though their biodiversity is compromised. Hence, it is important to distinguish clearly between fisheries production and conservation aspects of rivers where the former are important, particularly in a developing country context.

Natural flow regimes and hydrological variability (quantity, timing and duration of flows and floods and periods of low flows) are considered essential for maintaining biodiversity and fisheries, especially in strongly seasonal river systems (Poff *et al.* 1997). The Flood Pulse Concept (Junk *et al.* 1989) remains a robust and widely applicable paradigm in tropical floodplain rivers with predictable annual flood pulses, governing maintenance of biodiversity, energy flow and fisheries productivity. Maintaining the annual flood pulse in tropical floodplain rivers and the variable patterns of flows and floods in rivers with more erratic flow regimes should be the first priority in water management.

Research on flow-ecological relationships in large rivers and further development of conceptual, empirical and dynamic ecological models, are urgent research priorities (Arthington and Pusey 2003). Interim environmental flow prescriptions should be set now, in major rivers of conservation concern and those sustaining fisheries and livelihoods. Holistic ecosystem environmental flow methods such as DRIFT (King *et al.* 2003) and its fish component (Arthington *et al.* 2003a), using all information, including local ecological knowledge, models and professional judgement, are the most suitable methods for defining flow regimes in large river systems.

Sustaining river ecosystems and productive fisheries depends in part upon understanding the energetic basis of their productivity, linked to the trophic ecology of fish and food web structure. Food webs in large rivers are complex and influenced by many abiotic and biotic factors. Nevertheless, to inform management, we need a food web perspective on multispecies fisheries in large rivers, because stock dynamics are influenced by both bottom-up factors related to ecosystem productivity and by top-down factors influenced by relative densities of predator and prey populations. Research into the productive basis of fish populations and fisheries in different habitats is a priority (Winemiller 2003).

There is evidence of ecosystem overfishing in many tropical rivers and large long-lived species are endangered as a result. The implications of “fishing down the food web” (Pauly *et al.* 1998) and species loss for the sustainability, variability and management of fisheries, as well as for biodiversity protection, need to be explored further.

More research is required to understand basin-wide threat mechanisms, interactions and scales of response. Mitigation measures include the restoration of hydrological and sediment dynamics, riparian vegetation, river habitat diversity and floodplain connectivity (Tockner and Stanford 2002). More investment in monitoring and evaluation is required to determine the success of such efforts.

For most large river systems, essential information is lacking on biodiversity (of all aquatic biota), species distributions and habitat requirements of fishes, migration and spawning cues, all aspects of migration patterns, reproductive biology and population dynamics. Habitat (in its very broadest sense) may be used in assessments of ecological integrity, in quantifying environmental flows and in planning conservation strategies, as a surrogate for biotic requirements where data on the latter are limited. If habitat-based assessments must be used, a wide array of trophic levels should be included to improve the generality of habitat-based assessments (Tharme 1996).

Quantitative measures at the population level (yield, abundance, extinction risk) are important for decision-making on many issues, including trade-offs between water resources development and fisheries. Despite some fundamental gaps in ecological knowledge (e.g. the basis of floodplain production), fisheries models accounting for hydrological variability and exploitation impacts on large populations are becoming available and will allow a more detailed analysis of water management-fisheries interactions (Halls and Welcomme 2003). Further elucidating density-dependent and density-independent mechanisms that regulate and determine fish abundance is a key challenge. Understanding of proximate mechanisms underlying life history plasticity (including migration cues) requires further research.

A significant gap is the lack of data, theory and models for small and endangered populations where demographic stochasticity, depensation and metapopulation structure are significant factors in dynamics. This area should be addressed as a matter of priority, given the imperilled status of a significant proportion of riverine biota.

Major theoretical advances have been made in understanding how large rivers and their fisheries function. Further development of ecological theory for river biota and fisheries will provide a better basis for management and conservation in the longer term. This will require integration of field data collection, management experiments (i.e. “learning by doing” Walters 1997) and modelling.

Routine fisheries data collection should be focused more strongly on providing information relevant to key issues in river management. This will require a closer link between research, management and administration. Modelling should play a key role in synthesising information, formulating and testing hypotheses and improving data collection, experimental design and management actions.

Despite recent advances, the science underlying river and fisheries management is still beset by fundamental problems of uncertain knowledge and limited predictive capability (Bunn and Arthington 2002). Uncertainty arises both from irreducible ecosystem complexity and from uncertain transferability of general ecological understanding to specific situations (Poff *et al.* 2003). Uncertainty is such a pervasive factor in ecological management that it must be dealt with explicitly and constructively.

Adaptive management will often be the most effective way of resolving uncertainties, improving management and generating key ecological knowledge. Well-planned management experiments should be carried out and comprehensively documented far more widely than hitherto (Poff *et al.* 2003).

Meta-analysis also holds great potential to answer key ecological questions from the combined analysis of studies on individual sites and river basins. Studies in individual systems should report averages as well as variability, minimum and maximum values, to be amenable for inclusion in such quantitative syntheses. A paucity of comparative analyses was a conspicuous gap in papers submitted to LARS 2.

Already a range of modelling tools is available to support decision-making in river basin and fisheries management. Risk assessment can provide a framework for decision-making by explicitly including uncertainties, data and previous knowledge in quantitative frameworks. Modelling approaches can facilitate communication between stakeholders.

Beyond general principles at the conceptual level and volumes of international recommendations, there is a dearth of practical guidelines for managers to apply at the operational level. There are also few tools to help stakeholders assess various management options and trade-offs. A compendium of decision tools for river ecological and fisheries management should be compiled and maintained, to provide managers, stakeholders and decision makers with an up-to-date guide to available resources.

Conspicuous gaps at LARS 2 concern the ecological linkages between uplands, rivers, lowland floodplains, estuaries and coastal systems, even though recent research has highlighted the importance of flow-related and land-based processes affecting estuarine ecosystems and their fish stocks. The ecological roles of groundwater and surface-groundwater processes and the consequences of climate change for aquatic ecosystems and fisheries, also received very little attention in submitted papers. The design of fishery management practices, environmental flows, restoration strategies and conservation reserves to cope with potential impacts of climate change is a largely unexplored research frontier.

REFERENCES

Abell R. 2002. Conservation biology for the biodiversity crisis: A freshwater follow-up. *Conservation Biology*, 16: 1435-1437.

Abell R., Thieme M., Dinerstein E., & Olson D. 2002. *A sourcebook for conducting biological assessments and developing biodiversity visions for ecoregion conservation. Volume II: Freshwater ecoregions.* Washington, DC, World Wildlife Fund. 201 pp.

Abell R., Thieme M. & Lehner B. 2003. Ecoregion conservation for freshwater systems, with a focus on large rivers. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 2.* Food and Agriculture Organization of the United Nations & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/17. pp. 1-14.

Allendorf F.W., Bayles D., Bottom D.L., Currens K.P., Frissell C.A., Hankin D., Lichatowich J.A., Nehlsen W., Trotter P.C. & Williams T.H. 1997. Prioritizing Pacific salmon stocks for conservation. *Conservation Biology,* 11: 140-152.

Almeida O.T., Lorenzen K. & McGrath D.G. 2002. Impact of co-management agreements on the exploitation and productivity of floodplain lake fisheries in the lower Amazon. *Proceedings of the ninth international conference of the IASCP.* (Available at http://dlc.dlib.indiana.edu/documents/dir0/00/00/07/82/dlc-00000782-00/almeidao080502.pdf)

Aparico E., Vargas M.J., Olmo J.M & de Sostoa A. 2000. Decline of native freshwater fishes in a Mediterranean watershed on the Iberian Peninsula: A quantitative assessment. *Environmental Biology of Fishes,* 59: 11-19.

Arlinghaus R., Mehner T. & Cowx I.G. 2002. Reconciling traditional inland fisheries management and sustainability in industrialized countries, with emphasis on Europe. *Fish and Fisheries,* 3: 261-316.

Arnkvist G. & Wooster D. 1995. Meta-analysis: Synthesizing research findings in ecology and evolution. *Trends in Ecology and Evolution*, 10: 236-240.

Arrington D.A. & Jepsen D.B. 2001. Evaluation of ecosystem enhancement using growth rates of Centrarchid fishes. *Florida Scientist*, 64: 197-215.

Arrington D.A. & Winemiller K.O. 2003. Organization and maintenance of biological diversity in neotropical floodplain rivers. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 2.* Food and Agriculture Organization of the United Nations & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/17. pp. 25-36.

Arthington A.H. 1991. The ecological and genetic impacts of introduced freshwater fishes in Australia. *Canadian Journal of Fisheries and Aquatic Sciences Suppl. 48,* 1: 33-44.

Arthington A.H. & Bluhdorn D.R. 1994. Distribution, genetics, ecology and status of the introduced cichlid, *Oreochromis mossambicus,* in Australia. *In* D. Dudgeon & P. Lam, eds. Inland waters of tropical Asia and Australia: Conservation and Management. Mitteilungen Communications, *Societas Internationalis Limnologiae SIL*, 24: 53-62.

Arthington A.H. & Bluhdorn D.R. 1996. The effects of species interactions resulting from aquaculture operations. *In* D.J. Baird, M.C. Beveridge, L.A. Kelly & J.F. Muir, eds. *Aquaculture and water resource management*. Oxford, UK, Blackwell Science. pp. 114-138.

Arthington A.H., Tharme R.E., Brizga S.O., Pusey B.J. & Kennard M.J. 2003b. Environmental flows: Ecological importance, methods and future challenges. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 2.* Food and Agriculture Organization of the United Nations & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/17. pp. 37-66

Arthington A.H., Hamlet S. & Bluhdorn D.R. 1990. The role of habitat disturbance in the establishment of introduced warm-water fishes in Australia. *In* D.A. Pollard ed. *Introduced and translocated fishes and their ecological effects*. *Proceedings No. 8,* pp. 61-66. Canberra, Bureau of Rural Resources, Australian Govt. Pub. Service.

Arthington A.H., King J.M., O'Keefe J.H., Bunn S.E., Day J.A., Pusey B.J., Bluhdorn D.R. & Tharme R. 1992. Development of an holistic approach for assessing environmental flow requirements of riverine ecosystems. *In* J.J. Pigram and B.P. Hooper, eds. *Proceedings of an international seminar and workshop on water allocation for the environment.* Armidale, Centre for Water Policy Research, University of New England. pp. 69-76.

Arthington A.H. & Pusey B.J. 2003. Flow restoration and protection in Australian rivers. *River Research and Applications*, 19: 1-19.

Arthington A.H., Rall J.L., Kennard M.J. & Pusey B.J. 2003a. Environmental flow requirements of fish in Lesotho rivers using the DRIFT methodology. *River Research and Applications,* 19.

Arthington A.H. & Welcomme R.L. 1995. The condition of large river systems of the world. *In* C.W. Voigtlander ed. *Proceedings of the world fisheries congress.* New Delhi, Oxford and IBH Publishing Co. Pty Ltd. pp. 44-75.

Bain M.B. & Stevenson N.J. 1999. *Aquatic Habitat Assessment: Common Methods*. Bethesda, Maryland: American Fisheries Society.

Baird D.J., Beveridge M.C., Kelly L.A. & Muir J.F. 1996. *Aquaculture and Water Resource Management*. Oxford, UK, Blackwell Science.

Baird I.G. & Flaherty M.S. 2003. Beyond national borders: Links between an important Mekong River medium sized migratory carp fishery below the Khone Falls in southern Laos and bag net fisheries at stream mouths in northeast Cambodia. Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.

Baird I.G., Flaherty M.S. & Phylavanh B. 2000. *Rhythms of the river: Lunar phases and small cyprinid migrations in the Mekong River.* Champassak Province, Lao PDR, CESVI Project for environmental protection and community development in the Siphandone wetland. 42 pp.

Baran E., Makin I. & Baird I.G. 2003. Bayfish: A model of environmental factors driving fish production in the lower Mekong Basin. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 2*. Food and Agriculture Organization & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/17. pp.

Barbarino Duque A., Taphorn D.C. & Winemiller K.O. 1998. Ecology of the coporo, *Prochilodus mariae* Characiformes, Prochilodontidae and status of annual migrations in western Venezuela. *Environmental Biology of Fishes*, 53: 33-46.

Barlow C.G., Hogan A.E. and Rogers L.G. 1987. Implications of translocated fishes in the apparent extinctions in the wild of the Lake Eacham rainbowfish, *Melanotaenia eachamensis. Australian Journal of Marine and Freshwater Research*, 38: 897-902.

Bayley P.B. 1988a. Accounting for effort when comparing tropical fisheries in lakes, river-floodplains and lagoons. *Limnology & Oceanography*, 33: 963-972.

Bayley P.B. 1988b. Factors affecting growth rates of young tropical floodplain fishes - seasonality and density-dependence. *Environmental Biology of Fishes*, 21: 127-142.

Bayley P.B. 1989. Aquatic environments in the Amazon Basin, with an analysis of carbon sources, fish production, and yield. *Special Publication of the Canadian Journal of Fisheries and Aquatic Sciences,* 106: 399-408.

Boisneau & Mennesson-Boisneau 2003. Conservation strategies for diadromous fishes in Loire River France. Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.

Boon P.J. 2000. The development of integrated methods for assessing river conservation value. *Hydrobiologia,* 422/423: 413-428.

Boon P.J., Calow P. & Petts G.E. eds. 1992. *River Conservation and Management*. Chichester, UK, John Wiley and Sons. 470 pp.

Bovee K.D. 1982. *A guide to stream habitat analysis using the instream flow incremental methodology. Instream Flow Information, Paper 12.* Fort Collins, U.S. Department of Fisheries and Wildlife Service.

Bridges E.M., Ross D.G. & Thompson C.H. 1990. Soils of the Mary River alluvia near Gympie, Queensland. *CSIRO Division of Soils, Divisional Report No. 109.* 29 pp.

Brizga S.O., Arthington A.H., Pusey B.J., Kennard M.J., Mackay S.J., Werren G.L., Craigie N.M. & Choy S.J. 2002. Benchmarking, a 'top-down' methodology for assessing environmental flows in Australian rivers. *Proceedings of international conference on environmental flows for rivers*. Cape Town, SA, University of Cape Town. (available on CD)

Brookes A. 1992. Recovery and restoration of some engineered British river channels. *In* P.J. Boon, P. Calow & G.E. Petts, eds. *River conservation and management*. Chichester, UK, John Wiley and Sons. pp. 337-352.

Brocksen R.W. & Wisniewski J. 1988. *Restoration of aquatic and terrestrial systems*. Dordrecht, Kluwer Academic Publishers. 501 pp.

Brosse S., Lim P. & Lek S. 2003. Biodiversity conservation in the Garonne River France: Importance of side-arm channels and floodplain areas. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Bunn S.E., Pusey B.J. & Price P. eds. 1993. *Ecology and management of riparian zones*. Canberra, Land and Water Resource Research and Development Corporation *Occasional Paper Series No. 5/93*. 140 pp.

Bunn S.E., Davies P.M. & Mosisch T.D. 1999. Ecosystem measures of river health and their response to riparian and catchment clearing. *Freshwater Biology,* 41: 333-346.

Bunn S.E. & Arthington A.H. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management*, 30: 492-507.

Bunn S.E., Davies P.M. & Winning M. 2003. Sources of organic carbon supporting the food web of an arid-zone floodplain river. *Freshwater Biology*, 48: 1-17.

Bunn S.E. & Hughes J.M. 1997. Dispersal and recruitment in streams: Evidence from genetic studies. *Journal of the North Anmerican Benthological Society*, 162: 338-346.

Carvalho de Lima A. & Araujo-Lima C.A.R.M. 2003. Spawning migrations of characiform fishes in relation to water quality in rivers of the Amazon. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Chang J., Park Young-Seuk & Lek S. 2003. Conservation of endemic fishes in Upper Yangtze River, China. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Clifford N.J. 2001. Conservation and the river channel environment. *In* A. Warren & J.R. French, eds. *Habitat conservation: Managing the physical environment.* New York, John Wiley & Sons. pp. 67-104.

Coates D. 1998. Codes of practice for the stocking and introduction of fish. *In* I.G. Cowx, ed. *Stocking and introduction of fish*. Oxford, UK, Blackwell Science. pp. 383-396.

Cottingham P., Thoms M.C. & Quinn G.P. 2002. Scientific panels and their use in environmental flow assessment in Australia. *Australian Journal of Water Resources,* 5: 103-111.

Crook D.A. & Robertson A.I. 1999. Relationships between riverine fish and woody debris: Implications for lowland rivers. *Marine and Freshwater Research,* 50: 941-953.

Cowx I.G. 1994. Stocking strategies. *Fisheries Management and Ecology*, 1: 15-31.

Cowx I.G. & Welcomme R.L. eds. 1998. *Rehabilitation of Rivers for Fish*. Oxford, UK, Blackwells, 268 pp.

Cummins K.W. 1992. Catchment characteristics and river ecosystems. *In* P.J. Boon, P. Calow and G.E. Petts, eds. *River Conservation and Management*. Chichester, UK, John Wiley and Sons. pp. 125-135.

Cushing D.H. 1990. Plankton production and year-class strength in fish populations: An update of the match-mismatch hypothesis. *Advances in Marine Biology*, 26: 249-293.

Darwall W.R.T. & Vié J.C. 2003. Identifying important freshwater biodiversity sites. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Davies B.R., Thoms M. & Meador M. 1992. An assessment of the ecological implications of inter-basin water transfers and their threats to river basin integrity and conservation. *Aquatic Conservation Marine and Freshwater Systems*, 2: 325-349.

De Graaf G., Born B., Kamal Uddin A.M. & Marttin F. 2001. Floods, fish and fishermen. Dhaka, The University Press Ltd. 110 pp.

Denney, N.H., Jennings, S. & Reynolds, J.D. 2002. Life-history correlates of maximum population growth rates in marine fishes. *Proceedings of the Royal Society of London, Series B - Biological Sciences*, 269: 2229-2237.

Detenbeck N.E., DeVore P.W., Niemi G.J. & Lima A. 1992. Recovery of temperate-stream fish communities from disturbance: A review of case studies and synthesis of theory. *Environmental Management*, 16: 33-53.

Dettmers J.M., Wahl D.H., Soluk D.A. & Gutreuter S. 2001. Life in the fast lane: Fish and foodweb structure in the main channel of large rivers. *Journal of the North Anmerican Benthological Society*, 202: 255-265.

Dudgeon D. 2000. The ecology of tropical Asian rivers and streams in relation to biodiversity conservation. *Annual Review of Ecology and Systematics*, 31: 239-263.

Dugan P.J., Baran E., Tharme R., Prein M., Ahmed M., Amerasinghe P., Bueno P., Brown C., Dey M., Jayasinghe G., Niasse M., Nieland A., Smakhtin V., Tinh N., Viswanathan K. and Welcomme R. 2002. The contribution of aquatic ecosystems and fisheries to food security and livelihoods: A research agenda. *In Background papers of the challenge programme on water and food*. CGIAR. pp. 87-113.

Dunham J.B. & Rieman B.E. 1999. Metapopulation structure of bull trout: Influences of physical, biotic, and geometrical landscape characteristics. *Ecological Applications*, 9: 642-655.

Dunn H. 2003. Can conservation assessment criteria developed for terrestrial systems be applied to riverine systems? *Aquatic Ecosystem Health and Management*, 61: 81-95.

Dynesius M. & Nilsson C. 1994. Fragmentation and flow regulation of river systems in the Northern 3rd of the world. *Science*, 266: 53-762.

Elwood, J.W., Newbold, J.D., O'Neill, R.V., van Winkle, W. 1983. Resource spiralling: An operational paradigm for analyzing lotic systems. *In* T.D. Fontaine III, S.M. Bartell, eds. *Dynamics of Lotic Ecosystems*. Ann Arbor, Ann Arbor Science Publ. pp. 3-27.

Fagan, W.F. 2002. Connectivity, fragmentation, and extinction risk in dendritic metapopulations. Ecology, 83: 3243-3249.

FAO 2000. The state of fisheries and aquaculture. Rome, FAO.

FAO/DVWK 2002. Fish passes-design, dimensions and monitoring. Rome, FAO. 119 pp.

Faisal I.M. 2003. Managing international rivers in the GBM Region: Indo-Bangladesh perspectives. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Fashchevsky, B. 2003. Human impact on rivers in the Ponto-Caspian basin and their fish. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 1.* Food and Agriculture Organization & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/16. pp

Frissell C.A. 1997. Ecological principles. *In* J.E. Williams, C.A. Wood & M.P. Dombeck, eds. *Watershed restoration: Principles and practices.* American Bethesda, Maryland, Fisheries Society. pp. 96-115.

Frissell C.A., Liss W.J., Warren C.E. & Hurley, M.D. 1986. A hierarchical framework for stream habitat classification: Viewing streams in a watershed context. *Environmental Management*, 10: 199-214.

Fu Cuizhang, Wu Jihua, Chen Jiakuan, Wu Qianhong & Lei Guangchun 2003. Freshwater fish biodiversity in the Yangtze River Basin of China: Patterns, threats and conservation. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Galat D.L. & Zweimuller I. 2001. Conserving large-river fishes: Is the highway analogy an appropriate paradigm? *Journal of the North American Benthological Society*, 202: 266-279.

Gopal B. 2003. State of degradation and approaches to restoration of floodplain rivers in India. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 2.* Food and Agriculture Organization of the United Nations & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/17. pp. 79-90.

Gotelli N.J. & Taylor C.M. 1999. Testing metapopulation models with stream-fish assemblages. *Evolutionary Ecology Research*, 1: 835-845.

Gouraud V., Bagliniere J.L., Baran P., Sabaton C., Lim P. & Ombredane D. 2001. Factors regulating brown trout populations in two French rivers: Application of a dynamic population model. *Regulated Rivers Research & Management*, 17: 557-569.

Gregory S.V., Swanson F.J., McKee W.A. & Cummins K.W. 1991. An ecosystem perspective of riparian zones. *BioScience*, 41: 540-551.

Gross M.T., Coleman R.M. & McDowall R.M. 1988. Aquatic productivity and the evolution of diadromous fish migration. *Science*, 239: 1291-1293.

Groves C.R., Jensen D.B., Valutis L.L., Redford K.H., Shaffer J.M., Scott J.V., Baumgartner J.V., Higgins M.W., Beck A.B & Anderson M.G. 2002. Planning for biodiversity conservation: Putting conservation science into practice. *BioScience*, 52: 499-512.

Guegan J.F., Lek S. & Oberdorff T. 1998. Energy availability and habitat heterogeneity predict global riverine fish diversity. *Nature*, 391: 382-384.

Halls A.S. 1998. An assessment of the impact of hydraulic engineering on floodplain fisheries and species assemblages in Bangladesh. University of London, 526 pp. (Doctoral dissertation)

Halls A.S., Hoggarth D.D. & Debnath K. 1998. Impacts of flood control schemes on river fish migrations and species assemblages in Bangladesh. *Journal of Fisheries Biology*, 53 Suppl. A: 358-380.

Halls A.S., Debnath K., Kirkwood G.P. & Payne A.I. 2000. Density-dependent recruitment of Puntius sophore in floodplain waterbodies in Bangladesh. *J. Fish. Biol*, 56: 915-922.

Halls A.S., Kirkwood G.P. & Payne A.I. 2001. A dynamic pool model for floodplain river fisheries. *Ecohydrology and Hydrobiology*, 1: 323-339.

Halls A.S., Burn R. & Abeyasekera S. 2001b. Interdisciplinary multivariate analysis for adaptive co-management. *Final Technical Report Submitted to the Department for International Development*. 171 pp.

Halls A.S. & Welcomme R.L. 2003. Dynamics of river fish populations in response to hydrological conditions: A simulation study. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Harris J.H. & Gehrke P.C. 1994. Development of predictive models linking fish population recruitment with streamflow. *In* D.A. Hancock ed. *Population dynamics for fisheries management*. pp. 195-199. Camberra, Bureau of Rural Resources Proceedings, Australian Government Printing Service.

Harrison I.J. & Stiassny M.L.J. 1999. The quiet crisis: A preliminary listing of the freshwater fishes of the World that are extinct or "missing in action." *In* R.D.E. MacPhee ed. *Extinctions in near time: Causes, contexts, and consequences*. New York: Kluwer Academic/ Plenum Publishers. pp. 271-332.

Hickley P. & Bailey R.G. 1987. Fish communities in the eastern seasonal floodplain of the Sudd, southern Sudan. *Hydrobiologia*, 144: 243-250.

Hilborn R. & Mangel M. 1997. *The ecological detective.* Princeton: Princeton University Press. 315 pp.

Hobbs B.F., Ludsin S.A., Knight R.L., Ryan P.A., Biberhofer J. & Ciborowski J.J.H. 2002. Fuzzy cognitive mapping as a tool to define management objectives for complex ecosystems. *Ecological Applications*, 12: 1548-1565.

Hogan Z. 2003. The conservation of endangered giant fish in the Mekong River Basin. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Hoggarth, D.D. & Kirkwood, G.P. 1995. Technical interactions in floodplain fisheries of south and south-east Asia. *In* I.G. Cowx, ed. *Stock assessment in inland fisheries*. Oxford, UK, Fishing News Books. pp. 280-292.

Hoggarth D.D., Halls A.S., Dam R.K. & Debnath K. 1999. Recruitment sources for fish stocks inside a floodplain river impoundment in Bangladesh. *Fisheries Management and Ecology*, 6: 287-310.

Hughes R.M. & Hunsaker C.T. 2002. Effects of landscape change on aquatic biodiversity and biointegrity. *In* K.J. Gutzwiller, ed. *Applying landscape ecology in biological conservation*. New York, Springer-Verlag. pp. 309-329.

Hugueny B. 1989. West African rivers as biogeographic islands. *Oecologia*, 79: 235-243.

Humphries P., King A.J. & Koehn J.D. 1999. Fish, flows and floodplains: Links between freshwater fishes and their environment in the Murray-Darling River system, Australia. *Environmental Biology of Fishes*, 56: 129-151.

Huxel G.R. & McCann K. 1998. Food web stability: The influence of trophic flows across habitats. *American Naturalist*, 152: 460-469.

IUCN Species Survival Commission 2000. 2000 IUCN Red List of threatened species. (Available at: http://www.iucn.org/redlist/2000/index.html)

Jackson D.C. & Marmulla, G. 2001. The influence of dams on river fisheries. *FAO Fisheries Technical Paper,* 419: 1-44.

Jager H.I., Chandler J.A., Lepla K.B. & van Winkle W. 2001. A theoretical study of river fragmentation by dams and its effects on white sturgeon populations. *Environmental Biology of Fishes*, 60: 347-361.

Jager H.I., van Winkl, W. & Holcomb B.D. 1999. Would hydrologic climate changes in Sierra Nevada streams influence trout persistence? *Transactions of the American Fisheries Society*, 128: 222-240

Jefferies R.L. 2000. Allochthonous inputs: Integrating population changes and food-web dynamics. *Trends in Ecology and Evolution*, 15: 19-22.

Jenkins T.M., Diehl S., Kratz K.W. & Cooper S.D. 1999. Effects of population density on individual growth of brown trout in streams. Ecology, 80: 941-956.

Jensen F.V. 1996. *An introduction to Bayesian networks.* London, UCL Press. 178 pp.

Jordan F.J. & Arrington D.A. 2001. Weak trophic interactions between large predatory fish and herpetofauna in the channelized Kissimmee River, Florida, USA. *Wetlands*, 21: 155-159.

Joyeux J.C. & Ward A.B. 1998. Constraints on coastal lagoon fisheries. *Advances in Marine Biology*, 34: 73-199.

Junk W.J. 2002. Long-term environmental trends and the future of tropical wetlands. *Environmental Conservation*, 294: 414-435.

Junk W.J., Bayley P.B. & Sparks R.E. 1989. The flood pulse concept in river-floodplain systems. *In* D.P. Dodge ed. *Proceedings of the international large rivers symposium*. *Can. J. Fish. Aquat. Sci. Special Pub.*, 106: 110-127.

Junk W.J. & Wantzen K.M. 2003. The flood pulse concept: New aspects, approaches and applications - an update. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 2*. Food and Agriculture Organization of the United Nations & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/17. pp.117-140.

Kauffman J.B., Beschta R.L., Otting N. & Lytjen D. 1997. An ecological perspective of riparian and stream restoration in the western United States. *Fisheries*, 22: 12-24.

King A.J. 2002. Recruitment ecology of fish in floodplain rivers of the southern Murray-Darling Basin, Australia. Melbourne, Autstralia, Monash University. (Doctoral dissertation)

King J.M., Brown C. & Sabet H. 2003. A scenario-based holistic approach to environmental flow assessments for rivers. *River Research and Applications*, 19: (forthcoming)

King J.M., Cambray J.A. & Dean Impson N. 1998. Linked effects of dam-released floods and water temperature on spawning of the Clanwilliam yellowfish Barbus capensis. *Hydrobiologia*, 384: 245-265.

Koebel J.W. Jr., Harris S.C. & Arrington D.A. 1998. Restoration of the Kissimmee River Ecosystem in Central Florida, USA. *In* S.K. Majumdar, E.W. Miller & F.J. Brenner, eds. *Ecology of Wetlands and Associated Systems*. Easton, Pennsylvania, Pennsylvania Academy of Science. pp. 587-610.

Lae, R. 1997. Does overfishing lead to a decrease in catches and yields? An example of two West African coastal lagoons. *Fisheries Management and Ecology*, 4: 149-164.

Large A.R.C. & Petts G.E. 1996. Rehabilitation of river margins. *In* G. Petts & P. Calow, eds. *River restoration*. Oxford, UK, Blackwell Science. pp. 106-123.

Larinier M., Travade F. & Porcher J.P. 2002. Fishways: Biological basis, design criteria and monitoring. *Bulletin Francais de la Peche et de la Pisciculture*, 364 Supplement. 208 pp.

Larsen T., Thilsted S.H., Kongsba K. & Hansen M. 2000. Whole small fish as a rich calcium source. *British Journal of Nutrition*, 83: 191-196.

Leung B., Lodge D.M., Finnoff D., Shogren J.F., Lewis M.A. & Lamberti G.A. 2002. An ounce of prevention or a pound of cure: Bioeconomic risk analysis of invasive species. *Proceedings of the Royal Society of London, Series B - Biological Sciences*, 269: 2407-2413.

Lévêque C. 1995. Role and consequences of fish diversity in the functioning of African freshwater ecosystems: A review. *Aquatic Living Resources*, 8: 59-78.

Lewis W.M., Hamilton S.K., Rodriguez M.A., Saunders J.F. & Lasi M.A. 2001. Foodweb analysis of the Orinoco floodplain based on production estimates and stable isotope data. *Journal of the North American Benthological Society*, 20: 241-254.

Livingston R.J. 1997. Trophic responses of estuarine fishes to long-term changes of river runoff. *Bulletin Marine Science*, 60: 984-1004.

Lobon-Cervia J., Elvira B. & Rincon P.A. 1989. Historical changes in the fish fauna of the River Duero Basin. *In* G.A. Petts, H. Moller and A.L. Roux, eds. *Historical change of large alluvial rivers: Western Europe*. Chichester, UK, John Wiley & Sons. pp. 221-232.

Loneragan N.R. & Bunn S.E. 1999. River flows and estuarine ecosystems: Implications for coastal fisheries from a review and a case study of the Logan River, Southeast Queensland. *Australian Journal of Ecology*, 244: 431-40.

Lorenzen K. 1996. The relationship between body weight and natural mortality in fish: A comparison of natural ecosystems and aquaculture. *Journal of Fish Biology*, 49: 627-647.

Lorenzen K. 2000. Population dynamics and management. *In* M.C.M. Beveridge & B.J. McAndreeds, eds. *Tilapias: Biology and exploitation*. Dordrecht, Kluwer. pp. 163-225.

Lorenzen K. Aquaculture-based fisheries: Hatchery organisms in fisheries management and conservation. Oxford, UK, Blackwell Publishing. (forthcoming)

Lorenzen K. & Enberg K. 2002. Density-dependent growth as a key mechanism in the regulation of fish populations: evidence from among-population comparisons. *Proceedings of the Royal Society of London, Series B - Biological Sciences*, 269, 49-54.

Lorenzen, K. & Garaway C.J. 1998. How predictable is the outcome of stocking? *In Inland Fisheries Enhancements*. *FAO Fisheries Technical Paper*. 374. pp. Rome, FAO.

Lorenzen K., De Graaf G. & Halls, A.S. 2003. *A biomass dynamics model for assessing interactions between fisheries and water management in highly seasonal water bodies*. London, Imperial College.

Lorenzen K., Garaway C.J., Chamsingh B. & Warren T.J. 1998. Effects of access restrictions and stocking on small water body fisheries in Lao PDR. *Journal of Fish Biology*, 53 Supplement 1: 345-357.

Lorenzen K., Nguyen Khoa S., Garaway C.J., Arthur R.I., Chamsingh B., Litdamlong D., Siebert D. & Innes-Taylor N. 2000. *Impacts of irrigation and aquaculture development on small-scale aquatic resources. Final report to the DFID Environment Research Programme.* London, Imperial College.

Lorenzen K., Smith L., Nguyen Khoa S., Garaway C. & Burton M. 2003b. *Management of irrigation development impacts on fisheries. Final Report to the UK Department for International Development.* London, Imperial College.

Lowe-McConnell R.H. 1987. *Ecological Studies in Tropical Fish Communities*. Cambridge, Cambridge University Press. 382 pp.

McAllister D.E., Hamilton A.L. & Harvey B. 1997. Global freshwater biodiversity: Striving for the integrity of freshwater ecosystems. *Sea Wind*, 11: 1-140.

McAllister D.E., Parker B.J. & McKee P.M. 1985. *Rare, endangered, and extinct fishes in Canada.* Syllogeus No. 54: 192 pp. Ottawa, Canada, National Museums of Natural Sciences, National Museums of Canada.

Malmqvist B. & Rundle S. 2002. Threats to the running water ecosystems of the world. *Environmental Conservation*, 29: 134-153.

Matsubara H. Sakai H. & Iwata A. 2001. A river metapopulation structure of a Japanese freshwater goby, *Odontobutis obscura*, deduced from allozyme genetic indices. *Environmental Biology of Fishes*, 61: 285-294

Mayden R.L. & Wood R.M. 1995. Systematics, species concepts and the evolutionary significant unit in biodiversity and conservation biology. *American Fisheries Society Symposium*, 17: 58-113.

Meffe G.K. 1992. Techno-arrogance and halfway technologies: Salmon hatcheries on the Pacific coast of North America. *Conservation Biology,* 6: 350-354.

Miller R.R., Williams J.D. & Williams J.E. 1989. Extinction of North American fishes during the past century. *Fisheries,* 146: 22-38.

Minte-Vera C.V. 2003. Risk assessment of a floodplain migratory fish subject to fisheries and dam-operation procedures. Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.

Mol J.H., Resida D., Ramlal J.S. & Becker C.R. 2000. Effects of El Nino-related drought on freshwater and brackish-water fishes in Suriname, South America. *Environmental Biology of Fishes*, 59: 429-440.

Mosisch T.D. & Arthington A.H. 1998. A review of literature examining the effects of water-based, powered recreational activities on lakes and rivers. *Lakes and Reservoirs: Research and Management*, 3: 1-17.

Moyle P.B. & Light T. 1996. Biological invasions of freshwater: Empirical rules and assembly theory. *Biological Conservation*, 78: 149-161.

Naiman R.J. & Decamps H. 1997. The ecology of interfaces: Riparian zones. *Annual Review Ecology & Systematics*, 28: 621-658.

Naiman R.J., Bilb, R.E. & Bisson P.E. 2000. Riparian ecology and the management of the Pacific coastal rain forest. *BioScience*, 50: 996-1011.

Naiman R.J., Bunn S.E., Nilsson C., Petts G.E., Pinay G. & Thompson L.C. 2002. Legitimizing fluvial ecosystems as users of water. *Environmental Management*, 30: 455-467.

Oberdorff T., Guegan J.F. & Hugueny, B. 1995. Global patterns of fish species richness in rivers. *Ecography*, 18: 345-352.

Oberdorff T., Hugueny B. & Guegan J.F. 1997. Is there an influence of historical events on contemporary fish species richness in rivers? Comparisons between Western Europe and North America. *Journal of Biogeography*, 24: 461-467.

Olden J.D. & Poff N.L. 2003. Redundancy and the choice of hydrological indices for characterising streamflow regimes. *River Research and Applications*, 192: 101-121.

Parent S. & Schriml L.M. 1995. A model for the determination of fish species at risk - based upon life history traits and ecological data. *Canadian Journal of Fisheries and Aquatic Sciences*, 52: 1768-1981.

Pauly D., Christensen V., Dalsgaard J., Froese R. & Torres F. Jr. 1998. Fishing down marine food webs. *Science*, 279: 860-863.

Peterson J.T. & Kwak T.J. 1989. Modeling the effects of land use and climate change on riverine smallmouth bass. *Ecological Applications*, 9: 1391-1404.

Petersen R.C., Petersen L.B. & Lacoursiere J. 1992. A building block model for stream restoration. *In* P.J. Boon, P. Calow and G.E. Petts, eds. *River conservation and management*. Chichester, UK, John Wiley and Sons. pp. 293-309.

Petty J.T. & Grossman G.D. 1996. Patch selection by mottled sculpin Pisces: Cottidae in a southern Appalachian stream. *Freshwater Biology*, 35: 261-276.

Philippart J.C. 1995. Is captive breeding an effective solution for the preservation of endemic species? *Biological Conservation*, 72: 281-295.

Poff N.L., Allan J.D., Bain M.B., Karr J.R., Prestegaard K.L., Richter B.D., Sparks R.E. & Stromberg J.C. 1997. The natural flow regime - a paradigm for river conservation and restoration. *BioScience*, 47: 769-784.

Poff N. LeRoy, Allan J.D., Palmer M.A., Hart D.D., Richter B.D., Arthington A.H., Rogers K.H., Meyer J.L. & Stanford J.A. 2003. River flows and water wars: Emerging science for environmental decision-making. *Frontiers in Ecology and the Environment*, 16 due August 2003.

Polis G.A., Anderson W.B. & Holt R.D. 1997. Toward an integration of landscape and food web ecology: The dynamics of spatially subsidized food webs. *Annual Review of Ecology and Systematics*, 28: 289-316.

Post J.R., Parkinson E.A. & Johnston N.T. 1999. Density-dependent processes in structured fish populations: Interaction strengths in whole-lake experiments. *Ecological Monographs*, 69: 155-175

Power M.E. 1992. Habitat heterogeneity and the functional significance of fish in river food webs. *Ecology*, 73: 1675-1688.

Puckridge J.T., Sheldon F., Walker K.F. & Boulton A.J. 1998. Flow variability and the ecology of large rivers. *Marine and Freshwater Research*, 49: 55-72.

Pusey B.J. 1998. Methods addressing the flow requirements of fish. *In* A.H.Arthington & J.M. Zalucki, eds. *Comparative evaluation of environmental flow assessment techniques: Review of methods*. LWRRDC Occasional Paper Series 27/98. Canberra, Land and Water Resources R & D Corporation. pp. 66-105.

Pusey B.J. & Arthington A.H. 2003. Importance of the riparian zone to the conservation and management of freshwater fishes: A review with special emphasis on tropical Australia. *Marine and Freshwater Research*, 54: 1-16.

Pusey B.J., Arthington A.H. & Read M.G. 1995. Species richness and spatial variation in assemblage structure in two rivers of the wet tropics of north Queensland. *Environmental Biology of Fishes*, 42: 181-199.

Pusey B.J., Arthington A.H. & Read M.G. 1998. Freshwater fishes of the Burdekin River, Australia: Biogeography, history and spatial variation in assemblage structure. *Environmental Biology of Fishes*, 53: 303-318.

Pusey B.J., Burrows D. & Arthington A.H. 2003. The translocation of recreationally desirable fishes is detrimental to the maintenance of local biodiversity: Sleepy cod *Oxyeleotris lineolatus* and other translocated species in the Burdekin River, Australia. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Pusey B.J. & Kennard M.J. 1996. Species richness and geographical variation in assemblage structure of the freshwater fish fauna of the Wet Tropics region of northeastern Queensland. *Marine and Freshwater Research*, 47: 563-573.

Pusey B.J., Kennard M.J. & Arthington A.H. 2000. Discharge variability and the development of predictive models relating stream fish assemblage structure to habitat in north-eastern Australia. *Ecology of Freshwater Fishes*, 9: 30-50.

Reeves G.H., Benda L.E., Burnett K.M., Bisson P.A. & Sedell J.R. 1995. A disturbance-based ecosystem approach to maintaining and restoring freshwater habitats of evolutionarily significant units of anadromous salmonids in the Pacific northwest. *American Fisheries Society Symposium 17*: 334-349

Reckhow K.W. 1999. water quantity prediction and probability network models. *Canadian Journal of Fisheries and Aquatic Sciences*, 56: 1150-1158

Reiser D.W., Ramey M.P. & Lambert T.R. 1989. Considerations in assessing flushing flow needs in regulated streams. *In* J.F. Craig and J.B. Kemper, eds. *Regulated rivers: Advances in Ecology*. New York, Plenum Press. pp. 45-57.

Revenga C., Brunner J., Henninger N., Kassem K. & Payne R. 2000. *Pilot analysis of global ecosystems: Freshwater systems*. Washington, DC, World Resources Institute. 83 pp.

Ricciardi A. & Rasmussen J.B. 1999. Extinction rates of North American freshwater fauna. *Conservation Biology*, 13: 1220-1222.

Richter B.D., Baumgartner J.V., Wigington R. & Braun D.P. 1997. How much water does a river need? *Freshwater Biology*, 37: 231-249.

Robinson C.T., Tockner K. & Ward J.V. 2002. The fauna of dynamic riverine landscapes. *Freshwater Biology*, 47: 661-677.

Rochet M.J. & Trenkel V.M. 2003. Which community indicators can measure the impact of fishing? A review and proposals. *Canadian Journal of Fisheries and Aquatic Sciences,* 60: 86-99.

Roos N., Leth T., Jakobsen J. & Thilsted S.H. 2002. High vitamin A content in some small indigenous fish species in Bangladesh: Perspectives for food-based strategies to reduce vitamin A deficiency. *International Journal of Food Sciences and Nutrition,* 53: 425-437.

Rose K.A., Cowan J.H., Winemiller K.O., Myers R.A. & Hilborn R. 2001. Compensatory density dependence in fish populations: Importance, controversy, understanding and prognosis. *Fish and Fisheries*, 2: 293-327.

Saint-Paul U. 2003. Fisheries ecology of Amazonian inundated forests. Paper presented to the Second International Symposium on the Management of Large Rivers for Fisheries

Schmutz S. & Jungwirth M. 1999. Fish as indicators of large river connectivity: The Danube and its tributaries. *Archiv fur Hydrobiologie,* 1999 3: 329-348.

Sedell J.R., Ritchie J.E. & Swanson F.J. 1989. The river continuum concept: A basis for expected ecosystem behaviour of very large rivers. *In* D.P. Dodge ed. *Proceedings of the international large rivers symposium, Can. J. Fish. Aquat. Sci. Special Pub*., 106: 49-55.56

Shrestha T.K. 2003. Conservation and management of fishes in the large Himalayan rivers of Nepal. Paper presented to the Second International Symposium on the Management of Large Rivers for Fisheries.

So N. & Volckaert F.A.M. 2003. Preliminary results on the genetic diversity and structure of the migratory catfish. *Pangasius bocourti* in the Cambodian Mekong River. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Sparks R.E. 1992. Risks of altering the hydrologic regime of large rivers. *In* J. Cairns, B.R. Niederlehner & D.R. Orvos, eds. *Predicting ecosystem risk, Vol XX*. Princeton, USA, Princeton Scientific Publ. Co. pp. 119-152.

Sparre P. & Willmann R. 1991. Software for bio-economic analysis of fisheries: BEAM4. *FAO Fisheries Technical Paper 310*.

Stalnaker C., Lamb B.L., Henriksen J., Bovee K. & Bartholow J. 1994. The instream incremental methodology. A primer for IFIM. Biological Report 29. Washington, DC, Department of the Interior, National Biological Service.

Stein B.A., Kutner L.S. & Adams J.S. eds. 2000. *Precious heritage: The status of biodiversity in the United States*. New York, Oxford University Press. 416 pp.

Tharme R.E. 1996. Review of the international methodologies for the quantification of the instream flow requirements of rivers. Report to the South African Department of Water Affairs and Forestry, Pretoria, South Africa, 116 pp.

Tharme R.E. 2003. A global perspective on environmental flow assessment: Emerging trends in the development and application of environmental flow methodologies for rivers. *River Research and Applications.* 19. (forthcoming)

Thorpe J.H. & Delong M.D. 1994. The riverine productivity model: An heuristic view of carbon sources and organic matter processing in large river ecosystems. *Oikos* 70: 305-308.

Thorpe J.H., Delong M.D. Greenwood K.S. & Casper A.F. 1998. Isotopic analysis of three food web theories in constricted regions of a large river. *Oecologia*, 117: 551-563.

Tockner K. & Stanford J.A. 2002. Riverine flood plains: Present state and future trends. *Environmental Conservation*, 293: 308-330.

Toth L.A., Obeysekera J.T.B., Perkins W.A. & Loftin M.K. 1993. Flow regulation and restoration of Florida's Kissimmee River. *Regulated Rivers: Research and Management*, 8: 155-166.

Toth L.A., Arrington D.A. & Begue G. 1997. Headwaters restoration and reestablishment of natural flow regimes: Kissimmee River of Florida. *In* J.E. Williams, C.A. Wood & M.P. Dombeck, eds. *Watershed restoration: Principles and practices.* Bethesda, Maryland, American Fisheries Society. pp. 425-444

Toth L.A., Arrington D.A., Brady M.A. & Muszick D.A. 1995. Conceptual evaluation of factors potentially affecting restoration of habitat structure within the Channelized Kissimmee River ecosystem. *Restoration Ecology*, 3: 160-180.

Toth L.A., Melvin S., Arrington D.A. & Chaimberlain J. 1998. Hydrologic Manipulations of the Channelized Kissimmee River. *Bioscience*, 48: 757-764.

Trexler J. 1995. Restoration of the Kissimmee River: A conceptual model of past and present fish communities and its consequences for evaluating restoration success. *Restoration Ecology,* 3: 195-210.

Valentin S., Souchon Y., and Wasson J.G. 1994. Evaluation of hydro-peaking effects on fish community and habitat. *In* I.G. Crowx ed. *Rehabilitation of freshwater fisheries*. Oxford, UK, Fishing News Books. pp. 138-151

Vannote R.L., Minshall G.W., Cummins K.W., Sedell J.R. & Cushing C.E. 1980. The river continuum concept. *Canadian Journal of Fisehries and Aquatic Sciences*, 37: 130-137.

Van Winkle W., Railsback S.F., Holcomb B.D. Studley T.K., & Baldrige J.E. 1998. Individual-based model of sympatric populations of brown and rainbow trout for instream flow assessment: Model description and calibration. *Ecological Modelling*, 110: 175-207.

Walker K.F., Sheldon F. & Puckridge J.T. 1995. An ecological perspective on dryland rivers. *Regulated Rivers: Research and Management*, 11: 85-104.

Walters C.J. 1997. Challenges in adaptive management of riparian and coastal ecosystems. *Conservation Ecology*, 2: 1. (available at http://www.consecol.org/vol1/iss2/art1)

Ward J.V. 1989. The four-dimensional nature of lotic ecosystems. *Journal of the North American Benthological Society*, 8: 2-8.

Ward J.V. & Stanford J.A. 1983. The serial discontinuity concept of lotic ecosystems. *In* T.D. Fontaine & S.M. Barkeu, eds. *Dynamics of lotic ecosystems*. Ann Arbor, USA, Science. pp. 29-42.

Ward J.V. & Stanford J.A. 1995. Ecological connectivity in alluvial river ecosystems and its disruption by flow regulation. *Regulated Rivers: Research and Management*, 11: 105-119.

Ward J.V., K. Tockner & F. Schiemer 1999. Biodiversity of floodplain ecosystems: Ecotones and connectivity. *Regulated Rivers: Research and Management*, 15, 125-139.

Ward J.V., Tockner U., Uehlinger U. & Malard F. 2001. Understanding natural patterns and processes in river corridors as the basis for effective river restoration. *Regulated Rivers: Research and Management*, 117: 311-323.

Warren T.J., Chapman G.C. & Singhanouvong D. 1998. The upstream dry-season migrations of some important fish species in the Lower Mekong River of Lao PDR. *Asian Fisheries Science*, 11: 239-251

World Commission on Dams 2000. Dams and development: A new framework for decision making. The Report of the World Commission on Dams. London, Earthscan Publications, 448 pp.

Welcomme R.L. 1979. *Fisheries Ecology of Floodplain Rivers*. London, Longman. 377 pp.

Welcomme R.L. 1985. River Fisheries. *FAO Fish. Tech. Pap. No. 262*. Rome, FAO. 330 pp.

Welcomme R.L. 1988. International introductions of inland aquatic species. *FAO Fisheries Technical Paper* 294. 318 pp.

Welcomme R.L. 1999. Review of a model for qualitative evaluation of exploitation levels in multi-species fisheries. *Fisheries Management and Ecology*, 6: 1-20.

Welcomme R.L. 2001. Inland fisheries ecology and management. Oxford, UK, Blackwell Science Ltd., Fishing News Books. 358 pp.

Welcomme, R.L. & Bartley, D.M. 1998. Current approaches to the enhancement of fisheries. *Fisheries Management and Ecology*, 5: 351-382.

Welcomme R.L. & Hagborg D. 1977. Towards a model of a floodplain fish population and its fishery. *Environmental Biology of Fishes,* 21: 7-24

Welcomme R. & Halls A. 2003. Dependence of tropical river fisheries on flow. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 2.* Food and Agriculture Organization of the United Nations & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/17. pp. 267-284.

Williamson M.H. & Fitter A. 1996. The characters of successful invaders. *Biological Conservation*, 78: 163-170.

Winemiller K.O. 1989a. Ontogenetic diet shifts and resource partitioning among piscivorous fishes in the Venezuelan llanos. *Environmental Biology of Fishes*, 26: 177-199.

Winemiller, K.O. 1989b. Patterns of variation in life history among South American fishes in seasonal environments. *Oecologia,* 81: 225-241.

Winemiller, K.O. 1996. Dynamic diversity: Fish communities of tropical rivers. *In* M.L. Cody & J.A. Smallwood, eds. *Long-term studies of vertebrate communities*. Orlando, Academic Press. pp. 99-134.

Winemiller K.O. 2003. Floodplain river food webs: Generalizations and implications for fisheries management. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 2*. Food and Agriculture Organization of the United Nations & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/17. pp. 285-310.

Winemiller K.O. & Jepsen D.B. 2002. Migratory neotropical fish subsidize food webs of oligotrophic blackwater rivers. *In* G.A. Polis, M.E. Power & G. Huxel, eds. *Food webs at the landscape level*. Chicago, University of Chicago Press. (forthcoming)

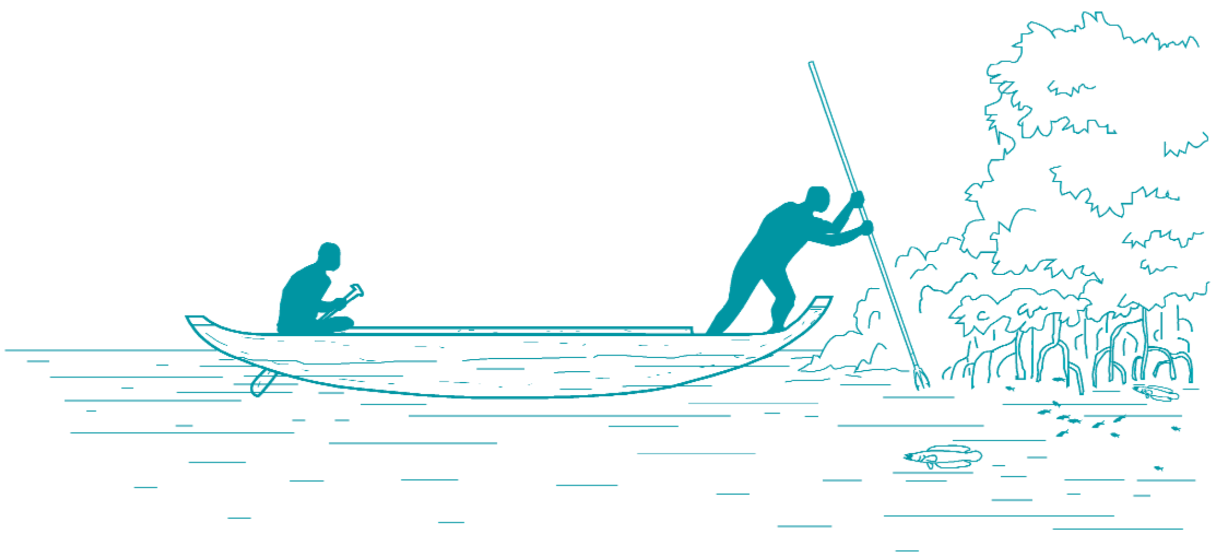
Winemiller, K.O. & Rose, K.A. 1992. Patterns of life-history diversification in North American fishes: Implications for population regulation. *Canadian Journal of Fisheries and Aquatic Sciences*, 49: 2196-2218.

Wissmar R.C. & Beschta R.L. 1998. Restoration and management of riparian ecosystems: A catchment perspective. *Freshwater Biology*, 40: 571-585.

Woodward G. & Hildrew A.G. 2002. Food web structure in riverine landscapes. *Freshwater Biology*, 47: 451-468.

Zalewski M. 2003. Ecohydrology - new conceptual tool for restoration and sustainable use of fisheries resources in rivers. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Zhong Y. & Power, G. 1996. Environmental impacts of hydroelectric projects on fish resources in China. *Regulated Rivers: Research and Management*, 12: 81-98.



SESSION 4 REVIEW

PEOPLE AND FISHERIES MANAGEMENT

Wolf Hartmann[1] Patrick Dugan[2] Simon Funge-Smith[3] Kent G. Hortle[4] Blaise Kuemlangan[5] Kai Lorenzen[6] Gerd Marmulla[7] Niklas Mattson[8] Robin Welcomme[9]

[1] Mekong River Commission, Fisheries Programme (FIP/MRRF), P.O. Box 7035, Vientiane, Lao PDR

[2] WorldFish Center (formerly ICLARM) Egypt Office, PO Box 1261, Maadi, Cairo, Egypt

[3] Food and Agriculture Organization of the United Nations, Regional Office for Asia and Pacific, 39 Phra Atit Rd., Bangkok 10200, Thailand

[4] Mekong River Commission, Fisheries Programme (FIP/AMCF), 186 Norodom Blvd., Phnom Penh, Cambodia

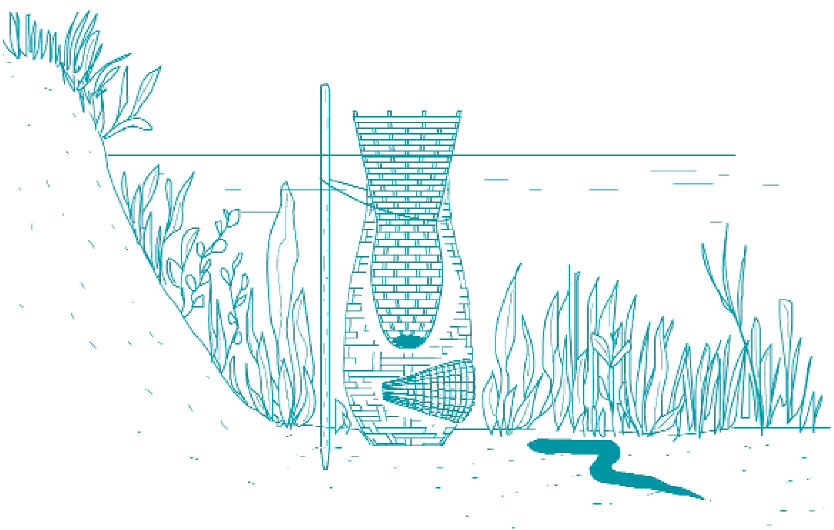
[5] Food and Agriculture Organization of the United Nations/Development Law Service, Legal Office (FAO/LEGN), Viale delle Terme di Caracalla, Rome 00100, Italy

[6] Department of Environmental Science and Technology, Imperial College, London SW7 2BP, UK

[7] Food and Agriculture Organization of the United Nations, Fisheries Department, Viale delle Terme di Caracalla, Rome, Italy

[8] Mekong River Commission, Fisheries Programme (FIP/AIMS), P.O. Box 7035, Vientiane, Lao PDR

[9] Renewable Resources Assessment Group, Department of Environmental Science and Technology, Imperial College of Science, Technology and Medicine, Prince Consort Road, London SW7 2AZ, UK



WHAT IS MANAGEMENT?

DEFINITIONS

Most definitions of management[1] are not specific as to who is doing what. They tend to be limited to a broader or narrower description of management tasks. Broader definitions are those which describe management as almost any activity that aims at conservation and sustainable utilization (Jensen, pers. comm.), comprising multiple decisions and actions affecting the magnitude and composition of fishery resources and the distribution of benefits from its products (Welcomme 2001). Narrower definitions present manage-

1 According to Collins English Dictionary (1992) the word 'to manage' comes from Italian *maneggiare* - to control, train (esp. horses), ultimately from Latin *manus* - hand.

ment as set of important tasks that may or may not include such activities as research, marketing, education of fisheries managers and others as important and integral parts of management[2] (Arlinghaus, Mehner and Cowx 2002; Degnbol and Nielsen 2002; Welcomme 2001). These definitions are important as they may answer questions as to who or what is managing or being managed and how and why this takes place. For the purpose of discussions in Panel 4 of this conference, we tend to agree with Blanckenburg (1982) that management is to utilise, guarantee and protect, increase production from and improve (inland fisheries) resources.

Why manage and what are main management functions?

According to Charles (1994) controlling the exploitation of fisheries through management is necessary for the following reasons: a) an increasing demand for fish and an increasing number of resource users may not only deplete resources but have the potential to drive them to extinction; b) conflicting ecological, social, economic and social goals inherent in many fisheries must be balanced through management and c) controls are needed over the rate of exploitation, to balance present-day needs with the maintenance of the resource at suitable levels in the future.

For our purposes, management functions in inland fisheries comprise the following (Pinkerton and Weinstein 1995): Policy decision-making (including researching the resource, planning, organizing users etc.); data collection/monitoring; regulating access; regulating harvest; enforcement (including awareness creation and policing); habitat and resource protection and enhancement; resource use coordination; and benefit maximization (harvest planning, product development, etc.).

Is inland fisheries management unique?

Inland fisheries management is part of natural resource management and shows many similarities with that of artisanal and industrial coastal and marine fisheries, as well as other natural resources, such as forestry, wildlife, irrigation, etc. with which it shares a number of important features, attributes and characteristics. Inland fisheries also depend on a package of resources, primarily water/water bodies and fish stocks, but also land, wood, forest, etc. The use of both aquatic and terrestrial resources is frequently governed by the same or similar values, customs and beliefs (COFAD GmbH 2001; Jackson 2003). Furthermore, inland fisheries are also subject to similar management policies and practices and are frequently under the jurisdiction of the same management agency as these other resources (e.g. Ministries of Agriculture, Livestock and Forestry, etc.)[3].

According to Degnbol (1998), fisheries management is just one of many manifestations of the management of social systems. There is, therefore, no reason to expect that inland fisheries management should be radically different from or that it may have evolved completely independent of the general historical development of social management. We will therefore, wherever adequate, compare and contrast inland fisheries management with the management of common-pool resources in general.

Resource types, property rights and management regimes

Two important characteristics of natural resources such as fish, game, forests and rangelands are the degree to which exclusion of users is difficult and the degree to which the use by one user subtracts from the benefits of others. In fact, such resources may provide a pool of benefits to be withdrawn from more

2 The FAO defines 'management' as an "Integrated process of information gathering, analysis, planning, consultation, decision-making, allocation of resources and formulation and implementation, with enforcement as necessary, of regulations or rules which govern fisheries activities in order to ensure the continued productivity of the resources and accomplishment of other fisheries objectives" (1995; 2001).

3 See Koehn and Nicol for special (specific resources) and standard management strategies (all natural resources) of the Murray-Darling Basin Commission (MDBC) in Australia. There, a special effort to rehabilitate native fish communities through the implementation of a long-term *Native Fish Strategy*, focussing on fish, is being carried out within an Integrated Catchment Management Policy (Koehn & Nicol 2003).

than one user and are thus called common-pool resources (Ostrom 2000). Resources with low excludability and high subtractability may be held under a variety of property rights and management regimes, but, due to their particular nature, are frequently held not in private property, but in state or common property or no property at all (also called 'open-access' and particularly prone to that phenomenon called "tragedy of the commons"[4]), or any combination thereof[5]. Property rights[6] are frequently subdivided into *use rights* (right of access to and withdrawal from the resource) and *control rights*, which, in fact, are rights to manage. Corresponding management regimes are *laissez-faire* (virtually no governance nor effective market-based regulation in the management of open access or common-pool resources); *market regulation* (management of non-common and common-pool resources determined by market mechanisms); *communal governance* (existence and potential of user-governance and local-level systems of common-pool resource management); *state governance* (central role of state in management of non-common and common-pool resources); and international governance (common-pool management that differs from state governance by features such as lack of centralised enforcement and reliance on persuasion and indirect penalties for breaking the rules) (McCay 1993).

HOW DO PEOPLE FIGURE IN MANAGEMENT AND WHAT ARE THE CONSEQUENCES?

The way in which resource users have been and are seen by resource managers has consequences for management. Table 1 is based on experiences taken mainly from forestry and identified three historical phases in the evolution of natural resource management (NRM).

Table 1: Resource users, approaches and consequences (Uphoff 1998)

Resource users	Approach	Consequences
"Adversaries"	Prohibitive approach	Limited effectiveness; needs ample government capacity
"Beneficiaries"	Integrative (conservation and development) approach	Rural communities offered incentives to desist from resource degradation; paternalistic; need to continuously reward to ensure cooperation; management goal perceived as serving interests of outsiders rather than communities
"Partners"	Integrating conservation and development goals by focusing on needs, interests, knowledge, values, capabilities of local populations, which are considered starting points in design and evolution of management regimes	As many accommodations are made to local interests and needs as well as modes of organization and management as compatible with conservation

4 According to Hardin (1968) the users of common-pool resources are caught in an inevitable process that leads to the destruction of the very resources on which they depend. The rational user of a commons makes demands on a resource until the expected benefits of his or her actions equal the expected costs. Because each user ignores costs imposed on others, individual decisions cumulate in tragic overuse and potential destruction of the resource in question. This problem of the commons has also been called "the fisherman's problem", because open-access fisheries provided important early illustrations of it (McCay 1993).

5 *Private property:* Individuals, families or legal entities have the right to undertake socially acceptable uses and exclude others from using the resource. *State property:* Property over which the state exercises management rights and defines access rules. State property is in most cases used by the citizens, within the given legal framework. *Common property:* 'Private' property of a group, which jointly uses the resource and has the right to exclude non-members. Management is usually undertaken by all group members or their representatives. *Open*-access*:* Everybody has a right to access a resource and withdraw from it; nobody has a right to exclude others from using it. Whether or not property rights are established over a natural resource and, if so, which property and management regimes are chosen, is influenced by various reasons within or outside of the resource (McCay 1993).

6 Property rights are sets of socially-defined rights to a resource; they determine "who may be where doing what and when".

Paraphrasing Murphree (on wildlife management in Southern Africa) Murombedzi (1998) distinguishes between the following three historical stages and their respective outcomes[7]:

Management against the people *(colonial/immediate post-colonial era):* Weakening or demise of local management institutions and mechanisms, with simultaneous incapacity of colonial and post-colonial state to manage at all levels; management based on imposed European laws and practices; individual user becomes focus of resource use regulations; local ecological knowledge (LEK) is not considered; local users loose control of resources; natural resource management in state of crisis (no substantive regulatory capacity at any level, resource use with little or no management)[8].

Management for the people *(the 1970s)*: Promulgation of new legislation (conservation agencies to engage in the provision of extension services and environmental education to the people in addition to traditional policing and enforcement efforts); no efforts however to include local people in the management decision-making, neither taking into account LEK or traditional regulations in developing the laws; no substantial break with European management approaches of the colonial epoch, but change in implementation of legislation away from policing and enforcement to accommodation; attempts were also made in some cases to elicit local support for the state's management initiatives through provision of handouts; no attempt was made to devolve rights to natural resources to the local communities; no significant improvement of natural resources management, as governments did not develop the additional capacities required to implement new programs and the absence of a rights for community participation in natural resource management meant that local communities themselves did not develop the capacities necessary to fill in the vacuum.

Management with the people *(from late 1970s onwards):* With governments crumbling under a heavy debt burden accrued from the earlier attempts at modernization and rural development, economic structural adjustment policies were implemented, designed to assist these economies to recover from the devastation of the debt burden; this required that governments downsize and initiate popular participation in development planning and implementation, seeking to co-opt the managerial capacities of the people; community participation in natural resource management becomes the pre-eminent natural resource management paradigm; the market is emphasized as the single most important regulatory mechanism; interestingly, in Southern Africa, the devolution of management control from the state first occurred to private land owners before it was extended to land-holders in other tenure regimes. The fundamental institutional reforms that made management with the people possible have included the devolution of government, tenure reforms, market reforms and the production of some form of benefit for individuals and communities engaging in natural resources management.

The fourth dimension in management would be "managing by the people" (Murombedzi 1998), "users as owner-managers" (Uphoff 1998), or "managing (with) the fishers" (adapted from Welcomme 2000, 2001).

PHASES AND TRENDS IN MANAGEMENT

Various authors have described the history of natural resources management, highlighting different

[7] There is a fourth stage, "managing by the people", which he views as the broadly desirable objective of current policy initiatives in sub-Saharan Africa (see Towards a Fourth Dimension in Management, below).

[8] According to Murombedzi (Murombedzi 1998), the 'King's game' concept was exported to define natural resource management in former British colonies. For most rural populations who had no legal access to natural resources, these resources actually became a liability, legally belonging to the state or some other powerful actor.

periods and trends of management development in marine and inland fisheries, or taking these as examples (Arlinghaus *et al*. 2002; Caddy and Cochrane 2002; McCay 2002; Welcomme 2001; Welcomme 2002). Based on these authors we suggest the following phases in fisheries management:

- Traditional[9] (non-industrial/pre-scientific) management; beginning: several thousand years ago;
- Conventional (traditional[10]/scientific/modern) management; beginning: in latter half of nineteenth century;
- Recent (Post-modern/participatory, ecosystem, etc.) management; beginning: in the early 1980s.

In the following paragraphs we will concentrate on conventional management and compare it with traditional management, in particular. Experiences made with the implementation of conventional management will then be contrasted with perceptions and aims of more recent or "post-modern" management approaches (McCay 2002). However while some authors see these phases in an almost chronological sequence (Caddy and Cochrane 2002), in our view and in the view of others (COFAD GmbH 2001), these phases often occur concurrently but not necessarily on the same level. Thus, resource management science may see itself in one phase, management administration in another and actual practical management on the ground may be carried out according to practices of a third. For example, traditional management is still the predominant method of managing inland fisheries in sub-Saharan Africa and many other countries in the South, with science, administration and other government services hardly having scratched the surface of the real fisheries. Obviously there are a number of reasons why the enlightenment gained on one level is not necessarily reflected on the others, such as the availability of information, reluctance to accept new ideas and paradigms, the intricacies of the policy process, the compatibility with the political system of the day, development priorities, the limited capacity or willingness of governments to implement management proposals on a significantly large scale, etc. (Almeida, Lorenzen and McGrath 2003; Batista 2003; Friend 2003; Hossain *et al.* 2003; McGrath, Cardoso and Sá 2003; Oviedo and Ruffino 2003a and b; Parveen and Faisal 2003; Ruffino 2003a and b;)

Conventional management

McCay (1998) characterizes conventional management as based on: utilitarian values; (commodity) production-oriented; single species and deterministic models and management; top-down; government- and expert-based scientific monopoly on data and analysis; the social level of resource use; and advisory, consultative roles for users. Experience has shown that as resource-based industries have developed and industrialized, resource management has tended to become specialized and centralized (Hanna 1998). Primary stewardship authority has accrued to the government at regional, state or national levels. Although various types of decision-making processes are possible in natural resource management, they have generally been top-down both in democratic countries and in others,

9 The term *traditional* has at least two connotations. The first connotation is that used by Scudder and Conelly (1985), for example, to describe fishing communities yet to be incorporated within a commercial fishery based on monetary transactions. However, they hasten to emphasize the dynamics brought about in traditional societies due to such phenomena as technical innovations (nylon, ice, engines, electronics), economic/social changes (commercialization, market integration, and social stratification: differentiation, specialization, changing gender roles, polarization, marginalization). Thus, traditional fisheries are (and always have been) parts of networks of commodity exchange, and are not static, since all societies, no matter how isolated, have histories which include both continuity and change as ongoing processes. This is the connotation that we use when we refer to *traditional*.

10 As explained by COFAD (2001), the second connotation of *"traditional"* (between inverted commas) describes a cultural continuity among a group of people, passed on in the form of attitudes, beliefs, practices, principles and conventions. It does not imply that such practices have been transmitted unchanged from pre-colonial or any other time, nor does it imply that a practice takes place in an overall 'traditional' context (see above). The continuity referred to here may relate to an individual practice and its appearance, the institutions governing and carrying out a practice, as well as their legitimacy, or the general cognitive background (the knowledge system) on which the practice is based (COFAD 2001). Thus, conventional fisheries management may very well classify as "traditional" management.

with decisions and rules developed centrally by government and communicated down to user groups. More specifically, the conventional approach to fisheries management was and still largely is to impose centralized regulations at national level through restrictions on gears, seasons, areas and access (through licenses and, in some marine fisheries, quotas). In addition to these classic measures, the introduction of stocking and environmental enhancement became important management instruments in inland fisheries since the latter half of nineteenth century (Welcomme 2001).

It was the demand for fisheries management that gave birth to fisheries science. The formation of national fisheries research organizations in the late nineteenth century resulted from politicians looking for ways to resolve disputes between fishers. These organizations brought together biologists from various backgrounds who formed the core of what later became a scientific discipline and community in its own right (Wilson 2000).

While the main emphasis was on marine fisheries, in inland waters investigations into lakes and small streams led to the development of limnology as a science in the early twentieth century. In the mid-1970s, research into reservoir fisheries received special attention as a result of dam construction. In 1985, LARS1 provided the first systematic presentation of investigations into large rivers with a worldwide coverage.

What is what in management?

A bewildering array of (often synonymously used) terms is being suggested in the specialist literature to describe the context and contents of fisheries management. In order to provide some kind of system, the following paragraphs are subdivided into

- *Policy* issues (or the ‘why and what?’) – such as goals, policies, principles/paradigms, purposes and objectives
- *Operational* issues (or: the ‘how?’) – such as strategies, levels, options and tools

Management goals, policies, purposes and objectives

The overall goal of conventional fisheries management is sustainability, or conservation defined as sustainable use (Arlinghaus *et al.* 2002; Welcomme 2000; Welcomme 2001). Policies for fisheries development and management should therefore aim at extracting only that amount of fish from the aquatic system that is consistent with the continuity of supplies at suitable levels into the future (Welcomme 2001). Most fisheries management policies explicitly aim at an increase in production while, at the same time, sustaining the resource, in its widest sense (COFAD GmbH 2001). Christensen *et al.* (1999) give as the overriding objective (or goal?) of NRM that no resource[11] should become depleted. Jackson (2003) hints at conservation as a means of maintaining a regional identity, promoting characteristics of political and economic independence.

While fisheries sustainability is in the foreground, Nielsen, Degnbol, Ahmed and Viswanathan (2002) point out that the overall goal for fisheries management should be ecosystem sustainability, not fisheries sustainability *per se*.

According to Charles (1992), there are three sets of policy objectives, each based on different fishery *paradigms*[12] : (Table 2)

[11] The very concept of natural ‘resources’ contains a bias toward evaluating the components of ‘nature’ in economic terms, assessing their use value more readily than assigning them any intrinsic value (Wallace *et al.*1996).

[12] Any more definitions? “Policy is a specific way of interpreting the world” and, “policy processes are essentially concerned with political decisions of access to and control over resources, and how benefits are distributed,” (Friend 2003).

Table 2: Fishery paradigms, policy objectives and concepts (adapted from Charles 1992)

Fishery paradigm	Policy objective	Concept[13]
Conservation	Conservation / resource maintenance	MSY
Rationalization	Economic performance / productivity	MEY
Social/community	Community welfare / equity	OSY

According to Welcomme (2001) the three major principles governing modern fisheries management are:

- Sustainability of fisheries
- Conservation of diversity of living aquatic resources
- Equitable distribution of benefits from fisheries and aquatic ecosystems

Within these principles, most fisheries management aims at a mix of purposes or objectives, which may include:

- Extractive objectives (fish protein supply; recreation)
- Non-extractive objectives (control of disease vectors, control of water quality and aesthetic/moral benefits)
- Government/fiscal objectives (revenue, foreign exchange earnings)
- Social objectives (income; equity of distribution of benefits; reduction of social conflict)
- Conservation objectives (sustainability and ecological objectives such as biodiversity)

Some of these objectives may be mutually exclusive. Thus, a decision must be made as to which of them fit the particular social, economic and political development criteria, priorities, principles and goals of the society in question. This also points to the concept that management is responsible for negotiating solutions in the light of diverging interests, a balancing act between the requirements for biologically sustainable resource use and economically optimal exploitation patterns, while being socially acceptable to all involved parties (Parveen and Faisal 2003; van Zaling *et al*. 1998; Welcomme 2001).

Strategies, levels, options and tools

Welcomme (2001) emphasizes regional differences in management strategies in inland fisheries. In developed economies, strategies aimed and still aim at a) conservation and b) recreational fisheries[14] and management focuses on the mitigation of environmental degradation, through such measures as stocking and habitat maintenance and rehabilitation. In developing economies, the management approach is said to be production-oriented. Management measures focus on a) intensification of production from inland waters through stocking and extensive aquaculture and b) on containing fishing effort and access to the fishery. The following (Table 3) strategies for managing inland waters in developed and developing countries have been identified (Arlinghaus *et al.* 2002):

From a spatial point of view, inland fisheries are managed at several different levels: local, regional, national, international. At the regional and international levels fisheries management can be transboundary.

13 MSY: MSY provides a reference point that predicts the level of effort at which the maximum amount of fish can be sustainably captured from a stock. The utility of MSY is now largely discredited and, in fact, it never formed a major component of inland fisheries policy (Welcomme 2001); the alternatives Maximum Economic Yield and Optimum Sustainable yield have not found favour either.

14 This goes back into European history when fishing and hunting were the privilege of a few, and where conservation and recreational fisheries by the upper classes brought hardship to the rural poor and provoked political unrest and the long heritage of poaching (McCay 1987).

Table 3: Difference in management strategies

	Developed Economies	Developing Economies
Objectives	Conservation/preservation; recreation	Provision of food, income[15] (commercial) food fisheries;
Mechanisms	Recreational fisheries; habitat rehabilitation; environmentally sound stocking; intensive aquaculture	Habitat modification; Enhancement, through intensive stocking; Extensive, integrated, rural aquaculture;
Economic characteristics	Capital intensive	Labour intensive

From a fishery systems point of view, there are three management levels, each with its own distinct set of tools: Managing the fish; managing the fishery; managing the environment.

Managing the fish

Fish are managed to improve production, to make up for shortfalls in production arising from over-fishing and environmental change and for conservation of threatened species and stocks (Welcomme 2000). The tools for this include stocking, species introduction or elimination and genetic modifications of stocks. Aquaculture represents the extreme of this trend to improve and intensify production from inland waters through increasing control of the fishes life processes.

Problem areas and open questions relating to this level of management are: a) the motivations underlying these kinds of intervention, which are frequently cosmetic, political and even cultural or religious; b) the biological efficiency and cost effectiveness of interventions, which is frequently, but by no means always, not proven (Carvalho and Sobrinho de Moura 1998; Hambrey 2002; Hambry 2002) and c) the doubts as to whether or not lower levels of government or fishing communities will be able to pay for these interventions when management has been devolved and/or privatised are particularly relevant in connection with the present trend to decentralise management and the responsibility for interventions.

Managing the fishery

Managing the fishery focuses on ensuring the sustainability of production and equitable distribution of benefits. Traditionally, inland fisheries management was approached using conventional models developed for marine fisheries, such as a strong centrally controlled management based on Maximum Sustainable Yield (MSY) and other population models. These conventional approaches have been found to be largely inappropriate due to the characteristics of inland fisheries and in particular those of floodplain rivers. Conventional approaches are also less useful in multi-species fisheries due to their data requirements. For the same reason modelling of inland fisheries is relatively absent.

The strategies, options and tools of inland fisheries management differ somewhat between inland waters in temperate zones and those in the tropics and sub-tropics. In temperate zones, water bodies show a limited number of species and a lesser biodiversity and here strong centrally controlled management was based on MSY. However, in the multi-species/multi-gear fisheries more common in the tropics management of the complex assemblages of fish is mainly

15 Kaunda and Chapotoka (2002) sources including riverine fisheries in poverty-stricken communities, due to pressures on catchments, river bank alterations, capture of spawning fish etc. “At the height of poverty the challenge to manage fisheries is great”.

based on the control of effort and length of fish caught when subject to fishing and environmental pressure.

The main goal of management regulations is to influence the behaviour of the fishery. Options for management depend to a large extent on the characteristics and context of the fishery. Main management options are:

- To maximise economic yield
- To maximise yield, but retaining the quality of the fish
- To manage for large species of high commercial value
- To maximise employment (increasing effort) and accept that the fishery will become fished-down

Management tools are:

- Input controls (which regulate fishing effort through such measures as gear restrictions, closed seasons and closed areas).
- Output controls (which regulate access to the fishery through such measures as licensing, auctioning off/contracting of temporary use rights/granting of permanent ownership rights, as well as such measures as quotas and bag limits and size restrictions on fish landed/marketed.

Problem areas for the management at this level are: a) the difficulty to legislate for different approaches to different fisheries; b) that the imposition of single legislation creates social inequalities and enforcement problems. This "crisis of fisheries management" has led to the idea of involving fishing communities in regulating processes, making possible a more flexible and localized approach to management.

Managing the environment

Environmental changes resulting from human activities may cause many different kinds of impacts on fisheries. For example, construction of reservoirs favours lentic over lotic species, pollution may favour those species that are more tolerant and reduction in physical habitat diversity or reduced water flows will tend to reduce overall abundance, diversity, productivity and the average size of fishes in the fishery. Of most immediate concern is the ongoing alteration of large river systems in the tropics for exploitation by other sectors, principally agriculture and hydroelectricity. Such river systems are species-rich and often support large, valuable and under-recognised river fisheries. Dams cause multiple effects on rivers and their fisheries and the negative effects are usually not internalised as costs in development projects, nor are they usually mitigated. Similarly, isolation of the floodplain (flood control/irrigation systems) via regulators and levees causes direct losses to the river fishery that are usually unaccounted and not mitigated.

Welcomme (2000, 2001) outlines typical strategies, measures and tools which can be applied under certain conditions to manage the environment for fisheries. These are:

- Do nothing (when pressures from competing uses are excessively strong);
- Protection (where there are natural or acceptable environmental conditions, legislation on reserves and protected areas may be important measures);
- Mitigation (where competing users are economically important, but the aquatic environment still benefits from long-term interventions, such as operation of water-treatment plants, maintenance of environmental flows, stocking, etc.)[16];
- Rehabilitation (where pressures from other users have eased, restoration of aquatic habitats to natural/quasi-natural conditions may be an option, through such measures as restoration of channel

16 Mitigation of the impacts of water management projects should be carried out when it is cost-effective. Worldwide there has in fact been very little mitigation of the impacts of dams and other WMPs. For example, in the lower Mekong Basin, there are many thousands of dams or weirs on tributaries, which disrupt fish migrations, yet there are only three fishways (in Thailand), despite their demonstrated effectiveness at low barriers. Also in the lower Mekong Basin, stratification causes well-documented impacts both within and downstream of many larger reservoirs, and the wildly fluctuating discharges from several hydroelectric dams cause major impacts downstream, yet there are no dams with measures to mitigate the impacts of seasonal stratification, nor with re-regulating ponds for hydroelectric discharges. Worldwide the situation is similar, with fishways in place on relatively few barriers, and destratification or multi-level offtakes, and re-regulation of discharges only recently becoming more common in the West. Mitigation of the impacts of floodplain isolation by improved design and operation of regulator/levee systems are now well-documented, but have yet to be acknowledged or applied outside Bangladesh, despite their low cost and likely high return. The reasons for the failure to incorporate mitigation in water management are complex, but are clearly not primarily technical.

diversity and longitudinal and lateral connectivity);

- Intensification through physical measures to supplement biotic measures (stocking, species introduction), such as fertilization of water bodies, brush parks, bunding of floodplains to create fish ponds, etc.

FROM TRADITIONAL TO CONVENTIONAL MANAGEMENT: A COMPARISON

Objectives, instruments and differences

Comparing goals, objectives and tools of traditional and conventional fisheries management show many similarities. In fact, few tools are new in inland waters and fisheries management (Rettig, Berkes and Pinkerton 1989; Welcomme 2000; Welcomme 2001).

Attempts at managing NRM and inland fisheries are ancient. There are many Biblical teachings against waste of natural resources and Pliny the Elder comments on soil erosion in ancient Rome. In Europe fishing regulations began early. The Romans limited the lengths of sturgeon landed in Rome as early as 400 BC. In England laws were passed in 1000 AD against the proliferation of fish fences in the major streams. Colbert limited the size of fish landed in the Loire fishing pressure in the 1600s. More recently habitat modifications led to overfishing and negative impacts on fish resources, giving rise to the development of privatized fishing rights, legislation aimed at preserving fish populations by controlling exploitation, definition of minimum sizes of fish caught, gear and temporal restrictions and other regulations. (Arlinghaus *et al.* 2002; Rettig *et al.* 1989; Welcomme 2001).

While fishing pressure worldwide may have been less than today, the very existence of fishing regulations are proof that there was an awareness of the limited nature of fish resources and the need to control and conserve inland fisheries (Welcomme 2001). Fisheries sustainability seems to have been an important concern of many traditional inland fisheries in Africa (Scudder and Conelly 1985)[17], South Asia (Soeftestad 2000) and the Americas (Rettig *et al.* 1989)[18].

Goals and objectives

Most traditional fisheries management systems contain goals and objectives similar to those found in modern fisheries management. The objective of sustainable resource use and resource conservation, for example, appears to be a feature common to both traditional and modern fisheries management[19]. Based on local knowledge and interlinked with traditional beliefs, customs and rules, traditional management systems may entail more than one objective, however. Equally common are objectives that reflect economic and social postulates. While aiming at optimising resource utilisation, these still contain elements of resource sharing and often aim to reduce conflict. Under most traditional regimes, for example, fishing for subsistence is open to all members of a group, a concession often made use of by women and children. The traditional method of regulating resource use in African inland fisheries is based on a social consent, which gives property rights over the resources to individuals, groups or communities. Based on such consent, property regimes are established, which determine the rights and responsibilities of the stakeholders and provide incentives to preserve the resource or even

17 Interestingly, Scudder and Conelly report from only 73% of their 91 analyzed cases of 'inland fishing societies' the existence of management strategies, of which about 90% are inadvertent, and the rest intentional.

18 However, reflecting on her observations during fieldwork in Western India, Baviskar (1995) comments: "While reverence for nature is evident in the myths and many ceremonies which attempt to secure nature's cooperation, that ideology does not [necessarily] translate into a conservationist ethic or a set of ecologically sustainable practices."

19 This doesn't mean, however, that there are no cases of resource depletion and extinction under traditional management regimes (McGoodwin 1990).

to invest into it. Property regimes, together with other prevailing norms and values, provide the framework within which management measures can be undertaken. The most common regime in inland fisheries in Africa and elsewhere is based on common property, where the right to use a resource is vested with a social entity. This does not mean, on the other hand, that traditional patterns of resource allocation would always be equitable: in some cases, it benefits privileged subgroups or keeps benefits from others. Political and institutional objectives, for example may pursue aims such as the preservation of the power status of traditional rulers or the allocation of economic benefits to specific individuals and groups within the community. If, for example, fees, tributes, or shares of the yield are demanded to access a fishery, their payment may serve to stabilise the institutions in charge of fisheries management or serve social purposes; for example, if they are used to support the needy. Similarly, traditional management approaches accommodate spiritual, religious and related objectives, often interwoven with the objectives previously mentioned. (COFAD GmbH 2001).

Managing the fish

Systems or measures for enhancement of fisheries and aquatic environments are found in many countries and regions of sub-Saharan Africa (COFAD GmbH 2001). Some presumably evolved over centuries, others have emerged fairly recently. Traditional fisheries enhancement systems and measures are implemented within frameworks of traditional resource management. As such, they are linked to a variety of objectives but the economic objectives of increasing physical and economic yields still have much greater. All systems and measures have in common a degree of management and intervention which goes beyond that of traditional capture fisheries property rights which are defined more narrowly than in capture fisheries. Traditional fisheries enhancement usually includes one or more of the following areas of intervention: movement of fish stocks, extent of water retention, water quality (fertility) and/or availability of fish feed. Often enhancement techniques are rooted in and combined with methods of fish catching, as for example the attraction or confinement of fish (see for example brush park fisheries as described by Welcomme 2002)

Modern fisheries enhancement depends largely on the introduction of non-native species to enhance commercial production or to improve sports fishing. These measures, most of which date back to pre-independence times, aimed at enhancing artisanal capture fisheries, but also led to the establishment of semi-industrial fisheries. Furthermore, some carp, bass and trout species have been introduced in African countries, mostly to enhance sport fishing. Other species, for example tilapias, have been introduced into areas where they were not endemic for pond culture or in the context of culture-based fisheries. Modern aquaculture technologies were first brought to sub-Saharan Africa by colonial powers, in particular the German, Belgian and French administrations. They involved freshwater pond culture only, to produce protein-rich food for the labour force. However, after the breakdown of colonial rule, most ponds were abandoned and pond culture retained the stigma of colonialism for some time. (COFAD GmbH 2001)

Managing fisheries

Traditional fisheries of South America, Africa and Asia apply management strategies and tools which include both inadvertent and intentional practices. The former including a wide range of behavioural patterns, customs and beliefs which indirectly conserve fish populations by restricting access to fishing, the latter were enforced with the explicit purpose to conserve fish populations through such measures as closed seasons and prohibition of certain gears (Scudder and Conelly 1985). The rationale of many management measures may be obscured by the socio-cultural and religious context in which they take place; their effect on the resource may sometimes appear to be a side-effect rather than intentional. Often, for example, rituals and magic are interwoven with fisheries management measures. Means, which are justified on primarily metaphysical grounds, may, in the knowledge system of African inland fishers, be part of goal oriented and intentional resource management. (COFAD GmbH 2001; Scudder and Conelly 1985; Soeftestad 2000; Welcomme 1979).

Managing the environment

Measures to conserve and improve the environment are well known in African and South Asian systems of traditional fisheries management, such as brush parks, etc. (COFAD GmbH 2001; Soeftestad 2000; Welcomme 1979; Welcomme 2002). Such measures aim to modify a habitat by introducing structures, which not only attract fish (such as fish aggregating devices (FADs) in capture fisheries), but also additionally provide periodic shelter, thereby improving stock recruitment, survival rates of juvenile fish and/or natural food supply. Other systems aim to retain water and fish with the help of physical structures. These systems are referred to as retention systems, e.g. through the creation of barriers, placement of fences and traps and construction of drain-in ponds or fish holes. In addition, modern management must deal with large-scale alterations to river systems, for which the principles of traditional management may apply, but which are of much larger scale.

Major differences between traditional and conventional management are the knowledge base for fisheries and fisheries governance, the former being based on science and the latter being based on centralized systems of management decision-making and enforcement (command and control). While much management was based on linear, deterministic science, fisheries scientists were already recommending the application of a more flexible and learning-oriented approaches and adaptive management in the 1970s. This was nothing new as it was quite common in traditional management systems with their emphasis on feedback learning and the treatment of uncertainty and unpredictability intrinsic to all ecosystems (Berkes, Colding and Folke 2000; Welcomme 1979).

Utilization and conservation

One of the major issues in natural resource management is to balance the demand for food by an ever-increasing population with the need to conserve natural resources for the future. In inland fisheries management there is therefore an increasing concern about the conservation of fisheries resources and their biodiversity and the perception of fishery decline and extinction of species. Strongly conservationist attitudes have emerged particularly in developed countries, while in the more food-hungry developing countries pressures continue to maintain high levels of harvest and utilization that might jeopardize the sustainability of the resource. However, in developing countries there is a growing realization that there is a need to protect resources from over-harvesting and conservation policies are being adapted to an increasing degree. The shift towards conservation is driving rapidly escalating attention towards river rehabilitation (reflecting social and cultural priorities) and restoration.

Past experiences and future needs in natural resource management, including management of inland fisheries, have been addressed by a number of international conventions and agreements, of which some are binding legal instruments and some not, such as:

- The Convention on Biological Diversity/CBD 1993
- The FAO Code of Conduct for Responsible Fisheries (FAO 1995)
- Agenda 21/UNCED 1992, a non-binding strategy for action to move countries towards sustainable development

Experiences and consequences

In the late 1970s and early 1980s, a number of authors declared that government management strategies had been shown to be completely ineffective (Scudder and Conelly 1985; Welcomme 1979). Welcomme (2001) later suggested that centralized management systems have proven impractical for the following reasons:

- Difficulties in enforcing the regulations
- Overcapacity generated by open-access nature of resource
- Inconsistencies inherent in trying to impose blanket legislation over diverse resources
- Lack of information, leading to arbitrary management prescriptions, leading to disregard of regulations by fishers

These deficiencies have caused a crisis in fisheries management in both marine and inland waters (Haraldsdottir 2000; McGoodwin 1990; Welcomme 2000). Similar crises were also reported from the management of other common-pool resources, such as irrigation etc. (Groenfeldt 1998).

In addition, actors both from within and outside the systems have increasingly challenged conventional management. For both main actors, i.e. government and users, limitations were identified. This led governments to contemplate the recognition of and support to traditional, community management arrangements. However, such arrangements were hampered by the heterogeneity of the user community and scale issues of the fishery, necessitating the existence of an actor operational at various levels. This again led to recognition of a need for co-management.

Changing patterns of resource use and management can be attributed to four main areas of change: public perception (such as environmental awareness, an awareness for our dependency on nature and the need for equitable benefit sharing as well as need for devolution of management to local levels); use patterns (in particular the conflict between use- and conservation-orientation, food vs. recreational fisheries and changes from pressure of social interest groups); demography (pressures from increasing population numbers and population distribution with consequences for urbanisation, pollution and utilisation of riparian areas); and changes in the nature of the resource from changing land-use patterns and climatic variations, orientation of fisheries [from subsistence to commercial], eutrophication and resulting changes of fish population patterns and last but not least from damming of rivers with the known consequences on up- and down-stream ecosystems (Schouten 2003; Welcomme 2000).

Due to these rapid changes, decisions in fisheries management can no longer be regarded as long-term and management is now seen to require flexibility and responsiveness. What is needed are consultative/adaptive systems in a co-operative effort between strong organizations of local fishermen and supportive outside agencies (both governmental and non-governmental), able to accommodate change (McGrath *et al.* 2003; Scudder and Conelly 1985; Welcomme 1979; Welcomme 2001).

Participatory management is the current philosophy in natural resource management (NRM). Its implementation will weaken government's centralised control and place a considerable part of the task of management with local communities. This process of devolution of management needs to be carried out in an orderly manner and hand in hand with the establishment of proper institutional infrastructure (Welcomme 2001).

POST-MODERN MANAGEMENT

What is new?

McCay (1998, 2002) characterizes post-modern approaches to management as based on utilitarian and land ethics values; multiplicities (species, habitat, ecological interactions, truths, discontinuities); humbler science; accepting uncertainty; adaptive and bioregional management; bottom-up, collaborative approaches; recognition of knowledge and expertise of users; acceptance of active, engaged user groups and communities.

She further highlights changes in language and discourse, the importance of community, diversity, participation and governance (McCay 2000) and scale (McCay 2002).

Discourse

In 1976, a federal government policy paper declared, “Fishing has been regulated in the interest of the fish. In the future it is to be regulated in the interest of the people who depend on the fishing industry” (Rettig *et al.* 1989).

In 1979, Welcomme declares the concept of MSY as inappropriate in river fisheries and advocates ‘adaptive management’. However, there is a conspicuous absence of any mention of user, participation, stakeholder or gender.

Scudder and Conelly (1985) emphasize the importance of participation of users in collaboration with government agencies in fisheries management. Fisheries management has moved away from an emphasis on fish stocks to a greater concern about livelihoods of the communities dependent on the fishery. There is an increased social and economic dimension in fisheries management and an increasing concern with equitable distribution of benefits from the fishery, conflict reduction within fishing communities and between fishing communities and others and gender participation in the fishery.

Scale

Changes in scales are suggested on various levels:

1. From fish to sector to system, including ecosystem[20] (McGrath *et al.* 2003; McGrath and Castro 2000).
2. From local to regional, national and international; migratory species have to be managed with a micro-regional perspective, while community management emphasizes a smaller geographical scale; therefore, scaling up of local to regional co-management is necessary; local (co-) management of regionally relevant habitats, e.g. deep pools (Abell, Thieme and Lehner 2003; Hartmann 2002; McGrath *et al.* 2003; Ruffino 2003b).
3. From users to stakeholders to general public involvement[21,22,23]. Stakeholders also include groups which previously were marginalized due

[20] The five principles of ecosystem-based management are (Wallace *et al.* 1996):

1) Desired ecological states and means to achieve them are socially defined; ecosystem boundaries are social constructions; managing human societies is part of maintaining healthy ecosystems; ecosystem-based management has a large social component.
2) Focus on protecting restoring critical components while viewing the system as a whole; views resource base in its entirety, holistic or integrated entity.
3) Ecosystem-based management requires larger spatial and temporal scales than has been the norm, in order to avoid near term resource management decisions that may overly restrict or foreclose future management options.
4) Ecosystem management characterized by open communication and collaborative decision-making.
5) Adaptable institutions – dynamic nature of ecosystems and experimental nature of adaptive ecosystem management. Given the complexities and uncertainties, sustainable management can only be achieved if management entities have strong learning capacities. An ecosystem approach to resource management requires administrative flexibility, for “no set of goals should be so firmly adopted that institutional adaptability is lost”.

Few embrace all themes/principles, some might even be considered contradictory. For example, the need to address resource management on larger spatial/temporal scales and the need to integrate data collection and monitoring seem to conflict with calls for decentralization of power and authority. Ecosystem management calls for open communication and decision-making, community and organizational learning, and co-operative approaches to management that cross jurisdictional boundaries.

to an emphasis on involvement of users/fishers in local management (Haraldsdottir 2000), as well as privileged groups, such as large landowners, representatives of other economic sectors, which so far were not contemplated under collaborative arrangements for local community management (Ruffino 2003b); stakeholders are also consumers, who my be influencing management through preferential shopping; McGrath *et al.* (2003) are suggesting a form of 'eco-labelling' to support co-managed fisheries[24].

Diversity and sustainability

Diversity and complexity is a major feature in riverine fisheries (Haraldsdottir 2000; McCay 2000; McGrath, Cardoso and Sá 2003; McGrath and Castro 2000).

While sustainability has been seen mainly as ecological sustainability, it has become clear that definitions of sustainable fisheries vary widely. The concept of sustainability must involve multiple use options, human concerns and objectives in addition to conservation goals. Thus, Charles (1994) suggests the simultaneous pursuit of four sustainability components:

- Ecological sustainability by maintaining stocks and species at levels that do not foreclose future options and maintaining or enhancing the capacity and quality of the ecosystem and the environment.
- Socio-economic sustainability focussing on well-being at the individual level.
- Community sustainability focussing on the well-being at the group level, maintaining and enhancing group welfare of participating and affected communities.
- Institutional sustainability, which is a prerequisite for the other three sustainability components, focussing on the maintenance of suitable financial, administrative and organizational capabilities and the manageability and enforceability of fishery regulations over the long-term.

Sustainable development policy would have to serve to maintain reasonable levels of each component. System sustainability would decline through a policy seeking to increase one element at the expense of another. That there will always be trade-offs between objectives. Long-term sustainability probably requires adaptive short to medium-term (adaptive) flexibility Suitable policy approaches are: living with uncertainty (adaptive management, management planning), coping with complexity (multidisciplinary research; integrated development and management strategies), improving local control (decentralized management, co-management) and establishing appropriate property rights and combining internal planning with suitable external diversification.

21 The need for public participation in natural resource decision making has been addressed by a number of international conventions and agreements, of which some are binding legal instruments and some not, such as Agenda 21/UNCED 1992, Principle 10: It was affirmed that the public's right of access to information, participation and justice in decision-making is instrumental in protecting the environment and in integrating environmental values into development choices; and UNECE (United Nations Economic Commission for Europe) Convention on Access to Information, Public Participation in Decision-making, and Access to Justice in Environmental Matters, "Aarhus Convention", 1998.

22 (Fuller 2002) describes in detail the process of stakeholder/public participation, including provision of information, mediation of views and interests and managing public communications as an important ingredient of this process.

23 See also Koehn and Nicol (2002) on stakeholder involvement in the MDBC"s Native Fish Strategy.

24 'Eco-labelling' or 'green labelling' is a new fisheries management instrument by which consumers can influence fisheries management by bringing pressure on manufacturers and exporters to buy fish only from certified fishers. It is a way to market a company as a responsible organization, contributing to the notion of sustainability (Constance 2001; Hersoug, Holm, & Ranes 1999).

Women in fisheries management

While previously most authors concentrated on women in fisheries emphasizing their roles in fish marketing etc., more recently attention is given to their involvement in fisheries management (Bunce, Townsley, Pomeroy *et al*. 2000; Haraldsdottir 2000; Hartmann 2002; Welcomme 2001). Women's involvement in fisheries management is increasingly being recognized. Women are involved in capture fisheries for home consumption or small-scale marketing. Where fishing is the major source of (monetary) income, women predominantly engage in fish processing and selling (including through large-scale operations). Women are involved in fisheries enhancement, for example in West Africa, where some women run larger enhancement facilities (brush parks, fish holes), requiring considerable investment and management efforts. Similarly, women also stock fish in confined water bodies. Women have played a role in aquaculture, although many of the aquaculture development programmes, in Africa for example, focussed on men regardless of the fact that their objective was subsistence production, i.e. production for home consumption, which is the domain of women in rural Africa. Women are important source of fisheries information and play leading roles in organising user unions in Southern India (Nieuwenhuys 1989).

Similarly, in reservoir fisheries co-management in the Mekong Basin, women have jointly developed fish marketing activities as a first step to address women's practical concerns and priorities in fisheries management planning and implementation. In fact, such practical concerns are directly interlinked with strategic women's concerns. The fact that additional income may be earned, which can change the situation for a woman and her family and even the community in which she lives, makes it an important management issue. Women in Thailand's Northeast have understood the link between lake management and fish marketing: They are interested in cage-culture in order to maximize benefit from the fisheries resource and guarantee supplies of raw material for their processing unit. In the Central Highland of Viet Nam, savings activities taken up prominently by women in fishing communities address a major problem in participatory management, funding and allows families, among other things, to improve living standards and reduces dependency on non-sustainable fishing methods, as well as to develop sources of income supplemental to fishing as a management measure. The involvement of women in natural resources management decision making is significant: almost 40 percent of participants in fisheries management planning and about 25 percent of leaders of fisheries management associations are women.

Governance[25]

It has been said that participatory fisheries management and, in particular, co-management, which are prominent features of post-modern environmental and fisheries management, is not about fisheries at all, but about governance. Thus, possibly the major difference between conventional and post-modern fisheries management is the way in which the fishery is governed. Interestingly, the same could be said about differences between traditional and conventional management, where at last one of two major differences are related to governance as well. Basically, this is not surprising, as fisheries management is not distorted by politics, as many complain, but is politics. Politics is how people decide things, or management is decision-making (Mikalsen and Jentoft 2001; Wilson 2000).

As we have seen, post-modern approaches to management focus on the involvement of fishers in participatory systems of power sharing between

25 'Governance' is defined as "The process of decision-making and the process by which decisions are implemented" (UNESCAP 2002 cit. in Petkova *et al*. 2002). 'Governance' is the sum of the institutions, processes and traditions which determine how power is exercised, how decisions are taken and enforced and how citizens have their say.

governments and fishing communities. It is expected that, in this way benefits can be drawn from modern scientific approaches as well as traditional, pre-scientific management systems (Welcomme 2001). Management still concentrates mainly on restrictions, but increasingly involves stakeholders, in particular fishermen, in management decision-making (planning) and management implementation (Welcomme 2002).

As Hanna (1998) observed, the top-down style of management has resulted in frequent problems and has shown itself frequently to be ineffective in the promotion of long-term sustainability. There are many cases of centralized decision-making that have led to poorly designed regulations, a lack of acceptance by user groups, low levels of compliance and ineffective controls on exploitation. Worldwide, the past several years have seen a growing interest in alternative institutional arrangements, in particular those that emphasize the periphery as a centre of authority, such as community-based (CBNRM) and co-management (CM).

Community-based management

The term ‘community-based’ distinguishes the emerging approaches from an earlier, possibly romantic, concept of community natural resource management, which refers to communities having full and generally autonomous responsibility for the protection and use of natural resources, that is, where local stakeholders take direct control of the resource allocation and exploitation, derived from or been modelled after indigenous systems of natural resource management, where local knowledge, norms and institutions have co-evolved over long periods of time with the ecosystem in question (Uphoff 1998). He however points out that such community NRM may be difficult to implement: where human populations and ecosystems are under stress and confronted with new conditions or new pressures, for example, from climate change, rapid population growth (natural or due to in-migration), availability of new technologies, weakening of local institutions, new tastes and demands within communities, or changed legal regulations and policy directions, etc.

Uphoff (1998) characterizes CBNRM as follows:

- It addresses both human and natural resource issues, such as the long-term benefit of present and future generations given the inefficiency of state management and objectives such as equity, poverty alleviation and empowerment of marginalized user communities.

- CBNRM as a strategy reflects in social and policy terms the parallel nestedness and connectedness of organisms, species, associations and ecosystems in the natural universe and the interdependence between micro and macro levels.

- CBNRM starts with communities as a focus for assessing natural resource uses, potentials, problems, trends and opportunities and for taking action to deal with adverse practices and dynamics, with cooperation and support from other actors linked horizontally (e.g. other communities) and vertically (e.g. higher level or external entities, such as local or district governments, regional bodies, government agencies, non-governmental organizations (NGOs), universities, or other organizations that have an interest in resource conservation and management).

- While in the past NRM was seen as the domain of either state sector institutions endowed with appropriate authority, expertise and other resources, or private sector institutions pursuing individual economic interests and benefits, CBNRM operates mostly in a middle sector of organizations such as user groups, community management committees, local councils, producer co-operatives and similar, though it works best when there are complementary, supportive public and private sector activities.

- While management by a central government agency will not qualify as CBNRM, any organization, governmental or other, either on its own or in combination, can undertake CBNRM. CBNRM is management at the local, community level.

- CBNRM is the management of natural resources under a detailed plan developed and agreed to by all concerned stakeholders. The approach is community-based in that the communities managing the resources have the legal rights, the local institutions and the economic incentives to take substantial responsibility for sustained use of these resources. Under the natural resource management plan, communities become the primary implementers, assisted and monitored by technical services[26].

Co-management

While other participatory relationships include consultative and advisory roles for local communities, co-management (CM) involves power sharing (Jentoft 1989). Co-management strategy is distinct from community-based management in that it explicitly recognizes that government agencies often must be involved in a community's affairs, for a variety of reasons including needs for resources not available in the community, while, at the same time, it recognizes the importance of community control over and responsibility for many aspects of resource management (McCay 1998). Thus, co-management is the sharing of authority and responsibility among government and stakeholders in a decentralized approach to decision-making that involves user groups as consultants, advisors, or decision-makers with government (Berkes *et al.* 1991; Pomeroy and Williams 1994; Sen and Nielsen 1996). By involving users and considering community aspirations in decision-making CM is expected to provide conditions for increased equity, efficiency and sustainability and thus offers the prospect of relief from some of the more negative aspects of centralized decision-making (Pomeroy and Williams 1994; Hanna 1998).

Co-management is especially applicable in river fisheries management because, like artisanal coastal fisheries many preconditions for CM are in place in rivers, such as locality, history and traditions. There are also specific needs for effective management due to the proximity to other sectors and to spillover effects such as pollution, habitat destruction, competition for space and population shifts. Though important pre-conditions, traditional tools/processes are inadequate to cope with pressures of entry whereby the fishery is expected to absorb excess labor.

Other conditions for successful co-management are: clear boundaries; membership criteria; scope and scale; management systems that intercept or overlap, that the fishery is embedded in general rural usage; the existence of organizational platforms such as a local all-stakeholder board or similar; linkages to scaled-up organizations, such as a coordinating regional board; cost-sharing in kind and out-of-pocket between co-managing partners; voluntary action; local autonomy, legal definition (Hanna 1998; Pomeroy, Katon and Harkes 2001).

Important background conditions and issues to be taken into account when promoting/implementing CM are (Hanna 1998):

- Property rights – some form of property rights are necessary for co-management, because without them there is no definition of legitimate participation or of the conditions that link user groups to each other and to the government. As long as rights are assigned and clearly specified, any type can provide the appropriate background for co-management. Without property rights, actions taken under co-management will be undermined.

26 http://www.cbnrm.net/resources/terminology/cbnrm.html

- Uncertainty – background conditions for all fisheries (ecological systems vary, markets expand/contract, policies change). Kind of uncertainty shapes expectations/behavior, affects links between users and government. Co-management can minimize the effects of uncertainty (broadening source of information, creating coordination between users, maintaining consistency in rules/incentives, clearly specifying procedures of decision-making).

- Boundaries – CM must be applied within clearly defined boundaries where decision-making is brought into line with ecological/political systems; define/limit number of legitimate users, areas of control, reference decision-making to an ecosystem. Costs of coordination/information gathering/monitoring/enforcement all affected by specification of boundaries.

- Scale – CM should be nested within larger institutional jurisdictions, requiring that co-management processes build compatible incentives at different levels.

- Participation and representation – linking stakeholders into management process. Defining and identifying stakeholders is a complex process, involving both traditional and emergent users. Task: Maximize representation strengthens links between stakeholders, so that decisions reflect full array of interests. Various levels/types of participation, depending also on human capital, decentralization policies, resources available for management.

There are two different main points of departure for the installation of participatory and co-management in natural resources in general and fisheries in particular. These main points can again be looked at from different angles, that is, the government's and the users' point of view:

- In developed countries, there is a trend to regain access to fisheries[27] on the part of excluded groups; there is a demand for less government and CM is seen as a corrective or alternative to overly centralized management systems (Kearney 1989; McGrath *et al.* 2003).

- In developing countries there is a co-option of the public by government to shift management costs to communities and improve management efficiency. This also increases legitimacy and compliance with management measures and reduces conflicts. There is also a demand for more government presence, resources and a lack of application of conventional fisheries management models (McGrath *et al.* 2003; Nielsen, Degnbol, Ahmed *et al.* 2002; Ruffino 2003b).

The main steps aimed at when setting-up co-management systems are (Welcomme 2001):

- Development and legitimating of local management capacity
- Development of overarching (multi-level) institutional structures
- Agreement on responsibilities, rights and relationships (definition of roles of co-managing partners)

Juinio-Meñez (2002) found that the immediate

27 The term "co-management" was first used in the late 1970s by US treaty tribes in western Washington State USA to describe the relationship they aspired to have with state managers, after having won court recognition of rights to fish. However, tribes had been barely able to exercise these rights, because the harvest was managed by the state in such a way that little fish (in this case, mostly salmon) remained by the time this migratory species reached the territories in which the tribes could legally fish. Only by recognizing the tribes' right to participate in planning and regulating the entire harvest (which he called "concurrent management") would their allocation right ever be exercised. There has been a tendency to apply the term co-management to mere operational rights, an inappropriate watering down of the term to a narrower, less powerful right. Co-management is misnamed unless it involves the right to participate in making key decisions about how, when, where, and how much fishing will occur (Pinkerton 2003).

objective of most of the 47 CBNRM fisheries projects in the Philippines was to organize small fishers in order to empower them to develop socially and integrate management interventions as part of the development process. The objective and aim of direct resource users being resource managers while attractive, is difficult to realize given the inherent constraints in resources and skills, the complexities of resource use and heterogeneity of riverine communities.

Participation depended on whether the activity had a positive or negative impact on the individual's interests. Participation in decision-making is mostly through consultation and its function is frequently recommendatory only, where decisions are subject to adoption/rejection by higher administrative units. Most members in the surveyed projects were passive participants. The tasks they participated in were data gathering, information provision and implementation of agreed-upon activities. Material incentives (food allowances etc. were important. Participation in 'strategic' activities of groups, committees etc. depended on individual skills and time availability. At higher levels participation was through representation (village elected officials, etc.). In short, project-initiated CBNRM was generally a leader-centered local institution with limited collective participation by a significant portion of local primary resource users and stakeholders. (Juinio-Meñez 2002)

Communities do not constitute legal entities in most jurisdictions, thus decentralization of management responsibilities is to local government bodies rather than to resource users themselves, yet this may be expected to be more efficient in eliciting community participation[28]. Local government authorities rarely devolve control over resources to levels below themselves (Juinio-Meñez 2002; McGrath *et al.* 2003).

Costs of resource management for co-managers and communities are the reduction in area of fishing grounds in the case of reserves, restrictions of use of regulated gears and limitations on access for fishers outside the immediate communities from water bodies such as in the Brazilian Amazon (Almeida *et al.* 2003). Active project local partners bear a greater cost in terms of participation in project initiatives. The greatest cost to project co-operators are the time and effort spent on various activities including training, meetings, conducting research, monitoring, which would have been otherwise been spent making a living (i.e. opportunity costs). These costs are borne differentially by various resource user groups depending on the degree of dependence on the fishing ground or fishing gear. Moreover, social and economic status has a bearing on the relative costs to participants and non-participants. In general, the most marginalized among the fisher groups (e.g. landless migrant fishers) are least able to participate in resources management initiatives. They are unable to forego opportunities to fish or spend time attending meetings instead of earning a living. They are also not likely to join organizations if more prominent individuals and/or families dominate these. Thus, where membership in a local organization is necessary to obtain project benefits as discussed below, they are effectively excluded from these opportunities.

Conflicts are mainly experiences by people who actively participate in management activities (e.g. threats from illegal fishers). These social conflicts lead to disruption of normally peaceful familial and communal relations and are high costs to participants. In Canada, consultative processes in externally-initiated CBNRM and co-management activities the projects analyzed consisted mainly of advice provided to line agencies, that is, "communication-up" to those who make decisions and "communication-down" to those

28 This form of decentralization is also called 'deconcentration' or 'administrative decentralization' to local branches of state agencies only, and is considered a weak form because the downward accountability from which many benefits are expected are not as well established as in democratic or political (strong) forms of decentralization ('devolution') (Ribot 2002).

who are affected; there was only limited degree of self-determination; implementation and enforcement by users of government regulations was perceived as beneficial: however, fishermen were not really involved in decision-making (Kearney 1989).

Participatory strategies

Juinio-Meñez (2002) proposes the following strategies to improve participation by local communities:

Local capacity building: including environmental education, livelihood training, community organizing, participatory research and monitoring.

Provision of incentives for participation: while many participants in co-management activities have remained positive despite the lack of immediate tangible benefits at the household level, e.g. increases in fish catch/income[29], the primary motivation for participation is personal socio-economic gain, which may lead to conflicts within organization in terms of prioritization of economic activities.

Livelihood development: in participatory projects is commonly rationalized with the premise that provision of alternative or supplemental livelihoods to fishers can contribute to resources management by reducing fishing pressure, allowing a recovery of depleted resources; alternatively, it is viewed as a means to address poverty; frequently, initiatives in livelihood development involve some form of enterprise development, often aiming specifically at attracting women to participate in aquatic management activities, conservation or development efforts; generally these are externally facilitated and funded often land-based micro enterprises and aquaculture trials; however, as many fishers like their occupation, the development of supplemental rather than alternative occupations may be a more realistic goal; this also builds on the existing occupational multiplicity of fisher households: among the constraints to livelihood development as a fisheries management measure are socio-cultural factors such as a mismatch of any introduced enterprise with the existing interests and skills of fishers and the economic scale of a livelihood intervention necessary to take people out of fishing.

Provision of use rights: provide important incentives to participate in such NRM activities as habitat protection/rehabilitation etc. in contrast to reforestation activities for example, formalized use rights for water bodies mostly lacking; however, there are cases were, recently, rules devised by local communities may be formalized and enforced by government agencies (Almeida *et al.* 2002).

Identification of sources of funding for CBNRM: The lack of financial resources to support CBNRM activities is the major constraint to their sustainability; income-generation options that contribute directly to resources management or enhancement should be explored and given priority in participatory aquatic management; apart from community-based fish culture, the suitability of market-based incentive systems, which are "environment and community friendly", should be explored (Phillips 2002).

Strengthening/support to co-management arrangements: Experience indicates that local communities and governments will continue to need support from external agencies particularly in capability building and resource generation; local governments are constrained with human and financial resources to effectively execute their mandate to manage natural

29 Similar reactions were observed in co-management initiatives in the Mekong Basin, where, though no increase in fish production could be observed after only one year, participants easily spell out such perceived benefits as 'improved communication', 'being taken serious by government agents' etc. (Hartmann 2002). From the Amazon it is reported that floodplain communities now reap, after 10 years of improved fisheries management, the benefits of significantly increased production (Oviedo & Ruffino 2003).

resources; communities and other local sectors are similarly constrained; the limited capabilities and resources of both local government and communities in effect severely hamper the ecological and socio-economic sustainability objectives; thus, despite potential conflicts in interest, workable mechanisms for co-management of aquatic resources have to be pursued earnestly).

Scaling-up and integration into a broader framework: Solutions to problems of NRM cannot be provided by fisheries or through community-based initiatives alone. Goals and objectives are best pursued within a holistic, integrated and multi-sectoral framework; furthermore, CBNRM and co-management should be placed within a broader framework of integrated river basin management, which takes into account ecological processes and connectivities and attempts to harmonize conflicting uses of various stakeholders in the basin; at the very least, village- or water body-level initiatives should be integrated within district/municipal/provincial or similar development plans; the formation of higher forms of alliances and networks built on common interests and aspirations is important in scaling up local impacts (e.g. network of co-management initiatives, communities managing deep pools, etc.) (Juinio-Meñez 2002; McGrath *et al.* 2003; McGrath and Castro 2000).

Community-based management and co-management: Initiated or emergent properties?

Ruitenbeek and Cartier (2001) question whether participatory NRM is an emergent property of complex bio-socio-economic systems which would develop without outside help, or if such systems have to be initiated.

If such systems are emergent properties, the questions then arise as to what this would mean for the relationship between the co-managing partners, what would the role of government be and how and by whom should such independent initiatives be supported.

Juinio-Meñez (2002) clearly states that, in the Philippines, CBNRM initiatives are largely externally initiated. Local communities are considered disempowered by outside agents, governmental or other, lacking capacity to initiate change; external agents to facilitate active and meaningful participation; the process are influenced by goals, objectives, biases of facilitators (Pomeroy *et al.* 2001).

From his Canadian example, Kearney (1989) learnt the lesson that co-management may depend on social movements already in progress (more than on institutional arrangements); it may be difficult to initiate co-management into a co-operative vacuum; co-management frequently is a second stage in the evolving struggle of a social movement; self-determination of a social group is not the starting point but instead the outcome of a long process. Any attempt by government, for whatever motives, to initiate co-management in the absence of a cooperative social movement among fishermen risks transforming co-management into co-optation (Oviedo and Ruffino 2003; Ruffino 2003a).

Government support

In CBNRM and more so in co-management, local communities work in partnership with local government units at village, district or municipal levels. Local government support for community initiatives may be through allocation of funds for the implementation of various management activities and the passing of legislation for harvest reserves or sanctuaries and gear regulations (Juinio-Meñez 2002). Frequently, government support through legislation, funding and enforcement is crucial to sustaining the co-management initiative. In particular, government support is essential for the sustainability of protected areas, which is a key element in many participatory management schemes. The extent to which local community initiatives and use rights are institutionalised through local government policies and budget allocations may be considered indicators of success of community initiatives in coastal resources management. The main role of government may be the provision of 'enabling conditions'. However, in actual fact, many governments are resource-starved and are unable and sometimes unwilling, to fulfil their supportive role (Juinio-Meñez 2002; McGrath *et al.* 2003; Nielsen *et al.* 2002).

CONCLUSIONS AND RECOMMENDATIONS

PEOPLE AND MANAGEMENT

Definitions of fisheries management are essential to identify the managers. These may include primary users and women in fishing communities. Broader definitions include conservation and sustainable utilization, while the narrower ones emphasize only certain sets of main management tasks.

There are several types of management, including traditional, conventional (centralized, science-based); those based on ecosystem management and participatory management (community-based management and co-management). Frequently these types co-exist, but on different levels. Where centralized management exists, policy makers and fishery managers should be aware of the need for flexibility in management plans. However, there is a wide recognition that conventional, centralized management has failed and there is a need for a general shift to more people-centered, participatory forms.

There remains a question as to what extent participatory management can be introduced externally as policy interventions. Successful forms of participatory management are frequently based on social movements. Thus, while it seems easy to give policy advice to introduce co-management, it should be kept in mind that this may be more disruptive than productive. It is important, therefore, to define the role of governments as providing appropriate conditions for participatory management.

There is an urgent need for training of co-managers, such as users and government staff, in new management roles; strengthening local government capacity; access to credit, strategic research; policy development and improvement of communication amongst all stakeholders.

AQUACULTURE AND ENHANCEMENT IN RIVER FISHERIES

One important difference between aquaculture and inland fisheries is that individual ownership of the aquaculture operation reduces the interactions that arise from multi-user common-pool resources. Aquaculture is typically less variable than a capture fishery since there is a higher degree of control over the system.

As relationships with the fishery change, aquaculture may become more attractive as a livelihood strategy for both fishers and farmers. There is a range of factors that may cause this including declining catches and the associated increased effort or time for fewer returns. Opportunities for income generation, market opportunities and the ability to control the system without the interference of others are also highly attractive. Aquaculture does provide livelihood opportunities, although the cost of entry may be too high for the very poor. Aquaculture can co-exist with fisheries providing fish during seasons when the wild fishery is low.

There is a lack of clarity of national policies (export income versus sustaining livelihoods) regarding aquaculture and inland fisheries. The result is a skewing of policy and development resources towards aquaculture.

There are opportunities for creative use of aquaculture tools in fisheries management such as broodstock replacement or enhancement of floodplains, small water bodies or rice fields.

Enhancement is the use of aquaculture technologies in natural aquatic systems, usually common pool resources. Enhancements can be highly effective in raising production and generating income if carefully matched to local ecological, institutional and socio-economic conditions. However, enhancements can have significant negative impacts on resident biota through ecological and genetic interactions, while they can add value to natural aquatic systems and provide incentives for their conservation.

The most important role for governments in enhancements is to support system development through research and adaptive learning to provide for better success of future enhancement applications in large river systems.

People and their river resources

Along most of the world's large tropical rivers rural households harvest a wide range of river resources, including crops, livestock, fish and wild animals and plants. Access to these resources and their contribution to livelihood strategies vary greatly with season, wealth, gender, ethnic group, household size and a wide range of other factors. River based livelihoods are dependent on the maintenance and sustainable use of these complex production systems. Efforts to improve management of river fisheries through greater engagement of rural people need to take explicit account of this resource and community complexity. Specifically it is recommended that:

- Improved management of river fisheries needs to be based upon explicit recognition of the complexity of river resource use and pursue appropriately integrated approaches.
- Development of such integrated management approaches for individual river systems needs to be rooted in detailed understanding of the livelihood strategies of the resource users.
- Improved understanding of rural households and their livelihood strategies requires effective interaction between these households and researchers. More active engagement by researchers with rural households and explicit gathering of information through participatory approaches involving these people is essential if this understanding is to be achieved.
- Household-based participatory research should be designed so as to inform management approaches with improved understanding of the political economy of river resources and the specific expectations and influence of different users and wider stakeholders. Information that is gathered on river resources and their use by different communities and households needs to reflect these resource-power relations.

Mitigation and management of the impacts of water management developments

Technical solutions exist for mitigation, but are very rarely implemented, especially in developing countries. Measures include, for example, fishways, which are often effective on low barriers, destratifiers in lakes and re-regulating ponds downstream of hydro-electric dams. Some frameworks for improvements include: international agreements, national statutes, including EIA legislation and Codes of Practice for civil engineering works and state or local-level instruments, including fish passage and fish habitat regulations. International agreements are not well implemented in protecting river fisheries and EIA legislation is also poorly implemented in developing countries and rarely results in effective mitigation of fisheries impacts. In part, poor outcomes for river fisheries arise because planners and engineers rarely hear about fisheries issues and do not receive clear advice on impacts and their mitigation from biologists. On a broader level, the most significant issue facing inland fisheries is competition for water. Irrigation, domestic water supply and electricity all compete directly and are subsidised worldwide, particularly in developing countries. A major reduction in per-capita water usage worldwide through more efficient water use is needed to meet the projected increases in world water demand and if any water is to be allocated for inland fisheries clear information on the importance and value of inland fisheries needs to be effectively communicated.

People and conservation

The concept of complexity implies that we have to live with uncertainty, that we are unable to accurately predict systems behaviour and that we cannot expect to be able to 'optimise' a system. This conclusion was challenged on the basis that natural systems could be predictable if we understand system functions. It was agreed that prediction of natural systems is possible and desirable to enable better management. However, empirical models are based on a range of observed, historical system states or configurations. Outside the observed range of configurations, the system may behave differently and predictions become increasingly unreliable and potentially misleading. River systems are currently under severe, unprecedented pressure from human activities. Under these circumstances, excessive reliance on prediction models based on historical observations is hazardous.

It was pointed out that uncertainty dominates our interaction with socio-ecological systems and that management should aim at maintaining system diversity and resilience rather than strive for optimisation. It was also noted that there is an abundant source of information already available from the World Commission on Dams regarding assessment of dams using a risks and rights based approach (www.dams.org).

- It is recommended that the potential consequences of using erroneous predictions for management are given due attention before final decisions are made.
- There is generally insufficient emphasis on ecosystem services and a tendency to value fisheries on a commodity basis. This ignores the complexity of inter-relationships between people and the resource. It was therefore recommended to raise this question at the World Water Forum.

River rehabilitation

In many existing situations we are forced to mitigate the impacts of other users. Once a river is modified, we have to rehabilitate it for some purpose, usually on a small scale. It was pointed out that to rehabilitate is very expensive and to avoid this we have to be more precise in talking to engineers. People already have the valuable knowledge and this should be used in new situations. A question was raised that due to the now mostly private developments, we have no more options to influence them. This opinion was rejected, as in allocating construction licences agreements must be signed on proper approach. In a number of countries large projects are strictly regulated.

Every effort should be made to rehabilitate the damaged ecosystem and every possible measure taken to prevent such damage in future water resource developments.

Legal issues

Law can inhibit or facilitate effective management. Law is also needed to provide legitimacy for management action. Where CBFM is pursued as a participatory form of management, it is important that the formal legal environment be examined before or when CBFM is being considered for utilization or trial. Specific legislative issues relating to CBFM include the need to ensure that the legal framework clearly states security and enforceability; the creation of ability and opportunity for rights holders to seek redress for violation; the nature and extent of recognition of locally promulgated rules; rules for interaction with other stakeholders, including the government. Protection of individuals against abuse of "local" power and protection of wider interests e.g. environment should also be considered. Other important features of an optimal legislative framework are: flexibility and integration of CBFM in the general fisheries management legal framework.

The following suggestions are made:

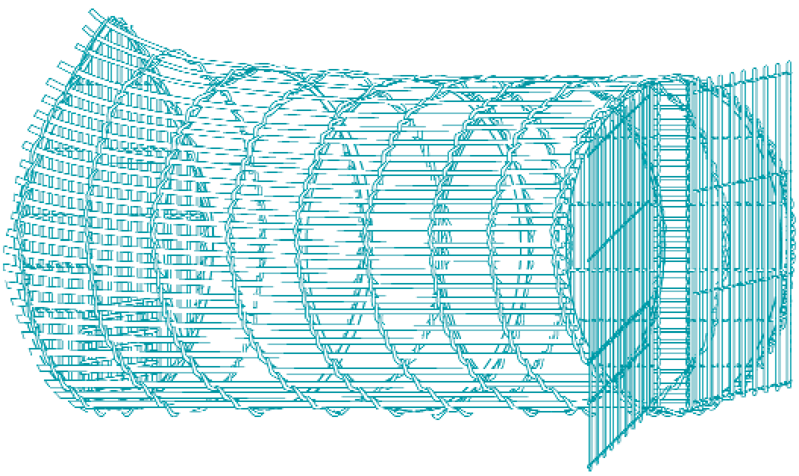
- CBFM should have a legal basis.
- There should be clear elaboration of the nature and extent of the powers, functions and rights allocated under CBFM in enabling legislation or regulations.
- Legal issues of CBFM should be dealt with in a multidisciplinary manner.
- Legal considerations and elements identified and presented could guide the design of reasonable legislative frameworks for CBFM.

However the actual nature and scope of such legislative frameworks depends largely on local circumstances and should be tailored to such circumstances.

COMMUNITY MANAGEMENT

Demand for co-management arrangements often arises in response to either excessive government control or the absence of government involvement in local resource use. Development of co-management systems is a long, slow process that requires major inputs of funds and the active involvement of user groups, NGOs and state agencies. In developing co-management systems there is often a conflict between equitable allocation of resources among different user groups and the need to insure that benefits of management go to those who bear the costs of managing the fishery. Institutional resistance to community participation in enforcement is another major problem. Considerable investment is required in training both state agency personnel and community leaders so they understand their new roles and have the skills needed to effectively perform them. While NGO involvement is often critical to developing co-management systems, it cannot substitute the role of either community groups or state agencies, since the long-term sustainability of the co-management system will depend on the degree to which these two groups have assimilated their roles. It was emphasized that:

- Co-management systems typically have high transaction costs for user groups compared to conventional management systems, therefore long-term sustainability will depend on providing user groups with the material conditions and institutional support needed to make their efforts as efficient as possible.
- Efficient institutional mechanisms for resolving conflicts are especially critical.
- Where restrictions on access are not feasible, effective mechanisms must be developed to control free riders and reward the efforts of those involved in maintaining the management system.
- Fisheries legislation and policies must be designed to provide a legal base for the co-management system.



REFERENCES

Abell R., Thieme M., & Lehner B. 2003. Ecoregion conservation for freshwater systems, with a focus on large rivers. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 2*. Food and Agriculture Organization & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/17. pp 1-14.

Almeida O., Lorenzen K. & McGrath D. 2002. Impact of co-management agreements on the exploitation and productivity of floodplain lake fisheries in the Lower Amazon.

Almeida O., Lorenzen K., & McGrath D. 2003. The commercial fishing sector in the regional economy of the Brazilian Amazon. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Arlinghaus R., Mehner T. & Cowx I. 2002. Reconciling traditional inland fisheries management and sustainability in industrialized countries, with emphasis on Europe. *Fish and Fisheries*, Vol. 2002, No. 3: 261-316.

Batista V. 2003. Spatial and temporal distribution of the fishery resources exploited by the Manaus fishing fleet. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Baviskar A. 1995.*The belly of the river: Tribal conflicts over development in the Narmada Valley.* Delhi, Oxford University Press.

Berkes F., Colding J. & Folke C. 2000. Rediscovery of traditional ecological knowledge as adaptive management. *Ecological Applications*, Vol. 10, No. 5: 1251-1262.

Berkes F., George P. & Preston R. 1991. Co-management: The evolution in theory and practice of the joint administration of living resources. *Alternatives,* 182: 12-18.

Bunce L., Townsley P., Pomeroy R. & Pollnac R. 2000. *Socioeconomic manual for coral reef management*. Townsville, Australia, Australian Institute of Marine Science.

Caddy J. & Cochrane K. 2002. A review of fisheries management past and present and some future perspectives for the third millennium. *Ocean & Coastal Management*, Vol. 2001, No. 44: 653-682.

Carvalho R.C.D.A. & Sobrinho de Moura J.H. 1998. Aspectos econômicos benefícios e custos de produção pesqueira - Pesquisa em açudes povoados com alevinos de Tilápia do Nilo, Tambaqui, Curimatã e outras espécies, Vale do Curú, Estado do Ceará, 1991-1996. PAPEC, Fortaleza/Ceará.

Charles A.T. 1992. Fishery conflicts. A unified framework. *Marine Policy*, Vol. September 1992: 379-393.

Charles A.T. 1994. Towards sustainability: The fishery experience. *Ecological Economics*, Vol. 11: 201-211.

Christensen S., Lassen H., Nielsen J. & Vedsmand T. 1999. Effort regulation: A viable alternative in fisheries mnagement? *In* D. Symes, ed. *Alternative management systems for fisheries*. Oxford, UK, Fishing News Books, Blackwell. pp. 179-187.

COFAD GmbH 2001. *Back to basics. Traditional inland fisheries management and enhancement systems in Sub-Saharan Africa and their potential for development*. Deutsche Gesellschaft, Eschborn/Tutzing.

Collins 1992. *Collins English Dictionary and Thesaurus*. Harper Collins Publishers.

Constance D. 2001. From “dolphin-safe” tuna to the Marine Stewardship Council: Ecolabelling in the fisheries sector. *The Common Property Resource Digest*, Vol. March 2001, No. 56.

Degnbol P. 1998. *Fisheries research in development*. Oslo, The Research Council of Norway.

Degnbol P. & Nielsen J. 2002. Educating fisheries managers as an integral part of management. Discussion note for the IIFET 2002 special session on building human capital. International Institute of Fisheries Economics and Trade IIFET 2002 Conference, August 19-22, Wellington, New Zealand.

FAO 1995. Guidelines for responsible management of fisheries. *In Report of the Expert Consultation on Guidelines for Responsible Fisheries Management*, FAO Fisheries Report No. 519. Rome, FAO.

Friend R. 2003. Fisheries data and policy. In R.L. Welcomme & T. Petr, eds. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Fuller B. 2002. Mediating apparently irreconcilable conflict - agricultural water use efficiency, CALFED, and California. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission*.

.

Groenfeldt D. 1998. *Organizing effective community-based groups: Lessons from the irrigation sector*. Washington, DC, Economic Development Institute, The World Bank,

Hambrey J. 2002. *Economic evaluation of some interventions in aquatic development.* Phnom Penh, Cambodia, Mekong River Commission.

Hambry J. 2002. *Financial analysis and risk assessment of selected aquaculture and fishery activities in the Mekong Basin.* Phnom Penh, Cambodia, Mekong River Commission.

Hanna S. 1998. Co-managing in small-scale fisheries: Creating effective links among stakeholders. *In International CBNRM Workshop*. Washington, DC, May 1998.

Haraldsdottir G. 2000. Tradition, co-management, diversity and the FAO in small-scale fisheries in Africa. *In* E.P. Durrenberger & T.D. King, eds. *State and community in fisheries management*. Westport, USA and London, Bergin & Garvey. pp. 131-148.

Hardin G. 1968. The Tragedy of the commons. *Science*, Vol. 1968, No. 162. pp. 1243-1248.

Hartmann W. 2002. *Fisheries Co-management in the Lower Mekong Basin*. MRC/FIP Annual Meeting, My Tho, Viet Nam, 11-12 June 2002.

Hersoug B., Holm P. & Ranes S.A. 1999. Three challenges to the future of fisheries management in Norway: ITQ’s, regional co-management and eco-labelling. *In* D. Symes, ed. *Alternative management systems for fisheries*. Oxford, UK, Fishing News Books, Blackwell. pp. 136-144.

Hossain M.A., Pareween S., Rahman M.A. & Mortuza M.G. 2003. Fish and fisheries of the major river system in the western part of Bangladesh in relation to fisher and socio-ecological sustainability. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Jackson D. 2003. Fisheries dynamics in the Yazoo River Basin. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 2*. Food and Agriculture Organization & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/17. pp. 103-116.

Jentoft S. 1989. Fisheries co-management. Delegating government responsibility to fishermen's organization. *Marine Policy*, 132: 137-154.

Juinio-Meñez M.A. 2002. Myths and realities of participation in Philippine CBCRM: Lessons from an analysis of who participates in what. Presented at "The Commons in an Age of Globalisation," the Ninth Conference of the International Association for the Study of Common Property, Victoria Falls, Zimbabwe, 2002.

Kaunda E. & Chapotoka O. 2003. The conflict between poverty and river system management: The case study of Malawi, Southern Africa. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Kearney J.F. 1989. Co-management or co-optation? The ambiguities of lobster fishery management in southwest Nova Scotia. In E. Pinkerton, ed. Co-operative management of local fisheries: New directions for improved management & community development. Vancouver, University of British Columbia Press.

Koehn J. & Nicol S. 2003. A strategy to rehabilitate native fish in the Murray-Darling Basin, South-Eastern Australia. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

McCay B.J. 1987. The culture of the commoners. Historical observations on old and new world fisheries. *In* B.J. McCay & J.A. Acheson, eds. *The question of the commons. The culture and ecology of communal resources*. Tucson, USA, University of Arizona Press. pp. 195-216.

McCay B.J. 1993. *Management regimes*. Stockholm, Beijer International Institute of Ecological Economics.

McCay, B.J. 1998. Co-managing the commons. *In* International CBNRM Workshop, Washington, DC, May 1998.

McCay B.J. 2000. Sea changes in fisheries policy: Contributions from anthropology. *In* E.P. Durrenberger & T.D. King, eds. *State and community in fisheries management*, Westport USA and London, Bergin & Garvey. pp. 201-217.

McCay B.J. 2002. Post-modernism and the management of natural and common resources. *The Common Property Resource Digest*, Vol. 2000, No. 54: 1-8.

McGoodwin J.R. 1990. *Crisis in the world fisheries. People, problems, and politics*. Standford, USA, Standford University Press.

McGrath D., Cardoso A. & Sá, E.P. 2003. Community fisheries and co-management in the lower Amazon floodplain of Brazil. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 2.* Food and Agriculture Organization & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/17. pp. 207-222.

McGrath D. & Castro F. 2000. From sector to system: Towards a multidimensional management in the Lower Amazon floodplain. In I.G. Cowx, ed. Management and Ecology of River Fisheries. Oxford, UK, Fishing News Books, Blackwell Science. pp. 388-399.

Mikalsen K. & Jentoft S. 2001. From user-groups to stakeholders? The public interest in fisheries management. *Marine Policy*, Vol. 25, No. 2001. pp. 281-292.

Murombedzi J. 1998. The evolving context of community-based natural resource management in sub-Saharan Africa in historical perspective. *In International CBNRM Workshop, Washington, DC, May 1998.*

Nielsen J., Degnbol P., Ahmed M. & Viswanathan K. 2002. Fisheries co-management - an institutional innovation. *In* Proceedings of the IIFET 2002 Conference, 19-22 August 2002, Wellington, New Zealand.

Nieuwenhuys O. 1989. Invisible nets: Women and children in Kerala's fishing. *MAST Maritime Anthropological Studies*, Vol. 2, No. 2. pp. 174-193.

Ostrom E. 2000. Private and common property rights. *In* B. Bouckhaert & G. de Geest, eds. *Encyclopedia of Law and Economics. Vol. II: Civil law and economics*, Cheltenham, UK, Edward Elgar. pp. 332-360.

Oviedo A. & Ruffino M. 2003. Addressing common demands of community fisheries in the Brazilian Amazon. Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.

Oviedo A. & Ruffino M. 2003. Addressing common demands of community fisheries in the Brazilian Amazon. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Parveen S. & Faisal I. 2003. Open-water fisheries in Bangladesh: A critical review. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission*.

Petkova E., Maurer C., Henninger N. & Irwin F. 2002. Closing the gap: Information, participation, and justice in decision-making for the environment. Washington, DC, World Resources Institute.

Phillips M. 2002. *Fresh water aquaculture in the Lower Mekong Basin*. Phnom Penh, Cambodia, Mekong River Commission.

Pinkerton E. 2003. The conceptualization of fisheries co-management in social science. *In* D.C. Wilson, J. Nielsen, & P. Degnbol, eds. *The fisheries co-management experience: Accomplishments, challenges, and prospects*. Dordrecht, Kluwer.

Pinkerton E. & Weinstein M. 1995. *Fisheries that work. Sustainability through community-based management*. Vancouver, Canada, The David Suzuki Foundation.

Pomeroy R.S., Katon B.M. & Harkes I. 2001. Conditions affecting the success of fisheries co-management: Lessons from Asia. *Marine Policy*, 25: 197-208.

Pomeroy R.S. & Williams M.J. 1994. *Fisheries co-mangement and small-scale fisheries: A policy brief*. Manila, International Center for Living Aquatic Resources Management.

Rettig R.B., Berkes F., & Pinkerton E. 1989. The future of fisheries co-management: A multi-disciplinary assessment. *In* E. Pinkerton, ed. *Co-operative management of local fisheries: New directions for improved management & community development*. Vancouver, Canada, University of British Columbia Press.

Ribot J.C. 2002. *Democratic decentralization of natural resources. Institutionalizing popular participation*. Washington, DC, World Resources Institute.

Ruffino M. 2003a. Participatory management of fisheries in the Brazilian Amazon. Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.

Ruffino M. 2003b. Provárzea - a natural resource management project for the amazon floodplains. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Ruitenbeek J. & Cartier C. 2001. *The invisible wand: Adaptive co-management as an emergent strategy in complex bio-economic systems*. Bogor, Center for International Forestry Research CIFOR.

Schouten R. 2003. *Threats to healthy fisheries in the Lower Mekong Basin*. Phnom Penh, Cambodia, Mekong River Commission. (forthcoming)

Scudder T. & Conelly T. 1985. *Management systems for riverine fisheries.* Rome, FAO.

Sen, S. & J.R. Nielsen 1996. Fisheries co-management: A comparative analysis. *Marine Policy*, 205: 405-418.

Soeftestad L.T. 2000. *Riparian right and colonial might in the Haors Basin of Bangladesh.* Presented at the 8th Conference of the International Association for the Study of Common Property IASCP, Bloomington, Indiana, United States, 31 May - 4 June 2000.

Uphoff N. 1998. *Community-based natural resource management: Connecting micro and macro processes and people with their environments.* Presented at International CBNRM Workshop, Washington, DC, May 1998.

Van Zaalinge N., Nao Thuok & Touch Seang Tana. 1998. *Where there is water, there is fish. Fisheries issues in the Lower Mekong Basin from a Cambodian perspective.* Paper presented to the Mekong Panel at the 7th Conference of the International Association for the Study of Common Property IASCP, 10-14 June 1998, Vancouver, Canada.

von Blanckenburg P. 1982. *Handbuch der Landwirtschaft und Ernährung in den Entwicklungsländern.* Verlag Eugen Ulmer, Stuttgart.

Wallace M.G., Cortner H.J., Moote M.A. & Burke S. 1996. Moving toward ecosystem management: Change in philosophy for resource management. *Politics & Society*, 3: 1-36.

Welcomme R.L. 1979. *Fisheries ecology of floodplain rivers*. London and New York, Longman.

Welcomme R.L. 2000. Principles and approaches for river fisheries management. *In* I. Cowx, ed. *Management and ecology of river fisheries*, Oxford, UK, Fishing News Books, Blackwell Science. pp. 331-345.

Welcomme R.L. 2001. *Inland Fisheries. Ecology and Management*. Oxford, UK, Fishing News Books, Blackwell Science.

Welcomme R.L. 2002. An evaluation of tropical brush and vegetation park fisheries Fisheries Management and Ecology, 9: 175-188

Welcomme R.L. 2002. Data requirements for inland fisheries management. In Proceedings of the FAO/MRC/Government of Thailand/ Government of The Netherlands ad hoc expert consultation on *new approaches for the improvement of inland capture fisheries statistics in the Mekong Basin*, 2-5 September 2002, Udon Thani, Thailand.

Wilson D.C. 2000. Fisheries Management as a Social Problem. *In* C. Sheppard, ed. *Seas at the Millennium*, *Vol. III*. London, Elsevier. pp. 153-164.

SESSION 5 REVIEW INFORMATION, KNOWLEDGE AND POLICY

D. Coates[1,2] T. Boivin[3] W.R.T. Darwall[4] R. Friend[5] P. Hirsch[6] A.F. Poulsen[7] R. Quirós[8] T.A.M. Visser[9] & M. Wallace[10]

[1] World Bank/GEF, Aquatic Resources Development, Management and Conservation Studies of the Fourth Fisheries Project, Dhaka, Bangladesh

[2] Current address for correspondence: Secretariat of the Convention on Biological Diversity, World Trade Centre, 393 St Jacques Street, Office 300, Montréal, Québec, H2Y 1N9, Canada

[3] Hatfield Consultants Limited, 201-1571 Bellevue Avenue, West Vancouver, British Columbia, V7V 1A6, Canada

[4] IUCN – The World Conservation Union, 219c Huntingdon Road, Cambridge, CB3 ODL, UK

[5] IUCN – The World Conservation Union, House 63, Soi 39, Sukhumvit Road, Bangkok 10110, Thailand

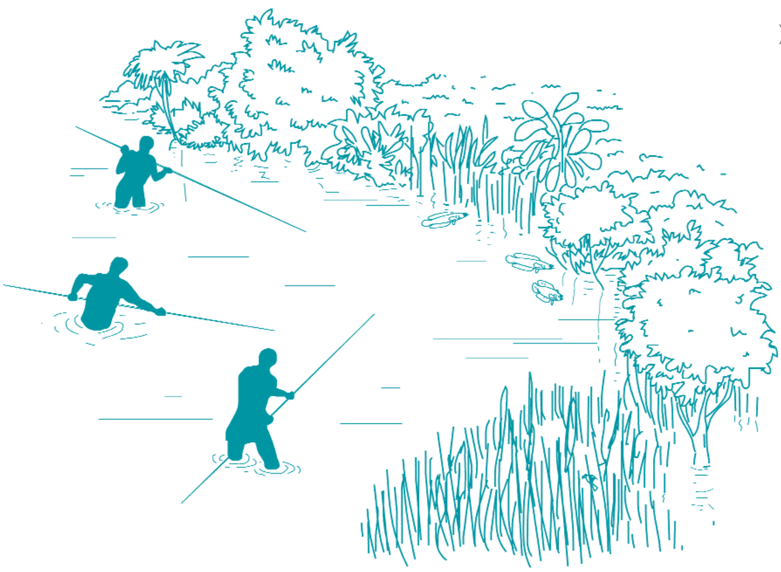
[6] Australian Mekong Resource Centre, School of Geosciences, University of Sydney, NSW 2006, Australia

[7] Assessment of Mekong Fisheries Component, MRC Fisheries Programme, Mekong River Commission, Vientiane, Lao PDR

[8] Sistemas de Producción Acuática, Facultad de Agronomía, Universidad de Buenos Aires, Av. San Martín 4453, (1417) Buenos Aires, Argentina

[9] Assessment of Mekong Fisheries Component, MRC Fisheries Programme, Udon Thani, Thailand

[10] Halcrow Consultants Ltd., UK



OVERVIEW

This review focuses on the links between information, knowledge and policies and in particular to identify gaps and areas where progress has been made and future needs. It assumes the following broad definitions: information – *facts or details*, knowledge – *information, understanding and skills that are gained through education and/or experience*; policy – *a plan, rule or way of acting, agreed or chosen*. The difference between information and knowledge is important. The latter recognises better the wealth of information available through informal knowledge based sources, particularly local knowledge held by riparian communities.

Policies are obviously important, or should be. The general descriptions of the dire state of river fisheries and biodiversity imply that policies are lacking, inappropriate and/or their implementation is ineffectual. Some contributions to the symposium argue that policy execution is poor because different stakeholders have different policies (official or otherwise). Others blame the lack of appropriate management methods and capacity. These differences must be disaggregated. It is symptomatic that not a single contribution to this symposium dealt with policy analysis in any depth leading to the conclusion that such an analysis is urgently required.

The session assumed that “river fisheries science” should be management focussed. In only a few cases are links to improved management apparently absent, but in too many others they are not well articulated. Very few contributions dealt with information requirements and systems directly (e.g. Boivin *et al.* 2003; Bush 2003; Friend 2003; Hirsch 2003; Lerner 2003; Poulsen, Hartman and Mattson 2003; Suntornratana and Visser 2003) and none do so comprehensively. Applied research should be objective focussed and tailored to the information needs for management and policy development. A major problem is that with biologically, socially and politically complex river fisheries, information needs and priorities are often far from clear. It was also concluded that the information for river fisheries should be reviewed more thoroughly than can be achieved here. The lack of a professional body to guide river fisheries science perhaps contributes to a certain degree of randomness in current approaches.

Scientists often assume that the production of information, even where pertinent, will lead to improved policies and management. That this is not the case is patently obvious from the multitude of authors who recognise that many management requirements are not technology or information based. Hirsch (2003) draws attention to the complex relationships between information, knowledge and policies for river fisheries and the need to consider issues of ownership, participation and lines of tension between the various stakeholders. The way in which information is produced and used is equally, if not more, important than the information itself (Hirsch 2003; Friend 2003; Poulsen *et al*. 2003). The need to change governance systems for river fisheries, including appropriate modifications of information generation and flow, policy generation and decision making mechanisms, is a clear message from this symposium.

Amongst the advances in technological approaches to information generation, the field of remote sensing deserves particular mention. Boivin *et al*. (2003) summarised the subject noting that the technology is becoming more accessible and affordable and being used more widely. Considerable interest was shown at this symposium in such approaches and several presentations and posters illustrated the value of the technology.

RIVER FISHERY STATISTICS

Current statistics for river fisheries might be mistakenly regarded as the first point of call for relevant information. However, Coates’ (2002) review of inland fisheries statistics in South-East Asia, noted an almost complete disconnect between national statistics and policies, planning and management. Constraints include the almost universal underestimation of river fisheries production and the general absence of accurate information on livelihoods dependency and biodiversity. A major drawback is that objectives, methods and assumptions for information generation are invariably based upon those derived for marine fisheries. There is an urgent need to develop information approaches more in-tune with the differing requirements for inland fisheries. The review is considered widely applicable to most other regions. Coates (2002) and FAO (1999) should be consulted for recommendations for improved approaches. Unless detailed investigations indicate otherwise, with few exceptions, policies for river fisheries should not be based upon current national statistics and no contributions to this symposium question this conclusion.

Contributions to this symposium show that there is in fact a great deal of useful information available on large river fisheries. The problem is often in collating existing information and addressing constraints between information, management and policy. Information in country or regional reviews is often enhanced by incomplete research information synthesised by local fishery experts (e.g. Hossain *et al.* 2003; Lae *et al.* 2003; Quiros 2003) or incomplete survey or census information. In general, observed trends often paint similar patterns of over exploitation, increasing participation, falling catches or changing species composition (e.g. Catela 2003). Such generalisations are rarely substantiated by conclusive data. Only one paper presented to this symposium (Poulsen *et al.* 2003) suggests methodologies for improving meaningful statistical information. Friend (2003) questions the need for improved statistics as a priority, arguing that a better approach is to empower local communities in management decisions.

Despite the diffuse and diverse nature of river fisheries there are good examples of local fisheries that can, in theory, easily yield accurate catch-effort data for monitoring of trends (e.g. van Zalinge *et al.* 2003; Parsamanesh 2003). Commercial large-scale operations can be monitored using conventional approaches as long as transboundary factors for migratory stocks are considered (Baird and Flaherty 2003). One-off research surveys (e.g. Béné 2003; Lalèyè *et al.* 2003; Poulsen and Hartman 2003; Petrere 2003) provide useful ‘snap-shot’ information. However, methods for using such information in sustained monitoring and management are not well established (Coates 2002).

A more holistic approach to information systems for large river fisheries is required. This includes a shift of emphasis from classical, marine fishery derived, catch-effort information to improved information on the environment and socio-economic parameters and especially livelihoods related information (e.g. Lae 2003; van Zalinge 2003). This should be integrated with improved co-management approaches whereby resource users are better empowered to set management objectives and are more fully involved in the information and policy process (e.g. Poulsen and Hartman 2003).

CLASSICAL FISHERY MANAGEMENT APPROACHES

Classical stock-assessment models attempt to predict the level of effort at which the maximum amount of fish can be sustainably captured from a single stock. It is often not a useful approach for river fisheries, except possibly for those in undeveloped river reaches which concentrate on a few large species (e.g. Catella 2003; Vaz and Petrere 2003). The approach also has value in highly developed river basins (Schramm 2003). Recreational and sport fisheries are usually important in both kinds of systems and stock assessment approaches can provide valuable fisheries management/policy information. Most of the general review papers presented at this symposium include the use of time-series catch data (Chen, Duan, Liu and Shi 2003; Fashchevshy 2003; Lae 2003; Petrere 2003; Quiros 2003; Schramm 2003; Slynko 2003a) and some of them also include fishing effort data, though in most cases continuity of data is not ideal (e.g. Jackson 2003; Slynko, Kiyashovka and Yakovlev 2003b). River fisheries are usually based on a large number of species and a wide range of fishing gears. Such multi-species, multi-gear, fisheries are not generally amenable to the more classical methods of stock evaluation. Moreover, fishery resources in large rivers are affected greatly by environmental factors (both natural and human induced). Environmental degradation and habitat loss, not excessive fishing effort, is reported as the major cause of declining fisheries in most rivers under stress. Multi-species models (see Welcomme 1999) predict better the behaviour of multi-gear riverine fisheries under both environmental pressure and increasing fishing effort (e.g. Chen *et al.* 2003; Faschevsky 2003; Lae 2003; Quiros 2003). The contributed papers are not explicit on how to separate the effects of overfishing and environmental change in complex systems where both effects are at play. Most relevant contributors to this symposium conclude that increased attention to management of the environment is required, but very few suggest how this can be best achieved. The suitability of catch-effort based approaches to river fisheries science is rarely addressed. It is therefore difficult to assess whether these approaches are adopted by choice, through proven management benefits, or whether they are a legacy of the marine fisheries roots of contemporary river fisheries science. Certainly, there are few cases cited where such approaches have actually resulted in improved management.

For the monitoring of fishing pressure, total fishing effort and catches, together with time-series data for water quality, for most important landing sites are argued to be a basic source of information (Baird and Flaherty 2003; Batista 2003). Such data can be easy and cheap to collect and are often a requirement for sound management (Evans 2003). This will also contribute to assessing important links between catches and hydrology. Large river floodplain fisheries exhibit a high degree of variation both between and within years. Long time series for data are therefore highly desirable, but often lacking due to the inability to sustain monitoring programmes. This is at least partly because knowledge/information systems are often externalised from users and stakeholders.

Methods of producing improved fisheries management information are implied in several papers and span several orders of spatial magnitude. These include at the basin level (Brenner *et al.* 2003; Darman 2003; Koehn 2003; Schramm 2003; Payne *et al.* 2003; Oliver 2003; Quiros 2003; Schiemer 2003; Sridar 2003), for long distance migratory fish (Baird and Flaherty 2003; Petrere 2003; Poulsen 2003), to fisher community involvement in fish management at the local level (Arjjumend 2003: Bocking 2003; Evans 2003; Friend 2003; Hirsch 2003; McGrath, Cardosa and Sa 2003; Poulsen and Hartman 2003; Ruffino 2003). Basin scale management requires linkages between fisheries and related environment policies, including sustaining migratory stocks. Riparian communities are better placed for improving policies for stock exploitation, resource management and environment protection at the local level. A major requirement, not yet adequately addressed, is to empower the latter group to have a major influence on environmental management, including at the basin level.

The papers presented at this symposium reflect the reality that river fisheries vary widely between regions. Relevant factors include management objectives, the state of the resources and environment, population pressures, levels of economic development and socio-political settings. Some of these factors are illustrated in Table 1. Policy development for large river fisheries needs to bear in mind this wide range of operating circumstances.

Table 1: A sample range of states of river fisheries and the potential applicability of stock assessment based management approaches

Management objective	Relevant fish size/habits	Maximisation	State of River Basin	Biodiversity Concerns Explicit in Management	Stock Assessment	Basin Examples	This Symposium Papers
Few and valuable large species	large size potamodromous	conservation (?) recreation	undeveloped or low developed	No	Yes	Upper Paraguay Amazon	Catella Vaz and Petrere
Few and less valuable large species	Large and medium size potamodromous	Economic Yield	Developing	No	No?	Ob-Irtysh basin Middle Parana Ponto-Caspian Region Orinoco Yangtze	Kasyanov Quiros Faschevsky Layman and Winemiller Chen
Any fish larger than minimum size for first reproduction	Medium and small size	Fish Yield	Developing	Not Prevailing	No?	Middle/lower Mekong Niger	Evans Lae
Limited management, fished-down fisheries, low value fish	Medium and small	Employment	Developing Developed	Not Prevailing	No?	Rio de la Plata Upper Mekong (?) Ponto-Caspian Region Yangtze Ganges-Bramaputra Niger Upper Parana Magdalena	Quiros Baird and Flaherty Faschevsky Chen Hossein, Das, Payne Lae Agostinho Mojica
Overall societal goals, preferred and possible state high valued fish	All sizes but still not many large	Conservation Recreation Aesthetics	Developed	Yes	Yes	Mississippi Murray-Darling Garonne	Brown Schramm Koehn and Nichol, Gehrke Brosse *et al.*

WATER RESOURCES MANAGEMENT

All relevant reviews at this symposium identify water resources management as a key factor in sustaining river fisheries and biodiversity. Not surprisingly, a large number of contributions to this symposium have explicit or implicit relevance to integrated water resources management (IWRM) in all regions (Table 2). IWRM is concerned with balancing spatially diverse multi-sectoral demands on the water resource system, normally within a defined policy framework that places socio-economic objectives uppermost alongside environmental protection and enhancement. IWRM strategies employ a mix of structural, non-structural, regulatory and economic measures to meet policy objectives. Water resource demands are viewed as either consumptive (permanently removing water from the system) or instream (maintaining flows and water quality within specified limits). River (including floodplain) fisheries are examples of instream demands, alongside navigation and maintenance of water quality requirements. River fisheries have faced competing demands from principally the agricultural, energy, urban and industrial sectors. Furthermore, these same pressures have resulted in increased demand for fish, leading often to unsound and unsustainable fishery practices.

Interventions in the river system will alter the regime and impact upon fisheries. A major challenge for IWRM planners is therefore to devise strategies that establish river fisheries at an appropriate and sustainable level consistent with a balanced achievement of policy objectives. Thus policy makers and decision-takers need to be informed about what levels are realistically achievable (given the competing demands), what trade-offs are possible and the significance of these. To assemble this information requires the capacity to know what river regime conditions exist and how these may be impacted by alternative interventions, together with how those conditions impact upon on fish populations and their sustainability.

Technologies to collect relevant water resources information are generally well developed. In some countries however, extremely little direct information on water use is available, particularly where irrigation is the main consumptive use. Monitoring the impacts of water resources interventions on people and the environment, particularly with respect to fish, is less comprehensively applied, particularly in the developing world. Nevertheless, as this symposium suggests, new technologies are being developed and both generic and location specific studies are being taken up (Table 2). Public awareness of these issues is growing as a result of higher educational standards and the advocacy of grass-roots organisations, although few papers reflect this important aspect of environmental management.

Table 2: Contributions to this symposium by subjects related to Integrated Water Resources Management

Authors	River system	Region	Authors	River system	Region
Methods of collection of relevant water resources information **No papers**					
Monitoring water resources and water management interventions **Monitoring technologies**					
Boivin, Coates, Werle	General	General	English *et al.*	General	Canada S. America
Rajyalakshmi	Godavari	India	Suntornratana	Songkram Mekong	Thailand Southeast Asia
General impact studies					
Baird and Flaherty	Mekong	Cambodia Southeast Asia	Wei	Yangtze	China
Monitoring of specific interventions and/or locations					
Adite	Mono	Benin, Africa	Ekanayake	Mahaweli	Sri Lanka India
Jabeen	Indus	Pakistan, India	Jutagate	Pak Mun, Mekong	Thailand

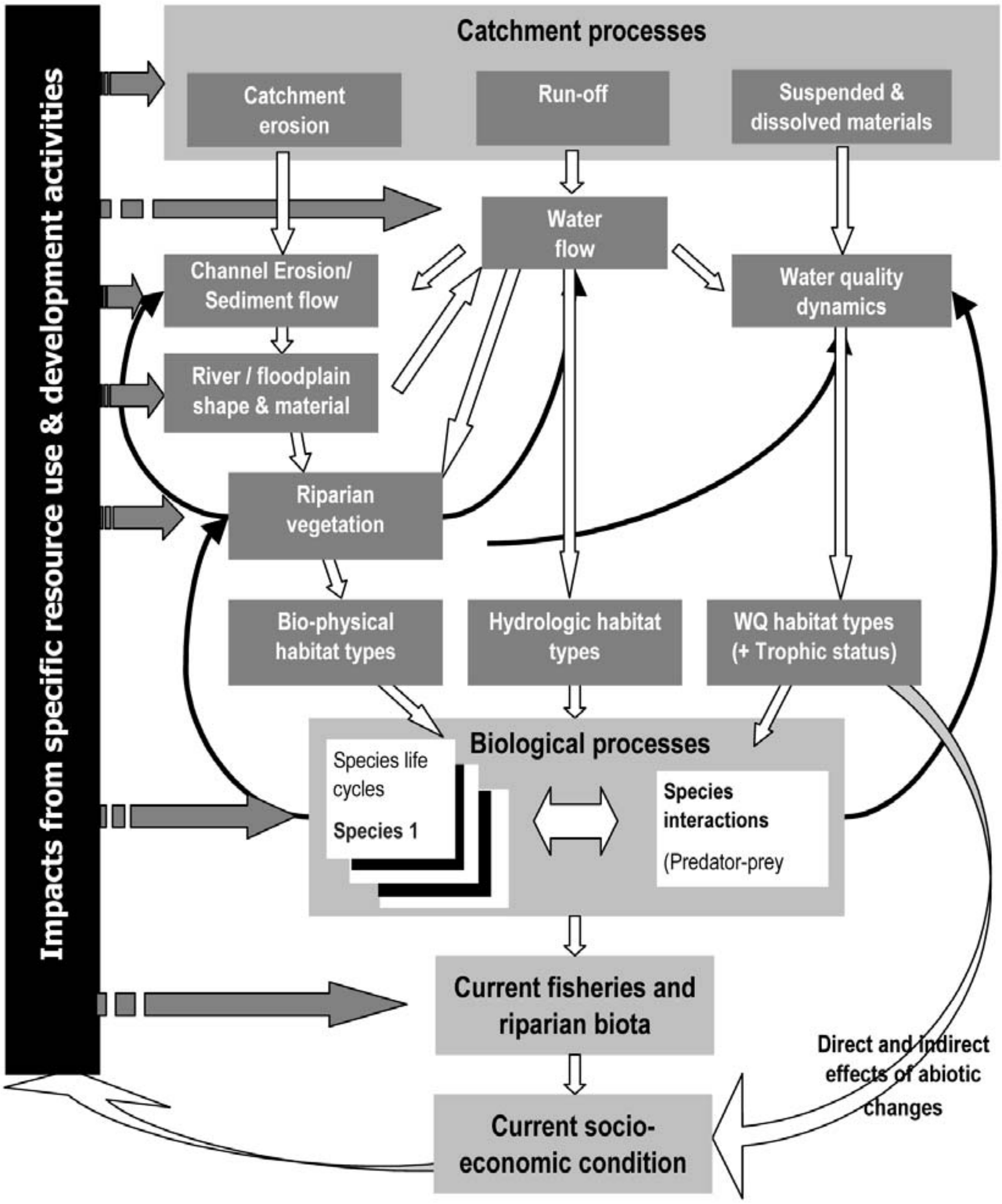
Authors	River system	Region	Authors	River system	Region
Kabir and Sharmin	Ganges, Brahmaputra	Bangladesh India	Slynko *et al.*	Volga	Russia Asia
Sripatrprasite	Pak Mun Mekong	Thailand Southeast Asia	Winter	Vecht Rhine	Netherlands Europe
Impacts of water resources management on fisheries					
Analytical techniques and models					
Arthington, Rall, Kennard	Orange	South Africa	Baran, Makin, Baird	Mekong	Cambodia, Southeast Asia
Halls and Welcomme	Brahmaputra	Bangladesh, India	Hortle *et al.*	Mekong	Southeast Asia
Humphries	Murray Darling	Australia	Junk	General	General
Kennard, Marsh, Pusey, Arthington	Mary	Australia	Marsh and Kennard	Mary River	Australia
Milhous	General	General	Morand	Mali -Niger River	Mali - Africa
Zalewski	General	General			
Studies leading to generic approaches					
Abell	General	General	Arrington and Winemiller	Orinoco	Venezuela, South America
Baras, Marmulla, Lucas	General	General	Brenner and Buisje	Rhine	Europe
Brosse, Lim and Lek	Garonne	France, Europe	Brummett	Rainforest rivers	Cameroon, Africa
Carvalho de Lima	Amazon	Brazil South America	Darman	Amur	Russia, Asia
Flotemersch	Yockanookany	USA North America	Gehrke	Murray Darling	Australia
Hossain *et al.*	Ganges	Bangladesh India	Layman and Winemiller	Orinoco	USA North America
Lim *et al.*	Kirindi Oya	Sri Lanka South Asia	Nguyen Khao *et al.*	Melun R.	Turkey Asia
Oz *et al.*	Melen	Turkey	Pacini	General	General
Pouilly	Mamore, Amazon	Bolivia South America	Poulsen	Mekong	Southeast Asia
Pusey and	N. Queensland	Australia	Pusey b	Burdekin	Australia
Quiros	La Plata	South America	Saint-Paul	Amazon	Brazil South America
Sousa, Fabre, Batista	Purus, Amazon	Brazil South America	van Zalinge	Mekong	Cambodia Southeast Asia
Welcomme and Halls	General	General	Winemiller	General	General
River specific studies					
Ahmed *et al.*	Titus Ganges	Bangladesh India	Alonso and Fabre	Amazon	Brazil, South America
Araujo-Lima	Amazon	Brazil, South America	Bart	Mekong	Southeast Asia

Authors	River system	Region	Authors	River system	Region
Boisneau	Loire	France, Europe	Brown	Susquehanna	USA, North America
Chen *et al.*	Yangtze	China	Crossa and Alonso	Amazon	Brazil, South America
Das *et al.*	Barak / Brahmaputra	India	De Silva	Nilwala	Sri Lanka India
Fashchevsky	Danube, Dneisr, Dnepr, Volga	Russia, Europe	Feunteun *et al.*	Loire	France Europe
Fu *et al.*	Yangtze	China	Hossain	Karnafuli R.	Bangladesh India
Jackson	Yazoo, Mississippi	USA N. America	Jimenez	Sao Francisco	Brazil
Kasyanov	Ob - Irtysh	Russia, Asia	Kurup *et al.*	Kabbini, Bharathapuzha, Chalakudy, Periyar and Kallada	India
Lae *et al.*	Niger	Africa	Lalaye	Oueme	Benin - Africa
Lewis	Orinoco	Venezuela South America	Mojica	Colombia Magdalena	Colombia South America
Nguyen Khao *et al.* b	Mekong	Lao PDR Southeast Asia	Olivier a	Rhone	France Europe
Ouch	Kompong Trelach, Mekong	Cambodia Southeast Asia	Petr	Amu Darya / Syr Darya	Russia Central Asia
Payne, Sinha, Singh and Huq	Ganges	Ganges India	Petrere	Amazon	Brazil, South America
Ruffino and Dalley	Amazon	Brazil	Schramm	Mississippi	USA South America
Shrestha	Koshi, Gandaki and Karnali	Nepal - India	Silvano	Jurua, Araguaia, Negro / Amazon	Brazil - South America
van Zalinge	Mekong	Southeast Asia	Vaz	Pantanal	Brazil South America
Information required from fisheries for sustainable management of water resources Management approach					
Abbott	Zambezi	Africa	Agostinho and Gomes	Parana	Brazil South America
Batista and Petrere	Amazon	Brazil, South America	Bene and Neiland	Logone Chari	Nigeria Africa
Chang, Park and Lek	Yangtze	China	Evans *et al.*	Guadiana Portugal	Portugal Europe
Filipe *et al.*	Guadiana	Portugal	Kibria	Ganges	Bangladesh
McGrath and Alcilene	Amazon	Brazil South America	Rai	Koshi, Gandaki and Karnali,	India Nepal

Authors	River system	Region	Authors	River system	Region
Oviedo and Ruffino Asia	Amazon	Brazil, South America	Sripatrprasite	Pak Mun, Mekong	Thailand Southeast
Assessment of socio-economic impacts					
Almeida, Lorenzen, Grath	Amazon	Brazil, South America	Bene and Neiland	Logone Chari	Nigeria Africa
Bush	Mekong	Lao PDR Southeast Asia	Hand and Voinov	Mekong	Cambodia Southeast Asia
Haque	Brahmaputra	Bangladesh	Kaunda	Malawi	Africa
Hassan	General	General	Kawanga	Luapula - Mweru	Zambia Africa
Alam	Buriganga	Australia	van Brakel *et al.*	Mekong	Southeast Asia
General assessment methods					
Darwall and Vie	General	General	Das	General	India
Flotemersch	General	USA North America	Friend	General	General
Halls, Shankar, Barr	General	General	Hogan	Mekong	S.E Asia
Lek, Brosse	Garonne	France Europe	Minte-Vera	Upper Parana Brazi	Brazil lSouth America
Means of influencing policies on water resources in relation to river and floodplain fisheries					
General knowledge of river systems					
Catella	Parana	Brazil South America	Faisal	Ganges, Brahmaputra, Meghna	Bangladesh, India
Gopal, Brij	General	India	Guo	Mekong	Viet Nam Southeast Asia
Education and awareness raising					
No Papers					
Appropriate political frameworks					
Arjjumend	Narmada	India	Castro	Amazon	Brazil, South America
Fuller	San Joaqqin Sacramento Rivers	USA North America	Gentes	General	Chile - South America
Koehn and Nicol	Murray Darling	Australia	Lerner	Mekong	Cambodia, Southeast Asia
Tun Myint	Rhine	Europe	Parveen	Ganges, Brahmaputra	Bangladesh India
Pettitt and Sim	Mekong	Cambodia Southeast Asia	Ruffino	Amazon	Brazil South America
Scanlon	Murray Darling General	Australia			

Institutional arrangements are often an impediment to comprehensive impact monitoring of interventions, with the often still-powerful water/agriculture /energy lobbies pitted against those from environment/fisheries. Institutional and policy reforms backed by new legislation are slowly redressing this situation, along with changing economic realities. There is a clear appreciation that the wider institutional issues need to be tackled.

The impacts of water resources management upon fisheries are complex with many factors to consider. Interventions directly impact on the physical and biological conditions, which in turn determine the quality of aquatic environment available for different species, thereby influencing socio-economic conditions and options (Figure 1).



■ **Figure 1:** Interactions between water resources use, physical and biotic factors, environment and fisheries in large rivers.

The relationships between physical interventions in the water resource system and the qualitative and quantitative conditions are relatively well understood and relatively easy to predict using a variety of well-established mathematical models. These tools are data intensive, however, requiring multiple geo-referenced layers of land, water, climate and physical information.

The relationships between qualitative and quantitative conditions in the water resource system and the productivity, diversity and sustainability of river and flood plain fishery resources is clearly complex and in need of continued study, as the wealth of papers submitted in this area reflects. It is particularly pleasing to note that many of these papers are directed at developing new analytical techniques as well as generic understanding of the issues. Scientists are always quick to claim limited data and understanding as a basis for demanding more research. But it is evident that there is already a clear basic understanding of how river fisheries function at the ecological, environment and social levels. Perhaps more than any other aspect of this symposium, the drawing together of this research is vital for the fisheries sector to lay claim to its share of water resources. There is a need to progress beyond the very generalised statements of the past to a coherent and rational justification of fisheries demands from the water sector. This requires stakeholders to articulate the case for river fisheries much better and to work closer with other users of water under an integrated policy and planning framework. It is clear that river fisheries managers are not doing this well enough.

Management of water resources requires strategies that provide a sustainable balance of socio-economic values gained from different uses in accordance with policy aims. In order to evaluate choices that include river and floodplain fisheries, the planner must be able to (i) know what range of conditions in the river system would be favourable to fisheries (and equally those which would not be) and (ii) given those conditions are provided what would be the socio-economic value of those fisheries under prevailing and future fisheries management practices. Then an analytical model linking the socio-economic costs of providing different conditions to socio-economic benefits of fisheries could be relatively easily constructed, based upon which trade-offs could be made with alternative uses of water. Whilst progress is being made in some of these areas it is not obvious from this symposium that river fisheries science has clearly and explicitly targeted these fundamental requirements. It should do so and urgently.

This symposium demonstrates that productivity and sustainability of river fisheries are *inter alia* a function of the way they are managed. The papers also show that evaluating the socio-economic benefits of fisheries requires a very clear understanding of the role of fisheries within society, locally, regionally and nationally. The conclusion has to be that fisheries and their nature are optional in rivers and subject to societal preferences. The mechanisms by which those preferences evolve and the information systems upon which they are based are therefore the most critical aspects of river fisheries management, yet the least studied.

Modern water resource management policies already commonly recognise the broad range of uses that a river system can be put to and the imperative of sustainable development. The inequities of the recent past have been highlighted with increasing recognition of the commercial and nutritional values of river and floodplain fishing and, in particular, the importance of the role that fishing plays in sustaining the poor and disadvantaged sectors of rural communities. This symposium has significantly reinforced this awareness. There are perhaps three key ways to further ensure that water resource management policies are appropriate to the needs of river and floodplain fisheries:

1. Improved knowledge

The socio-economic value of water for fisheries must be well understood; otherwise other uses inevitably will gain favour. Similarly, the opportunity costs of providing conditions favourable to fisheries need also to be evaluated, requiring that those conditions can be specified with reasonable confidence and transparency. Several papers reflect the value of taking a holistic view of fisheries within river basins and thus promoting a better understanding of these issues. Livelihoods based approaches also appear to offer an improved framework for making multi-sectoral comparisons of the benefits of developments. Further progress in this area is desirable as it is clear from this symposium that the outcome will likely be to the benefit of fisheries.

2. Education and awareness

Ideally, policies are supposed to reflect societal preferences. If the stakeholders are fully aware of the comparative importance of fisheries to them as individuals and to society as a whole, then policies will increasingly reflect that importance. None of the papers submitted directly address this important issue (Table 2). Fisheries science, in general, appears particularly inept at communication although it is clear that there is much useful and interesting information that could be used in well-targeted media campaigns.

3. Appropriate institutional, legal, regulatory and economic frameworks

Sound principles must be applied in all these four areas if policy decisions are to be effectively implemented. A number of papers address ways by which management at the sectoral level can be enhanced. There is also a clear message from this symposium that the lack of participation of relevant stakeholders (resource users) in policy formulation and implementation is a significant constraint to achieving sustainable development goals for river fisheries and natural resources more broadly. Governance issues override most others.

THE ROLE OF LOCAL KNOWLEDGE IN INFORMATION GENERATION

In most developed countries, the population at large is unlikely to have much direct interest in, or knowledge of river ecology. Scientists and technical specialists working on behalf of regulators and interest groups will dominate the information process, relying mostly on conventional scientific methods for their judgement (Lorenzen and Arthington 2003). In most developing countries the livelihoods of the majority of rural people are intimately linked to river ecology and local and traditional knowledge on relevant subjects is normally profound (Poulsen *et al.* 2003). Local knowledge is probably not more widely used because river fisheries science remains dominated by “westernised” approaches. This is counterproductive for improved participation of people in the information-knowledge-policy process and a significant waste of valuable knowledge.

Things are improving. There is an increasing awareness globally that conventional fisheries science, including its embedded information generation, is not adequate for management and policy-making in relation to river fisheries (e.g. Friend 2003; Poulsen *et al.*; Hirsch 2003). Traditionally, local knowledge has been disregarded in the “scientific” community, including fisheries science (Hirsch 2003). Attention is shifting to integrating local knowledge into the overall information systems upon which management decisions are based (Hirsch 2003; Friend 2003; Poulsen *et al.* 2003). Co-management is increasingly being advocated and implemented as a more sustainable management strategy for river fisheries compared to conventional management approaches (Bene and Neiland 2003; Evans 2003; Rai 2003; Kaunda and Chapotoka 2003; Bocking *et al.* (2003); Gentes 2003; Ruffino and Dalley 2003; McGrath and Cardoso 2003; Pettitt and Sim 2003; Koehn and Nicol 2003). Co-management implies the direct involvement of local resource users in the entire management cycle, including information generation (Coates 2002). Often, local knowledge can bring conventional sample data into context and connect isolated data sets from different sites within the ecosystem. Baird and Flaherty (2003), for example, used local fishers, in combination with their own sample data, to hypothesize on large-scale fish movements in the Mekong River basin. With the silver eel fishery of the Loire River in France, cooperation with local fishers is increasingly seen as the appropriate way to obtain appropriate data and information on which to base management plans (Feunteun *et al*. 2003). Since fishers are present in the environment throughout the year, they are beginning to be seen as "environmental sentinels and partners" by environmental authorities (Feunteun *et al.* 2003). Cooperative research is often seen as a way to get fishers onboard in the management of the resources but it is equally valuable in getting research to be more relevant and effective. Consensus building, across very clear lines of tension between agriculture and conservation interests in California, was successfully achieved through mediation, cooperation and collaborative research (Fuller 2003). Local knowledge can contribute significantly to increased understanding of ecosystems at various scales (Poulsen *et al.* 2003; Bocking *et al.* 2003).

Information, data and knowledge alone do not guarantee knowledge-based decisions. Acceptance of local knowledge has to be accompanied by involvement of stakeholders, including local communities, in the management and decision-making process (Friend 2003). The political 'reality' of information/policy environments determines the type of information that is available and/or used (Hirsch 2003).

ENVIRONMENT AND RIVER FISHERIES

Environmental factors and harvesting are the two major factors limiting and in many situations reducing, river fishery resources. Fish stocks, biodiversity and relevant livelihoods cannot be restored or maintained if important environmental influences are not sufficiently understood.

Basic information on fish ecology is fundamental to both fisheries and environmental management. This symposium has contributed to the growing information base on this subject in large rivers (e.g. Alonso 2003; Baird and Flaherty 2003; Carvalho de Lima and Araujo-Lima 2003; Getahun 2003; Hogan 2003; Kennard *et al.* 2003; Panjun 2003; So and Volckaert 2003; Vieira, Fabre and Araujo 2003). A number of basic information areas for fish assemblages remain relatively unknown including: habitat requirements (physical/structural requirements and water quality and flow over the full life cycle of the species); migration routes and population structure (for many species migration patterns are as yet unknown, making it difficult to manage the stocks effectively); environmental cues (what triggers biological events such as migrations or spawning?); interspecific interactions; river hydrology (deserves special attention as an influential driver for habitat, migration patterns, as a source of environmental cues and a modifier of ecosystem processes, food webs and species interactions). All of these requirements are overlain by a need to collect focused information from well-designed studies that address specific and clearly defined questions. A major constraint in river fisheries science remains the dominance of studies on fish. Other taxa are also important to fisheries and obviously as components of the river ecosystem (e.g. Flotemersch and Blocksom 2003; Hossain 2003; Sripatrprasite and Kwei Lin 2003). There is an urgent need to improve knowledge of these other groups

The standard methods of data collection continue to be through conventional scientific studies using "experts" and these were the most numerous types of papers presented at this symposium. More recently, increasing attention has been devoted to the compilation and use of local knowledge. This has proven particularly valuable in documenting fish distributions, habitat requirements and migration routes (Poulsen 2003). Community based studies are also being increasingly utilized both because they allow information to be collected cheaply over large geographical areas and because they promote community awareness and education as well as improved ownership of both resources and the knowledge/policy/management process.

In general fisheries have not been seen as ideal indicators of environmental stress in large rivers for several reasons. It is difficult, if not impossible, to disaggregate the impacts of fishing pressure and environmental stress on fish populations. Fish are also highly mobile and can move away from or through degraded areas. Particularly in large rivers, it often is difficult to obtain representative samples. The advantages of "auto-sampling" using fishers are often off set by the difficulties of obtaining accurate catch-effort data. Fish continue to be used as environmental sentinels, but usually in conjunction with other ecological indicators (e.g. Pouilly 2003) including other taxa, for example macro-benthos (Hossain 2003).

Environment information is currently constrained in three major ways: (1) knowledge is often lacking about fauna and flora (species/community levels) and ecological processes; (2) limited understanding (or monitoring) of interactions between human activities and the environment (including the effects of fishing) and (3) problems with access to information and its communication ("publication" of research is particularly a problem in developing countries coupled with poor information storage and retrieval support). Knowledge is often not passed on to, or used by, decision makers because of poor linkages, or because it is often not communicated in appropriate ways. Scientists often work in isolation from policy development and policy makers rarely attend technical or scientific meetings. This was reflected in the almost complete absence of policy-oriented papers presented at this symposium. Policy requires a good understanding of the technical issues, but also an appreciation of the cultural and community context to ensure that policy outcomes are achievable and appropriate. Scientists need to better consider this in research design and particularly in communication strategies.

Ecosystems, particularly large tropical rivers, are biologically complex. The realisation that they cannot be effectively managed on a species-by-species basis has prompted recent shifts towards ecosystem based management approaches (e.g. www.biodiv.org). A number of contributions to this symposium indicate further moves of river fisheries science in this direction. For example, "environmental-flows" (Arthington *et al*. 2003; Kennard *et al.* 2003; Pusey, Burrows and Arthington 2003; Scanlon 2003, Welcomme and Halls 2003), modelling and assessing links between environment and fish production (Barran, Makin and Baird 2003; Halls and Welcomme 2003; Lek 2003; Lewis 2003; Marsh and Kennard 2003: van Zalinge *et al.* 2003), system-wide remote sensing approaches (Boivin *et al*. 2003), ecosystem based conservation zones (Abell, Thieme and Lehner 2003; Filipe, Marques, Seabra *et al*. 2003) and other related approaches (Pouilly and Rodriguez 2003; Zalewski 2003). One of the most useful and enduring, ecosystem-based approaches to large river fisheries management (the flood-pulse concept) was also updated (Junk and Wantzen 2003). There is a need to better bridge the gap between ecosystem approaches and practical suggestions for improved policies and management. For example, Poulsen (2003) assesses migrations of a suite of species under an ecosystem framework and then looks at the implications of this for basin-wide management requirements. The dynamic nature of river ecosystems in both space and time has long been known to have a major influence upon river fisheries and is well documented in the scientific literature. It is tempting to speculate that our understanding of "ecosystem based" requirements for policies and management are perhaps further advanced for river fisheries science than in some related disciplines. It is incumbent upon river scientists to adopt such approaches more widely and explicitly, for the benefit of both river fisheries management and as potential approaches to the management of other natural resource systems. In particular, there is an urgent need to synthesise existing knowledge on this subject within a management/policy environment. We need to know what exactly is our level of understanding and what needs to be done next.

LIVELIHOODS RELATED INFORMATION

Despite the title and objectives of this symposium, only a small proportion of the contributed papers deal directly with livelihoods. This reflects the historical focus of fisheries research on management of the biological resource system, rather than the resource users. Things are improving. There is certainly more attention to social aspects of fisheries management than at the first LARS (Dodge 1989), even if an imbalance still exists.

There is a general tendency to misuse the term "livelihoods" as a contemporary substitute for "socio-economic". Its specific meaning is important to the discussion of information. Recent thinking on "Sustainable Livelihoods" (Carney 1998) emphasises people centred, dynamic, approaches, micro to macro linkages, adaptive livelihood strategies and attention to the range of "capitals" in use within livelihood frameworks – including social capital such as knowledge. Most of the discussions on livelihoods information at this symposium focus on the type of information and methodological approaches for gathering it. There is less attention to whom the information is for and its purpose. The capacity to participate effectively in decision-making processes is an important aspect of this livelihoods approach. Traditionally, the emphasis in the debate on fisheries information has been on providing information to "policy-makers and planners", rather than on empowering fishery dependent communities to be fully engaged in the knowledge-information-policy setting. There is a clear shift in emphasis in this direction amongst this symposium contributions (e.g. Hirsch 2003; Friend 2003; Poulsen 2003; Bene and Neiland 2003; Mojica and Galvis 2003; Ruffino 2003; Oviedo and Ruffino 2003) including in developed countries (Mackay *et al.* 2003; Bocking *et al.* 2003).

Much of the livelihoods work has come out of a realisation that it is often the poor and vulnerable who are either excluded or receive less (or no) benefits from development interventions. This is very pertinent when applied to trends in river basin development (e.g. Das 2003; Evans 2003; Gentes 2003; Gopal 2003; Gurumayum *et al.* 2003; Hirsch 2003; Hossain *et al.* 2003; Kaunda 2003; Lae 2003; McGrath and Cardoso 2003; Mojica and Galvis 2003; Oviedo and Ruffino 2003; Pacini 2003; Parveen and Faisal 2003; Quiros 2003; Ruffino and Daley 2003; van Zalinge *et al.* 2003).

Traditionally the focus on information for river fisheries has been on catch/production, composition and financial value including effort, gears, habitats etc. (e.g. Ahmed, Hossain and Akhteruzzaman 2003), the numbers of fishers (where data tend to focus on 'professional fishers', but occasionally within the household (Bush 2003), economic costs and benefits, input/output (particularly for aquaculture), consumption and nutrition (e.g. Bush 2003; van Zalinge *et al*. 2003), or is comparative between different livelihood activities (e.g. van Zalinge *et al*. 2003). Less attention is given to the significance of fishing in the context of other livelihood strategies, the distribution of benefits within and between households/communities and access and control over resources (including marketing of resources (Bush 2003), how management decisions are made and their distributional impacts (Evans

2003), the composition and dynamics of 'communities' and households, vulnerability and 'poverty' and linkages between all of these. Information should have some predictive value, particularly if the purpose is to inform initiatives to address poverty and vulnerability. Several papers concerning management, particularly co-management, identify the significance of institutional support to successful management regimes (e.g. McGrath and Cardoso 2003), but more detailed analysis of institutional aspects is conspicuously absent from this symposium contributions.

Local communities themselves best express the importance of fisheries to livelihoods, not by external assessments based upon incomplete or inappropriate criteria (Coates 2002). Bush (2003), for example, points to the level of importance placed upon capture fisheries by rural communities in contrast to more aquaculture-focussed policies of government agencies. Relative importance should include the value of "safety net" aspects of fisheries and social and cultural values. In developing regions, inland fisheries are often regarded as an activity for the poor (e.g. Hossain *et al.* 2003) but can also be an activity for the more wealthy that can fuel economic differentiation (Bene and Neiland 2003). There is an urgent need for a better understanding how fisheries and their management contribute to, or are affected by, wealth differentiation (Hossain *et al.* 2003, Kaunda and Chapotoka 2003). This is particularly important when advocating 'community fisheries' and co-management. The high economic value of river fisheries in many developed regions should also not be discounted, nor the facts that people there also have their livelihoods.

Livelihoods are impacted by change, such as resource depletion (Oviedo 2003), water management schemes (Das 2003), access to resources, markets and economics (e.g. Hossain 2003) and institutional and legal transformation (e.g. Evans 2003). Targeting of management or investment interventions (e.g. van Brakel, Muir and Ross 2003) can be used to identify opportunities to improve livelihoods. This requires that stakeholders identify livelihood benefits (e.g. Bush 2003) and the use of fishers more as a source of management information (Poulsen, Hartman and Mattson 2003).

Current methods of information generation for "livelihoods" tend to focus on "socio-economic surveys" which can be expensive to conduct and difficult to interpret. Participatory approaches can provide improved quality of information but the results are often less preferred to "hard data" by policy makers. Official statistics, if available, tend to be based upon the former. The two approaches are not incompatible and a combination of both is often desirable. A key requirement with either is to clearly establish the objectives of the information generation exercise and how the information fits into the desired policy generation framework (Hirsch 2003).

BIODIVERSITY

Approximately 30 contributions to this symposium dealt explicitly, in part or in whole, with the subject of "biodiversity". Of these, 25 (83 percent) dealt exclusively with fish and two dealt with dolphins (Beasley 2003; Trujillo *et al.* 2003). Although this symposium deals with "fisheries", in most rivers, particularly in the tropics, other taxonomic groups are also very important including molluscs, reptiles, amphibia, crustacea and plants. The lack of attention to these and other taxonomic groups is a major problem. Even for fish, our cumulative knowledge of individual species is very limited. Darwall (2003) and Abell *et al.* (2003) both argue for a more broad based approach to biodiversity management and for greater recognition for the importance of other non-commercial taxa in supporting the ecosystems that maintain fisheries. Appreciation for the role of all taxa within the food webs upon which the fisheries are based must be integrated into management thinking for those fisheries. Although the debate continues, many people believe that complex, more speciose ecosystems are more stable than simplified systems. Managers should adopt the precautionary approach and manage fisheries to maintain species diversity.

There is a significant bias in “biodiversity” related papers to biological studies of species or communities. But the definition of “biodiversity” most widely used (ref. Convention on Biological Diversity) includes the concepts of both genetic diversity and ecosystem diversity as of equal status to “species” diversity. Two descriptive contributions directly further our knowledge of genetic diversity in river fishes (Hogan 2003; So and Volckaert 2003) and a number of others dealing with fish populations imply links to genetic diversity (e.g. Poulsen 2003). There appears to be a limited but growing interest in “ecosystem diversity” through the “ecoregion” (Abell *et al.* 2003) and “ecosystems” (Arrington and Winemiller 2003; Zalewski 2003) approaches. Environmental flows is a related partially ecosystems based approach (Arrington and Winemiller 2003; Saint-Paul 2003; Welcomme and Halls 2003). Most reviews confirm that it is loss of ecosystem diversity (and habitat area and quality) that is the main cause of the declines in both fisheries and biodiversity. Despite the progress being made, river fisheries science needs to more clearly target ecosystems as a basis for management. For example, although many authors recognise the need for more holistic (ecosystems based) approaches, few have presented convincing examples of how this has, or can be, achieved. In this process, care must be taken that management proposals based upon largely ecological criteria include adequate attention to relevant social and political considerations.

An analysis of the combination of “biodiversity” with other subjects at this symposium reveals the expected bias towards biology/ecology based approaches and a large proportion of contributions are purely descriptive. Less attention is paid to social, political, livelihoods and management aspects of biodiversity. Significantly, all papers that link biodiversity to livelihoods and social aspects of fisheries are based on examples from developing countries (Darman and Simonov 2003; Das 2003; Hand 2003; Haque 2003). This reflects the very different perceptions of the importance of biodiversity between developed and developing regions. Clearly, in developing regions and especially the tropics, biodiversity in rivers is a livelihoods (as opposed to primarily a “species conservation”) issue. River fisheries science needs to focus better on the social and political dimensions of biodiversity conservation and management in large rivers. Linkages between biodiversity and economic development (including livelihoods) should be further elaborated, particular as this may influence investment policies for biodiversity related initiatives in large rivers. Until this link is made clear it will be difficult to convince donors that funding for the conservation of biodiversity will also provide benefits to help alleviate poverty.

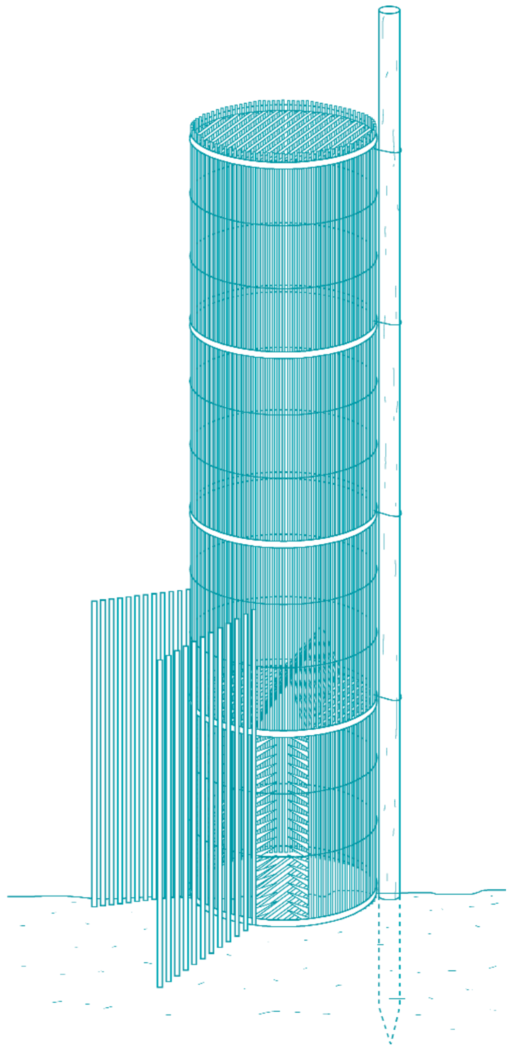
CONCLUSIONS AND RECOMMENDATIONS – A VISION FOR LARS 3

The utopian view of the status of river fisheries that should be reported at the next Large River Symposium (LARS3) would include their role in societies being fully acknowledged in policies and management, with fisheries, livelihoods and biodiversity all being sustained and improved - all fostered primarily through full participation of all stakeholders in the policy and management process, including information generation and those who depend most upon river resources, particularly the rural poor, empowered to influence management outcomes. Few would be optimistic that this will be fully achieved, but this symposium suggests that there is hope. Progress is being made on all these fronts. But how can changes to information, knowledge and policy processes help escalate this trend? The strongest argument is that fundamental changes to governance systems should stimulate the necessary adjustments.

River fisheries science can contribute by evolving in three major directions: better prioritisation of information needs for river fisheries, including fuller consideration of the political and governance processes under which information is generated and used, including clarified linkages between research and information objectives; by providing more and better ammunition to increase awareness of the importance of improved river management (and especially better identification and quantification of the importance of river fisheries to livelihoods and associated linkages with biodiversity); and by providing an improved understanding of the technical, biological, economic and social basis for improved management (and in particular, the development of improved and practical holistic approaches).

River fisheries science needs to make a significant shift from more classical, primarily biological, orientated research agendas. Recent moves towards more social, cultural and political considerations are welcome but there is still much to do. Neither should the social sciences be blind to the fundamental importance of river ecology. Barriers between disciplines need to be removed if a truly holistic research and management agenda is to develop. River fisheries scientists need to look beyond the narrow confines of the fisheries sector and in particular to focus on environmental, ecosystem and social management, including viewing fisheries within mixed livelihoods settings, as key requirements in their art. Improved water resources management requires fisheries to be fully engaged in relevant policy processes and to contribute information of use to other stakeholders (in particular articulating the social and economic values of fisheries and water requirements to sustain these benefits).

Improved information systems that lead to improved policies and management must be based upon efficient and effective communication strategies. This symposium demonstrates that river fisheries science is generating much relevant information. It is also interesting, when suitably presented, even to the non-specialist. But it is far from clear that this is being effectively communicated. We need the right information to be sent to the correct targets, in the most appropriate form, via the most appropriate channels. It is in this area that perhaps the most progress can be made.



REFERENCES

Abell R., Thieme M., & Lehner B. 2003. Ecoregion conservation for freshwater systems, with a focus on large rivers. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 2.* Food and Agriculture Organization & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/17. pp. 1-14.

Ahmed M.D.S., Hossain M.M. & Akhteruzzaman M. 2003. Floodplain gears of Bangladesh: A case study of Titas floodplain. *Abstract submitted to Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Cambodia, Mekong River Commission.*

Alonso J.C. 2003. Spatial and temporal pattern of the population structure and current state of fishing exploitation of the dourada *Brachyplatystoma flavicans*, Lichtenstein, 1819 along the system estuary-Amazonas-Solimões. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Arjjumend H. 2003. Displaced tribes set a model of participatory management of riverine fisheries: exploring the emergence of sustainable living aquatic resource management in Tawa river of Narmada valley, India. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Arrington A.A. & Winemiller K.O. 2003. Organization and maintenance of fish diversity in shallow waters of tropical floodplain rivers. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 2.* Food and Agriculture Organization & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/17. pp. 25-36.

Arthington A.H., Tharme R.E., Brizga S.O., Pusey B.J. and Kennard M.J. 2003. Environmental flow assessment with emphasis on holistic methodologies. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 2.* Food and Agriculture Organization & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/17. pp. 37-66.

Baird I.G. & Flaherty M.S. 2003. Beyond national borders: Links between an important Mekong River medium sized migratory carp fishery below the Khone Falls in southern Laos and bag net fisheries at stream mouths in northeast Cambodia. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Baran E., Makin I. and Baird I.G. 2003. Bayfish: A model of environmental factors driving fish production in the lower Mekong Basin. *Abstract submitted to Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Cambodia, Mekong River Commission.*

Batista V.S. 2003. Spatial and temporal distribution of the fishery resources exploited by the Manaus fishing fleet. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Beasley I. 2003. Abundance, distribution and conservation statues of the Irrawaddy Dolphin the inhabits of the Mekong River. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Béné C. & Neiland A.E. 2003. Contribution of inland fisheries to rural livelihoods in Africa: An overview from the Lake Chad basin areas. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 2.* Food and Agriculture Organization of the United Nations & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/17. pp. 67-78.

Bocking B., Link M.R., Nelson T. & MacKay K.T. 2003. Reinventing fisheries management in large river systems: Experience from cooperative research and management in western North American rivers. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Boivin T., Coates D., Werle D. & Baird J. 2003. Remote Sensing Applications for Information Generation and Monitoring of Large River Fisheries. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Brenner T., Buijse A.D., Lauff M., Luquet J.F. & Staub E. 2003. The present status of the river Rhine with special emphasis on fisheries development. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 1.* Food and Agriculture Organization & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/17. pp. 121-148.

Bush S.R. 2003. Comparing what matters with what is done: Fisheries and aquaculture in the Lao PDR. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission*.

Carney D. ed. 1998. *Sustainable Rural Livelihoods: What contribution can we make*? London, DFID.

Carvalho de Lima Á. & Araujo-Lima C. 2003. Spawning migrations of characiform fishes in relation to water quality in rivers of the Amazon. Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.

Catela A.C. 2003. The fishery in the south Pantanal, Brazil. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Coates D. 2002. Inland capture fishery statistics for South-east Asia: Current status and information needs. *RAP Publication 2002/11*. 115 p. Bangkok, Thailand, Regional Office for Asia-Pacific, Food and Agriculture Organisation of the United Nations.

Chen D., Duan X., Liu S. & Shi W. 2003. Status and management of fishery resources of the Yangtze River. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 1*. Food and Agriculture Organization of the United Nations & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/16. pp. 173-182.

Darman Y. & Simonov E. 2003. Amur/Heilong River Basin Initiative. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Darwall W.R.T and Vié J.C. 2003. Identifying important sites for conservation of freshwater biodiversity: Extending the species-based approach. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Das B.P. 2003. Socio economic issues of riverine fisheries in India: Impact of fish passes at barriers. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Dodge D.P. ed. 1989. *Proceedings of the international large rivers symposium*. *Can. J. Fish. Aquat. Sci. Special Pub.*, 106: 629 pp.

Evans P.T. 2003. Community fisheries development on the Tonle Sap Great Lake. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Fashchevsky B. 2003. Human impact on rivers in the Ponto-Caspian Basin and their fish. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 1*. Food and Agriculture Organization of the United Nations & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/16. pp. 183-198.

FAO. 1999. *Guidelines for the routine collection of capture fishery data.* Prepared for the FAO/Danida Expert Consultation. Bangkok, Thailand, 18-30 May 1998. *FAO Fisheries Technical Paper*. *No. 382*. Rome, FAO. 113pp.

Feunteun E., Boury P., Robinet T. & Boisneau P. 2003. Estimation of silver eel Anguilla anguilla L. production by large river systems: Collaboration between fishermen, scientists and decision-makers towards sustainable management of the resource. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Filipe A.F., Marques T., Seabra S., Tiago P., Ribeiro F., Moreira da Costa L., Cowx I.G. & Collares-Pereira M.J. 2003. Defining priority areas for fish conservation in riverine ecosystems. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission*.

Flotemersch J.E. & Blocksom K.A. 2003. Comparison of algal diatoms, benthic macroinvertebrate and fish sampling methods commonly used to assess condition of riverine ecosystems in the USA. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Friend R. 2003. Fisheries Data and Policy: Broadening the policy arena to inform decision-making. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Fuller B.W. 2003. Mediating apparently irreconcilable conflict - agricultural water use efficiency, CALFED, and California. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Gentes I.G. 2003. Water, power and ethnic conflict in the South Andean region. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Getahun A. 2003. Fish diversity and production in Ethiopian large rivers: Problems and prospects. Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.

Gopal B. 2003. State of degradation and approaches to restoration of floodplain rivers in India. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 2*. Food and Agriculture Organization of the United Nations & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/17. pp. 79-90.

Gurumaum S.D., Daimari P., Goswami B. & Choudhury M. 2003. Ecological status and fisheries of the rivers of north east India. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Halls A.S. & Welcomme R.L. 2003. Dynamics of river fish populations in response to hydrological conditions: A simulation study. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Haque M.M. 2003. Biodiversity and abundance of small indigenous fish species and their interrelation with the subsistence-level fishing livelihood in the Old Brahmaputra River, Mymensingh, Bangladesh. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Hirsch P. 2003. The politics of fisheries knowledge in the Mekong River Basin. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Hogan Z. 2003. New methods for the study of fish migrations in large rivers: Examples from the Mekong River Basin. Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.

Hossain M.M. 2003. Macro-zoobenthos an indicator of water pollution in the Karnafuli River-estuary, Bangladesh. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Hossain M.A., Parween S., Rahman M.H. & Mortuza M.G. 2003. Fish and fisheries of the major river system in the western part of Bangladesh in relation to fisher and socio-ecological sustainability. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Junk W.J. & Wantzen K.M. 2003. The flood pulse concept: New aspects, approaches, and applications - an update. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 2*. Food and Agriculture Organization & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/17. pp.117-140.

Kaunda E. & Chapotoka O. 2003. The conflict between poverty and river system management: The case study of Malawi, Southern Africa. *Abstract submitted to the Second International Symposium on the Management of Large*

Rivers for Fisheries. Phnom Penh, Mekong River Commission.

Kennard M.J., Marsh N.A., Pusey B.J. & Arthington A.H. 2003. Linking key attributes of the hydrological regime to ecological patterns and processes: Understanding relationships between fish and flow in an Australian sub-tropical river. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Koehn J.D. & Nicol S.J. 2003. A strategy to rehabilitate native fish in the Murray-Darling Basin, south-eastern Australia. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Laë R., Williams S., Malam Massou A., Morand P. & Mikolasek O. 2003. Review of the present state of knowledge of environment, fish stocks and fisheries of the River Niger West Africa. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 1.* Food and Agriculture Organization & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/16. pp. 199-228.

Lalèyè P., Chikou A., Ezin A., Philippart J.C. & Welcomme R. 2003. Fish and fisheries of the Oueme Delta, Bénin West Africa. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Lek S. & Brosse S. 2003. Modern modelling methods to predict fish communities in River. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Lerner M. 2003. Sesan Legal, Institutional and Policy Study. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Lewis W.M. Jr. 2003. Ecosystem function and the basis for fish production in the Orinoco river at its floodplain. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Lorenzen, K. & A.H. Arthington. 2003. Ecological basis for management and conservation. Session Review Paper. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 2.* Food and Agriculture Organization of the United Nations & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/17. pp

MacKay K.T., Bocking B., Link M.R. & Nelson T.C. 2003. Fisheries management in large river systems: Experience from cooperative research and management in western North American rivers. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Marsh N.A. & Kennard M.J. 2003. The importance of temporal scale in determining hydrology-ecology interactions. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

McGrath D.G., Cardoso A. & Sá E.P. 2003. Community fisheries and co-management in the Lower Amazon floodplain of Brazil. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the*

Management of Large Rivers for Fisheries Volume 2. Food and Agriculture Organization of the United Nations & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/17. pp. 207-222.

McGrath D.G. & Cardoso A. 2003. Co-Management of floodplain fisheries in the Brazilian Amazon. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Mojica J.I. & Galvis G. 2003. Present situation of the Magdalena river fisheries. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Olivier J.M. 2003. Scientific assessment of the Rhone river rehabilitation project. Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.

Oviedo A. & Ruffino M.L. 2003. Addressing common demands of community fisheries in the Brazilian Amazon. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Pacini N. 2003. Water for fish: Status and trends in the degradation of inland aquatic resources. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Parsamanesh A. & Kashi M. 2003. Catch/effort estimation in Karoon River Shooshtar-Ahvaz, Khoozestan Province, South West Iran. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Parveen S. & Faisal I.M. 2003. Open-water fisheries in Bangladesh: A critical review. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Payne A.I., Sinha R., Singh H.R., & Huq S. 2003. A review of the Ganges Basin; its fish and fisheries. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 1.* Food and Agriculture Organization of the United Nations & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/16. pp. 229-252.

Petrere M. Jr. 2003. Present status of the commercial fisheries in the West Amazon Basin. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Pettitt B. & Sim B. 2003. Conflict, governance and livelihoods: The challenge of community fisheries on The Tonle Sap, Cambodia. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Pouilly M. & Rodríguez M.A. 2003. Determinism of fish assemblage structure in neotropical floodplain lakes: Influence of whole-lake and supra-lake conditions. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 2.* Food and Agriculture Organization & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/17. pp. 243-266, Poulsen A.F. 2003. Fish movements and their implication for river basin management in the Mekong River Basin. *Abstract submitted to Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Cambodia, Mekong River Commission.*

Poulsen A.F. Hartman W. & Mattson N. 2003. The role of local communities in the generation of fisheries information based on the ecosystem approach. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Pusey B., Burrows D. & Arthington A.H. 2003. The translocation of recreationally desirable fishes is detrimental to the maintenance of local biodiversity: Sleepy cod *Oxyeleotris lineolatus* and other translocated species in the Burdekin River, Australia. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Quirós R. 2003. The La Plata River Basin international basin development and riverine fisheries. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 1.* Food and Agriculture Organization of the United Nations & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/16. pp. 253-272.

Rai A.K. 2003. Potential of indigenous riverine fish species in Nepal. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Ruamrudee P. 2003. Population biology of redtail barb *Discherlodontus asmeadi* Fowler, 1937 in the Sirinthon Reservoir, Ubon Ratchathani Province. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Ruffino M.L. 2003. Participatory management of fisheries in the Brazilian Amazon. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Ruffino M.L. & Dalley B. 2003. Amazon floodplain natural resources management. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Saint-Paul U. 2003. Fisheries ecology of Amazonian inundated forests. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Scanlon J. 2003. Legal aspects of environmental flows for healthy river systems. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Schiemer F., 2003. Ecological status and problems of the Danube River and its fish fauna: A review. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 1.* Food and Agriculture Organization of the United Nations & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/16. pp. 273-300.

Schramm H.L. Jr. 2003. Status and management of Mississippi River fisheries. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 1.* Food and Agriculture Organization of the United Nations & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/16. pp. *301-334.*

Sripatrprasite P. & Kwei Lin C. 2003. Stocking and recapture of freshwater prawn *Macrobrachium rosenbergii* in a run-of-river type dam Pak Mun Dam in Thailand. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Slynko Y.V. 2003a. Fish biodiversity of the Amur River. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Slynko Y.V., Kiyashko V.I. & Yakovlev V.N. 2003. Fish biodiversity in Volga River. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

So N. & Volckaert F.A.M. 2003. Preliminary results on the genetic diversity and structure of the migratory catfish Pangasius bocourti in the Cambodian Mekong River. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Sridhar M.K.C. 2003. River Niger: Neglect of degradation and prospects for recovery. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Suntornratana U. 2003. Fisheries information of the Songkhram River, North East Thailand. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Taber Hand R. 2003. Protein, fat and carbohydrate food security maintenance in the Mekong Basin: Racing for rice while fumbling with fish. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Trujillo F., González M., Galindo A., Diazgranados M. & Fuentes L. 2003. Interactions between River dolphins *Inia geoffrensis* & *Sotalia fluviatilis* and fisheries in the Amazon and Orinoco Basins. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Van Brakel M.L., Muir J.F. & Ross L.G. 2003. *Modelling for aquaculture related development, poverty and needs in the Mekong Basin.*

Van Zalinge N., Degen P., Pongsri C., Nuov S., Jensen J.G., Nguyen van Hao & Choulamany X. 2003. The Mekong River system. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 1.* Food and Agriculture Organization of the United Nations & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/16. pp. 335-358.

Van Zalinge N., Loeung D., Pengbun N, Sarkkula J. & Koponen J. 2003. Mekong flood levels and Tonle Sap fish catches. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Vaz M.M. & Petrere M. Jr. 2003. Yield per recruit of the pacu, *Piaractus mesopotamicus* Holmberg 1887 Pisces: Characidae in the Pantanal Mato-grossense, Brazil. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Vieira E.F., Fabré N.N. & Araújo L.M.S. 2003. Population structure of jaraquis *Semaprochilodus spp.* Schomburgki, 1841 in central Amazon hydrographic basin rivers. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

Welcomme R.L. 1999. A review of a model for qualitative evaluation of exploitation levels in multi-species fisheries. *Journal of Fisheries Ecology and Management*, 6: 1-20.

Welcomme R.L. & Halls A. 2003. Dependence of tropical river fisheries on flow. In R.L. Welcomme & T. Petr, eds. *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries Volume 2.* Food and Agriculture Organization of the United Nations & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/17. pp. 267-284.

Zalewski M. 2003. Ecohydrology - new conceptual tool for restoration and sustainable use of fisheries resources in rivers. *Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.*

THE PRESENT STATUS OF THE RIVER RHINE WITH SPECIAL EMPHASIS ON FISHERIES DEVELOPMENT

T. Brenner [1] A.D. Buijse[2] M. Lauff[3] J.F. Luquet[4] E. Staub[5]

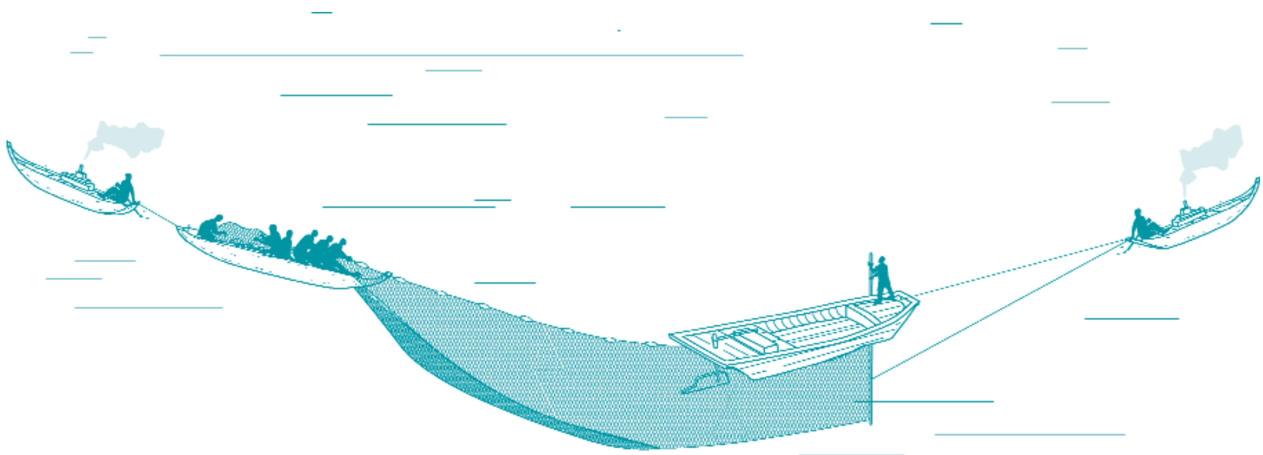
[1] Ministry of Environment and Forestry Rheinland-Pfalz, P.O. Box 3160, D-55021 Mainz, Germany

[2] Institute for Inland Water Management and Waste Water Treatment RIZA, P.O. Box 17, NL 8200 AA Lelystad, The Netherlands

[3] Administrations des Eaux et Forets, Boite Postale 2513, L 1025 Luxembourg

[4] Conseil Supérieur de la Peche, 23, Rue des Garennes, F 57155 Marly, France

[5] Swiss Agency for the Environment, Forests and Landscape, CH 3003 Bern, Switzerland



ABSTRACT

The Rhine basin (1 320 km, 225 000 km^2) is shared by nine countries (Switzerland, Italy, Liechtenstein, Austria, Germany, France, Luxemburg, Belgium and the Netherlands) with a population of about 54 million people and provides drinking water to 20 million of them. The Rhine is navigable from the North Sea up to Basel in Switzerland and is one of the most important international waterways in the world.

Key words: Rhine, restoration, aquatic biodiversity, fish migration

Floodplains were reclaimed as early as the Middle Ages and in the eighteenth and nineteenth century the channel of the Rhine had been subjected to drastic changes to improve navigation as well as the discharge of water, ice and sediment. From 1945 until the early 1970s water pollution due to domestic and industrial wastewater increased dramatically. Since then many measures have been taken by the riparian states, communities and by industry to reduce nutrients and pollutants. The total phosphorus inputs were reduced by 65 percent compared to 1985, the nitrogen inputs only declined by 26 percent.

Due to the improvement in water quality the number and abundance of the majority of fish species have increased and the Atlantic salmon (*Salmo salar* L.), which was formerly extinct, not only occurs in some tributaries but also reproduces naturally. In total over 60 species are present in the river basin. From its indigenous ichthyofauna of 44 species only Atlantic sturgeon (*Acipenser sturio* L.) has not been seen with certainty during the last decade. Most species other than the migratory species are self-sustainable, but the overall species composition is skewed towards a few ubiquitous ones, such as roach (*Rutilus rutilus* (L.) and bream (*Abramis brama* (L.). Twenty exotic species are present but nowhere dominate the fish community. New species (e.g. *Abramis sapa* Pallas, *Proterorhinus marmoratus* (Pallas) now appear more frequently as they reach the Rhine through the Rhine-Main-Danube canal. The commercial fishery is based mainly on eel (*Anguilla anguilla* (L.) and pikeperch (*Stizostedion lucioperca* (L.). Exploitation of migratory fish species is not remunerative and in the case of salmonids their fishing is banned. However, there is a flourishing recreational fishery. The “Salmon 2000 Programme” started by the Rhine Ministers of Environment under the coordination of the International Commission for the Protection of the Rhine (ICPR) has now been integrated in the programme on the sustainable development of the River Rhine “Rhine 2020” whose main objectives are ecology restoration, flood prevention and groundwater protection. Possibilities for the restoration of the River Rhine are limited by the multipurpose use of the river for shipping, hydropower, drinking water and agriculture. Further recovery is hampered by the numerous hydropower stations that interfere with downstream fish migration, the poor habitat diversity, the lack of lateral connectivity between main channel and floodplains and the cumulative unknown effects of thousands of synthesised components in water.

This paper describes the different national and international programmes for the restoration of the River Rhine, its tributaries and measures for the reintroduction of the Atlantic salmon such as stocking, habitat enhancement and construction of fish passages. The salmon has fulfilled a flagship role for a general improvement of the Rhine. The most significant positive recent development is the EU Water Framework Directive: EU member states are required to compile river basin management plans and rivers should have a good ecological status by the year 2015.

INTRODUCTION

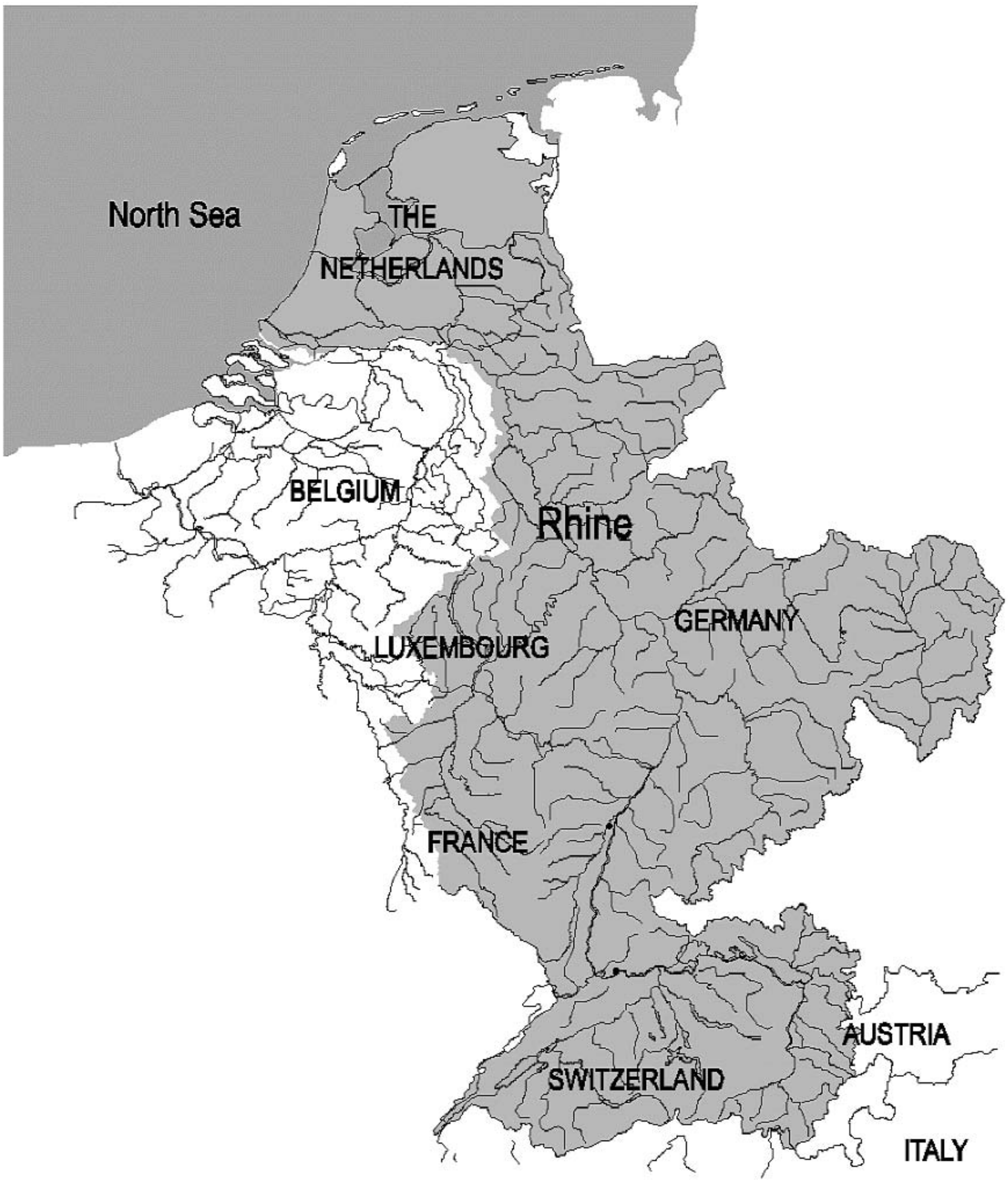
The River Rhine is 1 320 km long and flows from the Swiss Alps through Switzerland, France, Germany and the Netherlands to the North Sea. The 225 000 km^2 catchment area of the Rhine extends over parts of Switzerland, Italy, Austria, Liechtenstein, Germany, France, Belgium, Luxembourg and the Netherlands and is populated by about 54 million people (Table 1 and Figure 1). A number of industrial centres such as Basel, the Ruhr region and Rotterdam are situated along the Rhine, formerly a wild stream, meandering through a wide floodplain, today a vital shipping route. Each day approximately 450 ships pass the Rhine at Lobith - Bimmen. In the year 2000 the transport on the river at the Dutch – German border was about 162 million tonnes and is expected to rise up to approximately 199 million tonnes in 2015 (Wetzel 2002). The river is also of importance for the water supply for agriculture and the drinking water provision for about 20 million people. Twenty-one hydropower plants on the Rhine mainstream have a total installed capacity of 2 186 MW. River Rhine has suffered severely from stream regulation and pollution.

The first documented human influence on the river with regard to canal construction to regulate the discharge took place in the Roman era. The construction of dykes on floodplains began in the early Middle Ages with the development of agriculture. However,

Table 1: Hydrological characteristics of the River Rhine

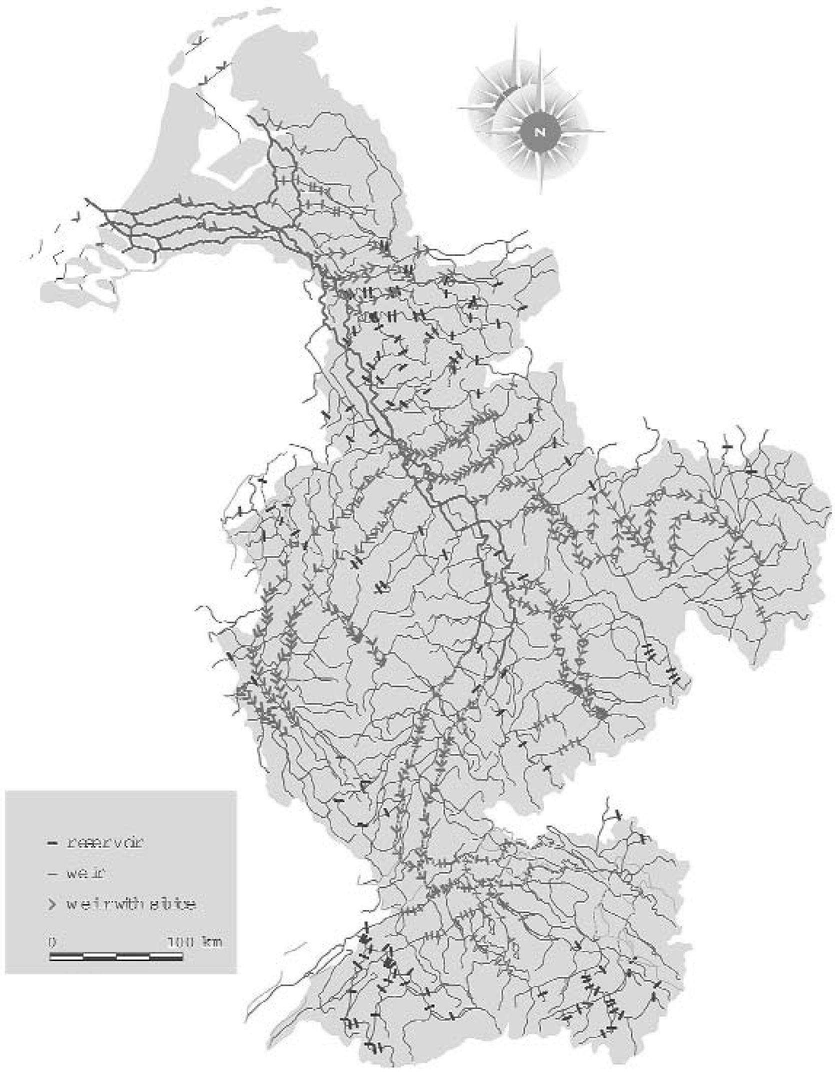
Total drainage area (km²)	185,000	225.000 (including "Alpine Rhine")
Total length (km)	1,250	1.320 (including "Alpine Rhine")
Mean discharge (m²/s)	2,280	**
Minimal discharge (m²/s)	590	**
Maximum discharge (m²/s)	11,800	**

** at Rees (Dutch border)



■ **Figure. 1.** The catchment area of the River Rhine until the eighteenth century the main channels were meandering and many river islands, floodplain forests and snag habitats were still present. Later on, the need for timber resulted in the disappearance of floodplain forests, whereas the wood was removed to facilitate shipping. River regulation began in the nineteenth century and was completed in the twentieth century with a series of weirs, locks and dams to control flooding, to produce hydropower and for shipping (Figure 2). The decline in water quality due to uncontrolled industrial and domestic discharges culminated in serious problems with drinking water and an overall degradation of the Rhine ecosystem from 1950 to 1970, when dissolved oxygen concentration became extremely low (Lelek 1989). As a result of the treatment of wastewater discharges during the 1970s – 1980s, dissolved oxygen levels returned to normal but nutrients, mainly nitrogen, still reach the river from diffuse agricultural sources. While concentrations of several heavy metals have been reduced over the last few decades, the sediments of the river forelands are still strongly contaminated and micropollutants are presumably the cause for the reduction in the bottom fauna (van den Brink, van der Velde, Buijse *et al*. 1996).

One can distinguish six stretches of the River Rhine:
The *Alpine Rhine* from its source in the Alps to Lake Constance.



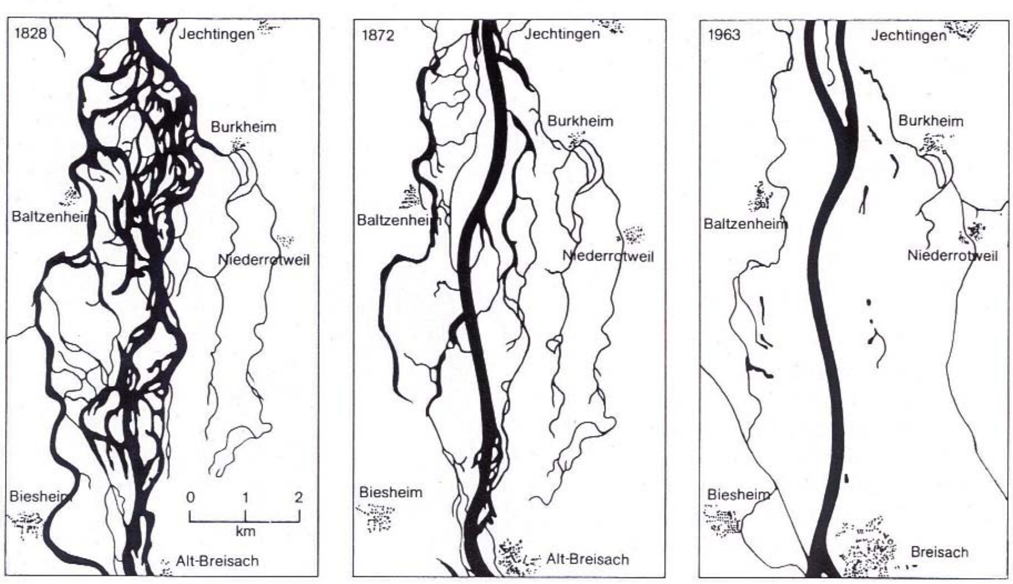
■ **Figure 2.** The Upper Rhine at Breisach (From ICPR 1991)

The *High Rhine* from the outflow of Lake Constance to approximately 170 km downstream at the city of Basel (This is the beginning of what is generally referred to be the Rhine). This stretch still has a riverine character despite having 11 dams with hydropower stations, as well as four dams upstream of the river Aare (Table 2).

Table 2: The most important tributaries of the River Rhine

Tributary	Length
Mosel (France and Germany)	550 km
Main (Germany)	524 km
Neckar (Germany)	370 km
Aare (Switzerland)	295 km
Lippe (Germany)	437 km
Ruhr (Germany)	235 km
Ill (France)	217 km

The *Upper Rhine* from Basle downstream to the city of Bingen. This was the most diversified part of the Rhine in the past and it is also known as the “furcation zone”. Swift stretches extend over a length of about 190 km. The canalisation of the *Upper Rhine*, the so-called Tulla rectification, was carried out between 1817 and 1876 and had tremendous environmental consequences (Figure 3). As a result, the length of the Rhine in this stretch had been shortened to 81 km (23 percent of total length). Furthermore, 2218 islands that existed until 1825 disappeared. The once braided river system with islands, sand and gravel flats – a highly diverse system of various habitats in a dynamic environment – was transformed into a petrified canal with high current velocities. To counterbalance erosion and sedimentation 10 dams were built, with hydropower plants and with locks for navigation. For safety reasons and easier navigation, the main river channel has a bypass, which is an artificial canal on the French territory (between km 173 and km 227). The hydropower plant in Kembs can take a maximum discharge of 1 400 $m^3\ s^{-1}$. The remaining water, with a mean discharge of 91 $m^3\ s^{-1}$, flows through the former river channel, the so-called “Rest-Rhine”. The minimum discharge in the summer period is 20 $m^3\ s^{-1}$ and the maximum is about 256 $m^3\ s^{-1}$. The first dam is about 700 km from the North Sea at Iffezheim and has been equipped in 2000/2002 with one of the largest fish passage structures in Europe. It is a modified vertical slot pass optimised by French and German fishery and hydraulic engineering experts. A fish pass for the next dam upstream at Gambsheim will be constructed in 2003/2004. The main tributary in this stretch on the right side is the dammed and navigable Main River, which is connected to the Danube system by the Rhine-Main-Danube canal. The River Ill flowing into the Rhine near Strasbourg is the most important French river in the Alsace region.



The Upper Rhine at Breisach:
1828: before the river development, 1872: after the Tulla realignment and 1963: after further canalization.

■ **Figure 3.** The Upper Rhine at Breisach (From ICPR 1991)

The *Middle Rhine* with its main tributary the Mosel River, also regulated, is located approximately midway between the 510 and 640 km mark. This stretch was declared in 2002 a world heritage site by UNESCO because of its beautiful landscape.

The *Lower Rhine* passes through the most populated and industrialized part of Germany before it flows into the Netherlands (Figure 3). In the Netherlands the Rhine enters a lowland area where it forms a river delta before it flows into the North Sea.

The *Delta* of the river has three branches and covers 25 000 km^2, which corresponds to 67 percent of the total surface area of the country. The River Waal/Merwede is the main branch discharging 65 percent of the water; the Lower Rhine-Lek discharges about 21 percent and the River Ijssel discharges only 14 percent. Three weirs regulate the Lower Rhine-Lek. A fish pass could be installed at the first weir in Driel. The two other weirs in Amerongen and Hagestein will be equipped with fish passes in 2003/2004. The major part of the discharge from the Waal, the Lower Rhine-Lek and the Meuse converges in the Rhine-Meuse delta and flows from there into the North Sea from various points. The most important are the Haringvliet sluices and the Nieuwe Waterweg. The barrages in the Haringvliet sluices have a discharge programme that ensures that the river discharge of the Nieuwe Waterweg is maintained at about 1 500 $m^3 s^{-1}$ to prevent saltwater penetration. Since most Dutch arms are strongly regulated by huge dams, free entrance for migrating fish species from the North Sea to the Lower Rhine estuary is only possible via the Nieuwe Waterweg near Rotterdam, a highly industrialised area with many harbours. All Rhine branches in the Netherlands are canalized and there is no natural river delta left. Since the closure of the Afsluitdam in 1932 and the Haringvliet in 1970 the tidal influence in the river estuary is very much reduced and the Haringsvliet-Holland Diep and Lake Ijssel are managed as freshwater lakes. This was part of a large plan to protect the densely populated delta of the Rhine, Meuse and Scheldt against flooding, to control the watersystem and improve the supply of fresh water. But this has also caused severe ecological damage. In the near future the Dutch government wants to partially open the Haringvliet sluices, to be followed up by a gradual opening of the gap. It is expected that these measures will improve the estuarine ecosystem. Initial experiments indicate that the fish migration is improved by partial opening of the barrier. Besides the barriers separating the river from the sea, there are no obstacles for fish migration in the Waal and Ijssel.

INTERNATIONAL REHABILITATION PROGRAMMES

International Commission for the Protection of the Rhine

The International Commission for the Protection of the Rhine against Pollution (ICPR; IKSR in German) was initiated by the Netherlands in the 1950s because of the concern over pollution of the Rhine and its implications for the drinking water supply. The ICPR started as a common forum of the member countries bordering the Rhine: Switzerland, France, Germany, Luxembourg and the Netherlands for periodical meetings and the formulation of pollution control agreements. On 1 November 1986, 10 to 30 tons of plant-protecting agents were discharged in fire-fighting water into the Rhine at the Sandoz plant in Schweizerhalle near Basel (Lelek 1989). This resulted in a massive fish kill, mainly of eel, of which an estimated 200 tonnes died. With this accident the extent to which the Rhine ecosystem was endangered became apparent and this stimulated the ICPR to promote an international river restoration plan called the Rhine Action Programme “Salmon 2000” (IKSR 1987; Brenner 1993). It has four goals:

- To create conditions that enable the return of higher trophic level species such as salmon;
- To protect the water quality of the Rhine to ensure it as a source of drinking water;

- To improve the sediment quality in order to enable the use or disposal of dredged material without causing environmental harm;
- To improve the North Sea quality in accordance with other measures aiming at the protection of this marine area.

Over the past two decades a gradual improvement of the quality of Rhine water has been achieved through close international cooperation. However, improving the water quality is not enough for creating a viable river ecosystem. Geomorphological aspects are also considered essential for ecological rehabilitation of the regulated Rhine and the International Commission for the Protection of the Rhine has developed the Ecological Master Plan to improve the ecosystem of the river (ICPR 1991).

Habitat diversity along the Rhine shows considerable deficits. Some stretches of the originally freely flowing Rhine and its numerous tributaries, such as the Mosel, Main and Neckar, have been turned into a series of impoundments. Numerous engineering measures along the main channel of the Rhine and of almost all its tributaries have fundamentally changed the hydrological and morphological conditions. More than 85 percent of the floodplains have been cut off from the Upper and Lower Rhine leading to a considerable loss of habitat and of animal and plant species typical of the river. The implementation of the Ecological Master Plan aims at counterbalancing the impacts.

The most important targets defined in the Ecological Master Plan for the Rhine are the restoration of the main stream as the backbone of the Rhine ecosystem and its main tributaries, their functioning as a habitat for migratory fish and preservation and protection, the improvement and extension of areas of ecological importance along the Rhine and in the Rhine valley to provide suitable habitats for autochthonous plant and animal species. These measures should allow the return of migratory fish species such as Atlantic salmon and the restoration of the connection between the river channel and the bordering riparian zones and floodplains. Furthermore, the aim of preservation and restoration is to increase the diversity of indigenous animals and plants, to increase spawning and nursery grounds, to create self-sustaining food chains and to create areas of refuge in case of large-scale contamination (Schulte,Wülwer-Leidig 1994). Since the adoption of this plan, numerous projects and studies have been carried out to improve fish migration (e.g. on the rivers Lek, Sieg, Ahr, Saynbach, Rhine at Iffezheim, Ill, Aare) and to restore spawning and feeding grounds in the Rhine and its tributaries. The results of the Rhine Action Programme in water quality, hydrology and ecology have been published (Weidmann and Meder 1994; Ministerium für Umwelt und Forsten 1996; ICPR 1994; IKSR 1999 a; IKSR b).

The most relevant present activities of the ICPR comprise the action plan for flood defence. Until 1993 floods, including flood-warning systems, were considered to be a local problem. The flooding of 1993 and 1995 on the rivers Rhine, Mosel and Meuse brought this topic to international interest. Dykes were at risk of bursting in the Netherlands and several hundred thousand people were evacuated. The damage was estimated to be several billion US dollars.

In January 1998 the Rhine Ministers adopted the “Action Plan for Flood Defence for the River Rhine”, that was aimed at the improvement of precautionary flood protection. This plan defines four action targets: (1) Reduce damage risks; (2) Reduce flood levels; (3) Increase awareness of flooding and (4) Improve the system of flood forecasting (Rother 2002, Conversion of Forecasts into Warnings; unpublished manuscript). The Action Plan will be implemented within the next 20 years. The reduction of damages by up to 10 percent is expected to be achieved by the year 2005 and up to 25 percent by 2020 (ICPR 1998).

The International Commission for the Protection of the Rhine (ICPR) produced an inventory of measures undertaken and underway for restoration and conservation of the Rhine (IKSR 2001). Measures for the improvement of the ecosystem include, flood prevention, water quality and ground water conservation. The measures with the regard to the improvement of the ecosystem are specified for the top of the catchment and for the Upper, Middle and Lower Rhine. Among the measures is the lowering of summer dykes (> 20 km^2 per section), reactivation of dammed old river branches and connection of floodplains with the main stream (>25 km^2 river branches, additional dredging is included), construction of fish passes at the existing power stations and dams (in the main stream and on the tributaries which are part of the diadromous-fish programme), nature improvement of more then 3 500 km of tributaries.

The programme of sustainable development of the Rhine River “Rhine 2020-programme for Sustainable Development of the Rhine” succeeds the successful “Rhine Action Programme” and is coordinated by the International Commission for the Protection of the Rhine (ICPR). The focal points of the future Rhine protection policy are: further improvement of the Rhine ecosystem, improvement of flood prevention and protection and groundwater protection. The execution of the EU Water Framework Directive will assist with the implementation of the essential parts of the programme “Rhine 2020”. Continued monitoring of the state of the Rhine and further improvement of water quality remain essential. The activities include the Rhine ecosystem improvement, restoration of the former habitat connectivity and of the up- and downstream fish migration from Lake Constance to the North Sea, as well as ecological enhancement of the tributaries as mentioned in the Programme on Migratory Fish. The programme “Rhine 2020” was drafted in an open dialogue among the Rhine bordering countries. Participating in the discussions were groups representing nature protection, flood protection, industry, agriculture, navigation and drinking water supply. There is great support for acceptance of the ICPR programme. Within the framework of this holistic approach monitoring of the progress is an essential part of the programme.

More than 45 individual flood prevention control activities are currently underway or in the planning phase between Basel and the Netherlands. Important retention areas have been created along the Upper Rhine, e.g. polders at Moder, Altenheim, Daxlander Aue, Flotzgrün, Strasbourg, an agricultural weir at Kehl and specific management of the hydroelectric power plants. On behalf of the ICPR and with reference to the EU Water Framework Directive a feasibility study for the restoration of the ecological connectivity for the Upper Rhine between Iffezheim and Basel and its tributaries is in progress. A preliminary report (October 2002) includes considerations of a possibility to reactivate this natural stretch of the Rhine. The first phase of this study is a review of the existing data and identification of goals which should be achieved regarding the ecological connectivity for individual fish species. The second phase should result in specific recommendations (Bericht 2002).

WATER FRAMEWORK DIRECTIVE OF THE EUROPEAN UNION

The EU Water Framework Directive was put into force on 22/12/2000 after more than 10 years of drafting and negotiations among the member states, Non-Governmental Organizations and numerous other stakeholders. The directive sets a common framework within which Member States must work to protect and enhance all natural surface, ground, coastal and estuarine waters and aims to achieve good water status in 15 years. Regulated water bodies have to be developed to their ecological potential. Furthermore, under this Directive, member states have to identify all the river basins situated within their national territory and assign them to the individual river basin districts. River basins covering the territory of more than one member state will be assigned to an international river basin district. For surface waters, the definition of ‘good’ is based on a new concept of ‘ecological quality’, taking into account biology, chemistry and their physical features. In this context, monitoring of water quality and its ecological condition is a key requirement. According to the timetable to the end of 2006 monitoring programmes have to be operational as a basis for the water management. Benthic invertebrates, fish and aquatic macrophytes are most frequently used as ecological indicators and were selected as indicators of the ecological status of rivers in the EU Water Framework Directive (European Union 2000). These measures coincide with the pre-existing monitoring programmes of the ICPR.

IRMA: Interreg-Rhine-Meuse-Activities

The EU funded project IRMA, “Interreg-Rhine-Meuse-Activities” for the improvement of flood prevention along the rivers Rhine and Meuse. The project was set up to finance a joint flood control programme within the catchment areas of the rivers Rhine and Meuse with approximately 191 000 km^2 and with 60 million inhabitants. Besides the EU member states, Switzerland is also participating in this programme on a project basis. As defined by the EU the main objective of the IRMA programme is:

“To prevent damage caused by floods to all living creatures and to important functions of the catchment area of the rivers and therefore to create a balance between the activities of the population in the areas, the socio-economic development and sustainable management of the natural water resources”.

This main objective combines three important elements:

- water management
- spatial planning
- damage prevention

Taking these elements into consideration, water should be retained in the catchments as much as possible. The rivers should have space to discharge and high water should have the opportunity to flow into retention areas and floodplains. The awareness of high water must be raised, knowledge must be improved, legislation drafted and favourable conditions created. The spatial planning, water management and risk management must be integrated into one policy concept in order to prevent flood damage.

By the end of 1999, when the committing period ended, 153 projects were approved with a total EU contribution of 141 million Euro as IRMA grants. National counterparts contribute approximately 278 million Euro. The total cost of the programme amounts to about 419 million Euro. The programme has improved cooperation among the member states in spatial planning, water management and damage prevention. All measures focus on the creation; restoration and preservation of the former overflow areas/retention basins and infiltration. Besides cooperation and knowledge transfer, the IRMA programme has produced a number of quantifiable indicators.

The projects will reduce the peak discharges by 0.5 percent to 20 percent and the maximum flood water level by lowering the maximum water levels to approximately 140 mm on average (2 mm to 1 200 mm). The serious floods in 1993 and 1995 resulted in a policy decision named “Room for the Rivers”. Following this concept the floodplain area will increase by approximately 215 km^2 and including this 368 km^2 of potential retention areas in the entire catchment of the rivers Rhine and Meuse are being restored. A total of 103 kilometres of previously straightened stretches of rivers and tributaries are subject of a re-meandering and re-development projects. Approximately 215 million m^3 of additional retention capacity is expected to be created, the bulk of this being along the Rhine, e.g. more than 60 million m^3 will become available along the Upper Rhine.

In the Netherlands the “Room for the Rivers” focuses predominantly on excavation of floodplains and retention areas in the hinterlands. The floodplains, however, contain diffuse contaminated sediments, a heritage of the twentieth century. The total amount of contaminated soils is estimated at 50-80 million m^3, with high levels of HCB, PCBs, DDT, PACs, Hg, Cu, Zn and As. Since the mid-1990s the focus of water management was directed towards water quantity while before that it was mostly water quality that was addressed.

Floodplain lakes

Floodplains contain a large number of water bodies, which have originated from spontaneous diversion of streams (former meanders, lakes with a permanent open connection with the main channel, oxbow lakes), from dyke bursts in the past (break-through lakes) and more recently from sand, gravel and clay extraction (pits). Depending on geomorphological and hydrological situation and on seasons these floodplain water bodies are subject to a variety of hydrological regimes. When they are connected to the river by flooding river channel fish may freely enter floodplains.

Secondary channels

Large temperate rivers have experienced dramatic environmental changes that have resulted in a loss of some fish species. But due to their dynamic nature, rivers and streams have shown a remarkable capacity for recovery. Following the water quality improvement, a gradual increase in species richness in the Rhine was noted during the 1980s. Presently, however, ecological improvement is stagnating, indicating that restoration measures must not only address water quality improvements. This stagnation is considered to be due to the poor habitat diversity that presently exists in these regulated rivers. In order to enhance the heterogeneity of aquatic biotopes and biodiversity of the aquatic fauna and flora the reconnection of abandoned channels to the main channels has been proposed.

One possibility for restoration of riverine biotopes is to create permanently flowing channels on the floodplain. Such channels can make a valuable contribution to the ecological rehabilitation of rivers. However, they have to be fitted into the landscape without affecting existing interests such as shipping and protection against flooding. Such channels have been established for example along the Upper Rhine in Leimersheim and along the Waal River, the main branch of the Lower Rhine, where two secondary channels were created in 1994. The results of a 5 year monitoring programme show that excavated secondary channels function as a biotope for riverine fish, including the more demanding rheophilic species (Simons *et al*. 2001).

Floodplain development

The floodplains along the main channel of the Rhine are normally enclosed by a low summer or minor dyke and a high winter or major dyke. The summer dykes enable agriculture on the floodplains and the winter dykes prevent the hinterland from flooding. Due to the presence of these dykes, the floodplains are at present separated from the main channel and the typical and most important aquatic-terrestrial transition zone has been lost.

However, the flood plains of the Rhine in the Netherlands have several hundred relatively large water bodies (1 – 200 ha) such as gravel pits. Several water bodies are connected with the river. Some water bodies are inundated only during winter and spring and are isolated from the main channel whereas others are inundated only at high water floods.

In the Netherlands, in 1989 river restoration started by connecting permanently water bodies on the floodplains to the main channel. At several locations of the floodplains, secondary channels were dug and isolated backwaters were connected with a downstream opening to the main channel. Only a few years after their creation, secondary channels provided nursery areas for rheophilic cyprinids. Connectivity of a water body with the main channel and the presence of flowing water are important factors for the structure of the young-of the-year (YOY) fish community in floodplain water bodies (Grift *et al*. 2001).

Spawning conditions for especially the rheophilic cyprinids (e.g. *Aspius aspius* (L.), *Leuciscus idus* (L.), B*arbus barbus* (L.), *Gobio gobio* (L.) have been declining dramatically. At present the eurytopic species *Abramis brama* (L.), *Blicca bjoerkna* (L.), *Rutilus rutilus* (L.), *Alburnus alburnus* (L.) and *Stizostedion lucioperca* (L.) dominate the riverine fish community.

Therefore, the development and restoration of floodplain waters offers increased habitat diversity for fish and benefits recruitment of fish larvae (Freyhof *et al*. 2000; Grift 2001). In a pilot study of 14 water bodies on the floodplains of the Lower Rhine 20 species were caught (Buijse and Vriese 1996).

The most important floodplains in Germany are at the Upper Rhine (Dister 1991), such as Rastatt (1800 ha), Kühkopf (2800 ha) and the Lampertheimer Rhine (500 ha). On the German Lower Rhine is the Xantener Altrhein (600 ha). The fish fauna of important spawning sites in different types of water bodies in the inundation area of the Upper Rhine between Philippsburg (km 388) and Mannheim (km 412) was studied by Gebhardt (1990). Inundation areas provide habitats for a variety of fish species, many of which spawn only there.

Aquatic biodiversity

Van den Brink *et al*. (1996) discusses the diversity of aquatic biota in the Lower Rhine. The present species richness in the main channels is still relatively low, despite major water quality improvements. Although the present biodiversity has vastly improved when compared with the situation a few decades ago, it is evident that many species are eurytopic, including many exotics. Further biodiversity recovery is hindered because of river regulation and normalization, which have caused the deterioration and functional isolation of main channel and floodplain biotopes. The importance of connectivity differs among the aquatic taxa. The authors conclude that floodplain lakes contribute significantly to the total biodiversity of the entire riverine ecosystem. The redevelopment of active secondary channels is required to restore the most typical riverine habitats and biota.

BIOLOGICAL MONITORING PROGRAMMES

National and international monitoring programmes

National (e.g. Bakker *et al*. 1998) and international (IKSR 2002 a, 2002c) monitoring programmes show the trends in the physical, chemical and ecological state of water bodies.

Aquatic macrophytes

The present diversity of aquatic macrophytes in the main channels of the Rhine is rather poor as compared with the former situation or with the present diversity in floodplain lakes. At present, about 70 percent of the species recorded have been found only in the floodplain lakes. The other 30 percent can be found both in the main channel and floodplain lakes biotopes. Although the historical data are scarce, it can be concluded that many species have disappeared or became rare. Deterioration of aquatic macrophytes in this regulated river is probably caused by increased river dynamics, e.g. larger differences between summer and winter water levels, higher stream velocities and a higher frequency of summer spates. The reduced number of oligo- and mesotrophic species and an increase in the eutrophic ones may indicate an increase in eutrophication. The number of exotic aquatic macrophytes in the Rhine and its floodplains is low.

Aquatic macroinvertebrates

During the latest surveys for the ICPR “Rhine 2020” Programme more than 300 species or higher taxa were recorded. Most of the species occurred in the Higher Rhine and in the southern Upper Rhine. The number includes 28 species or higher taxa of neozoa (exotics). Ship canals connecting the Rhine with the Rhone, Ems and Danube rivers enable the migration of aquatic fauna between these rivers, e.g. the invasion of the amphipod *Corophium curvispinum* from the Caspian Sea and also influencing the changes in the density of zebra mussel (*Dreissena polymorpha*) on the stones. The invasions are related to increases in salinity, nutrient load and to a higher water temperature. The exotics are well adapted to the higher chlorine concentration and higher water temperature in the river. The biomass of neozoa exceeds that of native species.

The dependence of the macroinvertebrates on dissolved oxygen content is shown in Figure 4. During the periods of low oxygen content the number of insects decreases drastically (IKSR 2002c).

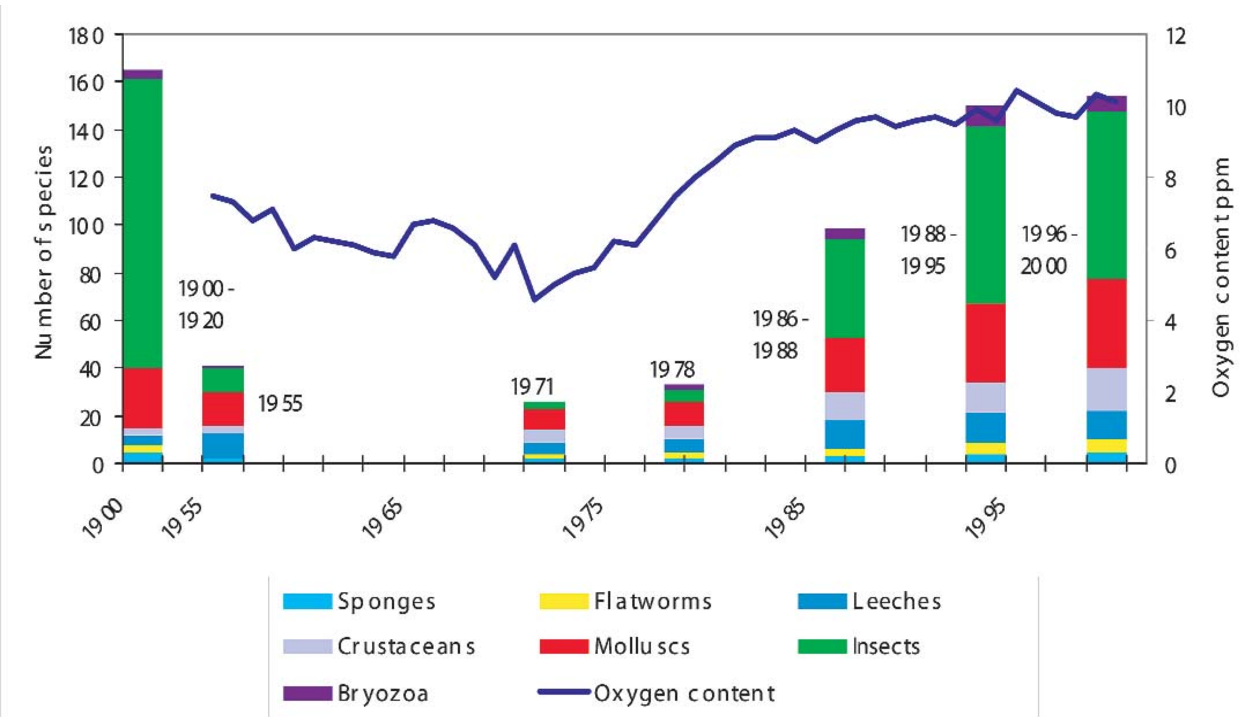
At present the Lower Rhine main channels have a low diversity of aquatic macroinvertebrates. Fifty-two percent of the aquatic insect taxa for which historical data exist occur only in the floodplain lake biotopes, 17 percent only in the main channels and 31 percent in both biotopes. Formerly, 46 percent of the insect species occurred in the floodplain lakes only, 37 percent in the channel biotopes and 17 percent in both biotopes. This means that the biodiversity of typical riverine taxa has been decreasing. On the other hand, unlike aquatic insects, the biodiversity of snails, mussels and especially macrocrustaceans is at present higher than that during the start of the last century (van den Brink *et al*. 1996).

Fish fauna and distribution

Lelek (1989) describes the historical changes in the fish fauna and a detailed information on the fish fauna in the Rhine is given in the publications of Lelek and Buhse (1992) and IKSR (1997; 2002 a). The latest information on the fish fauna in the Dutch part of the Rhine is summarized in Raat (2001).

The surveys are usually done by electro-fishing. The composition of the fish fauna in the Dutch Rhine is also monitored yearly by fyke and trawl fisheries. Information about the fish fauna also comes from surveys at the intakes to the water-cooling systems of power plants (Weibel 1991).

The biological inventory of 2000 (IKSR 2002 a) gave evidence of an impressive regeneration of the



■ **Figure 4.** Macroinvertebrates and oxygen content in the Rhine at Bimmen (From IKSR 2002 c) biocoenosis of the Rhine. Sixty-three fish species are present in the river basin (Tables 3 and 4; Figure 5). The indigenous ichthyofauna consists of 44 fish species and of these only the Atlantic sturgeon (*Acipenser sturio* L.) has not been recorded. Atlantic sturgeon disappeared because of excessive fishing, closure of the Rhine-Meuse delta and river channel degradation in the German part of the Rhine. The migratory allis shad (*Alosa alosa* (L.) and twaite shad (*Alosa fallax* Lacepede) which had disappeared from the river have again been recorded. Although blageon (*Leuciscus souffia* Risso) did not occur in the ICPR 2000 survey it is a common species in the Upper Rhine (Schwarz 1998). The stock of bullhead (*Cottus gobio* L.) seems to be more widespread, not only distributed in the Lower Rhine (Köhler, Lelek and Cazomier 1993). The presence of the young of rheophilous species such as barbel (*Barbus barbus* (L.) shows that the river provides enough dissolved oxygen for their existence.

Twenty exotic species are present but they do not dominate the fish community. Because of the connection of the Danube basin through the Rhine-Main-Danube canal new species, such as white-eye bream (*Abramis sapa* (Pallas) and tubenose goby (*Proterorhinus marmoratus* (Pallas), appear more frequently (Schadt 2000; Lelek 1996; Lelek and Brenner 2002). The white finned gudgeon (*Gobio albipinnatus* Lukasch) has appeared recently (Freyhof, Staas and

Table 3: Fish species in the River Rhine (Modified after IKSR 2002 a)

Fish species / Form	Scientific name	Incl. Iffezheim Year 2000	Occurrences Since 1996	Absent
Brook lamprey	*Lampetra planeri*	+	+	
River lamprey	*Lampetra fluviatilis*	+	+	
Sea lamprey	*Petromyzon marinus*	+	+	
Atlantic sturgeon	*Acipenser sturio*			X
Sturgeon	*Acipenser spec.*		+	
Beluga sturgeon	*Huso huso*		+	
Allis shad	*Alosa alosa*	+	+	
Twaite shad	*Alosa fallax*	+	+	
Atlantic salmon	*Salmo salar*	+	+	
Brown trout	*Salmo trutta*	+	+	
Sea trout	*Salmo trutta trutta*	+	+	
Arctic char	*Salvelinus alpinus*			
Brook trout	*Salvelinus fontinaliss*	+		
Rainbow trout	*Oncorhynchus mykiss*	+	+	
Common whitefish	*Coregonus lavaretus*		+	
Houting	*Coregonus oxyrhynchus*		+	
Grayling	*Thymallus thymallus*	+	+	
Smelt	*Osmerus eperlanus*	+	+	
Northern pike	*Esox lucius*	+	+	
Bream	*Abramis brama*	+	+	
White-eye bream	*Abramis sapa*	+	+	
White bream	*Abramis bjoerkna*	+	+	
Rissle minnow	*Alburnoides bipunctatus*	+	+	
Bleak	*Alburnus alburnus*	+	+	
Asp	*Aspius aspius*	+	+	

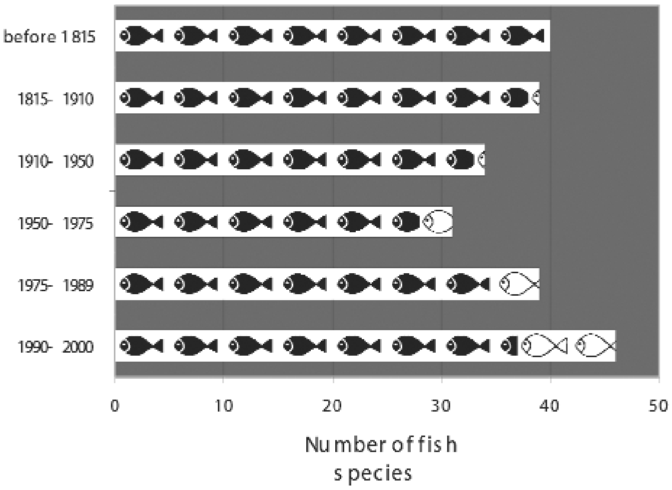
Fish species / Form	Scientific name	Incl. Iffezheim Year 2000	Occurrences Since 1996	Absent
Barbel	*Barbus barbus*	+	+	
Goldfish	*Carassius auratus*		+	
Crucian carp	*Carassius carassius*	+	+	
Prussian carp	*Carassius gibelio*	+	+	
Nose carp	*Chondrostoma nasus*	+	+	
Common carp (wild form)	*Cyprinus carpio*	+	+	
Common Carp	*Cyprinus carpio*	+	+	
Gudgeon	*Gobio gobio*	+	+	
Bullhead	*Cottus gobio*	+	+	
White-finned gudgeon	*Gobio albipinnatus*	+	+	
Tubenose goby	*Proterorhinus marmoratus*	+	+	
Grass carp	*Ctenopharyngodon idella*	+	+	
Bighead carp	*Hypophthalmichthys nobilis*		+	
Silver carp	*Hypophthalmichthys molitrix*		+	
White aspe	*Leucaspius delineatus*	+	+	
Chub	*Leuciscus cephalus*	+	+	
Ide	*Leuciscus idus*	+	+	
Dace	*Leuciscus leuciscus*	+	+	
Varione	*Leuciscus souffia agassizi*	+		
Minnow	*Phoxinus phoxinus*	+	+	
Stone moroko	*Pseudorasbora parva*	+	+	
Bitterling	*Rhodeus sericeus amarus*	+	+	
Roach	*Rutilus rutilus*	+	+	
Rudd	*Scardinius erythrophthalmus*	+	+	
Tench	*Tinca tinca*	+	+	
Vimba bream	*Vimba vimba*	+	+	
Cyprinid-Hybrids	-	+	+	
Spined loach	*Cobitis taenia*		+	
Wheatherfish	*Misgurnus fossilis*		+	
Stoan loach	*Barbatula barbatula*	+	+	
Sheat-fish	*Silurus glanis*	+	+	
American catfish	*Ictalurus spec.*		+	
Eel	*Anguilla anguilla*	+	+	
Burbot	*Lota lota*	+	+	
Stickleback	*Gasterosteus aculeatus*	+	+	
Ten-spined stickleback	*Pungitius pungitius*		+	
Sun perch	*Lepomis gibbosus*	+	+	
Ruffe	*Gymnocephalus cernuus*	+	+	
Perch	*Perca fluviatilis*	+	+	
Pike-perch	*Sander lucioperca*	+	+	
Flounder	*Pleuronectes flesus*	+	+	

Table 4: Fish distribution in the river Rhine 1990-2000 (Modified after IKSR 2002 a)

Fish species / Form	Scientific names	High Rhine	Upper Rhine	Middle Rhine	Lower Rhine	Rhine Delta	ICPR 2000 survey incl. Iffezheim	Absent	Indigenou staxon	Exotic taxon
Brook lamprey	*Lampetra planeri*	+	+			+	+		x	
River lamprey	*Lampetra fluviatilis*		+	+	+	+	+		x	
Sea lamprey	*Petromyzon marinus*		+	+		+	+		x	
Atlantic sturgeon	*Acipenser sturio*								x	
Sturgeon	*Acipenser spec.*		+			+				x
Beluga sturgeon	*Huso huso*		+							x
Allis shad	*Alosa alosa*		+		+		+		x	
Twaite shad	*Alosa fallax*		+		+	+	+		x	
Atlantic salmon	*Salmo salar*		+	+	+	+	+		x	
Brown trout	*Salmo trutta*	+	+	+	+	+	+		x	
Sea trout	*Salmo trutta trutta*	+	+	+	+	+	+		x	
Artic charr*	*Salvelinus alpinus*								x	
Brook trout	*Salvelinus fontinalis*		+				+			x
Rainbow trout	*Oncorhynchus mykiss*	+	+			+	+			x
Common whitefish	*Coregonus lavaretus*	+				+			x	
Houting	*Coregonus oxyrhynchus*					+			x	
Grayling	*Thymallus thymallus*	+	+				+		x	
Smelt	*Osmerus eperlanus*				+	+	+		x	
Northern pike	*Esox lucius*	+	+	+	+	+	+		x	
Bream	*Abramis brama*	+	+	+	+	+	+		x	
White-eye bream	*Abramis sapa*		+				+			x
White bream	*Abramis bjoerkna*	+	+	+	+	+	+		x	
Rissle minnow	*Alburnoides bipunctatus*	+	+				+		x	
Bleak	*Alburnus alburnus*		+	+	+	+	+		x	
Asp	*Aspius aspius*	+	+	+	+	+	+			x
Barbel	*Barbus barbus*	+	+	+	+	+	+		x	
Goldfish	*Carassius auratus*				+	+				x
Crucian carp	*Carassius carassius*	+	+	+	+	+	+		x	
Prussian carp	*Carassius gibelio*		+	+	+		+			x
Nose carp	*Chondrostoma nasus*	+	+	+	+	+	+		x	
Common carp (wild form)	*Cyprinus carpio*	+	+		+		+		x	
Common carp	*Cyprinus carpio*		+	+	+	+	+			x
Gudgeon	*Gobio gobio*	+	+	+	+	+	+		x	
Bullhead	*Cottus gobio*		+	+	+	+	+		x	
White-finned gudgeon	*Gobio albipinnatus*		+	+	+		+			(x)
Tubenose goby	*Proterorhinus marmoratus*		+	+			+			x
Grass carp	*Ctenopharyngodon idella*	+	+	+	+	+	+			x
Bighead carp	*Hypophthalmichthys nobilis*		+			+				x

** The distribution of the for the Alpine lakes indigenous species is restricted to the High Rhine catchment area, e.g. Lake of Constance.*

Fish species / Form	Scientific names	High Rhine	Upper Rhine	Middle Rhine	Lower Rhine	Rhine Delta	ICPR 2000 survey incl. Iffezheim	Absent	Indigenou staxon	Exotic taxon
Silver carp	*Hypophthalmichthys molitrix*		+							x
White aspe	*Leucaspius delineatus*		+	+	+	+	+			(x)
Chub	*Leuciscus cephalus*		+	+	+	+	+		+	x
Ide	*Leuciscus idus*	+	+	+	+	+	+			x
Dace	*Leuciscus leuciscus*		+	+	+	+	+		+	x
Varione	*Leuciscus souffia agassizi*		+							x
Minnow	*Phoxinus phoxinus*		+	+		+			+	x
Stone moroso	*Pseudorasbora parva*		+	+	+		+			x
Bitterling	*Rhodeus sericeus amarus*	+	+	+	+	+	+			x
Roach	*Rutilus rutilus*	+	+	+	+	+	+			x
Rudd	*Scardinius erythrophthalmus*	+	+	+	+	+	+			x
Tench	*Tinca tinca*	+	+	+	+	+	+			x
Vimba bream	*Vimba vimba*	+	+	+	+	+				x
Hybrid cyprinids	-		+	+	+		+			x
Spined loach	*Cobitis taenia*		+		+	+				x
Wheatherfish	*Misgurnus fossilis*		+		+	+				x
Stoan loach	*Barbatula barbatula*	+	+	+	+	+	+			x
Sheat-fish	*Silurus glanis*	+	+	+	+	+	+			x
American catfish	*Ictalurus spec.*			+						x
Eel	*Anguilla anguilla*	+	+	+	+	+	+			x
Burbot	*Lota lota*	+	+	+	+	+	+			x
Stickleback	*Gasterosteus aculeatus*	+	+	+	+	+	+			x
Ten-spined stickleback	*Pungitius pungitius*				+	+				x
Sun perch	*Lepomis gibbosus*	+	+	+	+	+	+			x
Ruffe	*Gymnocephalus cernuus*	+	+	+	+	+	+			x
Perch	*Perca fluviatilis*	+	+	+	+	+	+			x
Pikeperch	*Sander lucioperca*	+	+	+	+	+	+			x
Flounder	*Pleuronectes flesus*				+	+	+			x



		before 1815	1815- 1910	1910- 1950	1950 -1975	1975- 1989	1990- 2000
Indigenous taxon		40	38	33	28	35	37
Exotic taxon		0	1	1	3	4	9

■ **Figure 5**. Fish species development in the Lower Rhine (From Wetzel 2002)

Steinmann 1998; Freyhof *et al*. 2000), probably due to stocking. The present fish fauna is dominated by eurytopic cyprinids. Rheophilous species have declined in numbers and anadromous fish have become scarce or extinct. Because of their greater tolerance to environmental changes the dominant species are bream, white bream and roach. Phytophilous northern pike (*Esox lucius* L.) and rudd (*Scardinius erythophthalmus* (L.) decreased in density with the decline of riverine vegetation in the Rhine (Raat 2001). Sea lamprey (*Petromyzon marinus* L.) and river lamprey (*Lampreta fluviatilis* (L.) are common but have decreased in numbers due to the closure of the Zuiderzee in 1932 and the closure of the Haringvliet in 1970. However, since the 1980s captures of these species in the Netherlands have slightly increased.

Sea trout (*Salmo trutta trutta* L.) has been always present in catches throughout the Rhine and its tributaries. Several sea trout, captured and marked at the North Sea side of the Haringvliet, were found in the Rhine, thus proving that it migrates from the sea into the river (Bij de Vaate and Breukelaar 1999).

The Salmon 2000 Programme

In the past Atlantic salmon (*Salmo salar L.*) catches had declined in the Rhine from a total number of more than 200 000 fish in the second part of the nineteenth century to nil (ICPR 1991) (Figure 6). The last salmon was caught in the Rhine in 1957. The decline and disappearance of salmon from the Rhine was due to the following:

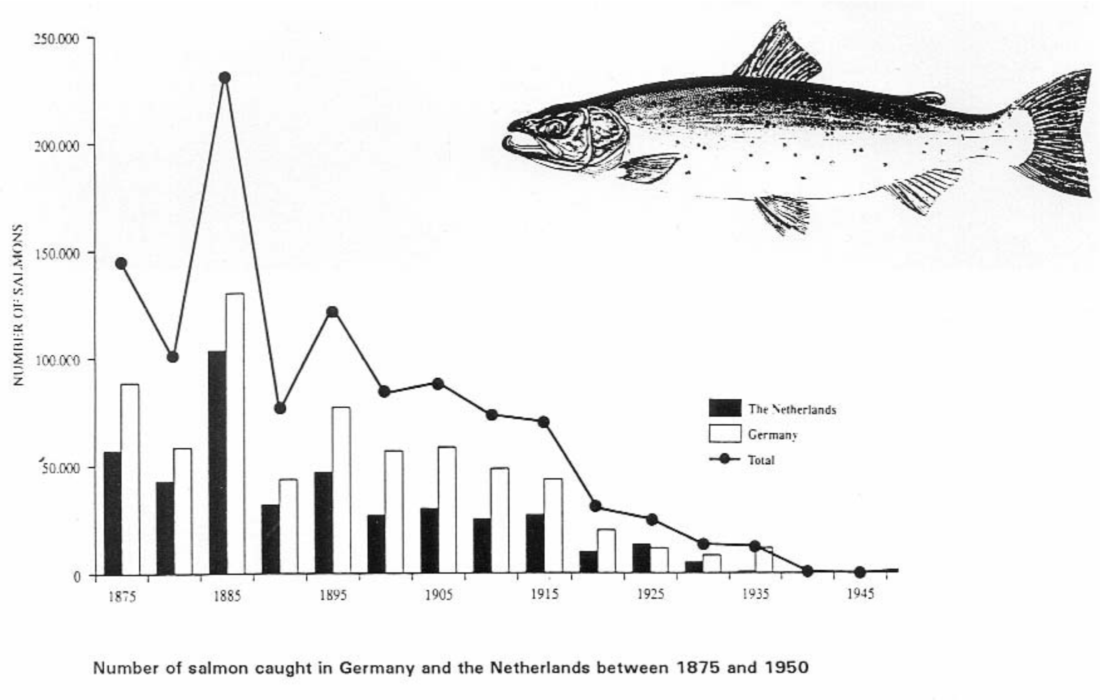
- Degradation and reduced number and area of spawning places
- Migration barriers in the main channel and the tributaries
- Closure of the major migration routes to the sea
- Water quality degradation
- Overfishing

The international Rhine Action Programme which started in 1987, one year after the Sandoz pollution disaster, included measures for the reintroduction of the Atlantic salmon. The first salmon migrated from the sea and the Lower Rhine into the Sieg River in 1990 (Steinberg *et al*. 1991). The return of the Atlantic salmon to the Rhine is seen as the result of the improved water quality, mainly better dissolved oxygen concentrations and of intensive repeated stocking in the upstream regions of the Rhine and its main tributaries.

Stocking activities with salmon of different salmon strains; spawning and nursery areas

Salmon of French origin have been stocked in the Upper Rhine and its tributaries in Switzerland since 1984 (Rey *et al*. 1996). A private group coordinated stocking until the end of 2002. At present it is paid for from the budget of the Kanton Basel-Stadt. Spawning and nursery areas are in the Rhine tributaries Wiese, Birs and Ergholz.

French salmon strains have been stocked in the French Rhine, the Ill and its tributaries, the Luxemburg river Sauer and the German rivers Ahr and Lahn and tributaries (Vauclin *et al*. 2000). The first young



■ **Figure. 6.** Number of salmon caught in Germany and the Netherlands between 1875 and 1950 (From ICPR 1991)

salmon were stocked in some tributaries of the Sieg in 1988. More than 500 000 salmon fry per year have been released since 1995 (Schmidt and Feldhaus 1999). Stocking takes place with salmon strains of different origins, e.g. from Ireland, Scotland, Norway, Denmark and Sweden. In future a new strategy will be practiced whereby the number of strains will be reduced to three or four and the smolts will be marked to allow better recording of upstream migrating fish (Molls pers. comm.).

The first natural reproduction of salmon was proved for the Sieg River system. Living yolksac fry of *Salmo salar* were found in natural redds in the rivers Sieg, Agger and Bröl in the winter 1993/94. Successful natural reproduction of salmon was also observed in the following years in the Sieg and in other tributaries of the Rhine, e.g. Ahr, Saynbach, Lahn, Ill, Bruche. The present condition of the spawning places and the presence of the migration barriers downstream and in the river, allows a small partial return of self-reproducing populations of salmon in the Rhine.

An assessment of the potential spawning places of the species showed an overall carrying capacity of the French part of the Rhine for Atlantic salmon of 344 100 yearling parr. Roche (1994) estimated a potential yearly return of 900 to 1 700 adults to the area, which requires spawning grounds of approximately 10 ha and nursery grounds of about 150 ha. An assessment of potential spawning and nursery grounds in the Rhine tributaries in Luxembourg (River Our) and in Germany indicates a potential return of a self-sustaining population of about 5 000 adults in the Rhine and its tributaries. The actual registered total spawning surface area for salmon and sea trout in the Rhine and its tributaries is 147.1 ha and 630.9 ha of nursery grounds (IKSR 1999b).

Based on the newer data, the Ill catchment area offers a potential of 49 ha of nursery grounds and 3.5 ha of spawning sites, which would allow the return of about 600 adults. This includes 24.7 ha of nursery areas and 1.8 ha of spawning sites in the Bruche. There are more registered areas in the Kinzig, a tributary of the main and the river systems of the rivers Sieg, Wupper, Dhünn, Eifelruhr, Volme and Weser (ICPR unpublished data).

Fish migration

Most migratory fish stocks declined often to extinction in the River Rhine as a result of poor water quality, combined with the construction of barriers and loss of spawning and nursery grounds (Lelek 1989). The construction of dams and enclosures on the rivers from the North Sea, such as Lake Ijssel and Haringvliet-Hollands Diep that have been transformed from brackish to freshwater bodies, have also had an important impact on the migratory fish species.

The most important impacts of dams are (Raat 2001):

- hampered fish migration through the Afsluitdijk and Haringvliet sluices;
- loss of the nursery function for marine and brackish-water fish species;
- increased danger of passive drift of freshwater fish into the sea at peak discharges;
- loss of the freshwater tidal area in the Biebosch;
- decreased mixing of river and seawater, leading to a concentration of eutrophic freshwater along the Dutch coast and hence to an increased risk of eutrophication.

Fish migration studies within the sea trout migration project

Investigations were started in December 1996 on sea trout and salmon migration routes from the North Sea into the Dutch part of the rivers Rhine and Meuse. These studies have been executed within the framework of the ecological restoration of both rivers. The purpose was to find out what problems these species face during their migration from the sea to the spawning grounds upstream. The fish were caught in the Dutch coastal area and marked with implanted transmitters. Migration was followed by means of fixed detection stations constructed on the banks of the watercourses, which potentially could serve as a migration route (Bij de Vaate and Breukelaar 1999). Two out of 19 detection stations were installed in Germany, one on the Rhine in Xanten and the second on the Sieg. Because of the relatively wide natural variations in conditions under which the migration takes place, fish tagging continued until June 2000. A total of 662 fish (582 sea trout and 80 salmon) were equipped with a transponder. It was concluded that the Nieuwe Waterweg was the most important route for upstream migration in the Lower Rhine. However, only few specimens reached the Lower Rhine and one sea trout returned to the open sea after having been in the Sieg River in August 2000.

Hydropower plants and fish migration

There are 21 hydropower plants on the Rhine mainstem, of which 10 are in Germany-France and 11 in Switzerland. The Mosel, Lahn, Main and Neckar are important tributaries to the Rhine and all of them are equipped with hydropower plants. Fish traps have been installed to check the migrating fish. In the Mosel River the downstream migration of eels is being investigated in a joint venture project of the German Federal Government in Rhine Palatinate and the electricity supply corporation RWE Power AG.

In the River Rhine fish can now migrate up to Iffezheim. With the construction of the fish pass in the next barrier in Gambsheim and the enhancement of the Rest Rhine salmon may reach Basel. The weir of Kembs in the Upper Rhine is provided with a fish pass. A feasibility study on behalf of the ICPR will show the functions of the rest of the Rhine as spawning and nursery areas for salmon and the restoration of the ecological connectivity.

Between April 1995 and March 1996 an in-depth study of upstream migrating fish was carried out on 13 fish passes of 9 hydropower plants of the Upper Rhine and the results were compared with the results of the first surveys of 1985 and 1986. Of 26 fish species barbel and eel dominated in the catches. It can be concluded that the functionality of the fish passes is restricted, mainly because of insufficient supply of attraction flow for the fish (Gerster 1998).

The hydropower plant in Rheinfelden in the Upper Rhine is over one hundred years old. There are plans to construct here a similar fish bypass as that at the hydropower station Ruppoldingen on the Aare River. The fish bypass in the Aare is 1.2 km long, 10 to 20 m wide and has a flow of 2 – 5 $m^3 s^{-1}$ (Gebler 2002). The fish bypass in Rheinfelden will be approximately 1 km long and 30 – 40 m wide. The discharge will be from 10 $m^3 s^{-1}$ to 35 $m^3 s^{-1}$.

There are a number of projects for conversion of riverbanks into shallow gravel banks with bays, such as at the Rhine in Rüdlingen, as an ecological compensation measure when issuing a new licence for the hydro power plant in Eglisau and for the creation of a shallow gravel bank with groynes in the Rhine at Rheinsulz. This project should enhance the environmental conditions for the nose carp (*Chondrostoma nasus* (L.), barbel and brown trout.

The fish pass in Iffezheim

The Iffezheim dam was built from 1970 to 1975 by France and Germany and equipped with a Borland type fish pass. For many reasons, such as the availability of water supply throughout the year, only a limited fish migration through the pass had been possible. During the International Rhine Rehabilitation Programme an agreement was signed by the French and German parties to construct new fish passes in Iffezheim and Gambsheim. Europe´s largest fish pass on the Upper Rhine was built at Iffezheim Württemberg from 1998 to 2000, financed by the EDF Group – Electricité de France (EDF) and Energie Baden (EnBW), the governments of France and Germany and the EU-LIFE-Programme, at a cost of approximately 7.3 million Euro. The fish pass opened in 2000. One million Euro was paid by the power station owner for additional measures. Over a distance of approximately 300 metres, fish pass through 48 pools and surmount an average elevation of 11 metres depending on the water level, between the downstream and upstream sections. The upper part of the pass consists of 37 individual pools, each with a surface area of 15 m^2 and a mean water depth of 1.5 m. For the passage of invertebrates (macrozoobenthos) the bottom of each pool is covered with a substrate made of large stones and additional passage holes. The water flows through the fish pass at a steady rate of 1.2 $m^3 s^{-1}$. An additional flow of 9.8 – 11.8 $m^3 s^{-1}$ comes from a turbine and feeds the distribution basin to improve the attraction flow for the fish. Heimerl, Ittel and Urban (2001) provide further technical details. The modified vertical slot pass has been designed to fit the needs of the majority of the fish species and allows especially the migration of anadromous fish species such as salmon, sea trout and shad. During the period from June 2000 to December 2002 continuous fish observations and counting stations recorded 33 fish species. For part of the time a video device also recorded fish moving through the fish pass, on some occasions fairly large numbers passing through (Heimerl, Nöthlich and Urban 2002). The main source of information came from a metallic fish-trap run jointly by French and German operators (Degel 2002).

During 2000 and 2001, 75 and 59 salmon and 383 and 216 sea trout were counted in the trap. Sea lampreys were also captured (205 individuals in 2001, none in 2000 because the monitoring started after their migration period), as well as a few shads (5 *Alosa alosa* and 1 *Alosa fallax*) (Table 5). 21 fish species were recorded in 2000, but only seven of them in numbers over 100. Two species dominated by number and weight: barbel (n = 3 586, with 3.14 tonnes out of a total of 6.1 tonnes) and bream (n = 1 123; 1.16 tonnes). In 2001, 29 species were recorded, with four main species: barbel (n = 6 593), nose carp, bream and asp, with 12.7 tonnes out of a total of 14.4 tonnes. The results of the first year and a half of monitoring can be summarized as follows:

1. The fish pass is mainly used by large and rheophilic cyprinids, the bream being the only non-rheophilic species of the four major fish species. This is understandable when considering that the length of the

pass is over 300 meters. The peak of fish migration takes place in May and June.

2. A significant number of migratory and large salmonids use the fish pass. The age of most of the salmon caught has been determined from scales.

3. Large numbers of asp were recorded for the first time. Such abundance of this species has not been assessed by other means of investigations, including electro-fishing. The observations at Iffezheim are likely to overestimate the proportion of asp in the Rhine fish communities because of the selectivity of the device, that appears to favour the big and fast swimming fish (see point 1.) and possibly due to a specific behaviour of this species.

4. The presence of previously not recorded vimba bream (*Vimba vimba* L.) and white-eye bream (*Abramis sapa* (*Pallas*) has been confirmed. Both cyprinids have colonized the Rhine from their original area of distribution in central Europe, passing through the Rhine-Main-Danube canal.

5. Many species occur in small numbers; a dozen of them appeared in less than 10 individuals in 2001.

6. The monitoring bias should be kept in mind. First, not all species are eager to enter nor able to ascend such a long migrating device. Second, the small species that do reach the upstream part of the fish pass (where the video camera and the trap are situated) have the possibility to bypass these

Table 5: Number of fish species ascending in the fish pass in Iffezheim in the years 2000 - 2002. (Data from Association Saumon Rhin and Conseil Supérieur de la Pêche)

	2000 * 13 June to 31 December	2001* 1 January - 31 December	2002 ** 4 March to 31 December
Atlantic salmon	(f) 75	59	94
Sea trout (a)	(f) 383	216	301
Sea lamprey (b)	0	205	57
Shads (c)	2	4	3
Eel (d)	230	339	255
Barbel	3 586	6 593	4 088
Bream (e)	1 123	2 341	2 778
Nose carp	558	2 592	2 135
Asp	386	1 228	2 646
Other species (g)	463	790	770
TOTAL	6 806	14 367	13 127

* Based on trapping
** Based on video counting

(a) only adults ascending (not smolts on downwards migration)
(b) migration monitored in 2000 due to the date of beginning
(c) both species : *Alosa alosa* and *Alosa fallax*
(d) counting not efficient due to escape between bars of the trap and passing through the video bypass
(e) *Abramis brama*
(f) values modified in October 2002 after full scale interpretation by Arnaud RICHARD (Conseil Supé rieur de la Pé che) and Jean-Luc BAGLINIERE (Institut National de la Recherche Agronomique). The numbers for these species given in previous publications were incorrect
(g) the number of other fish species was 21 in 2000, 29 in 2001 and 27 in 2002

monitoring tools using lateral canals that are closed with bars with interspaces of 3 cm.

In 2002, the video monitoring has been the main source of data and the trapping only took place at certain periods. Five migratory and 22 non-migratory fish species were recorded. From 4 March to 31 December, 94 salmon and 301 sea trout were counted. As in 2000, sea-winter salmon dominated the sample. Fifty-seven lampreys and about 200 eels have also been recorded. The monitoring has never worked for eels, because they can move through a bypass, thus escaping the video camera (or trap, as during the previous years). Nevertheless, qualitative data on their period of migration are being obtained. As for salmon, their number during the period is in the order of magnitude expected from calculations based on the number of juveniles stocked in the upper part of the basin, but rather on the lower level. The proportion of grilse and the scarcity of 3 winter-salmon (two individuals so far), which is consistent with the current situation and trends observed in salmon stocks worldwide, could be an adverse factor for good colonization of this part of the basin, because these small salmon are less able to pass some of the migratory obstacles not yet equipped with efficient fishways. A stocking strategy (stages of release and genetics) is being discussed in France and the other riparian states and the results will be presented for a wider discussion with the colleagues and biologists who collaborate in the salmon project in the Rhine basin, noticeably those involved within the framework of the International Commission for the Protection of the Rhine (ICPR).

Fish control station on the Sieg River in North Rhine-Westfalia

The Sieg is a typical middle range mountain river that rises in the Rothaar Mountains and flows after 153 km into the Rhine near Bonn. The natural character of the river is the reason for a varied fish population. From the beginning of the 1980s sea trout were observed to be migrating in this river. This led to a pilot project for the reintroduction of salmonids. Modern fish passes were built on all weirs of the lower stretch in North Rhine-Westphalia and upper stretch in Rhineland-Palatinate. This made the migration to important spawning sites and nursery areas possible. In the year 2000 a fish research and catching station, with a fish guidance system leading to a trap, was established downstream in the first weir. The fish caught can be temporarily stored. The trap is checked at least once a day throughout the year. The management and maintenance cost is financed by the federal states of North Rhine-Westphalia and Rhineland-Palatinate.

From June 2000 to December 2002, 468 adult salmon and 184 adult sea trout were captured. When catches at the other weirs are included, 631 salmon and 294 sea trout were captured. When taking into account the catch and recapture results the numbers can be doubled (Nemitz pers. comm.). Eleven other fish species were also recorded by the end of 2002.

COMMERCIAL AND RECREATIONAL FISHERIES

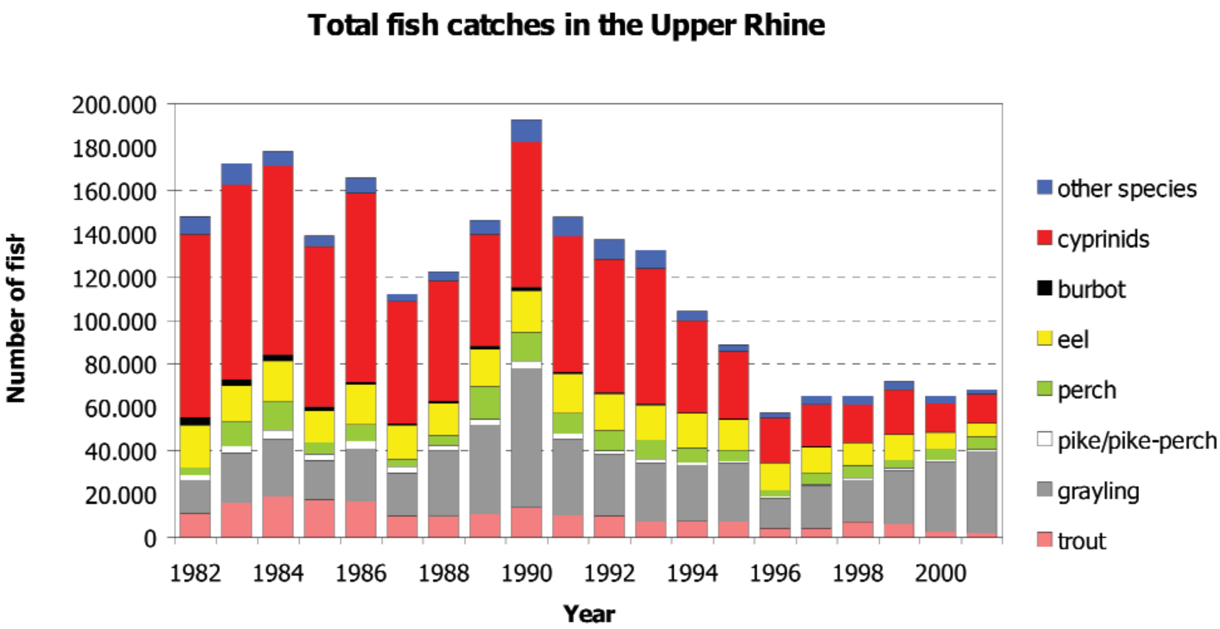
There are only two commercial fishers left on the High Rhine, one in Switzerland and one in Germany. Approximately 80 fishers practice traditionally fisheries on the Upper Rhine stretch downstream to Iffezheim. From Iffezheim downstream to the Dutch border about 48 are engaged in fisheries. Most of them fish in addition to their main business (Dr. Kuhn pers. comm.). About 25 fishers are active in the Rhine-Meuse delta, Lower Rhine-Lek and Ijssel. There are seine fisheries in the Haringvliet-Hollandsch Diep and the cyprinids caught are used for stocking inland waters. Eel is left as the most important commercial species. It is fished with fyke nets and electro-fishing. Eel fishing takes place in the Haringvliet-Hollandsch Diep and in the Ijssel in the Netherlands and in the main channel in Germany. But eel catches are declining because of lower elver recruitment during the last 10 years (Dekker pers. comm.). Pikeperch is fished with gill nets (van Doorn pers. comm.). According to Raat (2001) the commercial fisheries of the Rhine are very restricted at the present.

Recreational fisheries are practiced by several hundred thousand persons and take place in the main river channel and on floodplains. The main species targeted are cyprinids such as roach, bream, ide, pikeperch and northern pike. Fishing requires a licence. Every riparian state and each of the German federal states has its own fisheries legislation and regulations. Only few fisheries statistics are available. In this context the International Fisheries Commission for the Upper Rhine between Switzerland and the German federal state of Baden-Württemberg, which is in charge of the fisheries management, is an exception. The total fish catches in the Upper Rhine are related to a surface area of 2 475 ha (Figure 7).

CONCLUSIONS

With the improvement of water quality in the Rhine the dissolved oxygen concentrations are satisfactory for fish throughout the year. However, the biological quality of the Rhine still needs to be improved. The latest data confirm that both fish and macroinvertebrate communities contain very few stenotopic species, i.e. those with narrow ecological requirements. Often exotic species, so-called neozoa, dominate the benthic macroinvertebrates. While on a larger scale the number of species has increased, detailed examination of reaches and sections of the Rhine shows that locally the number of species has decreased. This seems to indicate that the variety of habitat structures in the Rhine is still limited. While all the former fish species with the exception of the Atlantic sturgeon have been re-established, the present fish fauna is dominated by eurytopic cyprinids and the number of rheophilous species has declined.

The results of the salmon programme for several tributaries of the Rhine (e.g. Sieg, Ahr, Our, Ill, Bruch) show that there is a good chance that a self-sustaining population of Atlantic salmon will become established. The success of the fish passage in Iffezheim will help to implement the next fish pass at Gambsheim. This will enable anadromous fish, such as salmon and sea trout, to bypass the dams across the Rhine and reach their spawning sites in the Rhine trib-

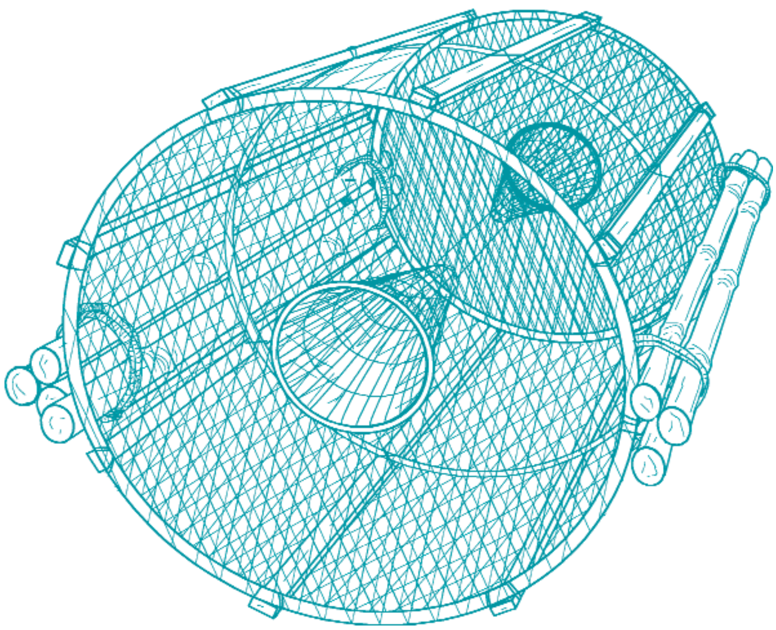


■ **Figure 7.** Total fish catches in the Upper Rhine utaries of the Black Forest and the Vosges Mountains. Still more ecological improvement is necessary for achieving this objective. While ecological restoration and flood protection are the major challenges the present socio-economic functions of the river pose serious constraints on achieving the ecological objectives.

Various forms of ecological rehabilitation in the Rhine have been identified: floodplain development for ecological improvement and flood prevention, optimisation of up- and downstream fish migration with an emphasis on the entrance of migrating species from the sea into the Rhine and its tributaries and the restoration of spawning and nursery areas. The success of the restoration projects depends mainly on their acceptance by local stakeholders such as ecologists, communal authorities, tourism, agriculture, forest administration and nature associations. From this socio-economic point of view an inquiry in the German Federal State of Rhineland-Palatinate shows that up to 90 percent of stakeholders support the protection and conservation of the species diversity in floodplain projects and this may be representative also for other regions.

An example of a successful partnership is the environmental non-governmental organizations (NGOs) partnership with the International Commission for the Protection of the Rhine (ICPR) (Buijse *et al*. 2002). The success of projects also depends on a close cooperation between ecologists and engineers. This is reinforced by the EU Water Framework Directive, which requires of member states a commitment to intensify protection and enhancement of the aquatic environment.

Commercial fisheries have a long tradition in the Rhine system. Today, however, commercial fishing it is practiced only on a small scale by a few fishers, whereas the recreational fisheries are ever increasing in the number of participants and intensity. Both types of fishery play an important role in nature protection and the sustainability of fish stocks.



REFERENCES

Bakker C., Noordhuis R. & Prins K.H. eds. 1998. Biological monitoring of national fresh water: Water system report Rhine 1995. *RIZA Report No. 98.047*.

Bericht. 2002. Machbarkeitsstudie für die Wiederherstellung der ökologischen Durchgängigkeit des Oberrheins, Phase 1, Analyse der derzeitigen Lage und Vorschlag für Ziele: *Vorläufiger Bericht, Okt:* 2002.

Bij de Vaate A. & Breukelaar A.W. 1999. Sea trout *Salmo trutta* migration in the Rhine Delta, The Netherlands. *In* IKSR, eds. *Internationales Rhein-Symposium Lachs 2000*. *Tagungsband*. pp. 78-84.

Brenner T. ed. 1993. Die Biozönose des Rheins im Wandel. *In Ministerium für Umwelt, Rheinland-Pfalz Lachs 2000*. Petersberg, Advanced Biology. pp. 63-68.

Buijse A.D. & Vriese F.T. 1996. Assessing potential fish stocks in new nature developments in flood-plains of large rivers in The Netherlands. *Arch. Hydrobiol Suppl*., 113: 1-4. pp. 339-343.

Buijse A.D., Coops H., Staras M., Jans L.H., van Geest G.J., Grift R.E., Ibelings B.W., Oosterberg W. & Roozen F.C.J.M. 2002. Restoration strategies for river floodplains along large lowland rivers in Europe. Freshwater Biology, 47: 889-907.

Degel D. 2002. Betriebserfahrungen und Ergebnisse der Reusenfischerei am Fischpass Iffezheim. *Wasserwirtschaft*, 924/5: 24-28.

European Union 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for community action in the field of water policy. Brussels. *Official Journal*, 327: 22.12.2001.

Freyhof J., Staas S. & Steinmann I. 1998. Erste Nachweise des Weißflossengründlings *Gobio albipinnatus* Lukasch 1933, im Rhein. *LÖBF-Mitteilungen*, 3: 75-77.

Freyhof J., Scholten M., Bischoff A., Wanzenböck J., Staas S. & Wolter C. 2000. Extensions to the known range of the whitefinned gudgeon in Europe and biogeographical implications. *Journal of Fish Biology*, 57: 1339-1342.

Gebhardt H. 1990. Die Bedeutung des Inundationsgebietes des Rheins als Laichgebiet für Fische. *In* R. Kinzelbach & G. Friedrich, eds. *Biologie des Rheins*. Stuttgart, New York, Gustav Fischer Verlag. pp. 435-453.

Gebler R.J. 2002. Der Neubau des Kraftwerkes Ruppoldingen-Umwelt. *Wasser, Energie, Luft – Eau, Énergie, Air*, 941/2: 31-35.

Gerster S. 1998. Fischpassanlagen der Hochrheinkraftwerke: Aufstiegskontrollen 1995/96 und Vergleich mit früheren Erhebungen. *Mitteilungen zur Fischerei*. Bern: Bundesamt für Umwelt, Wald und Landschaft No. 60, 5-137.

Grift R.E. 2001. *How fish benefit from floodplain restoration along the lower River Rhine*. Wageningen University. (Doctoral dissertation)

Grift R.E., Buijse A.D., van Densen W.L.T. & Klein Breteler J.G.P. 2001. Restoration of the river-floodplain interaction: Benefits for the fish community in the River Rhine. *Arch. Hydrobiol. Suppl.*, 1352-4: pp. 173-185.

Heimerl S., Ittel G. & Urban G. 2001. First operational experiences with one of the largest fish passages structures in Europe and applicability to other sites. *Proceedings of Hydro 2001: Opportunities and Challenges. The International Journal on Hydropower & Dams*. pp. 313-322.

Heimerl S., Nöthlich I. & Urban G. 2002. Fischpass Iffezheim – erste Erfahrungen an einem der größten Verbindungsgewässer Europas. *Wasserwirtschaft*, 924/5: 12-22.

ICPR. 1991. *Ecological* master plan for the Rhine. International Commission for the Protection of the Rhine against Pollution. Koblenz.

ICPR. 1994. *Salmon 2000.* International Commission for the Protection of the Rhine. Koblenz. 34 pp.

ICPR. 1998. *Flood control on the River Rhine – Action Plan*. International Commission for the Protection of the Rhine. Koblenz, Germany.

IKSR. 1987. *Aktionsprogramm Rhein.* Internationale Kommission zum Schutze des Rheins gegen Verunreinigung. Koblenz.

IKSR. 1997. Bestandsaufnahme der Rheinfischfauna 1995 im Rahmen des Programms Lachs 2000. Internationale Kommission zum Schutze des Rheins. Koblenz. 27 pp.

IKSR. 1999a. *Internationales Rhein-Symposium Lachs 2000, Tagungsband.* Internationale Kommission zum Schutze des Rheins. Koblenz. 311 pp.

IKSR. 1999b. *Ist der Rhein wieder ein Fluss für Lachse, Lachs 2000.* Internationale Kommission zum Schutze des Rheins. Koblenz. 62 pp.

IKSR. 2002a. *Rheinfischfauna 2000 - was lebt zwischen dem Rheinfall bei Schaffhausen und der Nordsee*. Internationale Kommission zum Schutze des Rheins. Koblenz. 46 pp.

IKSR. 2002b. Stand der Umsetzung des Programms zur Wiedereinführung von Wanderfischen in den Rhein bis Anfang 2003. Internationale Kommission zum Schutze des Rheins. (Draft report)

IKSR 2002c. *Das Makrozoobenthos des Rheins.* Internationale Kommission zum Schutze des Rheins. Koblenz. 49 pp.

Köhler C., Lelek A. & Cazemier W.G. 1993. Die Groppe *Cottus gobio* im Niederrhein – Merkwürdigkeit oder etablierter Bestandteil der Fischartengemeinschaft. *Natur und Museum*, 12: 373-386.

Lelek A. 1989. The Rhine River and some of its tributaries under human impact in the last two centuries. *In* D.P. Dodge ed. *Proceedings of the international large rivers symposium*. *Can. J. Fish. Aquat. Sci. Spec. Publ.*, 106: 469-487.

Lelek A. 1996. Die allochthonen und die beheimateten Fischarten unserer großen Flüsse – Neozoen der Fischfauna. *In* Gebhardt, Kinzelbach, Schmidt-Fischer, eds. *Gebietsfremde Tierarten*. Ecomed Verlag.

Lelek A. & Buhse G. 1992. *Fische des Rheins – früher und heute.* Springer-Verlag. Berlin Heidelberg. 214 pp.

Lelek A. & Brenner T. 2002. Fische. *In* Landesamt für Denkmalpflege Rheinland-Pfalz, eds. *Das Rheintal von Bingen und Rüdesheim bis Koblenz – Eine europäische Kulturlandschaft*. Mainz Verlag Philipp von Zabern. pp. 904-905.

Ministerium für Umwelt und Forsten, eds. 1996. *Wie sauber ist der Rhein wirklich Biomonitoring*. Petersberg, Advanced Biology. 148 pp.

Raat A. 2001. Ecological rehabilitation of the Dutch part of the River Rhine with special attention to the fish. *Regulated Rivers: Research Management*, 17: 131-144.

Rey P., Ortlepp J., Maurer V. & St Gerster 1996. Ruckkehr der lachse in Wiese, Birs und Ergholtz. BUWAL, *Schriftenreihe Umwelt*, 258: 118.

Roche P. 1994. Habitat availability and carrying capacity in the French part of the Rhine for Atlantic Salmon *Salmon salar* L. *Water Science and Technology*, 29: 257-265.

Schadt L. 2000. Neue Fischart im Main entdeckt: Marmorierte Grundel *Proterorhinos marmoratus*. *Fischer und Teichwirt*, 6: 217-218.

Schmidt G.W. & Feldhaus G. 1999. Zur Wiedereinbürgerung des Lachses im Siegsystem. *In* IKSR, eds. *Internationales Rhein-Symposium Lachs 2000*. Tagungsband. pp. 94-102.

Schulte-Wülwer-Leidig A. 1994. Outline of the Ecological Master Plan for the Rhine. *Water Science Technology*, 29: 273-280.

Schwarz M. 1998. Biologie, Gefährdung und Schutz des Strömers *Leuciscus souffia* in der Schweiz. *Mitteilungen zur Fischerei*. Bern, Bundesamt für Umwelt, Wald und Landschaft No. 59. 60 pp.

Simons J.H.E.J., Bakker C., Schropp M.H.I., Jans L.H., Kok F.R. & Grift R.E. 2001. Man-made secondary channels along the river Rhine The Netherlands: Results of post-project monitoring. *Regulated Rivers: Research Management*, 17: 473-491.

Steinberg L., Lehmann J., Marmulla G. & Schmidt G.W. 1991. Erster gesicherter Nachweis des Lachses, *Salmo salar* L., im Gewässersystem der Sieg seit über drei Jahrzehnten. *Fischökologie Aktuell*, 5: 2-3.

Van den Brink F.W.B., van der Velde G., Buijse A.D. & Klink A.G. 1996. Biodiversity in the Lower Rhine and Meuse river-floodplains: Its significance for ecological river management. *Netherlands Journal of Aquatic Ecology*, 302-3: 129-149.

Vauclin V. & Luquet J.F. 2000. Avancement du programme de restauration des poisons migrateurs du Basin du Rhin en Alsace, France 1991-1999. *Bull. Fr. Peche Piscic.*, 357/358: 293-309.

Weibel U. 1991. Neue Ergebnisse zur Fischfauna des nördlichen Oberrheins ermittelt im Rechengut von Kraftwerken. *Fischökologie*, 5: 43-68.

Weidmann H. & Meder H. 1994. Sandoz Rheinfonds. Forschung und Naturschutz. Basel, Sandoz International AG. 213 pp.

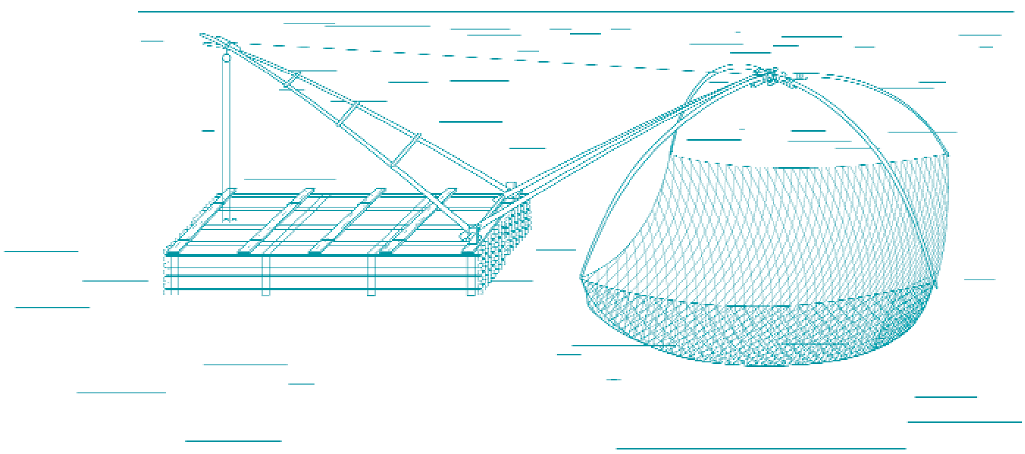
Wetzel V. 2002. Nutzung und Funktion des Rheins – Forderungen an eine integrierte Flussbewirtschaftung. *In* Federal waterways and shipping administration, eds. *Der Rhein – Europäische Wasserstraße mit Zukunft*., Koblenz. pp. 22-31.

RIVERS OF THE LOWER GUINEAN RAINFOREST: BIOGEOGRAPHY AND SUSTAINABLE EXPLOITATION

R.E. Brummett.[1] G.G. Teugels[2]

[1] The WorldFish Centre (formerly ICLARM), BP 2008, Yaoundé, Cameroon
R.Brummett@cgiar.org (corresponding author)

[2] Royal Museum for Central Africa, B-3080 Tervuren, Belgium teugels@africamuseum.be



ABSTRACT

The Lower Guinean rainforest of Southern Cameroon, continental Equatorial Guinea, Gabon and the People's Republic of the Congo and its associated biodiversity is being destroyed at a rate of 1 million ha per year by poorly regulated timber exploitation and slash and burn agriculture. An important component of the rainforest is the river that drains it. Although very little studied and poorly understood, these rivers drain over 500 000 km^2 and have been estimated to contain at least 500 fish species, of which a large percentage may be endemic. In the process of deforestation, the fish are being destroyed along with the trees and other wildlife.

Keywords: rainforest rivers, Central Africa, fish biodiversity, sustainable management

The rivers and swamps of the Lower Guinean forest comprise the Lower Guinean ichthyological province and possess different species from those of the Sudano-Nilotic province to the north and the Congo province to the East and South. The icthyofauna of these rivers is dominated by the Siluriformes (6 families, 23 genera, 102 species), the Characiformes (2 families, 20 genera, 62 species), the Cichlidae (17 genera, 54 species) the Cyprinidae (10 genera, 79 species) and the Mormyridae (14 genera, 49 species). Among these are a large number of ornamentals, many of which are rare and unusual, fetching high prices in Europe and North America.

The 8 million people who live in the Lower Guinean forest depend heavily upon the integrity of the river ecosystem for their livelihoods. Estimates from Cameroon put the productivity of capture fisheries in forest river basins at 1.1 tons km^{-2} yr^{-1}. Extrapolated to the entire Lower Guinean forest, this translates into a cash value of over US$1.4 thousand million per year, more than twice the value of all other non-timber forest products combined.

Increasing population and poverty, coupled with false valuations of rainforest biodiversity, have led to unregulated logging, habitat destruction and over-exploitation. In addition, fishing rainforest rivers increasingly involves the use of poisons that are highly destructive of the entire food web. New and diverse natural resource management and exploitation strategies are needed to add value to rainforest river ecosystems to justify their preservation and improve the livelihoods of rainforest communities.

INTRODUCTION

The Lower Guinean ichthyological province (Figure 1) extends in an arc along the NE corner of the Gulf of Guinea from the Cross River in the NW to just short of the Congo in the SE and includes some 50 major and minor rivers (Table 1). It is sandwiched in-between the Nilo-Sudan and Congo provinces. To the west and north, the Cross and Sanaga Rivers form the boundary with the Nilo-Sudan fauna. To the east and south, lies the Congo basin, separated from the Lower Guinean by a series of highlands, terminating with the Chaillu Mountains in the PR Congo. The river systems of the Lower Guinean province drain over 500 000 km^2 of tropical rainforest (Mahé and Olivry 1999), forming an integral part of the rainforest ecosystem.

■ **Figure 1.** Ichthyological provinces of Africa, based on Roberts (1975) as modified by Lévêque (1997) and redrawn according to new hydrological basin mapping published by FAO (2000). 1 = Maghreb, 2 = Nilo-Sudan, 3 = Upper Guinea, 4 = Lower Guinea, 5 = Congo Basin, 6 = Quanza, 7 = Zambezi, 8 = East Coast, 9 = Southern, 10 = Malagasy.

Table 1: Major rainforest river systems in the Lower Guinean icthyological province. Main tributaries are in parentheses. Alternative names are indicated with a slash. Data from: Hugueny (1989), Peyrot (1991a), Vivien (1991), Teugels, Reid & King (1992), Mahé & Olivry (1999).

River	Country	Length (km)	Watershed (km^2)	Discharge (m^3/s)	Number of Fish Species
Cross (Manyu, Mbu, Mé , Mfi)	Nigeria – Cameroon	600	70 000	570	166
NDIAN	Cameroon		>1 000		
MUNGO	Cameroon	200	4 570	164	32
Wouri (Dibomba, Makombé , Menoua, Nkam)	Cameroon	470	11 500	308	51
Sanaga (Djerem, Lom, Mbam)	Cameroon	1 043	131 000	2 072	124
Nyong (Mfoumou, Ké lé , So'o)	Cameroon	520	27 800	443	107
KIENKé /KRIBI	Cameroon	130	1 100		
LOBé	Cameroon	130	2 305	102	32
Ntem (Kom, Nlobo, Mboro. Mvila, Mvini)	Cameroon	460	26 300	290	110 +
RIO MUNI (MBINI)	Equatorial Guinea	365			
MITé Mé Lé	Equatorial Guinea				
Gabon (Mbé , Komo)	Gabon				
Ogooué (Abanga, Ayina, Dilo, Djoua, Ikoy, Ivindo, Lassio, Lé biri, Lekedi, Lé koko, Lé koni, Leyou, Lolo, Liboumba, Mounianzé , Mpassa, Mvoung, Ngounié , Nouna, Nsyé , Offoué , Okano, Oua, Sé bé , Wagny, Zadié)	Gabon	920	205 000	4 400	185
NKOMI	Gabon				
Ngové	Gabon				
Ndougou	Gabon				
MOUKLABA/NYANGA	Gabon				
Kouilou (Bouenza, Lé kourmou, Loué ssé , Mpoukou, Niari)	P.R. Congo	605	60 000	700	87

In addition to some 8 million people, the rainforest harbours the greatest biodiversity on the continent: 400 mammal species, 1 000 bird species and over 10 000 species of plant, of which some 3 000 are endemic (CARPE 2001). An integral part of this rainforest is the systems of swamps, creeks and rivers that drain it. Except for incomplete lists of species generated by European explorers and tropical fish fanciers, practically nothing is known about the ecology of these aquatic ecosystems. Without even clearly knowing what might be lost, a combination of human population growth and unregulated exploitation of rainforests for wood and bushmeat now threatens the integrity of this ancient ecosystem.

MATERIALS AND METHODS

Since September 2000, WorldFish Centre has been working with rainforest communities in the Lower Guinean ichthyological province of Southern Cameroon. In partnership with the Institut de Recherche Agricole pour le Développment (IRAD) a number of biological studies have been carried out on biodiversity, reproductive seasonality, sexual maturation and feeding habits of the ichthyofauna of the Nyong River. With the collaboration of the Ministere de l'Elévage, des Pêches et des Industries Animales de Cameroun (MINEPIA), additional work has been done on exploitation strategies and a needs assessment of fishing communities on the Ntem River. This latter particularly focused on the role of women in aquatic resource exploitation.

In addition to these academic studies, efforts are underway to organize fishing communities on the So'o, Mungo (Moliwe) and Ntem Rivers in an effort to improve the efficiency and sustainability of river exploitation and management. Groups have been formed by the villages themselves and these have acted as the interface between WorldFish Centre, the Government of Cameroon and the local population. These groups have identified ecotourism and exporting ornamental fishes as high priority activities.

The ultimate goal of this work is to establish functional village-based monitoring and management programs that would ensure the sustainability of new and diversified natural resource exploitation. As background to this effort, WorldFish Centre undertook an extensive survey of existing knowledge on the rainforest river ecosystem, its current uses and threats to its integrity. This paper reports the outcomes of this research and uses the documented perceptions of current resource users within the province to identify needs and indicate the direction for further work.

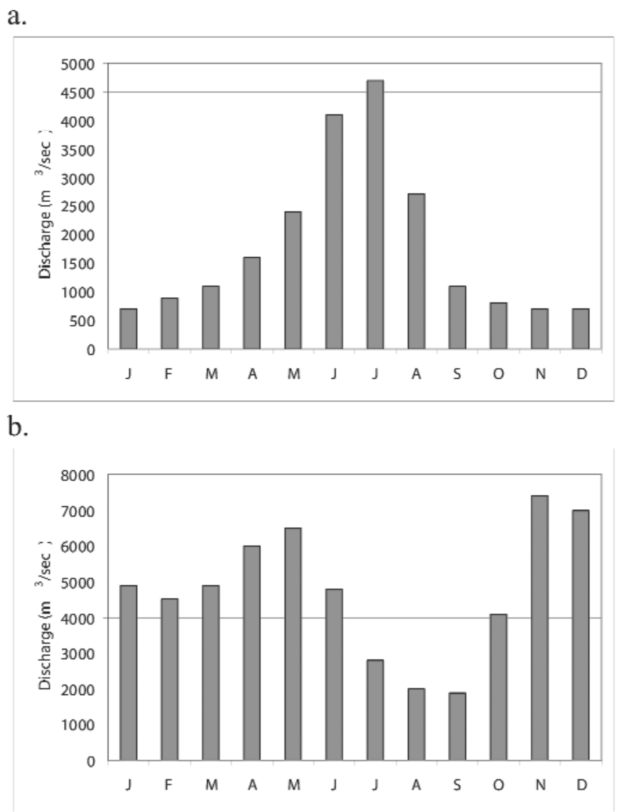
RESULTS AND DISCUSSION

Unlike the uplifting and rifting that affected eastern and southern Africa during the Miocene, the river courses in central Africa are extremely ancient, having not been substantially disrupted since the Precambrian (Beadle1981; Peyrot 1991a). Evidence reviewed by Lévêque (1997) seems to indicate that, at some time prior to the Miocene, there was a much greater overlap in African fish distribution than is currently the case. The Lower Guinean ichthyological province corresponds closely with the extent of humid forest refugia during the last dry phase of the continent, 20 000 – 15 000 years bp (Maley 1987; Schwartz 1991) and is similar to the distribution pattern of aquatic molluscs in the region (van Damme 1984). It seems likely that a more broadly distributed group of archaic taxa related to the modern species in the Lower and Upper Guinean provinces were repeatedly and/or progressively isolated during the several dry phases that reduced the extent of rainforest between 70 000 years bp and the present (Lévêque 1997).

In general, the aquatic resources of the Lower Guinean province are "blackwater" rivers, with a mean pH between 5 and 6 and electrical conductivity between 20 and 30 µS/cm. Water temperature is always between 20 and 30° C. The water in these rivers is clear and tea-coloured as a result of the low dissolved nutrient concentration, low light (due to narrowness of valleys, canopy cover and often cloudy skies) and the large amount of allochthonous vegetative matter that falls or flushes into the water from the surrounding forest (Welcomme and de Merona 1988).

In terms of hydrology, there are within the province two general types of river: 1) the tropical savannah type to the north (Cross, Mungo, Wouri, Sanaga), which have uni-modal discharge patterns (Figure 2a) and, 2) the 13 rivers that flow out of the present rainforest, which have a bimodal discharge pattern (Figure 2b). In general, the magnitude of fluctuation is greater in the north (up to 8 m on the

Lower Cross), while in the southernmost extent of the province, the partially spring-fed Niari and Nyanga exhibit minimal seasonality of flow (Peyrot 1991b).



■ **Figure 2.** Typical discharge patterns for rivers in the northern part of the Lower Guinean Ichthyological Province represented by the Sanaga River, Cameroon (a), and the southern part represented by the Oogoue River, Gabon (b). Data from Lévêque (1997).

Fish Biodiversity

When defining the currently used ichthyological provinces of Africa, Roberts (1975) noted an empirical similarity in terms of shared species and closely related taxa between the fish diversity of the Lower Guinean and that of the Upper Guinean province of the rainforests of Sierra Leone, Liberia and Côte d'Ivoire. Most ichthyologists seem to accept the general categories defined by Roberts, despite a lack of quantitative examination of the possible historical connection between the two provinces (Teugels, Reid and King 1992, Lévêque 1997).

In a review of West African riverine biodiversity, Hugueny (1989) found a strong correlation between species richness, watershed area and river discharge volume. Using these relationships, one finds that the fish fauna of the Lower Guinean ichthyological province's river systems are disproportionately rich in relation to their sizes (Teugels *et al.* 1992). For example: the Cross River, with a watershed of 70 000 km^2, has an estimated 166 species (1 spp 421 km^{-2}). The Nyong River has a watershed of only 28 000 km^2 and contains 107 species (1 spp 262 km^{-2}). On the other hand, the Niger River, with a watershed of 1 100 000 km^2 has 254 species (1 spp 4 331 km^{-2}). The Bandama, a rainforest river in Côte d'Ivoire with a drainage basin of 97 000 km^2, but with a fauna similar to that of the Nilo-Sudan, has only 95 species (1 spp 1 021 km^{-2}) (Hugueny and Paugy 1995). Even the Congo River with a watershed of 3 550 000 km^2 and a very stable flow regime that has existed for at least 3 million years (Beadle 1981) has only 690 species (1 spp/5145 km^2).

Annex A is a provisional list of the freshwater component of the fish biodiversity of the Lower Guinean ichthyological province. From the available literature, 29 families, 119 genera and 500 species have been identified with some reliability. Apart from the large number of small Cyprinodonts (of which 70 percent are from the genus *Aphyosemion*), the freshwater fauna is dominated by the Siluriformes (6 families, 23 genera, 102 species), the Characiformes (2 families, 20 genera, 62 species), the Cichlidae (17 genera, 54 species) the Cyprinidae (10 genera, 79 species) and the Mormyridae (14 genera, 49 species).

A relatively large percentage of fishes in the lower reaches of rainforest rivers are of brackish water or even marine origin and may occur as far as 300 km upriver (Reid 1989; Baran 2000). For example, the lower 80 km of the main channel of the Ntem River in the Campo-Ma'an National Park of Cameroon contains some 110 species, of which 57 are typically found in brackish water (Djama 2001). Teugels *et al.* (1992) noted that 20 percent of the fishes in the Cross River have marine affinities. These species are not included in Annex A.

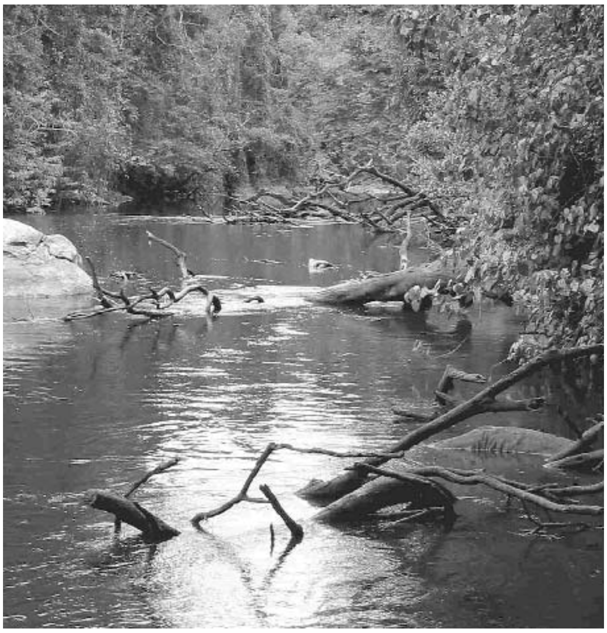
Endemism in rainforest fishes seems to be relatively high (Teugels and Guégan 1994), although it is very difficult from the scanty documentation to determine exactly how many of the single reports for a species are due to endemism, lack of adequate distribution data or simple misidentification (Stiassny 1996). In particular, the Cyprinodontiformes are prone to endemism, with some species occupying only a few hundred square meters of bog, or an isolated creek (Welcomme and de Merona 1988). These small fishes, of which there are at least 100 species in the province, account for a substantial portion of the overall species richness.

In addition, a number of fishes move up and down the river according to their reproductive seasonality. Cyprinids and Citharinids, in particular members of the genera *Labeo* and *Distichodus*, are reported by fishing communities in the Upper Cross and Ntem Rivers of Cameroon to undertake spawning runs during the latter part of the long rainy season (October-December) when rivers are swollen and marginal forests are flooded, providing cover and food for larvae and fry (Lowe-McConnell 1975; du Feu, 2001). The result of this is that species diversity measured over the year changes substantially according to which fishes are moving up or down stream at any particular point in time (Lowe-McConnell 1977).

The high fish species richness in the Lower Guinean province is probably the result of three main factors: 1) the relative stability of the hydrological regime in these rivers since the Eocene (compared to the Nilo-Sudan province), 2) the highly sculpted nature of the watershed (compared to both the Congo and Nilo-Sudan provinces) and, 3) the large number of microhabitats created in rainforest rivers by the forest itself.

Ecological Associations

The forested nature of the watershed is the major determinant of productivity and fish community structure in rainforest rivers. Stream width, depth, current velocity and substrate type have been identified as critical in determining the spatial distribution of most species (Lowe-McConnell 1975; Kamdem-Toham and Teugels 1997). These are all in one way or another, determined by the degree of canopy closure over the river from the surrounding forest. The low primary productivity in rainforest water means that food webs are mostly based on allochthonous plant materials from the forest. The hydrological regime and water temperature are directly influenced by the presence of the forest. The large amounts of dead wood influence depth and current velocity and provide shelter from predation, thus partitioning the stream and creating a large number of microhabitats (Figure 3).



■ **Figure 3.** The So'o river, Cameroon in mid-April 2002 showing the large amounts of allochthonous wood that creates both structure and food producing surface in rainforest river ecosystems. Photo by the author.

Both species diversity and richness increase as one moves downstream from swamp, to first-order forest stream (of which there are a particularly large number in African rainforests) to medium-sized tributary to the main channel, primarily through the addition of species rather than through replacement (Géry 1965; Welcomme and de Merona 1988; Kamdem-Toham and Teugels 1998). Flooded swamp forest, either permanent or annual, is a typical feature of rainforest river headwaters. These contain very low dissolved oxygen and very high carbon dioxide concentrations (pH is in the range of 4-5), but large quantities of allochthonous materials on a substrate of organic mud that generates abundant food for those species with accessory breathing organs or resistance to very low oxygen concentrations. A large number of larval fishes that survive by breathing from the air-water interface use the flooded forest as a nursery making this biotope particularly important to overall ecosystem integrity.

First order rainforest streams are typically <5 m wide, <50 cm deep and are characterized by long stretches of shallow riffle interrupted by deeper, lower-velocity pools into which fish shelter during periodic dry spells when streams stop flowing. Relief in rainforests tends to be low, so current velocity seldom exceeds 0.5 m/sec. Canopy closure ranges between 25 and nearly 100 percent. Substrate is typically composed of leaf-covered sand or gravel.

Medium-sized streams are transitional zones (Lévêque 1997). As one proceeds downstream, they feature decreasing canopy closure, current velocity, allochthonous material and electrical conductivity and increasing depth, fine sediment, large boulders, dissolved oxygen and pH.

The main channel of rainforest rivers is the most stable biotope and offers the greatest range of microhabitats (Welcomme and de Merona 1988). Citing Gosse's (1963) work on the Yangambi portion of the Zaire River, which is broadly similar to Lower Guinean ecosystems and shares a certain percentage of their biodiversity, Lowe-McConnell (1975) noted that, within the main channel, fish species richness and abundance are higher in shallow marginal waters along banks and islands than in mid-river. Gosse developed a "bank coefficient" that relates the length of water-bank contact (including bays, islands, etc.) to species richness. In these areas, sheltered from the main current, abundant aquatic vegetation representing a number of genera (*Anubias, Crinum, Commelina, Limnophyton, Nympahea, et al.*) creates habitats for a wide variety of species and their offspring (Kamdem-Toham and Teugels 1998).

The nature of forest river food webs means that most species rely on carnivory or detritivory of one type or another for survival and growth, planktivory being especially rare. Invertivores are the largest feeding guild in swamps and forest streams, while omnivory and herbivory are more common as one proceeds downstream. In general, fishes with highly specialized diets are more common downstream due to the larger number of specialized feeding niches (microhabitats). Although the high degree of evolutionary adaptation by fishes to the variety of rainforest river habitats means that for every family of fishes there seem to be a species or life-history stage for every habitat, some general trends among family preferences are evident (Table 2).

The Cyprinodontiformes of the genus *Aphyosemion* are typical species of small forest streams, often with very restricted distributions. In rainforest rivers, they are associated with shallower riffles through woody debris, moderate velocity and a closed canopy, abundant leaves on a gravel substrate and dense aquatic vegetation. They have two basic reproductive strategies, either laying eggs directly on or into the substrate, or laying adhesive eggs that stick to aquatic plants and individuals exhibit a certain amount of flexibility between the two (Sterba 1966). They eat mostly insect larvae. Cyprinodonts are

Table 2: General patterns of fish family distribution across habitats and ecological niches within rainforest rivers. Habitats are modified from the system adopted by Lowe-McConnell (1975) based on the categories of Matthes (1964).

Habitat	Detritvores	Planktivores	Herbivores	Invertivores	Carnivores	Omnivores
Main Channel, Pelagic	Alestiidae	Clupeidae Denticipidae?			Alestiidae Centropomidae	Alestiidae Cyprinidae
Main Channel, Benthic	Bagridae			Cyprinidae	Bagridae	Bagridae
Second & Third Order	Citharinidae Cyprinidae Mormyridae			Mochokidae Mormyridae	Gobiidae	Mochokida
Streams Including Marginal-Littoral & Quiet Backwaters of the Main Channel Forest Streams	Cichlidae Citharinidae Cyprinidae Mormyridae	Poeciliidae	Alestiidae Cichlidae Citharinidae Mochokidae	Anabantidae Cichlidae Cyprinidae Mochokidae Mormyridae Polypteridae Schilbeidae	Channidae Malapteruridae Nandidae Notopteridae Polypteridae	Alestiidae Bagridae Cichlidae Clariidae Mochokidae
Swamps	Citharinidae			Amphilidae Anabantidae Aplocheilidae Bagridae Clariidae Cyprinidae Mochokidae Poeciliidae Schilbeidae	Amphilidae Cichlidae Hepsetidae Mastecembelidae	Alestiidae Clariidae Kneriidae Mochokidae
	Clariidae Mormyridae			Anabantidae Mormyridae Pantodontidae Phractolaemidae	Channidae Eleotridae Protopteridae	Clariidae Mornyridae Polypterdae

important forage species, being consumed by a wide variety of carnivorous species. In addition, they have considerable value as ornamentals and have been widely exported by aquarium fanciers.

There are a wide variety of Siluriformes in rainforest rivers, the most characteristic and commercially important as food fish being members of the Bagridae and Mochokidae, particularly the genera *Auchenoglanis*, *Parauchenoglanis* and *Synodontis*. These catfishes live in larger streams where they spend most of their time under heavy cover amongst submerged branches and tree roots under the banks, emerging at night to feed on benthic invertebrates. Little is known about their reproduction, but at least some species move into marginal swamps or weedy areas during high water to spawn.

The Citharinidae and Cyprinidae undertake large-scale reproductive migrations and so vary in habitat over the course of their life cycle. During the latter part of the long rainy season (October-December) large numbers of these fish move from the main channel up into first order streams where they reproduce en masse, leaving their offspring to feed in the forest, while themselves returning downstream. Their lifestyles and diets are extremely varied, ranging from piscivory to herbivory. Although full of bones, the larger species are important as food for human communities.

The Cichlidae tend to prefer smaller streams and quiet backwaters. They represent the entire range of diets from herbivory to piscivory and the juveniles of some species even eat detritus. Their complex social behaviours and vibrant colours make them attractive aquarium fish, but most species are small and they are not common in local fish markets. Cichlids breed year round in shallow marginal areas where the majority provide substantial levels of parental care.

The Mormyridae are well adapted to the variety of habitats available in forest rivers and exist in most of them, but the majority are found in second order streams of moderate depth and current. While some Mormyrids are diurnal shoal feeders, most are nocturnal insectivores probing about in the sediments for larval forms and using their electrical generating ability to navigate and identify conspecifics in the dark. They reproduce during high water periods when flooded swamps are available as nurseries. Mormyrids contribute substantially to the commercial and subsistence fisheries of the forest.

As in other river systems on other continents, juveniles and adults of many rainforest river species occupy different habitats in order to avoid competition and/or cannibalism. In general, adults tend to dominate areas with good foraging opportunities leaving smaller/younger individuals to shallower and swifter habitats where larger individuals cannot reach. Smaller species in general tend to be more specific in their habitat preference than are larger species (Kamdem-Toham and Teugels 1997).

CURRENT EXPLOITATION SYSTEMS

Welcomme (1976) estimated the total number of first order rainforest streams in Africa at over 4 million with a combined total length equal to half of all watercourses, making these the largest single riverine ecosystem on the continent. Of the 8 million people who live in the Lower Guinean rainforests, nearly 20 percent are more or less fulltime fishers. Estimates from Cameroon put the productivity of capture fisheries in forest rivers basins at 1.1 tonnes km^{-2} yr^{-1} (du Feu 2001). Extrapolated to the entire Lower Guinean forest, this translates into a cash value of approximately US$1.4 thousand million per year, more than twice the value of all other non-timber forest products combined. Average fish consumption in Cameroonian rainforests is around 47 kg $person^{-1}$ $year^{-1}$, compared to 10 kg for the general population (Obam 1992).

Fishing in rainforest rivers is severely constrained by the large quantities of wood that accrue in the streambed. By far the most common types of gear are passive set nets, traps and hook-lines of which there are a great variety in accordance with the diversity of the fish fauna. Also common, is a hook-and-line fishery dominated by small children and mainly targeting immature cichlids.

Seasonal spawning migrations are reported for a number of species, ("most" according to Lowe-McConnell, 1975). Fishing communities have learned to take advantage of these runs by constructing mesh barriers constructed of tree trunks and branches, bound together by vines and held in place by large stones (Figure 4). At the height of the rains, these structures are submerged and gravid adults pass easily over them. After spawning and spending several months upstream in flooded forests to forage, the adults once again head back downstream. However, by this time the water levels have declined and the fish find themselves trapped when they try to avoid the barrier. Juveniles apparently pass through the mesh without problem.

■ **Figure 4.** A traditional fish dam constructed with locally available materials on the main channel of the So'o River, a tributary of the Nyong in South-Central Cameroon. Fish migrating upstream at high water to feed in flooded forests and spawn can swim over the top of the dam. As water levels decline, returning adults are captured while juveniles pass through the mesh.

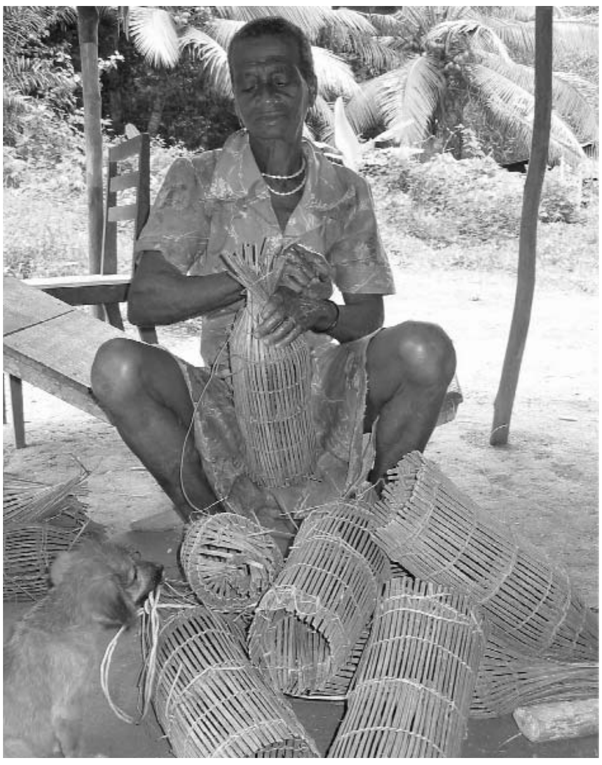
In Cameroon, a special type of reproductive event, known as the "dok" takes place during the long rains in October-November. Doks involving *Labeo batesii* and *Distichodus spp*. have been documented in the Upper Cross and the Ntem, respectively. They typically last no more than a few hours or days. According to du Feu (2001), who interviewed fishers on the Upper Cross River in Cameroon, the village is alerted to the imminence of the spawning event by the upstream movement of fish. Two hours after the fish have passed, the water turns white with milt, at which time the villagers set nets to block the return of spawned out adults on their return downstream. Men do the fishing with cast nets or even clubs, while women clean and smoke the catch. Eggs are normally not taken to ensure the continuation of the runs for future generations.

There are at least two traditional fisheries that are allocated entirely to women. One involves the construction of small earthen dams across first order forest streams during the dry season to capture small Channids, Clariids and Mastecembelids. As water levels decline, the dams prevent fish from migrating downstream. When the water gets low enough, the women wade in and bucket out the remainder, catching the fish by hand or with the help of baskets. This practice is widespread in both the Lower Guinean and Congo ichthyological provinces and adds substantially to the protein intake of forest communities. Another fishery that is the exclusive domain of women is the use of woven basket traps to catch the freshwater prawn, *Macrobrachium vollenhovenii* (Figure 5).

■ **Figure 5.** Fishing for freshwater prawns (*Macrobrachium vollenhovenii*) using woven basket traps is a traditional activity reserved exclusively for women in the Ntem River Basin.

Village leaders normally regulate access to a fishery. Such management techniques as prohibiting the collection of fish eggs during spawning runs and the prohibition of certain gears are traditionally enforced through the use of magic charms or "ju-ju". Villagers are free to fish as long at they follow the basic regulations. Visiting fishers, of which there are considerable numbers (an estimated 80 percent of fishers on Cameroonian rivers are of Malian or Nigerian origin) must first seek permission of the village leadership and then pay a token fee, normally in the form of palm wine or a percentage of the catch.

Despite these traditional management systems, over-fishing has become an increasing problem as the human population grows and puts increasing pressure on resources. In addition, the use of fish poisons has become increasingly frequent. Some of these are from local plants and cause only temporary harm, but most poisoners now use Lindane or Gammelin 20, an organochlorine insecticide used in cocoa production and highly destructive of the entire food web. Human deaths have been reported as a result of eating poisoned fish. A recent survey conducted on the Ntem



River just upstream from the Campo-Ma'an Forest Reserve in Southern Cameroon found that insecticide fishing had completely disrupted local aquatic ecosystems and had permitted the extension of the range of the electric catfish, *Malapterurus electricus* into the small rivers where they were previously not found. Because of the powerful shocks emitted by this fish, women have been forced to abandon their traditional dam fishing in the area.

INTEGRATED WATERSHED MANAGEMENT

The productivity of rainforest river ecosystems depends upon maintaining the integrity of the entire series of biotopes of which it consists. Without the forest, there would be no material inputs that feed the fish in the lower reaches. Without the first and second order rainforest streams, there would be no reproductive migrations and, consequently, the number and diversity of fish would be drastically reduced. Without the main channel system, the overall productivity of the river would be seriously diminished.

Unfortunately, increasing population and poverty, coupled with false valuations of rainforest biodiversity have led to habitat destruction and over-exploitation (Stiassny 1996). The Congo Basin has already lost an estimated 46 percent of its rainforest to logging and conversion to agriculture and continues to lose forested watershed at an average rate of 7 percent per year (Revenga *et al.* 1998). In addition, these forests are being harvested in a largely irresponsible manner that not only takes out the valuable timber, but also crushes the under story, alters stream courses and increases runoff and siltation. Roads, saw mills and other infrastructure associated with logging attracts people into the forest, resulting in wholesale transformation of the ecosystem (Burns 1972, Garman and Moring 1993).

Kamdem-Toham and Teugels (1999) described the changes that occur in and around the rainforest rivers in the Ntem River basin as a result of poorly managed logging operations:

- Absence of forest canopy above streams
- Heavy siltation
- Abundant primary production (algae)
- Uniform watercourse; absence of riffles; pools dominant habitat type
- No cover/shelter for fish

In terms of water quality, these changes in habitat resulted in large decreases in water clarity and dissolved oxygen and large increases in temperature and conductivity. In undisturbed sites, water was clear brown with a mean temperature of 23.5°, dissolved oxygen between 2.5 and 4.2 mg l^{-1} (measured at noon) and electrical conductivity between 20 and 30 υS cm^{-1}. In sites affected by logging, the water was cloudy with a mean temperature of 34°, dissolved oxygen of <1.0 mg l^{-1} and average electrical conductivity of 48 υS cm^{-1}. Changes of this magnitude can wreak havoc on aquatic life and may last for many years (Chutter 1969; Growns and Davis 1991).

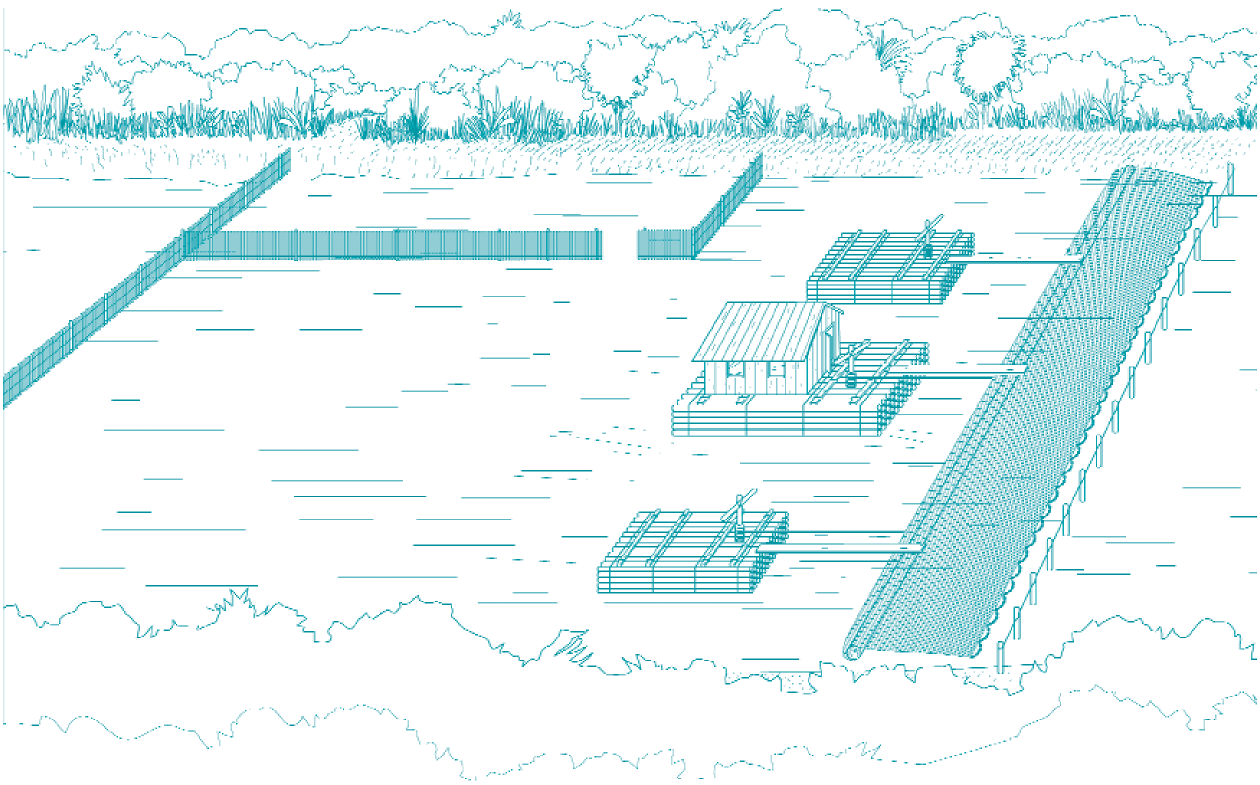
Forestry management practices exist that could substantially reduce the negative impacts of logging (Davies and Nelson 1994; Smith, Brown and Pope 2001). An economic and social re-evaluation of rainforest river fisheries in relation to timber exploitation might encourage changes in current forest management policy (CARPE 2001). However, substantial work needs to be done if the vested interests of politicians and logging companies are to be thwarted.

A first step is the generation of expert systems that can be used to monitor the status of aquatic ecosystems as changes take place in the watershed. Several attempts have been made at the generation of a workable Index of Biotic Integrity (IBI) such as that used to track changes in temperate zone streams, but parameterisation has been a problem. The best effort to date in Central Africa is that of Kamdem-Toham and Teugels (1999), but gaps still exist. Existing datasets on aquatic biodiversity and ecology in Central Africa are weak, at best and this makes it very difficult to develop quantitative tools (Lévêque 1997).

Coupled with this valuation exercise should be the development of improved management and exploitation strategies that could actually increase the value of aquatic ecosystems and justify their preservation, while at the same time improving rural livelihoods. Forest river ecosystems are currently unmanaged and unregulated in any formal sense. The Department of Fisheries in Cameroon does not even have a policy or planned program of work on riverine ecosystems outside of a number of small dams (M.O. Baba, Director of Fisheries, personal communication, Yaoundé, April 2002). The most widely promoted method of increasing the productivity of aquatic ecosystems in Central Africa is to increase fishing pressure through the introduction of subsidies on motors and other fishing equipment and this without any clear idea as to the size of the resource or level of current exploitation.

While some increased pressure might be warranted in some areas, the upper limit for this strategy is probably already in sight for most places. Careful regulation of fishing gear and seasons based on scientific data might be a more widely applicable strategy for increasing catches of certain species in some rivers. In addition, integrated aquaculture in rainforest watersheds could take advantage of abundant water supplies and organic matter and might even be used in stock-enhancement or ranching where feasible or necessary. This might not be exclusively limited to the traditional food fishes. Species with value (both locally and internationally) as ornamental aquarium fishes are unusually abundant in rainforest rivers and fetch much higher prices per kilogram than food fish (Tlusty 2002).

Working with communities to both develop the tools and manage ecosystems might be worth trying (CARPE 2001). WorldFish Centre community based management of aquatic ecosystems program in Bangladesh has produced positive outcomes. Other agencies working in the rainforest, most notably the Centre for International Forestry Research (CIFOR) and the World Wildlife Fund (WWF) have had some success in community forestry management and such efforts need to be strengthened and broadened to include the most valuable non-timber forest product of them all: rainforest fishes.



REFERENCES

Baran E. 2000. Biodiversity of estuarine fish faunas in West Africa. *Naga, The WorldFish Centre Quarterly,* 234: 4-9.

Beadle L.C. 1981. *The inland waters of tropical Africa, second edition*. London, Longman. 475 pp.

Burns J.W. 1972. Some effects of logging and associated road construction on northern California streams. *Transactions of the American Fisheries Society*, 1011: 1-17.

CARPE. 2001. Congo Basin information series. Central African Regional Program for the Environment. Gland, Switzerland, World Wildlife Fund.

Chutter F.M. 1969. The effects of silt and sand on the invertebrate fauna of streams and rivers. *Hydrobiologia,* 341: 57-76.

Davies P.E. & M. Nelson. 1994. Relationships between riparian buffer widths and the effects of logging on stream habitat, invertebrate community composition and fish abundance. *Australian Journal of Marine and Freshwater Resources*, 45: 1289-1305.

Djama T. 2001. *Inventaire qualitatif de poisons dans l'UTO Campo-Ma'an. Document 11.* Project d'Aménagement et de Conservation de la Biodiversité de Campo-Ma'an, Kribi, Cameroon.

Du Feu T.A. 2001. Fish and fisheries in the southern zone of the Takamanda Forest Reserve, Southwest Cameroon. Consultant's report to the Cameroonian-German project: Protection of Forests around Akwaya PROFA, GTZ, Yaoundé, Cameroun.

FishBase. 2000. Electronic database on fishes. International Center for Living Aquatic Resources Management, Penang, Malaysia.

Garman G.C. & Moring J.R. 1993. Diet and annual production of two boreal river fishes following clearcut logging. Environmental Biology of Fishes, 36: 301-311.

Géry J. 1965. Poissons du Basin d l'Invindo. Biologica Gabonica, 1: 375-393.

Gosse J.P. 1999. Document for the study of the zoogeography of African freshwater fishes. (http://www.naturalsciences.be/science/collections/africanfish). Royal Brussels, Belgian Institute of Natural Sciences.

Growns I.O. & Davis J.A. 1991. Comparison of the macroinvertebrate communities in streams in logged and undisturbed catchments 8 years after harvesting. Australian Journal of Marine and Freshwater Resources, 42: 689-706.

Hugueny B. 1989. West African rivers as biogeographic islands: Species richness of fish communities. Oecologia, 79: 236-243.

Hugueny B. & Paugy D. 1995. Unsaturated fish communities in African rivers. American Naturalist, 146: 162-169.

Kamdem-Toham A. &. Teugels G.G. 1997. Patterns of microhabitat use among fourteen abundant fishes of the lower Ntem River Basin Cameroon. Aquatic Living Resources, 10: 289-298.

Kamdem-Toham A. & Teugels G.G. 1998. Diversity patterns of fish assemblages in the Lower Ntem River Basin Cameroon, with notes on potential effects of deforestation. Archives of Hydrobiology, 1414: 421-446.

Kamdem-Toham A. & Teugels G.G. 1999. First data on an index of biotic integrity (IBI) based on fish assemblages for the assessment of the impact of deforestation in a tropical West African river system. Hydrobiologia, 397: 29-38.

Lévêque C. 1997. Biodiversity dynamics and conservation: The freshwater fishes of tropical Africa. Cambridge, UK, Cambridge University Press.

Lowe-McConnell R.H. 1975. Fish communities in tropical freshwaters. London, Longman.

Lowe-McConnell R.H. 1977. Ecology of fishes in tropical waters. London, Edward Arnold.

Mahé G. & Olivry J.C. 1999. Les apports en eau douce à l'Atlantique depuis les côtes de l'Afrique intertropicale. In Sciences de la terre et des planets. C.R. Academie de Sciences de Paris, 328: 621-626.

Maley J. 1987. Fragmentation de la forêt dense humide et extension des biotopes Montagnards au quaternaire récent. Palaeoecology of Africa, 18: 207-334.

Matthes H. 1964. Les poissons du Lac Tumba et de la région d'Ikela. Etude systématique et écologique. Annales, Série 8, Sciences Zoologiques 126. Terverun, Belgium, Musée Royal de l'Afrique Centrale.

Obam A. 1992. Conservation et mise en valeur de forêts au Cameroun. Yaounde, Cameroun, Imprimerie National.

Peyrot R. 1991a. La géologie de l'Afrique centrale. In R. Lanfranchi & B. Clist, Aux Origines de L'Afrique Centrale. Centre International des Civilizations Bantu, Libreville, Gabon, Centre Culturels Français d'Agrique Centrale.

Peyrot R. 1991b. Hydrologie de l'Afrique centrale. In R. Lanfranchi & B. Clist, Aux Origines de L'Afrique Centrale, Centre International des Civilizations Bantu, Libreville. Gabon, Centre Culturels Français d'Agrique Centrale.

Reid G.M. 1989. The living waters of Korup rainforest: A hydrobiological survey report and recommendations with emphasis on fish and fisheries. WWF Report 3206/A8:1. Gland, Switzerland, World Wildlife Fund.

Revenga C., Murray S., Abramovitz J. & Hammond A., 1998. Watersheds of the world: Ecological value and vulnerability. Washington, DC, World Resources Institute.

Roberts T.R., 1975. Geographical distribution of African freshwater fishes. Zoological Journal of the Linnaean Society, 57: 249-319.

Schwartz D. 1991. Les paysages de l'Afrique centrale pendant le quaternaire. In R. Lanfranchi & B. Clist, Aux Origines de L'Afrique Centrale, Centre International des Civilizations Bantu, Libreville, Gabon, Centre Culturels Français d'Agrique Centrale.

Smith F., Brown A.V. & Pope M. 2001. Meiofauna in intermittent streams differ among watersheds subjected to five methods of timber harvest. Hydrobiologia, 464: 1-8.

Sterba G. 1966. Freshwater fishes of the world. London, Studio Vista Ltd.

Stiassny M.L.J. 1996. An overview of freshwater biodiversity with some lessons from African fishes. Fisheries, 219: 7-13.

Teugels G.G. & Guégan J.F. 1994. Diversité biologique des poisons d'eaux douces de la Basse-Guinée et de l'Afrique Centrale. In G.G. Teugels, J.-F. Guégan & J.-J. Albaret, eds. Diversité biologique des poissons des eaux douces et saumâtres d'Afrique. Annales Sciences Zoologiques. Tervuren, Belgium, Musée Royal de L'Afrique Centrale. 275 pp.

Teugels G.G., Reid G. & King R.P. 1992. Fishes of the Cross River Basin: Taxonomy, zoogeography, ecology and conservation. Annales Sciences Zoologiques, Terverun, Belgium, Musée Royale de l'Afrique Centrale. 266 pp.

Tlusty M. 2002. The benefits and risks of aquacultural production for the aquarium trade. Aquaculture, 205: 203-219.

Van Damme D. 1984. The freshwater mollusca of northern Africa. Developments in Hydrobiologia 25. Dordrecht, The Netherlands, W. Junk Publishers.

Vivien J. 1991. Faune du Cameroun: Guide des mammifères et poissons. Yaoundé, Cameroun, GICAM et Ministère de la Coopération et du Développement.

Welcomme R.L. 1976. Some general and theoretical considerations on the fish yield of African rivers. Journal of Fish Biology, 8: 351-364.

Welcomme R.L. & de Merona B. 1988. Fish communities in rivers. In C. Leveque, M.N. Bruton & G.W. Sentongo, eds. Biology and Ecology of African Freshwater Fishes, Collection Travaux et Documents. Paris, Editions de l'ORSTOM. 216 pp.

Annex A. A provisional list of the freshwater fishes of the Lower Guinean Ichthyological province defined by Roberts (1975) and modified by Lévêque (1997). To compile this list, fish lists from Vivien (1991), Teugels *et al.* (1992), Kamdem Toham & Teugels (1997), Gosse (1999) and FishBase (2000) were compared and rationalized. Species with brackish or marine affinities are not included.

FAMILY	GENUS	Species
Alestiidae	*Alestes*	*bartoni*
		batesii
		jacksonii
		macrophthalmus
		schoutedeni
		taeniurus
		tessmanni
		tholloni
	Brycinus	*imberi*
		intermedius
		kingsleyae
		longipinnis
		macrolepidotus
		nurse
		opisthotaenia
	Alestopetersius	*hilgendorfi*
	Arnoldichthys	*spilopterus*
	Brachypetersius	*gabonensis*
		huloti
		notospilus
	Bryconaethiops	*macrops*
		microstoma
		quinquesquamae
	Hydrocynus	*forskalii*
	Micralestes	*acutidens*
		elongatus
		humilis
	Nannopetersius	*ansorgii*
		lamberti
	Phenacogrammus	*major*
		stigmatura
		urotaenia
	Rhabdalestes	*septentrionalis*
		smikalai
Amphilidae	*Amphilius*	*baudoni*
		brevis
		longirostris
		pulcher
		thysi
	Doumea	*typica*
	Paramphilius	*goodi*
	Phractura	*ansorgii*
		brevicauda
		clauseni
		gladysae
		intermedia
		longicauda
		scaphyrhynchura
Anabantidae	*Ctenopoma*	*garuanum*
		kingsleyae
		maculatum

FAMILY	GENUS	Species
		nebulosum
		nigropannosum
		petherici
	Microctenopoma	*nanum*
Aplocheilidae	*Aphyosemion*	*abacinum*
		ahli
		amieti
		amoenum
		arnoldi
		aureum
		australe
		avichang
		bamilekorum
		batesii
		bitaeniatum
		bivittatum
		bualanum
		buytaerti
		calliurum
		cameronense
		celiae
		cinnamomeum
		citreinpinnis
		coeleste
		cyanostictum
		dargei
		edeanum
		elberti
		escherichi
		exigoideum
		exiguum
		fallax
		franzwerneri
		fulgens
		gabunense
		gardneri
		georgiae
		hanneloreae
		heinemanni
		hera
		herzogi
		hofmanni
		jorgenscheeli
		kekemense
		kouamense
		lamberti
		loennbergii
		louessense
		lugens
		maculatum
		marmoratum
		mimodon
		mirabile
		ndianum
		ocellatum
		oeseri
		ogoense

FAMILY	GENUS	Species
		ottogartneri
		pascheni
		passaroi
		primigenium
		puerzli
		punctatum
		pyrophore
		raddai
		rectogoense
		riggenbachi
		robertsoni
		rubrolabiale
		schluppi
		seegersi
		sjoestedti
		splendidum
		splendopleure
		striatum
		thysi
		tirbaki
		volcanum
		wachtersi
		zygaima
	Diapteron	*abacinum*
		cyanostictum
		fulgens
		georgiae
	Epiplatys	*berkenkampi*
		callipteron
		esekanus
		grahami
		huberi
		infrafasciatus
		neumanni
		sangmelinensis
		sexfasciatus
		singa
Bagridae	*Anaspidoglanis*	*ansorgii*
		boutchangai
		macrostoma
	Auchenoglanis	*ahli*
		ballayi
		guirali
		longiceps
		monkei
		pantherinus
		pietschmanni
	Chrysichthys	*aluuensis*
		auratus
		dageti
		filamentosus
		furcatus
		nigrodigitatus
		ogooensis
		persimilis
		longidorsalis
		nigrodigitatus

FAMILY	GENUS	Species
		ogooensis
		persimilis
		thysi
		walkeri
	Parauchenoglanis	*akiri*
		altipinnis
		buettikoferi
		fasciatus
		grandis
		guttatus
		maculosus
	Platyglanis	*depierrei*
Centropomidae	*Lates*	*niloticus*
Channidae	*Parachanna*	*africana*
		insignis
		obscura
Cichlidae	*Chilochromis*	*duponti*
	Chilotilapia	*rhoadesii*
	Chromidotilapia	*batesii*
		finleyi
		guentheri
		loenbergi
		kingsleyae
		linkei
	Gnathochromis	*pfefferi*
	Gobiocichla	*ethelwynnae*
	Hemichromis	*bimaculatus*
		fasciatus
		stellifer
	Konia	*dikume*
		eisentrauti
	Myaka	*myaka*
	Nanochromis	*riomuniensis*
	Oreochromis	*macrochir*
		schwebischi
	Parananochromis	*caudifasciatus*
		gabonicus
		longirostris
	Pelvicachromis	*pulcher*
		subocellatus
		taeniatus
	Pungu	*maclareni*
	Sarotherodon	*caroli*
		galilaeus
		linnellii
		lohbergeri
		melanotheron
		mvogoi
		steinbachi
	Thysochromis	*ansorgii*
	Tilapia	*bakossiorum*
		bythobates
		cabrae
		cameronensis
		camerunensis
		deckeri

FAMILY	GENUS	Species
		flava
		guineensis
		gutturosa
		imbriferna
		kottae
		margaritacea
		mariae
		nyongana
		snyderae
		spongotroktis
		tholloni
		thysi
	Tylochromis	*sudanensis*
		trewavasae
Citharinidae	*Congocharax*	*gossei*
		spilotaenia
	Distichodus	*engycephalus*
		hypostomatus
		kolleri
		notospilus
		rostratus
	Hemistichodus	*vaillanti*
	Ichthyoborus	*monodi*
	Nannaethiops	*unitaeniatus*
	Nannocharax	*altus*
		fasciatus
		intermedius
		latifasciatus
		maculicauda
		micros
		ogoensis
		parvus
		rubrolabiatus
		rubrotaeniatus
	Neolebias	*ansorgii*
		axelrodi
		kerguennae
		powelli
		trewavasae
		unifasciatus
	Phago	*loricatus*
	Xenocharax	*spilurus*
Clariidae	*Channallabes*	*apus*
	Clariallabes	*attemsi*
		brevibarbis
		melas
		pietschmanni
	Clarias	*agboyiensis*
		buthupogon
		camerunensis
		ebriensis
		gabonensis
		gariepinus
		longior
		maclareni
		macromystax

FAMILY	GENUS	Species
		jaensis
		pachynema
		plathycephalus
		submarginatus
	Gymnallabes	*alvarezi*
		typus
	Heterobranchus	*longifilis*
Clupeidae	*Cynothrissa*	*ansorgii*
	Laeviscutella	*dekimpei*
	Pellonula	*leonensis*
		vorax
	Sierrathrissa	*leonensis*
	Thrattidion	*noctivagus*
Cyprinidae	*Barboides*	*gracilis*
	Barbus	*ablabes*
		aboinensis
		aloyi
		altianalis
		alvarezi
		aspius
		batesii
		bourdariei
		brazzai
		brevispinis
		brichardi
		bynni
		callipterus
		camptacanthus
		cardozoi
		carens
		catenarius
		chlorotaenia
		compinei
		condei
		diamouanganai
		guirali
		holotaenia
		hypsolepis
		inaequalis
		jae
		lagoensis
		lucius
		malacanthus
		martorelli
		mbami
		micronema
		miolepis
		mungoensis
		nigeriensis
		nigroluteus
		occidentalis
		prionacanthus
		progenys
		rouxi
		roylii
		stauchi

FAMILY	GENUS	Species
		punctitaeniatus
		stigmatopygus
		sublineatus
		sylvaticus
		taeniurus
		tegulifer
		thysi
		trispilominus
	Garra	*dembeensis*
	Labeo	*annectens*
		batesii
		camerunensis
		coubie
		cyclorhynchus
		lukulae
		ogunensis
		parvus
		senegalensis
		variegatus
	Leptocypris	*crossensis*
		niloticus
	Opsaridium	*ubangense*
	Prolabeops	*melanhypoptera*
		nyongensis
	Raiamas	*batesii*
		buchholzi
		nigeriensis
		senegalensis
	Sanagia	*velifera*
	Varicorhinus	*fimbriatus*
		jaegeri
		mariae
		sandersi
		steindachneri
		tornieri
		werneri
Denticipidae	*Denticeps*	*clupeoides*
Eleotridae	*Eleotris*	*daganensis*
		feai
	Kribia	*kribensis*
Gobiidae	*Awaous*	*lateristriga*
	Sicydium	*crenilabrum*
Hepsetidae	*Hepsetus*	*odoe*
Kneriidae	*Grasseichthys*	*gabonensis*
	Parakneria	*abbreviata*
Malapteruridae	*Malapterurus*	*electricus*
Mastacembelidae	*Aethiomastacembelus*	*marchei*
		sexdecimspinosus
	Caecomastacembelus	*batesii*
		brevicauda
		cryptacanthus
		decorsei
		flavomarginatus
		goro
		longicauda
		marchei

FAMILY	GENUS	Species
		marmoratus
		niger
		sanagali
		sclateri
		seiteri
Mochokidae	*Atopochilus*	*savorgnani*
	Chiloglanis	*batesii*
		cameronensis
		disneyi
		micropogon
		niger
		polypogon
	Hemisynodontis	*membranaceus*
	Microsynodontis	*batesii*
	Synodontis	*albolineatus*
		annectens
		batesii
		eupterus
		guttatus
		haugi
		marmoratus
		nigrita
		obesus
		ocellifer
		polyodon
		rebeli
		robbianus
		schall
		steindachneri
		tessmanni
Mormyridae	*Boulengeromyrus*	*knoepffleri*
	Brienomyrus	*adustus*
		batesii
		brachyistius
		curvifrons
		hopkinsi
		kingsleyae
		longianalis
		longicaudatus
		sphecodes
	Campylomormyrus	*curvirostris*
		phantasticus
	Gnathonemus	*petersii*
	Hippopotamyrus	*castor*
	Isichthys	*henryi*
	Ivindomyrus	*opdenboschi*
	Marcusenius	*abadii*
		brucii
		conicephalus
		friteli
		mento
		moorii
		ntemensis
		paucisquamatus
	Mormyrops	*anguilloides*
		batesianus
		caballus

FAMILY	GENUS	Species
		zanclirostris
	Mormyrus	*caballus*
		felixi
		hasselquistii
		rume
		tapirus
		thomasi
	Paramormyrops	*gabonensis*
	Petrocephalus	*ansorgii*
		ballayi
		catostoma
		guttatus
		microphthalmus
		simus
	Pollimyrus	*adspersus*
		lhuysi
		marchei
		pedunculatus
		polylepis
		walkeri
	Stomatorhinus	*polylepis*
		walkeri
Nandidae	*Polycentropsis*	*abbreviata*
Notopteridae	*Papyrocranus*	*afer*
	Xenomystus	*nigri*
Pantodontidae	*Pantodon*	*buchholzi*
Poeciliidae	*Aplocheilichthys*	*camerunensis*
		luxophthalmus
		scheeli
		spilauchen
	Hylopanchax	*stictopleuron*
	Hypsopanchax	*catenatus*
		zebra
	Plataplochilus	*cabindae*
		loemensis
		miltotaenia
		ngaensis
		terveri
	Procatopus	*aberrans*
		nototaenia
		similis
Phractolaemidae	*Phractolaemus*	*ansorgii*
Polypteridae	*Erpetoichthys*	*calabaricus*
	Polypterus	*retropinnis*
Protopteridae	*Protopterus*	*dolloi*
Schilbeidae	*Parailia*	*occidentalis*
		pellucida
	Pareutropius	*buffei*
		debauwi
	Schilbe	*brevianalis*
		djeremi
		grenfelli
		intermedius
		micropogon
		multitaeniatus
		mystus
		nyongensis

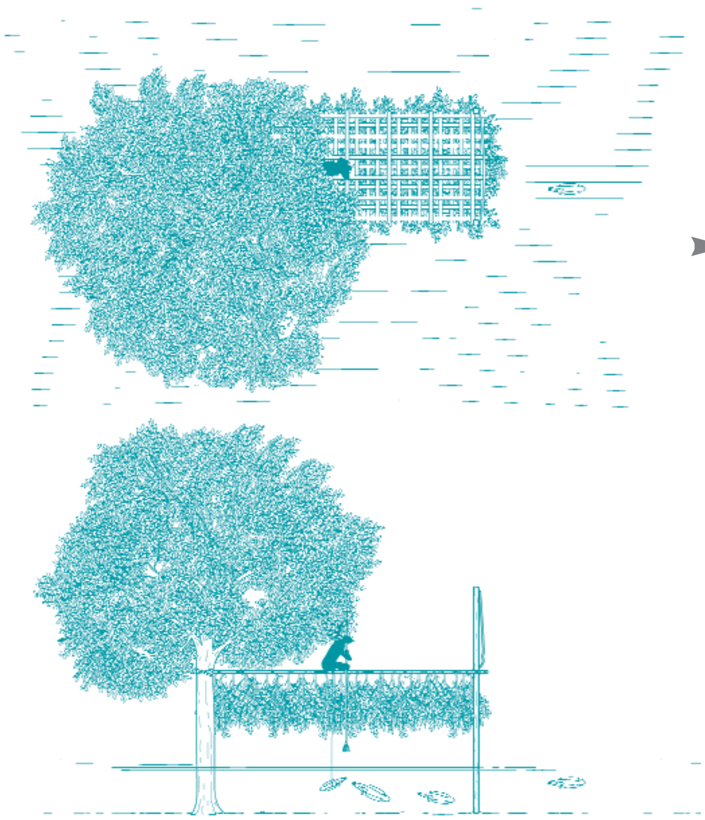
STATUS AND MANAGEMENT OF FISHERY RESOURCES OF THE YANGTZE RIVER

D. Chen[1 2] X. Duan[2] S. Liu[2] W. Shi[3]

[1] Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan 430071, P.R. China

[2] Yangtze River Fisheries Research Institute, Chinese Academy of Fishery Sciences, Jingzhou 434000, P.R. China

[3] Freshwater Fishery Research Center, Chinese Academy of Fishery Science, Wuxi 214081, P.R. China



Key words: Yangtze River, fishery resources, management options

ABSTRACT

The Yangtze River is the largest river in the Peoples Republic of China. It is 6 300 km long and drains 1.8 million km^2 of land. It delivers 1 000 billion m^3 of freshwater into the Shanghai Bay. The basin can be divided into three parts, the upper reaches, the middle reaches and the lower reaches. The “three reaches” approach is mainly supported by fish distribution patterns and hydrological alterations. The fish fauna of the Yangtze River system comprises over 370 species (178 genera, 52 families, 17 orders), of which cyprinids (Cyprinidae) account for 51 percent, loaches (Cobitidae) 6.9 percent, bagrids (Bagridae) 6.9 percent, Homalopteridae 5.5 percent, gobies (Cobiidae) 4.4 percent and other families 24.9 percent. There are 126 fish species in the lower Yangtze. In the middle Yangtze, there are over 140 fish species, most of which are either semi-migratory or resident. In the upper Yangtze, there are over 180 fish species. Historically, the Yangtze River system supported large runs of anadromous fish species. The late 1960s to early 1970s had seen the highest catch of Chinese shad and sturgeon in China. However, the migratory fish populations of both anadromous species began to decline in the early 1980s as a result of overfishing, pollution, water projects and habitat loss. There is a general indication that the fishery resources of the Yangtze are underexploited. This is based on the size and quality of the species landed, the current production compared with that of previous periods and the main species. It is recommended that (a) the Fisheries Management Council be strengthened, substituting the present authoritarian system by participatory management by the fisheries community, (b) commercial fisheries be managed by the quota system and improved by catching underexploited species, (c) an adaptive management approach be adopted that takes into account natural environmental variations and (d) the need for planning for an integrated development of the whole Yangtze River fishery be recognized. The paper makes suggestions for fishery management in response to the existing problems.

INTRODUCTION

The Yangtze valley is the most developed freshwater fisheries area in China, with abundant fish resources and long history of fisheries. The area has been called “the cradle of freshwater fisheries production”, with production accounting for about 60 percent of the national total freshwater fish catch (Chen Liu and Duan 2002). The Yangtze fish catches have decreased or fluctuated after a historical record of 0.45 million tonnes in 1954 (Ke and Wei 1993). In the last decade, the catch has fallen below 0.10 million tons, with a notable depletion of migratory and semi-migratory fish stocks, the primary reasons being the destruction of the aquatic ecosystem and overfishing. This paper focuses on measures taken for strengthening fishery administration at various levels, for comprehensive harnessing of water resources and for research as a way of rehabilitating the Yangtze fisheries.

MATERIALS AND METHODS

Fishery resources of the Yangtze River were investigated between 1971 and 2000. Statistical data were obtained from the Fishery Bureau of Agricultural Ministry of China. Local and national monitoring stations provided environmental and hydrological data. All data were analysed by SAS software.

RESULTS AND DISCUSSION

FISH FAUNA AND ITS DISTRIBUTION

The fish fauna of the Yangtze River system comprises over 370 species (178 genera, 52 families, 17 orders), of which cyprinids (Cyprinidae) account for 51 percent, loaches (Cobitidae) 6.9 percent, bagrids (Bagridae) 6.9 percent, Homalopteridae 5.5 percent, gobies (Cobiidae) 4.4 percent and other families 24.9 percent (Wu 1984).

The major species of economic importance are black carp (*Mylopharyngodon piceus* (Rich.), grass carp (*Ctenopharyngodon idella* (C. et V.), silver carp (*Hypophthalmichthys molitrix* (C.et V.), bighead carp (*Aristichthys nobilis* (Rich.), common carp (*Cyprinus carpio* (L.), crucian carp (*Carassius auratus* (L.), blunt snout bream (*Megalobrama amblycephala* Yih), whitefish (*Hemisalanx brachyrostralis* (Fang), silurid catfish (*Silurus asotus* (L.), copper fish (*Coreius heterodon* (Bleeker), Chinese shad (*Macrura reevesii* (Rich.), anchovy (*Coilia mystus* (L.), Chinese sturgeon (*Acipenser sinensis* Gray), paddle fish (*Psephurus gladius* (Martens), Chinese sucker (*Myxocyprinus asiaticus* (Rich.) and eel (*Anguilla japonica* Temm. et Schl.). The distribution of the fish species varies from section to section of the river.

There are 126 fish species, most of them migratory, in the lower Yangtze. In the fisheries of Jiangsu Province, anchovy accounts for about 50 percent of the catch, shad and eels for 20 percent, common carp, silurid catfish, black carp, grass carp, silver carp, bighead, whitefish, etc. for 30 percent. The catch from the lower Yangtze accounts for 63 percent of the total (Table 1).

There are over 140 fish species in the middle Yangtze most of which are semi-migratory (black carp, grass carp, silver carp, bighead carp and some other) and resident species (common carp, crucian carp, etc.). The catch from the middle Yangtze accounts for 34 percent of the total (Table 1).

There are over 180 fish species in the upper Yangtze. Copper fish is the main species, accounting for about 40 percent of the catch, common carp and Chinese sturgeon (before the damming of the Yangtze River at Gezhouba) acount for up to 15 percent each, *Leiocassis longirostris* accounts for 10 percent. Other major species are *Procypris rabaudi*, *Spinibarbus*, *Varicorhinus simus*, grass carp and *Elopichthys bambusa*. The catch from the upper Yangtze accounts for 3 percent of the total (Table 1).

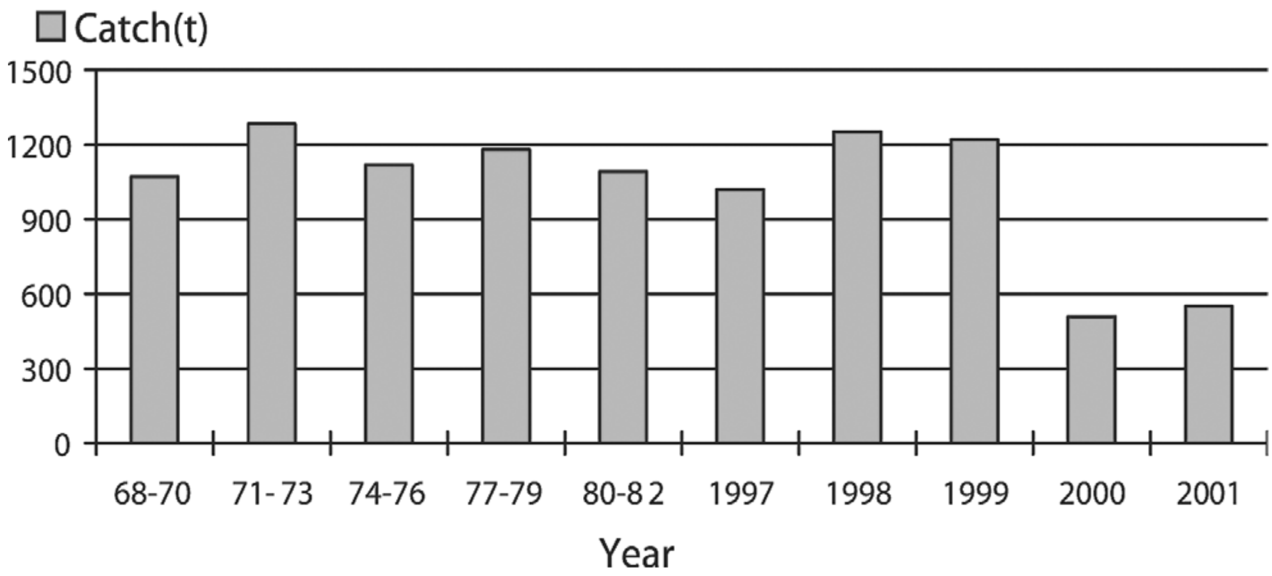
Major fish species

Anchovy

Anchovy is found mainly in Shanghai City and Jiangsu Province. In both places the production accounts for about 70-80 percent of the total catch. The annual catch fluctuates between 250 and 400 tonnes. A historical maximum of 4 000 tonnes was reached in 1973. Although the catch has been fluctuating in the last decade to some extent, it has generally been stable (Figure 1).

Table 1: The distribution of fish species along the Yangtze River

SECTION	**Upper Yangtze**	**Middle Yangtze**	**Lower Yangtze**
Number of fish species	126	140	180
Major fish species	copper fish, common carp, grass carp, *Leiocassis longirostris*, *Procypris rabaudi,* *Spinibarbus*, *Varicorhinus simus,* *Elopichthys bambusa*	copper fish, black carp, grass carp, silver carp, bighead carp, common carp, crucian carp, Chinese sturgeon	anchovy, Shad, Eel, common carp, silurid catfish, black carp, grass carp, silver carp, bighead, whitefish
Catch percentage	3% of the total	34% of the total	63% of the total



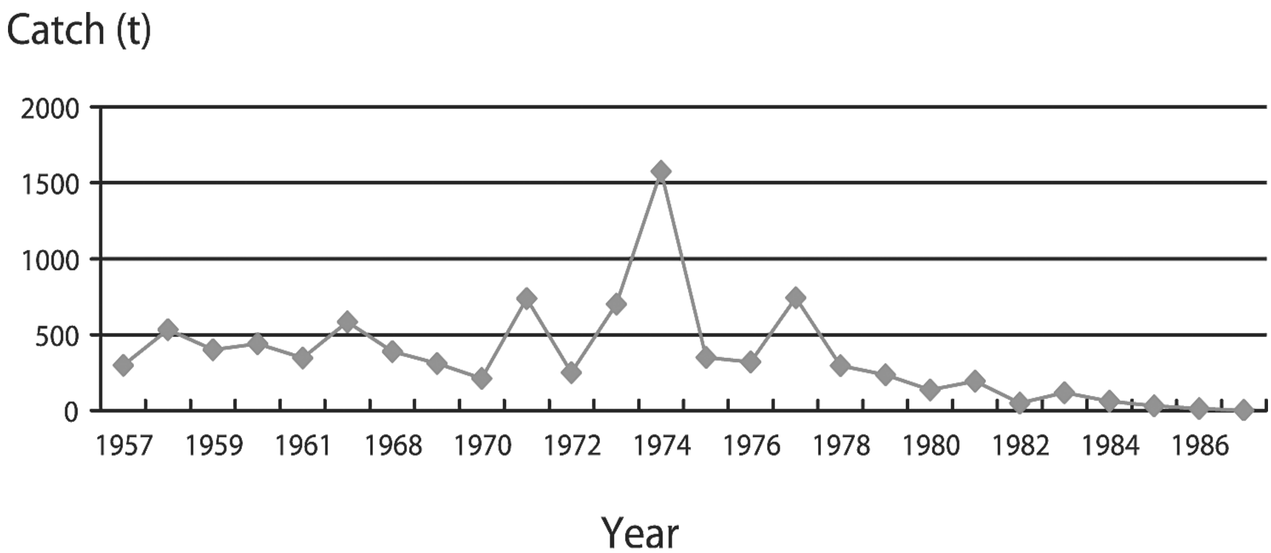
■ **Figure 1.** The annual catch of anchovy

Chinese shad

Chinese shad is an anadromous fish species. Before 1962 its annual catch from the Yangtze River was about 500 tonnes. After 1968 the catches decreased, with only 70 tonnes captured in 1971. In 1974, a record of 1 570 tonnes were harvested, this to be followed by a dramatic decline to 12 tonnes in 1986. Chinese shad is now endangered to the point of extinction (Figure 2).

Chinese sturgeon

This is also an anadromous species. Before the Yangtze River was dammed at Gezhouba, the annual catch fluctuated between 391 and 636 individuals, averaging 517 annually (Anon. 1988; Fu 1985). After the damming, the annual mean catch from 1981 to 1987 was 378 individuals, representing 73 percent of that before damming (due to the ban on sturgeon fishing). There is



■ **Figure 2.** The annual catch of Chinese shad great concern that when the Three Gorges Dam is completed, the spawning grounds of Chinese sturgeon below the dam may disappear or become dysfunctional (Kynard, Wei and Ke 1995).

Black carp, grass carp, silver carp and bighead carp

The percentage of black carp, grass carp, silver carp and bighead carp in the total catch from the Yangtze River has been declining (Liu, Chen and Zhan 2002). While in 1982 these carps accounted for 84 percent of the catch in Anhui Province on the lower Yangtze, they decreased to 36.8 percent in the 1990s. In the middle reach of the river in the Yichang section of Hubei Province the carps accounted for 80-90 percent of the catch in the 1960s, but only 22 percent in 1974 and 0.52 percent to 5 percent in the recent decade.

Copper fish

The copper fish dominates the catch from the upper Yangtze. In 1974, it represented 60.8 percent of the catch in the Wanxian and Yibin sections. Before the damming the catches were stable, but afterwards there was a steep decrease. In 1982, the fish accounted for about 10 percent and in 1986 for only 4.7 percent of the total catch. During the period 1981 to 1987 catches in the Yichang section below the dam increased to 50-60 percent of the total catch.

Common carp, crucian carp and silurid catfish

These are the most widely distributed resident species. They account for 40-50 percent of the total catch from the middle and lower Yangtze and for 60.6 percent of the total from the Jialing River (the upper Yangtze). The proportion of these species in the catch remains relatively stable in spite of the decreasing total catch.

Paddlefish

Stocks of paddlefish are gradually declining and the individual size is becoming smaller. According to statistics, only about ten individuals are caught annually in the Yichang section. The average weight of most individuals is now below 30 kg. Only rarely is an individual over 50 kg captured. And the species is now rated as one of the rare fish species.

Leiocassis longirostis

This is another rare fish species. It is distributed in all sections of the river. Its flesh is tender and the taste delicious. The swim bladder, when dried, can be processed into fish maw, a well-known Chinese dish. The pen-holder-line fish maw produced in Shishou City, Hubei Province has enjoyed fame at home and abroad. Previously, several thousand kg of fish maw was processed for export, but now it cannot be found in the markets and catches of the adult fish have declined.

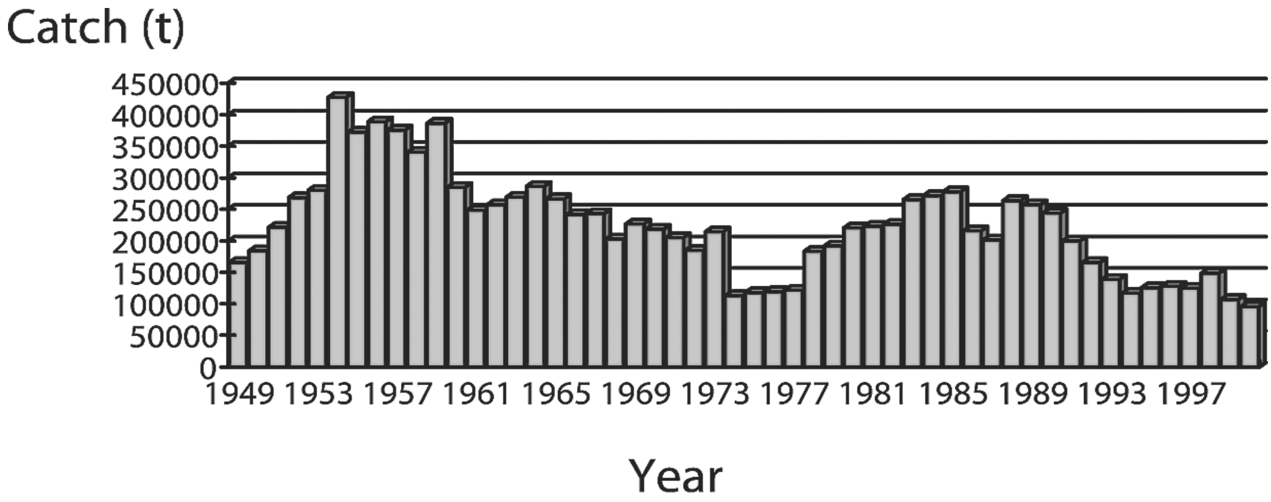
Chinese sucker

The Chinese sucker is also rated as rare. Formerly, in the Yangtze it represented about 13 percent of the total catch from the Mingshan section. In the last decade its stocks have been gradually depleted. Only ten old fish have been caught annually from the section from Yichang to Shishou, Hubei Province. Few individuals weigh over 10 kg and the majority are about 5 kg.

FISH CATCHES

Between 1949-2000 the Yangtze annual fish catches fluctuated between 0.10 and 0.44 million tonnes (Figure 3) and the average annual catch for this period was 0.25 million tonnes. There was an increase in catches from 1949 to 1954, reaching a historical record. From 1955 to 1960, the mean annual catch was 0.35 million tonnes, from 1961 to 1967, 0.26 million tonnes, from 1968 to 1982, 0.21 million tonnes and from 1983 to 2000, 0.13 million tonnes, showing a steady decline.

On the whole, the catch from the upper Yangtze tended to rise, but sometimes fluctuated over a small range owing to variations in the composition of fish fauna in this reach. From 1949 to 1954 the catch fluctuated between 4 756 and 6 339 tons, averaging 5 527



■ **Figure 3.** The annual catch from the Yangtze River

tonnes annually. From 1955 to 1960, the catch fluctuated from 6 327 to 422 tonnes, with an average of 6 932 tonnes. From 1961 to 1967, the catch fluctuated from 5 327 to 6 260 tonnes, average 5 503 tonnes. From 1968 to 1983, the catch fluctuated from 5 184 to 14 227 tonnes, average 7 353 tonnes. From 1983 to 2000, the catch fluctuated from 4 184 to 14 886 tonnes, average 7 753 tonnes per year.

The catch from the middle and lower Yangtze River fluctuated between 0.09 and 0.44 million tonnes, with a mean annual catch of 0.24 million tonnes. The catch rose from 1949 to 1954, when the historical record was set with 0.44 million tonnes. From 1955 onwards, it was on the decrease or it fluctuated. The mean annual catch was 0.35 million tonnes for the period 1955 to 1966, 0.25 million tonnes for 1961 to 1967, 0.18 million tonnes for 1968 to 1982 and 0.11 million tonnes for 1983 to 2000.

Reasons for the decline in fisheries

Destruction of the aquatic ecosystem

Blockage of passage for semi-migratory species by isolation of lakes from rivers

The famous fish ecologist G. V. Nikolsky believed that the origin and diversity of fish fauna in the Yangtze River is due to its floodplains. The development of the fish fauna is closely related to the periodic floods. While most fish species spawn in running water, laying drifting eggs, the fry enters floodplain lakes to feed and grow there. The adults retreat from the lakes to the river for wintering and/or spawning. Most riverine fish species have a dark back and white belly, which is an adaptation for living in open waters.

Over the last 30 years, more than 7 000 drainage sluices were constructed in the Yangtze valley. With the exception of the lakes Dongting and Poyang, which are still connected with the Yangtze, all other lakes are isolated from the river, preventing the fish to migrate from lakes into the river. This has prevented fish fry and elvers from entering lakes to feed and grow, as well as preventing the return of broodstock to the river or the sea for spawning. The result has been a decline in recruitment of many fish species.

Blockage of spawning migrations by dams

Since the foundation of the People’s Republic of China, over 50 000 reservoirs, including the Gezhouba Hydroelectric Project and Three Gorges Dam have been constructed. Today, the main channel of the Yangtze River and many of its tributaries are dammed and migration of migratory and semi-migratory fish species is blocked. Destruction of spawning habitats has led to a reduced recruitment and substantial decrease in catches. The construction of the Wanan Dam on the upper Ganjiang River in 1986 destroyed the spawning habitats of the anadromous Chinese shad and almost led to its disappearance. The completion of the Gezhouba Hydroelectric Project in 1981 blocked spawning migrations of Chinese sturgeon and copper fish. As a result, the rate of recruitment of Chinese sturgeon decreased by 80 percent.

Destruction of spawning grounds by land reclamation from lakes

In the past 40 years, when the priority was given to grain production, large areas of land were reclaimed from lakes by building dykes. For example, 80 000 hectares were reclaimed from Lake Poyang (Qian, Huan and Wang 2002), resulting in a reduction of fish spawning grounds by 50 percent and 160 000 hectares of land were reclaimed from Lake Dongting (Liao, He and Huang 2002), resulting in a loss of 36 percent. Land reclamation not only destroyed the spawning grounds of some resident fish species, but also affected the recruitment rate, both of which resulted in a decline in fish catches.

Impact of water pollution on migration, feeding, growth and survival of fish

With the rapid development of industry in the Yangtze valley, the amount of industrial wastewater and urban sewage discharged into the river has been increasing. Now in certain sections of the river the water is highly polluted. In the year 2000 in 21 cities along the river there were over 2000 spot pollution sources, discharging 14.2 billion tonnes of waste (Chen, Sun and Qu 2002). The discharge of wastewater and sewage into the river resulted in the pollution of water and fish food organisms, destruction of spawning grounds, depletion of broodstock, decreasing fish production and in a high fish mortality in certain sections of the Yangtze River.

Overfishing

There are over 160 kinds of fishing gears used in the Yangtze River (Duan, Chen and Liu 2002), of which the most harmful are small mesh fyke nets, fyke nets made of ramie cloth, fish mazes, drop nets, damming nets and trap nets. According to the statistical data, in Banhu village in Lake Poyang, 85 tonnes of fish (including 0.3 million young common carp, black carp, grass carp, bighead and silver carp) were caught with small mesh fyke nets. In Luhu village, Yuanjiang County, the juveniles of the major economic fish species accounted for 61.5 percent of the catch using small mesh fyke nets made of ramie cloth. In Shongmensan village on Lake Poyang, over 600 kg of shad juveniles of less than 1 g were caught by this gear annually, accounting for 17.15 percent of the total catch in 1973. In one day, 4 800 kg of fingerlings of over 10 cm were caught by three mazes in Dongting village, Yueyang County, Hunan Province. Before the damming of the Yangtze River at Gezhouba, over 1000 sturgeon were caught by fyke nets in Jiayu section in 15 days, one thousand or so by trap nets in Xupu section, Jiangsu Province, in two months and several thousand by stake nets in the waters around the Chougming Island (Wei 1997). The damage caused to juvenile fish by harmful fishing gears and methods is considerable. One reason for the fishing of juveniles in those days was the lack of control by the responsible administration.

MANAGEMENT OPTIONS

STRENGTHENING ADMINISTRATION OF THE YANGTZE FISHERY

In order to enhance the Yangtze valley fishery it is necessary to establish and strengthen fishery administration agencies at various levels in the Yangtze valley, to formulate better fisheries laws and regulations and to enforce them. The activities should include rationalisation of the fishery, protection of fishery resources and improvements in management such as licensing; fishing gear and net mesh size restrictions, length limits and seasonal restrictions. Also, there should be some attention to co-management approaches in the Yangtze River fisheries.

Emphasis on rehabilitation of aquatic environment

Aquatic ecosystems consist of many components that interact with each other. A change in one component will influence the ecosystem including the fish assemblages. Over thirty years of experience has shown that isolation of lakes from rivers, damming of rivers, land reclamation from lakes, water pollution and overfishing damages or destroys fish habitats and ultimately results in severe depletion of fish stocks, as experienced in the Yangtze River. In order to develop fisheries for the people in the Yangtze valley, emphasis should be placed on a comprehensive rehabilitation of water resources. Hydraulic structures should be constructed for protection and enhancement of fish habitats. Wastewater should be disposed according to water quality criteria endorsed by the government. Land reclamation should be forbidden from lakes and fisheries should be managed to protect the sustainability of fishery resources.

Chinese sturgeon and Chinese sucker are already rated as rare fish species. Their stocks have been depleted and some species are endangered to a point of becoming soon extinct. It is difficult to restore such fish species merely by forbidding the fishing of broodstock. Stocking should be another way of increasing their stocks. Some endangered species have been successfully artificially propagated and their fry reared in hatcheries, from which the young fish have been regularly released in a variety of water bodies. It is suggested that if a million fingerlings of each of the rare species are released in the Yangtze annually, this would lead to a 30 000 to 50 000 tonne increase in annual production, which is equal to 1/6 of the present catch from the Yangtze.

Enforcement of closed areas and seasons to enhance fish reproduction

Broodstock and juveniles of shad should be protected and the protection of their spawning grounds enforced to ensure that the juvenile stocks are not destroyed (Shi and Wan 2002). The capture of elvers should be strictly controlled and their resources protected. Closed seasons should be introduced and enforced in order to protect fish breeding in the whole river in the spring.

Ban on fry capture from the Yangtze River

Because of the isolation of lakes from the Yangtze River, catches of the four major commercial fish species have drastically decreased. Fish farmers usually collect fish fry from the river and transfer it to lakes to enhance fish yields. This may result in a certain success, but it leads to a depletion of the stocks of the four major carps in the river. Transfer of fry into lakes from the river without the possibility for the return of adults is detrimental. In order to ensure that there will be sufficient stocks in the river, the quantity of fry removed from the river should be limited.

Ban on harmful fishing gear and methods and introduction of size limits

Fishing gears and methods that damage juvenile fish stocks must be banned, mesh size for various types of nets strictly controlled and minimum allowable catch sizes for individual fish species introduced.

Intensification of research

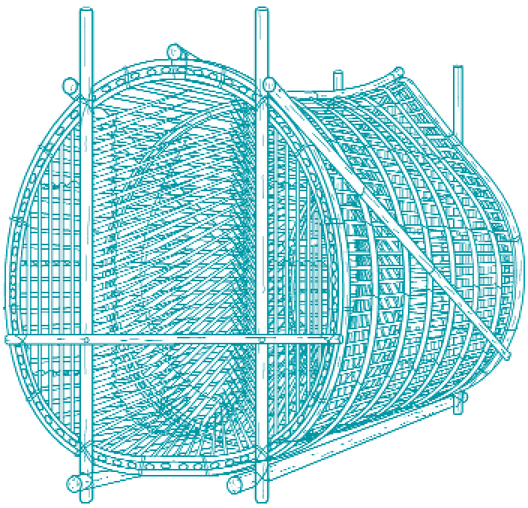
The rehabilitation and management of Yangtze fisheries must be based on both policy and science. Although a considerable amount of research has been done on Yangtze fisheries in the last forty years, administrators directed most of it. Scientific research was uneven, full of ups and downs for the lack of a comprehensive programme of sufficient duration and consistency. Some projects ended prior to their completion. The instability of research (by research institutes), superficial character of research work and absence of a follow-up led to incomplete data collection.

The present status of Yangtze fishery resources and the deterioration in the aquatic environment of the

Yangtze shows that future research should focus on biology, ecology, fish culture techniques, resource enhancement, protection of natural spawning areas, protection of migratory and semi-migratory species. Future management should also put more emphasis on social aspects of fisheries.

ACKNOWLEDGEMENTS

The Management Commission of the Yangtze Fishery Resources coordinated the field surveys and the Fishery Bureau of the Agricultural Ministry of China assisted with data collection. We thank Mr Yonghua Chang for the critical review of the manuscript.



REFERENCES

Anonymous. 1988. *The biology of sturgeons in the Yangtze and their artificial propagation*. Chendu: Sichuan Scientific & Technical Publishing House. pp. 19-79. (in Chinese)

Chen D.Q., Liu S.P. & Duan X.B. 2002. A preliminary study of the fisheries biology of main commercial fishes in the middle and upper reaches of the Yangtze River. *Acta Hydrobiologica Sinica*, 26: 622-626. (in Chinese)

Chen J.C., Sun Z.Z. & Qu J.H. 2002. Water pollution and its toxicity to fishes in the major areas of the lower reaches of the Yangtze River. *Acta Hydrobiologica Sinica*, 26: 640-646. (in Chinese)

Duan X.B., Chen D.Q. & Liu S.P. 2002. Studies on status of fishery resources in Three Gorges reservoir reaches of the Yangtze River. *Acta Hydrobiologica Sinica*, 26: 611-616. (in Chinese)

Fu Z.J. 1985. The artificial propagation of Chinese sturgeon below Gezhouba Dam. *Freshwater Fisheries*, 1: 1-5. (in Chinese)

Ke F.E. & Wei Q.W. 1993. Effects of Yangtze Gorges Project on fishery resources. *Freshwater Fisheries*, 6: 15-18. (in Chinese)

Kynard B., Wei Q.W. & Ke F.E. 1995. Use of ultrasonic telemetry to locate the spawning area of Chinese sturgeon. *Chinese Sci. Bul.*, 40: 668-671. (in Chinese)

Liao F.C., He W. & Huang X.R. 2002. Studies on present situation and change trend of Dongting lake fishery resources and environment. *Acta Hydrobiologica Sinica*, 26: 627-633. (in Chinese)

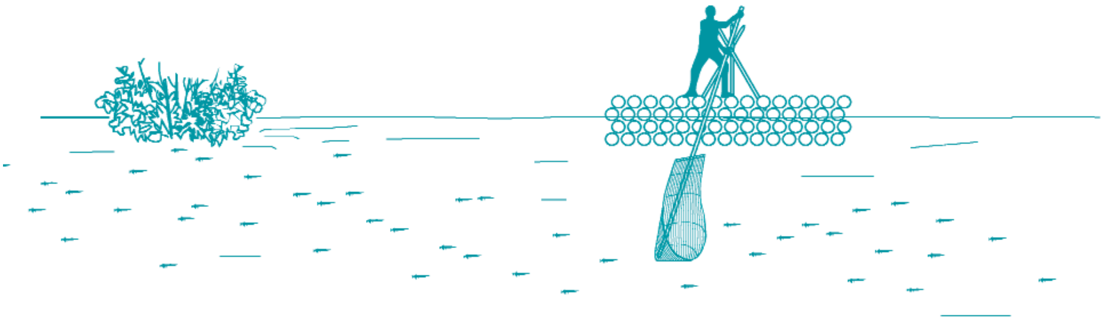
Liu S.P., Chen D.Q. & Zhan J.B. 2002. Studies on the natural resources of the four major Chinese carps in Laojianghe oxbow. *Acta Hydrobiologica Sinica*, 26: 634-639. (in Chinese)

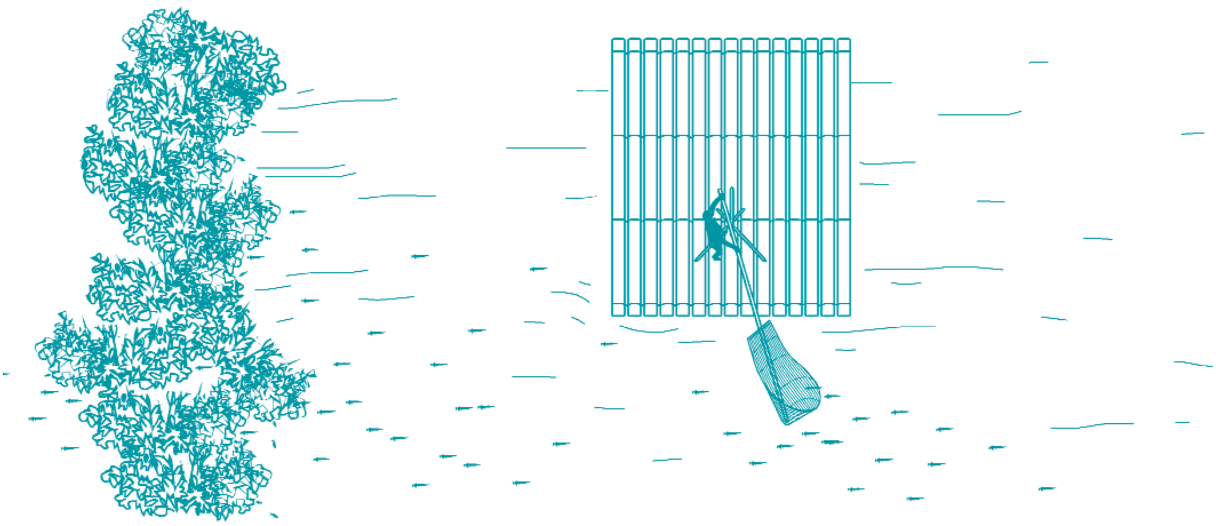
Qian X.E., Huan C.G. & Wang Y.M. 2002. The status of fishery resources of Poyang lake and its environmental monitoring. *Acta Hydrobiologica Sinica*, 26: 617-621. (in Chinese)

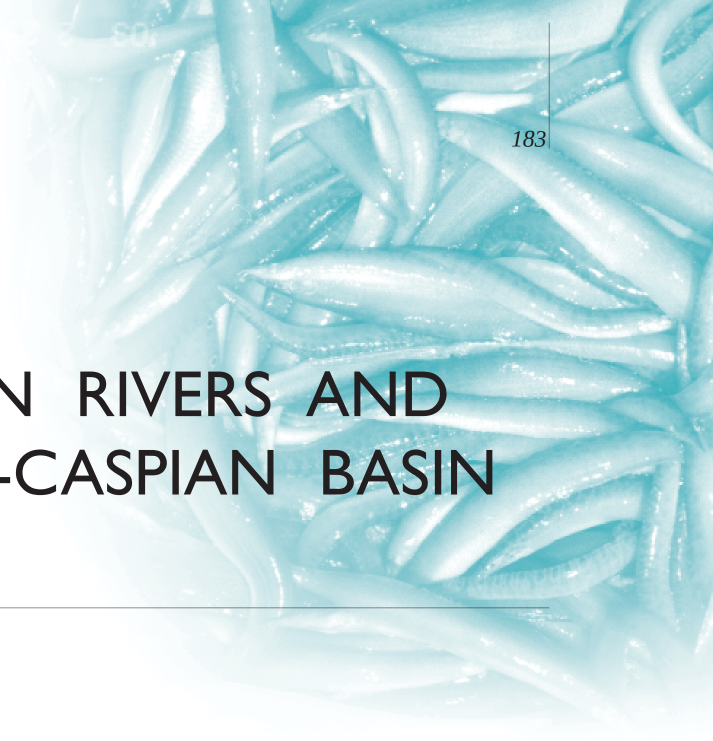
Shi W.G. & Wan B. 2002. Status of tapertail anchovy resources in the estuaries of the Yangtze River. *Acta Hydrobiologica Sinica*, 26: 653-660. (in Chinese)

Wei Q.W. 1997. Biology, fisheries and conservation of sturgeons and paddlefish in China. *Environmental Biology of Fishes*, 48: 241-255.

Wu X.W. 1984. *Ichthyology of Yangtze River*. Beijing: Sciences Press. (in Chinese)







HUMAN IMPACT ON RIVERS AND FISH IN THE PONTO-CASPIAN BASIN

B. Fashchevsky

International Sakharov Environmental University, 48-99 Kalinovskogo Street, 220086 Minsk, Republic of Belarus

Key words: Ponto-Caspian rivers, dams, reservoirs, pollution, fishways

ABSTRACT

Fifty years ago up to 650 000 tonnes of fish were captured annually from the rivers of the Ponto-Caspian basin. Among them were valuable sturgeon, bream, carp, pikeperch, sabre fish and catfish. Since then engineering modifications of rivers, such as dams and irrigation systems, direct withdrawal of water and pollution from a variety of sources have had a major impact on the aquatic environment, including fish stocks. At present there are 74 engineering structures in the basin of the Danube that interfere with the free flow: 87 on the Dniester, 650 on the Dnieper, 653 on the Don, 58

on the Kuban, 812 on the Volga, 79 on the Kura, 22 on the Terek and 91 on the Ural. The result has been a degradation of fish stocks and a steep decline in catches especially of the most valuable species such as sturgeon, salmonids and migratory freshwater herring, all of which have lost their spawning grounds. Semi-migratory bream, pikeperch, carp and sabrefish have also been affected. Changes in water regime have altered the areas and the timing of flooding, interfering with the spawning of fish. As the fish reproduction rate declined, the catches declined as well. Great losses of fish are taking place in irrigation pumping stations, with millions of especially young fish ending on irrigated fields. In some rivers pollution further aggravates the situation. In the former countries of the USSR the declining living standards and an increase in unemployment have led to widespread poaching. The degradation of fish stocks has been to some extent reduced by repeated stocking of some rivers with sturgeon and some other young fish produced in hatcheries.

INTRODUCTION

The Ponto-Caspian region covers 3.4 million km^2, encompassing the basins of the Black, the Azov and the Caspian seas. The major rivers in this region are the Volga, Danube, Dnieper, Dniester, Don, Kuban, Terek and Kura. They, together with many smaller rivers, provide spawning grounds for migratory and semi-migratory fish. Fifty years ago 600 to 650 thousand tonnes of valuable fish were caught in the former Soviet territorial waters of the Ponto-Caspian basin, including about 200 000 tonnes of semi-migratory and migratory sturgeons, herrings, bream, carp, roach, pikeperch and sabrefish.

The life history of these fish is closely linked both with the sea and with rivers. In 1936 the total catch of migratory and semi-migratory fish in the Black-Azov seas basin was 198 000 tonnes (Rass 1965). By 1959, after the completion of dams on the Dniester, Dnieper, Don and Kuban, catches decreased to about 60 000 tonnes. Sturgeons declined from 6 900 tonnes in 1936 to 1 200 tonnes in 1959 and in the same period pikeperch declined from 74 500 tonnes to 10 800 tonnes, bream from 47 200 tonnes to 5 200 tonnes, herring from 5 700 tonnes to 2 400 tonnes.

This paper discusses the ecological situation of the major rivers of the Ponto-Caspian system following the implementation of large-scale water regulation projects in their basins. Dams and reservoirs, irrigation systems, direct withdrawal of water into transfer canals, pumping of young fish into canals, discharge of waste waters from industry, settlements, agricultural projects, as well as poaching have led to degradation of major fish populations and to a catastrophic decline in fish stocks and catches, especially of the migratory and semi-migratory fish.

In the part of the Ponto-Caspian region that formerly belonged to the USSR there are 2 526 reservoirs with a total volume of 310 km^3, including 74 reservoirs with a total volume of 3 km^3 on the Danube, 87 with 3.68 km^3 volume on the Dniester, 650 with 47.4 km^3 on the Dnieper, 653 with 31.4 km^3 on the Don, 58 with 4.4 km^3 on the Kuban, 812 with 190.4 km^3 on the Volga, 22 with 0.8 km^3 on the Terek, 79 with 20.4 km^3 on the Kura and 91 with 4.9 km^3 on the Ural. There are also numerous pumping stations taking water directly from the river channels.

Reservoirs have permanently flooded former spawning grounds of beluga (*Huso huso* (L.), Atlantic sturgeon (*Acipencer sturio* L.), Russian sturgeon (*Acipencer gueldenstaedti* Brandt), Persian sturgeon (*Acipencer persicus* Borodin), bastard (spiny) sturgeon (*Acipencer nudiventris* Lovetzky), starred sturgeon, also called sevruga (*Acipencer stellatus* Pallas), Black Sea salmon (*Salmo trutta labrax*), Caspian salmon (*Salmo trutta caspius*), inconnu (*Stenodus leucichthys* Guldenstadt), Caspian shad (*Alosa caspia* Eichwald), black backed shad (*Alosa kessleri* (Grimm), Black Sea shad (*Alosa pontica* Eichwald). Spawning grounds of semi-migratory species such as bream (*Abramis* spp), zander or European pikeperch (*Stizostedion lucioperca* L.), European carp (*Cyprinus carpio* L.), sabrefish (*Pelecus cultratus* (L.) and others have remained, but owing to the change in the water regime, the periods and areas of flooding of the spawning grounds have changed, as well as the thermal and sediment regimes. The changes in the hydrological regime have resulted in reduced spawning intensity, which has resulted in lower catches.

Semi-migratory and riverine fish suffer great losses from pumping millions of young fish onto irrigated fields. Pollution affects the reproduction of fish in rivers, estuaries and deltas and in the adjacent sea. Apart from raw or poorly treated sewage, industrial waste waters and return waters from agriculture fields also contribute to the pollution. Even now, when the volume of industrial production has decreased by 30-40 percent in comparison with the year 1991, the maximum admissible concentrations (MAC) of organic matter (oil products, phenols, pesticides, etc.) and heavy metals are exceeded tenfold. The dissolution of the USSR, followed by a decrease in the living standard and increase in unemployment in the catchments of the rivers entering the Azov and the Caspian seas, has led to a widespread poaching of fish. It is estimated that poachers capture at least five times more fish than are declared in official catch statistics. This has led to a decrease in the number of broodstock and a lower rate of recruitment.

To compensate for the losses, numerous fish breeding farms were constructed, with an annual output of 70 million sturgeons and over 2 billion semi-migratory young fish. These measures compensated for the decline in migratory and semi-migratory fish stocks but by no means restored the damage caused by the impact of dams. Fishways were constructed on some dams on the Volga, Don and Kuban rivers to enable the upstream migration of fish. Their efficiency proved to be low, especially for large and slow moving fish such as sturgeons. In general, the situation in the Ponto-Caspian basin rivers is dire and quickly deteriorating. The world should be concerned as more than 90 percent of the world stocks of sturgeon are present in this region.

MAJOR RIVERS

There is a strong link between the migratory and semi-migratory fish populations in the Ponto-Caspian basin and the sea.

The Black Sea covers 423 000 km^2, its mean depth is 1 271 m and its maximum depth 2 245 m. The following major rivers enter the sea: Danube, Dniester, Southern Bug and Dnieper, plus several other smaller rivers.

The Kerch Strait joins the Azov Sea to the Black Sea. It has an area of 37 600 km^2, mean of depth of 6.8 m and a maximum depth of 13.3 m. That part of the Black Sea with a depth of less than 100 metres accounts for fully one third of the total area of the sea and half of this, including the Karkinitsky Gulf, is situated in its northwestern part and about one third is in the Azov Sea. The Black Sea is stratified into two layers: the upper layer extends to 100-150 m depth and contains plankton, nekton and benthos; below it is a layer saturated with hydrogen sulfide and inhabited only by bacteria.

The upper layer of the Black Sea has two sublayers, i.e. the surface layer down to 25-50 m and an inner layer, from 50 m to 125-150 m, distinguished by their temperature regimes. The temperature of the surface layer has a wide range from 27°C in the summer to 7-8°C in the winter. In shallow water this variability is even greater: from 30°C in the summer to –1.4°C in the winter. The water of the inner layer has much smaller annual temperature amplitude from 6 to 8.5°C. In a depth of 50-100 m the water temperature stays within the range of 0.1-2°C (Kuksa 1994).

The Black and Azov seawater has lower salinity than the ocean. The salinity of the surface layer in the open part of the Black Sea is 17.4-18.3‰ and at a depth of 50-100 metres is within 18.4-20‰. In the shallow northwestern part of the Black Sea in July-August the salinity is 13-16‰, in the Azov Sea it is 10.5-12‰. From the connection of the Azov Sea with the Black Sea to the head of the Taganrogsky Gulf the salinity decreases from 5 to 1‰. Near the mouths of rivers the salinity is 1‰.

The ichthyofauna of the surface layer of the Black and Azov seas can be divided into three groups:

- Strictly freshwater fish, which rarely or never move away from the river mouth: sterlet (*Acipenser ruthenus* L.), pike (*Esox lucius* L.), crucian carp (*Carassius carassius* (L.), tench (*Tinca tinca* (L.), rudd (*Scardinius erythrophthalmus* L.), white bream (*Blicca bjoerkna* (L.) and some others.
- Fish that propagate in rivers and some feed in seas: semi-migratory and migratory fish of various origins: pikeperch (*Stizostedion lucioperca* L.), roach/taran, vobla (*Rutilus rutilus* (L.), eastern bream (*Abramis brama* (L.), pontic-sturgeons, migratory herrings, Atlantic salmons;
- Marine warmwater loving fish of Mediterranean origin: European anchovy (*Engraulis encrasicolus* (L.), European sprat (*Sprattus sprattus* (L.), common scad or mackerel/stavrida (*Trachurus trachurus* (L.) and some others.

The existence of this fauna depends greatly on changes in the climate and on the regime of riverflow regime and also on the type of fishery.

The Danube

With a catchment area of 817 000 km^2, a length of 2 860 km and an average annual discharge of 202 km^3 the Danube is the second largest river in Europe. The Danube basin is one of the more densely populated regions of Europe: mean population density here exceeds 90 persons km^{-2}. The Danube River flows through eight countries and is important as a source of hydropower and irrigation water for a million hectares of agricultural land and as a waterway. The Danube has been regulated by large-scale hydraulic structures such as many dams; several canals, including the Danube-Black Sea, Rhine-Main-Danube and Odra-Elbe-Danube; and the irrigation system Danube-Tisa-Danube. The total volume of reservoirs is approximately 80 km^3 (Yatsyk, Kovalenko and Lelyavsky 1993). The annual water consumption from the Danube River is estimated at 75-80 km^3, of which 27-28 km^3 are lost to the system.

A great quantity of untreated or insufficiently treated water, as well as industrial and agricultural waste waters that contain a wide spectrum of poisonous compounds is discharged into Danube along its whole length. Polluted discharges are particularly intense in the middle and lower reaches. The concentrations of dissolved minerals in Danube water has recently increased by a factor of 1.4-1.7, reaching 427 mg L^{-1}, including Ca - 47.8 mg L^{-1}, Mg - 17.5 mg L^{-1}, Na+K - 49.8 mg L^{-1}, HCO_3 - 198 mg L^{-1}, SO_4 - 62 mg L^{-1} and Cl - 46.5 mg L^{-1} (Chernyavskaya, Denisova and Babich 1993).

The concentrations of dissolved oxygen range from 5.8 to 11 mg L^{-1} and the pH along the whole length of the river ranges from 7.5 to 8.6. These narrow ranges of dissolved oxygen and pH indicate that development of phytoplankton in the Danube water is weak and, accordingly, there is a lower intensity of photosynthesis. The reason for this is the high velocity of the current and a high turbidity. Values of COD and BOD range from 7.8 to 20 mg L^{-1} and from 1.2 to 5.0 mg L^{-1}, respectively. The main organic pollutant is an oil product, which mostly varies within 0.01-0.2 mg L^{-1}, but may reach up to 1 mg L^{-1} in some areas. Phenols form another large group of organic pollutants and their concentrations range from 0.0 to 0.034 mg L^{-1}. Concentrations of surfactants as a whole do not exceed the maximum allowable concentration (MAC), being within a range of 0.05-0.1 mg L^{-1}. The most significant pesticide pollutant of the Danube water is 4.4-dichlorodiphenyltrichloroethane (DDT) and its metabolite DDE, whose concentrations range from 0.014 to 3.81 mg L^{-1}. High concentrations of DDT (up to 57.4 mg kg^{-1}) have been found in benthic deposits in the mouth of the river (Chernyavskaya *et al*. 1993).

Concentrations of dissolved and suspended forms of copper and zinc exceed MAC along the entire length of the Danube River. Concentrations of nickel and cadmium are much lower than MAC. The highest concentrations (0.021 µg L^{-1}) of dissolved mercury are found in the waters of the Bulgarian stretch of the Danube. The content of radionuclides of caesium-134 and 137 and strontium-90 in the water from the downstream Galats to the upstream Vienna slowly increases from 5.85 bq m^{-3} to 48.1 bq m^{-3}. On the Ukrainian stretch of the Danube we find increasing concentrations of radionuclides of caesium, which is explained by the washing of the radionuclides into the river with rain and snowmelt water.

The phytoplankton of the Danube comprises 529 species of algae. The diatoms and green algae are most broadly represented. Cyanobacteria and *Euglena* in the Danube are not very diverse and do not reach large populations due to the high turbidity of the water. The zooplankton of the Danube channel is comparatively poor. Mean numbers during the vegetation period do not exceed 7000 ind. m^{-3}, reaching 14 000 ind. m^{-3} in the summer, mainly rotifers and copepods. The biomass of summer zooplankton is 162 mg m^{-3}. Autumn zooplankton of the Danube channel is extremely poor: no more than 200 ind. m^{-3}, with a biomass of only 7 mg m^{-3}. Persistent pesticides together with polychlorinated biphenyls are found in all river fish and invertebrate species (Komarovsky, Karasin and Chernina 1993). The levels of pesticide accumulation in organs and tissues of the main groups of fish are within the range of 0.001-0.1 mg kg^{-1}. The accumulation of pesticides in fish indicates that the Danube is polluted by persistent substances that are absorbed into the food chain.

THE DNIESTER

The Dniester is a semi-mountainous river that flows through the territory of the Ukraine and Moldova. The catchment area is 72 100 km^2 and the length of the river 1 352 km. The Dniester has its beginning on the slopes of the Carpathians, at an altitude of about 900 metres and eventually enters the Black Sea. In the upper part the river (up to the town of Galich) has the character of a mountain river. Downstream of Galich the current becomes quieter but the valley continues to be narrow and deep. Below the town of Mogilyov-Podolsky the valley widens. Below the city of Tiraspol the Dniester enters lowlands and the valley is between 8 and 16 km wide. The predominant source of water is snowmelt and rain. The average annual discharge is estimated to be 10.1 km^3, or 320 m^3 s^{-1}. In the winter, ice-jams form along the river.

Of the 87 reservoirs in the basin of the Dniester, two are considered here: the Dniestr reservoir, situated above the town of Mogilyov-Podolsky, is 678 km from the mouth of the river and the Dubossary reservoir, near the town of Dubossary, 351 km from the mouth. Both are multiple use reservoirs including irrigation, water supply, hydroelectric production, fisheries and recreation.

Development of industry and intensification of agriculture, especially by using mineral fertilizers and pesticides, has led to an increase in the concentration of some chemicals in the river water. For example, concentrations of DDT in water of the Dubossary reservoir range within 0.15-0.61 µg L^{-1}, DDD, 0.51-0.62 µg L^{-1}, DDE, 0.50-0.58 µg L^{-1}, etc. Below the Dubossary reservoir the quality of water becomes better due to self-purification, with a concentration of DDT of 0.26 µg L^{-1}, DDD, 0.42 µg L^{-1} and DDE, 0.22 µg L^{-1}. The concentration of the total dissolved solids of the Dniester water has also changed. Fifty years ago, in the period of snowmelt floods, it was 230-300 mg L^{-1} while at present it is 300-350 mg L^{-1}. In the summer-autumn period and during the winter low flows the concentration has increased from 440-600 mg L^{-1} to 500-700 mg L^{-1}. The chemical composition of water is dominated by calcium carbonates/bicarbonates (Gorbatenky, Byzgu and Kunichan 1986).

The Dnieper

The catchment area of the Dnieper covers 504 000 km^2 and the river is 2 200 km long making it one of the largest rivers of Europe. The river originates on the Valdai Heights and flows through Russia (485 km), Belarus (595 km) and for 115 km forms the border between Belarus and the Ukraine. Then it flows for 1 005 km through the Ukraine. The Dnieper can be divided into three reaches:

- The Upper Dnieper, from the source to the city of Kiev, with a length of 1 375 km. In this reach the main tributaries are the Berezina, Sozh, Prypyat and Desna and prior to the construction of dams their water quality determined the Dnieper River chemical composition.
- The Middle Dnieper, which runs for 570 km from Kiev to Zaporozhye. It receives the following major tributaries: the Ross, Sula, Psel, Vorskla, Orel and Samara rivers.
- The Lower Dnieper runs for 340 km, from Zaporozhye to the mouth of the river.

The upper river lies in the forest zone, the middle one in the forest-steppe and steppe zones and the lower river in the steppe zone. In the upper reach, from the source to Dorogobuzh, the river flows between low-lying banks covered by forest; below the city of Mogilyov, it flows through a hilly terrain: the valley here is narrow and without floodplain. Between Mogilyov and Kiev the valley of the river widens, with a floodplain 14 km wide and covered with meadows and bushes. The middle and lower Dnieper (from the mouth of the Prypyat to Kakhovka) has a chain of reservoirs: Kiev, Kanev, Kremenchug, Dneprodzerzhinsk, Dneprov (formerly Zaporozh) and Kakhov. Only below the city of Dneprodzerzhinsk does a small stretch of natural channel remain. There are some 650 reservoirs in the Dnieper basin. They have a total volume of 47.4 km^3 and a water area of 8 147.6 km^2.

The main source of water in the Dnieper is snowmelt. The average annual water discharge at the mouth of the river is 53 km^3 or 1 681 m^3 s^{-1}. The spring snowmelt floods generate 60-70 percent of the annual flow. In summer there are periods of low flow and in autumn there are short floods caused by heavy rain. From Kakhovka to the mouth the channel of the river is meandering and the Dnieper divides into branches and arms, which end in the Dnieper-Bug estuary. The Dnieper-Bug estuary enters a Black Sea gulf near the shores of the Ukraine. The gulf juts 55 km into the land, has a width of 7.4-16.7 km and a depth of 5.5 m. The water in the gulf has a salinity of 2-4.5‰ and freezes in winter.

The presence of the cascade of reservoirs has changed the Dnieper's hydrological and hydrochemical regime. In addition, the river has been polluted by radioactive elements resulting from the Chernobyl reactor catastrophe. Flow regulation has resulted in an increase in nitrite and phosphate concentrations. Ammonium concentrations have increased in the middle and lower Dnieper but did not change in the upper Dnieper. The concentration of iron considerably decreased due to its sedimentation in reservoirs and accumulation in bottom deposits (Denisova, Timchenko and Nahshina 1989). The regulation of the Dnieper has led to periods of intensive development of phytoplankton, especially of cyanobacteria, which cause water blooms in the reservoirs.

Survey of radioactive caesium 137 in the bottom deposits of reservoirs in the Dnieper cascade gives the following concentrations: in Kiev 2.5 cu km^{-2}, Kanev - 0.7 cu km^{-2}, Kremenchug - 0.25 cu km^{-2}, Dneprodzerzhinsk - 0.4 cu km^{-2}, Dneprov - 0.1 cu km^{-2}

km^2, Kakhov - 0.1 cu km^{-2} (Izrael, Vakulovsky and Vetrov 1990). Bream, white bream, roach and pikeperch from Kiev reservoir showed the following concentrations of heavy metals: lead in muscular tissue exceeding MAC by a factor of 40, in fins and scales by a factor of 10-12, in gills by a factor of 2 and in gonads by a factor of 4-5. Elevated concentrations of cadmium are found in tissues of bream, exceeding MAC by a factor of 1.5-6 (Savchenko 1997).

The Don

The Don flows through Russia (73 percent) and the Ukraine (27 percent). It has a catchment of 422 000 km^2 and a length of 1 967 km. The Don is one of the main sources of fresh water in the basin of the Azov Sea. It starts on eastern slopes of highlands near the town of New-Moscow and flows into the Taganrogsky Gulf of the Azov Sea. In its upper reaches the river is confined to a narrow valley, where the main tributaries are: the Nepryadva, Krasivaya Mecha, Seyim and Voronezh. In its middle course (before the town Kalach-on-the Don) the valley broadens, with a wide floodplain reaching 6 km in places. The middle course ends in Tsimlyansk reservoir, which has a maximum depth of 36 m. From the dam to the mouth of the river, the Don flows in a wide valley (20-30 km) with a large floodplain and in some areas the river is 20 m deep. Below the city Rostov-on-the Don the Don makes a delta which covers an area of 340 km^2. Before the construction of the Tsimlyansk reservoir and the Volga-Don navigable canal the average annual discharge in the mouth of the Don was 29.5 km^3 and the annual average flow rate was 935 m^3 s^{-1}; following damming the average annual flow was reduced to 160 m^3 s^{-1}. Tsimlyansk dam was closed in 1953. It has a multiple use, including hydropower generation, water supply for settlements and industries, irrigation, navigation and fishery. When full the reservoir contains 23.9 km^3 of water, which is 9 percent more than its average annual flow rate in this section (22.3 km^3). The reservoir is 360 km long.

Over the years there has been considerable increase in the total dissolved solids in the Don water. Concentrations of sulphates have increased 2.6-2.8 times, chlorine and magnesium 2 times, sodium and potassium 2.3-3.1 times and the total dissolved solids (TDS) concentration has increased 1.6 times in recent years. In the Taganrogsky Gulf, which has an important fishery especially for migratory and semi-migratory fish, TDS have increased 4.6 times, largely due to increases in chlorine (6 times), sulphates (2.8 times) and sodium (5 times).

In the spring, at the beginning of the summer and in late autumn the phytoplankton of Tsimlyansk reservoir is dominated by diatoms (*Stephanodiscus*, *Cyclotella*, *Melosira* and *Asterionella*), in some years reaching a biomass of 45 g m^{-3}. From June to October the phytoplankton consists mainly of cyanobacteria, which may cause an intensive bloom. Abundant zooplankton feeds on the rich phytoplankton and bacterioplankton. Of the 169 species of zooplankton, the most common are 13 species of rotifers, 8 species of cladocerans and 8 species of copepods. Two species of Polychaeta, (*Hypania invalida* and *Hypania kowalewskyi*), and two of Mysidacea, (*Mesomysis intermedia* and *Mesomysis kowalewskyi*), have been introduced in Tsimlyansk reservoir with the objective of enriching the food base of bream, pikeperch and other fish. The largest biomass of benthos is reached from October to May, ranging from 4 to 10 g m^{-2} (Pirozhnikov 1972). An average biomass of phytoplankton of 15 g m^{-2} is present in the summer to autumn period. The average biomass of zooplankton is 10 g m^{-2}. The average biomass of zoobenthos in different parts of the reservoir ranges from 0.8 g m^{-2} to 26 g m^{-2} (Isaev and Karpova 1989).

The State Water Committee of Russia provided the following information on discharges of wastewater from point sources into the Don for the year 2001: oil products – 260 tonnes; suspended matter – 25 610 tonnes; sulphates – 302 790 tonnes; chlorides – 179

510 tonnes; total phosphorus – 1 284 tonnes; nitrogen – 842 tonnes; phenols – 220 tonnes; ammonia – 3 228 tonnes; nitrates – 7 747 tonnes; nitrites – 284 tonnes; pesticides – 4 tonnes; surfactants – 116 tonnes; greases and oils – 1 008 tonnes; iron – 540 tonnes; copper – 9.3 tonnes; zinc – 18.2 tonnes; nickel – 0.92 tonnes; chromium – 3.5 tonnes; aluminum – 8.7 tonnes; lead – 0.72 tonnes; hydrogen sulphide – 6.85 tonnes; magnesium – 16 444 tonnes; manganese – 3.32 tonnes; fluorine – 112 tonnes; calcium – 28 tonnes; silicon – 2.82 tonnes.

The Don River has 75 species and subspecies of fish, including lampreys, sturgeons (beluga, sterlet, Russian sturgeon, starred sturgeon), herrings (*Caspialosa brashnikovi* Borodin, *Caspialosa kessleri pontica* Eichwald, *Caspialosa caspia tanaica* Grimm, *Clupeonella delicatula* Nordmann, *Clupeonella delicatula caspia* Svetov), pike, carps, loaches (*Gobitis taenia* (L.), *Misgurnus fossilis* (L.), *Noemacheilus barbatulus* (L.), *N. merga* (Krynicki), catfishes, burbots, zanders, silverside, gobies and channel catfish (North American catfish). Channel catfish has been introduced from North America.

The Kuban

The Kuban is formed by the confluence of the Ullukan and Uchkulan rivers, which rise on the slopes of Mt. Elbrus. The length of the Kuban River is 870 km, the catchment area 57 900 km^2. The average annual discharge at its mouth is 12.8 km^3. From the source to the town of Nevinnomysk the Kuban River flows in a deep and narrow canyon with steep slopes and rapids. A dam for supplying water to the Nevinnomysky canal has been constructed near Nevinnomysk. In the middle stretch the river flows in a wide valley with terraced slopes. Below the mouth of the Laba River the valley broadens and the river floodplain reaches a width of 20 km, to narrow to 3-4 km towards the river mouth. Between the mouths of the Laba and Afips rivers there are the Adygeyskie wetlands (300 km^2), while the Zakubanskie wetlands (800 km^2) are situated below the Afips River. The Protoka branches off 16 km upstream from the sea and as a result the delta of the Kuban River covers an area of some 4 300 km^2. The characteristic feature of the Kuban delta is the exceptional developments of estuaries, which cover 1 200 km^2, have a volume of 1.1 km^3 and a mean depth of 0.9 meter. These estuaries have an important role for the Kuban ichthyofauna, as they serve as both spawning and breeding grounds.

Over 3 km^3 of water is withdrawn from the Kuban River and discharged into the Nevinnomysky canal (constructed in 1948) and the Big Stavropolsky canal (constructed in 1967), which form part of the Kuban-Egorlyksky and the Kuban-Kalaussky irrigation systems. Krasnodar is the largest reservoir on the Kuban River, constructed in 1975 to develop irrigation and fisheries and for flood prevention in the Lower Kuban. Krasnodarsk reservoir has a catchment of 45 900 km^2. The full capacity of the reservoir is 2.4 km^3 and the useful capacity 2.16 km^3. The length of the reservoir is 46 km, the mean depth 5.5 m and the maximum depth 20 m. The Krasnodar dam has a fish lift for the transfer of migratory and semi-migratory fish from downstream to upstream. The Kuban River has a long period of floods, from May to August, fed predominantly by snowmelt. In the upper stretch of the river snowmelt and ice-melt water provides 49 percent of annual flow, while near the city of Krasnodar the snowmelt supplies 34 percent of the annual flow, with rain and groundwater providing 66 percent of the annual flow. The flow of the Kuban River has changed greatly as a result of its regulation and due to the irrevocable withdrawal of water for transfer to other basins for irrigation. During the period of fish reproduction in May-August the water volume passing through the river near the town of Kropotkin has been reduced from 3.5 km^3 to 2 km^3. As a result about 50 percent of the spawning grounds have been lost and the rest have been flooded by Krasnodar reservoir.

There has been a gradual increase in sulphates, magnesium, chlorine, potassium and sodium. Despite an increase in the water flow in the early 1980s, the concentration of TDS remained unchanged; this is explained by increased discharges of return waters from irrigated fields. The following shows the concentrations of pollutants entering the river with wastewater from point sources in 2001: oil products – 130 tonnes; suspended matter – 26 000 tonnes; sulphates – 37 250 tonnes; chlorides – 22 530 tonnes; total phosphorus – 467 tonnes; total nitrogen – 1 455 tonnes; ammonium – 495 tonnes; phenols – 130 kg, pesticides - 3.83 tonnes; nitrates – 4 925 tonnes; surfactants – 11 tonnes; grease and oil – 287 tonnes; iron – 80 tonnes; copper – 1.35 tonnes; zinc – 2.23 tonnes; nickel – 580 kg; chromium – 1.55 tonnes; aluminium – 2.27 tonnes; magnesium – 952 tonnes; nitrite – 72 tonnes; fluorine – 8.5 tonnes; and tannin – 315 tonnes.

Phyto- and zooplankton in the Kuban River are very poor due to high turbidity, which in terms of suspended solids reaches 200 g m^{-2} in the Upper Kuban and 650-700 g m^{-2} in the Lower Kuban. While the bottom fauna of the Kuban River is poor; the life in the branches of the delta is much richer.

The ichthyofauna of the Kuban River changes greatly from the river source to its mouth. The uppermost stretches of the river are inhabited only by trout, which prefer clean and cold water. Some 18 species of fish are found in the middle stretch of the river, in its unregulated part. Most of them are barbel (*Barbus barbus* (L.), bleak (*Alburnus alburnus* (L.), chub, rifle minnow (*Alburnoides bipunctatus* Bloch), gudgeon (*Gobio gobio* (L.), Donets ruffe (*Gymnocephalus acerinus* Guldenstadt), white bream, Colchian undermouth (*Chondrostoma colchian* Kessler), asp, sabrefish and catfish. A small number of lake or river fish (carp, bream, roach, rudd) and migratory fish (starred sturgeon, vimba, Caspian shemaya) have been reported. After the confluence with the Belaya River into the Kuban 25 additional species have been recorded, including Russian sturgeon and the Black Sea shad. Nearer the mouth the ichthyofauna of the channel part of the Kuban River is enriched by many estuarine and sea species.

Before the regulation the river had 39 species of fish, including the sturgeons beluga and sterlet and in recent years grass carps and silver carps have been introduced. Krasnodar reservoir has functioned as a sedimentary basin and this has made the downstream river channel suitable for gobies, smallmouth bufalo, Black Sea roach, flat needlefish and some other fish, which were previously unable to live there because of the high turbidity.

THE CASPIAN SEA, THE VOLGA AND URAL RIVERS

The Caspian is the largest endorheic brackish lake on earth. About 15 000 years ago it was part of a large sea that was joined with the ocean. The Caspian Sea is situated in arid and semi-arid zones and its shores are shared by Russia, Kazakhstan, Turkmenistan, Iran and Azerbaijan. The sea covers 435 000 km^2, the mean depth is 183 m and maximum depth 1,025 m. A number of rivers enter the sea, among them the Volga, Ural, Kura, Terek, Samur, Sulak, Sefidrud.

The northern part of the sea is shallow (up to 10 m) and in winter it freezes for 2-3 months. The water temperature reaches 30°C in this part in summer. In the middle and the southern parts of the sea the winter temperature does not fall below 5.9°C. Salinity in the northern part of the Caspian ranges from 5‰ (1‰ near the river mouth) to 12.6‰, which are similar values to those in the Azov Sea. The salinity of the middle and the southern parts of the Caspian Sea is 12.6-12.9‰, which is lower than in the open waters of the Black Sea.

The fish fauna of the Caspian Sea includes 75 species and 17 subspecies; there are 47 species and subspecies that prefer brackish water and 13 migratory and 26 semi-migratory species. There are only 6 strictly marine species, half of them being introduced quite recently. Also recently the Caspian fishery was affected by a sharp drop in the water level between 1936 and 1977, followed by a rapid rise and by the construction of many large dams on the major inflowing rivers, the Volga, Ural, Terek and Kura.

The Volga

The Volga basin constitutes the largest part of the Caspian Sea catchment. With an area of 1 360 000 km^2, length of 3 531 km and average annual flow of 245 km^3, the Volga is the largest river in Europe. Its tributaries, the Kama and the Oka rivers, greatly influence the water regime of the mainstem Volga. There is a cascade of large reservoirs on the Volga: the Ivankovo, Uglich, Rybinsk, Gorkov, Cheboksary, Kuybyshev, Saratov and Volgograd reservoirs. In addition, three large reservoirs, the Kamsk, Votkinsk and Nizhnekamsk, have been constructed on the main tributary of the Volga River, the Kama River. Altogether, in the Volga basin there are 812 reservoirs with a total volume of 190.5 km^3 and a water area of 27 239 km^2. The majority of these reservoirs, both large and small, were constructed to supply water to industry and cities as well as for irrigation.

Below the Volgograd dam (the lowest in the cascade) the Volga valley cuts into the lowlands for more than 400 km, as the river continues towards the Caspian Sea. Above the city of Volgograd the Akhtyuba branch of the river separates from the Volga, following it in parallel. The area between the Volga and the Akhtyuba is called the Volgo-Akhtyubinsk floodplain. The width of the floodplain ranges from 12 km to 40 km. The floodplain is crossed by many arms and canals as well as having many shallow floodplain lakes, locally called "ilmens."

The width of the Volga channel between Volgograd and the river delta ranges from 0.6 to 2.2 km, with depths from 2.5 m to 35 m in pools. As it approaches the Caspian Sea, the Volgo-Akhtyubinsk floodplain becomes wider and forms a delta. The delta of the Volga River is one of the largest deltas in the world, covering 24 292 km^2.

Concentrations of most of the dissolved anions and cations, as well as nitrogen and phosphorus, increase downstream. The highest concentrations of phosphorus were recorded in Ivankov and Cheboksary reservoirs. The concentration of the total nitrogen increases from 1.28 to 1.77 mg L^{-1}. Organic matter concentrations are lower in the middle and lower reservoirs, in spite of a higher primary production as compared with that in the upper reservoirs. This is related to the higher water temperature in the middle and lower reservoirs and to a faster rate of decomposition of the organic matter. The morphometric and hydrographic characteristics of the Volga reservoirs are presented in Table 1.

As a result of flow regulation the water regime of the lower Volga has been altered. Prior to this there were spring snowmelt floods (April-June), which represented 57 percent of the annual flow, summer-autumn low-flow period (July-November), representing 29 percent of the annual flow and winter low-flow period, with 14 percent of the annual flow. Now the river behaves as follows: spring snowmelt flood (38 percent), summer-autumn low flow (34 percent) and winter low flow (28 percent). The annual pattern of peaks and lows of water level in the lower Volga has changed, with the water level mainly determined by discharges through the Volgograd hydroelectric power station. The water level rises sharply and reaches the maximum level in spring. This level lasts 36 days instead of the previous 59 days. This is followed by a sharp fall in water level in summer.

River flow regulation has resulted in a decrease in suspended loads in the lower Volga, as the sediments are being deposited in reservoirs. Prior to dam construction the suspended sediment transport was 19.3 million tonnes, but currently it is 8 million tonnes only (Tarasov and Beschetnova 1987). All ion concentrations have increased (Table 2).

Chlorine concentration increased by 80 percent and sulphates by 22 percent; although carbonates hardly changed, calcium increased by 8 percent, magnesium by 20 percent, the sum of potassium and sodium

Table 1: Morphometric and hydrographic characteristics of the Volga reservoirs

Reservoir	Average annual flow km^3	Water surface area km^2	Shallows, depth less than 2 m %	Maximum volume of reservoir km^3	Useful volume of reservoir km^3	Mean depth of resrvoir M	Maximum depth of reservoir M
Ivankovo	9.65	327	47	1.12	0.81	4.0	14
Uglich	13.6	249	36	1.24	0.81	5.5	23
Rybinsk	35.2	4 550	21	25.42	16.67	6.0	30.4
Gorkov	52.5	1 591	23	8.81	2.78	6.4	22.0
Cheboksary	112	2 274	-	13.85	5.7	6.1	20.0
Kuybyshev	239.7	6 450	16.5	58.0	34.6	9.4	32.0
Saratov	247	1 831	18.5	12.86	1.75	7.0	30.0
Volgograd	251	3 117	37	31.45	8.25	10.1	37

by 63 percent and total dissolved solids by 16 percent. The annual range of the concentration of the individual ions narrowed. The maximum concentrations are presently reached during the period of snowmelt floods rather than during the summer or winter periods as it was before the flow regulation. As a result of the construction of reservoirs, phosphorus concentrations have decreased by a factor of approximately 2 in the lower Volga. The dissolved oxygen concentrations are higher and there are no more sudden mortalities of aquatic organisms due to the low dissolved oxygen concentrations. The Volga River remains severely polluted. In 2001 the river received the following quantities of pollutants: oil products – 2 370 tonnes; suspended matter – 164 540 tonnes; sulphates – 736 460 tonnes; chlorides – 1 863 070 tonnes; total phosphorus – 10 877 tonnes; total nitrogen – 10 765 tonnes; ammonium – 38 611 tonnes; phenols – 11 tonnes; nitrates – 22 656 tonnes; nitrites – 3 789 tonnes; surfactants – 947 tonnes; greases and oils – 4 425 tonnes; iron – 2 431 tonnes; copper – 45 tonnes; zinc – 142 tonnes; nickel – 43 tonnes; chromium – 32.2 tonnes; mercury – 20 tonnes; aluminum – 987 tonnes; acetone – 1.47 tonnes; vanadium – 16.5 tonnes; benzene – 690 kg; hydroxenon – 140 kg; dichloroethane – 7.8 tonnes; tin – 5.1 tonnes; lead – 13 tonnes; hydrogen sulphide – 41.5 tonnes; carbon bisulphide – 1.05 tonnes; antimony – 590 kg; cadmium – 2.8 tonnes; cobalt – 3.3 tonnes; magnesium – 11,209 tonnes; manganese – 163 tonnes; methanol – 190 tonnes; arsenic – 760 kg; turpentine – 3.0 tonnes; tannin – 9 718 tonnes; and fluorine – 552 tonnes. It is important to note that many pollutants (pesticides, oil products, mineral fertilizers, etc.) enter rivers with the surface flow.

The Ural

The Ural is shared between Russia and Kazakhstan. The river has its beginning in the southern Ural Mountains at an elevation of 640 m. The catchment area is 231 000 km^2 and the length 2 428 km. The Ural River enters the Caspian Sea next to the town of Atyrau (Kazakhstan) through a delta that has two arms,

Table 2: Chemical composition of the Volga River water before and after the regulation of the Lower Volga (Tarasov & Beschetnova 1989)

Period	Cl Mg L^{-1}	SO_4Mg L^{-1}	HCO_3 Mg L^{-1}	Ca Mg L^{-1}	Mg Mg L^{-1}	Na+K Mg L^{-1}	$\sum$ ions
Before	19.8	49.8	122.4	47	9.0	13.3	261
Afer	35.8	60.7	122.9	51.1	10.8	21.7	303

the Yaitsky and the Golden. The delta covers 700 km^2. In its upper reaches the Ural River is a mountain river with a turbulent current. It then flows into the Yaitsky swamp which it leaves as a quiet river flowing through a valley that slowly broadens to 5 km. Below the town of Verkhneuralsk the Ural is a lowland river with a wide floodplain, covered by meadows and floodplain lakes. Two reservoirs, situated far upstream (1 810 km and more from the river mouth), do not have a major influence on the hydroecological regime of the river.

However, numerous pumping stations situated along the length of the river withdraw about 40 percent of its annual flow. The main source of water for the Ural River is snowmelt. The spring snowmelt floods the lower Ural River from the end of March to the beginning of June. These are followed by small rain floods, after which the flow stabilises for the rest of the year. In the snowmelt flood the river floodplain is over 10 km wide in its middle course, in the delta less then 10 km wide.

In the upper course the water level fluctuates by 3-4 m, in the middle and lower course by 9-10 m and in delta by 3 m. The average annual flow near the city of Orenburg is 104 $m^3\ s^{-1}$ and near the settlement of Kushum 400 $m^3\ s^{-1}$. Concentrations of the TDS range from 400 to 690 mg L^{-1}. Concentrations of microelements and organic matter do not exceed the maximum admissible concentrations.

The fish fauna of the Ural consists of 60 species and is very similar to that of the Volga, but the Ural has bastard sturgeon, which are absent from the Volga. One should point out that the Ural is the only river flowing into the Caspian Sea in which the natural hydrological regime has been preserved over a large stretch of the river, in this case for 1 810 km, where the first upstream dam is situated.

HUMAN IMPACTS ON FISH STOCKS

The recent intensive fishing of the Black Sea has had serious impact on fish stocks and other marine biota resources. There has been a sharp drop in mackerel and bonito catches, the Black sea scad seems to have emigrated out of the Black Sea and dolphins have suffered from a variety of diseases. Planktonic *Mnemiopsis* (Ctenophora) was introduced into the Black Sea from the Atlantic Ocean and in autumn 1989 its biomass reached 1 billion tonnes. As a consequence *Mnemiopsis* reduced the biomass of plankton available to fish by 3 to 5 times as well as feeding on fish fry.

Human activities have led to a decline in the stocks of sturgeons and semi-migratory fish, both of which have declined. The decline in predatory fish has resulted in an increase in the stocks of small fish with a short life cycle, such as European anchovy (*E. encrasicolus* (L.), European sprat (*S. sprattus* (L.) and small mackerel.

The construction of reservoirs has led to changes in the ichthyofauna of the Dniester River. As spawning grounds of migratory and semi-migratory fish became inaccessible, species with these habits disappeared from most of the river. Rheophilous fish disappeared from the reservoirs. The numbers of lookups (*Culter* spp), white-eye (*Abramis sapa* (Pallas) and river perch (*Perca fluviatilis* L.) have increased sharply and they now account for 15-17 percent of the total catch. Presently 85 species of fish live in the lower Dniester and the Dniester Gulf, the most numerous of which are carp (*Cyprinus carpio* (L.), gobies (Gobiidae) and perches (Percidae). The most commonly fished species are bream, carp, pikeperch, roach, sabrefish, pike and white bream. They represent 1,030 tonnes of the total mean annual catch of 1 180 tonnes (Greze, Polikarpov and Romanenko 1987). Since 1978 the annual catch of the exotic silver carp (*Hypophthalmichthys molitrix* (Valenciennes) and grass carp (*Ctenopharyngodon idella* (Valenciennes) is 30 to 60 tonnes.

A comparison of fish catches in the Dnieper River before and after the construction of the Kakhov dam shows that:

- Before the dam construction. The average annual total catch was 5 000 tonnes. Of this the migratory beluga, Russian sturgeon, starred sturgeon and herrings represented 161 tonnes (3.3 percent of the total catch); semi-migratory species roach-taran (*Rutilus rutilus* (L.), bream, vimba, sabrefish, carp and pikeperch represented 1 816 tonnes (36.8 percent); freshwater fish pike, rudd (*Scardinius erythrophthalmus* (L.), asp (*Aspius aspius* (L.), crucian carp, catfish, river perch, gobies and other species 1 268 tonnes (25.7 percent); and kilka (*Clupeonella cultiventris* (Nordmann) 1 687 tonnes (34.2 percent).

- After the dam construction. The average annual total catch was 6 980 tonnes. Of this migratory fish represented 31 tonnes (0.4 percent); semi-migratory fish 796 tonnes (11.4 percent); freshwater fish 608 tonnes (8.7 percent); and kilka 5 545 tonnes (79.5 percent). One can see that the catches of migratory, semi-migratory and freshwater fish have declined dramatically, although the total catches increased by 40 percent for kilka, a fish of little value. Sturgeons, sabrefish, asp and gobies have lost fishery importance (Greze *et al*. 1989). The total annual catch from all Dnieper reservoirs ranges from 16 000 to 21 000 tonnes.

Until recently the Azov Sea was one of the richest bodies of water in the world. In the mid-1930s over 300 000 tonnes of fish were caught there annually, which equals a yield of 85 kg ha^{-1}. Anadromous fish dominated, having very favourable spawning grounds covering some 600 000 ha (Volovik 2001).

Rapid changes in the sea ecosystem started in the 1950s, when not only the major affluent rivers (the Don and Kuban) but also their tributaries and other small rivers were dammed. The development of industry, intensification of agriculture and growth of municipal economies led to a discharge of great quantities of pollutants into the rivers and the Azov and Black seas. In those days there were few restrictions to prevent this. Pollution, regulation of water flow in rivers, invasion of *Mnemiopsis* and overfishing resulted in decline in fish catches from 200 000 tonnes to 15 000 tonnes by the end of the twentieth century.

The most serious situation is in the Caspian Sea, where the sturgeon population was once the most numerous and diverse in the world and a large number of semi-migratory fish also inhabited the sea. In the 1980s the annual catch of sturgeons reached 25 000-30 000 tonnes and production of black caviar was 2 000 tonnes. In the 1960s sturgeon hatcheries were constructed which annually released from 60 000 000 to 100 000 000 sturgeon fingerlings. However, a serious decline in sturgeon catches started from the end of the 1980s (Table 3). A similar decline took place with other species of fish, except kilka (Table 4).

The stocks of sturgeon in the Caspian Sea have declined by a factor of 5, but the stock of starred sturgeon has declined by a factor of 8.5 and the semi-migratory fish catches have decreased by a factor of 11. The dire state of the sturgeons is explained by many factors, but the most important one is the loss of spawning areas. In the Volga 85 percent of the spawning areas were lost, those of beluga completely disappeared, those of Russian sturgeon were reduced by 60 percent and of starred sturgeon by 40 percent (Nikonorov, Maltsev and Morgunov 2001). There are no important spawning grounds of sturgeons left downstream of the Volgograd reservoir, for they have been subjected to sharp fluctuations in water level resulting from the operation of the Volgograd hydroelectric power station. The fluctuations cause mass destruction of sturgeon eggs. In 30 percent of female sturgeons, oocytes have been found to be resorbed.

Table 3: Numbers (millions) and catches (tonnes) of sturgeons in the Caspian Sea (Lukyanenko 2002)

Catches	Year		
	1968	1987	1998
Sturgeons (all)	228	101	42.2
Beluga	-	14	7.6
Russian sturgeon	129	45	23
Starred sturgeon	99	42	11.6
Sturgeons (all) (t)	22 000	21 000	2 000

Table 4: Fish catches (tonnes) in the rivers of the Caspian Sea

Species	Year						
	1932	1940	1950	1960	1970	1978	1999
Semi-migratory	241 900	165 100	201 900	112 400	44 300	20 000	22 800
Freshwater	62 000	25 800	34 000	32 100	42 800	27 000	20 000
Kilka	81 800	136 500	56 100	54 900	1 800	1 200	4 600
Vobla (roach)	-	-	53 000	16 900	9 400	5 000	3 600
Salmon	900	1 100	400	10	10	20	8
Kilka	6 900	8 900	21 600	176 000	423 200	315 400	150 547

There are also unfavourable conditions in the Ural-Caspian and Kura-Caspian regions. The irrevocable water consumption from the Ural River takes away 50-60 percent of the annual flow and 90 percent of larvae and young sturgeon perish and do not reach the sea. The fishing pressure leaves only 20 percent of the broodstock to reach their spawning grounds. The falling of the level of the Caspian Sea from the 1930s to 1977 had a great influence on the reproduction of semi-migratory fish, as the salinity in their feeding grounds in the northern Caspian increased. Since then, however, the situation has improved as a result of a rise in the Caspian sea water level by almost 2 m..

An effort to stock reservoirs with broodstock with the hope that this would restore fish stocks did not work. Between 1989 and 2000 fish catches from the main reservoirs of the Volga cascade continued their decline. In Kuybyshev reservoir catches fell 1.91 fold, in Saratov reservoir 3.43 fold and in Volgograd reservoir 5.13 fold (Sechin, *et al*. 2002).

The increased water consumption and growth of ecologically harmful industries in the Volga basin further worsened the quality of water. The data regarding point sources of pollution mentioned earlier reveal only the tip of the pollution “iceberg,” for there are many diffused sources, especially of pesticides, nitrogen, phosphorus, oil products and phenols, which increase the pollution of the river. The toxic substances entering the Caspian Sea disturb the structure and function of the ecosystem. In 1984 a myopathy, a degenerative disease of muscles, attacked Volga-Caspian sturgeons. Other serious changes were also discovered in the diseased fish: disruption of ionic homeostasis, distrophy and necrosis of the liver, changes in kidneys and sexual glands and disruption of gametogenesis and gonadogenesis. DDT and other pesticides were found to persist in the tissues and organs of such fish. Cadmium, nickel, mercury, lead, copper and other heavy metals have been found in fish livers (Kuksa 1994).

Despite a recent increase in the Volga River flow rate and thus an improved self-purification, in the sea and especially in the coastal zone pollution levels remain very high. Due to an increase in the level of the Caspian Sea and increased freshwater input the conditions for semi-migratory fish have improved. But these changes have by no means benefited the sturgeons.

Many experts believe that sturgeons could disappear from the Caspian Sea basin during the twenty-first century.

RECOMMENDATIONS

It is recommended that:

- The impact of selected factors influencing migratory and semi-migratory fish be studied. These impacts include: hydraulic engineering constructions; pollution; introduction of harmful exotic species that are dangerous for the ecosystem (e.g. *Mnemiopsis*);

- Hatchery-produced young sturgeons be stocked in the Volgo-Caspian, the Azov and Black Sea (Altukhov and Evsyukov 2002);

- The effectiveness of artificial spawning grounds be evaluated;

- That discharge of waste water into rivers from both point and diffusion sources be gradually decreased and eventually stopped;

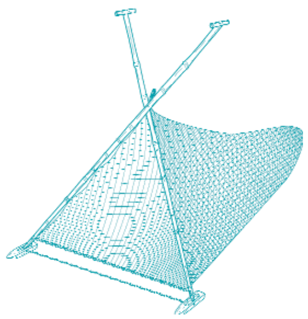
- Rice production in the deltas of the rivers Volga, Kuban, Terek and several others should be stopped and the deltas used only for fisheries;

- The volume of water transferred from the Kuban River into the basins of other rivers through Nevinnomysky and Bolshoy Stavropolsky canals be reduced;

- Tsimlyansk reservoir be stocked in the period of spring snowmelt flood when spawning grounds for migratory and semi-migratory fish are available;

- Volgograd, Saratov and Kuybyshev dams be removed to save the Caspian Sea sturgeon;

- Two International Commissions be established, one for studies of the Black-Azov Seas and their catchments, the other for studies of the Caspian Sea with its catchment. The programmes of these Commissions would have as a major objective achieving a long-term improvement of the environment in both watersheds, including the above proposals.



REFERENCES

Altukhov Y.P. & Evsyukov A.N. 2002. Overproduction of young fish in hatcheries as a cause of degradation of the Volga Russian sturgeon. *Reports of the Russian Academy of Science*, 3802: 273-275.

Chernyavskaya A.P., Denisova A.I. & Babich I.I. 1993. The chemical composition of the Danube water. *Water Resources*, 20: 440-446.

Denisova A.I., Timchenko V.M. & Nahshina E.P. 1989. *Hydrology and hydrochemistry of the Dnieper and its reservoirs*. Kiev, Naukova Dumka. 216 pp.

Gorbatenky G.G., Byzgu S.E. & Kunichan L.A. 1986. Mineralization and ionic content of the Dniester water and prediction of changes in human impact. *In Modern state ecosystems of the Dniester River and reservoirs.* Kishinev, Kodru.

Greze V.N., Polikarpov G.G. & Romanenko V.D. 1987. *Nature of the Ukraine seas and internal waters.* Kiev, Naukova Dumka. 224 pp.

Isaev A.I. & Karpova E.I. 1989. *Fisheries in reservoirs*. Moscow, Agropromizdat. 255 pp.

Izrael Y.A., Vakulovsky V.S. & Vetrov V.A. 1990. *Chernobyl: Radioactive pollution of the natural environment.* Leningrad, Gidrometeoizdat. 296 pp.

Komarovsky F.Y., Karasina F.M. & Chernina Z.V. 1993. Bioaccumulation of the persistent pesticides in fish of the Danube. *Water Resources*, 20: 520-522.

Kuksa V.I. 1994. *Southern seas: The Aral, Caspian, Azov and Black in conditions of anthropogenic stress*. Sankt-Peterburg, Gidrometeoizdat. 319 pp.

Lukyanenko V.I. 2002. Destruction threat of the Caspian sturgeons and urgent measures in their rescuing. *Utilization and Protection of Natural Resources in Russia Bulletin*. No. 5-6.

Nikonorov S.I., Maltsev S.A. & Morgunov S.V. 2001. The problems of natural spawning of sturgeons and the ways of their decision. *Fish Economy*, No. 5: 42-44.

Pirozhnikov P.A. 1972. The biological resources of reservoirs: History of investigations, state, fish-economy significance. *News GOSNIIORH*, 77: 5-77.

Rass T.S. 1965. *The fish resources of European seas of the USSR and possibilities of their replenishment by acclimatization*. Moscow, Nauka. 107 pp.

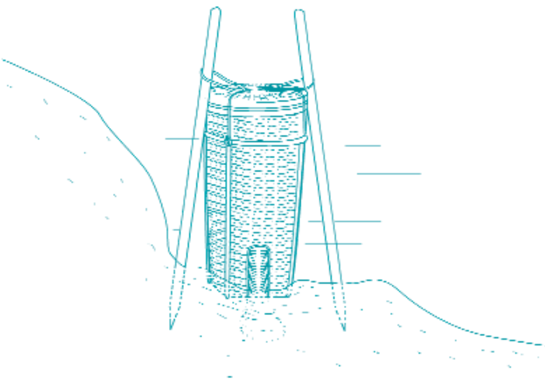
Savchenko V.K. 1997. *The ecology of the Chernobyl catastrophe.* Minsk: Nauka and Technica. 224 pp.

Sechin Yu. T., Lvova L.D. & Shashulovaskaya S.Yu. 2002. Raw base and fishing in internal water bodies of Russia. *Fish Economy,* No. 3: 39-42.

Tarasov M.N. & Beschetnova E.I. 1987. Hydrochemistry of the Lower Volga under regulation of flow. *Hydrochemical Materials,* Vol. CI, Gidrometeoizdat. 120pp.

Volovik S.P. 2001. Ecological and fish-economy problems of the Azov Sea. *Fish Economy*, No. 4: 22-23.

Yatsyk A.V., Kovalenko P.I. & Lelyavsky V.V. 1993. Water management assessment of the Danube Basin. *Water Resources*, 20: 426-429.

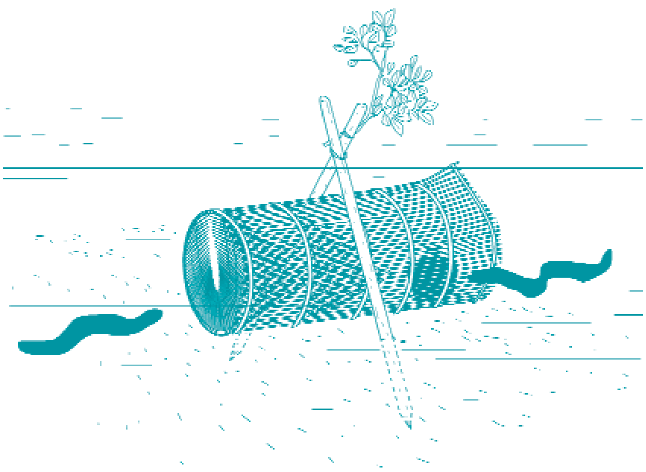


REVIEW OF THE PRESENT STATE OF THE ENVIRONMENT, FISH STOCKS AND FISHERIES OF THE RIVER NIGER (WEST AFRICA)

R. Laë[1] S. Williams[2] A. Malam Massou[3] P. Morand[4] O. Mikolasek[5]

[1] IRD, BP 1386, 99 341, Dakar, Senegal
[2] Department of Agricultural Economics, Obafeni Awolowo University, Ile-Ife, Osun State, Nigeria
[3] INRAN, Département GRN, BP 429, Niamey, Niger
[4] Centre de Recherche Halieutique, Avenue Jean Monnet - B.P. 171, 34203, Sète, France
[5] CIRAD-GAMET, TA 30/01, 34398 Montpellier Cedex 5, France

Correspondence to: Raymond Lae, IRD, Route des Hydrocarbures, Bel-Air, BP 1386, 99341 Dakar, Senegal



Key words: Niger River, biodiversity, capture fisheries, aquaculture, management

ABSTRACT

The Niger River is the fourth most important river in Africa. It is 4 200 km long with an estimated watershed area of 1 125 000 km^2. It traverses a variety of ecological areas shared by a number of countries in the West African Region: Guinea, Mali, Niger and Nigeria for its main course; Cote d'Ivoire, Burkina Faso, Benin, Chad and the Cameroon for its tributaries. The mean annual flow is 6 100 m^3 s^{-1}. Since the beginning of the century, the Niger River has been subjected to several natural and anthropogenic perturbations: first, a very long drought period started in the 1970s when the discharges decreased strongly and the areas

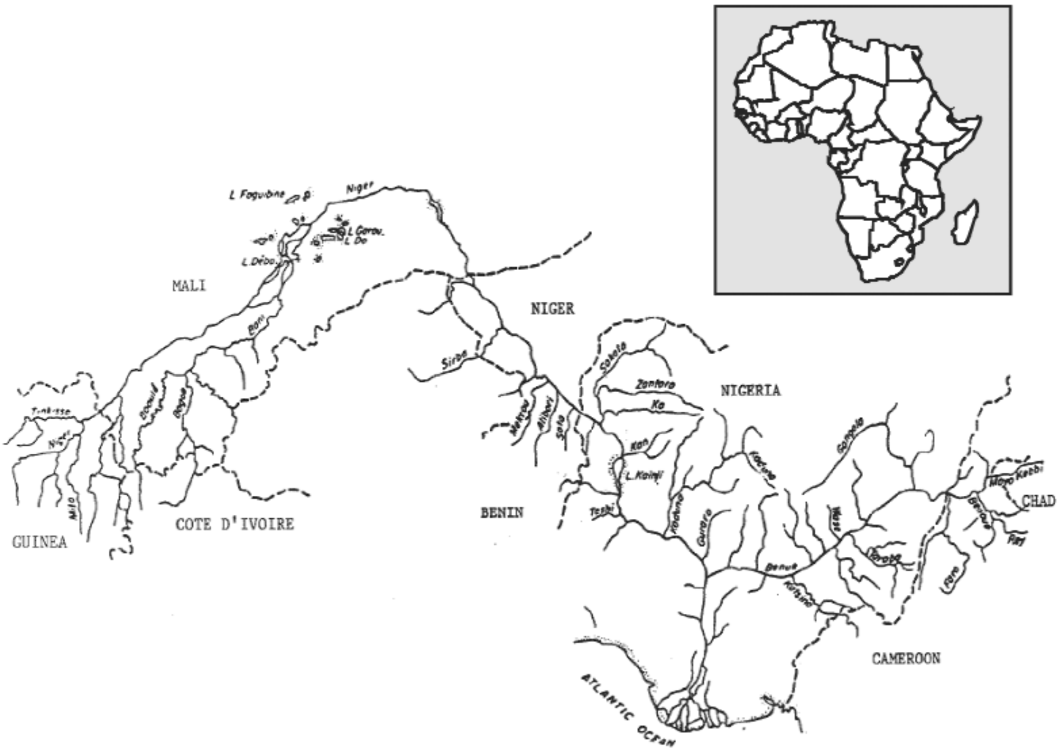
flooded were considerably reduced. Second, the building of dams and numerous irrigated perimeters fed by water pumping modify the hydrologic conditions of the Niger, increasing the effects of drought. These hydrological variations led to changes in the flora of the river-floodplain system and also to fragmentation or disappearance of habitats usually occupied by numerous fish species. The biological cycle of the fish that were adapted to the former hydrological cycle was modified to varying degrees, although the species richness of the river evaluated at 260 fish species did not change. Nevertheless, fish abundance changed from 1968 to 1989, fish landings declined from 90 000 metric tonnes to 45 000 metric tonnes in the central delta and large-sized species were gradually eliminated to be replaced by a sequence of small-sized and more productive species. The river is fished by dynamic and labour intensive small-scale fisheries, conducted by full and part time fishers, using diverse fishing gears adapted to various biotopes and seasonal variations in the ecosystem and the fish communities. Women play an important role in fish processing (drying or smoking fish) and marketing. In several countries around the Niger River watershed, the fish stocks have been reduced by dramatic increases in fishing activities. Aquaculture has been introduced as an accepted strategy to meet the very high demand for fish products. Aquaculture was introduced in Nigeria and Cote d'Ivoire in the 1950s based on indigenous species of tilapias and catfishes but is still in an embryonic state. The River Niger Commission was created in 1964 and evolved in 1980 into the Niger Basin Authority (NBA) to promote cooperation among the member countries and to develop its resources, notably in the field of energy, water resources, industry, agriculture, forestry exploitation, transport and communications.

GENERAL INFORMATION ON THE NIGER RIVER

The Niger River is the fourth longest river in Africa (4 200 km). It is classified as a Sudanian river as it drains the arid Sahellian savannah for the main part of its course (Figure 1). The Niger River rises in the Fouta Djalon mountains of Guinea and flows northeast through Mali where it forms a seasonally inundated floodplain of 20 000 km^2 known as the Central Delta. North of Gao in Mali, the river bends sharply to the southeast, travels through Niger, the Republic of Benin and Nigeria where the river enters the Gulf of Guinea. It is joined in its lower course by its major tributary, the Benue, that rises in the Adamoua massif of Cameroon from where it is fed by rivers originating on a high central plateau.The Niger has a coastal delta which covers 36 260 km^2, most of which is heavily forested and also a costal fringe of saline mangrove swamps, estuaries and freshwaters (Welcomme 1985).

The Niger River plays an essential role in the life of a densely populated and large region of West Africa. It is an important waterway both for navigation associated with active trading (in Mali from Koulikoro to the Niger bend and in Nigeria on the lower Niger River) and for small canoe traffic over the whole of its course. The riparian, rural populations benefit from its important fish resources. Its floodplains and floodplain tributaries in the inner delta are used for the cultivation of rice, cotton and wheat. In addition, the floodplains are vital to the cattle-herding nomads who use the access to water and the pastures that are created anew every year as the water recedes. New developments (hydroelectric and irrigation dams) are now liable to give the river a significant economic role.

Information concerning the River Niger in Guinea, Mali, Niger and Nigeria is rather poor, often qualitative and descriptive, with few quantitative data, mostly scattered in various reports and research studies. In the past hydrobiological investigations focused on important economical ecosystems, such as the



■ **Figure 1 .** Rivers and lakes of the Niger-Benue system (Welcomme 1972).

Central Delta of the Niger or Lake Kainji in Nigeria. The quality and accuracy of information may vary greatly from one country to another or from the main channel of the river to lakes or floodplains.

WATER INPUT, WATER QUALITY AND HABITAT MODIFICATION

Natural environment

Guinea, Mali, Niger, Benin and Nigeria, are traversed by the Niger River and Cameroon, Burkina Faso and Côte d'Ivoire by its tributaries. The course of the Niger can be subdivided into four parts (Brunet-Moret *et al*. 1986a, 1986b):

The Upper Niger Basin is limited downstream by the entry of the river into the Central Delta. In Guinea, the Niger River receives four important tributaries: Tinkisso, Niandan, Milo and Sankarani. The Bani River has much of its course in Côte d'Ivoire but joins the Niger River in Mali at Mopti. It is formed by three major tributaries: Baoulé, Bagoé and Banifing.

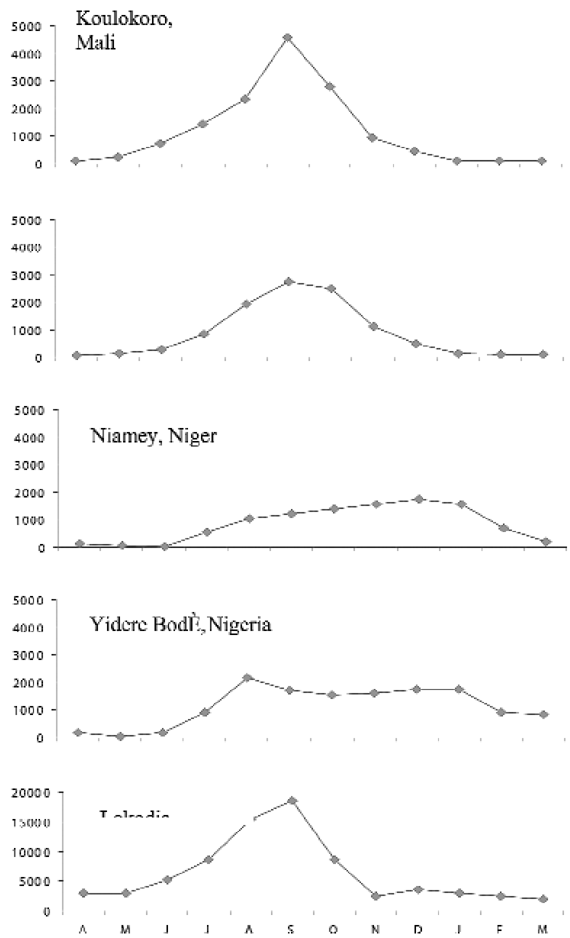
The Central Delta is situated downstream of Segou. The rivers Niger and Bani feed this large area. Flooding occurs in July and August, with 90 percent of the water coming from Guinea and Côte d'Ivoire. The highest floods cover the whole basin in September and October. Subsidence begins in November and December and the lowest water levels are in April and May when the floodplain pools dry up and only the rivers Niger and Bani and some lakes retain water. During a good hydrological period there is a three-month time lag between the onset of the flood in the south (Ke Macina) and in the north (Dire) of the delta. During the same hydrological cycle, flooded areas can vary from 20 000 km^2 at the maximum flood, to 3 500 km^2 at the end of the low water season (Raimondo 1975).

The Middle Niger Basin stretches from the point of discharge of the Central Delta at Lake Faguibine to the border of Nigeria. Water inputs from left bank tributaries (Tossaye to Malanville) and right bank tributaries coming from Burkina Faso are insignificant. However, the right bank tributaries coming from Benin (Mekrou, Alobori and Sota) induce local floods in Benin, with their maximum in September. This is as important as the Guinean flood, which takes place in March. The Niger River is 550 km long within Niger and its floodplains cover approximately 600 km^2 during the flood season and 90 km^2 during the dry season.

The Lower Niger Basin stretches from the Nigerian border from Niger about 162 km north of Lake Kainji to the point of discharge into the sea. The Sokoto River joins the Niger approximately 75 km downstream of the Nigerian border. This tributary extends upstream with a broad floodplain for about 387 km (Hughes and Hughes 1991). There are many major tributaries in Nigeria, including the rivers Anambra, Sokoto, Rima, Kaduna, Gbako and Gurara along the Niger River up to the confluence with the Benue at Lokoja. The Benue river also has significant tributaries, the Gongola, Taraba, Donga, Katsina-Ala and Mada Rivers. The Benue itself originates in the Adamaoua Mountains in Central Cameroon and has a total length of approximately 1 400 km. The upper reaches of the Benue and Niger in Nigeria form narrow valleys and contain falls and rapids. Most of the lower portions, however, are free of rapids and have extensive floodplains (3 000 km^2 and 1 800 km^2, respectively) and braided stream channels. In the south, the Niger forms a vast delta which covers 36 260 km^2 and consists of a network of distributaries where saline water penetrates for a considerable distance (Van den Bossche and Bernacsek 1990). Wetlands cover over 15 000 km^2 in this area and are separated by numerous islands (Van den Bossche and Bernacsek 1990; NEDECO 1959, 1961; Scott 1966; Ita 1993). There are definite wet and dry seasons which give rise to changes in river flow and salinity regimes. During the wet season (May-October) salinity falls to almost zero throughout the delta. River flow in the dry season (November-March) is still sufficient to keep the maximum salinity in the mouth at $28^{0}/_{00}$. Studies in the Bonny estuary, which is part of the delta, showed that salinity, conductivity, pH, dissolved oxygen and alkalinity exhibited spatial and temporal variations (Dublin-Green 1990). The lowest salinities of $14\text{-}24^{0}/_{00}$ and the maxima of $19\text{-}31^{0}/_{00}$ were recorded in the late wet season and late dry season, respectively, in both the upper and lower reaches of the estuary. On the basis of salinity, the Bonny estuary can be classified into three zones (Blaber 1997): upper reaches (mesohaline at all seasons except in the late dry season, salinity $< 18^{0}/_{00}$), middle reaches (polyhaline at all seasons, salinity $18\text{-}27^{0}/_{00}$) and lower reaches (polyhaline at all seasons, salinity above $27^{0}/_{00}$).

Hydrology

The flood of the upper and middle Niger lasts from July to November with the low-water period from December to June. As the river receives tributaries from different climatic areas, the merging of the different flood regimes may produce a second peak, as in the north of Nigeria (Figure 2). In the lower course of the Niger, the river receives water from the Benue, its



■ **Figure 2.** Evolution of flood regimes in the Niger River from Mali to Nigeria.

major tributary, as well as important local precipitation that strongly increases the flow.

Climate and recent climatic changes

The seasonal pattern and amount of rainfall in any one region of the river depends on the latitude and the position of ITCZ (intertropical convergence zone), which migrates from 5 N (December to March) to 20 N (July-August). Consequently, the Niger River passes through four main climatic areas (Table 1):

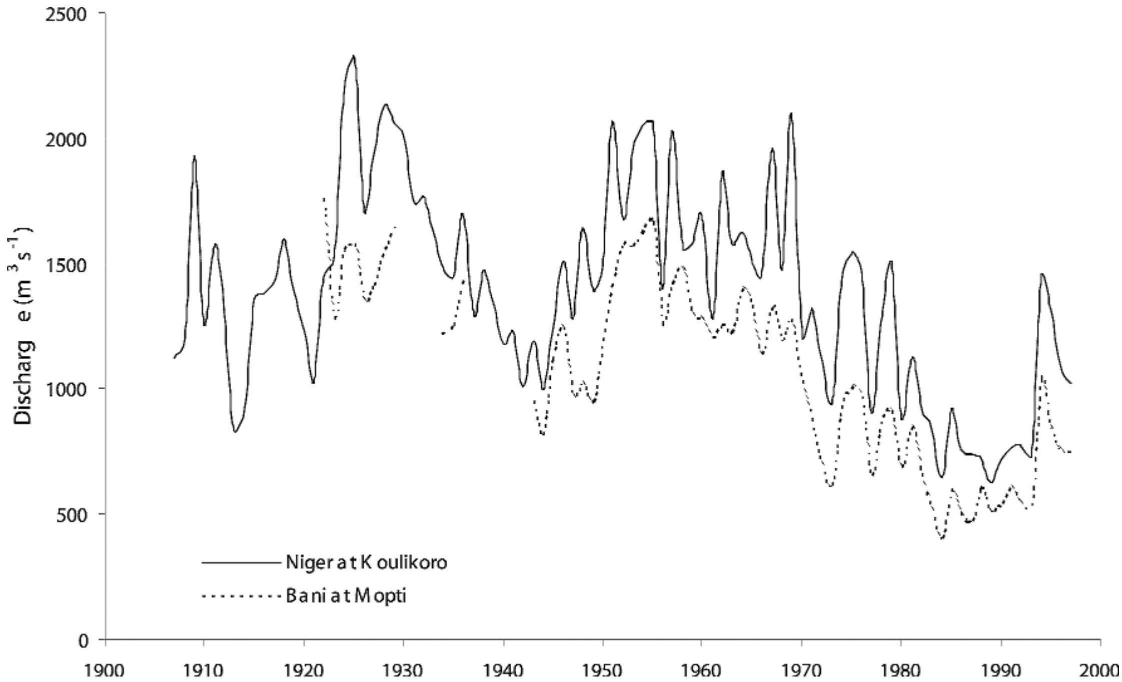
Table 1: Climatic characteristics of the whole Niger basin (temperature T, relative humidity U and inter-annual precipitations).

	Guinea		Mali		Niger		Nigeria	
Parameter	**Macenta**	**Siguiri**	**Bamako**	**Gao**	**Niamey**	**Kandi**	**Jebba**	**Onitsha**
T° ann. average	24	26.9	28.5	29.6	28.9	27.8	41.5	38
T° x month (x)*	(3)34.6	(3) 38.0	(4)39.4	(5) 42.6	(4) 41.4	(3) 38.8	(5) 48	(6) 38.5
T° n month (n)*	(12)14.0	(1)13.8	(1)17.6	(6) 27.7	(5) 27.3	(4) 25.2	(12) 12	(12) 27.5
° x ann % **	96	85	73	55.5	62.0	80.7	75	99
° n ann % **	58	39	33	18.1	26.7	39.7	32	65
1/2 (° x+° n) % March	69	40	26	23.5 (march)	19.6 (march)	34.9 (feb)	29	67
1/2 (° x+° n) % August	85	81	79	64.1	75.4	81.9	65	85
P (inter-annual precipitation) mm	2 100	1 250	985	255	585	1 053	680	3 100
Number of dry months ***	1 to 2	<u>6</u>	7	10	8	6 to 7	3 to 5	1 to 2

* ( ) : maximum temperature (x) and minimum (n) month number
** Ux and Un = maximal and minimal annual average relative humidity;
(Ux + Un)/2 = average relative humidity of the driest (March) and wettest (August) month
*** According to the definition of Gaussen, one month is considered as dry when Pmm < 2T° C

- The tropical transitional zone at the head of the Niger basin and its affluent, with a rainy season which is 8 months long from April to November and annual precipitations higher than 1 500 mm;
- The Sudanian zone extending from the north of Guinea and Côte d'Ivoire to the south of Mali in the west and again in the north of Nigeria in the East. Annual precipitation ranges from 750 to 1 500 mm, with a 5 to 7 month rainy season;
- The Sahelian/sub-desert zone covering the Central Delta and the river downstream from it in Mali and Niger. Precipitation ranges from 250 to 750 mm, with one rainy season of 3 to 4 months;
- The equatorial zone in southern Nigeria (terminal delta), characterized by two rainy seasons, two dry seasons and a very high precipitation (4 000 mm). In Nigeria, primarily the distance from the ocean to the hills determines the climate and as such the temperature is always warm and precipitation decreases from the coast in the south to the Sahel in the north (650 mm).

The regularity of droughts has been among the most notable aspects of Sahelian climate in recent years, particularly in the drier regions in Mali, Niger and northern Nigeria. There are similarities in the long-term discharge pattern of the rivers Bani and Niger, as shown in hydrological data collected since the beginning of the century: 1913, 1945 and 1972 are years of unusually low discharges for these two rivers (Figure 3). The rate of water flows recorded for the decade 1980-1990 are by far the lowest recorded since



■ **Figure 3.** Average annual discharge rates (m^3/s) for the Niger river at Koulikoro and the Bani river at Mopti (La° & Mah° 2002).

the beginning of the century (Mahé *et al*. 2002). The occurrence of wet and dry years is not randomly distributed in time (Lévêque 1995).

This regular decrease of water flows has modified the way in which the floodplains are flooded. In the Central Delta, for instance, the areas flooded during the drought were considerably reduced as was the duration of the flood. Quensière (1994) estimated the maximum flooded area to be 43 900 km^2 in 1957, as against only 9,500 km^2 in 1984. Adjacent lakes can show different flooding pattern situations according to rising amplitude (Koné 1991). Thus there are (i) lakes that are fed annually by the flood: *Faguibine, Fati, Oro, Tele, Korientzé*; (ii) lakes that are only fed in average years (hydrology of 1988): *Aougoundo and Niangay*; (iii) lakes that are only fed in wet years (hydrology 1979): *Korarou, Tanda, Kabara*; and (iv) lakes that are fed in very wet years (hydrology of 1969): *Daounas*.

Vegetation

The vegetation cover of floodplain lakes has been well documented in Daddy, Wari and Mohammed (1989) and effects of dryness on the various vegetal types of floodplains by Deceuninck (1989). If the flood lasts for less than 3 months *Vetiveria nigrita* (long-lived grass) replaces *Echinochloa stagnina*, *Oryza longistaminata* and some aquatic plants. The immediate consequence of this is to modify the biotic capacity of floodplains that normally offer abundant and varied food to fish during the flood.

In Lake Kainji, the emergent aquatic macrophytes include *Echinochloa stagnina*, *Cyperus distans*, *Pistia stratiotes*, *Nymphaea lotus*, *Lemna paucicosta*, *Phragmites karka*, *Ipomoea aquatica*, *Sacciolepis africana* and *Ceratophyllum demersum*, of which *E. stagnina* represents the major component. In 1971, emergent macrophytes were estimated to cover only 0.5 percent of the lake surface area versus 8.9 percent in 1977 (Obot 1984). The grass mat serves as spawning and feeding ground for numerous fish species (Ita 1984; Balogun 1988) and as livestock fodder during the dry season. The aquatic emergent vegetation represents an obstacle for small craft navigation.

Nigeria has the third largest mangrove forest in the world. It consists mostly of red mangrove, *Rhizophora racemosa*, with its characteristic stilt or prop roots. The mangrove floor is important for a lot of smaller flora and fauna and so ultimately for the whole food chain. Other trees include the smaller black mangrove and white mangrove. A unique salt fern can be found in higher areas of mangroves, while the exotic nypa palm (*Nypa fruticans*) colonizes cleared areas. Other types of vegetation include freshwater raphia swamps, floodplain forest and upland rainforest (Moses 1990).

HUMAN IMPACTS

Irrigation and dams

Water was regarded for a long time as an inexhaustible resource but the recent drastic reduction of floodplains and the drying out of some sections of the Niger (Niamey in June 1985) has raised concerns of the local people. Marie and Témé (2002) identify the following activities as removing more water from the river:

- Traditional irrigation based on natural immersion (Mali, Niger, Nigeria),
- Improvement of the traditional system by controlled immersion at rising water level (construction of dams, polders and other structures for the control and circulation of water in channels),
- Entirely controlled water diversions (Baguineda irrigated perimeter and Niger Office in Mali),
- Control of water by pumping, exploited collectively or individually (areas of Mopti, Tombouctou: mainly Dire for the culture of corn and Gao. This is a general feature of riparian agriculture on the Niger).

There are relatively few impoundments on the Niger River as compared to other major river systems. However, four dams have been built on the main river or its tributaries that have created reservoirs as follows:

Lake Selengue: A hydroelectric dam was built in 1980 in Selengue on the Sankarani River upstream of Bamako to provide electricity for the Mali capital. The reservoir surface area is 400 km^2 and during the flood the flow rate of the river entering the reservoir is estimated at 123 $m^3\ s^{-1}$.

Lake Markala: The dam was built in 1943 at Markala 250 km downstream of Bamako in Mali in order to store water for gravity irrigation of a depression that was formerly an arm of the Niger. This new area, known as the "Office du Niger", allowed a significant development of agriculture and currently produces rice and sugar cane. For this purpose up to 158 $m^3\ s^{-1}$ of water is used, representing 5 percent of the river flow during the flood.

There is only one hydroelectric dam in Niger at Kandaji, except for a submersible dam that provides the capital Niamey with drinking water. As the hydrological cycle is disrupted downstream, a co-operation agreement between Mali and Niger allows for artificial flood releases at low waters to maintain a minimal flow.

Lake Kainji: The only mainstream impoundment on the Niger River is Lake Kainji in Nigeria, located about 1 200 km upstream from the mouth of the river. The hydroelectric dam was built from 1962 to 1968 and the surface of the reservoir when full is about 1 300 km^2.

Lagdo Reservoir: The upper course of the Benue River was impounded in 1982 for hydroelectric power generation, irrigation and fisheries. The surface of the reservoir covers 700 km^2.

All these structures have had an impact on the natural dynamics of the river downstream of the dams and on fish abundance and diversity. The impacts are not always documented or clear (Petts *et al*. 1989). In Mali, the Markala and Selengue dams have contributed to an increase in the impact of drought by further lowering the already reduced flood flows: the annual loss in total fish catches in the Central Delta is estimated to be 5 000 tonnes (Laë 1992a). The dams also affect upstream fish production by disrupting longitudinal migrations of fish. But electric power production at Selengue, which requires large volumes of water, has created better flows during the dry season than those encountered before the Sahelian drought. Consequently, the survival rate of spawners has increased ensuring adequate reproductive success every year (Laë 1992a). The better flows have allowed the development of seasonal rice culture in irrigated areas, with water releases ranging between 80 to 100 $m^3 s^{-1}$ that translates to 70 percent of the average river flow (Marie and Témé 2002).

In Nigeria, changes in the fish fauna of the Niger followed the construction of the Kainji dam (Lelek and El Zarka 1973; Adeniji 1975). Fish catches between Jebba and Lokoja decreased by 50 percent in the three-year period from 1967 to 1969 (Otobo 1978). This was amplified by changes in the fish community composition with a decline of Characidae, Mormyridae and Clariidae and an increase of predatory species like *Lates niloticus* or some Bagridae species (Sagua 1978). In the same way, downstream the fisheries of the Anambra basin registered a 60 percent decline, following the drying out of the floodplains caused by the construction of the dam (Awachie and Walson 1978).

In the Niger Delta, environmental problems are complex, interconnected and caused by many factors including flooding and erosion. Land degradation and direct loss of land to habitation and cultivation are common problems throughout the Niger Delta arising mainly from flooding and erosion. Flooding, which normally lasts from three to five months annually, has been made worse by dam construction on the Niger River over the last 30 years. The loss of sediment input to the delta has increased the rate of coastal and river bank erosion.

POLLUTION

Invasive species

The presence of water hyacinth was noted in several countries crossed by the Niger River and its tributaries: Benin, Burkina Faso, Côte d’Ivoire, Mali, Niger and Nigeria (Akinyemiju 1987; Akinyemiju and Imevbore 1990; Akinyemiju 1993a, 1993b; Harley 1994; Chikwenhere 1994; Dembele 1994; Olaleye and Akinyemiju 1996, 1999, 2002). Water hyacinth is not present upstream of Bamako but it proliferates at the points of discharge of polluted water where concentration of organic matter is high (Bamako and Segou). Biological control, using weevils (*Neochetina bruchi* and *N. eichhorniae*), was effective in Mali in permanent sites such as ponds but must be sustained every year in the sites subjected to river rise and fall.

In Niger, since 1989 the river has been invaded by water hyacinth obstructing fishing activities. Currently the invasive plant is present over more than 60 percent of the river course interfering with fishing gears in favourable fishing areas (floodplains and backwaters). It is also modifying the water ecosystem by depletion of inorganic nutrients essential for primary production. In addition, the combined effects of droughts and human impacts (itinerant agriculture, overgrazing, abusive wood cutting) has led to an increase in erosion, removal of muddy banks, considerably reduced water volume and modified water quality (e.g. high turbidity, deoxygenation). No chemical pollution from industrial or urban effluents has been reported in Niger.

Water hyacinth is also of concern in both fresh water and brackish water sectors of the delta.

Environmental pollution

In Nigeria, people inhabiting the Niger Delta have suffered extensive environmental pollution and the crisis is still on going. Chief among the pollutants is oil. The Niger Delta is endowed with immense natural resources, particularly crude oil. Nigeria's refining started in late 1965 near Port Harcourt. Later three other refineries were built in 1978, 1980 and 1990 increasing Nigeria's refining capacity to 445 000 barrels per day. In addition, Nigeria has the largest natural gas reserves in Africa, with 21.2 billion cubic meters per day produced in 1988. As a consequence, environmental problems arise from oil and gas-related development activities, oils spills, refinery operations, oil transportation, gas flaring, dredging of canals and land taken for the construction of facilities. Areas near such outfalls are subjected to chronic pollution, which is of significance for fish resources and fisheries (Robinson 1997; Egborge 1998; Akinyemiju and Imevbore 1990; Akinyemiju 1993a, 1993b, 1994; Olaleye and Akinyemiju 1996, 1999, 2002).

STATUS OF FISH BIODIVERSITY

Species richness of the Niger River

The fish communities of the Niger River belong to the Nilo-Sudanian Province. The Upper Niger and Central Delta harbour 130 to 140 species (Daget 1954; Lévêque, Paugy and Teugels 1990), which belong to 62 genera and 26 families. In the middle Niger, 98 species belonging to 22 families, have been recorded (Coenen 1986; Daget 1962; Bacalbasa-Dobrovici 1971). Among these species, 83 are regularly fished while 15 are of a very small size and/or are very rare. In the lower Niger, 160 species have been recorded in Lake Kainji (Ita 1978, 1993; Balon and Coche 1974), with 9 fish families of economic importance. On the Benue River, 113 species were collected in the Mayo-kebbi (Blache *et al*. 1964) versus 128 in the Benue River (Stauch 1966). Until recently, the fauna of the Niger Delta was largely ignored, due to the inaccessibility of the riverine and swampy areas. The Delta has a lower diversity of freshwater fish than recorded in equivalent biotopes in West Africa. When comparing lagoon and estuarine ecosystems, there are 79 species in the Lagos lagoon of Nigeria (Fagade and Olaniyan 1972, 1973, 1974), 130 species in the Ebrie lagoon (Albaret 1994) and 102 species in the Fatala estuary in Guinea (Baran 1995). By 2002 there were a total of 311 freshwater fish species recorded from the rivers and lakes of Nigeria.

All these species have adapted to the seasonal and inter-annual variations of the hydrological cycle of the river both in freshwater and brackish water ecosystems involving a succession of favourable and unfavourable environments and the appearance and disappearance of natural habitats. Feeding, growth and mortality are closely linked to the seasons. For instance, spawning of most of the species takes place at the beginning of floods (Benech and Dansoko 1994), growth is restricted to rising and high waters, while mortality rates are higher during the declining water level and dry season. Fish breeding and feeding migrations are dependent on water discharges. In response to the variations in the hydrological cycle, fish community composition and abundance can change greatly from one season or one year to another.

Grouping of species in ecological classes

In freshwater ecosystems, two major groups of fish can be identified on the basis of their adaptive strategies (Quensière 1994):

1. Migratory fish exploit environmental variability and have high fecundity and a short breeding period at the beginning of the flood. As spawners concentrate in few sites and fish later disperse in the whole river, genetic mixing is enhanced. Some species such as *Hydrocynus brevis* and *Bagrus bayad* are short distance migrants while others such as *Alestes baremoze, Alestes dentex* and *Brycinus leuciscus*, are long distance migrants.
2. Opportunistic species are less mobile and show various behavioural and physiological adaptations that help them to survive in the anoxic environments of floodplains. Some species have anatomical features such as lungs (*Protopterus annectens, Polypterus senegalus*), arborescent respiratory organs (*Clarias anguillaris, Heterobranchus bidorsalis*),

supra-branchial organs (*Ctenopoma kingsleyae*) or highly vascularised intestines (*Heterotis niloticus*, *Gymnarchus niloticus*). Other species show physiological or behavioural modifications including breathing from the water surface film (Cichlidae, *Hemisynodontis membranaceus*). These species generally have low fecundity but can breed several times a year. Survival of the young is improved by various degrees of parental care ranging from territorial behaviour associated with nest building to mouth brooding.

The relative abundance of these two groups depends on the variability of the hydrological cycle both in space and time (Lowe-McConnell 1975).

In brackish water, the great seasonal changes in the salinity regime of the delta, with periods of high and low salinity, has led to the classification of the fish into three groups according to their seasonal distribution.

Group 1. Species that occur in the system throughout the year and can tolerate the great change in salinities between the dry and wet seasons. Most fall into the marine migrant category and include the commercially important clupeid *Ethmalosa fimbriata*. The remainder are freshwater species: *Chrysichthys nigrodigitatus*, *Sarotherodon melanotheron* and *Tilapia guineensis*.

Group 2. Species found in the system only between December and May (mainly dry season) when the salinity fluctuates between $0.5^{0}/_{00}$ and $28^{0}/_{00}$. They are all marine migrants and all juveniles.

Group 3. Species found only when salinities fall below $1^{0}/_{00}$. They are primarily freshwater species such as *Schilbe mystus*, *Clarias lazera*, *Lates niloticus* and Mormyridae.

Endangered species and species that have disappeared

In river-floodplain ecosystems, the end of the dry season is marked by a fall in Shannon index diversity with a relative increase of some families such as Cichlidae, Clariidae and Centropomidae (Laë 1995). As the same species are affected by a long-term drought, this phenomenon could be extrapolated to an inter-annual scale as is shown by analysis of fresh fish traded in the port of Mopti (Mali) (Quensière 1994).

Before 1970, fish communities were typical of good flood regimes with a remarkable abundance of *Synodontis* spp, *Polypterus senegalus* and *Gymnarchus niloticus.*

From 1973 to 1979, the nine most abundant species were similar but secondary species disappeared or became infrequent. At the same time, the relative abundance of *Clarias anguillaris*, *Heterobranchus bidorsalis*, *Chrysichthys auratus*, *Bagrus bayad*, *Schilbe mystus* and *Auchenoglanis occidentalis* increased.

From 1985 to 1991, changes in population structure accelerated and species such as *Citharinus citharus*, *Alestes* sp., *Synodontis* sp. and *Heterotis niloticus* joined the group of secondary species. On the other hand, *Bagrus bayad*, *Clarias anguillaris* and *Chrysichthys auratus* increased in catches.

These modifications illustrate the reaction of fish stocks to drought and increasing fishing effort and reinforce the observations of Roberts (1975) concerning adaptations of fish communities to various stresses. In the Central Delta, some species were very rare at least until the end of the drought period (1994): *Heterotis niloticus*, *Distichodus* spp, *Citharinus citharus*, *Bagrus docmak*, *Polypterus senegalus*, *Malapterurus electricus*, *Clarotes laticeps* while others disappeared from the catches: *Gymnarchus niloticus*, *Parachana obscura*, *Arius gigas*, *Citharidium ansorguii*, *Hepsetus odoe*, *Alestes macrolepidotus* (Laë

1994, 1995; Wetlands International 1999). However, most of these species are relatively abundant in other places in Mali (Lake Selengue) and reversion to more normal hydrological regimes would probably lead to the re-invasion of the delta by these species, either because they are still there or because they would migrate back into the delta from upstream or downstream areas.

In Niger, field observations do not substantiate the fact that some species are becoming rare. The notable differences between the inventories of Daget (1962) and Coenen (1986) relate to the absence of 2 species, *Arius gigas* and *Papyrocranus afer*, but only for taxonomic reasons. Nevertheless, in a context of droughts, river species are less underprivileged than those undertaking lateral migrations towards adjacent floodplains. Even if biodiversity is not endangered at a national level, it could be at a local one. Coenen (1986) showed that the condition of fisheries of Gaya bay (at the border between Niger and Benin) was giving serious cause for concern. The fall in fish recruitment due to drought, combined with strong fishing effort, lead to a lowering of length of fish caught to a point when juveniles form the major part of fish landings. However, the promised collapse is still not observed.

In Nigeria, as in the other Niger River countries, all natural lakes and reservoirs are supplied with fish by the inflowing rivers, The fish stocks in these major rivers are replenished from the adjacent floodplains after each flood season during which the fish breed. Drought or damming will disrupt the natural cycle of flooding which is bound to affect fish species diversity both in the natural or artificial aquatic ecosystems as well as in the wetlands. Given the size of its basin higher species diversity might be expected for the Nigerian reaches of the river than is the case. Welman (1948) listed 181 species; Reed (1967) listed 161 species from Northern Nigeria while White (1965) listed 145 species within the upper Niger (future Lake Kainji area). Ita (1993) reported that fish species in the Anambra, Kaduna and Sokoto/Rima, the major tributaries of the Niger, are low in diversity, in the range of 23, 28 and 22 species, respectively. Ita (1993) also noted that Lake Kainji topped the list with a total of 160 species, followed by Jebba reservoir with 52 species. While Lake Kainji Lake retained some of the riverine features within its northern arm, the number of species declined after impoundment from 160 to approximately 97. Ita (1993) reported that this decline is to be expected because of the reduction in the flow rate affected flow dependant species adversely. Some mormyrids, for example, disappeared as soon as the impoundment was completed, although these fish species were still found in some of the inflowing rivers. In conclusion, the low species diversity is linked to the dam location that is nearer to a tributary than to a confluence of the main rivers. This characteristic is linked to the rapids and rocky terrain preferred by a limited number of freshwater species.

INTRODUCTION OF EXOTIC SPECIES

Very few species have been introduced in Guinea and Mali. In Guinea *Oreochromis niloticus* was introduced in 1986 from Liberia for aquaculture but it has not established itself in the wild. In Niger, no exotic species were caught in natural environments (river and ponds) although some introductions of common carp (*Cyprinus carpio*), coming from Nigeria, were reported. Future introductions of exotic species for fish farming are not to be excluded. Selection of spawners for fish farming in ponds should be done from local species because some experiments showed that local strains have similar or better growth performances than the already domesticated ones (*Oreochromis niloticus* and *Clarias anguillaris*, Bouake stocks, Côte d'Ivoire) or wild ones coming from other rivers in West Africa (Senegal, for instance). This precaution will make it possible to safeguard the genetic resources of the Nigerian species without contamination and introgression risks.

In Nigeria, nine species were introduced since the 1970s, mainly for aquaculture: *Cirrhinus mrigala* and *Labeo rohita* from India, grass carp

Ctenopharyngodon idella, common carp *Cyprinus carpio* from Austria and Israel, silver carp *Hypophthalmichthys molitrix*, channel catfish *Ictalurus punctatus* and *Micropterus salmoides* from USA, guppy *Poecilia reticulata* from the UK and *Xiphophorus maculatus*. Among these species, only *Cyprinus carpio* is widely used for aquaculture. *C. carpio, P. reticulata* and *X. maculates* are probably established in the wild but their ecological effects are unknown.

STATE OF FISHERIES

Artisanal fishing is very intensive in fresh and brackish waters, with clear seasonal variations characterized by a decrease in exploitation at the time when fish is dispersed in floodplains or during the rainy season. Fishers modify their fishing techniques according to hydrological cycle (Daget 1949; Laë *et al*. 1994; Laë and Morand 1994). Environmental degradation has resulted in a diversification of fishing methods with the emergence of new technologies adapted to fish rejuvenation and the extension of fishing to new biotopes.

NUMBER OF FISHERS INVOLVED IN FISHING

Fishers can be classified into three main groups (Laë *et al*. 1994):

I Artisanal fish harvesters, using rudimentary gears (two-hands nets, harpoons) and only fishing in ponds and channels. They are extremely numerous but for them fishing is a minor activity for personal consumption. To this group belong Malinké in Guinea, Rimaïbe, Marka and Bambara in Mali, Haoussa and Zarma in Niger.

II Sedentary fishers living in permanent villages or camps are scattered among the fishing communities along the river and its distributaries. They practice traditional fishing during declining or low waters and use more standard techniques like gill nets or seine nets. They usually have secondary activities and are of Bozo or Somono origin in Guinea and Mali, Sokoto or Sorko in Niger.

III Migrant fishers forming units with intensive fishing activities (Bozo in Mali, Ijaws, Itsokos, Urhobos, Ilajes, Adonis, Junkuns and Hausawas in Nigeria). Their fishing gears and techniques are modern and specialized. As they move far from their villages, they cannot conduct other activities. In Mali they have to pay a royalty (maaji) for fishing (Fay 1989; Kassibo 1990). In Nigeria entry into the fishery is free even if they, like the local fishers, join the fishers' cooperatives within which they participate actively in the management and/or co-management of the aquatic resources with the local water chiefs called 'Bulamas" or "Sarkin Ruwa". Fish is always processed and marketed in order to reduce fish losses to the minimum. There is a degree of control of access to water bodies by the sedentary fishers and farmers that conflicts with the extensive fishing strategies developed by migrant fishers.

In Guinea, fishery statistics are rare. Several missions of experts were carried out to evaluate continental fishing and fish culture (e.g. Matthes 1993). The number of professional or full time fishers is perhaps 6 000 and fish catches may reach 6 000 to 8 000 tonnes y^{-1}. According to fragmentary data collected by interviews, fishers work from 90 to 170 days a year. Their individual annual catch ranges from 0.9 to 2.3 tonnes y^{-1}. The main fishing gears used are hand lines, bow nets, stow nets, gill nets, cast nets, multihook lines.

In Mali, the population of the delta increased significantly from 70 000 Bozos and Somonos in 1967 (Gallais 1967) to 80 000 in 1975 (Ministere des Ressources Naturelle et de L'Elevage 1975) and 225 000 in 1987, of which 62 000 were active fishers (Quensiere 1988; Morand, Quensiere and Herry 1990). On Lake Selingue, the number of fishing units is about 800 and the fishers are mainly coming from the Central Delta. The latter use fishing structures and practices of their birth village (Laë and Weigel 1995).

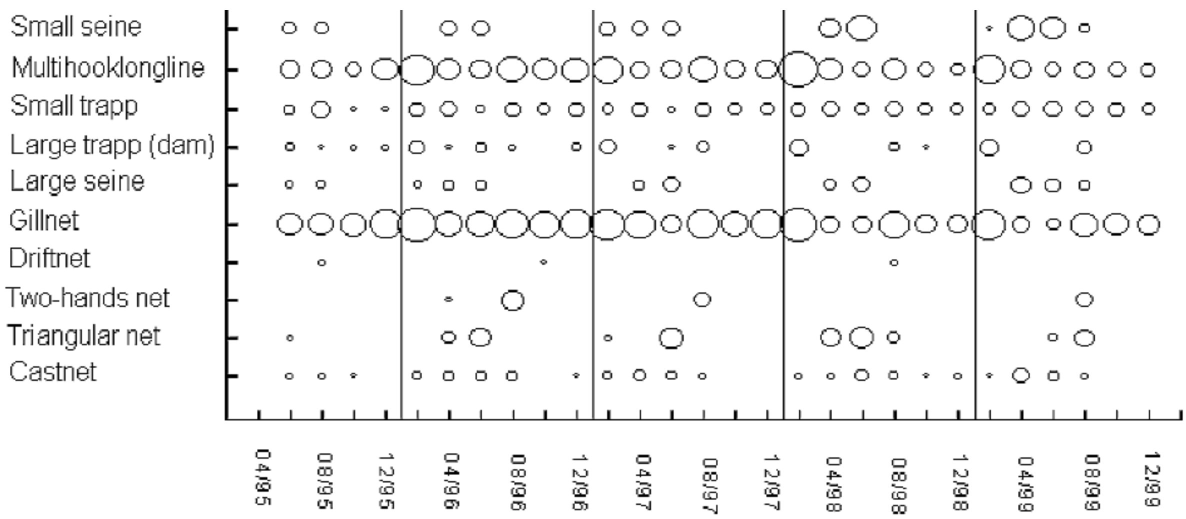
In Niger, fishing is practiced all the year. During the 1960s, there were roughly 1 500 active fishers (Daget 1962; Bacalbasa-Dobrovici 1971) and 2 600 in 1980 (Sheves 1981; Price 1991). From 1983 to

1985, fishing effort declined by 50 percent due to the Sahelian drought and relatively high fishing pressure (Malvestuto and Meredith 1989). As in Mali fishing effort doubled during the 1970s.

In the lower Niger, the number of fishers in freshwater ecosystems is estimated at 10 000 on the Niger River, 6 300 on Lake Kainji, 3 900 on Lagdo reservoir and 5 140 on the Benue River (Ita 1984; van der Knaap, Malam, Bouba *et al*. 1991; Welcomme 1985). National household surveys have no disaggregated data on the number of fishers involved in fishing activities on the Niger River. The estimated population is about one million fishers divided between the north-west and south-west portion of the Niger River in Nigeria including the Niger Delta in the southern zone. The population of fishers has decreased greatly between 1990 and now, because of lack of Governmental input subsidies for the purchase of canoes, nets and outboard engines. In the Niger Delta, the brackish water sector is an important component of the artisanal fisheries but there is no adequate information on the numbers of canoes and fishers operating in the brackish water area. The number of canoes operating in the estuaries, lagoons and inshore ranged from 95 127 (95 percent non- motorized) in 1971 to 109 638 (81 percent non-motorized) in 1984. It is apparent that the non-motorized canoes operate mostly in creeks, estuaries and coastal lagoons. The following is the total number of artisanal fishers by category in the Delta: there were 264 144 full-time fishers in 1991 as compared with 666 320 in 2000; in 1991 there were 192 958 part-time fishers as compared to 486 566 in 2000; and in 1991 there were 9 500 occasional fishers as compared to 24 422 in 2000 (Federal Department of Fisheries Statistics 2000). The grand total recorded for 1991 was 466 602 compared to 1 177 308 in 2000.

GEAR AND CATCH LEVELS, COMPOSITION

Artisanal fishing adapts to the cycle of flooding and retreat of water over floodplains. Water reaches floodplains via channels and backwaters, which ensures lateral extension of the flood. During the falling water, fish that stayed for 4 to 5 months on the floodplains return to the river. Rising and dropping water level and fish migrations involve significant



■ **Figure 4.** Fish gear utilization in the Central Delta of the Niger from 1995 to 1998 (bimonthly surveys). Circles are proportional to fishing intensity. In 1998, small seines are more used during the dry season to the detriment of gillnets (Kodio, Morand, Dienepo *et al.* 2002).

space-time variability in fish abundance and consequently a change in location of fishing areas during the year. Variations in water level also prevent using the same fishing gear throughout the year. In estuaries, the same is required due to seasonal changes in water salinity. There is a very close relationship among fished biotopes, hydrological seasons and fishing gears (Figure 4). Seasonal fishing techniques are essential for ensuring sufficient yield in order to satisfy the needs of the fishers.

Fishing gears used on the Niger River can be grouped into six major categories:

Active fishing methods

- hunting gears (harpoons, used mainly in ponds in process of draining)
- launched or push nets (triangular nets, two-hands nets, cast nets, frequently used by occasional fishers)
- seines: small seines handled by one or two men at low water, or large seines (purse seines or beach seines) from 400 to 1 000 m total length, operated by a team of 20 fishers;

Passive fishing methods

- gill nets (mono- or multi-filaments nets, for fishing at the surface, at medium depth or just above the bottom). Fixed nets or drift nets, with small or large meshes, are adapted to target specific species
- traps (small traps used in shallow water and large traps that are 5 m long and of 2 m height. The latter are used for damming entirely some river arms during the falling water)
- lines (baited lines fishing close to the bottom and unbaited multi-hook lines that block demersal fish)

In the Central Delta, the total fish catch was estimated at 48 600 tonnes in 1990-1991 and fish were captured mainly using fixed and drift nets (40 percent). The most frequently used mesh sizes ranged from 20 to 35 mm knot-to-knot. The rest of the fish was captured using small traps (15.7 percent), cast nets (14.9 percent), multi-hook lines (10.6 percent), large (7.8 percent) and small (4.3 percent) seines. The fish were captured by migrant fishers (59.2 percent), sedentary fishers (36.1 percent) and farmer-fishers (4.7 percent). Seventy-six species were recorded in the fish landings, many of which occurred in small numbers (Laë 1995). Seventeen species accounted for 85 percent of the total catch. Cichlidae dominated (26.6 percent), with *Oreochromis niloticus* (10.2 percent), *Tilapia zillii* (8.3 percent), *Sarotherodon galileus* (6.2 percent), *Oreochromis aureus* (1.9 percent). Clariidae (*Clarias anguillaris*) were also well represented, with 18.7 percent of the total. They were followed by Characidae (13.6 percent) with *Brycinus leuciscus* (6.2 percent), *Hydrocynus brevis* and *H. forskali* (5.2 percent) and *Alestes* (2.2 percent), then Bagridae (11 percent), with *Chrysichthys* (5.4 percent), *Bagrus* (2.8 percent) and *Auchenoglanis* (2.7 percent), Cyprinidae, with *Labeo* (5.3 percent) and Centropomidae (*Lates niloticus* 3.8 percent).

In Nigeria, the fishing gears used in the estuaries are mainly longlines locally called “*lingo*”, castnets (“*brigi*”), clap nets, unbaited long lines with closely arranged hooks locally called “*mari mari*” and set and drift gill nets. Large gill nets and fixed gear for harvesting fish and shrimp predominate. The demersal target species exploited by artisanal fishing units are croakers (*Pseudotolithus*), threadfins (*Galeoides, Pentanemus*, *Polydactylus*), soles (*Cynoglossus*), marine catfish (*Arius*), brackish water catfish (*Chrysichthys*), snapper (*Lutjanus*), grunters (*Pomadasys*), groupers (*Epinephelus*) and the estuarine white shrimp (*Palaemon*). Bonga (*Ethmalosa*) dominates the pelagic fishery but there are modest catches of shad (*Ilisha*), sardine (*Sardinella*), various jacks (*Caranx* spp.) and Atlantic bumper (*Chloroscombrus*).

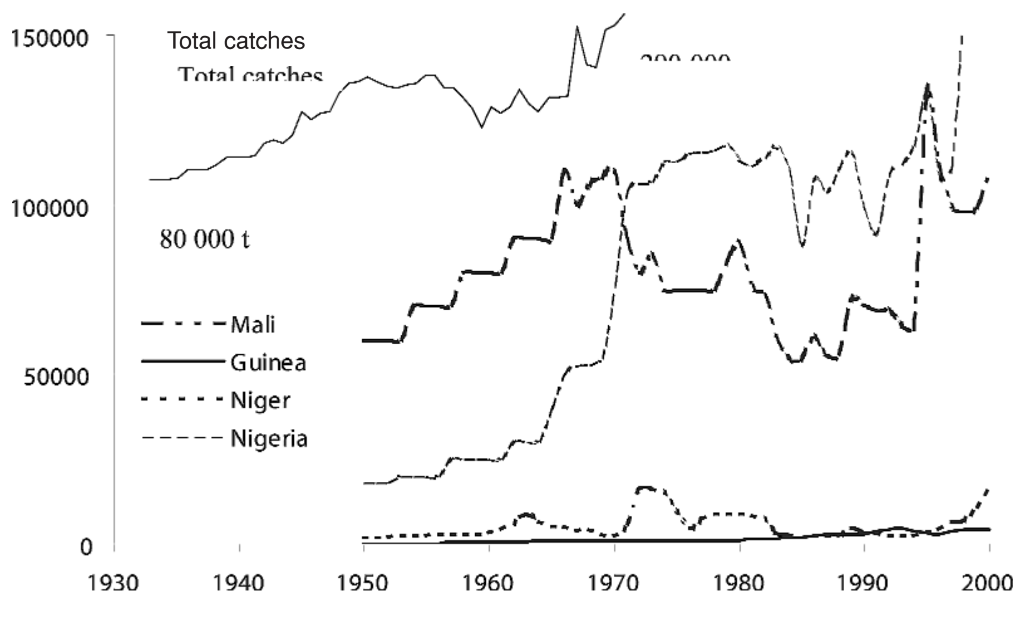
Apart from fishers, birds also prey upon stocks. In Nigeria, 74 species of aquatic birds are associated with Lake Kainji and the littoral zones and open water support most of the birds, feeding on *Sarotherodon galilaeus*, *Oreochromis niloticus* and *Chrysichthys nigrodigitatus,* among others (Okaeme *et al*. 1989; Ita 1993). In the Central Delta, birds are omnipresent and fish predation is obviously far from being negligible. This aspect is evoked by Welcomme (1979) who estimated that birds could represent the main source of predation in the floodplains.

Historical fish catch, actual fish catch and trends

Although historical data are rare, it is possible to trace the main changes over a period of about fifty years. In the 1940s, fishing was free and profitable, fish were abundant and the number of fishers was relatively low (Daget 1949). For instance, Blanc, Daget and d'Aubenton (1955) recommended that fishing be intensified in the Central Delta in order to reduce the number of adult fish and to support juvenile growth.

Later on fishing pressure increased strongly due to a growing number of fishers (doubling every 20 years). Intensification of fishing also resulted from the introduction of synthetic nets - according to Durand (1983) the use of nylon could have increased the fishing effort by a factor of 20 - and absence of control over the fishing due to the weakening of traditional authorities (Fay 1989). On the Niger River modern fishing gears were introduced including synthetic gill nets, multihook lines, cast nets and large seines. There has been an increase in individual practices as opposed to the formerly restricted traditional techniques. At the same time drought and high fishing effort led to targeting more juveniles and reducing mesh size (Laë and Weigel 1994). Thus, while 50 mm mesh was used before 1975, the use of 30 to 50 mm mesh-sized nets dominated from 1975 until 1983 and this was further reduced after 1983 to the now dominant 24 to 33 mm mesh-sized nets. Motorized boats were not introduced because of their high cost and the cost of maintenance and fuel.

The total annual catches on the Niger River and its tributaries are estimated to be about 300 000 tonnes. Fish catches (Figure 5) in Guinea (maximum of 4 000 tonnes) and Niger (maximum of 16 000 tonnes) are insignificant when compared with those in Mali (maximum of 133 000 tonnes) or in Nigeria (maximum of 161 000 tonnes). From 1950 to 1970, the growth of fishing on the Niger River led to an increase in annual

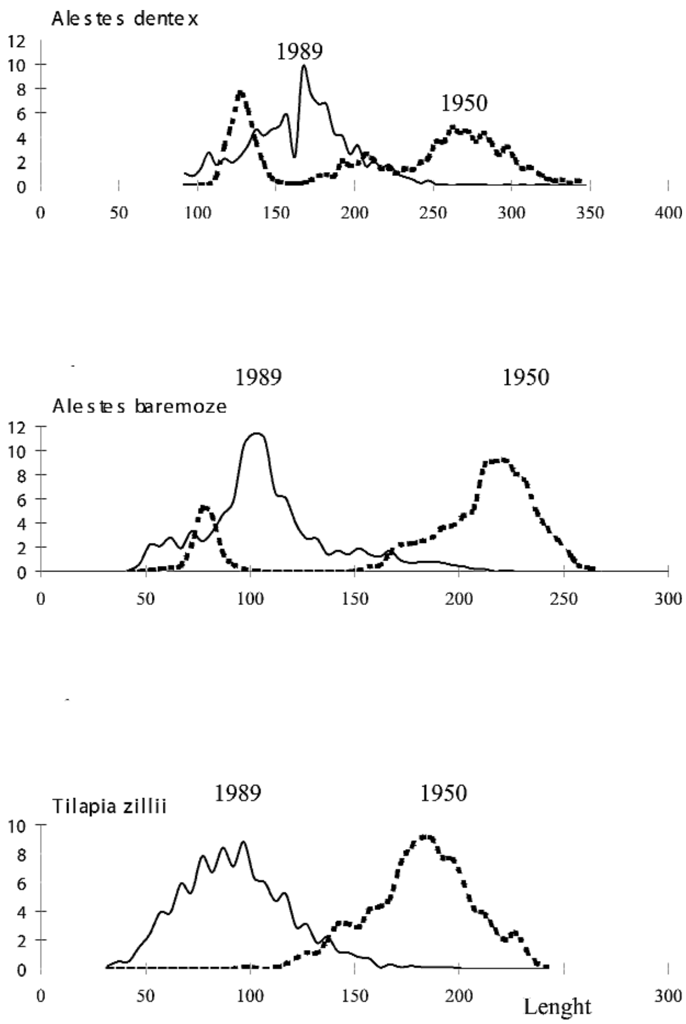


■ **Figure 5.** Annual fish landings (metric tonnes) in continental waters of Guinea, Mali, Niger and Nigeria. Insert gives total fish landings in the Niger basin from 1950 to 2000. From FAO statistical data.

fish landings from 80 000 tonnes to 200 000 tonnes. Thereafter fish production showed large fluctuations with a general downward trend from 209 000 tonnes in 1973 to 167 000 tonnes in 1991. This drop in catch was directly linked to the decrease in flooded areas due to the drought that prevailed in West Africa (Laë 1992b). Since 1995, the total fish landings have been increasing (288 000 tonnes), mainly due to better floods in the Central Delta.

In Niger, in the 1960s annual fish landings were about 4 000-5 000 tonnes, with a catch per fisher of 2.7-3.3 tonnes (Daget 1962; Bacalbasa-Dobrovici 1971). In 1978, before the drought years, total catches were close to 7 000 tonnes (Talatou 1995) and then dropped in 1983, 1984 and 1985 to 1 600 tonnes, 1 200 tonnes and 900 tonnes, respectively (Malvestuto and Meredith 1989). This was undoubtedly the result of the severe Sahelian drought. Since 1985, the annual fish catch fluctuates from 2 000 tonnes to 4 000 tonnes, depending on freshwater input and more recently (1999 and 2000) it has been reaching over 10 000 tonnes. (FAO statistical data).

In Mali, yields showed a rising trend from 40 kg ha^{-1} in 1968 to 120 kg ha^{-1} in 1990 due to an increase in productivity caused by the shift of the fishery to younger and smaller fish (Laë 1995). This was a consequence of increasing fishing pressure resulting from floodplain area reduction and concentration of fishing activities. Changes in the environment and increasing fishing pressure have lowered the average size of long lived fish species, such as *Alestes dentex*, *A. baremoze* and *Tilapia zillii* in fish catches between the 1950s and 1990s (Daget 1952, 1956; Laë *et al*. 1994) (Figure 6).



■ **Figure 6.** Evolution of catch length for Alestes dentex, Alestes baremoze and Tilapia zillii from 1950 to 1989 in the Central Delta of the Niger River (La° 1995).

IMPORTANCE OF LOCAL CONSUMPTION, FISH TRADING AND FISH PROCESSING

Considerable disparity exists at country level, but generally fisheries are labour intensive. An estimated 20 percent of the total agricultural workforce is directly or indirectly involved in the sector. Women play an important role in fish processing and marketing. Most of this employment is generated in remote inland or coastal areas, far from the main urban settlements, thereby helping to slow down the rural exodus.

In Guinea, marine fish landings are about 120 000 tonnes versus 4 000 tonnes for freshwater fish. As a consequence, even if continental consumption and trading is locally important, it is negligible at a national level.

In Mali, the fisheries sector is of major importance in the national economy, as it contributes to food security, job creation and increases the national wealth. With the return of normal floods, the sector recently consolidated its functions concerning the maintenance of social balance in Malian populations (Breuil and Quensière 1995): with a 100 000 tonnes annual production, the current fish consumption is about 10.5 kg habitant^{-1} y^{-1} versus 7.8 kg hb^{-1} yr^{-1} for meat consumption. The fishery sector generates 284 000 employment opportunities including 71 000 directly for production. This accounts for approximately 7.2 percent of the working population. With a gross added value of about 30 billion FCFA, the whole fishing network contributes approximately 4.2 percent to gross domestic product. The fisheries sector also contributes to the trade balance: over the last 20 years the marketing of fish has evolved under the impact of drought, lower catches and population growth, the last of which has led to an increase in fish consumption. Today, a significant proportion of fish formerly exported to Côte d'Ivoire, Ghana and Burkina Faso is now sold internally. Fish processing is essential because it is impossible to quickly distribute a product that is highly perishable. The proportion processed in Mali accounts for 75 percent of total catches. The major processing techniques are drying, smoking and burning. In spite of the use of chemicals such as K' Othrine and Gardona for slowing down fish deterioration, long storage involves significant losses of the processed fish, estimated between 15 and 20 percent by Coulibaly *et al*. (1992).

Three fish marketing channels can be identified starting from the fishing camps: (i) wholesale markets which first centralize, then redistribute the fish production towards distant areas; (ii) medium wholesale markets located in production and consumption centers; (iii) retail markets in cities and villages (Breuil and Quensière 1995). Fish is transported from fishing places by fishers themselves or their representatives, by tradesmen who move from camp to camp, or by wholesalers. Transport is generally by large canoes, trucks or vans. Trips between fishers camps and wholesale markets are simple and involve only a small number of middlemen whereas redistribution towards retail markets requires the intervention of many more.

In Niger, fish supply is limited but fish demand is also reduced by the low purchasing power of potential consumers. Fish consumption is about 0.3-0.5 kg hb^{-1} yr^{-1} versus 7 kg hb^{-1} yr^{-1} for meat consumption, but may reach 0.8-1.2 kg hb^{-1} yr^{-1} in urban environments (Lobet and Abdoulkadry 1993). This estimate does not take into account subsistence farming which could reach 15 to 20 percent of total production. Freshwater fish imports from Burkina Faso and Nigeria and fish exports to Nigeria have been stable over the last few years. Fresh fish coming from Mali could make a more important contribution since saltwater fish imports (nearly 1 000 tonnes of chinchard from Senegal and Ivory Coast) have stopped following the devaluation of the franc CFA in 1994.

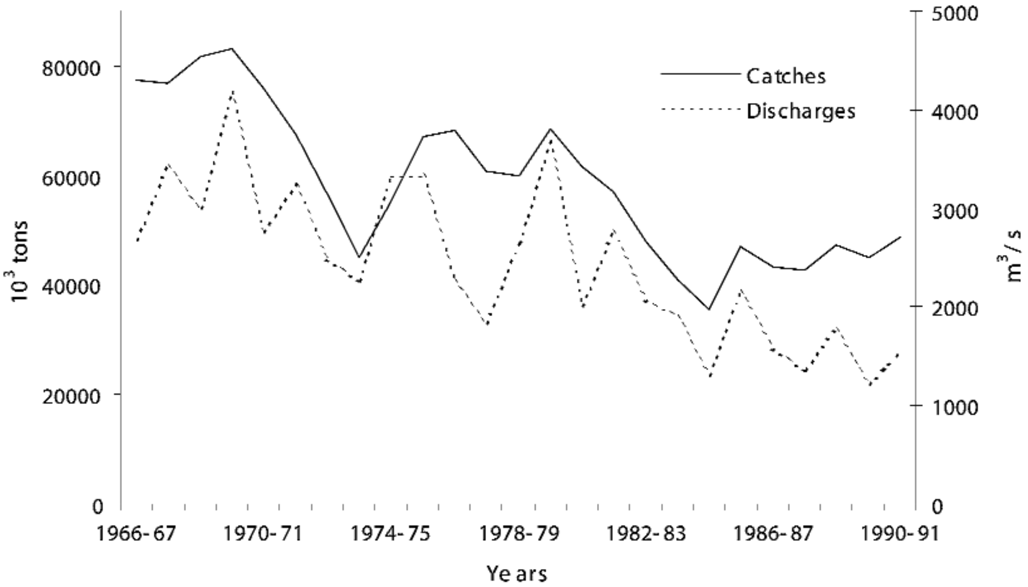
In Nigeria, in 2000 the total fish landings were about 467 098 tonnes, with more than two thirds coming from artisanal and industrial marine fisheries. In the mid-1960s, estimates indicated that Nigerian fisheries annually harvested 120 000 tonnes of fish and imported 180 000 tonnes, mostly air-dried. In 2000, 236 801 tonnes came from coastal and brackish waters, 181 268 tonnes from inland rivers and lakes, 25 720 tonnes from aquaculture, 23 308 tonnes from industrial and marine fisheries and 557 884 tonnes were imported. The total fish consumption was 1 024 981 tonnes. The per caput supply was 6.95 kg hb^{-1} yr^{-1}. At that time the population of the Niger Delta was about seven million people and it is increasing at about three percent a year. The total Nigerian population is more than 110 million and represents an important demand for fish. In this context more than 500 000 tonnes of fish are imported as against an export of only 8 200 tonnes. Frozen fish is imported to supplement local production. Consumption of frozen fish increased nearly tenfold between 1971 and 1990. Imported frozen fish are usually small pelagic species originating from elsewhere in the region (e.g. S*ardinella* from Mauritania, horse mackerel from Namibia), but sizeable amounts of herring or mackerel are also imported from Europe, notably from the Netherlands. Retail traders buy the fish in blocks and, after thawing, usually sell it "fresh" or smoked. Prices of imported frozen fish are relatively low and often depress fish prices on local markets.

MAIN REASONS BEHIND THE DECLINE IN FISH CATCHES

The upper and middle Niger River have been strongly modified from 1950 to 1990 by two consecutive droughts, by the building of dams and by a rapid intensification of fishing activities. The impact was mainly felt in the Central Delta. The two drought periods, which occurred in 1973 and 1984, were responsible for a decrease in the flow of the rivers Niger and Bani. Consequently, there was a modification of the floodplains and the areas flooded were considerably reduced, as was the duration of floods. From 1969 to 1986 floodplains contracted from 20 000 km^2 to 5 000 km^2 and their fish production decreased from 90 000 tonnes to 45 000 tonnes (Figure 7). The decrease in fish landings is directly linked to the reduction of flooded land (Welcomme 1986; Laë 1992b) and, knowing the water discharge entering the delta at the beginning of the flow, it is possible to predict fish catches for the following fishing year (Laë and Mahé 2002).

Markala dam, built in 1943 and Selengue dam, built in 1984, increase the effects of drought by further lowering the already reduced flood flows. The annual loss in total catches in the Central Delta, due to the two dams, was estimated to be 5 000 tonnes (Laë 1992a).

The increase in fish yields observed since the drought period (40 kg ha^{-1} y^{-1} in 1968 compared to 120 kg ha^{-1} y^{-1} now) comes from an increase in the concentration of fish, an increase in intra- and inter-specific fish competition and an increase in vulnerability to fishing equipment. Considerably higher fishing intensity is certainly responsible for the increasing dominance of young fish: in 1950 the average age at capture of *Alestes dentex* and *A. baremoze* was over 2 years (Daget 1952) and that of *Tilapia zillii* was almost 3 years (Daget 1956). In 1990, many species were bei caught in their first year (Laë 1992b), including *Labeo senegalensis* (86 percent of 0+ in catches), *Brycinus leuciscus* (82 percent), tilapias (82 percent for *Sarotherodon galilaeus*, 78 percent for *Tilapia zillii* and 68 percent for *Oreochromis niloticus)*, *Lates niloticus* (76 percent) and *Chrysichthys auratus* (72 percent). By contrast, other species such as *Chrysichthys nigrodigitatus*, *Alestes dentex*, *Auchenoglanis biscutatus*, *Brycinus nurse* and *Alestes*



■ **Figure 7.** Plots of catch (metric tonnes) in the central delta of the Niger and Niger River discharge at Koulikoro upstream of the delta (La° & Mah° 2002).

baremoze seem to be fished at a greater age as the percentage of 0+ fish in the catches varies between 20 percent and 40 percent. The weighted average of all catches showed that 69 percent were 0+ fish. The increase in productivity thus comes from younger fish stocks the growth rates of which have declined and longevity increased with fish weight (Peters 1983).

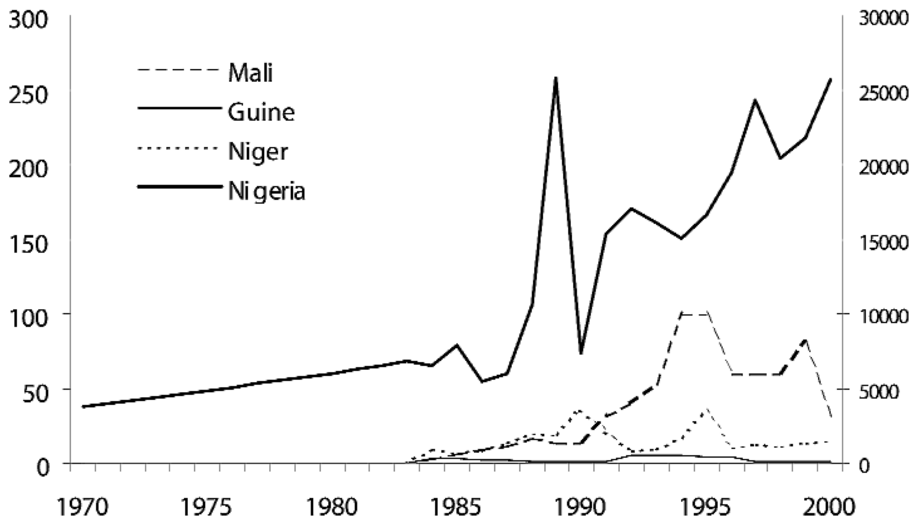
Another factor responsible for the decline in fish stocks is watershed degradation as a result of the combined effect of drought and human activities (itinerant agriculture, overgrazing, illegal cutting of wood). In Niger, this results in an increase in erosion and higher silt loadings, which, in turn, leads to formation of considerable sandbanks. Muddy habitats are destroyed, water volume is reduced and water quality deteriorates, as indicated by a high turbidity and low dissolved oxygen concentrations.

FISH FARMING

Aquaculture has not been a traditional practice in Africa and remains a new form of food and income generating activity, in spite of various efforts to improve its development and utilization since the 1950s. Aquaculture statistics (Figure 8) in West Africa are often not very accurate because of the relatively low economic profile of the sector and the lack of financial resources to monitor developments and rural production. However, one can distinguish between traditional and modern fish farming.

Traditional fish farming: Fishers used to build brush parks in some backwaters that are joined with the river during floods, in order to retain the largest fish (Oswald, Mikolasek and Kodako 1998). After several months without fishing, a collective fishing is organized during the dry season by traditional authorities. This practice is widespread in Mali, Niger and Nigeria where temporary ponds are also used for fish stocking and grow-out. In most cases, landowners are still in charge of fish resources. In Niger traditional acadjas are also used in Dole pond (Oswald *et al*. 1998) where fermented bran (1 or 2 kg) may be added every day. The time before harvesting can vary between 3 weeks and six months.

Modern fish farming: Malian aquaculture is of a recent date and aims to make good the deficits in fish production caused by the Sahelian droughts (Breuil and Quensière 1995). In the past several financial backers were involved in aquaculture development:



■ **Figure 8.** Annual fish farming production (metric tonnes) in continental waters of Guinea, Mali, Niger and Nigeria. Production of Guinea, Mali and Niger is very low (< 100 tonnes/year). From FAO statistical data.

USAID from 1979 to 1982 in the irrigated perimeters of San, OUA in 1986 to encourage fish culture in ponds of the irrigated channels of the Niger Office; a French NGO (AFVP) in 1987 to improve village fish culture (200 ponds); UNDP from 1987 to 1992 supporting a fish farming development project. The projects mainly concerned *Oreochromis niloticus* and *Clarias gariepinus* (village pisciculture). The strong competition between intensive fish culture, mainly for markets and prices and fishing did not allow its development. Commercial fish culture is not adapted to local conditions whereas auxiliary fish culture using improved fishponds finds some success with fishers. For a long time Niger sought fish farming techniques that would be best suited to its situation as a landlocked country. Fish farming is often associated with major projects such as intensive breeding of tilapias in the Niger River (Mikolasek *et al*. 1997) or extensive fish production in ponds (Doray *et al*. in press). Except for a few operations where the actors are easily identifiable, nothing is known about local fish culture. However, effective fish farming exists on a small scale in Niger, independently of international projects and funding (Mikolasek, Massou and Allagdaba 2000). These practices started recently, mainly from the 1980s. Private initiatives and local know-how emphasize the real opportunity for aquaculture development although this remains a minor activity at national level (Mikolasek *et al.* in press).

The recent development of the sub-sector has not been homogeneous and only a few countries have registered significant increases in production. Nigeria, one of the Niger basin countries, made significant progress during the last 30 years, with a growth in fish production from 4 000 tonnes in 1970 to 25 720 tonnes in 2000. Nigeria is the most important aquaculture producer in the sub-Saharan Africa. More than twenty species of fish are farmed, with fish production mainly based on tilapias, catfishes and cyprinids. While fishers are not entirely involved in fish farming activities on the Niger River, the fish supply crisis is leading local and state government extension officers to discuss this as an alternative fish production strategy for poverty alleviation and food security strategy.

PRINCIPAL MANAGEMENT MEASURES

Major challenges to be faced by integrated management and community-based management

Sustainable productivity of the Niger River fisheries depends both on the quality of the aquatic environment and on the hydrological conditions. Strong inter-annual variability of the natural environment points to the need for resilience in the fish species. The following factors make the plateau model appropriate for the analysis and management of fisheries: intensive fishing activities would not result in a decrease in total catch, as usually suggested and fish landings would remain relatively constant even when fishing pressure is increased threefold beyond the point when the asymptote is reached. In floodplain-river ecosystems the existence of a leveling off or plateau has been observed by many authors (Ryder 1965; Welcomme 1989; Laë 1992b, Laë 1997) and simulated (Welcomme and Hagborg 1977; Morand and Bousquet 1994; Bousquet 1994). Adoption of this model will strongly reduce the negative direct impact of fishing effort and fish landings on fish. Indeed, the risk of true biological overexploitation (collapse of fish stocks by overfishing) is very low for these artisanal fisheries, as long as destructive techniques (poison, explosives, etc.) are not used and as long as a minimal quantity of spawners survives at the end of the low water season, i.e. at the end of the fishing period.

This model emphasizes the environmental conditions as being particularly significant. This is a major challenge because, except for natural drought, the degradation of the river observed for several decades is generally caused by economical activities not involved in the fishing sector - management of floodplains for rice, pumping and water uptake for different agricultural crops, arms and channels filling due to wind, alluvial inputs related to desertification or deforestation of closed areas, gravel extraction for construction, pollution from pesticides used in agriculture, industrial or urban wastes, river bed degradation and pollution by gold extraction activities, oil and gas production.

Another challenge for Sahelian fisheries management is to arbitrate between the various private or public fisheries stakeholders. The goal is to better respond to economical or socio-political demands, which usually represent divergent interests. For example if it is accepted that fish production in river and floodplain ecosystems is limited by natural conditions, which group of fishers should be given access to the fishery: the migrant fishers (professional), or the resident ones (often farmer-fishers)? The choice is difficult because the level of legitimacy of the two groups is not the same, the results in terms of fishing performance (production reliability) will not be the same and the benefit received by local managers will consequently differ. Similar arguments pertain in brackish waters where artisanal and industrial fisheries are in competition for different ecophases of the same fish species.

The choice of which processing and marketing sectors to promote when people involved in fresh or processed fish trade are rarely the same and added values are differently shared by these two sectors is difficult. It is, similarly, difficult to decide which institutions (government services, micro- or macro-local authorities, professional associations) should benefit from receipts and taxations collected from fishing, marketing and distribution activities.

It is clear that the main needs as regards fishery management in the Niger basin relate to two major areas, namely environmental degradation and socio-economical priorities.

NATIONAL AND INTERNATIONAL LAWS AND INITIATIVES

Until the beginning of the 1990s in Mali, as in the other countries of the Niger basin, the government was the owner of all water areas. For this reason, the government tried to apply, at least in theory, a centralized management model. This was based on the payment of licenses for fishing rights, on the supply of technical and logistic support and technology transfer and on the enforcement of a national regulation to prevent overfishing (e.g.: minimum mesh sizes). This model of management responded imperfectly to the management needs, as it was in total contradiction with the former traditional practices and this has caused many problems. Another weakness of this system was that it was to be uniformly applied to the whole country, which prevented the adaptation of management to the variety of natural environments and fishing practices. The government mode of management, largely based on coercion, required significant institutional costs. All these shortcomings pointed to the need for a change in the contractual relations between the official owner (government) and the users of the fish resources.

At the end of the 1980s Mali tried to change its fishing governance processes by improving the involvement of stakeholders in management. This process was strongly accelerated with the introduction of a decentralization policy in 1995. It remains to be seen whether the new fishing management model is efficient in dealing with the key questions of Sahelian fisheries management.

Environmental policies are both limited by strong financial problems and hard resistance to changes resulting from various pressure groups that are water or watershed users. Nevertheless, little progress has been achieved on river environment conservation in spite of Mali being a member of the Niger Basin Authority and in spite of the recent creation of the River Niger Agency in Mali. The relative weakness of fisheries administration in Mali does not allow it to strongly defend the interests of the sector within national authorities in charge of the regional planning. However, implementation of the decentralization policy allows real progress with regard to problems of arbitrations on socio-economic priorities at local level. Elements of policies for the establishment of participation and partnership conditions with fishing communities have been applied by public administrations. Among them are the following:

The capacity to adopt specific regulations in the local context: legislation makes provision for development of differentiated rules such as "local conventions", which can vary according to the regions and fishing places. There already exists a decentralized administrative structure (e.g. Office of Rural Development of Selengue for Lake Selengue) for each large lake fishery endowed with a significant competence for managing their fisheries.

The creation of recognized authorities allowing the participation of communities in the development, implementation and supervision of management measures: these are the "fisheries councils", which will assist elected representatives of territorial communities in their decisions concerning fishing.

The possibility to restrict open access and to implement local management: in 1995 legislation introduced the concept of "piscicultural land" at the level of local authorities (specifically rural communes established by decentralization), which allows them to control fishing pressure on fish resources, in accordance with the new prerogatives that the decentralization laws confer to them.

Decentralization empowers local authorities to manage the fish resources of government land (the Niger River and lakes). Two conditions are required: local authorities have to make an official request and to prove that they are able to deal with the management of the resources by developing a planning process. Taxes collected as part of this management could then be paid, partly, to the general budget of the local collectives, a quota being reassigned to the government.

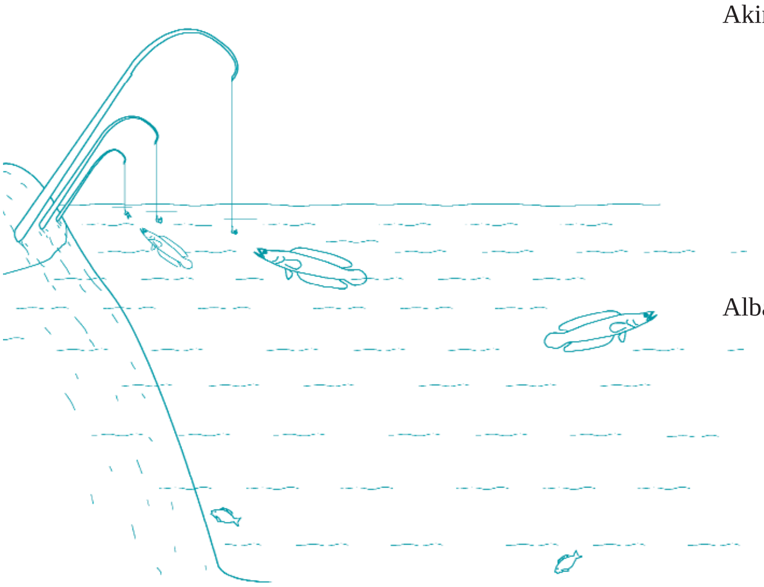
In Niger, a number of inter-state organizations cooperate in management of the Niger River resources: the Niger Basin Authority (NBA), the Authority for Development of Liptako-Gourma Area (ALG), AGRHYMET and ACMAD. In addition, cooperation agreements concerning water resource management exist between Niger and Mali, Niger and Nigeria. It is now accepted that development of capture fisheries and fish farming, which is a priority of the government, must be considered through a transfer of responsibilities from the government to a civil society and through promotion of local initiatives and the private sector. The framework could rely on the three following: (i) participative and local management of the river ecosystem (conservation) and fish resource by fisher communities; (ii) fishery management of the permanent and temporary ponds by the local populations; (iii) development and integration of fish farming in irrigated culture areas.

The first two rest on: (i) know-how and existing initiatives (Oswald *et al*. 1998; (ii) a process moving toward local development as part of community-based management (water and fish); (iii) an already elaborate legal tool allowing public property management by a private person; and (iv) biotechnical models for fish community management.

In the short term, this approach requires legal work to draw up enforcement texts within the fisheries law. In the longer term, socio-juridical studies are needed to identify organisational structures to be proposed to managers and operators. This process requires a good knowledge of both fish resource appropriation and management styles by local people and existing production systems.

The main expected results are: creation of fishing reserves, better protection of floodplains, better use of traditional knowledge, harmonization of management rules between the different countries sharing these resources, better local communities liability in resource management and better control of fish handling techniques. All these measures must lead to the autonomy of the future organization structures.

In Nigeria, the Code of Conduct for Responsible Fisheries (CCRF) that was prepared and adopted by governments under the aegis of the United Nations Food and Agriculture Organization, is being promoted as a strategy for fisheries management nationally as well as regionally. Thus, Nigeria and 25 other West and Central African countries participating in the on-going Sustainable Fisheries Livelihood Program by DFID and FAO are obligated to bring this document to the notice of all fishing communities within the country. Currently, the DFID/FAO Sustainable Fisheries Livelihood Program (SFLP) is the platform that is being used to disseminate this information. It is hoped that capacity building of the extension agents will in the long run improve the promotion of SFLP and CCRF which will lead to rehabilitation of the aquatic resources in particular fish species that are at risk of extinction in the upper and lower basins of the Niger River.



REFERENCES

Adeniji E.O. 1975. Observations on agriculture and fisheries downstream of the Kainji dam. *In* A.M.A. Imevbore & O.S. Adegoke, eds. *The ecology of lake Kainji, the transition from river to lake*. Ile-Ife, Nigeria, University of Ife Press. pp. 181-186.

Akinyemiju O.A. 1987. Invasion of Nigerian waters by water hyacinth. *J. Aquat. Plant Manag.*, 25: 24-26.

Akinyemiju O.A. 1993a. *Herbicidal control of water hyacinth: A pilot demonstration at Ere fishing channel, Ogun State, Nigeria.* A report submitted to Ogun State Agricultural Development Project OGADEP, Abeokuta, Nigeria.

Akinyemiju O.A. 1993b. *Herbicidal control of water hyacinth at Abiala Creek, Delta State, Nigeria.* A Final Report for Shell Petroleum Development Company, Warri, Nigeria.

Akinyemiju O.A, eds. 1994. *Baseline and post-impact ecological studies following application of Glyphosate to control water hyacinth at Abiala Creek, Delta State, Nigeria.* A Final Report for Shell Petroleum Development Company, Warri, Nigeria.

Akinyemiju O.A. & Imevbore A.M.A. 1990. *Herbicidal control of water hyacinth in Nigeria: A field pilot demonstration at Kofawei Creek, Igbokoda, Ondo State, Nigeria.* A Final Report submitted to the Presidency, Federal Republic of Nigeria, Lagos.

Albaret J.J. 1994. Les poissons: biologie et peuplements. *In* Durand, Dufour, Guiral & Zabi, eds. *Environnement et ressources aquatiques de Côte d'Ivoire. Tome II, Les milieux lagunaires*. pp. 239-279. Paris, Éditions de l'ORSTOM. 550 pp.

Awachie J.B.E. & Walson E.C. 1978. Atalla fishery of the lower Niger, Nigeria. *CIFA Tech. Pap./Doc. Tech. CPCA*, N° 5: 296-311.

Bacalbasa-Dobrovici N. 1971. Rapport au Gouvernement du Niger sur le Développement et la Rationalisation de la Pêche sur le Fleuve Niger. AT N 2913. Rome, FAO/PNUD.

Balogun J.K. 1988. *The bio-ecology of the Niger perch, Lates niloticus Linn. in the Kainji Lake*. Department of Zoology, University of Ibadan, Nigeria. (Doctoral dissertation)

Balon E.K. & Coche A.G. 1974. Lake Kariba: A man-made tropical ecosystem in Central Africa, *Monogr. Biol.*, 24: 767 pp.

Baran E. 1995. Dynamique spatio-temporelle des peuplements de poissons estuariens en Guinée - relations avec les milieux abiotiques. Université de Bretagne Occidentale, France. 225 pp. (Doctoral dissertation)

Blaber S.J.M. 1997. Fish and fisheries of tropical estuaries. Chapman and Hall. *Fish and Fisheries Series*, 22: 367 pp.

Blache J., Miton F., Stauch A., Iltis A. & Loubens G. 1964. Les poissons du bassin du Chad et du bassin adjacent du Mayo Kebbi. Étude systématique et biologique. *Mém. ORSTOM*, 4: 483 pp.

Blanc M., Daget J. & d'Aubenton F. 1955. Recherches hydrobiologiques dans le bassin du moyen Niger. *Bull. Ifan*, 17, Sér. A. 17 pp.

Benech V. & Dansoko F. 1994. La reproduction des espèces d'intérêt halieutique. *In* J. Quensière ed. *La pêche dans le Delta Central du Niger*. IER-ORSTOM-KARTHALA. pp. 10-25.

Bousquet F. 1994. Des milieux, des poissons, des hommes: Étude par simulation multi-agents. Le cas de la pêche dans le Delta Central du Niger. Lyon University. (Masters thesis)

Breuil C. & Quensière J. 1995. Éléments d'une politique de développement durable des pêches et de la pisciculture au Mali. MLI/91/005-PAMOS, Rome, FAO. 89 pp.

Brunet-Moret Y., Chaperon P., Lamagat J.P. & Molinier M. 1986a. Monographie hydrologique du fleuve Niger. Tome I – Niger Supérieur, Éditions de l'ORSTOM, *Coll. Monographies Hydrologiques*, 8. 396 pp.

Brunet-Moret Y., Chaperon P., Lamagat J.P. & Molinier M. 1986b. Monographie hydrologique du fleuve Niger. Tome II – Cuvette lacustre et Niger Moyen, Éditions de l'ORSTOM, *Coll. Monographies Hydrologiques*, 8. 506 pp.

Chikwenhere G.P. 1994. Biological control of water hyacinth *Eichhornia crassipes* in Zimbabwe, result of a pilot study. *FAO Bulletin Phytosanitaire*, Vol. 424: 185-190.

Coenen E. 1986. *Résultats des études ichthyo-biologiques sur le Niger*. Projet Développement des Pêches, Ner/79/018.

Coulibaly A., Gerbe A., Stomal B., Weigel J.Y. 1992. *Etude des filières traditionnelles de transformation du poisson au Mali*. Rapport Iare-Isfra-Orstom-Resed. 155 pp.

Daddy F., Wari M. & Mohammed A. 1988. Wetland studies: Natural resources evaluation of Tatabu floodplain and the restoration of Lake Tatabu Ndakolowu, Niger State, Nigeria. *NIFFR Annual Report*, 50-60.

Daget J. 1949. La pêche dans le Delta Central du Niger. *Journal de la Société des Africanistes*, 191: 1-79.

Daget J. 1952. Mémoire sur la biologie des poissons du Moyen Niger. Biologie et croissance des poissons du genre Alestes. *Bull. Inst. Fr. Afr. Noire A*, 14: 191-225.

Daget J. 1954. Les poissons du Niger Supérieur, *Mémoire de l'IFAN*, No. 36, Dakar.

Daget J. 1956. Mémoire sur la biologie des poissons du Moyen Niger. Recherches sur *Tilapia zillii* Gerv. *Bull. Inst. Fr. Afr. Noire* A, 18: 165-233.

Daget J. 1962. Les poissons du Fouta-Djalon et de la basse Guinée. *Mem. IFAN*, 65. 207 pp.

Deceuninck V., 1989. Etudes nationales pour l'aquaculture en Afrique. 24. Mali. *FAO Fisheries Circular*. 770.24. Rome, FAO.

Dembele 1994. La jacinthe d'eau, un nouveau fléau pour les cours d'eau du Mali. *Sahel Pvinfo CILSS/UCTR/PV No. 63*, Juillet 1994: 12-14.

Doray M., Mikolasek O., Boureima A. & Oswald M. Savoir-faire paysan et exploitation piscicole de mares temporaires en zone sahélienne: cas du village de Tafouka Niger. *In* D. Orange, R. Arfi, M. Kuper, P. Morand & Y. Poncet, eds. *Gestion Intégrée des Ressources Naturelles en Zone Inondables Tropicales*. Paris: IRD. (forthcoming)

Dublin-Green C.O. 1990. The foraminiferal fauna of the Bonny Estuary. A baseline study. *Technical paper of the Nigerian Institute of Oceanography and Marine Research*, N 64: 1-27.

Durand J.R. 1983. The exploitation of fish stocks in the Lake Chad region, Lake Chad: Ecology and productivity of a shallow tropical ecosystem. *In* C.J.P., D.J.R. & L.C. eds. *Monographiae Biologicae*, 53: 425-481.

Egborge A.B.M. 1998. *Some solutions to water problems in the Niger Delta.* Paper presented at the First Urhobo Economic Summit on Oil, Gas and Sustainable Development, Nov. 27-28 1998.

Fagade S.O. & Olaniyan C.I.O. 1972. The biology of the West African shad, *Ethmalosa fimbriata* Bowdich in the Lagos lagoon. *Journal of Fish Biology*, 4: 519-533.

Fagade S.O. & Olaniyan C.I.O. 1973. The food and feeding interrelationship of the fishes in the Lagos lagoon. *Journal of Fish Biology*, 5: 205-227.

Fagade S.O. & Olaniyan C.I.O. 1974. Seasonal distribution of the fish fauna of the Lagos lagoon. *Bulletin de l'IFAN 34 A*. pp. 244-252.

Fay C. 1989. Systèmes halieutiques et espaces de pouvoir: Transformation des droits et des pratiques de pêche dans le Delta Central du Niger Mali, 1972-1982. *Cah. Sci. Hum*., 251-2: 213-236.

Federal Department of Fisheries FDF 2000. Fisheries statistics of Nigeria. Victoria Islands, Lagos, Nigeria.

Gallais J. 1967. Le Delta intérieur du Niger, étude de géographie régionale. *Mém. IFAN*, Dakar-Paris, Larose, Vol. I & II. 621 pp.

Harley K.L.S. 1994. *Eichhornia crassipes* Mart. Solms-Laubach. *In* R. Labrada & J.C. Parker, eds. *Weeds management for developing countries*. pp. 123-124. *FAO Plant Production and Protection Paper No. 120*. Rome, FAO. 384 pp.

Hughes R.H. & Hughes J.S. 1992. *A Directory of African Wetlands*. IUCN, Gland, Switzerland and Cambridge, UNEP, Nairobi, Kenya, WCMC, Cambridge, UK. 820 pp.

Ita E.O. 1978. An analysis of fish distribution on Kainji Lake, Nigeria. *Hydrobiologia*, 58: 233-244.

Ita E.O. 1984. Lake Kainji, Nigeria. *In* J.M. Kapetsky & T. Petr, eds. Status of African reservoir fisheries. *FAO CIFA Technical Paper No. 10*. pp. 44-104.

Ita E.O. 1993. Inland fisheries resources of Nigeria. *CIFA Occasional Paper No. 20*. Rome, FAO. 120 pp.

Kassibo B. 1990. L'organisation sociale de la pêche dans le Delta Central du Niger. Genèse et évolution des systèmes de production halieutique. *In Études halieutiques du Delta Central du Niger*. ORSTOM-IER, actes de l'atelier de Bamako, 20-23 Novembre 1990. 38 pp.

Kodio A., Morand P., Dienepo K. & Laë R. 2002. La dynamique de la pêcherie du Delta Intérieur du Niger revisitée à la lumière des données récentes. Implications en termes de gestion. *In* D. Orange, R. Arfi, M. Kuper, P. Morand & Y. Poncet, eds. *Gestion intégrée des Ressources Naturelles en zone inondable tropicale*. IRD éditions, Colloques et Séminaires. (sous presse)

Koné M. 1991. Pêches collectives et aménagement des mares dans le Delta Central du Niger. Rapport de stage, Montpellier, USTL-CREUFOP. 44 pp.

Laë R. 1992a. Impact des barrages sur les pêcheries artisanales du Delta Central du Niger. *Cahiers d'Agricultures*, 2: 14-21.

Laë R. 1992b. Influence de l'hydrologie sur l'évolution des pêcheries du Delta Central du Niger de 1966 à 1989. *Aquatic Living Resources*, 52: 115-126.

Laë R. 1994. Effects of drought, dams and fishing pressure on the fisheries of the Central Delta of the Niger River. *International Journal of Ecology and Environmental Sciences*, 20: 119-128.

Laë R. 1995. Climatic and anthropogenic effects on fish diversity and fish yields in the Central Delta of the Niger River. *Aquatic Living Resources*, 81: 45-58.

Laë R. 1997. Does overfishing lead to a decrease in catches and yields? An example of two West African coastal lagoons. *Fish. Manag. Ecol.*, 3: 101-116.

Laë R., Maiga M., Raffray J. & Troubat J.J. 1994. Évolution de la pêche. *In* J. Quensière, eds. *La pêche dans le Delta Central du Niger*, IER-ORSTOM-KARTHALA. pp. 143-163.

Laë R. & Morand P. 1994. Typologie des cycles d'activités halieutiques: ménages sédentaires et petits migrants du secteur de Mopti. *In* J. Quensière ed. *La pêche dans le Delta Central du Niger*, IER-ORSTOM-KARTHALA. pp. 287-294.

Laë R. & Weigel J.Y. 1994. Adaptabilité des pêcheurs aux changements environnementaux et économiques. *In* J. Quensière ed. *La pêche dans le Delta Central du Niger*, IER-ORSTOM-KARTHALA. pp. 295-310.

Laë R. & Weigel J.Y. 1995. Diagnostic halieutique et propositions d'aménagement: l'exemple de la retenue de Selengue Mali. FAO-PAMOS. 73 pp.

Laë R. & Mahé G. 2002. Crue, inondation et production halieutique: Un modèle prédictif des captures dans le Delta Intérieur du Niger. *In* D. Orange, R. Arfi, M. Kuper, P. Morand & Y. Poncet, eds. *Gestion intégrée des Ressources Naturelles en zone inondable tropicale*. Paris: Éditions de l'IRD, Colloques et séminaires, à paraître.

Lelek A. & El Zarka S. 1973. Ecological comparison of the preimpoundment and postimpoundment fish faunas of the Niger River and Kainji lake, Nigeria. *Geophys. Monogr.*, 17, 655-660.

Lévêque C. 1995. River and stream ecosystems of north-western Africa. *In* C.E. Cushing, K.W. Cumins, G.W. Minshall, eds. *Ecosystems of the world*: *River and stream ecosystems*. Amsterdam NDL, Elsevier; Lausanne, CHE. pp. 519-536.

Lévêque C., Paugy D. & Teugels G. 1990. La faune des poissons d'eaux douces et saumâtres de l'Afrique de l'Ouest, tome I et II, ORSTOM/MRAC, *Collection Faune Tropicale*, No. XXVIII. Paris, France.

Lobet H. & Abdoulkadry D. 1993. *Enquête sur la Structure de consommation du poisson et le comportement d'achat et de motivation du consommateur*. Niamey, Ministère de l'Hydraulique et de l'Environnement de la République du Niger Action de Développement de l'Aquaculture au Niger. 56 pp.

Lowe-McConnell R.H. 1975. *Fish communities in tropical freshwaters: Their distribution ecology and evolution*. London and New York, Longman. 337 pp.

Mahé G., Bamba F., Orange D., Fofana L., Kuper L., Marieu B., Soumaguel A. & Cissé 2002. Dynamique hydrologique du Delta Intérieur du Niger Mali. *In* D. Orange, R. Arfi, M. Kuper, P. Morand & Y. Poncet. eds. *Colloques et séminaires*, Éditions de l'IRD, Paris. (à paraître)

Malvestuto S.P. & Meredith E.K. 1989. Assessment of the Niger River fishery in Niger 1983-85 with implications for management. *In* D.P. Dodge ed. *Proceedings of the international large rivers symposium*. *Can. J. Fish. Aquat. Sci. Spec. Publ.*, 106: 533-544.

Marie J. & Témé B. 2002. *Gestion des ressources et aménagement du fleuve Niger. Des connaissances scientifiques pour la décision publique*. Paris, IRD Éditions. 11 pp.

Matthes H. 1993. *Rapport de la mission d'évaluation de la pêche continentale et de l'Aquaculture en République de Guinée*. Rome, FAO. 94 pp.

Mikolasek O., Patout O., Lazard J. & Massou M. 1997. Le développement à l'épreuve du concret: l'exemple de l'aquaculture en cages flottantes sur le fleuve Niger. *In* K. Fitzsimmons ed. *Tilapia aquaculture, proceedings from the fourth international symposium on Tilapia in aquaculture volume 2*. pp. 483-498. Orlando, Florida, November 9-12, 1997. Northeast Regional Agriculture Engineering Service.

Mikolasek O., Massou M. & Allagdaba E. 2000. Appropriation et gestion des espaces piscicoles nigériens par les populations villageoises riveraines. In: D. Gascuel, P. Chavance, N. Bez & A. Biseau, eds. *Les espaces de l'halieutique*. Paris, IRD. pp. 517-526.

Mikolasek O., Oswald M., Boureima A. & Massou A.M. Savoir-faire paysan et pisciculture au Niger. Communication in Colloque International sociétés rurales au Sahel, quel avenir Niamey, Niger, 18 et 19 Novembre 1999. Co-organisé par l'Université de Lausanne Suisse et l'Université Abdou Moumouni de Niamey. (sous presse)

Morand P., Quensière J. & Herry C. 1990. Enquête pluridisciplinaire auprès des pêcheurs du Delta Central du Niger: plan de sondage et estimateurs associés. *ORSTOM ed. SEMINFOR*, 4: 195-211.

Morand P. & Bousquet F. 1994. Modélisation de la ressource: Relations entre l'effort de pêche, la dynamique du peuplement ichtyologique et le niveau des captures dans un système fleuve-plaine. *In* J. Quensière ed. *La pêche dans le Delta Central du Niger*. IER-ORSTOM-KARTHALA. pp. 267-281.

Ministere des Ressources Naturelle et de L'Elevage. 1975. Direction nationale des eaux et forêts. Opération Pêche Mopti, Rapport Annuel. Mopti, Mali.

NEDECO Netherlands Engineering Consultants. 1959. *River studies and recommendations on improvement of Niger and Benue*. Amsterdam, The Netherlands, North Holland Publishing Company.

NEDECO Netherlands Engineering Consultants. 1961. *The waters of the Niger Delta*. The Hague, Netherlands Engineering Company.

Obot E.A. 1984. Studies on the productivity of *Echinochloa stagnina* beauv. *In* The Kainji Lake Basin of northern Nigeria. University of Ife, Nigeria. (Doctoral dissertation)

Okaeme A.N., Stopford G., Haliru M. & Wari M. 1989. Survey of aquatic birds and their contribution to Lake Kainji fisheries. *In* National Institute for Freshwater Fisheries Research, Annual Report. pp. 28-30.

Olaleye V.F. & Akinyemiju O.A. 1996. Effect of glyphosate N-Phosphonomenthyl glycine application to control *Eichornia crassipes* Mart. on fish composition and abundance in Abiala Creek, Niger Delta, Nigeria. *J. of Environmental Management*, 47: 115-122.

Olaleye, V.F. & Akinyemiju O.A. 1999. Flora and fauna of Abiala Creek, Niger Delta, Nigeria. *J. of Aquatic Sciences*, 14: 61-65.

Olaleye, V.F. & Akinyemiju O.A. 2002. Planktonic community regeration in a post-herbicidal water hyacinth *Eichhornia crasssipes* Mart. *J. of Aquatic Sciences*, 17: 21-26.

Oswald M., Mikolasek O. & Kodako Y. 1998. *Projet de développement de la pisciculture en milieu rural, Marché n 91/005/MHE/DFPP - Rapport final*. Niamey, Ministère de l'Hydraulique et de l'Environnement du Niger Direction de la Faune de la Pêche et de la Pisciculture DFPP / CIRAD-EMVT, Juillet 1998. 97 pp.

Otobo F.O. 1978. Commercial fishery in the middle Niger, Nigeria. *CIFA Tech. Pap./Doc. Tech. CPCA, N5*. pp. 185-208.

Peters R.H. 1983. *The ecological implications of body size*. Cambridge, UK, Cambridge University Press. 329 pp.

Petts G.E., Imhof J.G., Manny B.A., Maher J.F.B. & Weisberg S.B. 1989. Management of fish populations in large rivers: A review of tools and approaches. *In* D.P. Dodge ed. *Proceedings of the international river symposium. Can. J. Fish. Aquat. Sci. Spec. Publ.*, 106: 578-588.

Price T.L. 1991. Gestion "scientifique" et connaissances locales: Le projet pêches au Niger. *In* G. Dupré ed. *Savoirs paysans et développement*. Paris, Editions Karthala. pp. 473-487.

Quensière J. ed. 1988. Études halieutiques du Delta Central du Niger. Premiers résultats. *In* ORSTOM-INRZFH *Enquête statistique auprès des pêcheurs*. Actes de l'atelier de Bamako, 7-9 Juin 1985. 5 pp.

Quensière J. ed. 1994. La pêche dans le Delta Central du Niger, approche pluridisciplinaire d'un système de production halieutique, IER/ORSTOM/KARTHALA, Paris, France.

Raimondo P. 1975. Monograph on operation fisheries, Mopti, in consultation on fisheries problems in the Sahelian Zone, Bamako, Mali 13-20 Nov. 1974. *CIFA Occas. Pap.*, 4: 294-311.

Reed W. 1967. *Fish and fisheries of Northern Nigeria*. Ministry of Agriculture, Northern Nigeria.

Roberts T.R. 1975. Geographical distribution of African freshwater fishes. *Zool. J. Linn. Soc*., 57: 249-319.

Robinson D., 1997. *Ogoni: The Struggle Continues*. World Council of Churches, Nigeria. 106 p.

Ryder R.A. 1965. A model for estimating the potential fish production of north temperate lakes. *Transactions of the American Fisheries Society*, 94: 214-218.

Sagua N.O. 1978. The effect of Kainji Dam, Nigeria on the fish production in the River Niger below the dam at Faku. *CIFA Tech. Pap./Doc. Tech. CPCA No. 5*. pp. 209-294.

Scott, J.S., 1966. Report on the fisheries of the Niger Delta special area. Harcourt. Niger Delta Dev. Board Port. 109 pp.

Sheves G. 1981. *Établissement de centres communautaires de pêche artisanale au Niger, analyse économique*. FAO/UNDP, Document de Travail No. 4. 37 pp.

Stauch A. 1966. Le bassin Camerounais de la Bénué et sa pêche. *Mém. ORSTOM 15*. 152 pp.

Talatou H. 1995. Synthèse des activités de pêche de 1974 à 1990. *In Atelier national sur la pisciculture et la pêche au Niger, Kollo du 26 au 30 Décembre 1994*. pp. 54-58. Kollo: Ministère de l'Hydraulique et de l'Environnement de la République du Niger & Mission Française de Coopération et d'Action Culturelle Action de Développement de l 'Aquaculture au Niger.

Van der Knaap M., Malam A., Bouba G., Pala A. & Zourmba P. 1991. Résultats du recensement des pêcheurs autour du lac Lagdo, Février 1990, MEAVSB, Rapport NEB/PECHE/TECH/91/01.

Van den Bossche, J.P. & Bernacsek G.M., 1990. Source book for the inland fishery resources of Africa, *CIFA Technical Paper*, 182. Rome, FAO. 411 p.

Welcomme R.L. 1972. The inland waters of Africa, *CIFA Tech. Pap*. 1: 117 pp.

Welcomme R.L. 1979. *Fisheries ecology of floodplain rivers*. London, New York, Longman. 317 pp.

Welcomme R.L. 1985. River fisheries. *FAO Fisheries Technical Paper, No. 262*. 330 pp.

Welcomme R.L. 1986. The effects of the sahelian drought on the fishery of the central delta of the Niger River. *Aquaculture and Fisheries Management*, 17: 147-154.

Welcomme R.L. 1989. Review of the present state of knowledge of fish stocks and fisheries of African Rivers. *In* D.P. Dodge ed. *Proeedings of the International River Symposium, Canadian Special Publication on Fisheries and Aquatic Sciences*, 106: 515-532.

Welcomme R.L. & Hagborg D. 1977. Towards a model of a floodplain fish population and its fishery. *Environmental Biology of Fishes*, 2: 7-24.

Welman J.B. 1948. Preliminary survey of the freshwater fisheries of Nigeria. Lagos, Nigeria, Government Printer,.

Wetlands International 1999. Atelier sur la conservation de la biodiversité des poissons en Afrique de l'Ouest, région de Mopti Mopti du 24 au 27 août 1999.

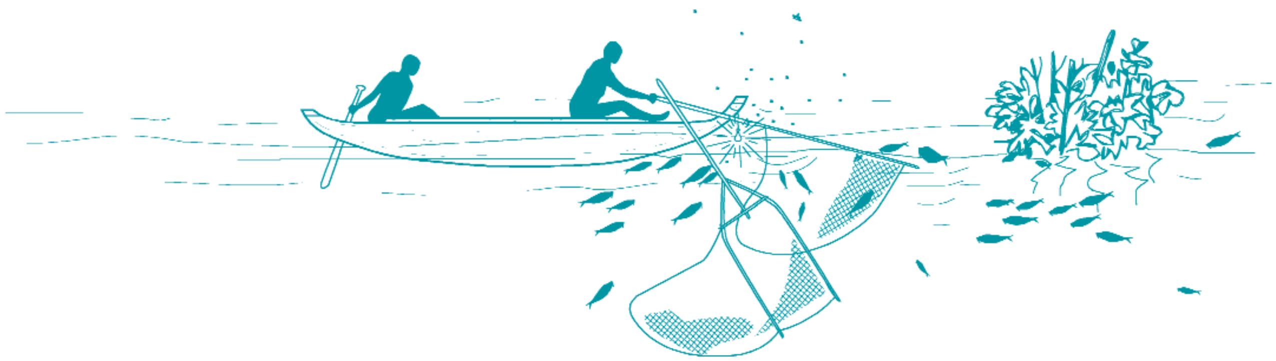
White E., ed., 1965. The first scientific report of the Kainji biological research team. 88 pp.

A REVIEW OF THE GANGES BASIN: ITS FISH AND FISHERIES

A.I. Payne[1] R. Sinha[2] H.R. Singh[3] S. Huq[4]

[1] Imperial College, University of London, UK
[2] University of Patna, Bihar State, India
[3] University of Allahabad, Uttar Pradesh, India
[4] International Institute for Environment and Development (IIED), London, UK

All correspondence to: Dr A.I. Payne, Imperial College, 47 Prince's Gate, London SW7 2QA UK
E-mail: i.payne@imperial.ac.uk



ABSTRACT

The Ganges Basin drains an area of 814 800 km^2, spans the countries India, Nepal and Bangladesh and is occupied by around 200 million people. In its lower sectors it contains some of the highest population densities in the world and also includes major urban areas. There is pollution from industrial and domestic sources. There is also an intense demand for water principally for agriculture. In India all tributaries of the Ganges are controlled by barrages, which divert an estimated 66 percent of the flow for large-scale irrigation. Water is returned with reduced quality and increased chemical contamination. The barrages form barriers across the river. The largest is the Farraka Barrage, which diverts most of the flow down the Hooghly Canal and has been the source of considerable

political disagreement between India and Bangladesh, although a Water Sharing Agreement was reached in 1995. The upland cold-water zone in Nepal and northern India has a diverse fish community characterised by migratory and specialised torrent species. This region is thought to have suffered from the effects of erosion from excessive forest clearance. The fish zone extends up to some 1 680 m altitude although fishing probably does not extend above 1 200 m. Fishing yields are comparable to lowland African rivers of the same order. The upland rivers support a significant fishery, which provides an unseen contribution to the welfare of the rural mountain population. The fishery across the whole of the lowland basin is driven by demand from Calcutta and Bengal where fish eating predominates. The proportion of major carps in the fishery declined from 43.5 percent to 29 percent by 1972-76 and 13 percent today. The reduction in dominant species may explain the success of enhancement programmes in several parts of the basin. The anadromous hilsa has also declined due to the Farrakah Barrage and the inaccessibility of the connecting canal. Significant reductions in catches of around 1 600 tonnes or 13 percent over 10 years were found at Allahabad and on the Ganges (Padma) in Bangladesh. Subsequent analysis shows that most of the reduction was due to reduction in rainfall and that there was a close correlation between catches and river discharge or rainfall. Clearly, any basin activity which affects discharge will impact on many aspects of river usage. India has been pursuing the Ganga Action Plan to help control pollution and conserve biodiversity. Bangladesh has a National Water Management Plan and National Environmental Management Plan with aims to integrate water availability amongst multiple uses and generally to regulate water quality and conserve biodiversity. In addition to national regulatory environments, there are also annual tri-partite discussions between the states of the basin to increase international regulation. All of these policies and actions contribute to the long-term status and prospects of the basin.

INTRODUCTION

The basin is located 70-88°30' east and 22°-31° north (Figure 1). The total drainage area exceeds 1 060 000 km^2 and the basin is the fifth largest in the world (Welcomme 1983). The length of the main channel from the traditional source of the Gangotri Glacier in India is some 2 550 km. The course of the river is characterised by steep torrential upper reaches and extensive, meandering lower courses. The catchment area encompasses India (80.1 percent of the total basin area), Nepal/Tibet (19.3 percent basin area) and Bangladesh (0.6 percent basin area). Virtually, all of the Nepal Himalayas are included in the catchment area and the basin occupies 25 percent of the land area of India. Altitude within the basin ranges from 8 848 meters above sea level (masl), the peak of the high Himalayas, to sea level in the coastal deltas of India and Bangladesh.

■ **Figure 1.** Ganges River Basin (from Cumming 1993)

Vast amounts of sediment are transported downstream by the river and distributed across the fringing floodplains during the period of inundation. Ultimately, a large proportion of the sediment is transported beyond the coastal delta and into the Bay of Bengal. Estimates of the quantity of topsoil transported through the main channel are of the order of 240 million $m^3\ yr^{-1}$ (CPCB 1984). The waters of the Ganges carry one of the highest sediment loads of any river, with a main annual total of 1 625.6 x 10^6 tonnes compared to, for example, 406.4 x 10^6 tonnes for the Amazon.

The annual volume of water discharged by the Ganges is the fifth highest in the world, with a mean discharge rate of 18.7 x $10^3\ m^3\ sec^{-1}$ (Welcomme 1985). Within the catchment area there exists extreme variations in flow, both spatial and seasonal, to the extent that the mean maximum flow is 52.3 times greater than the mean minimum flow (Welcomme 1985). Estimates of the maximum extent of land prone to flooding throughout the basin vary considerably but are of the order of 295 km^2 in India and 77 000 – 93 000 km^2 in Bangladesh, although the latter value is the combined flooded area due to the confluence of the Ganges, Brahmaputra and Meghna, in that country. The flood regime varies along the course of the river and rainfall values differ locally but the predominant pattern is for a low flow dry season from January to May and a wet season from July to November, with a peak flow usually in August (CPCB 1984). The flood season is more protracted in the lower sections of the river. The main sources of water in the basin are direct seasonal rainfall, mainly from the south west and glacial and snowmelt during the summer. There is some debate as to the relative roles of precipitation in the upstream catchment area or local rains in the annual flooding patterns (Chapman 1995). The main channel of the Ganges carries a lot of sediment that makes it very turbid. In the upland regions, however, some of the inflowing streams and tributaries are exceptionally clear. Those that are clear are spring fed, whilst those which are turbid with a high sediment load, are snow fed. Spring fed streams come from clean underground sources, usually at moderate or lower altitudes. The snow fed streams result from the melting of snow and glaciers from the heights of the Himalayas, which wash down heavy loads of sediments from the underlying moraines. The sediment is generally pale grey in colour and can be very heavy. In this respect, the waters of the upper Ganges closely resemble those of the Solimoes, the main stem of the Amazon. The water of the Solimoes has been classified as a “white water” by Sioli (1964), typified by a heavy pale sediment load, an alkaline pH and relatively high total dissolved solids. This has been attributed to the effects of erosion by snowmelt on young, relatively un-weathered mountains, which in the case of the Amazon derives from the Andes. All of these characteristics are shared with the Ganges which can be regarded similarly as a “white water” derived from the Himalayas which are themselves geologically young and un-weathered. There is considerable concern in the upland regions, particularly in Nepal, that deforestation and degrading land practices are leading to increased erosion with higher sediment loads and changed flooding patterns within the river. Given the nature of the river and the lack of quantitative data this has been difficult to confirm.

The main channel of the Ganges begins at the confluence of the tributary rivers, Bhagirathi and Alaknanda, which descend steeply from the upper Himalayas, at Devprayag some 520 masl (Table 1). This then cuts through steep gorges to emerge into the Gangetic plain at Hardwar. Hereafter, the river meanders eastwards for 2 290 km across the plain to Farakka, close to the border with Bangladesh. Just downstream of Farraka the main channel divides into two branches, the Bhagirathi which flows south to the Hooghly and Calcutta and the Padma, which flows into Bangladesh. Both feed a number of distributaries to form one large delta and floodplain, which includes the Sundarbans mangrove area.

The main channel receives a number of major tributaries. The northern tributaries that enter on the left bank after descending from the Himalayas in Nepal, principally the Karnali (Ghaghara), the Buri Gandak, Gandak and Kosi Rivers. There are also southern tributaries, principally the Yamuna, Son, Chambral and Damodar. The northern tributaries provide around 60 percent of the water within the basin.

The Ganges Basin provides, therefore, geographically and environmentally very diverse features that are reflected in its resources. It is also politically diverse since it is shared by three countries and, moreover, is one of the most populous places on earth. Around 450 million people live in the basin, at an average density of over 550 km^{-2}, which in certain localities and particularly in the delta, rises over 900 km^{-2}. There is, consequently, a considerable demand and competition for resources, particularly the water itself. Most of the tributaries are controlled by irrigation barrages and there are two major barrages across the main channel, one at Hardwar which abstracts much of the water at this point to irrigate the doab region and one at Farakka which diverts water down to Calcutta and which has been the source of much dispute between India and Bangladesh. All of these structures modify the flow of the river and may considerably influence fish distribution. Further impacts are felt on the fertile floodplains where empolderment for rice farming is practised, to the extent that some 40 percent of the floodplains of Bangladesh have been modified. Fish and fisheries are both an important resource and activity in their own right but also provide indicators of the overall impact of anthropogenic changes over the basin. The numbers of people and also the extent of industrialisation further mean that both domestic and industrial pollution will affect the aquatic environment. This also emphasises the need for a unified approach to management of the basin and it is for this reason that the name of Ganges is used here although it is known locally as Ganga in India and Padma in Bangladesh.

The literature on the Ganges is rather fragmented and tends to reflect work done on a national basis. To provide a basin-wide approach, this has been brought together (Temple and Payne, 1995) as a starting point. In addition to referring to national literature, the present review also draws upon a survey carried out into environmental, fisheries and socio-economic factors along the Ganges valley, from the upper reaches in Nepal to the delta in Bangladesh, which has been requested elsewhere (Payne and Temple 1996). The river can be segregated into a number of physical sections for purposes of discussion:

- Upland reaches – source at 4 100 masl, 25 km to Rishikesh (Figure 1) at 360 masl, includes union of Bhagirathi and Alaknanda Rivers at Devprayag (510 masl) gradient 1:67.
- Equivalent range in northern tributaries to point where they enter the Gangetic plain.
- Upper plains – Rishikesh to Allahabad (58 km masl) with main intersection with plain at Hardwar (310 masl) with mean gradient 1:4100.
- Middle plains – Allahabad to Farakka through the lowlands of Uttar Pradesh, Bihar and West Bengal, with fringing floodplains. Includes the large floodable area of the Bihar Wetlands where the Kosi joins the main river.
- Lower plains – the delta in Bangladesh and India, which includes the Sundarbans and an extensive floodplain.

PHYSICO-CHEMICAL CONDITIONS

In general terms, the Ganges water is alkaline with a pH above 8 and a conductivity of 160-410 μs (Table 1). The alkaline pH reflects underlying soluble calcerous rocks in parts of the catchment area. The conductivity, which increases along the length, is relatively high. Most tropical rivers have a conductivity less than 400 μs, but many in Africa and South America, including the Amazon and the Congo, for example, have conductivities less than 150 μs (Welcomme 1985). This is a function of the relative youth of the mountains in the catchment area and the sedimentary nature of some of the underlying parent material. The northern tributaries have similar characteristics.

Table 1: Hydrologiccal data for various sites along the Ganges basin by altitude

RIVER	SITE	ALTITUDE (m amsl)	WATER TEMPRATURE (C)	pH	CONDUCTIVITY
Alaknanda (10/93)	Srinagar	580	16.6	8.08	159.8
	Bagwan	510	17.1	8.30	194.3
Ganga (10/93)	Kaudiyala	440	17.5	8.20	168.9
	Rishikesh	360	21.3	8.13	241.0
	Hardwar	310	20.8	8.49	263.0
	Patna	48	25.1	—-	293.0
Upper Padma (10.94)	Rajshahi	38	17.8	8.14	410.0
Lower Padma (10/94)	Mowra	22	19.4	8.46	309.0
Gorai (10/94)	Khulna	20	20.6	8.10-8.50	377-785

Temperature shows considerable downstream variation and is probably a major environmental factor influencing the distribution and nature of fish communities (Table 1).

Seasonal variation in temperature is quite marked. In the upland sector (580 masl) temperatures range from 16.5-18.7°C for October to May respectively. At the major transitional zone of Rishikesh/Hardwar the recorded range was 20.8-20.4°C between the same periods. The upland tributary of the Son Kosi showed a range of 15-20.6°C over the similar period.

Once on the plains the rivers warm up rapidly, for example, temperatures can be up to 4°C higher only 30 km below the transitional zone of upland to plains. Downstream at Allahabad, seasonal temperature ranges can be from 15.1-29.1°C or at Patna in Bihar 18.6-33°C. Equally, in the southern tributary of the Yamuna the average seasonal range is 14.9-29.1°C.

There does, therefore, appear to be two rather different temperature regimes between upland and lowland sectors, with a relatively well-marked transitional point between them. The main upland snow-fed rivers do not reach more than 21°C, which is the highest recorded temperature at the transitional point on the river. This is the point at which there is also a major change in the physical nature of the river from erosional to depositional zones, i.e. rocks to sand and also where the cold-water fish communities cease to be found. It is also where the river changes from being torrential, turbulent and running through steep gorges to a wider, deep river running between sand banks, often with a fringing floodplain.

FISH RESOURCES

A species list is provided in Appendix 1.

Surveys in Nepal have shown no fish records beyond an altitude of 1 650 masl (Shrestha 1978) and fisheries have not been noted above 1 800 masl (Jha 1992). In the appended list (Appendix 1) the uppermost point on the main stem of the Ganges is the Alaknanda, 460-1 600 masl (Singh, Badala and Dobriyal 1987) where the fish zone probably ends. Slightly below this is a sample from the upper Ganges in the Garwhal region (460-310 masl) above the transition zone at Rishikesh/Hardwar. The sample for the northern tributary of the Kosi (79-600 masl) takes into account both lowland and upland species for the river as a whole (Khan and Kamal 1980). The results of two-year surveys at Allahabad and Patna are included for the upper and middle plains. A comprehensive survey from the Padma in Bangladesh represents the delta and floodplain (FAP 17 1994; ODA 1997).

In total for the whole freshwater sector 161 species are recorded. Other species counts have included estuarine species or have been confined to one country of the Basin (e.g. Talwar 1991; Rahwan, 1989). River sectors will vary as to what proportion of these species they contain. Thus the number recorded for the Kosi is 103 or 63 percent of the total. Numbers will also increase as further surveys are done.

The Alaknanda has the lowest number of species for any sector of the river. However, a total of 41 is still appreciable for a single cold, upland river and gives an indication as to how relatively rich the cold upland communities are. The community of the Alaknanda is characterised by a few specialised cyprinid types, specifically the snow trouts *Schizothorax/Schizothoraichthys spp*, the mahseers (*Tor spp*) and small *Garra spp*, together with some of the mountain loaches, *Noemacheilus spp* and the highly specialised sisorid torrent cat fishes, *Glyptothorax spp*. (Appendix 1). A typical day's fishing is likely to produce representatives of each of these groups although the emphasis is always upon the snow trouts and mahseers, with regard to numbers.

The fish community of the upper Ganges is very similar to that of the Alaknanda, although a few lowland species begin to appear, such as *Mastacembelus* and *Channa* so that the final species total is a little higher at 54. Again, however, numerically the snow trout and mahseers would tend to dominate the fishery.

The snow trout and mahseers are both migratory and it is essential to understand their movements in order to interpret their role in the fishery. The snow trout, *Schizothorax spp*, migrates upstream and is reported to spawn in March to June at water temperatures ranging from 14-21°C in the Himachal Pradesh (Negi 1994). It is generally regarded as tolerating waters from 8°C to 22°C. Spent individuals and the presence of fry in October may suggest a longer or later spawning period in the Garhwal Himalaya. For the mahseers, upstream migration takes place at the beginning of the monsoon and they may spawn during the period of July to September (Negi 1994). The common species, *Tor putitora* (Hamilton), could have three peaks between February and September.

The rivers and few lakes of the Ganges Basin in Nepal contain more than 130 species (Shrestha 1990). The upland waters have a similar cold-water fish community to the upper waters of the main stem of the Ganges and Alaknanda in India. This does not extend into the Terrai, the lowland area of Nepal, beyond the transition zone, where the rivers are wider, warmer and meander more than those of the more torrential upper reaches, in particular the snow melt streams of the Himalayas. The lowland regions have a similar fauna (Smith 1991; Shrestha 1990) to that of the other sections of the lowland Ganges of the plains (Appendix 1).

The lowland sites at Allahabad, Patna and Bangladesh showed considerable similarities with communities dominated by cyprinids, particularly major carp species and catfishes. A distinction can be made between main channel migratory species, such as the major carps and the floodplain resident species that are often small and have accessory respiratory systems and prolific reproduction.

In the delta region of Bangladesh, some from the estuary start to appear such as the scieanid, *Scieana coiter*, the mullets, *Rhinomugil corsula* and *Sicomugil cascasia*. Particularly significant is the anadromous *Tenualosa ilisha* or 'hilsa', which was still recorded as far up river as Allahabad in the 1993 - 1994 survey (Appendix 1).

It is perhaps significant that the highest individual total of species (103) is for the Kosi River, which included both upland and lowland communities (Khan and Kamal 1980). The other northern tributaries are also quite rich in species, with 74 being recorded for the Karnali and 69 for the Mahakali (Shrestha 1990).

FISHERIES IN THE BASIN

COLD WATER UPLAND FISHERIES

The cold-water upland fisheries can be defined as those occurring in waters with temperatures up to 21°C, the limit of the snow trouts. Otherwise, they have been related to the temperature tolerance of introduced salmonids, i.e. 0-20°C (Jhingran 1991). These fisheries are those dependent upon the typical fish communities of the Himalayan sector of the Basin. The approximate boundary in India is at Hardwar (230 masl), as the river leaves the Siwalik range and enters the plains and in Nepal where the northern tributaries enter the Terrai. There may be some overlap of species since the major carps, more typical of the lowland communities, can extend to 250-450 masl in Nepal (Shrestha 1978). There are, for example, tributaries in the mountains, such as the Seti which arise below the snow line and which are relatively warm and in which snow trout seem to occur only seasonally (Payne and Temple 1996).

The mountain fisheries have been very poorly documented. The steep gorges of the Himalayan regions of India and Nepal render fishing a difficult and hazardous operation. The variety of habitats and difficulty of the environments give rise to a variety of fishing techniques (Shrestha 1994). The commonest is the cast net, where the rivers meander and also found here, in both India and Nepal, is a long-line technique which has a series of nylon constricting loops, which act as snares, rather than hooks which is particularly effective for snow trouts. This is variously called the “fase”, “passo” or “gill net”. Originally the snares were made of horsehair and dangled from a rod (Shrestha 1979). In addition to these, the use of dynamite is common and also of electricity by using car batteries or connecting with insulated wires to overhead power lines. Traps are also common in some places.

There are reported to be very few professional fishers in the upland region but a widespread general participation in fishing activity. In the Kuman Himalayas of Uttar Pradesh, snow trout are estimated to provide 20-80 percent of the catch, with mahseers contributing 20-27 percent (Bhatt and Pathak 1992). There appear to be two peaks in the catch of snow trout; the first in June/July during the rising waters of the early rains and the second in September/October as the river waters begin to fall. The minimum catch rates are generally through the winter season. For mahseer, the peak landings occur during May/June and this coincides with upstream movement for spawning. It is considered that in the Himalayan reaches, the catches are related more directly to water temperature than to altitude (Bhatt and Pathak 1992). Both snow trout and mahseer may migrate downstream during cold spells, which inevitably leads to decline in the upstream landing.

Distribution of mountain fisheries in the Indian Basin is necessarily patchy owing to the steep inaccessible gorges through which the river runs in this region. In addition, however, the extreme sanctity of certain points on this river, which is central to the Hindu faith, means that fishing is often forbidden in such places. Examples of such points are the towns of Hardwar and Rishikesh where the River Ganges first meets the plains and Devprayag where the two main upstream branches unite. Here, vegetarianism is expected and fishing is totally prohibited on religious grounds. Similarly, much of the main channel from the plains up to its source is a route of pilgrimage where the consumption of flesh, fish or fowl is not encouraged. Markets are, therefore, very limited.

A catch survey has been carried out on the Bhagirathi River, a headwater feeder tributary in the Garhwal Himalayas (Sharma 1984; Sharma 1988), close to the site of the Tehri Dam. Eight different methods of fishing were documented and 23 species of fish recorded. The most common were the snow trouts, *Schizothorax* (3 species) contributing between 61 and 74 percent of the catch over a year. The sites ranged from 1 855 masl to Tehri at 770 masl with seasonal temperatures kept between 10.2 and 19.4°C by snowmelt near the source.

Surveys along a number of stretches of upland rivers in India and Nepal showed significant fishing activity along most of them (Payne and Temple 1996). Estimates of catches at four points along the Alaknanda in the Garhwal Himalaya showed a range of between 1 035 to 2 475 kg km^{-1} $year^{-1}$ with an average around 1 650 kg km^{-1} $year^{-1}$. A lower tributary, the Nayer, produced 621 kg km^{-1} $year^{-1}$ whilst a tributary of the Bahgirathi yielded 2 250 kg km^{-1}. This last estimate reflects a genuine abundance of fish and not just fishers and markets. These, however, migrate in for a short period of the year in the pre-monsoon, March to June, to give a peak in fishing rather later than at most sites where fishing takes place throughout the low-water season, from October to March. This may indicate that the tributary is in an upper reach spawning area.

In Nepal, surveys have been carried out in the Seti, Trisuli, Narayani and Rapti Rivers of the Gandaki Basin and Sun Kosi and Indrawati Rivers of the Kosi Basin. All showed varied significant activity usually by part-time or occasional fishers for home consumption or a little extra money but some professional fishers had recently migrated in from the Terrai and India, even as far away as Bombay, to escape competition elsewhere. An estimate of catch rates of the Seti River (270 masl) gave 1 490 kg km^{-1} $year^{-1}$ composed of a mixture of warm and cold-water species.

In considering the cold-water upland areas of the Ganges Basin, an average estimate of some 1.5 tonnes km^{-1} for annual fish production is indicated. The limits of the cold-water area can be defined at its lowest limit by this distinction of snow trout at around 180 masl but more realistically by the temperature less than 21°C throughout the year. The upper altitudinal limit is unlikely to extend much beyond 1 600 masl since most species of commercial importance do not extend up the rivers of the Himalaya much beyond this (Shrestha 1978). At such altitudes the opportunities for fishing are also scarce and difficult. The upper limit for significant fishing activity may well be 1 200 m or less.

Welcomme (1974) found the catch rates for African rivers to fall mainly within 1-15 tonnes km^{-1} $year^{-1}$. However, catch rates increased significantly downstream. Thus, for example, a river around 100 km from its source would yield in the order of 1 tonnes km^{-1} $year^{-1}$. The upland rivers surveyed in the Ganges Basin are this order of difference from the source and their yields are comparable. Since there are a number of dams for hydropower projects under planning in this region, such order of magnitude estimates are useful to enable a value to be put on the fish resources.

WARM WATER LOWLAND FISHERIES

The fisheries from Hardwar to West Begal are rather different in nature to those of the upland Himalayan region both with regard to the species taken and fishing activities.

Surveys were initially conducted in 1957 by the Central Inland Capture Fisheries Research Institute, Barrackpore, (CIFRI) and regular updating of data between 1957 and 1981-82 showed no indications of any significant changes in fishing intensity in the middle reaches of the main channel and lower sections of the Yamuna (Natarajan 1989). The implication was, therefore, that any observed changes in catch rates found during coincidental fisheries surveys, represented changes in abundance of fish stocks concerned. However, a subsequent report of CIFRI (Jhingran 1991) indicated a perceptible rise in the occurrence of fishing villages, number of fishers and diversity of gears by the mid-eighties. There are 22 fish marketing centres on this stretch of the River Ganges, of which 5 are major and there are 4 centres on the Yamuna. The marketable surplus of fish for each part of the river is brought to these centres, which provided the focal point of the 22-year catch survey sequence carried out by CIFRI (Natarajan 1989).

Fishers can be categorised as “professional”, “part-time” or otherwise. It is clear, however, that true professional fishers fall into a well-defined social category of sub-castes. This often renders their fishing villages distinctive and identifiable. There are no indications, however, of the extent of part-time or occasional fishing among essentially non-fishing groups, which is often a feature of floodplain fisheries elsewhere, including Bangladesh.

As with the upland areas of the Indian sector of the River Ganges, the religious influence on dietary habits along the river itself implies that local markets are unevenly distributed throughout the basin. The major market within the basin is West Bengal in general and Calcutta in particular. The Bengali people of India (West Bengal) and Bangladesh (East Bengal) have a long tradition of eating fish and almost certainly create much of the demand throughout the lowland area of the basin. There are instances of catches on the western rim of the basin in Rajasthan being transported more than 1 500 km by train to Calcutta to reach a suitable market.

The main gear types used in the lowland areas are seine or dragnets, gill nets, scoop nets, cast nets, long lines and traps. However, within these broad categories are a diversity of types and sizes (Bilgrami and Datta Munshi 1985), which are often designed to catch a particular range of fish species.

Most fishery surveys so far conducted on the River Ganges, both in the Yamuna and the main channel have been based upon selected landing centres (Jhingran 1991). The earliest surveys, between 1958-59 and 1965-66, were based on totals of daily arrivals of fish for the Yamuna at centres at Agra and Allahabad and for the main Ganges channel at centres downstream at (west to east) Kanpur, Varanasi, Buxar, Ballia, Patna and Bhagalpur.

During this period, the migratory hilsa formed a major component of the catch from the middle and lower reaches of the main river, contributing 25-39 percent of the total catch between Varanasi and Ballia, just above Patna in Bihar. Hilsa was recorded as far upstream as Allahabad at the junction of the Yamuna River with the main channel, some 900 km from the Hooghly estuary and the Indian Ocean, but hilsa is rarely found penetrating upstream of the River Ganges as far as Kanpur, or upstream of the Yamuna as far as Agra.

In the middle reaches of the Ganges at this time, the most important single group were the major carps (catla, mrigal, rui and calbasu). Together they constituted 53 percent of the catch at Agra, 45 percent at Kanpur and 38 percent at Allahabad, but declined somewhat towards the lower reaches, where they generally accounted for 19-26 percent at Patna and beyond (Table 2). Amongst the major carps, mrigal (*Cirrhinus mrigala*) tended to predominate in the upper stations, with catla contributing a much smaller proportion. This proportion appeared to become more equal downstream. Since the 1958-66 period *L. calbasu* has

Table 2: Changes in catch composition downstream from Allahabad between 1958 and 1994

	Allahabad				Patna		Padma (Bangladesh)	
	58-66+	72-76+	79-80+	93-94*	58-66+	93-94*	83-84	93-94
L.rohita	8.0	3.0	1.5	2.1	8.5	0.4		1.6
C. catla	8.1	3.5	3.3	2.9	5.4	1.8		3.9
C.mrigala	17.2	9.6	5.4	2.2	11.9	1.3		0.0
L. calbasu	4.5	12.9	11.4	9.2	0.7	0.5		0.5
major carps	38.0	29.0	21.6	16.4	26.5	4.0	1.7	6.0
M.seenghala	16.6	7.3	9.5	16.0	9.0	1.3		0.0
M. aor		11.2	8.2	23.9		4.9		0.8
W. attu	6.0	5.2	4.1	4.4	8.5	1.3		0.4
hilsa	9.4	4.9	1.3	0.1	12.1^x	0.6	40.0	47.2
Others	30.0	42.2	55.5	39.2	43.9	87.9	58.3	45.6
Mean Recorded Catch (mt. pa)	209.0	117.0	155.0	245.0	91.6	49.4	10 488.0	688.0
Range + (mt. pa)	263.0		174.0					
Range - (mt. pa)	193.0		128.0					
Weight major carps (mt)	79.1	34.0	29-59	54.0	22.0	2.4	174.0	41.0
Weight hilsa (mt)	20.2	5.7	2.2	0.5	12.1	0.3	4 193.0	282.0

Key:
+ from Jhingran (1991)
** from Payne and Temple (1996)*
from DOF (1991)
from FAP 17 (1994), based on survey, not on catch data
x - was 37-39% upstream at Ballia and Buxar

become the commonest of the major carps around Allahabad rather than *C. mrigala*.

The total catches from each landing centre do not appear to show any consistent trends. It is possible that they vary with environmental and hydrological factors. There do, however, appear to be reduced catches of major carps and hilsa over time, particularly at Patna (Table 2). Estimates of catches in the original 1957 survey estimated total annual catches from the rivers Yamuna and the Ganges stretch from Allahabad to Farakka at 770 tonnes and 275 tonnes respectively, which gave a consistent relative yield of 0.75 tonnes km^{-1} and 0.77 tonnes km^{-1} for the two stretches (Natarajan 1989).

Yield from Allahabad has varied between 5.1-10.6 kg ha^{-1} and at Bhagalpur between 16.8 and 26.3 kg ha^{-1} and they show no apparent trend. Yield at Buxar does appear to have declined from 23.1 kg ha^{-1} in 1958-62 to 4.5 kg ha^{-1} by 1981-84. These yields are low compared to values achieved in the true floodplains of Bangladesh where values of 80-160 kg ha^{-1} have been recorded. They are also low on a worldwide scale where yield might typically fall between 40 and 80 kg ha^{-1}. These values for the River Ganges are, however, obtained solely from the commercial fishery and take no account of the subsistence fishery, although fish is not a favoured part of the diet in this region.

In addition to the fisheries of the main channel, there are also those of the northern tributaries, in particular the rivers Gandak, Buhri Gandak and the Sapta Kosi. All of these rivers meander through the alluvial plains in northern Bihar and, during the monsoons often produce large floodwater areas known as the North Bihar Wetlands. Extensive fishing takes place in these floodplains but this is not well documented (Ahmed and Singh 1990; Ahmed and Singh 1991). In 1965-66 the oxbow lakes of the Burhi Gandak sub-basin alone covered an area of 36 000 ha which provided a fishery of 2 900 tonnes yr^{-1} (Natarajan 1989). The natural flow of many of the Northern tributaries such as Kosi, Gandak, Rapti and Sarju, has, however, been affected by a number of hydraulic engineering schemes. For example, the construction of canals for water diversion and flood control along flood prone low-lying areas. It is reported that such schemes have greatly restricted access to breeding grounds for major carps and other species (Natarajan 1989), not to mention the Gangetic dolphin, *Platanista gangetica* (Smith 1991). Canal projects for water diversion and flood control schemes are regarded as factors largely responsible for diminished production. Nevertheless, these floodplains remain extensive and require assessment. In recent years, stock enhancement by the release of hatchery-reared fingerlings has been attempted. This fishery was reported to be widespread and to be jeopardising the natural recruitment of stock.

Further downstream the river spills out into the delta, which is characterised with a large floodplain and interaction with the estuarine zone. The floodplain is most extensive in Bangladesh and production from the rivers and their associated floodplains varied from 460 000 tonnes in 1983-84 to 561 824 tonnes in 1996-97 (DOF 1998). The largest single component of the inland fisheries in general is hilsa, which migrates up river from the estuary and the Bay of Bengal to spawn. It constitutes around 13 percent of all inland fisheries and 42 percent of river catches. Total riverine catches have been declining from 90 000 tonnes in 1983-84 to 84 463 tonnes in 1988-89 (DOF 1991) although there has been something of a resurgence to around 60 000 tonnes since 1996. Of this riverine total in Bangladesh, the Ganges (Padma) contributes around 4-5 percent but apparent declines have been even more marked, from 12 095 tonnes to 1 641 tonnes over the same period, but again with something of a resurgence after 1995 (Table 3).

The other constituents of the catch are categorised as major carps, catfishes, live fish (any other species with accessory respiratory organs) shrimp and miscellaneous species (DOF 1982 *et seq.*). The last tends to be the largest, containing as it does, largely small, floodplain dwelling species. The major carps generally provide a small percentage of the catch, being between 3-5 percent for all rivers but only 0.2-2.5 percent for the Ganges (Padma), tiny even com-

Table 3: Annual catch (tonnes) records from Padma River (Lower Ganges) upper and lower combined. From Department of Fisheries Annual Reports, Bangladesh. For explanation of categories, see text.

species	1983-84	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97
Total Major Carp	171	181	92	75	20	6	75	77	63	26	79	183	735	365
Total Hilsha	4 193	5 253	1 815	2 643	2 207	968	566	565	730	812	1 401	3 314	3 380	2 278
Total Big Shrimp	213	214	10	67	173	20	2	8	7	43	29	17	84	51
Total Other Carp	3	3	45	31	15	2	23	24	5	3	10	31	108	0
Total Cat Fish	869	1 041	268	413	122	82	51	126	58	108	308	733	3 033	1 240
Total Small Shrimp	135	144	63	171	203	180	27	138	57	85	254	676	451	376
Total Various	4 875	5 259	1 600	1 897	464	1 149	1 291	925	721	1152	2 152	2 356	3 436	2 177
Total Live Fish	29	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Snake Head	0	0	0	0	0	0	0	4	0	0	9	0	24	2
Total Annual Catch (tonnes)	10 488	12 095	3 893	5 297	3 204	2 407	2 035	1 867	1641	2 229	4 242	7 310	11 251	6 489

pared to upstream areas such as Patna in India. If floodplain catches are included in Bangladesh, along with those from rivers, the major carps may constitute 6-10 percent.

In the Padma itself, major carp catches have reached very low levels (Table 3) but it is notable that from 1994-97 up to 10 times more were caught. This coincides with stock enhancement programmes in the floodplain (Payne and Cowan 1995) with ‘escapes’ likely to have augmented the natural recruitment.

Overall catch per fishers is declining due partly to the growth in the population of fishers. As more people become landless, fishing becomes increasingly the only option. However, most people of the 80 million or so living on the floodplain fish at some time and at least 13 million people are part-time fishers.

The pattern of fishing along much of the Ganges is similar in that there is a major peak in the pre-monsoon season (May-July) and a second peak in the post-monsoon season (October-December). This largely coincides with the migratory movements of many fish species, particularly amongst the catfishes and cyprinids. Within these periods, peaks can be a little later at downstream sites. In fact, on the Yamuna the pre-monsoon peak can be as early as April (Payne and Temple 1996). The earlier upstream trigger for the pre-monsoon peak could be the first impact of snowmelt water from the mountains.

The largest single component of catches in the middle Ganges is the catfishes, which are mainly migratory. At the confluence of the Ganges with its major tributary, the Yamuna near Allahabad, a combination of catfishes and major carps (*Cirrhrus mrigala, Labeo rohita, Catla catla, Labeo calbasu*) accounts for over 30 percent of the catches throughout the year. The same is also mainly true for the main stem of the Ganges at Allahabad except the contribution of major carps is less and other types predominate on occasion. This pattern is true of the high water season in the vicinity of Patna and other types become more prominent in the low water season. In the Ganges (Padma) section of the delta in Bangladesh by far the most dominant species of the catch is hilsa (FAP 17 1995), which can be 45-47 percent of the catch although this shows considerable annual variation (Table 3). Catfishes and major carps are much less prominent here.

In many ways, the major carps are key indicators of the Ganges system. They were originally a dominant group in the river and floodplain eco-system. They are amongst the most highly regarded of the fish species with respect to commercial value and also for aquaculture. In the first recorded survey of Gangetic fishes (Hamilton 1822), they are reported as “abounding” and “very common” in the rivers and tanks of the system. Even at this time, *L. rohita* was reputed to be cultured. Historical data (Table 2) indicate that since the early sixties the proportion of major carps in the catches around Allahabad (Jhingran 1991) was some 43.5 percent. It fell through the seventies and eighties until most recently it reached only 20.5 percent (Table 2). Similarly, around Patna the decline has been from around 27 percent to 4 percent of the catch (Table 2). Traditionally the major carps were plentiful in Bangladesh but the proportion currently recorded is only around 6 percent. Unfortunately, there is no good historical data for comparison but they have been just a few percent of the catch since 1982.

The most plentiful location for major carps is around the Yamuna/Ganges confluence, where sizeable individuals of 7-8 kg are not unusual. Fishing down of an ecological community tends to lead to the elimination of the larger species first (de Graaf *et al.* 2001) and the selective market demand from Bengal and Calcutta must have enhanced this process. In addition, there is a considerable small-scale industry in trapping major carp larvae, which drift down the river after spawning to supply the large aquaculture industries of India and Bangladesh. There are a large number of fry catching stations along the Ganges either side of the border and in India alone, in order to stock 1.6 million ha of ponds and tanks approximately 32 billion major carp seed can be required. A decade or so ago only 10 percent of this was available from hatcheries and whilst this has increased over time, the catching of wild fry still continues. The natural mortality rate of fry is, of course, very high but it has to be considered that entrapment on this scale may contribute to the decline of the species and, most importantly, the spawning stock. The major carps are given some protection, for example, the Fish Act of Bangladesh specifies a minimum size for capture but it is difficult to enforce over the delta.

Another fish that has declined markedly in some areas is hilsa, particularly above the Farakka Barrage in the Indian sector. At Allahabad, which is around the highest point this anadramous species reaches in its migration, the proportion in the catch has declined from around 10 percent in 1956-66 to 5 percent by 72-76 to less than 1 percent by 93-95 (Table 2). At Patna, hilsa has declined even more dramatically (Kumar *et al.* 1987) and most recently has fallen from 12 percent in 1952-66 to around 1 percent by 1993-95 (Table 2). Just above Farakka, the total annual catch fell from 19 tonnes before the Barrage was finished in 1972, to 1 tonne (Chandra 1994). The fish are most plentiful from December to April at this point.

In Bangladesh, the total catch of hilsa has oscillated between 97 000 tonnes (1993) and 71 370 tonnes (1994) over the period 1984-1997, with an average of 85 700 tonnes (Rahman 2001). This is the product of three major rivers and their combined estuary and its contribution to overall catch is around 13 percent. The Ganges alone showed a reduction in the Bangladesh fishery, from 4 193 tonnes in 1983-84, to 968 tonnes in 1988-89 and generally constituted around 40-50 percent of the catch (Table 2). Whilst fish are present throughout the year, the peak in the Ganges (Padma) itself from July to November with a peak of mature fish in September (Payne and Temple 1996). The consensus in Bangladesh is that the hilsa stocks or fishery has shifted from inland to esturarine/coastal regions and that the catches are declining. However, like most of the riverine fisheries, they are diffuse and show considerable fluctuations so that keeping representative statistics is always a difficult task.

There has been much conjecture whether the populations of hilsa that are found in Bangladesh and India are homogenous (Rahman 2001) since this in an important point for their management. A recent genetic analysis of hilsa populations in Bangladesh has indicated that they belong to more than one gene pool (Rahman and Naerdal 2001).

Those species contributing most to the catch in lowland reaches are: the Schilbeids, *Ailia coila* (Hamilton), *Clupisoma garua* (Hamilton), the cyprinid *Oxygaster spp;* the catfishes, *Rita rita* (Hamilton), *Mystus* spp and *Aorichthys aor* (Hamilton); *Setipinna phasa* (Hamilton) and *Aspidoparia morar* (Hamilton). Despite the attention given to the major carps and hilsa, these species are now important components of catches in many areas and require more attention (Payne and Temple 1996).

Prawns can also be a major element of the catch and, at Patna, for example, can amount to 25 percent the weight of the total catch. This is of a similar order to that which can be found downstream in the Ganges in Bangladesh (FAP 17 1994). In addition, valuable *Macrobrachium* spp., the migrating freshwater prawn, can also be found throughout the delta and upstream as far as Patna. Prawns, however, are not taken in any numbers at Allahabad and it appears that the limit of these prawns lies between Varanassi and Allahabad. Where floodplains have been empoldered in Bangladesh it has been suggested that the relative increase of prawns in catches is an indicator of loss of biodiversity (de Graaf *et al.* 2001).

In the middle reaches of the Ganges between Allahabad and Patna, with its marked marginal floodplain, the floodplain resident species amount to between 1 and 5 percent by weight. On the floodplains of Bangladesh they constitute around 65 percent (FAP 17 1994). These "black fishes" (Welcomme 1985) such as *Anabas spp*, *Mastacemblus spp and Channa spp* have a remarkably resilient life cycle. Each year, the floodplains drain down and most dry season refuges are drained or fished intensively yet each following year their numbers bounce back. They probably have extreme r-selected population characteristics. As the fishing pressure builds up and more and more poor people enter the fishery, it is the remarkable characteristics of these small fishes that sustains the production and helps to keep poverty and malnutrition at bay.

There are linkages between the warm water lowland river and the cold upland communities. Low numbers of the mountain migratory mahseer, *Tor tor*, appear in lowland catches at Allahabad almost exclusively during the winter period of January to March when water temperatures are between 17 and 22 ºC. They are also recorded at Patna. These individuals probably represent the extremity of the downstream migration of mahseer from the northern tributaries of the Gogra, Gandaki and Kosi (Figure 1) from the Himalayas. The disappearance of the fish in March will mark the start of their upstream migration to spawn in the streams and tributaries of the mountains. The situation is probably complicated, however, by the existence of barrages across all three northern tributaries at the Indo-Nepal border. The opening of the gates causes fish to be swept downstream (Sinha pers. comm.). There is also the possibility of these and other barrages causing isolated populations as they have with the Gangetic dolphin, *Platanista gangetica* (Smith 1991). *Tor tor* does also occur in some of the southern tributaries, including the Tons, the Ven and the Paisuni, as they descend from the central shield.

There are also linkages of the middle reaches of the Ganges with the estuary in addition to that for hilsa. The giant river catfish, *Pangasius pangasius* is known to make long distance movements upstream from estuaries where the non-breeding adults tend to reside and feed. This has been recorded at sites on the Yamuna at Allahabad largely between December and March although not yet at Patna, en route for the estuary. It is quite plentiful in catches from the Ganges in Bangladesh where, in fact, it amounts to 8 percent of the annual catch (FAP 17 1994). The species may be less prominent than in earlier times when a significant fishery for it occurred in the Gangetic estuarine areas during July and August (Talwar and Jhingran. 1991). In the Mekong *P. pangasius* is recorded as migrating up to 1 000 km upstream from the estuary (Lowe-McConnell 1975). Allahabad is some 1 200 km from the estuary.

DISCUSSION

The aquatic systems of the Basin are diverse and productive. Already the resources are under pressure from human intervention and this is likely to increase in future. The current population of the Basin is around 500 million, which by 2031 could increase to over a billion, almost half of which could be below the poverty line (Chapman 1995). Perhaps the greatest single impact at present is for the diversion and storage of water from the river for irrigation. The annual run-off into the Ganges Basin is approximately 469 billion m^3. Of this, an estimated 85 billion m^3 is diverted by barrages, either into canal systems for irrigation and storage or for hydroelectric schemes. Of this diverted water, 60 percent is accounted for by canal projects (Natarajan 1989). Every major tributary has at least one barrage across it. On each northern tributary from Nepal there are barrages at the border region with India. Near Hardwar, the water of the main stem of the Ganges is diverted by a major barrage into the Upper Ganga Canal that was built in 1854 and is largely used to irrigate 3.7 million ha of land with some electricity is also being generated. The main stem, below the barrage is reduced to a very low flow through much of the year.

This system of barrages greatly compartmentalises the ecosystem and certainly presents major barriers to migrations of fish, which may have a general effect on fish distribution as described elsewhere (Linfield 1985). They represent an artificial demarcation between the upland and lowland systems of the Ganges and, to some extent; they must act as sediment traps. In other cases, the presence of barrages can accentuate problems of pollution by reducing downstream flows for effluent disposal, particularly in the dry season, which can produce chemical barriers to fish distribution (Natarajan 1989; Temple and Payne 1995). There will be continued pressure to increase the area of croplands under irrigation within the lowland areas, as it is a principal means whereby crop production can keep up with population increases in future. A significant proportion of water diverted for irrigation is returned to the river although at a lower quality. The influence of micro-pollutants, which are related to the extent of the use of agro-chemicals, is uncertain but is likely to increase as the pressure to intensify agricultural production proceeds.

In the Indian sector alone, more than 150 000 km^2 of the Ganges Basin is irrigated using some 85 000 m^3 of river water and 49 500 m^3 of groundwater but this, as in most irrigation systems, has led to extensive problems of soil salinisation. As a result the salt load of the returning irrigation water over 6.3 million tonnes of salt are estimated to be added to the water annually (CPCB 1984). However, observations on conductivity levels in the main river suggest this has yet to have major effects on the salt concentration of the river as a whole (Table 1).

The largest barrage of all is Farakka. This was completed in 1975 and was built without consultation with the downstream user state, Bangladesh (or East Pakistan as it was until 1972), the border of which is 17 km downstream. The barrage is designed to regulate river water discharge and to divert a major part of the dry season flow along the Hooghly Canal towards the Bhagirathi – Hooghly and Calcutta rivers. There are also other barriers beyond the canal on the Baghirati itself. In 1995 a formal water sharing agreement was made between India and Bangladesh that agreed to minimum downstream flows and ensures annual meetings to discuss issues between the states.

The impact of the Farakka Barrage complex upon the system would seem to include a progressive reduction in the significance of the hilsa fishery upstream of the Barrage (Table 2) as the route from the estuary via the Bhagirathi arm has been impeded. A further possible effect is that the reduction in flow down the Ganges (Padma) below Farakka allows greater incursions of tidal saline water into the south-western region of Bangladesh, thereby reducing suitable land and water for agriculture (Islam 1992). It is, however, difficult to substantiate in this dynamic fluctuating tidal environment with great annual variations, mainly because of a lack of historical, baseline data. This indicates the importance of good pre and post implementation studies around such structures. As it is, the estuarine hilsa fishery of the Bangladesh delta seems to be maintained.

Within the delta of Bangladesh the principal process of compartmentalisation is not of the river itself but of the floodplains to facilitate the cultivation of rice. Some 40 percent of the floodplain has been modified by empolderment for flood control and irrigation. This has led to a compartmentalisation of distribution of fish particularly the migratory "white fishes" which includes all the major carps. As elsewhere in the Ganges Basin (Tables 2 and 3) the catches of major carp have declined markedly in Bangladesh, for example, the major carp portion of the catch on Seimanganj floodplain declined from 66.4 percent in 1967 to 13 percent by 1984 (Tsai and Ali 1985).

The compartmentalisation of the floodplains may well have contributed to this. A systematic investigation of the impacts of flood control and irrigation schemes on fisheries showed that under conditions of complete flood control reductions could be 81 percent. Under controlled flooding or partial empolderment there is no significant difference in catch with averages of 100-110 kg ha^{-1} inside and out (FAP 17 1994; de Graaf *et al.* 2001). What does happen, however, is that there is a reduction in bio-diversity within polders of 19-25 percent but, most significantly, a reduction in migratory species up to 95 percent with the main emphasis being on the small floodplain resident species or black fishes. Given the fishing effort that can be deployed on these species in compartments during the dry season, their regular resurgence indicates very resilient life cycle strategies. Up to 59 percent of annual variance in catches can be due to effort under these circumstances (de Graaf *et al.* 2001).

To contrast this loss of species and valuable elements of the catch as well as to boost recruitment into local populations, major interventions are being undertaken on the floodplains of Bangladesh to redress the situation, either by direct stock enhancement with fry or juveniles (Jhingran 1997; Payne and Cowan 1998) or through habitat improvement and restoration (Payne and Cowan 1998). In the largest scale intervention, 60 000 ha were stocked with 50 million carp fingerlings, a mixture of indigenous major carps, Chinese and common carps, over five years which resulted in an incremental fish production of 20 811 tonnes (Payne and Cowan 1998). There is also evidence that recruitment has been augmented in the wider river populations (Table 3). Stocking interventions, however, may be accompanied by undesirable social consequences including the further exclusion of poor and vulnerable groups from participation in a fishery that has increased in value.

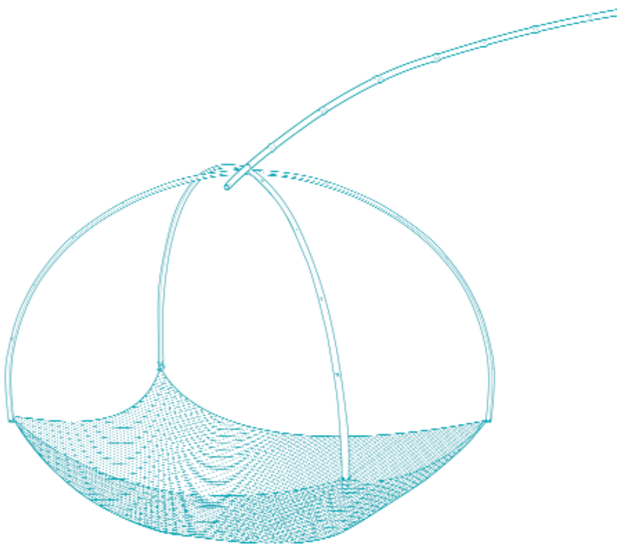
As well as enhancement, recruitment may be increased by such processes as habitat restoration. An exercise in habitat restoration which focussed on the clearing of silted channels connecting floodplains to the main river channel increased the proportion of migratory species caught subsequently, including major carp from 2 percent of the catch to 24 percent, and increased the yield 6-fold, from 1860 kg to 11 384 kg per year throughout the study area (CNRS 1995). In these ways, some of the impacts of compartmentalisation of the floodplains are being addressed in the delta in a continuing fashion but many problems remain, particularly regarding management and governance issues.

In the upland areas of the basin in Nepal, the greatest impacts are said to be due to erosion and increased sediment load from deforestation and from the need to impound water for hydropower generation. The extent of forest removal and increased erosion, however, is difficult to assess. There is evidence that deforestation is a long-term, historical process that may not have accelerated greatly in recent times (Messerli and Hofer 1995). It has also been shown that for a basin the size of the Ganges, the sediment delivery ratio is less than 10 percent and that consequently the main channel carries only a modest amount of sediment from the mountains and that, consequently, anthropogenic influences in the mountains have only a limited impact on the plains (Hamilton 1987). It is possible that most of the sediment in the main river comes from storage places and channel erosion (Messerli and Hofer 1995).

The other feature of upper basin use is the harnessing of the rivers for hydropower. Nepal has a great potential for hydropower but as yet only 0.27 percent of its assessed potential is being employed. The rather scattered nature of its own population renders micro projects and run-of-the river schemes good options for domestic generation but the export potential of electricity to northern India and beyond is a commercial imperative. Generating electricity on this scale seems to involve large storage dams which have a number of negative impacts including, as a barrier to fish distribution, possible resettlement of displaced people, disturbance of fragile environments both at the site and downstream and the need to provide roads and services. The upland rivers certainly have a significance in the rural economies, which has been under-estimated, and it is, therefore, essential that proper evaluations be carried out on the advantages and disadvantages. Under ideal circumstances run-of-the-river projects can avoid many of the environmental disadvantages of storage dams but cases can be seen in Nepal where all the water of the river passes down the adduction tunnel with negligible flow remaining between inlet and outlet. This can provide as much a barrier to fish and navigation as a dam wall. Proper planning and management is required.

Other anthropogenic effects in the basin include pollution. At present, it is of local significance and largely a feature of the Lower Basin where urbanisation and industrialisation are proceeding. The Ganges Basin is reported to carry some 200 tonnes of biological oxygen demand (BOD) per day gross pollution. However, it is still relatively localised and focussed on urban centres including Hardwar, Kanpur, Varanasi and Diamond Harbour near Calcutta (Kumra 1995). In addition, the national capitals of New Dehli and Dhaka both have significant impacts. The dry, low water season poses the greatest problems of dilution and dispersal of pollutants. Probably the worst section is between Kanpur and Allahabad largely due to discharges from the industries of Kanpur, which include tanneries, metalworking and dairies. This appears to be related to the decline in catch of fisherfolk from 30-40 kg to 15 kg per day downstream of the town (Kumra 1995). Elsewhere, although loads can be quite high, the river disperses them quite rapidly. Even at Varanassi, the main effluent plume is confined to near the city and the river recovers some 20 km downstream. Nevertheless, national governments are concerned and the government of India has been implementing the Ganga Action Plan to start cleaning up the river and preventing it from becoming worse whilst in Bangladesh, the Global Environment Fund is promoting pollution protection. At least at Patna, general water quality has recently improved with, for example, BOD being cut by 75 percent over a decade (Payne and Temple 1996).

In general, the status of the Ganges Basin reflects the transitional nature of the economies of the constituent states. In developed countries, the greatest problems are commonly gross domestic and industrial pollution and abstraction whilst in developing countries it is frequently degradation of the basin through inappropriate land use, erosion and habitat loss. All of these processes are occurring in the Ganges and probably provides a number of case studies and lessons to learn for basins currently occupied by poorer states as their economic condition improves with development. There is, however, no overall management concept for the international basin as a whole. There is no international basin management authority such as exists on the Mekong with the Mekong River Commission and no regular fora for making basin-wide management decisions or for regularly sharing information. Critical information on hydrology and satellite imagery can often be classified for security reasons. Using basin-wide data can add dimensions to predictability and management options. For example, using upstream Indian rainfall data in relation to time series of Bangladesh catch data can help predict the likely impact on fish yields three years later (Payne and Temple 1996). Taking into account all data on the fishes, the fishing communities and development needs it is possible to plan for fisheries management across Asian river basins including the Ganges (Hoggarth *et al.* 1999). A basin-wide approach to management is essential for the economic and environmental sustainability of such large river systems.



REFERENCES

Ahmed S.H., & Singh A.K. 1990. Scope, prospects, problem and development of floodplains Chauro of Bihar for fish production. *Fishing Chimes Patna*, November 1990.

Ahmed S.H., & Singh A.K. 1991. River systems of Bihar: Scope prospects, potentialities and conservation of capture fisheries. *Fishing Chimes Patna*, November 1991: 51-56.

Bhatt S.D. & Pathak J.K. 1992. *Himalayan environment: Water quality of the drainage basins.* Almora, India, Shree Almora Book Depot. 318 pp.

Bilgrami K.S. & Dalta Munshi J.S. 1985. *Ecology of the River Ganges: Impact of human activities and conservation of aquatic biota Patna to Farukka. Final Technical Report.* Bhagalpur, India, Bhagalpur University. 104 pp.

BWDB 1986. *Bangladesh water resources and demands for the year 2025*. C.F. Tsai M. Youssouf Ali, eds. Dhaka, Government of Bangladesh Water Development Board, The University Press Ltd. pp. 199-212

Chandra R. 1994. Some endangered, vulnerable and rare miscellaneous fishes of the Ganga River System: *Hilsa ilisha* and *Setipinua phasa*. Barrackpore, India, Central Inland Capture Fisheries Resource Institute. pp. 7-11.

Chapman G.P. 1995. The Ganges plains. *In* G.P. Chapman & M. Thompson, eds. *Water and the quest for sustainable development in the Ganges Valley*. London, Mansfield Publishing. pp. 113-129.

Chapman G.P. 1995. The Ganges and Brahmaputra Basins. *In* G.P. Chapman & M. Thompson, eds. *Water and the quest for sustainable development in the Ganges Valley*. London, Mansfield Publishing. pp. 3-24.

CNRS. 1995. *Community-based fishing management and habitat restoration project, Annual Report.* July 1994-June 1995.

CPCB. 1984. *Basin sub-basin inventory of water pollution. The Ganga Basin Part I*. New Dehli, Central Board for the Prevention of and Control of Water Pollution CPCB, Department of Environment. 204 pp.

Cumming D. 1993. *World river series: Ganges*. London, Wayland Publishers Ltd.

DOF. 1991. *1998 Fish catch statistics of Bangladesh 1990-91*. Dhaka, Department of Fisheries, Government of Bangladesh.

FAP 17. 1994. *Flood control action plan, study 17. Dhaka, Fisheries Studies and Pilot Project. Final Report*. Government of Bangladesh/ODA. 197 pp.

De Graaf G., Born B., Kemal Uddin A.M. & Martin F. 2001. *Floods, fish and fishermen*. Dhaka, The University Press Ltd. 110 pp.

Hamilton F. 1822. *An account of the fishes found in the River Ganges and its branches*. Edinburgh, UK, Constable and Co. 405 pp.

Hamilton L.S. 1987. What are the impacts of Himalayan deforestation on the Ganges - Brahmaputra Lowlands and Delta? Assumptions and facts. *Mountain Research and Development*, 1: 256-263.

Hoggarth D.D., Cowan V.J., Halls A.S., Aeron-Thomas M., McGregor J.A., Garaway C. A., Payne A.I. & Welcomme R.L. 1999. Management guidelines for Asian floodplain river fisheries. Rome, *FAO Fisheries Technical Paper 384*. Part 1, 63 pp., Part 2, 117 pp.

Islam N. 1992. Indo-Bangladesh common rivers: The impact on Bangladesh. *Contemporary South Asia*, 1: 203-225.

Jha P.K. 1992. *Environment and man in Nepal. Know Nepal Series No. 5*. Bangkok, Craftsman Press, 110 pp.

Jhingram A.G. 1997. Stock enhancement in the floodplain fisheries of northeastern Bangladesh. *In* C. Tsai & M.Y. Ali, eds. *Openwater fisheries of Bangladesh*. Dhaka, The University Press Ltd. pp. 183-198.

Jhingram V.G. 1991. *Fish and fisheries of India, revised and enlarged third edition*. New Dehli, Hindustan Publishing Corp. 727 pp.

Khan H.A. & Kamal, M.Y. 1980. On a collection of fish from the Kosi Bihar. J. Bombay Nat. Hist. Soc., 76: 530-534.

Kumar D., Chitranshi V.R. & Singh M.P. 1987. *Fishery of the River Ganga around Patna and its conservation.* Symposium on the impact of current land use pattern and water resources development. Barrackpore, India, Central Inland Capture Fish. Resource Institute. 77 pp.

Kumra V.K. 1995. Water quality in the River Ganges. *In* G.P. Chapman & M. Thompson, eds. *Water and the quest for sustainable development in the Ganges Valley*. London, Mansell Publishing Ltd. pp. 130-140.

Linfield R.J. 1985. An alternative concept to home range theory with respect to populations of appinids in major river systems. *J. Fish Biol*., 27: Suppl. A 187-196.

Lowe-McConnell R.H. 1975. *Fish Communities in tropical freshwaters*. London, Longmans Ltd. 337 pp.

Messerli B. & Hofer T. 1995. Assessing the impact of anthropogenic land use change in the Himalayas. *In* G.P. Chapman & M. Thompson, eds. *Water and the quest for sustainable development in the Ganges Valley*. London, Mansell Publishing Ltd.

Natarajan A.V. 1989. Environmental impact of Ganga Basin development on the gene pool and fisheries of the Ganga River system. *In* D.P. Dodge ed. *Proceedings of the international large rivers symposium. Can. Spec. Publ. Fish. Aquat. Sci*., 106: 545-560.

Negi S.S. 1994. *Himalaya fishes and fisheries.* New Dehli, Ashish Publishing. 291 pp.

ODA. 1997. Impacts of flood control and drainage with or without irrigation FCD/I projects on fish resources of fishing communities in Bangladesh. Executive Summary of Final Report, FAP 17.

Payne A.I. & Cowan V.J. 1998. Review of stock enhancement in the floodplains of Bangladesh. *In* J. Petr ed. FAO/DFID Expert Consultation on Inland Fisheries Enhancements. *FAO Fisheries Technical Paper 374.* Rome, FAO. pp. 153-158.

Payne A.I. & Temple S.A. 1996. *River and floodplain fisheries in the Ganges Basin. Final Report.* DFID Fisheries Management Science Programme R 5485, London, MRAG Ltd. 177 pp.

Rahman M.J. 2001. *Population biology and management of Hilsa strand, Tenualosa ilisha.* Bangladesh. University of Hull, UK. 252 pp. (Doctoral dissertation)

Rahman M.A. & Naerdal G. 2000. Population Genetic Studies of Hilsa strand, Tenualosa ilisha Hamilton in Bangladesh waters: Evidence of the existence of separate gene pools. *Fisheries Management and Ecology*, 7: 401-411.

Rahwan A.K.A. 1989. *Freshwater fishes of Bangladesh.* Dhaka, Zoological Society of Bangladesh. 364 pp.

Sharma R.C. 1984. Ichltyofauna of the snow fed River Bhagirathi of Garhwal Himalayas. *Uttar Pradesh J. Zool*., 4: 208-212.

Sharma R.C. 1988. Fish and fisheries of the snow fed River Bhagirathi of Garhwal Himalayas. *Proc. Nat. Acad. Sci. India*, 58 B 4: 181-192.

Shrestha T.K. 1990. Rare fishes of the Himalayan waters of Nepal. *J. Fish Biol.*, 37: Suppl. A 213-216.

Shrestha T.K. 1979. Techniques of fishing in Nepal: Innovation and development of loop line sharing. *J. Museum of Natural History, Tribuvan University, Kathmandu,* 3: 121-138.

Shrestha J. 1978. Fish Fauna of Nepal. *J. Museum of Natural History, Tribuvan University, Kathmandu*, 2: 33-43.

Shrestha J. 1994. *Fishes, fishing implements and methods of Nepal.* Gwalior, India, Gupta Publishing. 150 pp.

Singh H.R., Badala, S.P. & Dobriyal A.K. 1987. Geographical distribution list of ichthyofauna of the Garhwal Himalaya with some new records. J. Bombay, *Nat. Hist. Soc*., 84: 126-132.

Sioli H. 1964. General Features of the Limnology of Amazonia. *Int. Ver. Theor. Agnew. Limnol*., 15: 1053-8.

Smith B.D. 1991. Status and conservation of the Ganges River dolphin, Platanista gangetica in the Karnali River, Nepal. *Biological Conservation*, 66: 159-169.

Talwar P.K. 1991. Pisces. *In Fluvial Resources of the Ganga, Part I.* New Dehli, Government of India. pp. 59-145.

Temple S.A. & Payne A.I. 1995. *The Ganges Basin: An overview for fisheries*. London, DFID Fisheries Management Science Programme, MRAG Ltd. 362 pp.

Tsai C. & Ali L. 1985. Open water fisheries carp management programme in Bangladesh. *Fisheries Information Bulletin*, 24: 51 pp.

Welcomme R.L. 1974. Some general and theoretical considerations of the fish production of African rivers. *CIFA Occasional Paper 3*. Rome, FAO, 26 pp.

Welcomme R.L. 1985. River fisheries. *Fish Technical Paper 202*. Rome, FAO, 330 pp.

APPENDIX 1. COMPONENT FISH SPECIES AT VARIOUS SITES DOWN THE GANGES BASIN

Key:

1. Alaknanda River	altitude 460-1500 m	(Singh et al. 1987)
2. Upper Ganga River, Garhwal	altitude 70-600 m	(Singh et al. 1987)
3. Kosi River	altitude 70-600 m	(Khan and Kamal 1980)
4. Allahabad fishery	altitude 82 m	
5. Patna fishery	altitude 37 m	
6. Padma River Bangladesh (Ganges)	altitude 30 m	(FAP 17 1994)

FAMILY NAME	SCIENTIFIC NAME	River Sectors (see Key)					
		1	2	3	4	5	6
CYPRINIDS							
CYPRIDIDAE	*Schizothorax richardsonii*	v	v	v			
	Schizothorax sinuatus	v	v				
	Schizothorax plagiostomus	v	v				
	Schizothorax curvifrons	v	v				
	Schizothorax niger	v	v				
	Schizothorax intermedius	v	v				
	Schizothorax micropogon	v	v				
	Schizothoraichthys esocinus	v	v				
	Schizothorax annandalei			v			
	Tor tor	v	v		v		
	Tor pititora	v	v	v			
	Tor chilinoides	v	v				
	Crossocheilus latius	v	v	v		v	v
	Lissocheilus hexagonalepis			v			
	*Raiamas (*Barilius) *bola*	v	v				v
	Barilius everzardi						v
	Barilius bendelisis	v	v				
	Barilius barna	v	v	v			
	Barilius barila	v	v	v			
	Barilius vagra	v	v	v			
	Barilius shacra		v	v			
	Garra prashadi	v	v				
	Garra lamta	v	v	v			
	Garra annandalei			v			
	Chagunius chagunio	v	v	v		v	
	Danio aequipinnatus		v	v			
	Danio dengila			v			
	Danio devario	v	v	v			v
	Brachydanio rerio		v				v
	Rasbora daniconius		v	v			
	Labeo dero	v	v	v			
	Labeo dyocheilus	v	v				
	Labeo boga		v	v			v
	Labeo bata			v	v	v	v
	Labeo calbasu			v	v	v	v
	Labeo angra			v			
	Labeo pangusia			v			
	Labeo gonius			v	v	v	v
	Labeo sindensis			v			
	Labeo rohita			v		v	v

FAMILY NAME	SCIENTIFIC NAME	River Sectors (see Key)					
		1	2	3	4	5	6
	Catla catla			v		v	v
	Cirrhinus mrigala			v		v	v
	Cirrhinus reba			v		v	v
	Aspidoparia jaya			v		v	
	Aspidoparia morar			v	v	v	v
	Puntius chilinoides			v			
	Puntius chola		v	v			v
	Puntius clavatus			v			
	Puntius conchonius		v	v			v
	Puntius guganio						v
	Puntius gelius			v			v
	Puntius sarana		v	v		v	v
	Puntius sophore		v	v		v	v
	Puntius ticto		v	v		v	v
	Puntius phuntunio		v				v
	Puntius terio						v
	Puntius spp				v		
	Ablypharygodon mola			v		v	v
	Chela laubuca			v		v	v
	Chela cochius						v
	Oxygaster argentea			v			
	Oxygaster bacaila			v	v	v	v
	Oxygaster gora			v			
	Oxygaster phulo			v			v
	Esomus danricus		v				v
	Osteobrama cotio			v	v	v	v
PSILORHYNCHIDAE	*Psilorhynchus pseudechensis*			v			
	Psilorhynchus balitora						v
HOMALOPTERIDAE	*Balitora brucei*			v			
COBITIDAE	*Botia dayi*			v			
	Botia dario						
	Botia historionica	v	v			v	v
	Botia lohachata			v			
	Botia geto	v					
	Noemacheilus botia		v	v			v
	Noemacheilus montanus	v	v				
	Noemacheilus rupicola	v	v	v			
	Noemacheilus bevani	v	v				
	Noemacheilus savona	v	v	v			
	Noemacheilus multifasciatus	v	v				
	Noemacheilus scaturigina		v	v			
	Noemacheilus zonatus	v					
	Noemacheilus corica						
	Lepidocephalus guntea	v	v	v		v	v
	Acanthophthalmus pangia			v			
	Lepidocephalus annandalei			v			
AMPHIPUOIDAE	*Amphipnous cuchia*			v			v
CATFISHES							

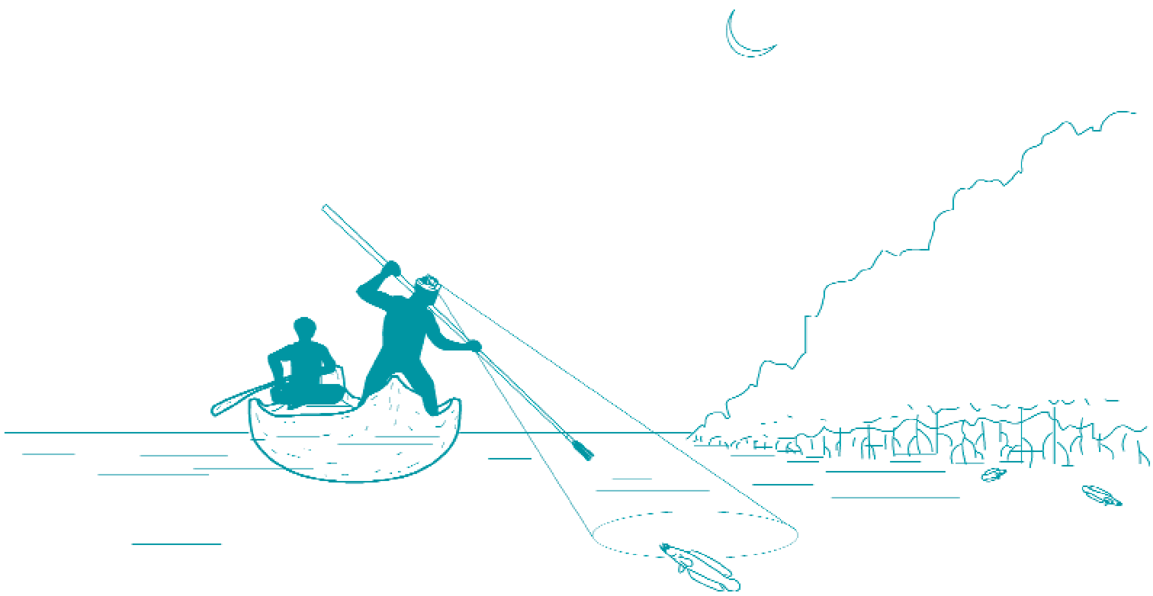
FAMILY NAME	SCIENTIFIC NAME	River Sectors (see Key)					
		1	2	3	4	5	6
AMBLYCEPTIDAE	*Amblyceps mangois*	v	v	v			
SISORIDAE	*Glyptothorax cavia*	v	v	v			
	Glyptothorax pectinopterus	v	v				
	Glyptothorax madraspatanum	v					
	Glyptothorax annandalei			v			
	Glyptothorax horai			v			
	Glyptothorax telchitta			v		v	v
	Glyptothorax trilineatus	v					
	Glyptothorax brevipinnis	v	v				
	Glyptothorax conirostris	v	v				
	Pseudecheneis sulcatus	v	v	v			
	Hara jerdoni						
	Hara hara						
	Bagarius bagarius			v	v	v	v
	Gagata cenia			v	v	v	v
	Gagata nangra			v			v
	Gagata viridescens			v			v
	Gagata youssouli						v
SCHILBEIDAE	*Clupisoma montana*			v			
	Clupisoma garua	v	v	v	v	v	v
	Clupisoma naziri						v
	Eutropichthys vacha			v	v	v	v
	Ailia coila			v	v	v	v
	Pseudeutropius atherinoides			v		v	v
PANGASHDAE	*Silonia silondia*			v	v	v	v
	Pangasius pangasius				v		v
BAGRIDAE	*Aorichthys aor*			v	v	v	v
	Aorichthys seenghala			v		v	v
	Mystus bleekeri			v			v
	Mystus cavasius					v	v
	Mystus vittatus		v	v		v	v
	Mystus tengra				v	v	v
	Rita rita			v		v	v
	Leiocassis rama			v	v		
SILURIDAE	*Wallago attu*			v	v	v	v
	Ompok bimaculatus						v
	Ompok pabda					v	v
HETEROPNEUSTIDAE	*Heteropneustes fossilis*			v		v	v
CLARIIDAE	*Clarias batrachus*			v		v	v
CLUPEIFORMES (Herrings)							
NOTOPTERIDAE	*Notopterus notopterus*			v	v	v	
	Notopterus chitala				v	v	v
ENGRAULIDAE	*Setipinnia phasa*			v	v	v	v

FAMILY NAME	SCIENTIFIC NAME	River Sectors (see Key)					
		1	2	3	4	5	6
CLUPEIDAE	*Gudusia chapra*			v	v	v	v
	Hilsa ilisha				v	v	v
	Corica soborna						v
MASTACEMBELIDAE	*Mastacembelus armatus*		v	v	v	v	v
	Macrognathus aculeatus			v		v	v
CHANNIDAE	*Channa punctatus*			v	v	v	v
	Channa striatus			v		v	v
	Channa marulius			v		v	v
	Channa orientalis			v			v
	Channa gachua		v				
MUGILIDAE	*Rhinomugil corsula*			v	v	v	v
	Sicamugil cascasia					v	v
	Liza parsia						v
BELONIDAE	*Xenentodon cancila*			v	v	v	v
CYPRINODONTIDAE	*Aplocheilus panchax*			v			v
GOBIIDAE	*Glossogobius giuris*			v		v	v
	Brachygobius nununs						v
	Awaous stamineus						v
	Apocryptes bato						
ANABANTIDAE	*Colisa fasciatus*			v	v		v
	Colisa lalia			v			v
	Colisa sota						v
	Colisa labiosus						v
	Anabas testudineus					v	v
CENTROPOMIDAE	*Chanda nama*			v		v	v
	Chanda ranga			v			v
	Chanda baculis						v
NANDIDAE	*Nandus nandus*			v			
PRISTOLEPIDAE	*Badis badis*						v
SCIAENIDAE	*Sciaena coitor*			v	v	v	v
	Pama pama						v
CYNOGLOSSIDAE	*Cynoglossus*						v
	Euryglossapan						v
TETRAODONTIODAE	*Tetraodon cutcutia*			v		v	v
TOTAL NUMBER OF SPECIES	**161**	**41**	**54**	**103**	**30**	**56**	**93**

THE PLATA RIVER BASIN: INTERNATIONAL BASIN DEVELOPMENT AND RIVERINE FISHERIES

R. Quirós

Sistemas de Producción Acuática, Facultad de Agronomía, Universidad de Buenos Aires, Av. San Martín 4453, (1417) Buenos Aires, Argentina



ABSTRACT

Environmental changes in large river basins are subject to forces external to the water and to biological issues. Before 1960, the Plata River Basin was almost undeveloped. The regulation of the Parana for hydroelectricity has been increasing since the early 1970s. Water in reservoirs of the upper Parana Basin currently comprises more than 70 percent of the mean annual discharge at its confluence with the Paraguay River. The expansion of hydroelectric generation in the upper basin brought with it an increase in industry, agriculture, transport and settlements. These in turn have resulted in significant increases in deforestation, soil erosion, changes in water quality and reduced fisheries opportunities in both the upper and lower basins.

Key words: Plata River, impacts, fisheries

The fisheries of the Plata Basin are lightly to moderately exploited compared to other subtropical and tropical floodplain fisheries. The fisheries were traditionally based on large potamodromous fish caught from a fish community containing a relatively high frequency of the detritivorous *Prochilodus*. The catch per fisher per day now ranges from 11 to 30 kg for reservoirs situated in the Brazilian upper basin to more than 110 kg in the lower middle Parana River. Catch rates drop to 8-10 kg of high value fish fisher^{-1} day^{-1} at the Parana-Paraguay confluence and for the Pantanal fishery. Striking differences in the fish species structure of the catch are noticeable between reservoir and floodplain fisheries and among floodplain fisheries themselves. We have identified three main fishery states in the Plata Basin across broad temporal and spatial scales. A relatively undisturbed state corresponds to the unregulated river, when fishing effort was relatively low to moderate. Here catch is mainly dominated by high value large siluroids and characins. This state is represented by fisheries at the Pantanal and the Parana-Paraguay confluence and to a lesser extent by some of the remnant lotic reaches at the upper Parana. A second fishery state corresponds to the developed river, with floodplains disturbed by river regulation and other developmental activities. Here the fisheries are still supported by potamodromous fish but fish size at capture is usually lower. Fishing effort is usually higher, the contribution by weight to the catch of less valuable *Prochilodus* has increased and exotics are usually included in fish catches. The disturbed floodplain fishery state is represented by fisheries of most of the lower basin and at the few unregulated reaches of the upper Parana. Fisheries in riverine reservoirs represent a third, relatively highly disturbed fishery state. The catch of potamodromous fish frequently descends well below 50 percent of the total catch and fish catches are often dominated by blackfish species, less dependent on river flows and with an increasing importance of exotic fish species. Fish size is lower as well as fish value at landing. The Plata Basin fisheries represent almost all of these states at the same time in different parts of the basin.

INTRODUCTION

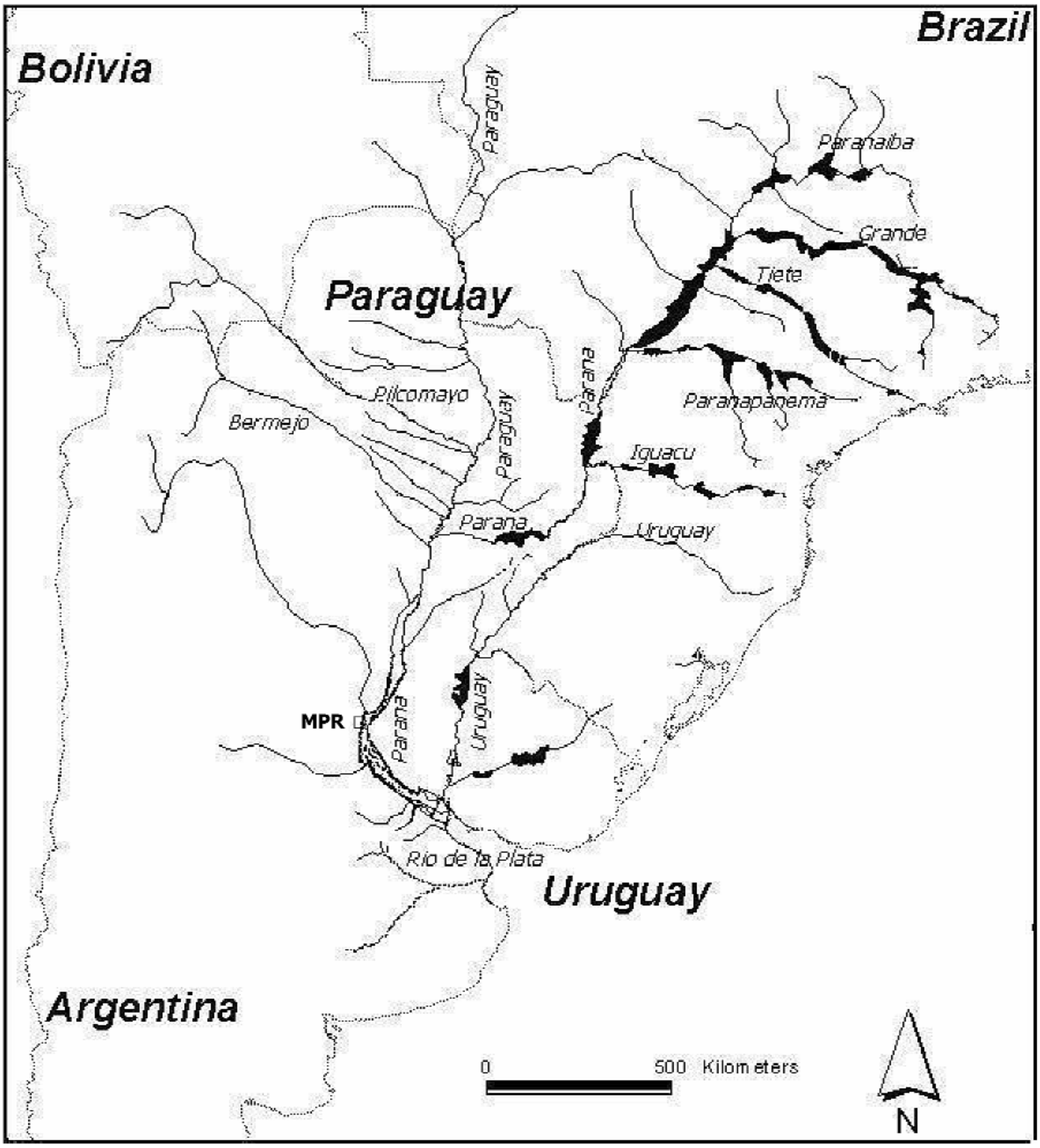
Development planners look to the unique hydrological characteristics of each river to determine the physical capability of the whole river, developed as a unit, to meet the needs of water-dependent users. For most planners the basin is the appropriate unit for thinking about development. Moreover, for international rivers integrated development provides an incentive for the basin countries to benefit from economies of scale. However, despite the economic incentives to co-operate, the technical, legal, institutional and above all political difficulties in the way of successful common development are formidable (UN 1990).

Most of the world's large rivers are greatly affected by human activity (Welcomme, Ryder and Sedell 1989). Large scale, long-term environmental changes in large river basins are subject to forces that are external to the water and to biological issues. The regulation of the upper Parana for hydroelectricity has been increasing noticeably since the early 1970s. Therefore, we suggest that historic trends in La Plata River Basin development are an adequate framework for a study of the impact of development on water resources and biological communities and to analyse adequate measures to protect riverine fisheries from development activities (Quiros 1990). All over the world fishers try to maximize inputs using less effort. For the La Plata Basin we expect that they are trying to get the best and most valuable fish and that high value large potamodromous fish are their main target. We shall use the large piscivorous fish captured as a tracer to integrate the fishery attributes and, moreover, the environmental quality that sustains this fishery.

The main purpose of this paper is to overview some striking historical events in the La Plata River Basin development and to relate these events to its current environmental and fisheries state. When compared with other subtropical and tropical floodplain fisheries, the Plata Basin is lightly to moderately exploited for fisheries.

THE PLATA RIVER BASIN

The Plata River Basin (Figure 1) drains large parts of Argentina, Bolivia, Brazil, Paraguay and Uruguay. With an area of 3.2 10^6 km^2, it is the second drainage system in South America and the fourth largest in the world. The Plata River Basin consists mainly of three sub-basins: the Parana, the Paraguay and the Uruguay river basins (Figure 1). The Parana River flows 4 000 km southwards from its sources in the Precambrian Brazilian Shield to its mouth in the Pampa Plain discharging 20 000 m^3 s^{-1} in the Plata River. The Paraguay River extends 2 670 km southwards from its sources in the western hills of the Brazilian Shield at 300 m of altitude to its confluence with the Parana River. The "Pantanal" depression, situated 270 km south from the Paraguay sources, receives water from the Paraguay River itself and from many other tributaries. The Pantanal has a natural regulatory effect on the middle and lower Paraguay River discharge. The Uruguay River flows 1 800 km from its sources in southern Brazil and discharges 5 000 m^3 s^{-1} in the Plata River.



■ **Figure 1**. The Plata river basin. MPR, middle Parana River.

Climatic conditions in the basin cover a wide range, with tropical areas at the sources of the Parana and Paraguay Rivers, subtropical in parts of Argentina, Brazil and Paraguay, warm temperate in parts of Argentina and Uruguay and arid areas in the sub-Andean region. With this variety of climates, fertile soils, mineral resources, water resources and the potential offered for hydroelectric energy and navigation, a large proportion of the population of the riparian states has settled within the basin and many national urban and industrial centers are also located there. More than 110 million people inhabit the Plata River Basin. Although differences between national and basin boundaries make statistical comparisons difficult among countries, Tables 1 and 2 are indicative of the importance of the basin in southern South America, both demographically and in economic terms, with reference to gross national product (Barberis 1990). Development is not evenly distributed in the basin. For example, Brasil in the upper basin consumes more than three times electric power than all the other countries in the basin (Table 3).

Table 1: Total country area and total country population in the basin (from Barberis 1990).

Country	% total country area in the basin	% area	% total country population	% total basin population
Argentina	29	32	68	23
Bolivia	19	6	22	2
Brazil	17	44	45	68
Paraguay	100	13	100	4
Uruguay	80	5	97	3

Table 2: National and basin gross national products (GNP) (modified from Barberis 1990).

Country	% national GNP in the basin	% of total GNP in the basin
Argentina	70	33
Bolivia	35	1
Brazil	60	60
Paraguay	100	3
Uruguay	95	3

Table 3: Energy consumption in the Plata river basin (source World Bank, 1998).

	Commercial energy use kg of oil equivalent/10^6	Electric power consumption kwh/10^6
Brazil	179486	305047
Other countries	76193	83433

THE INTERNATIONAL JOINT COMMISSION

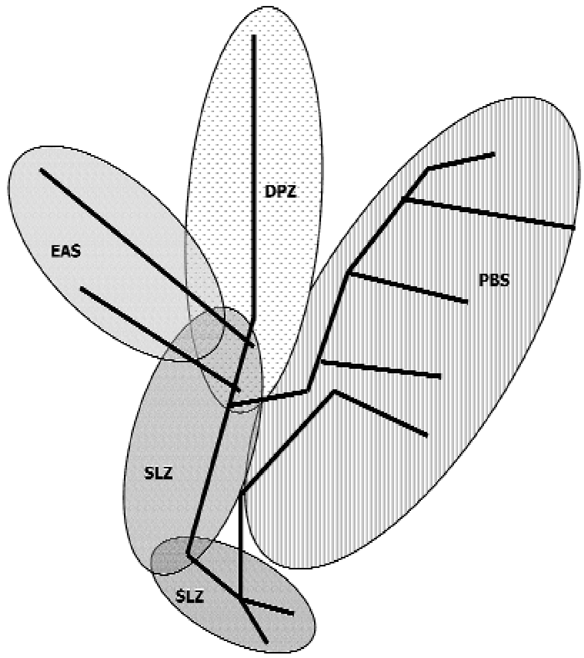
The idea of La Plata River Basin as a unit for development and international co-operation arose towards the 1960s. The Foreign Ministers of the five basin countries met and declared the decision of their Governments "to carry out a joint and integral survey of La Plata Basin, with the view to the realization of a program of multinational, bilateral and national works, useful for the progress of the region". The main areas to be considered, in relation to water resources, are navigation, hydroelectricity, domestic water supply, sanitation, industrial water use and flood control. The Brasilia Treaty of 1969 does not give attention to environmental or fisheries issues (Barberis 1990). The Treaty provides for joint action of the member states, but without interfering with "those projects and enterprises that they decide to carry out in their respective territories".

In practice, the institutional system has not worked well, partly due to the lack of a permanent technical arm. Discussions of the technical groups frequently involve non-technical participants with political bias, resulting in an outcome based on negotiations rather than on scientific and technical grounds. In addition, resolutions of the Conference of Ministers and the Co-ordinating Intergovernmental Committee (CIC) are in the nature of recommendations only and lack any legal force. The competence of the institutional mechanism has been tested and found wanting, in a number of cases (Barberis 1990).

RIVER BASIN AND FISHERIES DEVELOPMENT

SOURCES OF FLOODS AND NUTRIENTS

As with other multicausal complex systems, environmental effects on large river fisheries should be addressed in the multivariate context of riverine ecology. The interaction between hydrology and geomorphology is a good basis to start a wide analysis of the past and present riverine fisheries (Quiros and Cuch 1989). The complex interplay of geomorphology, hydrology and development will determine many of the fisheries characteristics at the basin level. For fisheries analyses, the La Plata River Basin can be subdivided in four main regions (Figure 2):



■ **Figure 2.** Main fishery regions for the Plata basin, as described in text.

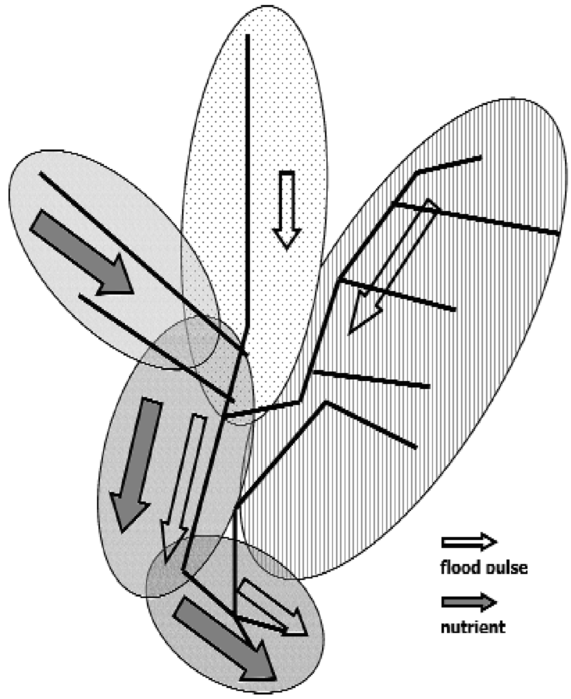
EAS: Erosive Andean sub-basins comprising the upper Pilcomayo and upper Bermejo Rivers. Formerly erosive at high sloped headwaters, but presently with highly erosive catchments as a result of mining, deforestation and agricultural activities. Depositional reaches downstream at the Chaco-Pampa Plain. Relatively high nutrient levels. Relatively low water discharges.

PBS: Precambrian Brazilian Shield drainages containing the most important upper Parana tributaries and upper and middle Uruguay reaches. Formerly low erosion at headwaters and interspersed with depositional floodplain zones. At present with highly erosive catchments, mainly due to deforestation and agricultural activities. Floodplains highly reduced by dams. Highly influenced by industrial activities. Presently regulated by cascades of reservoirs that retain sediment and nutrients. Relatively low nutrient levels. Highly important water discharges.

DPZ: depositional floodplain zones interspersed with Brazilian Shield emergences. Mainly contains the upper and middle Paraguay. Originally low erosive at headwaters but presently lightly erosive catchments by agricultural and mining activities. Comparatively low water discharge and nutrient levels.

SLZ: sedimentary middle and lower reaches with massive floodplains at the Chaco-Pampa Plain. Principally consists of the lower Pilcomayo, lower Bermejo, lower Paraguay, middle and lower Parana, lower Uruguay and the Plata River. Industry and annual crops influence at lower reaches. High water discharges and highly depositional at the Parana Delta and the Plata River. Relatively high nutrient levels.

For the middle and lower reaches of the Parana, the origins of the floods and of the sedimentary nutrient loads do not coincide (Figure 3). The spatial difference between the sources of floods and nutrients interacting with the river regulation would have important implications for the riverine dynamics and fisheries for both upper and lower depositional river reaches. As the river with the major discharges in the upper basin, the upper Parana provides the flood pulse to middle and lower river reaches. The Paraguay flows only modulate this pulse (Figure 1). Upper Parana and Paraguay Rivers provide the water for floods in the lower basin (Figure 3). These waters, mainly originating from the heavy rainfall on the Brazilian Precambrian Shield, usually have a relatively lower nutrient content (Maglianesi 1973). The effect of nutrient decrease is amplified by sediment retention in reservoir cascades (Tundisi 1981; Tundisi *et al.* 1991). On the other hand, main sources of nutrients to middle and lower Parana reaches are the headwaters of rivers originating in the Andean ranges (Figures 2 and 3).



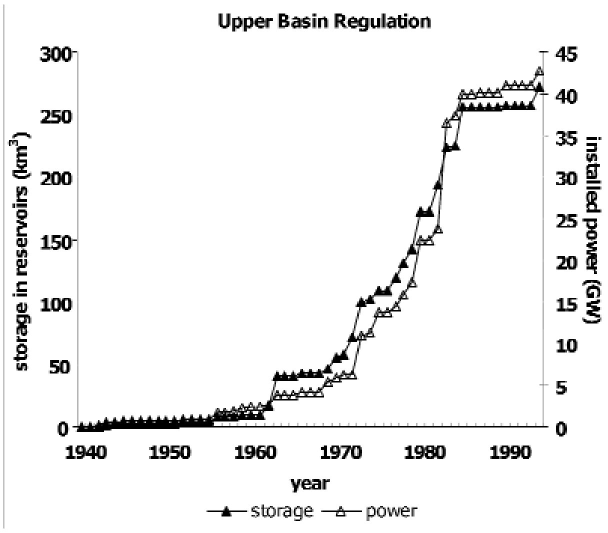
■ **Figure 3.** Main pathways of the flood pulse and the sedimentary transport to the lower basin river reaches.

DEVELOPMENT OF THE PLATA RIVER BASIN

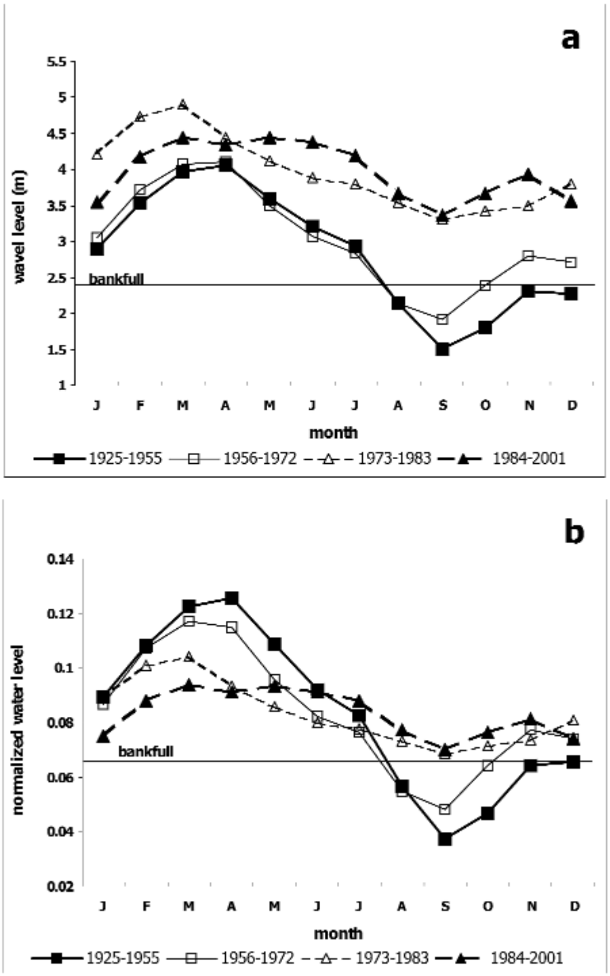
River regulation

The Parana River runs 5 000 km from its headwaters to its mouth in the Plata River. More than 3 000 km of the upper reaches of the main river and most of its tributaries have been transformed into cascades of reservoirs (Figure 1) (Petrere *et al.* 2002). The upper Plata Basin regulation for hydroelectricity has been increasing noticeably since the early 1970s (Figure 4) (OEA 1985; Quiros 1990) and 70 percent of rivers are now affected by dams (Agostinho *et al.* 2000). Water in reservoirs located in the upper Parana Basin comprises more than 70 percent of the Parana mean annual discharge at its confluence with the Paraguay River (Figure 1) and the upper Parana is the most regulated river in the world (Agostinho *et al*. 2000). Before most of the reservoirs were formed, the middle Parana River showed a regular annual cycle, usually reaching its peak in autumn (March-April) and its minimum flow in late winter (September) (Figure 5a) (Bonetto 1986). However, the natural hydrological regime of the middle and lower Parana reaches has been altered by the operation of upper basin dams (Quiros 1990). These dams have resulted in an increase in minimum water levels in the middle reaches of the Parana and an extended period of floods (Figure 5). Although run-of-the river dams do not have the possibility to control river flow at high waters, downstream control effects are important at low water states. In order to optimize energy production, upstream dams retain water in reservoirs during high and falling water levels to release it during the low water level. These effects are noticeable when round year normalized hydrologic levels were analyzed (Figure 5b). In the middle Parana, water was over the unregulated river bankfull level (2.2 – 2.4 m at Santa Fe Harbor) most of the time during the last 30 years (Figure 5). In the middle and lower Parana Basin the river has lost several of its main characteristics, water cycles are less intense among and within years and water is on the floodplain most of the year (Figure 5). When the differences between maximum and minimum hydrological levels are compared among years for both the unregulated and the regulated river (Table 4), a marked decrease in the amplitude of the flood pulse is evident (Figure 6).

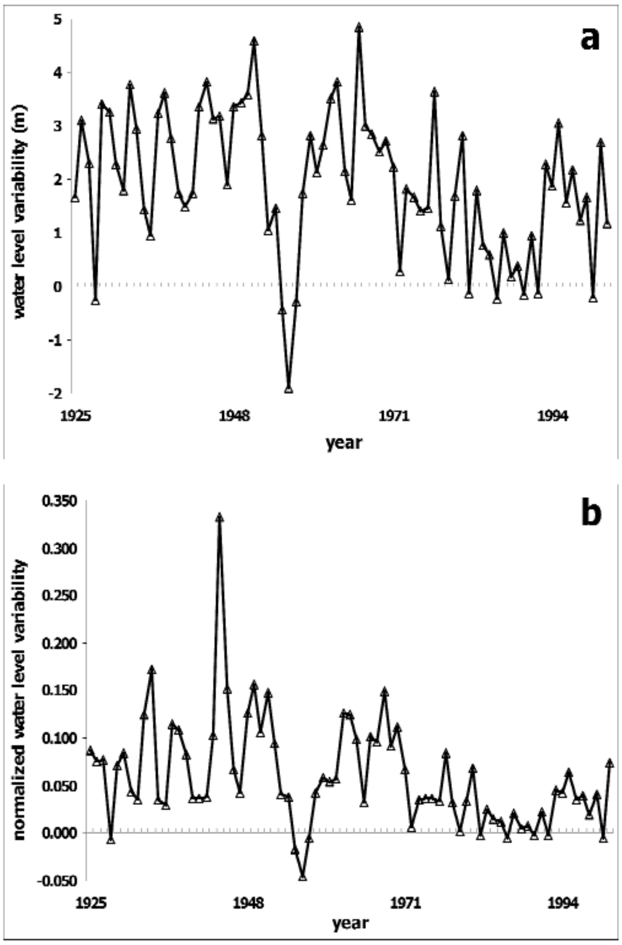
Several dams have been constructed in the Uruguay River Basin and at the headwaters of some tributaries of the Bermejo River and on other small tributaries of the rivers Paraguay and middle Parana. However, the basins of the Paraguay and Uruguay rivers may be considered to be mostly unregulated. This has important consequences for the functioning of the river-floodplain ecosystem. Sediment sources of Andean origin are still available for essential nutrient loading to the lower Paraguay and the middle Parana River (Figure 3).



■ **Figure 4.** The upper Plata basin regulation.



■ **Figure 5**. Water level variation in the middle Parana river (Santa Fe City) for the undeveloped and developed periods. a) actual data; b) round year normalized data



■ **Figure 6.** Water level at the maximum (March) minus water level at the minimum (September) for the middle Parana River (Santa Fe City). a) actual data; b) round year normalized data.

Table 4: Flood pulse amplitude in the middle Parana river (Santa Fe City) for non-developed and developed river periods.

Period	March-September (m)	Relative March-September
1925-1945	2.45	0.087
1946-1970	2.36	0.076
1971-1984	1.48	0.034
1985-2002	1.12	0.024

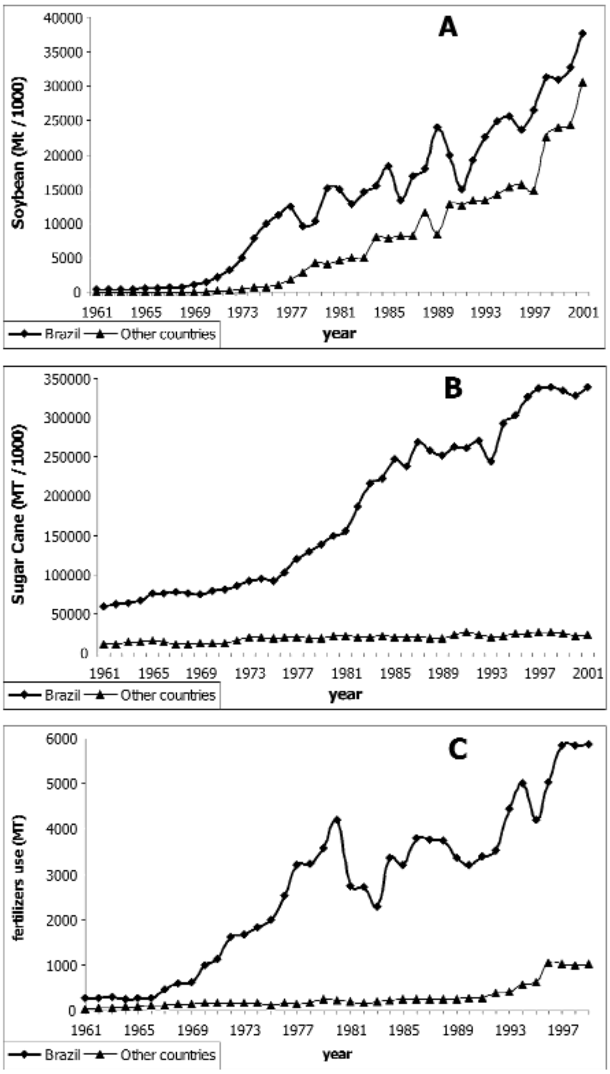
The basin development

The level of development among the countries of the Plata Basin development is not even (Table 2). Most of the industry and agriculture of Brazil and Argentina is concentrated in the higher and the lower Parana Basin, respectively. The Paraguay River Basin is mainly agricultural, although mining has become relatively important there as well. The upper Uruguay drainage is agricultural, but industry is also important. Cattle rearing is also significant in both the upper and the lower basins (Quiros 1990).

Development in the Plata Basin has been concomitant with river regulation, mainly in Brazil. Industrial development in the upper basin has been directly related to energy availability and energy consumption in Brazil has been rapidly increasing since 1968 paralleling the increase in energy generated by Brazilian hydroelectric plants (Quiros 1990).

The Plata Basin development is a paradigm for South America. Prior to 1960, the Rio de la Plata River Basin was scarcely developed (see Figure 5). Industrial development in the lower basin started earlier than in the upper basin and had a small increase in the early 1960s. Since the early 1970s industrial and agricultural development has been fast, mainly in the upper basin, responding to the increased availability of electric energy generated by hydroelectric plants (compare Figures 2 and 7). In the upper basin, industry, mining and both agricultural cultivated area and intensity have been increasing from the early 1970s to the present (Figure 7). It can be said that for all the basin countries, most of the fertilizers and other chemicals used by basin countries in agriculture and industry have been used in the Plata Basin.

Information on water quality in the Plata River Basin is scarce, scattered and even contradictory. Suitable international water quality monitoring programs are still to be implemented (CIC 1993). Water quality assessment based on national data is needed. In view of the level of resources that countries can put at the disposal of this activity, the strategies for water



■ **Figure 7.** Some indicators of development for the Plata basin. A. Soybean production (t x 1000); B. Sugar cane production (t x 1000); C. Use of fertilizers (t), for Brazil and the sum of other countries in the basin.

quality assessment will be developed according to minimum levels of monitoring operations mainly in main rivers (CIC 1993). While the most common national requirements are for drinking water of suitable quality, at present each member country has its own water quality standards. The different national water quality guidelines are reflected in different assessments of water quality in the rivers of the basin.

However, some studies in both the upper and the lower basin have confirmed what was expected from trends for some development indicators (macro-pollution variables) showed above (Figures 4 and 7). Developmental activities represent hazards to the health and integrity of fisheries resources (Quiros 1990). Some studies (e.g. Maglianesi 1973; Bonetto 1976; Tundisi 1981; Tundisi *et al.* 1991; Andreoli 1993), both in the upper and the lower basin, have shown different levels of pollution and water quality degradation. Other studies executed by governmental and bilateral agencies in the lower basin have shown significant levels of chloride pesticides in the major rivers and reservoirs. Andreoli (1993) reported the presence of agrotoxic substances in the upper Parana Basin. His research showed that 91 percent of 1 816 water samples contained residues of at least one agrotoxic substance. Agrochemical and industrial toxic concentrations in mussels for two coastal sites in the Rio de La Plata are elevated (IMW 1993). Angelini, Seigneur and Atanasiadis (1992) have reported organochloride pesticides and PCB residues in all sampled fish for the lower Uruguay River and Salto Grande reservoir. Similar results were obtained at the Parana confluence with the Paraguay River and for some lower Parana affluents. As expected, heavy metal levels were usually higher for top predators. However, we cannot assess here the water quality state for the Plata River Basin because water quality data for the basin, as well as water quality reports, are scarce, scattered and often contradictory.

PLATA RIVER BASIN FISHERIES

The main fish characteristics of the Parana River were reviewed by Agostinho and Julio (1999), Agostinho *et al.* (2000) and by Bonetto (1986) who separately catalogued the fish faunas of the upper and lower reaches, respectively. Quiros and Cuch (1989); Quiros (1990); Espinach Ros and Delfino (1993); Petrere and Agostinho (1993) and Petrere *et al.* (2002) have all described the status of the fisheries of different parts of the La Plata Basin. Quiros and Cuch (1989) and Fuentes and Quiros (1988) described the structural characteristics of the lower basin fisheries. The fisheries period 1945-1982 for the lower Plata Basin was analyzed with emphasis on dynamic relationships between fish catch and hydrology for the lower basin (Quiros and Cuch 1989) and on fishery development activities in the river basin (Quiros 1990, 1993).

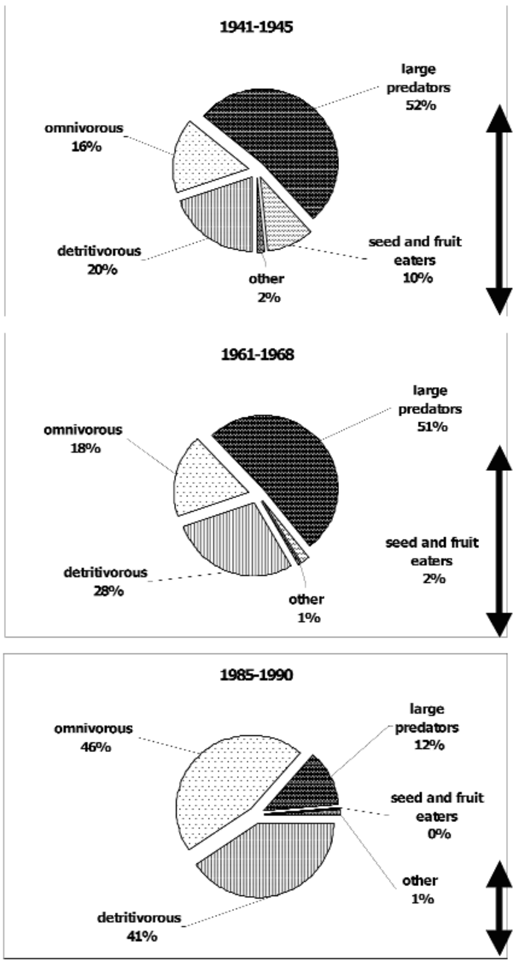
The best historical records for the Plata Basin fisheries are for fish landing sites situated in the lower basin during the 1935-1983 period (Quiros and Cuch 1989; Quiros 1990). For the pre-dam, unregulated river period (1935-1971), fish landings in the lower basin consisted of 6-9-year old fish, mainly large individuals of potamodromous fish (Quiros 1990). It can be assumed that the situation was similar in the other rivers of the undeveloped upper basin during this period. However, for the post-dam (1972-1983) regulated river period, in the middle Parana fish age at landings decreased to 4-6 years old. For this period the estimate of the total catch was 10 000 tonnes yr^{-1}. It is estimated that some 60 000 tonnes yr^{-1} of fish, mainly the detritivorous *Prochilodus*, are captured in the middle Parana today.

Historic fish catches in the lower basin

Fisheries before development were based on large potamodromous fishes (Table 5), mainly siluroids and some characins (Paiva 1984; Petrere 1989; Quiros and Cuch 1989; Petrere and Agostinho 1993). There was a higher proportion of large detritivorous at depositional zones (Bonetto 1986; Quiros and Cuch 1989) and at many river headwaters during seasonal fish migrations (Godoy 1967; Bayley 1973; Payne and Harvey 1989; Smolders, Guerrero Hiza, van der Velde *et al.* 2002). High valued large piscivorous were also captured in the pre-development period (Figures 8a and b). River regulation and basin development have led to some striking changes in fisheries in both the upper and the lower basin. The obligatory migratory fish abundance has sharply decreased in the upper basin and the size of potamodromous fish decreased appreciably in the remnant floodplains in the upper basin (Petrere and Agostinho 1993; Petrere *et al.* 2002). In the middle and lower depositional reaches (Figures 2 and 3), the proportion of the detritivorous *Prochilodus* in fish catches gradually increased when compared with the large piscivorous fish (Figure 8). Several fish species, mainly fruit and seedeaters, disappeared from zones where they were abundant during the predevelopment period. The exotic common carp has become abundant in the lowland depositional rivers but not in fish catches (Quiros 1990).

Table 5: Main fish species taken by fisheries in the Plata river basin.

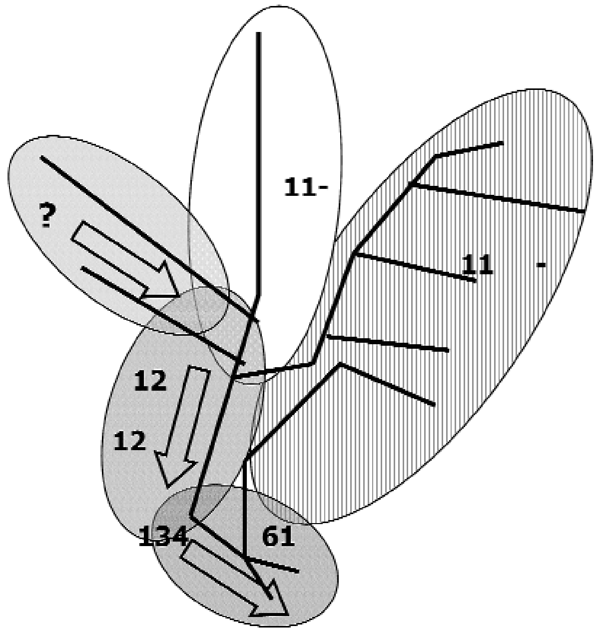
Whitefish Species	Blackfish species
Large predators	Native species
Pseudoplatystoma corruscans	*Hoplias malabaricus*
Pseudoplatystoma fasciatum	*Hypophthalmus edentatus*
Salminus maxillosus	*Serrasalmus spp.*
Luciopimelodus pati	*Rhinelepis aspera*
Pinirampus pinirampu	*Pimelodus maculatus*
Paulicea lutkenii	*Pimelodus clarias*
	Geophagus brasiliensis
Detritivores	other blackfish
Prochilodus lineatus	
Prochilodus platensis	Exotic species
	Cichla monocolus
Omnivores and benthivores	*Plagioscion squamosissimus*
Leporinus spp.	*Oreochromis spp.*
Leporinus obtusidens	
Pterodoras granulosus	
other Doradidae	
Seed and fruit eaters	
Brycon orbignyanus	
Piaractus mesopotamicus	



■ **Figure 8.** Historical changes in the structure of fish capture from the main channel, lower middle Parana River (Rosario City). Double arrow indicates the relative amplitude for the flood pulse.

Present fisheries in the Plata River Basin

The complex interplay between geomorphology and hydrology determines many of the biological characteristics of large river-floodplain systems (Quiros and Cuch 1989). Fish abundance in the developed basin, as estimated from the catch per fisher per day (Figure 9), is actually ordered as would be expected from the conceptualisation of a large river-floodplain system as a continuum from its sources to its estuary, interspersed with relatively extensive floodplains where a diminished slope is evident. In this view, fish abundance would be lower at the upper reaches with relatively higher slopes, running on old and hard rocks and poorly developed soils, as compared with the higher fish abundance at the lower, low sloped depositional reaches. This pattern is actually displayed for the La Plata River Basin (Figure 9) despite development. The catch per fisher per day now ranges from 11-30 kg for reservoirs situated in the Brazilian upper basin to more than 110 kg in the lower middle Parana River and more than 300 kg at the Rio de la Plata River (Table 6). Catch rates drop to 8-10 kg of high value fish fisher^{-1} day^{-1} at the Parana-Paraguay confluence and for the Pantanal fishery.



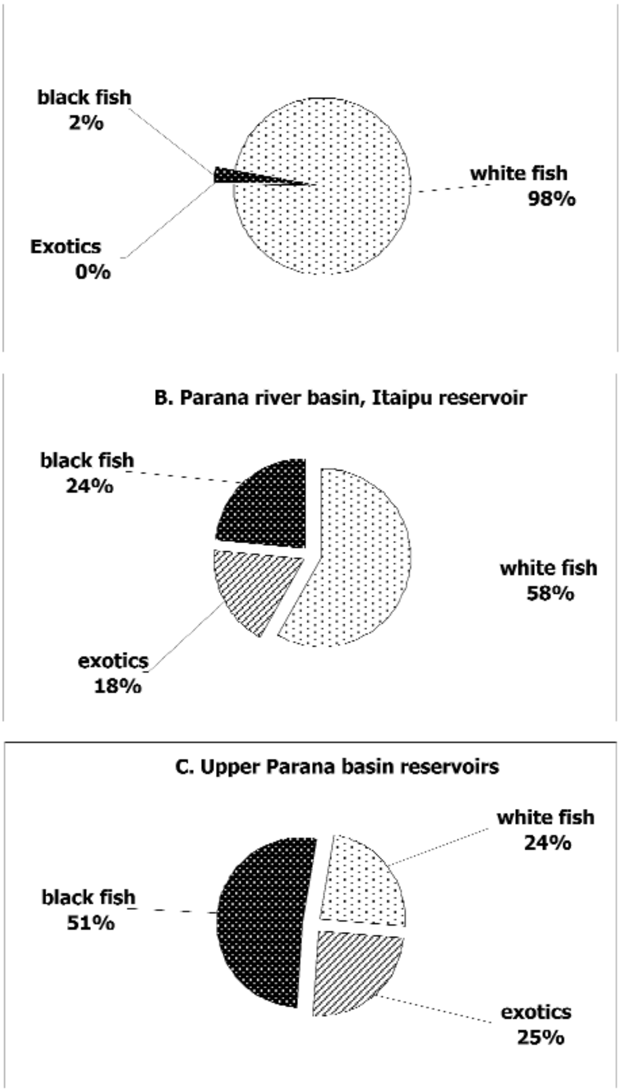
■ **Figure 9.** Catch per unit effort (kg/fisher/day) for fisheries regions as defined in text (from Quiros & Cuch (1989) and Petrere & Agostinho (1993).

However, the fish and the fisheries characteristics for the developed period differ according to the intensity of development and the position of each river reach in the basin. Striking differences in the fish species structure of the catch are noticeable between reservoir and floodplain fisheries (Figure 10) and among floodplain fisheries themselves.

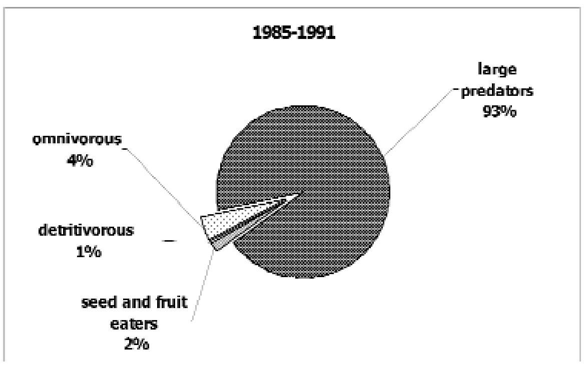
Table 6: Catch per unit effort in the Parana River below the Itaipu dam for the 1982-1984 period (from Quiros & Cuch (1990) compared with catch per unit effort for Brazilian reservoirs situated in the upper Parana basin (from Petrere & Agostinho (1993) and Petrere *et al.* (2002)). CPUE, catch per unit effort (kg/ fisher/day).

Parana river reaches	CPUE	Upper Parana reservoirs	CPUE (a)
Lower upper Parana	18.3	Jupia	24.6
Upper middle Parana	11.9	Agua Vermelha	22.6
Middle middle Parana	120.9	Barra Bonita	27.0
Lower middle Parana	133.9	Ibitinga	10.9
Isolated delta distributary	12.1	Promissao	29.6
Rio de la Plata river	614.5	Nova Avanhandava	15.2
		Itaipu	11.8

(a), recalculated from original data.



■ **Figure 10.** Actual fish catch composition for the Plata river basin fisheries.

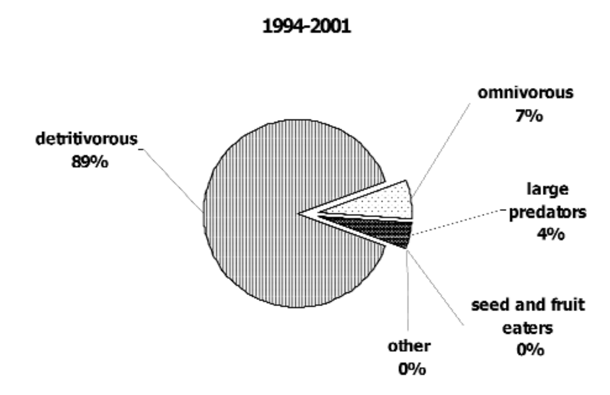


■ **Figure 11.** Structure of the catch at the main channel, upper middle Parana river (Parana-Paraguay confluence) (from Canon Veron 1992a, 1992b).

Fisheries retain several of their original characteristics in unregulated and less developed river reaches, although many changes are still evident (Figure 2, DPZ and EAS zones). For these reaches, large potamodromous fish are still present in the catch and are highly preferred by fishers, but the abundance of large piscivores is lower (Quiros 1990) and fish size at catch is noticeably smaller for most river reaches (Petrere *et al.* 2000; Quiros and Vidal 2000). Small numbers of relatively large piscivorous fish are still captured in river reaches where fisheries are highly regulated for recreation (Canon Veron 1992a, 1992b) (Figure 11). At the Parana-Paraguay confluence mesh size is usually regulated. Such management measures reserve the large piscivores for sport fishers, but they usually also lead to low fish catches with a minor proportion of the smaller omnivorous and detritivorous fishes. As in the Pantanal fisheries (Petrere *et al.* 2002), *Prochilodus* is the predominant species in these depositional river reaches. These fisheries resemble the fishery in an undeveloped river, in spite of their being controlled by very restrictive fishery regulations (Figure 10a). Still, the trophy size and large piscivores abundance have been decreasing during the last two decades at the Parana-Paraguay confluence and at the rest of the Paraguay River reaches (Paiva 1984). Fisheries for detritivorous fish stocks in some river headwaters during cyclic migrations are still important independently of development activities although some negative impact on fish is probable (Payne and Harvey 1989; Smolders *et al.* 2002).

Un-dammed but more regulated and developed lowland rivers (Figure 2, SLZ zones), may be impacted by upstream hydroelectric dams that may create unsuitable habitats for fish that are adapted to normal main channel conditions because they increase river flows during periods that were formerly low waters (Figure 5) or change flows at random (Quiros and Vidal 2000). Migratory whitefish are still the basis for fisheries (Figure 10a). Fishing pressure on the detritivorous *Prochilodus* has increased heavily at the lower depositional reaches during the last decade, as shown by a large increase in fish catches (from 10,000 t y^{-1} to

60,000 tonnes y^{-1}) and by the composition of freshwater fish exported to Brazil and other South American and African countries (Figure 12). It should be noted that, when compared with other river reaches, the detritivorous *Prochilodus* is the most abundant fish species at highly depositional zones (Bonetto, Cordiviola de Yuan, Pignalberi *et al.* 1969; Quiros and Baigun 1985). This type of fishery represents a second fishery state corresponding to a developed river with flooplains still present. The concurrent development activities can also impact negatively on fish. Several signs of environmental stress on fish assemblages have been reported for the lower basin (Quiros 1990). Changes in fish species composition in commercial landings in the lower basin have been studied by Fuentes and Quiros (1988). During the last five decades the most noticeable changes were the decrease in landings of the fruit and seed eater species *Piaractus mesopotamicus* (Holmberg), *Brycon orbignyanus* (Val.), the top predators *Paulicea lutkenii* (Steindachner) and *Salminus maxillosus* (Val.), some fish species of marine lineage and an increase in landings of the detritivorous *Prochilodus lineatus* (Holmberg) (formerly *P. platensis*) (Quiros 1990). There was also a noticeable decrease in the frequency of the top predators *Pseudoplatystoma fasciatum* (Eigenmann and Eigenmann) and *Pseudoplatystoma corruscans* (Spix and Agassiz) in landings from the lower middle Parana and Uruguay southwards to the Rio de La Plata (Quiros 1990).



■ **Figure 12.** The structure of the freshwater fish (potamodromous) exportations from the middle and lower Parana River for the 1990-2001 period (source National Authority for Fisheries, Argentina).

For the dammed and highly regulated river reaches (Figure 2, PBS zone), potamodromous fish abundance declined concomitantly with river regulation and development. Hydroelectric dams have created inappropriate habitats for migratory whitefish because they acted as barriers to crucial fish migrations. In river reaches that were transformed into a cascade of reservoirs, potamodromous white fish are absent or their abundance has drastically diminished (Figure 10b and c). The catch of potamodromous fish frequently declines well below 50 percent of the total catch. In reservoirs, fisheries are based mainly in native, floodplain-related low-value black fish and with a sizeable proportion of exotics in the catch (Petrere and Agostinho 1993; Petrere *et al.* 2002) (Table 5). Fisheries in the most recently created reservoirs may represent an intermediate state of fisheries degradation (Figure 10b), especially where open river-floodplain reaches are still present upstream (Delfino and Baigun 1991; Agostinho, Julio and Petrere 1994). However, as was stated recently by Brazilian fishery scientists, the damming of the upper Parana and a high density of human population have contributed to the reduction in fish catches and the disappearance of potamodromous fish species from the upper basin (Petrere *et al.* 2002). Reservoir fisheries in the upper basin represent a third, highly disturbed fishery state.

DISCUSSION AND CONCLUSIONS

The development of a large river basin is a dynamic process, with any form of development tending to induce both environmental change and further development. Thus, an expansion of hydroelectricity brings with it an increase in industry, agriculture, transport and settlements (Mather 1990). These in turn will result in significant increase in soil erosion, greater withdrawals of water, changes in water quality, reduced fisheries opportunities and probably need for protection of investments against hazards such as flooding. At present, this general statement is of application to Plata River Basin. However, it is difficult to assign causal relationships between river regulation and basin development and the concomitant change in fish assemblages.

The Plata River Basin is a developing river basin and each country member has distinct water related demands and requirements. Equally, each of the countries imposes pressures on the water environment and often on other countries in competition for river resources, including fishery resources. An agreement, which forms the Treaty of the La Plata Basin, was ratified by the five national states and remains in force. The main constraints to unified development and management are political. Sustainable development makes it unrealistic to consider any country in isolation and it is very necessary to be aware of country needs and impositions on basin resources in order to integrate them within the framework of a feasible multi-purpose basin management plan and to adapt this to progressive changes. The Plata Basin is not a heavily populated river basin, with population density of approximately 35 people per square kilometre. Detrimental impact on fisheries, therefore, would be expected to be more related to the industrial and agricultural development using environmentally unfriendly practices, rather than the present population density and fishing pressure. It has been reported that contamination of fish with toxicants commonly used in industry and agriculture has been on the increase during the last decade. There has been also an increase in the number of conflicts among artisanal, commercial and recreational fishers (Quiros 1993).

The Plata River Basin receives its water and nutrients from different sub-basins. This is also valid for a number of other large rivers. Floodwaters may originate on nutrient poor old Precambrian shields, or may arrive from the relatively young alpine ranges and their piedmonts. This will determine their nutrient content and sediment loads. Many fish are very much dependent on floods (Junk, Bayley and Sparks 1989; Bayley 1995) but it is highly probable that fish productivity in sedimentary river reaches may be also highly dependent on nutrient and organic matter loads (Vannote *et al.* 1980; Quiros and Baigun 1985). In order to preserve some of the pristine fish populations of large rivers, some characteristics of the flood pulse should be preserved (Bayley 1991, 1995; Quiros and Vidal 2000). Most river characteristics are lost as a result of damming. As for other large rivers, large potamodromous fish are highly vulnerable to river regulation and changing flows (Quiros and Vidal 1990, among many others). Fish abundance usually decreased in large reservoirs and fish communities change towards smaller non-migratory shorter-lived fish species. This pattern is known also for other reservoirs in the basin (Gomes and Miranda 2001). However, when catch per unit of effort (CPUE) for reservoirs in the upper basin is compared with that of an unregulated river reach in the lower basin, the difference in the total CPUE does not appear to be related to the various levels of development within the basin. The present large catches of detritivorous fish in river reaches with large floodplains can be expected to decline when further development takes place in rivers of Andean origin. To sustain a productive fishery an important part of a high-nutrient sedimentary load should be conserved.

In the lower basin, fish abundance has been historically high in depositional river reaches where floodplains are highly developed and connected (Quiros and Baigun 1985; Quiros and Cuch 1989). Fish abundance increases in river reaches the wider the floodplain as compared with the width of the main channel. However, on such floodplains the monetary value of fish is relatively low due to the high dominance of the detritivorous *Prochilodus* in catches. The opposite is true where the floodplain is narrower. There the mean annual fish abundance is lower but the catch comprises mainly larger, high valued, non-detritivorous potamodromous fish. Fisheries regulations, usually only weakly enforced throughout the basin, are more rigorously applied in the latter reaches.

Riverine fish populations usually change in response to fishing and environmental stress (Welcomme 2001). In the most developed river reaches in the Plata River Basin, potamodromous fish species declined and exotic fish species increased in relation to the total number of species taken by fisheries (Petrere *et al.* 2000). On the other hand, for the less developed reaches large potamodromous fish still dominate the fishery despite the large number of species in the system (Bonetto 1986; Agostinho *et al.* 2000). Many factors may contribute to explain changes in the species composition in fish landings under changing environments.

We have identified three main fishery states for the Plata Basin across broad temporal and spatial scales. A relatively undisturbed state corresponds to the unregulated river, when fishing effort was relatively low to moderate. Here catch is mainly dominated by high value large siluroids and characins. This state is represented by highly regulated recreational fisheries at the Pantanal and the Parana-Paraguay confluence and to a lesser extent by some of the remnant lotic reaches at the upper Parana. A second fishery state corresponds to a developed river, with floodplains disturbed by river regulation and other developmental activities. Here the fisheries are still supported by potamodromous fish but fish size at capture is usually lower. Fishing effort is usually higher, the contribution by weight to the catch of less valuable *Prochilodus* has increased and exotics are usually included in fish captures. The disturbed floodplain fishery state is represented by fisheries of most of the lower basin and at a few unregulated reaches of the upper Parana. Fisheries in riverine reservoirs represent a third, relatively highly disturbed fishery state. The catch of potamodromous fish frequently descends well below 50 percent of the total catch and fish catches are often dominated by blackfish species, less dependent on river flows and with an increasing importance of exotic fish species. Fish size is lower as well as fish value at landing. The Plata Basin fisheries represent almost all of these states at the same time in different parts of the basin.

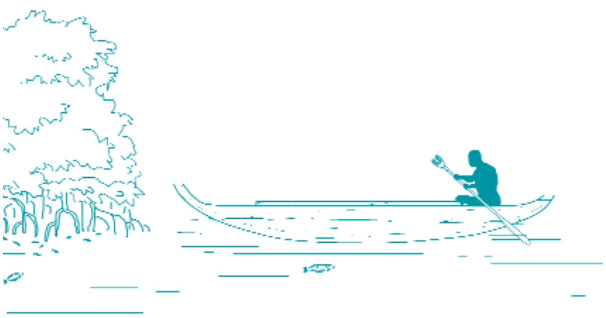
The fishing effort on the Brazilian territory is usually higher than in other countries of the basin (Petrere and Agostinho 1993; Espinach Ros and Delfino 1993), but the lower Plata River Basin is one of the few sites worldwide that exports freshwater fish from capture fisheries. Riverine fish exports (mainly *Prochilodus*) to other South American and African countries have been increasing during the last decade, but fish quality is more than doubtful.

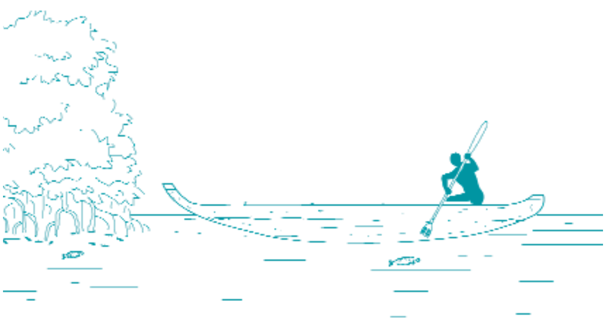
Many fish species inhabiting large river-floodplain systems have two distinct centers of concentration and fish migrate between the two (Welcomme 1985). Because large potamodromous fish need to migrate relatively long distances by main channels to complete their life cycles, these fish species are highly vulnerable in front of river dams. Despite river regulation, potamodromous fish retain their migration patterns evolved in pristine riverine systems (Quiros and Vidal 2000). Therefore, both untimely changes in flood pulse intensity and changes in flood pulse variability will be expected also to affect adversely potamodromous fish populations in open river reaches situated downstream from regulated river sections. As for other large rivers, periodic fluctuations in the abundance of fish is displayed for non-dammed river reaches especially in relation to past flood events (Quiros and Cuch 1989; Smolders *et al*. 2002).

A modification of discharge pattern is generally detrimental to fish production, which is highly dependent on seasonal inundation of floodplains for breeding and feeding. The regulated nature of the system initially led us to expect negative effects on landings in the lower basin; instead we have found that total fish catch per unit area was almost constant for the 1945-1984 period (Quiros and Cuch 1989). However, industrial “macropollution variables” have had a negative impact on commercial landings for most species (Quiros 1990). On the other hand, moderate enrichment with organic substances in a less variable environment can increase the carrying capacity for detritivorous and bentophagous fish. In conclusion: changes in fish assemblage composition and other signs of environmental stress on fish assemblages appear to be in agreement with a regulated river-floodplain system impacted by toxic substances used in agriculture and industry and lead us to conclude that Plata River Basin fisheries are from lightly to highly affected by development activities, depending principally on development intensity upstream.

ACKNOWLEDGEMENTS

R. Quiros acknowledges research support from the Consejo Nacional de Investigaciones Cientificas y Tecnologicas (CONICET). I also thank Maria Boveri for insightful comments and Hugo T. von Bernard for technical assistance.





REFERENCES

Agostinho A.A. & Julio Jr. H.F. 1999. Peixes da Bacia do Alto Rio Parana. *In* R.H. Lowe-McConnell, eds. *Estudos ecológicos de comunidades de peixes tropicais*. Editora da Universidade de Sao Paulo, Sao Paulo, Brasil. pp. 374-400.

Agostinho A.A., Julio Jr. H.F. & Petrere Jr. M. 1994. Itaipu reservoir Brazil: Impacts of the impoundment on the fish fauna and fisheries. *In* I.G. Cowx, ed. *Rehabilitation of freshwater fisheries*. Fishing News Books. Bondman, UK. pp. 171-184.

Agostinho A.A., Thomaz S.M., Minte-Vera C.V. & Winemiller K.O. 2000. Biodiversity in the High Parana River floodplain. *In* B. Gopa, W.J. Junk & J.A. Davis, eds. *Biodiversity in wetlands: Assessment, function and conservation, volume I.* Leiden, The Netherlands, Backhuys Publishers. pp. 89-118.

Andreoli C.V. 1993. The influence of agriculture on water quality. Prevention of water pollution by agriculture and related activities. *Proceedings of the FAO Expert Consultation*. Santiago, Chile, 20-23 October 1992. Water Reports 1. pp. 53-65.

Angelini N., Seigneur G. & Atanasiadis A.V. 1992. Investigacion de residuos de sustancias organocloradas en peces del rio Uruguay. Publicaciones de la Comision Administradora del Rio Uruguay CARU. *Serie Tecnico-Cientifica No. 1*. pp. 36-42.

Barberis J.A. 1990. La cuenca del Rio de La Plata. *In River and lake basin development. Proceedings of UN interregional meeting on river and lake basin development with emphasis on the Africa region*. Addis Ababa, Ethiopia, 10-15 October 1988. New York, United Nations. 428 pp.

Bayley P.B. 1973. Studies on the migratory characin, *Prochilodus platensis* Holmberg 1988 Pisces, Characoidei in the River Pilcomayo, South America. *Journal of Fish Biology*, 5: 25-40.

Bayley P.B. 1991. The flood pulse advantage and the restoration of river-floodplain systems. *Regulated Rivers: Research & Management*, 6: 75-86.

Bayley P.B. 1995. Understanding large river-floodplain ecosystems. *BioScience*, 45: 153-158.

Bonetto A.A. 1975. Hydrologic regime of the Parana River and its influence on ecosystems. *Ecological Studies*, 10: 175-197.

Bonetto A.A. 1976. Calidad de las aguas del rio Parana. Introduccion a su estudio ecologico. Buenos Aires, Direccion Nacional de Construcciones Portuarias y Vias Navegables. 202 pp.

Bonetto A.A. 1986. The Parana River system. *In* B.R. Davies & K.F. Walker, eds. *The ecology of river systems*. Rotterdam, The Netherlands, Dr. Junk Publications. pp. 541-556.

Bonetto A.A., Cordiviola de Yuan E., Pignalberi C. & Oliveros O. 1969. Ciclos hidrológicos del rio Parana y las poblaciones de peces contenidas en las cuencas temporarias de su valle de inundación. *Physis Buenos Aires*, 29: 213-224.

Canon Veron M.B. 1992a. Pesca comercial en el rio Parana Corrientes, Argentina durante el periodo 1985-1988. *Ambiente Subtropical*, 2: 103-123.

Canon Veron M.B. 1992b. La pesca comercial en el rio Parana Chaco, Argentina. *Ambiente Subtropical*, 2: 125-149.

CIC. 1993. Reunion de Contrapartes Tecnicas de Calidad de Aguas y Alerta Hidrologico. Abril, 1993. Comite Inter-gubernamental Coordinador de los Paises de la Cuenca del Plata. 39 pp.

Delfino R. & Baigun C. 1991. Comunidad de peces del embalse de Salto Grande. *In* Vila, I. eds. *Trabajos presentados al Segundo Taller Internacional sobre Ecologia y Manejo de Peces en Lagos y Embalses*. Santiago, Chile, 28 septiembre - 3 octubre 1987. COPESCAL Doc. Tec. 9. pp. 7-30.

De Godoy M.P. 1967. Dez anos de observacoes sobre periodicidade migratoria de peixes do Rio Mogi Guassu. *Revista Brasileira de Biolologia*, 27: 1-12.

Espinach Ros A. & Delfino R. 1993. Las pesquerias de la Cuenca del Plata en Bolivia, Paraguay, Argentina y Uruguay. *In* COPESCAL, eds. *Informe de la Sexta Reunion del Grupo de Trabajo sobre Recursos Pesqueros*. Montevideo, Uruguay, 10-13 de mayo de 1993. FAO Informe de Pesca 490. Roma, FAO. pp. 36-51.

Ferraz de Lima J.A. 1987. A pesca no Pantanal do Mato Grosso rio Cuiaba: Importancia do peixes migradores. *Acta Amazonica*, 16/17: 87-94.

Fuentes C.M. & Quiros R. 1988. Variacion de la composicion de la captura de peces en el rio Parana, durante el periodo 1941-1984. Instituto Nacional de Investigacion y Desarrollo Pesquero. Mar del Plata, Argentina. *Serie Informes Tecnicos del Departamento de Aguas Continentales*, 6: 78 pp.

Gomes L.C. & Miranda L.E. 2001. Riverine characteristics dictate composition of fish assemblages and limit fisheries in reservoirs of the upper Parana River Basin. *Regulated Rivers: Research and Management*, 17: 67-76.

IMW 1993. *The international mussel watch. A global assessment of environmental levels of chemical contaminants. Initial Implementation Phase. Draft Final Report, March 1993.* Coastal Research Center, Woods Hole Oceanographic Institution.

Junk W., Bayley P. & Sparks R. 1989. The flood pulse concept in river-floodplain systems basin. *In* D.P. Dodge ed. *Proceedings of the international large rivers symposium. Can Spec. Publ. Fish. Aquat. Sci.*, 10: 110-127.

Maglianesi R.E. 1973. Principales caracteristicas quimicas y fisicas de las aguas del Alto Parana y Paraguay Inferior. *Physis Buenos Aires*, 32: 185-197.

Mather T.H. 1990. Planificacion y ordenacion del aprovechamiento y la conservacion de cuencas fluviales y lacustres. River and lake basin development. *Proceedings of an interregional meeting on river and lake basin development with emphasis on the Africa Region.* Addis Ababa, Ethiopia, 10-15 October 1988. New York, United Nations. pp. 126-155.

Paiva M.P. 1984. Aproveitamento de recursos faunisticos do Pantanal do Matto Grosso: pesquisas necessarias e desenvolvimento de sistemas de producao mais adequados a regiao. *Empresa Brasileira de Pesquisa Agropecuaria EMBRAPA. Documentos 7*. Brasilia, Brasil. 71 pp.

Payne A.I. & Harvey M.J. 1989. An assessment of the *Prochilodus platensis* Holmberg population in the Pilcomayo River using scale-based and computer-assisted methods. *Aquaculture and Fisheries Management*, 20: 248-253.

Petrere Jr. M. & Agostinho A.A. 1993. La pesca en el tramo brasileño del rio Parana. *In* COPESCAL, eds. *Informe de la Sexta Reunion del Grupo de Trabajo sobre Recursos Pesqueros*. Montevideo, Uruguay, 10-13 de mayo de 1993. FAO Informe de Pesca 490. Roma, FAO. pp. 52-72.

Petrere Jr. M., Agostinho A.A., Okada E.K. & Julio Jr. H.F. 2002. Review of the fisheries in the Parana/Pantanal Basin. *In* I.G. Cowx, ed. *Management and ecology of lake and reservoir fisheries*. Oxford, UK, Blackwell Science. New Fishing Books, Blackwell. pp. 123-143.

Quiros R. 1990. The Parana River Basin development and the changes in the lower basin fisheries. *Interciencia*, 15: 442-451.

Quiros R. 1993. Inland fisheries under constraints by other uses of land and water resources in Argentina. *In Prevention of Water Pollution by Agriculture and Related Activities. Proceedings of the FAO Expert Consultation*. Santiago, Chile, 20-23 October 1992. Water Reports 1. pp. 29-44.

Quiros R. & Baigun C. 1985. Fish abundance related to organic matter in the La Plata River Basin, South America. *Transactions of the American Fisheries Society*, 114: 377-387.

Quiros R. & Cuch S. 1989. The fisheries and limnology of the lower La Plata Basin. *In D.P. Dodge*, ed. *Proceedings of the international large rivers symposium*. *Can. Spec. Publ. Fish. Aquat. Sci.*, 106: pp. 429-443.

Quiros R. & J.C. Vidal. 2000. The cyclic behavior of potamodromous fishes in large rivers. *In* I.G. Cowx, ed. *Management and Ecology of River Fisheries*. Oxford, UK, Blackwell Science. New Fishing Books. Blackwell. pp. 71-86.

Smolders A.J.P., Guerrero Hiza M.A., van der Velde G. & Roelofs J.G.M. 2002. Dynamics of discharge, sediment transport, heavy metal pollution and sabalo *Prochilodus lineatus* catches in the lower Pilcomayo river Bolivia. *River Research and Applications*, 18: 415-427.

Tundisi J.G. 1981. Typology of reservoirs in Southern Brasil. *Verh. Internat. Verein. Limnol.*, 21: 1031-1039.

Tundisi J.G., Matsumura Tundisi T., Calijuri M.C. & Novo E.M.L. 1991. Comparative limnology of five reservoirs in the middle Tiete River, S. Paulo State. *Verh. Internat. Verein. Limnol.*, 24: 1489-1496.

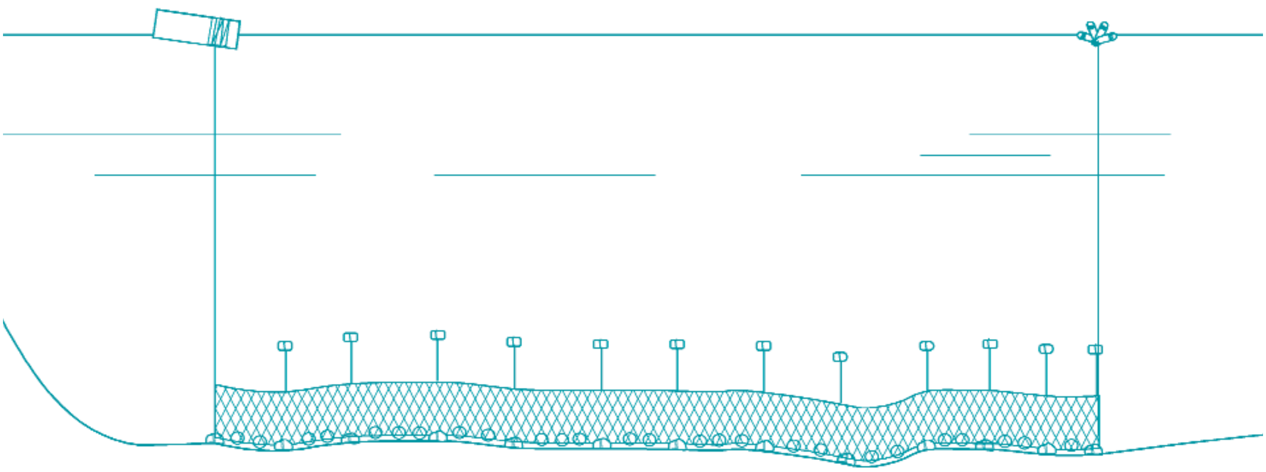
UN. 1990. River and lake basin development. *Proceedings of UN interregional meeting on river and lake basin development with emphasis on the Africa region*. Addis Ababa, Ethiopia, 10-15 October 1988. New York, United Nations. 428 pp.

Vannote R.L., Minshall G.W., Cummins K.W., Sedell J.R. & Cushing C.E. 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences*, 37: 130-137.

Welcomme R.L. 1985. *River fisheries*. FAO Fisheries Technical Paper 262. 330 pp.

Welcomme R.L. 2001. *Inland fisheries: Ecology and management.* Oxford, UK, Blackwell Science, New Fishing Books, Blackwell. 358 pp.

Welcomme R.L., Ryder R.A. & Sedell J.A. 1989. Dynamics of fish assemblages in river systems - a synthesis. In D.P. Dodge, ed. Proceedings of the international large rivers symposium, Can. J. Fish. Aquat. Sci. Spec. Publ., 106: 569-577.



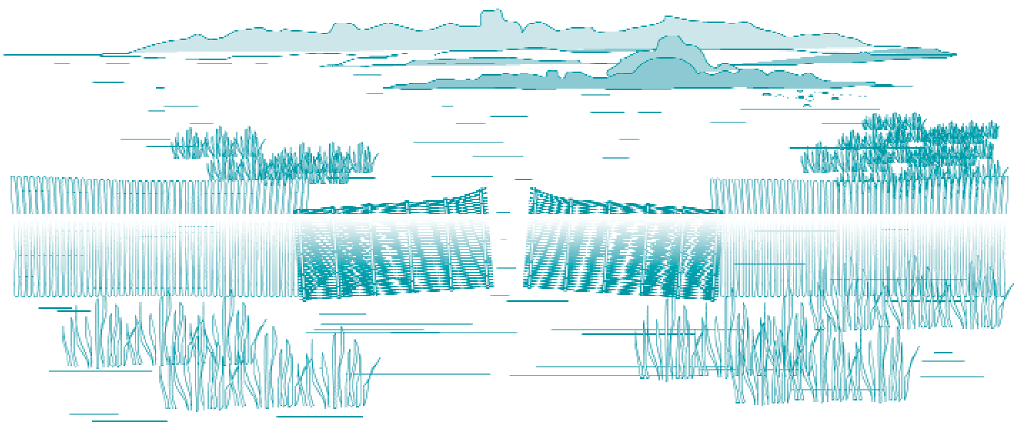
ECOLOGICAL STATUS AND PROBLEMS OF THE DANUBE RIVER AND ITS FISH FAUNA: A REVIEW

F. Schiemer[1] G. Guti[2] H. Keckeis[1] M. Staras[3]

[1] Inst. of Ecology and Nature Conservation, Dept. Limnology, Univ. Vienna, A-1090 Vienna, Althanstr. 14, Austria

[2] Hungarian Danube Research Station, Hungarian Academy of Sciences, H-2131 Göd, Jávorka U. 14, Hungary

[3] Danube Delta Research Institute, Babdag Str. 165, RO-8800 Tulcea, Romania



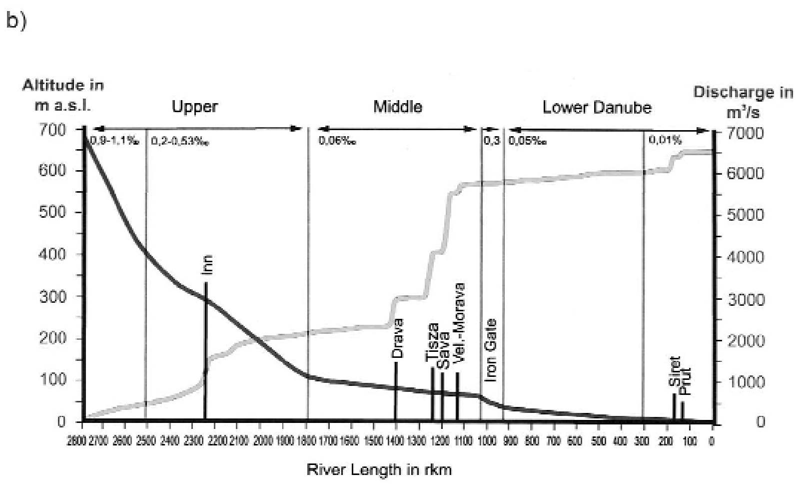
ABSTRACT

The ecological status of the Danube River and its fisheries prior to 1988 has been summarised by Bacalbasa-Dobrovici (1989) for the first International Large River Symposium. Since then the situation has changed in many ways: the trends of river–floodplain disintegration initiated by the major river regulation schemes in the nineteenth and early twentieth centuries accelerated. Moreover, further hydropower dams were built along the course of the river and its major tributaries, further reducing the ecological integrity of the river-floodplain systems in several stretches. On the other hand, a number of mitigation schemes were initiated e.g. in Austria, Hungary and Romania in order to compensate for the continuing losses of riverine landscapes. The measures taken to control water pollution were partially successful and water quality along the river has shown a general improvement. The overall deterioration of riverine habitats due to pollution, river engineering and land use is reflected in the high number of endangered fish taxa. The main cause for the decline of many species is the continuing loss of riverine littoral habitats due to river engineering Therefore the main focus of river management in several of the riparian countries is on the conservation of riverine biota, a stronger incorporation of ecological aspects in river engineering and the development of restoration programmes. Several

international schemes have been proposed to undertake concerted action to improve the overall situation. There is a sound scientific basis for ecologically orientated river management along the Danube: over the past 20 years, environmental conditions, fish ecology and fisheries have been intensively studied at several research institutions by means of large-scale field surveys and experimental studies. These results allow the present ecological status to be redefined. New concepts for commercial and recreational fisheries as well as floodplain restoration were developed. The present contribution synthesises recent developments in fish ecology and fisheries of the Danube and concentrates on key management issues.

THE DANUBE: ITS CATCHMENT, GEOGRAPHY AND HYDROGRAPHY

The Danube flows over nearly 3 000 km from the Black Forest to its delta in the Black Sea, passing through Europe from west to east. It is an international river, flowing through nine countries – Germany, Austria, Slovakia, Hungary, Croatia, Serbia and Montenegro, Bulgaria, Romania and the Ukraine (Figure 1). Thus, the river connects the West, Central and East European countries. The Danube Basin can be divided into three regions. The Upper Danube extends from the Black Forest to the Devin Gate below Vienna, the Middle Danube from the Devin Gate to the Iron Gate where it passes in the Southern Carpatians and the Balkan Mountains and finally the Lower Danube through the Romanian and Bulgarian lowlands. The Danube Delta at the Black Sea is the second largest in Europe with an area of 5 640 km^2. The Upper Danube (Figure 1) is characterized by a steep gradient of 0.2-1.1‰, the Middle and Lower Danube by a low gradient, except for the cataracts of Iron Gate (Laszloffy 1967; Liepolt 1967).



■ ***Figure 1.*** a) The Danube River basin
b) Longitudinal profile of the slope (indicated are the main differences in slope) and the mean discharge (from: Waterway transport on Europe's lifeline, WWF, Vienna, 2002).

With a mean discharge of about 6 500 $m^3 s^{-1}$ at its mouth the Danube is the second largest river in Europe and twenty-first in the world. The hydrological regime of the upper region is characterized by high runoff from the Alps. The main Alpine tributaries are the Lech, Isar and Inn. Maximum discharge rates in this zone are due to the runoff from snowmelt in the Alps between May to August. Increases in discharge to the Middle Danube come mainly from the Save (46.6 percent), Tisza (34 percent) and Drava (29 percent). Below the Tisza and Save there is a characteristic change in the seasonal runoff pattern, with a maximum in April and May and low discharge rates from August to January (Benedek and Laszlo1980; Hock and Kovacs 1987). The Danube exhibits high water level fluctuations in the range of several meters; for example in Mohacs (Hungary) fluctuations exceed 9 m. Large alluvial areas with extensive floodplains exist in unconstrained sections (Tockner, Schiemer and Ward 1998; Tockner *et al*. 2000). The width of the present inundation area downstream of Vienna and in the middle basin varies between 1 and 5 km, in the lower basin between 5 and 10 km.

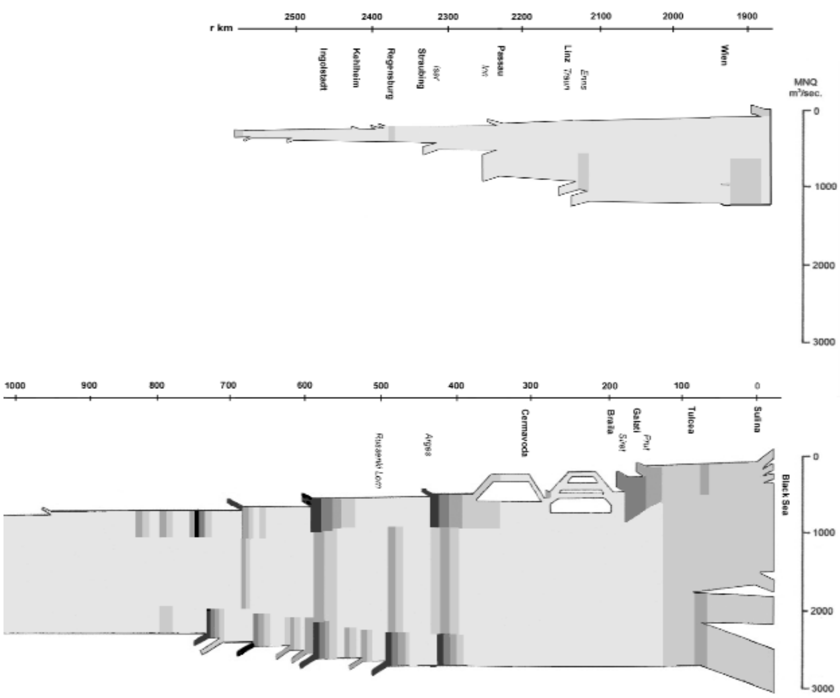
The multi-purpose use of the river is of vital importance for the more than 82 million people inhabiting its 800 000 km^2 basin. The use of the catchment and the river itself has had strong impacts on the environmental conditions of the river-floodplain system (Khaiter *et al*. 2000; Bloesch 1999, 2001).

HUMAN IMPACTS: WATER QUALITY AND RIVER ENGINEERING

Water Quality

Water pollution caused by the high population density and heavy industrialization in the drainage area is a major problem of the Danube. The first and very provisional attempt to map the water quality was made in a monograph on the Danube (Liepolt 1967). More recently Schmid (2000) has given an overview on the Danube and its tributaries.

Between the 1950s to1970s low water quality was found downstream of cities and industrial zones in Germany and Austria. The worst pollution was recognized below industrial centres in Kelheim, Regensburg, Linz and Vienna (quality class III-IV), where pollution temporarily reached class IV (polysaprobity). The self-purification capacity of the Danube during this period had decreased considerably due to toxic effects of industrial wastewaters. Some susceptible fish species in the Upper Danube, such as *Cottus gobio* and *Phoxinus phoxinus*, became rare or disappeared from the main channel of the Danube.



■ ***Figure 2.*** *Water quality along the Danube. Indicated are the river kilometres, major cities and tributaries. The width is given according to the mean flow. The colour code for water saprobity was transferred to a scale of shading: II: opaque, II-III: light gray, III: gray,III-IV: dark gray, IV: black (from Wachs 1997).*

Construction of water purification stations at the beginning of the 1980s considerably improved the water quality almost to the goal of class II (Wachs 1997) and the fish species, which had disappeared from some river segments, re-established themselves (Figure 2).

The water quality situation in the Lower Danube was quite different. Very little information is available for the period 1950 to1975 for the lower section of Middle Danube and for the Lower Danube. Large stretches were considered to have an acceptable water quality of class II due to high dilution. Russev (1979) reviewed the status of water quality and recognized a general and clear trend of water quality deterioration, with low water quality below larger cities. The worst conditions (polysaprobity, IV) were below industrial centres along the whole river course. The pollution remains very serious due to industrial growth and insufficient pollution control measures. The impact of strongly polluted tributaries, e.g. in Romania and Bulgaria the Lom (IV), Ogosta (IV), Olt (IV), Osam (IV), Russenski Lom (IV), can be identified in short stretches of Danube (Figure 2). High flow and self-purification of the Danube improve the situation downstream to saprobity classes II-III.

With regard to heavy metals the situation in the Lower Danube is serious. Concentrations of some of the elements are nearly two orders of magnitude higher compared to the upstream regions. The TNMN (transnational monitoring network) (TNMN-Yearbook of 1998, 2000) assessment in 1998 gave a range of dissolved elements between 0.01-0.1 $\mu g\ l^{-1}$ for cadmium (Cd) in the upper and middle section and 0.9-1.5 $\mu g\ l^{-1}$ below the Iron Gate. The values for lead (Pb) were 0.8-1.2 $\mu g\ l^{-1}$ versus 20-40 $\mu g\ l^{-1}$. Chromium and copper concentrations are also elevated in the Lower Danube. The report of the "Joint Danube Survey" in 2001 shows the spatial distribution of selected elements in suspended solids and sediments along the river course. The report indicates particularly serious pollution in the lower sections of the river, downstream of Novi Sad (Joint Danube Survey-Technical Report of the ICPDR, 2002). Wachs (2000) studied the heavy metal contamination in the water suspended matter, fine sediments and fish in the Upper, Middle and Lower Danube. He concluded that there is a general increase in the lower section, which is reflected most clearly in cadmium and mercury (Hg). Using his evaluation scheme (Wachs 1998) found "very heavy pollution" levels (III-IV) and excessive pollution levels (IV) and higher concentrations of Cd, Cr, Cu, Hg and Zn in the lower reaches.

A harmonized sampling network has been developed recently. The International Commission for the Protection of the Danube River, (ICPDR) established in 1998, is instrumental in successful monitoring of the Danube River System. The International Association coordinated earlier, hydro-biological studies and water quality assessments for Danube Research (IAD), founded in 1956 within the International Association of Theoretical and Applied Limnology (Bloesch 1999).

River Regulation and Construction of Hydropower Dams

The key environmental issues of the Danube, as in other large European and North American rivers (Stanford *et al.*1996) result from effects of regulation and engineering. The morphological changes caused by engineering measures, although very serious, have been smaller on the Danube than on the Rhine or the Rhone (Bloesch 2002; Bloesch and Sieber 2003).

In the Upper Danube, including Slovakia and Hungary, the process of intensive engineering began in the nineteenth century with the goal of improving navigation, flood control and drainage of riverine wetlands for agriculture. In Austria, for example, the regulation of the Danube started in 1875. The main engineering approach was to create a single, straightened channel, stabilized by riverside embankments and rip-raps (Figure 3). The former side-arms of the original braided system were cut off. Weirs had to be built on the side arms in order to retain the water level in the wetlands. Levees completely cut off parts of the former floodplains from erosive, scouring flood flow. These measures resulted in major changes in the river profile, slopes, transport of bed sediments and suspended load and runoff characteristics (Schiemer 1999). The immediate effects were:

a) Enormous loss of inshore habitat, large floodplain areas and flood retention capacity
b) Reduced hydrological connectivity between river and floodplains and reduced geomorphic processes
c) Concentration of erosive forces in the main channel and consequently a deepening of the river bed
d) Shortening of the river course (for example in Hungary from an original length of 472 km to 417 km, i.e. by nearly 15 percent)

River regulation initiated trends which are still continuing: a lowering of the water table, combined with sedimentation and conversion of floodplains to dry land leading to permanent changes and a loss of aquatic habitat. Deepening of the Danube riverbed has been observed in the last two decades. In the free-flowing Austrian and the Slovakian part the water level at average discharge rate (MQ) has decreased by 1 to 2 m over the past 50 years as a result of reduced bed load transport (due to upstream dams), higher erosion in the channelized river and large-scale dredging to maintain a waterway for shipping. The deepening of the channel in relation to the floodplain areas and the inflows into side channels has considerably affected the timing and volume of the amount of water entering the side arms and floodplain. In some years and seasons, some of these arms dried up completely and this part of the floodplain was not flooded. However, in spite of the effects of river regulation, the remaining parts of the floodplain were still subjected to the rhythmical pulses of the floods and its fish stocks and catch responded to the hydrological regime (Holcik and Bastl 1976; Holcik 1996).

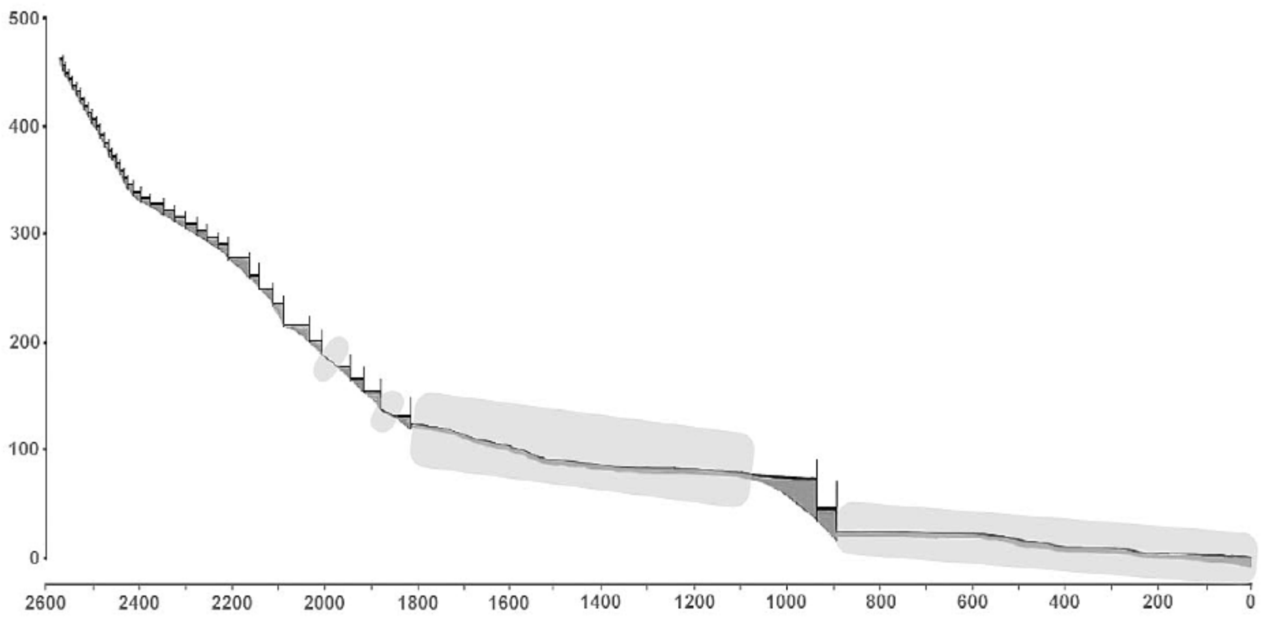
■ **Figure 3.** The Danube regulation at Vienna. The figure shows the braided network of channels and the engineered channel. The river regulation started in 1875.

A major environmental concern is related to the construction of hydropower dams. The Danube has a high potential for hydropower generation that has been largely exploited. Forty-nine base-load hydroelectric power dams are situated in the Upper Danube and three major barrages in the Middle Danube (Gabcikovo, Iron Gate 1 and 2). Figure 4 shows the position of the dams along the whole river course. The construction of impoundments results in severe environmental degradation due to the:

- Loss of ecological diversity
- Destruction of the former shoreline
- Lack of connectivity between the river and the groundwater table
- Almost complete lack of connectivity between the river and its floodplain due to side dams
- Change of the alluvial forests to dry deciduous forests, with a concomitant loss of terrestrial diversity

The impoundments have a short retention time and low water temperature (Schiemer and Waidbacher 1992).

Between 1978 and 1992 a major power plant was constructed below Bratislava in Slovakia (Gabcíkovo River Barrage System, GRBS) with considerable negative environmental impact despite warnings about possible environmental effects (Holcik *et al*. 1981). After the construction of the GRBS and its operational introduction in October 1992 the former ecosystem of the inland delta was replaced by an artificial system of more or less isolated habitats (Lösing 1989; Holcik 1990, 1998; Balon and Holcik 1999). The dam has had a major impact on the floodplains on the Hungarian side (Szigitöz area) (Guti 1993). After the damming of the Danube in 1992, most of the water from the storage reservoir has been diverted through its aboveground level concrete canal along the left-hand side of a river dyke to the Gabcikovo hydroelectric power station. The old riverbed of the Danube is now receiving 250-600 $m^3\ s^{-1}$ instead of the former 2 000 $m^3\ s^{-1}$. Due to this the water level of the old Danube is 3-5 m below the level of the former floodplain and the contact between the side arms and the Danube is interrupted. The remaining northern (Slovakian) side arm system is supplied with up to 240 $m^3\ s^{-1}$. A fish pass built



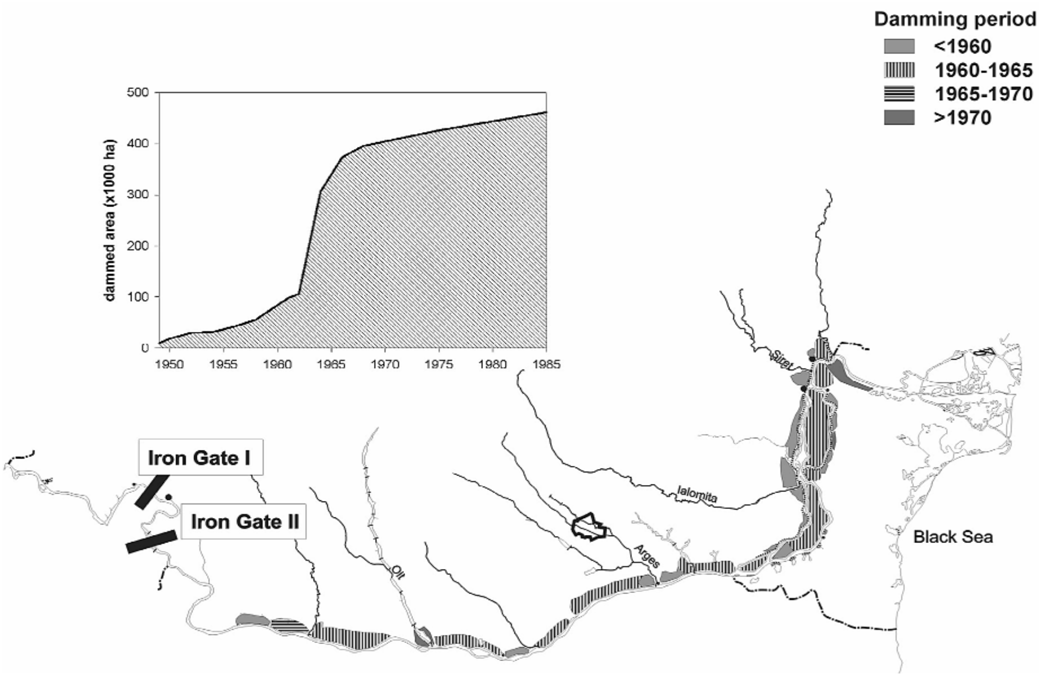
■ **Figure 4.** The position of dams along the river course. The free-flowing sections are shaded.

between the old riverbed and the lower part of the side-arm system does not function well. There is no longer any natural pulse flooding of the inland delta. While the former floodplain has been artificially flooded several times, this did not simulate the natural floods, as the level, timing and duration were different from the natural floods.

On the Lower Danube the construction of barrages Iron Gate I at km 942.5 in 1970 and Iron Gate II at km 863 in 1984 has interrupted longitudinal connectivity of the river and resulted in a physical separation from the Middle Danube. The impoundments have had major consequences with regard to the downstream diurnal flow regime and the transport of suspended sediments and bed load (Bondar 1994). The daily water level variation in the Bulgarian and Romanian can be as high as 1 m day^{-1} and variation in water discharge 1 000 m^{3} s^{-1} day^{-1} (Buijs, Uzunov and Tzankov 1992). The sediment transport from the Middle Danube has been reduced, while downstream mean annual erosion in the Romanian and Bulgarian sections has increased. The transport of sediments into the delta was reduced from 67.5 million tonnes year^{-1} in the period 1921 to 1960 to 52 million tonnes year^{-1} in the period 1981-1983 (Bondar 1994).

In this respect the “silicon hypothesis” advocates that the flux of silicon to the Black Sea is considerably reduced due to diatom blooms occurring in the reservoirs. This has led to an overall decrease in silicon concentrations in coastal waters in the Black Sea (Milliman 1997; Ittekkot, Humborg and Schafer 2000). The resulting changes in the ratios of nutrients, e.g. Si:N:P cause a shift in phytoplankton populations.

The separation of the river from its floodplain by side levees in the lower Danube had a major impact on the overall environmental situation and fisheries. This took place upstream of the delta at the end of the 1950s. The former flood pulse was reduced and as a consequence the former inundation areas were also strongly reduced (Figure 5): of the 5 000 km^{2} of the former floodplain only 15 percent is still being temporarily flooded. In 1921 the ratio river length (km): floodplain (ha) was 1:612. This was reduced to 1:118 in 1976 (Bacalbasa-Dobrovici 1989). The water retention capacity at floods was reduced from about 15.6 10^{9} m^{3} to 4.0 10^{9} m^{3}· The water level in the Danube increased by 0.6-0.8 m at maximum discharge of 13 000-15 000 m^{3} s^{-1} (Bondar 1977).



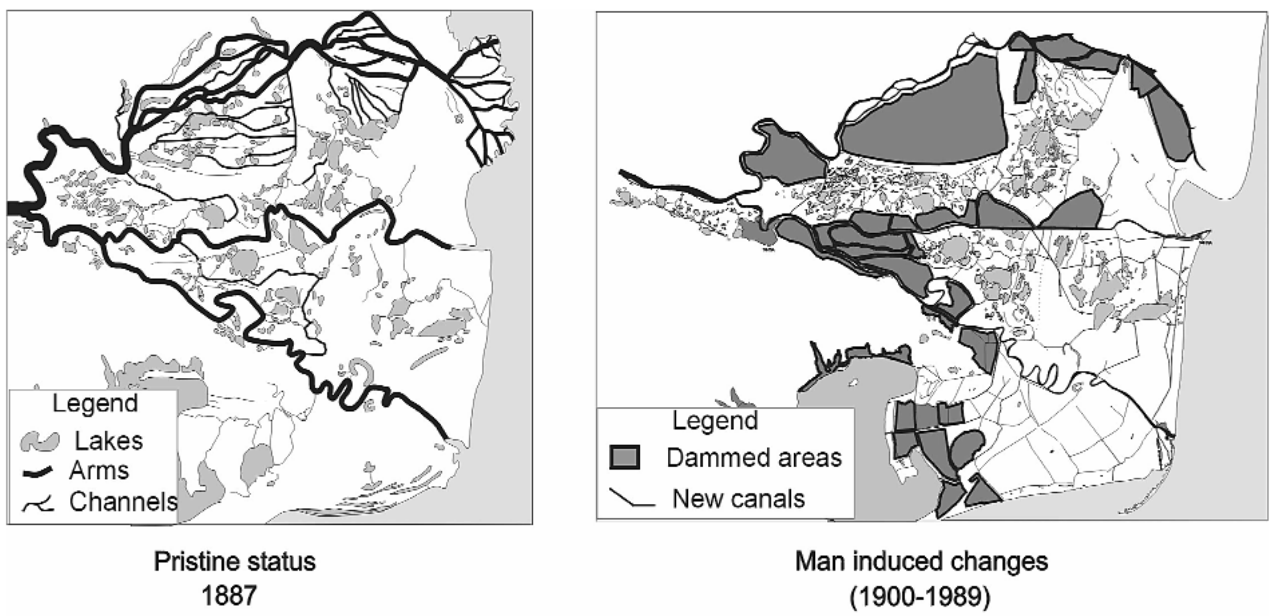
■ **Figure 5.** Disconnection of floodplains in Romania due to the construction of levees. The insert quantifies the increase in dammed area with time.

The Danube Delta including adjacent oxbow lakes and lagoons covers some 5 640 km^3 (about 20 percent in the Ukraine, 80 percent in Romania). Major changes took place between 1960-1989, when 1 000 km^3 were poldered in the Romanian part for agriculture, forestry and fish culture. The fluvial backwaters in the Ukraine have been isolated from the river for aquaculture since the 1960s, whereas the frontal marine lagoons in the Romanian and Ukraine parts were isolated from the sea and used as a reservoir for irrigation purposes after the 1970s (Figure 6). The total length of the channels in the Romanian Delta increased from 1 743 km to 3 496 km (Gastescu, Driga and Anghel 1983). The water discharge from the river to the delta wetlands increased from 167 $m^3 s^{-1}$ before 1900 to 309 $m^3 s^{-1}$ during 1921-1950; 358 $m^3 s^{-1}$ during 1971-1980 and 620 $m^3 s^{-1}$ during 1980-1989 (Bondar 1994). Despite these engineering measures over 3 000 km^2 of the wetlands, including the Razim-Sinoie lagoon and the adjacent Ukrainian secondary delta (250 km^2), remain connected to the river and represent the largest nearly undisturbed wetland in Europe. About 50 percent of the area is permanently aquatic; the rest is seasonally flooded.

BIODIVERSITY OF FISH

Large rivers and their riparian zones are hot spots of biodiversity. Biodiversity levels can be compared across a range of scales e.g. from whole river systems to river segments, lateral and longitudinal gradients within a floodplain, down to the level of single habitat types (Ward, Tockner and Schiemer 1999). Fluvial geomorphic processes provide the habitat diversity and the specific habitat conditions for characteristic species assemblages and result in high levels of habitat diversity, local species richness and differences between habitats and consequently, overall species richness of a river section.

The fish fauna of the Danube is well known from historical studies (Marsilius 1726; Heckel and Kner 1858). The total number of fish species along the whole course is in the order of 100 species. The generally high diversity is due to the zoogeographical significance of the Danube as a major migration route for a diverse Central Asian and Ponto-Caspian fauna (Balon, Crawford and Lelek 1986). From an ecological point of view, this diversity is due to rhithral conditions in most of the Upper Danube and potamal condi-



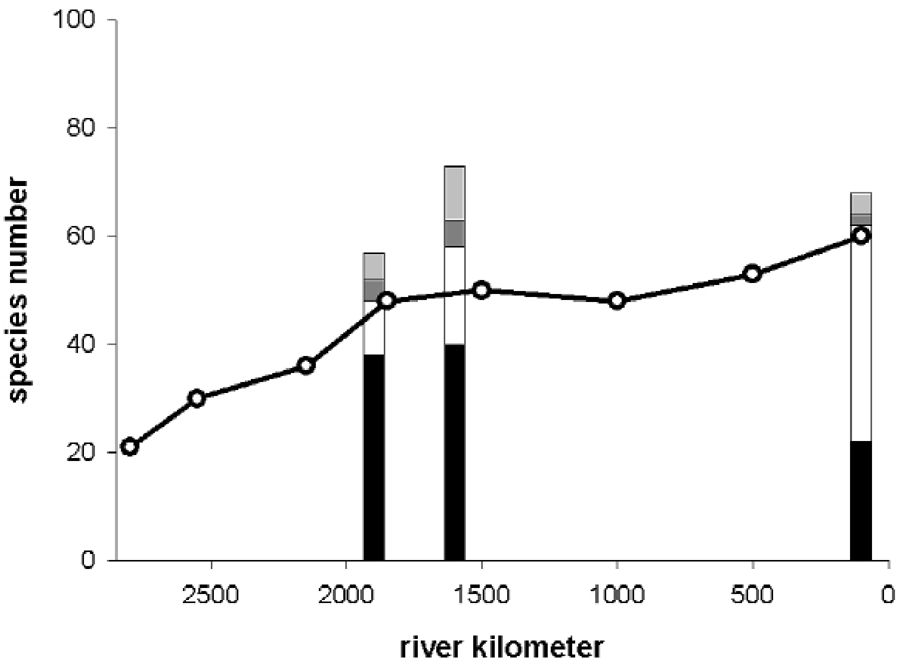
■ **Figure 6.** Loss of floodplain habitat in the Danube Delta during the last century due to polder construction compared to its pristine status.

tions in alluvial zones with extended floodplains and rich habitat downstream from Austria.

Balon (1964) provided an overview of the distribution pattern of individual species along the river course. The longitudinal distribution of species (Figure 7, solid line) is based on his list. Diversity increases in the Upper Danube from the rhithral sections downstream to the extended alluvial plains in Austria. Highest diversity is found in the transition zone between foothills and lowlands, where the gradient change results in an extended braided network of numerous side arms of the Danube. High habitat diversity and the dense ecotonal structure have created the diverse combinations of environmental conditions suitable for the assembly of different fish species (Schiemer 2002; Ward *et al*. 1999). Further downstream in the Middle and Lower Danube species numbers remain fairly constant. In the lowest section in Romania diversity increases again due to invaders from marine and brackish water habitats. The recent status of the fish fauna in Austria, Hungary and Romania is presented as histograms (Figure 7). Table 1 provides species lists from the Danube in these countries with comments on the status of individual species. Information is given on whether a species is a recent immigrant, or an exotic form. The status of endangerment distinguishes if a species is extinct (EX), critically endangered (CE: population strongly declining, habitat deficiencies extremely severe, near extinction), endangered (E) or vulnerable (VU: declining population, fragmented populations). For several species the existing data are deficient (DD). The state of endangerment is discussed below. Comments are made on recent immigrants and exotic species.

Immigrants

During the last 10 years a number of new fish species have been recorded upstream and downstream of the Devin Gate, apparently immigrants from brackish water. Until 1990 in the Upper and Middle Danube the gobiids were represented only by the tube-nosed goby *Proterorhinus marmoratus*. In 1994 *Neogobius kessleri* was discovered in the Upper Danube. More recently three further species, *N. gymnotrachelus*, *N. melanostomus* and *N. fluviatilis*, were discovered



■ **Figure 7.** Biodiversity of fish of the Danube and the floodplains along the river course. The line gives species numbers according to the review of Balon (1964). the histograms give the present status of the Danubian fish fauna in Austria, Hungary and Romania according to Table 1. Black: endangered; white: not endangered; dark grey: immigrants; light grey: introduced species.

Table 1: Comparison of the present state of the fish fauna of the Danube in Austria, Hungary and Romania. Occ.= Occurrence, Cat.= Category: EX = extinct; exotic; Imm. = Immigrants; CE = critically endangered; E = endangered; VU = vulner-able; DD = data deficient

	Austria		Hungary		Romania	
SPECIES	Occ	CAT	Occ	CAT	Occ	CAT
Eudontomyzon mariae (Berg, 1931)			+	E	+	
Acipenser gueldenstaedtii Brandt & Ratzeburg, 1833		EX		EX[1]	+	CE
Acipenser huso Linnaeus, 1758		EX		EX[2]	+	CE
Acipenser nudiventris Lovetzky, 1828		EX		EX[3]		EX
Acipenser ruthenus Linnaeus, 1758	+	CE	+	VU	+	VU
Acipenser stellatus Pallas, 1771		EX		EX[4]	+	CE
Acipenser sturio Linnaeus, 1758						EX
Anguilla anguilla (Linnaeus, 1758)	+		+		+	
Lepomis gibbosus (Linnaeus, 1758)	+	exotic	+	exotic	+	exotic
Micropterus salmoides (La Cepé de, 1802)			+	exotic		
Alosa immaculata Bennett, 1835				EX	+	
Alosa tanaica (Grimm, 1901)			+		+	
Alosa maeotica (Grimm, 1901)					+	VU
Clupeonella cultriventris (Nordmann, 1840)					+	
Atherina boyeri Risso, 1810					+	
Esox lucius Linnaeus, 1758	+	E	+		+	VU
Umbra krameri Walbaum, 1792	+	CE	+	VU	+	VU
Lota lota (Linnaeus, 1758)	+	CE	+	VU	+	VU
Abramis ballerus (Linnaeus, 1758)	+	E	+	VU	+	
Abramis brama (Linnaeus, 1758)	+		+		+	
Abramis sapa (Pallas, 1814)	+	VU	+	VU	+	
Alburnoides bipunctatus (Bloch, 1782)	+	VU	+	VU		
Alburnus alburnus (Linnaeus, 1758)	+		+		+	
Aspius aspius (Linnaeus, 1758)	+	E	+	VU	+	
Barbus barbus (Linnaeus, 1758)	+	VU	+		+	
Barbus peloponnesius Valencienns, 1842			+	VU		
Blicca bjoerkna (Linnaeus, 1758)	+		+		+	
Carassius carassius (Linnaeus, 1758)	+	CE	+	VU	+	
Carassius gibelio (Bloch, 1782)	+		+		+	
Chalcalburnus chalcoides (Gueldenstaedt, 1772)				EX		EX
Chondrostoma nasus (Linnaeus, 1758)	+	E	+	VU	+	
Ctenopharyngodon idella (Valenciennes, 1844)	+	exotic	+	exotic	+	exotic
Cyprinus carpio Linnaeus, 1758 (wild form)	+	CE	+	E	+	CE

SPECIES	Austria Occ	Austria CAT	Hungary Occ	Hungary CAT	Romania Occ	Romania CAT
Gobio albipinnatus Lukasch, 1933	+	VU	+		+	
Gobio gobio (Linnaeus, 1758)	+	VU	+			
Gobio kesslerii Dybowski, 1862	+	CE	+	VU	+	VU
Gobio uranoscopus (Agassiz, 1828)	+	CE	+	E		
Hypophthalmichthys molitrix (Valenciennes, 1844)	+	exotic	+	exotic	+	exotic
Hypophthalmichthys nobilis (Richardson, 1845)			+	exotic	+	exotic
Leucaspius delineatus (Heckel, 1843)	+	CE	+	VU	+	VU
Leuciscus borysthenicus (Kessler, 1859)					+	
Leuciscus cephalus (Linnaeus, 1758)	+		+		+	
Leuciscus idus (Linnaeus, 1758)	+	CE	+	VU	+	
Leuciscus leuciscus (Linnaeus, 1758)	+	E	+	VU		
Pelecus cultratus (Linnaeus, 1758)	+	E	+	VU	+	
Phoxinus phoxinus (Linnaeus, 1758)	+	VU	+	VU		
Pseudorasbora parva (Temminck et Schlegel, 1842)			+	exotic	+	exotic
Rhodeus sericeus (Pallas, 1776)	+	E	+		+	
Rutilus meidingeri (Heckel, 1851)	+	E	+	Imm		
Rutilus pigus (La Cepé de, 1803)	+	CE	+	VU		
Rutilus rutilus (Linnaeus, 1758)	+		+		+	
Scardinius erythrophthalmus (Linnaeus, 1758)	+		+		+	
Tinca tinca (Linnaeus, 1758)	+	VU	+	VU	+	VU
Vimba vimba (Linnaeus, 1758)	+	VU	+	VU	+	
Cobitis elongatoides Bacescu & Mayer, 1969	+	VU	+	VU	+	
Misgurnus fossilis (Linnaeus, 1758)	+	CE	+	VU	+	VU
Sabanejewia balcanica (Karaman, 1922)			+		+	
Sabanejewia bulgarica Drensky, 1928)			+	VU		
Barbatula barbatula (Linnaeus, 1758)	+		+	VU		
Ameirurus melas (Rafinesque, 1820)			+	exotic		
Ameiurus nebulosus (Lesueur, 1819)			+	exotic		
Ictalurus punctatus (Rafinesque, 1818)			+	exotic		
Silurus glanis Linnaeus, 1758	+	CE	+		+	VU
Gymnocephalus baloni Hol?é k & Hensel, 1974	+	VU	+	VU	+	VU
Gymnocephalus cernuus (Linnaeus, 1758)	+		+		+	
Gymnocephalus schraetser (Linnaeus, 175	+	VU	+	VU	+	VU
Perca fluviatilis Linnaeus, 1758	+		+		+	
Percarina demidoffi (Nordmann, 1840)					+	Imm
Perccottus glenii Dybowski, 1877						
Sander lucioperca (Linnaeus, 1758)	+		+		+	
Sander volgensis (Gmelin, 1788)	+	VU	+	VU		EX
Zingel streber (Siebold, 1863)	+	CE	+	VU	+	VU

SPECIES	Austria		Hungary		Romania	
	Occ	CAT	Occ	CAT	Occ	CAT
Zingel zingel (Linnaeus, 1766)	+	E	+	VU	+	VU
Syngnathus abaster Risso, 1859					+	
Gasterosteus aculeatus (Linnaeus, 1758)	+		+		+	
Pungitius platygaster (Kessler, 1859)					+	VU
Mugil cephalus Linnaeus, 1758					+	
Liza aurata (Risso, 1810)					+	
Liza saliens (Risso, 1810)					+	
Cottus gobio Linnaeus, 1758	+	E	+	VU		
Cottus poecilopus Heckel, 1836						
Hucho hucho (Linnaeus, 1758)	+	CE	+	E		
Oncorhynchus mykiss (Walbaum, 1792)	+	exotic	+	exotic		
Salmo labrax Pallas, 1811	+	VU	+	VU	+	CE
Salvelinus fontinalis (Mitchill, 1814)	+	exotic	+	exotic		
Thymallus thymallus (Linnaeus, 1758)	+	VU				
Coregonus peled (Gmelin, 1788)	+		+	Imm		
Coregonus albula (Linnaeus, 1758)			+	Imm		
Coregonus renke (Schrank, 1783)			+	Imm		
Platichthys flesus (Linnaeus, 1758)					+	
Benthophiloides brauneri Belling & Iljin, 1927					+	CE
Benthophilus stellatus (Sauvage, 1874)					+	
Gobius ophiocephalus (Pallas, 1814)						EX
Knipowitschia cameliae Nalbant & Otel, 1995					+	CE
Knipowitschia caucasica (Berg, 1916)					+	
Neogobius eurycephalus (Kessler, 1874)					+	
Neogobius fluviatilis (Pallas, 1814)			+	VU	+	
Neogobius gymnotrachelus (Kessler, 1857)	+	Imm			+	
Neogobius kessleri (Gunther, 1861)	+	Imm	+		+	
Neogobius melanostomus (Pallas, 1814)	+	Imm	+		+	
Neogobius syrman (Nordmann,1840)			+		+	
Proterorhinus Marmoratus (Pallas, 1814)	+	Imm	+	VU	+	

downstream of Vienna. Recent ichthyological studies demonstrate the role of the Danube as a dispersion corridor (Kautman 2000, 2001; Wiesner, Spolwind, Waidbacher *et al*. 2000; Strásai and Andreji 2001).

Exotic Species

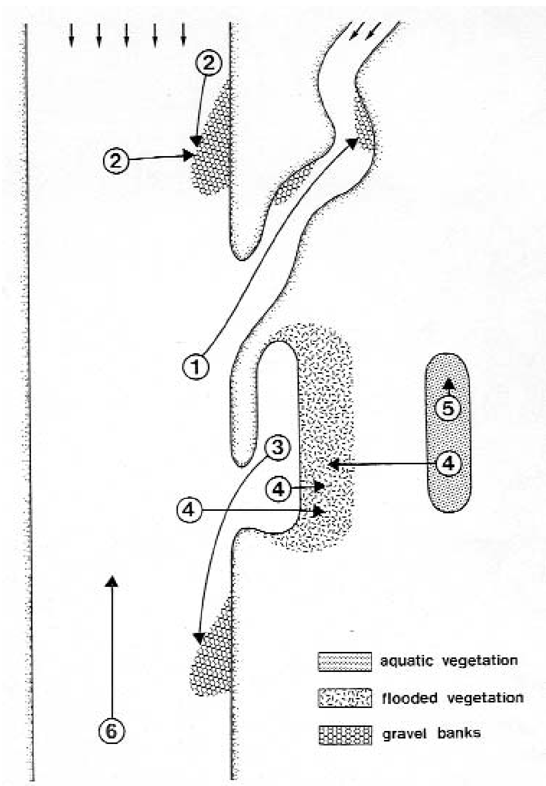
About 15 species have been introduced during the last century: *Carassius gibelio, Pseudorasbora parva, Lepomis gibbosus* are considered naturalised. The Chinese carps *Ctenopharyngodon idella, Hypophthalmichthys molitrix* and *Aristichthys nobilis* have reproductive populations in the Lower Danube (see below).

Carassius gibelio (giebel carp) appeared in the Lower Danube in the first quarter of the last century (Banarescu 1968, 1997) but was very rare until 1970. The expansion thereafter was followed by an invasion in the Middle Danube and Upper Danube. In the Romanian Danube Delta the Giebel carp population became very large: the catch statistics from 1970-2001 show a contribution up to 40-60 percent of the total catch. This invasive potential was explained by its specific reproductive flexibility (gynogenesis). The invasive population was first represented in an unisexual, gynogenetic form (Balon 1962; Holcík 1980). Aggressive feeding behaviour is an advantage in competition with native species. In Slovakia the first males appeared in 1992 and since then males form a permanent part of the population.

Ctenopharyngodon idella (grass carp) was introduced in fish farms in the Danube Delta in 1962, in order to increase productivity and to control aquatic vegetation in the ponds. In 1970 their presence in the wild was recorded, but systematic recording did not start until 1981. Natural reproduction appears to take place in years when suitable conditions occur (Giurca 1980). Because of their rheophilic nature the species is more abundant upstream from the delta. In 1992, a massive occurrence of young silver carp (*Hypophthalmichthys molitrix)* was recorded in the lakes of the upper part of the Danube Delta (Staras, Cernisencu and Constantin 1993). In some years large numbers of larvae are present in the Danube River as a result of successful natural spawning, which depends on two conditions: water temperature above 22°C and increased water velocity after summer rainfalls, from 2 to 5 km h^{-1} (Staras and Otel 1999).

FISH GUILDS AND THEIR ECOLOGICAL REQUIREMENTS

The high biodiversity is explainable by habitat diversity and the existence of several guilds. Guilds can be grouped according to their specific requirements in the course of the life cycle. Appropriate spawning habitats, feeding habitats and refuge from harsh environmental conditions have to be available. Spatial heterogeneity and the connectivity of habitat patches are critical for population dynamics. For large European rivers we have distinguished 5 guilds according to the preferred zones of occurrence of adults and the spawning and nursery grounds (Schiemer and Waidbacher 1992) (Figure 8).



■ **Figure 8.** Schematic presentation of main habitat requirements of six fish guilds. Circles: preferred habitats of adults; arrows: spawning and nursery sites. 1: rhithralic, 2: rheophilic A, 3: rheophilic B, 4: eurytopic 5: stagnophilic, and 6: anadromous species (modified after Schiemer & Waidbacher 1992).

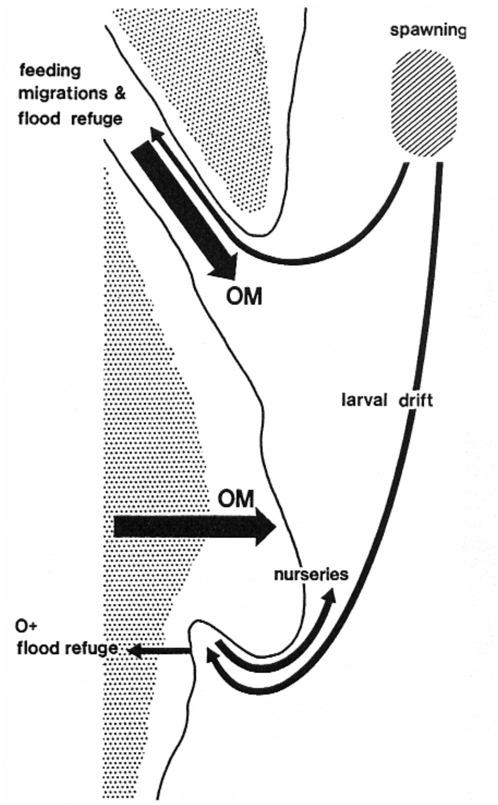
- Riverine species dependent on the connectivity of the river with its tributaries. This group requires rhithral conditions for spawning and during the early life stages (e.g. *Hucho hucho*).
- Riverine species with spawning grounds and nurseries in the inshore zone of the river itself. Group 1 and 2 are now frequently referred to as Rheophilic A.
- Riverine species with a preference for low-current conditions (e.g. connected backwaters) during certain periods in the adult stage (e.g. feeding grounds or winter refuge), but with spawning grounds and nurseries in the river. Such species are referred to as Rheophilic B.
- Eurytopic species (habitat generalists found both in rivers and various types of stagnant water bodies. Some of these species require flooded vegetation as spawning area, e.g. *Esox lucius*).
- Limnophilic species confined to various microhabitats of the floodplain (e.g. disconnected former river branches) with strong development of submerged vegetation.

Considering the whole river system at least one more guild needs to be added, namely anadromous species like sturgeons. They require integrity at a catchment scale in the form of appropriate migration routes from their brackish or marine adult habitats to their upstream reproductive areas.

Six species of sturgeons are or have been native to the Danube. Before the blockage of the migration routes four anadromous species ascended as far as the Upper and Middle Danube to spawn. Smaller scale anadromous migrators spawning in the Delta lakes or the Lower Danube reaches include *Alosa* spp, some of which form the basis of a commercially important fisheries e.g. in the Delta lakes.

Rheophilic species bound to the riverine habitats form the largest group, followed by eurytopic forms that live both under lotic and lenitic conditions. The smallest guild consists of the limnophilic species tied to stagnant water bodies (Schiemer *et al*. 2001a). In a lateral transect from the river to the fringing wetlands, arranged on a gradient of decreasing connectivity to the river the diversity of fish species decreases (Schiemer 1999, 2000). This pattern has been confirmed for the Slovakian and Hungarian sections (e.g. Guti 1993, 2002). In the limnophilic group a specific assemblage of blackwater species such as *Umbra krameri* and *Misgurnus fossilis* occurs in the large floodplains which are found exclusively in strongly fragmented and vegetated pools in the floodplain wetlands (Schiemer 1999; Schiemer *et al*. 2001a) and more commonly in the lakes of the Danube Delta with low connectivity to the river and with dense vegetation along the reed belt (Navodaru, Buijse and Staras 2001). The high diversity in the river itself is due to the co-occurrence of rheophilic and eurytopic forms. In the large European rivers the rheophilic guilds - depending on lotic habitats - contain the highest number of species. Some of them (Rheophilic B) require connectivity between the river and the floodplains to have complementary habitat for feeding and as a winter refuge (e.g. *Abramis ballerus, Aspius aspius*, *Leuciscus idus* in the Danube). These species are excellent indicators of lateral connectivity between lotic and lenitic conditions. The various species exhibit distinct patterns of niche differentiation; e.g. the Danubian percids (*Zingel zingel*, *Z. streber, Gymnocephalus schraetseri*, *G. baloni)* or the various species of *Gobio* exhibit clear differences with regard to the preferred current velocity.

Over the past 15 years the requirements of some of these species have been studied in detail with regard to their field occurrence as well as experimentally with regard to their specific eco-physiological requirements and performances and their functional response to major environmental variables (Table 2). We found that during spawning and early life history most riverine species are bound to the inshore zone of the river, where they require a variety of structural properties for successful recruitment (Figure 9):



■ **Figure 9.** Schematic representation of quality criteria of inshore zones with respect to their value as fish nurseries. The scheme indicates the river shoreline with a connected backwater and gravel bar (hatched). Stippled area = terrestrial vegetation; OM = organic material (from Schiemer *et al*. 2001a).

Table 2: Studies on the ecology and eco-physiology of critical stages of Danubian fish

1. Early life history
Schiemer and Spindleer 1989; Schiemer and Zalewski 1992; Wintersberger 1996a, 1996b; Keckeis *et al.* 1996a; Kamler *et al.* 1996; Keckei, Bauer-Nemeschkal and Kampler 1997; Winkler, Keckeis, Reckendorfer *et al.* 1997; Kamler, Keckeis and Bauer-Nemeschkal 1998; Flore and Keckeis 1998; Flore, Reckendorfer and Keskeis 2000; Flore. Keckeis and Schiemer 2001; Keckeis *et al* 2001; Reckendorfer, Keckeis, Tiitu et al. 2001; Schiemer *et al.* 2001a; Keckeis and Schiemer 1992; Schiemer *et al.* 2003

2. Reproductive phase
Keckeis, Franckiewicz and Schiemer 1996b; Kamler and Keckeis 2000; Keckeis 2001

3. Habitat linkage and ecological integrity
Schiemer and Spindler 1989; Schiemer and Waidbacher 1992; Kurmayer, Keckeis, Schrutka *et al*. 1996; Schiemer 1999; Jungwirth *et al.* 1999; Schiemer 2000; Schiemer 2002; Hirzinger, Keckeis, Nemeschkal *et al.* 2003

- Spawning sites must be in close proximity and connected to larval microhabitats. Emerging larvae drift passively to these nursery zones. Population losses are generally higher in channelized rivers with lower flow diversification.
- Diversified inshore structure to cover ontogenetic niche shifts with regard to the velocity of the water current, substrate type and food.
- Connected side arms or inshore retention zones are significant production areas for food for larvae (in the sense of the Inshore Retention Concept (Schiemer, Keckeis, Reckendorfer *et al*. 2001b).
- Shallow sloping embankments and littoral diversification are required to function as buffer zones and refugia for 0+ fish against washout effects in the event of strong water level fluctuations and floods.

Such complex requirements have become the main restriction for the existence of a highly adapted fish fauna in large rivers under regulated conditions (see below).

HUMAN IMPACTS VERSUS ECOLOGICAL REQUIREMENTS OF FISH

Changes in the river environment result in a change in fish species composition and also endanger the aquatic fauna in its totality. Under the impact of human interference the fish fauna has deteriorated in many sections of the Danube. This has been manifested in:

- Extinction of species (Table 1)
- High number of endangered species (Table 1)
- Qualitative and quantitative decline of fisheries
- Change in fish composition from habitat specialists (rheophilic and stagnophilic) to eurytopic forms

The causes are manifold and often cumulative and have to be specifically analysed and addressed in individual situations, be it a river stretch or a particular fish species.

The major negative impacts are:

- Loss of longitudinal connectivity of the river system caused by hydropower dams
- Loss of floodplain habitats and the interaction between rivers and floodplains
- Loss of riverine inshore structure

River regulation and damming have also resulted in a:

- Change in the hydraulics and flow regime
- Change in the thermal pattern due to faster runoff and reduced inshore retention

Additional negative influences are:

- Effects of shipping
- Poor water quality
- Overfishing, illegal fishing, inappropriate fisheries regulations, etc.

The high state of endangerment of former abundant or common fish species in the Upper and Middle Danube and the decline in catch in the Lower Danube are signs of a critical situation where management and mitigation are required.

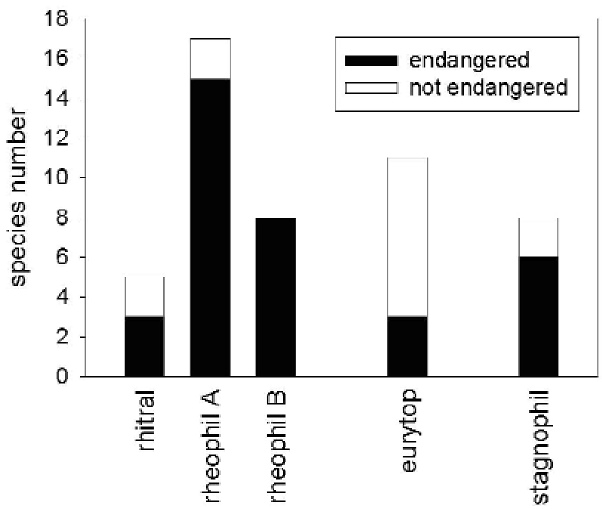
Sturgeons are of main concern from a conservation point of view as well as for fisheries. The anadromous sturgeons became extinct in the Upper and Middle Danube due to the blocked migration route at the Iron Gate. However, already in the nineteenth century the catch statistics in the Middle and Lower Danube had declined due to overfishing. The past and present status of sturgeons has been discussed by Hensel and Holcik (1997); Guti (1998); Bacalbasa-Dobrovici (1998); Navodaru, Staras and Banks (1999); Reinartz (2002) and Reinartz *et al*. (2003).

While a high proportion of the original fauna (nineteenth century status) still exists, a large number of formerly common species shows declining populations. Many taxa have become threatened and are on the Red List. From Table 1 it becomes clear that their number is higher in the upper parts of the Danube than in the Lower Danube and the delta.

The main deficiencies in the Upper Danube plus Slovakia and Hungary result from river engineering and damming which has caused a decline of the ecological integrity of the river-floodplain ecosystem (Karr 1991; Jungwirth, Muhar and Schmutz 2000; Schiemer 2000).

The most destructive effects are caused by the construction of hydropower dams, which result in a reduction of flood pulses and a blockage of fish migration into the floodplain system (which represent spawning and feeding grounds and winter refuges for a number of species). Dams also result in a reduction of appropriate spawning and nursery habitats for rheophilic species within the channel. The composition of the fish fauna in the dammed channel changes from a rheophilic-dominated assemblage to eurytopic forms (Schiemer and Waidbacher 1992). After the Gabcíkovo River Barrage System was put in operation in October 1992, a loss of species and the decline in fish density and productivity has been noted both on the Slovakian and the Hungarian side (e.g. Guti 1993; Balon and Holcik 1999). Phytophilous spawners like wild carp and pike have lost their spawning grounds and declined rapidly. The dramatic alterations of both the hydrological regime and the structural diversity resulted in a decrease of the food resources and a loss of spawning, feeding and wintering grounds for fish. Consequently, the mean annual fish catch, calculated for the period after the damming of the river, declined by 87 percent when compared with the period 1961-1972 (Holcík 1998; Balon and Holcík 1999).

But even in the remaining un-dammed sections the situation is critical. Figure 10 exemplifies the status of the fish fauna in the largest free-flowing stretch (approximately 50 km river length) of the Austrian Danube from Vienna to Bratislava. The area has received IUCN status as a National Park because of the extensive functional floodplains. Since the water quality is good and there is no overfishing it is quite apparent that the critical state is due to a loss of habitat diversity and structural properties. The state of endangeredness is different for the various guilds. It is interesting to note that a limnophilic guild consisting of species which are bound to small, isolated and strongly vegetated waterbodies on the outer floodplain borders, such as *Umbra krameri, Misgurnus fossilis* and *Carassius carassius,* are critically endangered due to the loss of formerly extensive fringing wetlands which covered large areas prior to regulation. The graph clearly shows that the rheophilic guild contains the highest number of species and also the highest percentage of endangered ones.

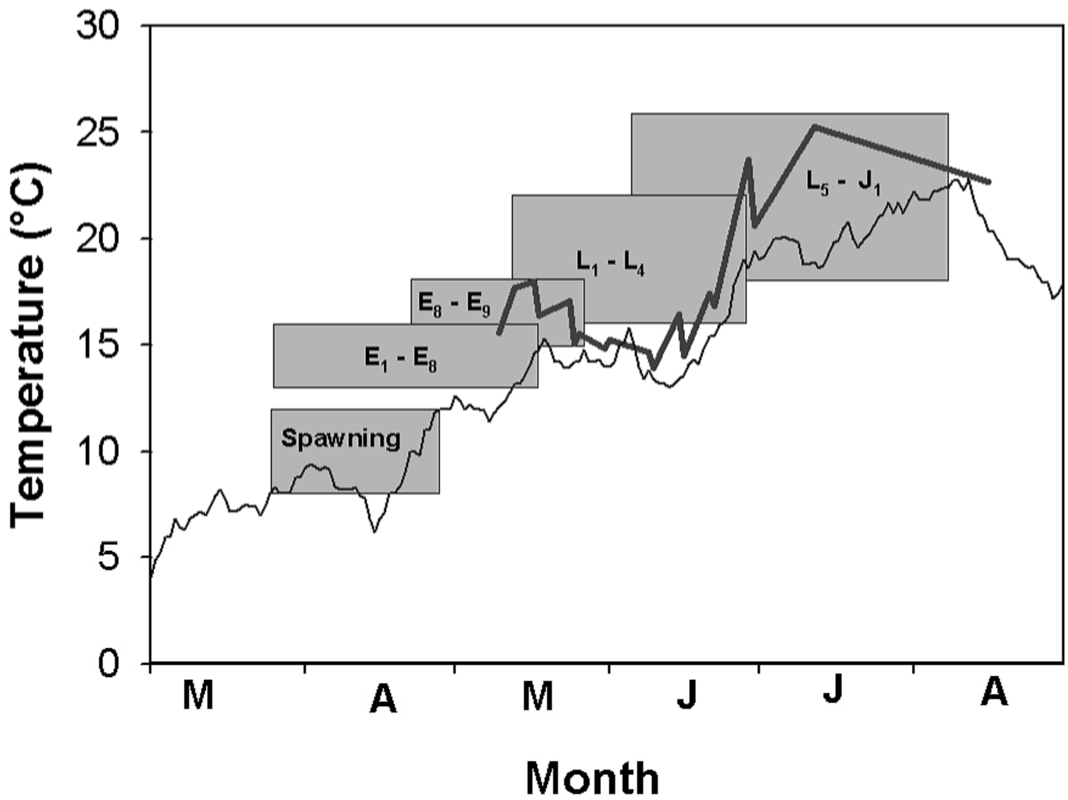


■ **Figure 10.** Guild structure of fish and the number of endangered fish species in the different ecological guilds in the free-flowing Austrian section downstream of Vienna to the Slovakian border.

The early life is critical: the match or mismatch between environmental conditions and requirements during the embryonic and early larval phases is decisive for recruitment (Copp 1989; Schiemer, Spindler, Wintersberger *et al*. 1991; Schiemer *et al*. 2001a). Most of the rheophilic species are bound in the reproductive and the 0+ phase to the inshore areas of high structure and low flow and high productivity (Inshore Retention Concept, Schiemer *et al*., 2001b) (see above). The shoreline structure is thus a decisive characteristic for the existence of a highly specific Danubian fish fauna. Richly structured inshore zones have become a rare commodity in regulated rivers. For example, the approximately 50 km long free-flowing section of the Austrian Danube contains only 18 larger gravel bars of 0.5-2 km length, which form potential fish nurseries. Of these 18 zones only 6 provide high quality conditions for recruitment. This represents approx. 15 percent of the total shore length. Sixty percent are linear embankments made out of ripraps that are virtually devoid of fry. An index of shoreline configuration for such gravel bars correlates strongly with the species number in the 0+ stage and the occurrence and number of rare and endangered species. The quality of inshore zones depends on the interaction between geomorphology and hydrology and on the degree to which two dynamic processes are matched: the ontogenetic change in requirements and the hydrological dynamics of the river, which result in a continuous change of microhabitat locations and conditions. Considering the strong diurnal hydrological fluctuations occurring in large rivers, the inshore zones represent a highly stochastic environment for the early life history stages. Structural heterogeneity of the shoreline is a buffer against population losses (Schiemer *et al*. 2001a). It is likely that this extent of shore structure is inadequate for long-term maintenance of the characteristic fish associations. This is indicated by the decline in formerly common species observed during recent years.

For a detailed understanding of the ecological requirements, experimental studies are required. *Chondrostoma nasus,* which has become a key species for river conservation and for highlighting the environmental conditions of large European rivers (Penáz 1996; Schiemer, Keckeis and Kamler 2003) has been our main experimental animal in recent years. The value of such detailed studies is shown in Figure 11 which exemplifies the mismatch between the temperature requirement during early ontogeny vis-à-vis the field temperatures in the free-flowing Danube downstream of Vienna. The thick line is based on the daily hydrographic readings at 7 a.m. in the main channel. The thin line represents the temperature recording in the inshore zones. It illustrates the high significance of the inshore retention zones: it is apparent that the temperature regime of the inshore storage areas becomes decoupled from main channel conditions to a degree that depends on water retention and exchange. Local temperature conditions are highly significant for temperature-dependent processes of species bound to the littoral. The inserts in Figure 11 show the time of occurrence of different stages of *Chondrostoma nasus* in the field, the width of the blocks indicates their temperature optima, based on experimental data. This shift in temperature optima is in agreement with the environmental temperature increase in rivers after the spawning period of *Chondrostoma nasus*, which usually occurs in March and April. It is apparent that river engineering has reduced the synchronisation between the physiological programme of a characteristic species and the conditions in regulated rivers. Suboptimal temperature results in reduced growth, which leads to a prolonged development through the critical stages with accumulated risks and mortality. We have good evidence that this mismatch also holds good for other environmental conditions like food supply and current velocity pattern. With regard to the latter, wave actions and short-term disturbances in the nursery zones caused by heavy navigation are other critical factors. A detailed analysis showed that the tow and splash pattern, a high variability of water velocities and the translocation of the larval microhabitats, which results from passage of ships, increases larval mortality rates (Hirzinger *et al*. 2002).

The situation in the Lower Danube is similarly critical especially with regard to the fishery, for three reasons: reduction of floodplain areas by side dams and polders, poor water quality and uncontrolled and badly managed fisheries.



■ **Figure 11.** Temperature in the main channel of the Danube at Vienna (thin line) and in the inshore storage zones (average value of the 3 microhabitats) during the spawning and early life history development of *C. nasus* in 1994. The inserted boxes are defined by duration of spawning and of consecutive developmental stages in the field (length of boxes), and by the repective ranges of optimum temperatures (height of boxes). Embryonic (E), larval (L) and juvenile (J) developmental stages determined according to Penaz (1996). Modified from Keckeis *et al.* (2001).

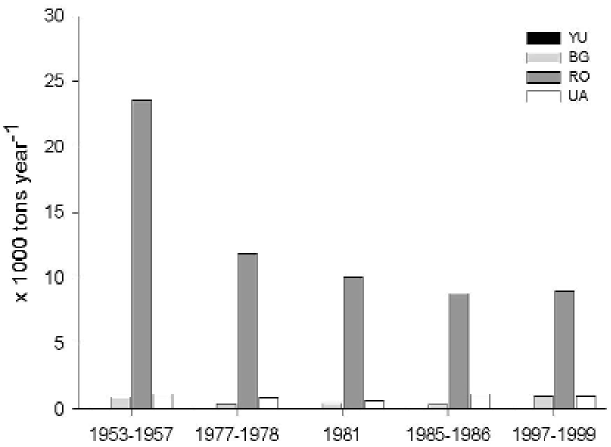
STATUS OF FISHERIES

Bacalbasa-Dobrovici at LARS 1 (1989) presented a survey on “The Danube River and its Fisheries”. According to the statistics supplied by the “Joint Commission for the Application of the Fishery Convention in the Danube”, the average annual catch of commercial fisheries in tonnes for the period from 1958 to 1983 was approximately 150 in Slovakia, 900 in Hungary, 1 300 in Serbia and Montenegro, 800 in Bulgaria, 20 000 in Romania and 3 000 in the Ukraine. We can use these long-term averages (1958-1983) as a starting point for a discussion on the more recent development and the present-day situation.

In Germany, Austria and Slovakia commercial fisheries are practically zero, however recreational fisheries play a major role. Their quality shows a continuous decline due to the poor connectivity between the river and its floodplain. The value of the multi-species recreational fisheries has been badly hurt by the construction of hydropower dams. In Slovakia, for example, the catch has considerably declined due to the construction of the Gabcikovo dam. The mean annual catch in the period 1961-1979, before the start of the GRBS construction, amounted to 102.7 tonnes and consisted to a large extent (46.1 percent) of economically preferred species such as *Cyprinus carpio, Esox lucius*, *Stizostedion lucioperca*, *S. volgensis, Aspius aspius, Tinca tinca* and *Silurus glanis.* In the period 1993-1996, after the GRBS was built and put in operation the mean annual catch dropped to 26.8 tonnes (Holcik, *in litt.*). The fisheries development is described by Guti (1993) in the Szigetköz floodplain in Hungary, strongly affected by the GRBS. The floodplain area is used both for commercial and recreational fisheries. The total catch declined from 207.5 tonnes in 1976 to 77.4 tonnes in 1992, showing a decreasing trend despite higher recreational fishing activity. Popular fish on the market such as pike and carp decreased significantly.

How is the development in the Lower Danube, where commercial fisheries still play a significant role? Antipa (1916) described the situation at the beginning of the last century, when the river was in a near pristine state. Its further development was analysed by Bacalbasa-Dobrovici (1989, 1998). Until 1960 the main controlling factor was the hydrology of the river. The positive relationship between catch statistics and the flood pulses was already recognized by Antipa (1916). After 1960 anthropogenic influences like damming, formation of irrigation reservoirs, eutrophication, pollution, introduction of exotic species and overfishing became the major factors affecting the fish.

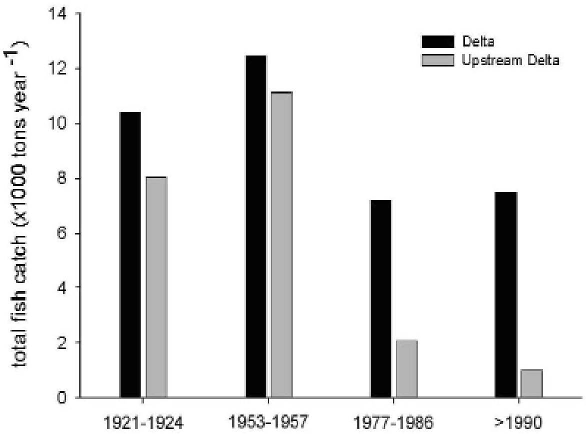
Figure 12 shows the changes in the riparian countries according to official catch statistics. In Romania, which has the most significant fisheries, the catch declined drastically. The strongest decline occurred during the 1960s as an immediate response to the reduction of floodplain areas: until the 1960s the floodplains downstream of Iron Gate II produced nearly 50 percent of the Romanian catch (Figure 13). They were a key habitat for the semi-migratory species like carp, ide, pikeperch and catfish. The drop occurred despite increasing fishing effort due to the unemployment and open access after the collapse of the communist state-controlled system (Bacalbasa-Dobrovici 1998). At the Bulgarian side of the Danube the number of commercial fishers increased from 363 in 1986 to 2000 in 1998. A less drastic but also strong decline in fish catches resulted from the polder construction within the delta.



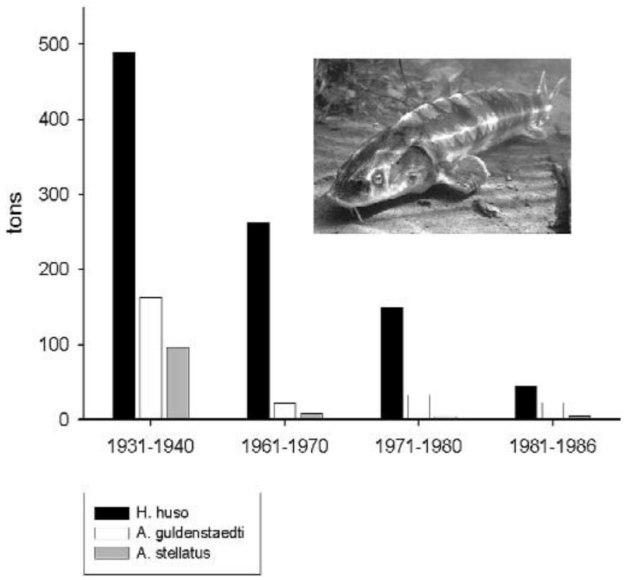
■ **Figure 12.** Development of total catches in the riparian countries over the period 1953-1999 (official fisheries statistics)
1953-1957 : Bacalbasa-Dorovici (1995)
1977-1978 : Report of Joint Commission of the International Agreement of Fishing in the Danube River (JCI-AFD), 21st Session, 1979, Budapest
1981 : Bacalbasa-Dobrovici (1989)
1985-1986 : Report of JCIAFD, 28th session, 1987, Bratislava
1997-1999 : National Report on Third FAO/East Fish Technical Consultation, Bulgarian State Fisheries Inspectorate, 1998, Bacalbasa-Dobrovici (1998), Rapid Rural Appraisal Techniques (RO)

Anadromous sturgeon fishery

Over the centuries sturgeons have formed the basis of a large and significant commercial fishery, renowned throughout the world (Reinartz *et al*. 2003). In the 1960s and 1970s this fishery yielded between 80 and 300 tons of fish each year mainly in Romania, the Ukraine, Bulgaria and former Yugoslavia. In the last 10 to 20 years the fishery has strongly declined, with official records of 25-30 tons per year (Figure 14). A study carried out in 1997-1998 using Rapid Rural Appraisal technique revealed, however, that official catch records represent no more than 10 percent of the actual catch size (approx. 385 tons; 56 percent in Romania, 30 percent in the Ukraine, 12 percent in Bulgaria, 2 percent in former Yugoslavia) (Navodaru *et al*. 1999).



■ **Figure 13.** Development of total catches in the Romanian Danube vs. the Delta during the period 1921-1986 (official fisheries statistics).
1921-1924 : Fisheries statistics
1953-1957 : Bacalbasa-Dobrovici (1995)
1977-1986 : Report JCIAFD, 21st and 28th Session
>1990 : Bacalbasa-Dobrovici (1992,1998)



■ **Figure 14.** The decline of sturgeon fisheries according to the official catch statistics.

There is a general consensus that the decline in official catches is indicative of a real decline in the Danube Basin sturgeon populations due to a combination of factors such as blockage of migration routes, overfishing, pollution and habitat loss. The damming of the Danube has interrupted the traditional migration of sturgeons. Natural spawning sites have been drastically reduced but still exist downstream of the barrages. The main factor affecting sturgeon stocks is overfishing. Overfishing has caused increased mortality of adult sturgeons, while the size of breeding sturgeon has been decreasing. Breeders are also becoming less and less likely to complete a second migration in the river and the average age of sturgeon has been declining. Overfishing means a decreasing chance that mature specimens will reach spawning areas. The number of fishers has more than trebled since the fully state-controlled system collapsed. The use of more effective gears (monofilament gill nets) has increased as well as stress factors during migration and spawning (e.g. injuries by unbaited hooks).

In order to improve the situation of the fishery of the Lower Danube a transnational framework for common management has to be re-established: The Joint Commission of the International Agreement on Fishing in the Danube River (JCIAFD) established in 1958 has not been active since 1990. The riparian countries have undergone a major transition from a State-controlled to a market system. The legislation and implementing agencies have failed to keep pace with the extent of changes. Legislative structures in all of the countries have to be reviewed in the light of international standards. Main targets have to be:

- Improved and common monitoring system (catch statistics after 1990 are unreliable; the lack of data on fishing effort and catches hampers fish stock management);
- Legal framework and fishery regulations should be harmonized between the countries with regard to closed seasons, fishing methods and gears (e.g. the destructive use of un-baited hooks; this method has been banned in Romania and the Ukraine but is permitted and used intensively upstream in Bulgaria and Serbia for sturgeons) (Bacalbasa-Dobrovici 2002);
- Illegal fisheries require stronger control including international control of the black market (for example, the export of caviar since 1998 in Romania clearly demonstrates that the actual catch of sturgeons is much higher than listed in the official catch statistics).

CONCLUSIONS

1) The current environmental status of the Danube is not satisfactory, for example with respect to the requirements set by the EC Water Framework Directive.

2) The loss of ecological integrity started more than 100 years ago with the large river regulation schemes. The interruption of connectivity between floodplains and the river has intensified as a result of the construction of dams, which has had an accelerating impact on the free-flowing sections due to the disruption of the gravel transport in the river. The lowering of the water level has been caused by bed erosion.

3) The problems have been intensified by pollution, shipping and uncontrolled fisheries.

4) The deterioration of the environment is not only endangering the fish fauna and reducing the potential of the fisheries but is also problematic for other forms of the river use, such as recreation and drinking water supply as well as affecting the self-purification potential of the river floodplain system.

5) For management an efficient monitoring system is required. Fish are the single most important bioindicator group for assessing the status of ecological integrity.

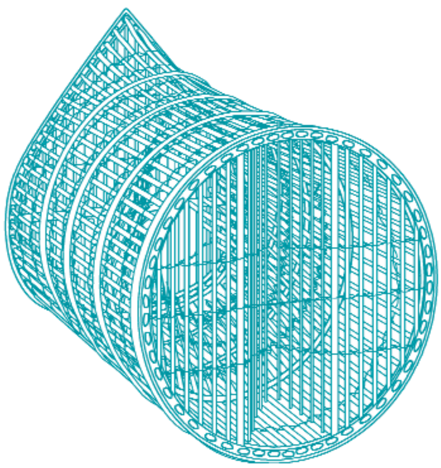
6) Fisheries in the Lower Danube are an important issue because of their economic significance.

7) Conservation and restoration: there have been many efforts to conserve and restore the remaining floodplains. The examples are the establishment of the Alluvial Floodplain National Park in Austria in 1996, Gemenc floodplain area in Hungary – National Park since 1996, the Kopacki Rit Nature Park in Croatia, the Srebarna Lake in Bulgaria, the Danube Delta. Restoration programmes to restore the connectivity between floodplains and the river have been started or are in the planning phase. These programmes are highly significant for improving the ecological functions of the river system (Schiemer *et al*. 1999).

8) The ecology of the Danube requires international attention and harmonized management.

ACKNOWLEDGEMENTS

We acknowledge the help of J. Holcik in providing information on the Slovakian Danube and the constructive criticism by J. Bloesch on an earlier version of the manuscript.



REFERENCES

Antipa G. 1916. Fisheries and fishing in Romania. *Publicatiile fondului V. Adamachi VIII*, Bucharest, *Academia Romana*. 794 pp. (in Romanian)

Bacalbasa-Dobrovici N. 1989. The Danube River and its fisheries. *In* D.P. Dodge, ed. *Proceedings of the international large rivers symposium, Can. J. Fish. Aquat. Sci. Spec. Publ.,* 106: 455-468.

Bacalbasa-Dobrovici N. 1991. Fish population evolution 1985-1988 in the last built reservoir iron gate II. *Proceedings of the International Association for Theoretical and Applied Limnology,* 24: 2524-2527.

Bacalbasa-Dobrovici N. 1992. The present status of the Romanian Danube River fishery. *Proceedings of the symposium aquaculture and fishing in future, Galati,* 23-29.

Bacalbasa-Dobrovici N. 1995. The effects on fisheries of non-biotic modifications of the environment in the East-Danube river area. *In* J.S. Alabaster, ed. *Habitat modification and freshwater fisheries.* Bodmin, Cornwall, Butterworth. pp. 13-27.

Bacalbasa-Dobrovici N. 1998. Ecological problems of the Danube fishery. *Proceedings of the international symposium aquarom, '98, Galatzi*. pp. 62-64. (in Romanian)

Bacalbasa-Dobrovici N. 2002. Is the Carmacs fishing in the Lower Danube and in the Romanian territorial waters an advantage to the riverine Danube countries? *Internat. Assoc. Danube Res.,* 34: 459-66.

Balon E.K. 1962. Ökologische Bemerkungen über die Standorte der Donaufische mit einer Beschreibung des Fundes des *Carassius auratus gibelio* Bloch, 1783 und *Alburnoides bipunctatus* Bloch, 1782. *Vestník cs. Spol. Zool.,* 26: 331-51.

Balon E.K. 1964. Verzeichnis und ökologische Charakteristik der Fische der Donau. *Hydrobiologia,* 24: 441-52.

Balon E.K., Crawford, S.S. & Lelek A. 1986. Fish communities of the upper Danube Germany, Austria prior to the new Rhein-Main-Donau connection. *Env. Biol. Fish.,* 15: 243-71.

Balon E.K. & Holcík J. 1999. Gabcíkovo river barrage system: The ecological disaster and economic calamity for the inland delta of the middle Danube. *Env. Biol. Fishes*, 54: 1-17.

Banarescu P. 1968. *Fauna R.P.R. Pisces-Osteichthyes*. Editura Academiei, Bucuresti.

Banarescu P. 1997. Carasul, specie autohtona in apele noastre? *Vanatorul si Pescarul Roman,* 8: 17-20. (in Romanian)

Benedek P. & Laszlo F. 1980. A large international river: the Danube. *Prog. Wat. Tech.*, 13: 61-76.

Bloesch J. 1999. The international association for Danube research IAD: Its future role in Danube research. *Large Rivers 11/3, Arch. Hydrobiol. Suppl.*, 115/3: 239-259.

Bloesch J. 2001. The Danube River Basin - The other cradle of Europe: The limnological dimension. *Academia Scientiarum et Artium Europaea: Proceedings 1st EASA Conference The Danube River: Life Line of Greater Europe*. Budapest, Nov. 9-10, 2001. pp. 51-79.

Bloesch J. 2002. The unique ecological potential of the Danube and its tributaries: A report on the 33rd IAD-Conference in Osijek, Croatia, 3-9 September 2000. *Arch. Hydrobiol. Suppl. Large Rivers*. 13/1-2: pp. 175-88.

Bloesch J. & Sieber U. 2003. The morphological destruction and subsequent restoration programmes of large rivers in Europe. *Arch. Hydrobiol. Suppl. Large Rivers,* 141/1-2. (forthcoming)

Bondar C. 1977. Modificari ale regimului hidrologic prin amenajarile hidrotehnice pe Dunarea inferioara. *Hidrotehnica,* 224: 87-89 (in Romanian)

Bondar C. 1994. Referitor la alimentarea si tranzitul apelor Dunarii prin interiorul deltei. *Analele ICPDD*, III/2: 259-61 (in Romanian)

Buijs P.H.L, Uzunov Y. & Tzankov K. 1992. Water quality profile of the Danube River along the Bulgarian-Romanian stretch. *ICWS report 92.01.* Amsterdam. 70 pp.

Copp G.H. 1989. The habitat diversity and fish reproductive function of floodplain ecosystems. *Env. Biol.*, 26: 1-26.

Flore L. & Keckeis H. 1998. The effect of water current on foraging behaviour of the rheophilic cyprinid *Chondrostoma nasus* L. during ontogeny: Evidence of a trade-off between energetic gain and swimming costs. *Regulated Rivers: Research and Management*, 14: 141-54.

Flore L., Reckendorfer W. & Keckeis H. 2000. Reaction field, capture field and search volume of 0+ nase, *Chondrostoma nasus* L.: Effects of body size and water velocity. *Can. J. Fish Aquat. Sci.*, 57: 342-350.

Flore L., Keckeis H. & Schiemer F. 2001. Feeding, energetic benefit and swimming capabilities of 0+ nase *Chondrostoma nasus* L. in flowing water: An integrative laboratory approach. *Arch. Hydrobiol. Suppl.*, 135: 409-24.

Gastescu P., Driga B. & Anghel C. 1983. *Caracteristici morfohidrografice ale Deltei Dunarii, Hidrobiologia, t17. Academia Romana.* (in Romanian)

Giurca R. 1980. The development and maturation of *Ctenopharyngodon idella* Val. in the Lower Danube, *Bulet. de Cerc. Pisc. II*, 55-80. (in Romanian)

Guti G. 1993. Fisheries ecology of the Danube in the Szigetöz floddplain. *Opusc. Zool. Budapest,* XXVI: 67-75.

Guti G. 1998. Sturgeons in the Hungarian section of the Danube and draft program for their artificial propagation. *Miscellanea Zoologica Hungarica,* 12: 89-91.

Guti G. 2002. Significance of side-tributaries and floodplains for the Danubian fish populations. *Large Rivers/Arch. Hydrobiol. Suppl.,* 141/1-2: 151-63.

Heckel R. & Kner R. 1858. Die Süsswasserfische der Österreichischen Monarchie mit Rücksicht an die angrezenden Länder. Leipzig, W. Engelmann. 338 pp.

Hensel K. &. Holcik J. 1997. Past and current status of sturgeons in the upper and middle Danube River. *Env. Biol. Fishes,* 48: 185-200.

Hirzinger V., Bartl E., Weissenbacher A., Zornig H. & Schiemer F. 2002. Habitatveränderungen durch schifffahrtsbedingten Wellenschlag und deren potentielle Auswirkungen auf die Jungfischfauna in der Donau. *Österreichs Fischerei,* 55: 238-43.

Hirzinger V., Keckeis H., Nemeschkal H.L. & Schiemer F. 2003. The importance of inshore areas for adult fish distribution along a free-flowing section of the Danube, Austria. *River Res. Appl.,* 19: 1-13.

Hock B. & Kovács G. 1987. A large international river: The Danube, summary of hydrological conditions and water management problems in the Danube Basin. Laxenburg, Austria, IIASA-Workingpaper.

Holcik J. 1980. Possible reason of the expansion of *Carassius auratus* Linnaeus, 1758 Teleostei, Cyprinidae in the Danube River Basin. *Int. Revue ges. Hydrobiologie,* 65: 673-79.

Holcik J. 1990. Effects of hydraulic engineering on habitat and fish community in river anabranches of the middle Danube. *In* Management of freshwater fisheries. Van W.L.T. Densen, B. Steinmetz & H.R. Hughes, eds. *Proceedings of a symposium organized by the European Inland Fishery Advisory Commission*. Göteborg, Sweden, 31 May-3 June 1998. Pudoc, Wageningen. pp. 14-24.

Holcik J. 1996. Ecological fish production in the inland delta of the Middle Danube, a floodplain river. *Env. Biol. Fishes,* 46: 151-65.

Holcik J. 1998. Impact of the Gabcíkovo water works construction and operation on the recreational fishery in the Slovak segment of the Danube River. *In* M.N. Bacalbasa-Dobrovici, G. Vasilescu & L. Oprea, eds. *Fisheries management in the Danube River Basin Rauta. Extended abstracts of contributions presented at the international symposium Aquarom '98, Galati, Romania,* 18-22 May 1998. pp. 64-65.

Holcik J. & Bastl I. 1976. Ecological effects of water level fluctuation upon the fish populations in the Danube river floodplain in Czechoslovakia. *Acta Sc. Nat. Brno,* 10: 1-46.

Holcik J., Bastl I., Ertl M. & Vranovsky M. 1981. Hydrobiology and ichthyology of the Czechoslovak Danube in relation to predicted changes after the construction of the Gabcíkovo-Nagymaros River Barrage System. *Práce Lab. Rybár. Hydrobiol.,* 3: 19-158.

Ittekkot V., Humborg C. & Schäfer P. 2000. Hydrological alterations and marine biogeochemistry: A silicate issue? *BioScience,* 509: 776-82.

Jungwirth M., Muhar S. & Schmutz S. 2000. Fundamentals of fish ecological integrity and their relation to the extended serial discontinuity concept. *In* M. Jungwirth, S. Muhar & S. Schmutz, eds. Assesing the ecological integrity of running waters *Hydrobiologia,* 422/423: 85-97.

Kamler E. & Keckeis H. 2000. Reproduction and early life history of *Chondrostoma nasus*: implications for recruitment a review. *Pol. Arch. Hydrobiol.,* 47: 73-85.

Kamler E., Keckeis H. & Bauer-Nemeschkal E. 1998. Temperature-induced changes of survival, development and yolk partitioning in *Chondrostoma nasus. J. Fish. Biol.,* 53: 658-82.

Karr J.R. 1991. Biological integrity: A long neglected aspect of water resource management. *Ecological Applications,* 1: 66-84.

Kautman J. 2000. Tri nové druhy ryb na Slovensku. Three new fish species of Slovakia. *In* S. Lusk. & K. Halačka, eds. *Biodiverzita ichtyofauny ?R III. Ústav biologie obratlovc? AVCR, Brno*, 29-36. (in Slovak)

Kautman J. 2001. The first occurrence of *Neogobius gymnotrachelus* Pisces, Gobiidae in the Slovak Danube. *Folia Zoologica,* 50: 79-80.

Keckeis H. 2001. Influence of river morphology and current velocity conditions on spawning site selection of *Chondrostoma nasus* L. *Archiv Hydrobiol. Suppl.,* 35: 341-56.

Keckeis H. & Schiemer F. 1992. Food consumption and growth of larvae and juveniles of three cyprinid species at different food levels. *Environ. Biol. Fishes*, 33: 33-45.

Keckeis H., Bauer-Nemeschkal B. & Kamler E. 1996a. Effects of reduced oxygen level on the mortality and hatching rate of *Chondrostoma nasus* embryos. *J. Fish Biol.,* 49: 430-440.

Keckeis H., Frankiewicz P. & Schiemer F. 1996b. The importance of inshore areas for spawning nase *Chondrostoma nasus* Cyprinidae in a free-flowing section of a large river Danube, Austria. *Arch. Hydrobiol. Suppl. 113 Large Rivers,* 10: 51-64.

Keckeis H., Kamler E., Bauer-Nemeschkal E. & Schneeweiss K. 2001. Survival, development and food energy partitioning of nase larvae and early juveniles at different temperatures. *J. Fish Biol.,* 59: 45-61.

Khaiter P.A., Nikanorov A.M., Yereschukova M.G., Prach K., Vadineanu A., Oldfield J. & Petts G.E. 2000. River conservation in central and eastern Europe incorporating the European parts of the Russian Federation. *In* P.J. Boon, Davies B.R. & G.E. Petts, eds. *Global perspectives on river conservation: Science, policy and practice.* New York, John Wiley & Sons. pp. 105-26.

Kurmayer R., Keckeis H., Schrutka S. & Zweimüller I. 1996. Macro- and microhabitats used by 0+ fish in a side arm of the River Danube. *Arch. Hydrobiol. Suppl. Large Rivers,* 13: 425-32.

Lászloffy W. 1967. Die Hydrographie der Donau. *In* R. Liepolt, ed. *Limnologie der Donau*. *Schweizerbart'sche Verl. Stuttgart I*. pp. 16-57.

Liepolt R. 1967. *Limnologie der Donau*. Schweizerbart'sche Verl.Stuttgart. 591 pp.

Lösing I. 1989. Ökologische Probleme des Donau-Stausystems Gabcikovo-Nagymaros CSSR, Ungarn. *Natur und Landschaft,* 64: 64-67.

Marsilius A.F. 1726. Danubius pannonico-mysicus, observationibus geographicis, astronomicis, hydrographicis, historicis, physicis perlustratus et in sex Tomos digestus. Tomus IV. *De piscibus in aquis Danubii viventibus*. Hagae Comitum, Amstelodami. 89 pp.

Milliman J.D. 1997. Blessed dams or dammed dams? *Nature,* 386: 325-327.

Navodaru I., Staras M. & Banks R. 1999. Management of the sturgeon stocks of the Lower Danube System. *Proceedings of the Conference on the Delta's state-of-art protection and management.* pp. 229-37.

Navodaru I., Buijse A.D. & Staras M. 2002. Effects of hydrology and water quality on the fish community in Danube Delta lakes. *Intern. Rev. Hydrobiol.*, 872-3: 329-48.

Penáz M. 1996. *Chondrostoma nasus* – its reproduction strategy and possible reasons for a widely observed population decline – a review. *In* A. Kirchhofer & D. Hefti, eds. *Conservation of endangered freshwater fish in Europe.* pp. 279-85. Bern, Birkhäuser Verlag.

Reinartz R. 2002. Sturgeons in the Danube River: Biology/status/conservation: A literature study conducted on behalf of IAD, Bezirk Oberpfalz and Landesfischereiverband Bayern e.V. 150 pp.

Reinartz R., Bloesch J., Rins T. & Stein H. 2003. Sturgeons are more than caviar: A plea for revival of sturgeons in the Danube River. *Arch. Hydrobiol. Suppl. Large Rivers*. (forthcoming)

Reckendorfer W., Keckeis H., Tiitu V., Winkler G., Zornig H. & Schiemer F. 2001. Diet shifts in 0+ nase, Chondrostoma nasus: Size-specific differences and the effect of food availability. *Archiv Hydrobiol. Suppl.*, 135: 425-40.

Russev B. 1979. Saprobiologische Übersicht der Donau. *Special Issue: XIX. Jubiläumstagung Donauforschung, Bulg. Akademie d. Wiss.* Sofia, 1979. pp. 32-45.

Schiemer F. 1999. Conservation of biodiversity in floodplain rivers, *Large Rivers*, 11: 423-38.

Schiemer F. 2000. Fish as indicators for the assessment of the ecological integrity of large rivers. *Hydrobiologia*, 422/423: 271-278.

Schiemer F. 2002. Fische als Bioindikatoren und Naturschutzziel von großen Fließgewässern. *Verhandlungen der Gesellschaft für Ichthyologie*, 3: 19-35.

Schiemer F. & Spindler T. 1989. Endangered fish species of the Danube River in Austria. Regulated Rivers: Research Management, 4: 397-407.

Schiemer F. & Zalewski M. 1992. The importance of riparian ecotones for diversity and productivity of riverine fish communities. *Neth. J. Zool.*, 42: 323-35.

Schiemer F., Baumgartner C. & Tockner K. 1999. Restoration of floodplain rivers: The Danube restoration project. *Regulated Rivers: Research Management*, 115: 231-44.

Schiemer F., Keckeis H., Winkler G. & Flore L. 2001a. Large rivers: The relevance of ecotonal structure and hydrological properties for the fish fauna. *Arch. Hydrobiol. Suppl.*, 135: 487-508.

Schiemer F., Keckeis H., Reckendorfer W. & Winkler G. 2001b. The inshore retention concept and its significance for large rivers. *Arch. Hydrobiol. Suppl.*, 135: 509-16.

Schiemer F., Spindler T., Wintersberger H., Schneider A. & Chovanec A. 1991. Fish fry associations: Important indicators for the ecological status of large rivers. *Verh. Internat. Verein. Limnol.*, 24: 2497-2500.

Schiemer F. & Waidbacher H. 1992. Strategies for conservation of the Danubian fish fauna. *In* P.J. Boon, P. Calow & G.E. Petts, eds. *River Conservation and Management*. Chichester, UK, John Wiley. pp. 364-84.

Schiemer F., Keckeis H. & Kamler E. 2003. The early life history stages of riverine fish: Ecophysiological and environmental bottlenecks. *CBP Part A*, 133: 439-49.

Schmid R. 2000. Water quality of the Danube and her tributaries - 1995. Explanations to the River Danube water quality map. Gewässergüte der Donau und ihrer Nebenflüsse - 1995. Erläuterungen zur Gewässergütekarte der Donau. State Office for Regional Water Management Regensburg and IAD General Secretary Vienna, April 2000. *Wasserwirtschaftsamt Regensburg und Generalsekretariat IAD Wien*, April 2000.

Stanford J.A., Ward J.V., Liss W.J., Frissell C.A., Williams R.W., Lichatowich J.A. & Coutant C.C. 1996. A general protocol for restoration of regulated Rivers. *Regulated Rivers: Research Management*, 12: 391-413.

Staras M. 2001. Restoration programme in the Danube Delta: Achievement, benefits and constraints. *In Proceedings of the Conference on River Restoration.* The Netherlands, Wageningen. pp. 95-101.

Staras M. & Otel V. 1999. The evidence regarding natural spawning of silver carp species *Hypophthalmichthys molitrix* Val. in the Danube river. *Scientific Annals of the Danube Delta Institute,* 7: 183-87.

Staras M., Cernisencu I. & Constantin G. 1993. New data concerning presence of silver carp *Hypophtalmichthys molitrix*, Val in the Danube river and Delta. *Scientific Annals of Danube Delta Institute,* 2: 259-62. in Romanian

Strásai I. & Andreji J. 2001. Býčko riečny zatial’ posledný invázny druh z čel’ade býčkovitých. The monkey goby so farthe last invasing species from the gobiids family. *Pol’ovníctvo a rybárstvo,* 5311: 43-45. (in Slovak)

Tockner K., Schiemer F. & Ward J.V. 1998. Conservation by restoration: The management concept for a river floodplain on the Danube River in Austria. *Aquatic Conservation: Marine and Freshwater Systems,* 8: 71-86.

Tockner K., Baumgartner C., Schiemer F. & Ward, J.V. 2000. Biodiversity of a Danubian floodplain: Structural, functional and compositional aspects. *In* B. Gopal, W.J. Junk, & J.A. Davis, eds. *Biodiversity in wetlands: Assessment, function and conservation I.* pp. 141-159.

Wachs B. 1997. Zustand und Qualität der Donau. Verantwortung für einen europäischen Strom. *Schriftenreihe des Bundesamtes für Wasserwirtschaft,* 4: 28-51.

Wachs B. 1998. A qualitative classification for the evaluation of the heavy metal contamination in river ecosystems. *Verh. Internat. Verein. Limnol.*, 26: 1289-1294.

Wachs B. 2000. Heavy metal content in Danubian fish. *Large Rivers 11/4 – Arch. Hydrobiol. Suppl.*, 1154: 533-56.

Ward J.V., Tockner K.& Schiemer F. 1999. Biodiversity of floodplain river ecosystems: Ecotones and connectivity. *Regulated Rivers: Research Management,* 15: 125-39.

Water Quality in the Danube River Basin. 1998. *TMNN-Yearbook.* Vienna, ICPDR, 2000.

Waterway Transport on Europa´s Lifeline, the Danube. Vienna, WWF Report. 2002.

Wiesner C., Spolwind R., Waidbacher H., Guttmann S. & Doblinger A. 2000. Erstnachweis der Schwarzmundgrundel Neogobius melanostomus Pallas, 1814 in Österreich. *Österreichs Fischerei,* 53: 330-31.

Winkler G., Keckeis H., Reckendorfer W. & Schiemer F. 1997. Temporal and spatial dynamics of 0+ Chondrostoma nasus at the inshore zone of a large river. *Folia Zoologica,* 46: 151-68.

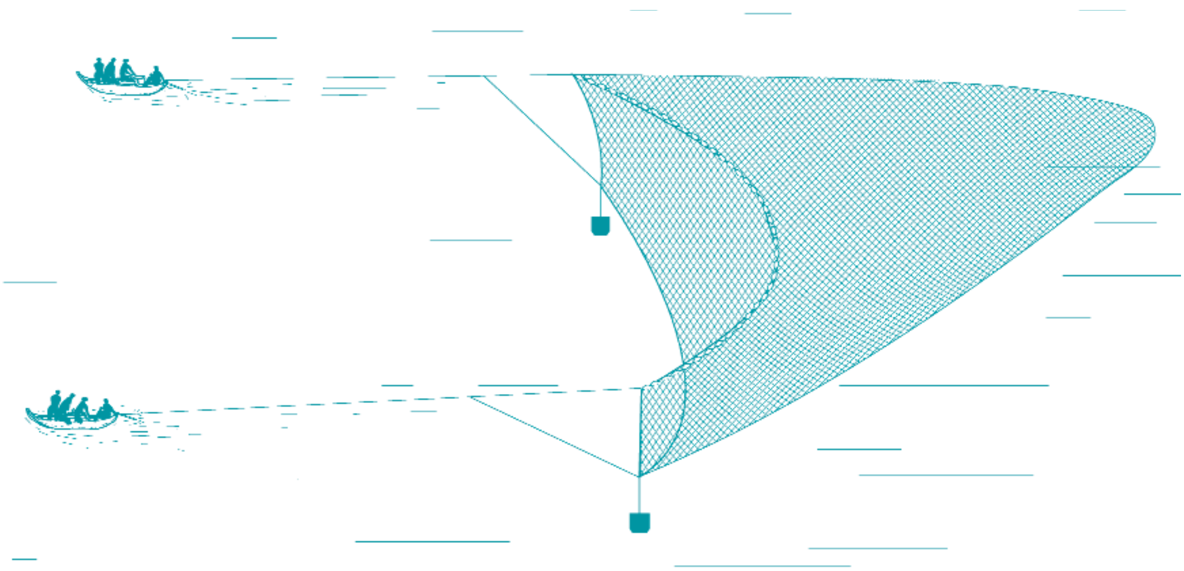
Wintersberger H. 1996a. Species assemblages and habitat selection of larval and juvenile fishes in the River Danube. *Arch. Hydrobiol. Suppl. 113 Large Rivers,* 10: 497-505.

Wintersberger H. 1996b. Spatial resource and species assemblages of larval and juvenile fish. *Arch. Hydrobiol. Suppl.*, 115: 29-44.

STATUS AND MANAGEMENT OF MISSISSIPPI RIVER FISHERIES

H.L. Schramm Jr.

U.S. Geological Survey, Mississippi Cooperative Fish and Wildlife Research Unit Mississippi State, Mississippi 39762 USA E-mail: hschramm atcfr.msstate.edu



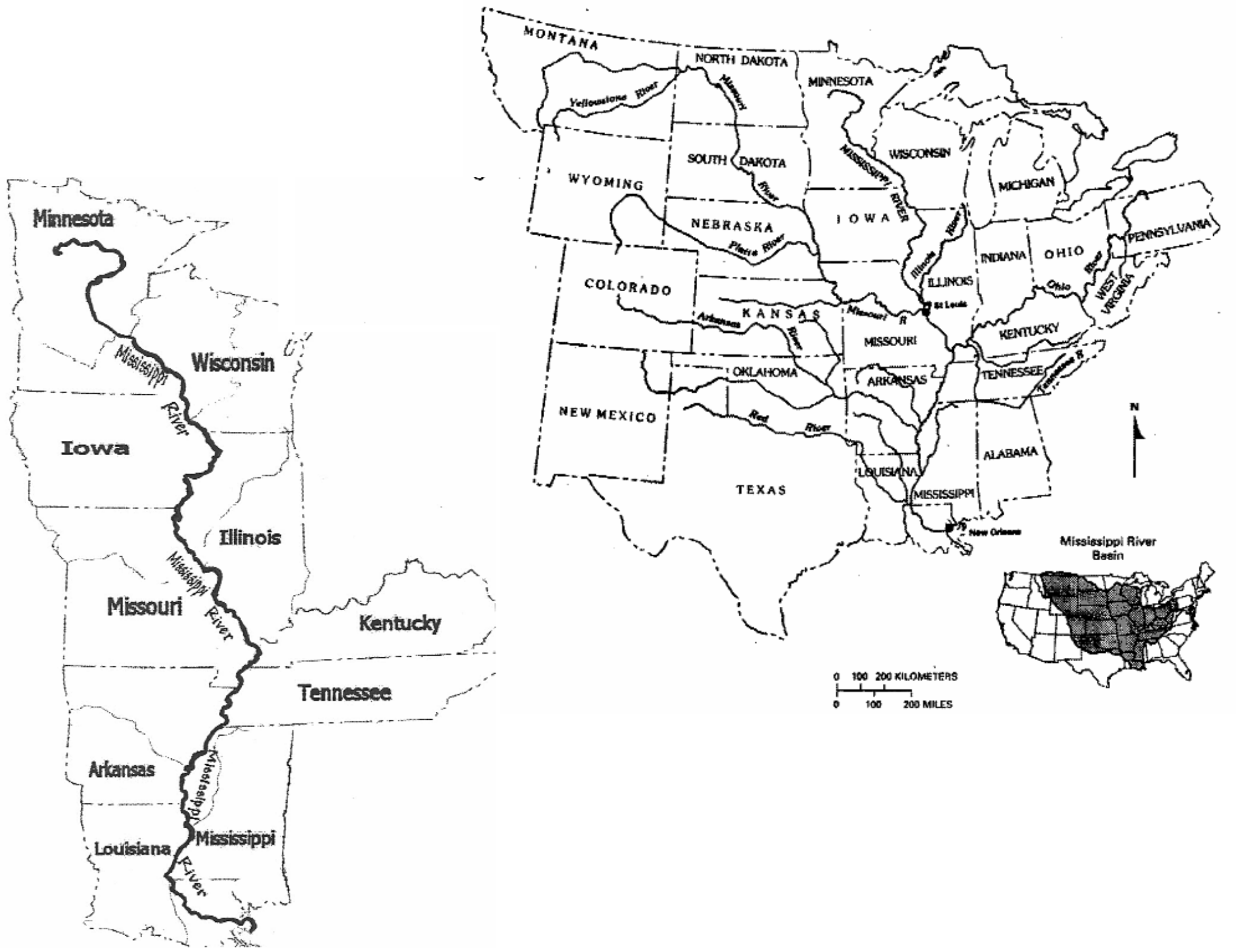
ABSTRACT

The Mississippi River has been variously altered for navigation and flood control but supports a diverse and relatively productive fish assemblage. In the upper, impounded reach, commercial fish harvest has increased for most species since 1945. The upper reach provides an extensive and moderately used recreational fishery resource. Limited information for the lower, un-impounded reach of the Mississippi River indicates commercial harvest is increasing. Neither the commercial nor recreational fisheries appear to be over harvested; however, fisheries for sturgeon and paddlefish should be carefully monitored. Future fisheries production may be threatened by loss of aquatic

habitat, altered spatial and temporal aspects of floodplain inundation and nuisance species invasions. Water quality in most reaches has improved substantially from formerly severely degraded conditions. Navigation traffic affects fish survival and recruitment and increases in navigation are forecast. Future conservation and management of the fisheries and aquatic resources of the Mississippi River will require substantial investment in effective assessment programs and achieving societal recognition of the diverse values of the resource.

INTRODUCTION

The Mississippi River is the largest river in North America. Its 3.25 million km^2 watershed includes parts of two Canadian provinces and parts or all of 31 U.S. states (Figure 1). Daily discharge (measured in the lower river at Vicksburg, Mississippi) ranges from 3 568 to 55 558 m^3 s^{-1} and averages 17 358 m^3 s^{-1}. The Mississippi and its major tributaries - the Arkansas, Illinois, Missouri and Ohio rivers - have been central to the social and economic development of the United States. As a major transportation corridor, the river has been greatly altered for navigation and by developments in its watershed and floodplain for agriculture, industry and urbanization. Comprehensive treatments of the historic and present conditions in the Mississippi River are provided in Scarpino (1985); Fremling *et al.* (1989); Baker, Killgore and Kasul (1991); Rasmussen (1994); Weiner *et al.* (1998); U.S. Geological Survey (1999) and Fremling and Drazkowski (2000).



■ **Figure 1.** Mississippi River basin and Mississippi River. Mississippi River basin figure from Meade (1995).

Ten thousand years ago, the Mississippi River was a continuum typical of a floodplain river. Beginning as a small stream in the forested headwaters of Lake Itasca, Minnesota, the river flowed through virgin forests and unbroken prairie to its deltaic outlet into the Gulf of Mexico in Louisiana. From headwaters to the mouth, the river increased in size and discharge and decreased in slope. Initially, the young river flowed through a small valley bordered by wetlands and lakes. Along its downstream course, the river changed from a single to a braided channel in its mid-reaches and finally to a meandering, constantly changing channel downstream. Its valley changed rather steadily from a narrow floodplain flanked by tall bluffs upstream to a vast, flat floodplain downstream.

In its present form, the Mississippi River changes dramatically and rather incrementally along its 3 731 km journey from headwaters to the Gulf of Mexico. The headwaters reach, the upper 824 km from Lake Itasca to St. Anthony Falls, Minnesota, flows alternately through forests and wetlands. Dams have been built to form 11 small reservoirs and modify the elevation and discharge of several natural river lakes. These dams variously function for flood control, electric generation, water supply, or recreation.

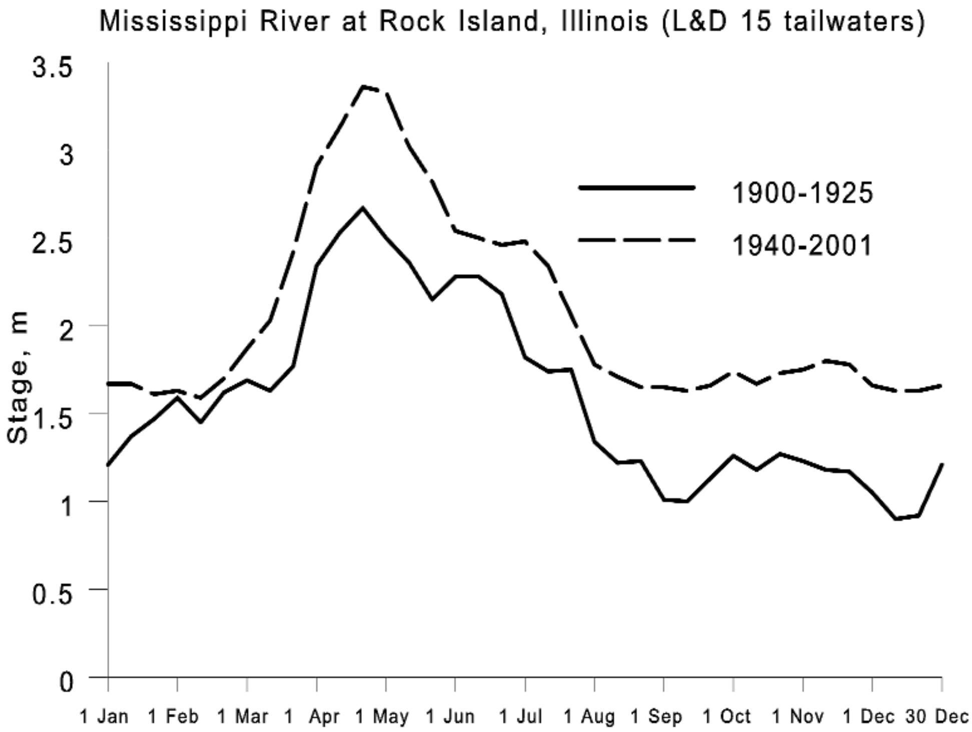
The Upper Mississippi River (UMR) reach stretches 1 075 km from St. Anthony Falls to Alton, Illinois, a few km above the confluence with the Missouri River[1]. The UMR is impounded by 28 locks and dams built for commercial navigation and one dam (Keokuk, Iowa) built for navigation and hydropower generation. These dams are operated to maintain minimum navigation channel depth (9 feet, 2.7 m); thus, the dams have little effect on the river stage and discharge during spring floods. The dams, however, have increased the river elevation throughout the annual cycle (Figure 2). The timing and relative increase during the spring rise resembles the pre-dam condition, but the natural summer drawdown and the autumn rise are missing. Throughout the UMR, the dams have increased the area of aquatic habitat at low-water river stage from 971 km^2 before dams to 1 495 km^2 after dam construction, essentially permanently inundating 23 percent of historic wetlands and seasonally inundated floodplain (49 km^2 of marsh and 820 km^2 of floodplains; J. Rogala, U.S. Geological Survey, unpublished data). Navigation channel depth and alignment in the open river is maintained by wing dykes[2], closing dykes[3], bank revetment[4] and dredging. Most of these structures are remnants of the former channel before impoundment, but some are new and many require

[1] Terminology for different reaches of the Mississippi River is not uniform among different management agencies. For example, the Upper Mississippi River Conservation Committee defines the UMR as the reach of the Mississippi River from St. Anthony Falls, Minnesota, to the confluence with the Ohio River at Cairo, Illinois. The terminology adopted in this paper was chosen for its ecological utility.

[2] Wing dikes are large rock riprap structures that extend from the shore into the main channel. The surface elevation of most dikes is 2-3 m above low water elevation in the MMR and LMR. In the UMR, dikes constructed before impoundment remain in place and, for the most part, remain at or below normal navigation pool surface elevation. The dikes are placed to divert the flow of water, thereby both controlling the path of the main channel and directing the energy to scour the navigation channel. Usually multiple dikes are placed in a longitudinal series, with shorter dikes upstream; these groups of three or more dikes are called dike fields.

[3] Closing dikes, like wing dikes, are large rock riprap structures placed to block or reduce flow to a secondary channel or backwater, thereby increasing flow in the main channel. The main channel contains the thalweg and is used for navigation. Secondary channels are former main channels or channels created when the flow of the river cuts across a point bar forming a new channel. Dike fields often are used to close secondary channels and backwaters.

[4] Revetments are installed on high energy banks to armor the river bank against erosion. Although various materials have been used in the past, present-day revetments consist of large (>0.3 m) rock riprap or, in the LMR, articulated concrete mattress (concrete slabs approximately 30 cm x 70 cm x 7 cm thick connected by stainless steel wire) for lower bank (from 1-3 m above low water elevation to the toe of the channel) protection and large rock riprap for upper bank protection.

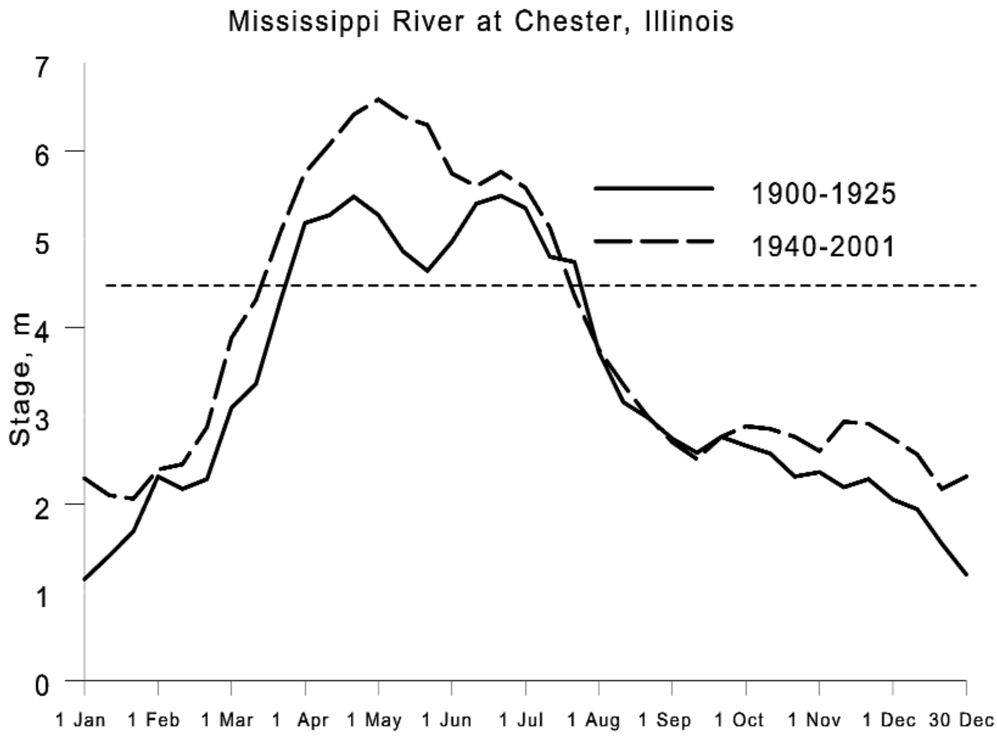


■ **Figure 2.** Average stage at Upper Mississippi River Lock and Dam 15 tailwaters, Rock Island, Illinois. 1900-1925 is pre-impoundment; 1940-2002 is post-impoundment.

routine maintenance. The navigation channel retains substantial flow even during low river stages; however, flows through aquatic habitats lateral to the navigation channel are greatly reduced resulting in off-channel sedimentation, stagnation and deep-water habitat loss. Because the dams, to maintain a minimum navigation depth, dampen drawdown, less floodplain is exposed during lower-flow periods and less floodplain area is inundated during the annual spring rise. In the lower third of the UMR, the natural bluffs flanking the floodplain diminish and the floodplain expands laterally. Here, levees and railroad embankments have been built relatively close to the riverbank to contain floodwaters and reclaim fertile bottomlands for agriculture, reducing the floodplain to a fraction of its former area.

Downstream from the confluence of the Missouri River, the Mississippi flows un-dammed for 1 834 km to Head of Passes where it branches into several distributaries that carry water to the Gulf of Mexico. The 314 km reach from the mouth of the Missouri River to the mouth of the Ohio River is referred to as the Middle Mississippi River (MMR) by management agencies. Flows from the Missouri River almost double the volume of water flowing through the MMR (Meade 1995). The 1 570 km reach from the Ohio River to Head of Passes is referred to as the Lower Mississippi River (LMR). Water from the Ohio River increases Mississippi River discharge 150 percent (Meade 1995). Although discharge and channel size differ between the two reaches, both share similar hydrologic conditions, methods and levels of channelization and loss of connectivity with the historic floodplain. Thus, I will refer to the MMR and LMR collectively as the Aopen River reach. The MMR fluctuates an average of 4 m throughout the year (Figure 3), while the LMR, influenced by Ohio River discharge (60 percent of LMR discharge), fluctuates an average of almost 10 m (Figure 4). Nevertheless, hydrographs of the two reaches are similar. As in the UMR, the U.S.

Army Corps of Engineers is mandated to maintain a 9-feet (2.7 m) deep, 300-feet (91 m) wide navigation channel in the open river reach. To maintain access to harbours and cargo ports and to preserve waterfront developments, it is also necessary to maintain current channel alignment. Navigation channel depth and alignment in the open river is maintained by wing dykes, closing dykes, bank revetment and dredging. Historically, the open river reach had a seasonally inundated (active) floodplain that extended from several to almost 200 km from the riverbank. A continuous (except for breaks at tributary river mouths) levee system lining both banks of the MMR and LMR was completed after the record 1927 flood and has severed the floodplain from the river. In the MMR, levees have reduced the active floodplain (the portion inundated by the spring flood pulse) by 50 percent (Duyvejonck 2002). Throughout the 1 000 km LMR, the levees have severed connection of the river from 90 percent of its historic 103 000 km² floodplain.

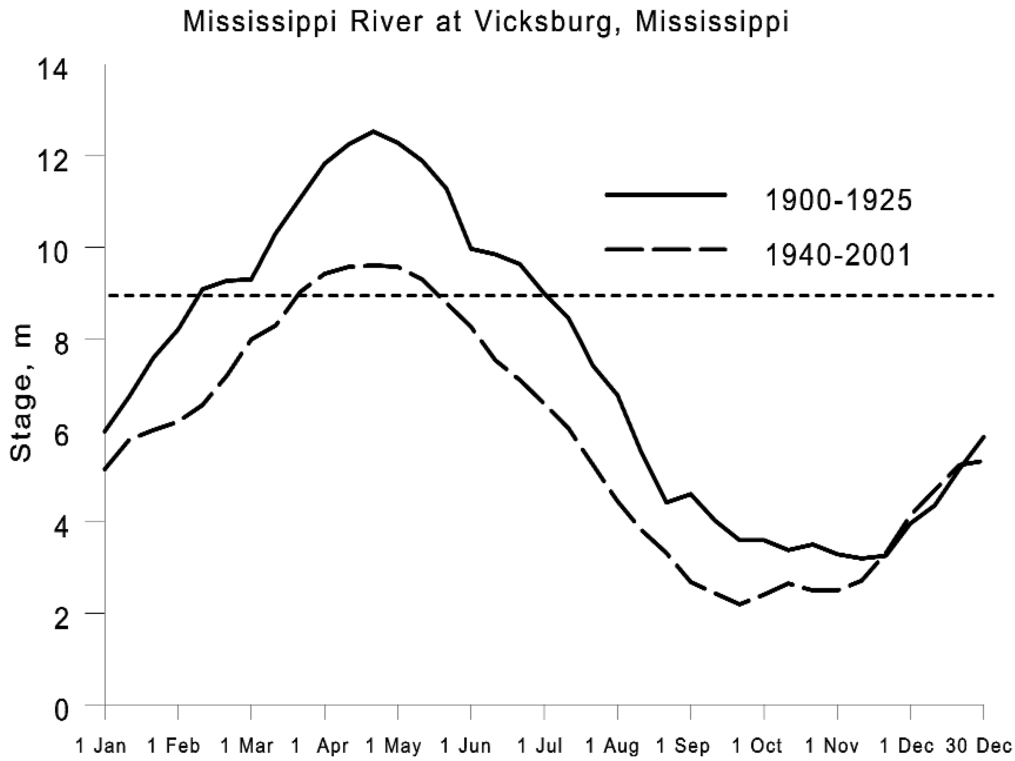


■ **Figure 3.** Average stage in the Middle Mississippi River, Chester, Illinois. 1900-1925 is before mainline levee construction; 1940-2002 is after mainline levee construction.

Classification of river reaches based on the form and consequences of anthropogenic perturbations is convenient, even desirable, from both ecological and management perspectives. The ecological structure and function of the headwaters, UMR and open river segments are expected to differ and these differences should influence assessment and research questions. Similarly, management goals and strategies are expected to differ among reaches. However, it also is important to recognize that each reach represents a continuum as the river traverses a latitudinal gradient, grows with each added tributary and the amount of floodplain increases (Schramm, Eggleton and Minnis 1999).

FISHERIES HABITAT

Several ecological classification schemes have been developed to delineate and define the diversity of Mississippi River habitats (e.g. Sternberg 1971; Cobb and Clark 1981; Baker *et al.* 1991; Wilcox 1993). Although illuminating habitat diversity, defining the different habitats and providing a foundation for



■ **Figure 4**. Average stage in the Lower Mississippi River, Vicksburg, Mississippi. 1900-1925 is before mainline levee and cutoff construction; 1940-2002 is after mainline levee and cutoff construction. Horizontal dashed line is bank full stage, the stage at which floodplain inundation begins.

effective fisheries and habitat assessment (e.g. stratified sampling), the classification systems are neither uniform, nor necessarily applicable, throughout the entire Mississippi River. For example, a widely used classification for the UMR recognizes main channel, channel border (which can be a very extensive habitat in the lower portions of the navigation impoundments), slough (side channels with current) and backwater lake habitats (Sternberg 1971; Rasmussen 1979). A second scheme developed for the UMR by Wilcox (1993) lists 44 different aquatic habitats. In addition to physical location, Wilcox uses other parameters (i.e. depth, current velocity and turbulence, water temperature, dissolved oxygen, suspended solids, light, substrate type and cover type) to further define aquatic habitats. A classification scheme developed for the LMR recognizes channel, natural and revetted banks, lentic and lotic sandbars, two types of abandoned channels and three types of floodplain lakes or ponds (Baker *et al*. 1991). Undoubtedly, habitat diversity was greater prior to channelization and impoundment. Nevertheless, if only diversity of current velocity (up to 3 m s^{-1}), substrate, depth (up to 40 m) and aquatic vegetation (headwaters and UMR only) conditions are considered, the Mississippi River, even in its altered state, provides diverse fish habitats. Water level fluctuations further increase habitat diversity as rises transform some lentic habitats to lotic and terrestrial habitats become diverse, complex aquatic habitats.

Baker *et al*. (1991) used multivariate analyses to delineate habitats. Although a progressive and promising approach, the results of such analyses are constrained by inability to measure habitat conditions (e.g. current direction and velocity are usually measured near the surface), by selectivity of fish sampling gear and by temporal fluctuations in river stage and discharge. Although Baker *et al*. (1991) described their resulting habitat delineations as microhabitats, the inherent variability in river conditions over a spatial scale greater than several meters precludes considering a habitat even as homogeneous as a sand bar as a single microhabitat. Further, habitat use changes over time as both river conditions and biological requirements follow their seasonal chronology. In the LMR, the abundance of several fishes at steep natural banks (a microhabitat listed by Baker *et al*. 1991) varied significantly when current velocity was reduced, suggesting a single variable changing over time can determine habitat suitability for a species (Schramm *et al.* 1998; Schramm *et al.* 1999). Conversely, changes at the macroscopic level also can affect fish abundance. The abundance of fishes collected in a sandbar habitat changed significantly following hydraulic changes in the adjacent channel, even though the physical conditions of the areas sampled remained similar over time (Schramm *et al*. 1999).

FISHERIES RESOURCES

As would be expected for a river that grows from a first to a tenth or eleventh order stream (Strahler 1952) and flows more than 3 500 km from its origin in a cool temperate climate to its subtropical outlet, the Mississippi River supports a rich fish assemblage. In their comprehensive assessment, Fremling *et al.* (1989) list 193 freshwater species in 27 families for the Mississippi River. Although no thorough ichthyofaunal surveys have been conducted in at least the past 30 years, additional inventories have been compiled since 1989 (Baker *et al*. 1991; Pitlo, Van Vooren and Rasmussen 1995; Warren, Burr, Walsh *et al.* 2000). Table 1 is offered as a current assessment of Mississippi River fishes. The table includes those species reported by Fremling *et al.* (1989); Baker *et al.* (1991); Pitlo *et al.* (1995) and Warren *et al*. (2000) and has been reviewed by six ichthyologists familiar with Mississippi River fauna (Table 1). Excluded from the table are fishes considered strays (i.e. fishes likely from a tributary or from stocking) by Fremling *et al*. (1989) and Pitlo *et al.* (1995) and marine species collected only in the lower 150 km of the river. Information from the published papers and reports cited elsewhere in this paper was supplemented with synoptic life history information available in Carlander (1969, 1977, 1997); Pflieger (1975); Becker (1983); Robison and Buchanan (1988); Etnier and Starnes (1993); Mettee, O'Neil and Pierson (1966) and Ross (2001) to qualitatively designate habitat zones each species is likely to occupy and to classify it as backwater dependent, riverine dependent, or peripheral. Limited and inconsistent information precluded the use of quantitative classification procedures. Given the lack of a standardized habitat classification, the insufficiency of data for a microhabitat approach (*sensu* Baker *et al.* 1991) and the paucity of information about habitat requirements, preferences and tolerances of even some of the common Mississippi River fishes, I have assigned each species to one or more of three habitat zones: main channel[5], channel border[6] and backwater[7]. Fishes are considered backwater dependent if they require conditions such as no current, soft-sediment bottom, or aquatic or inundated terrestrial vegetation during at least some portion of their life cycle. Although usually present in a variety of habitats in the backwater zone, these conditions may also be found in isolated areas of the channel border zone. Riverine-dependent fishes are those that require flowing water and sand, gravel, or rock substrate during at least some portion of their life cycle; these conditions may be found in the main channel or channel border zones. A species is considered peripheral to the Mississippi River if available life history information indicates that the species inhabits tributary rivers or streams, prefers small rivers or streams, or avoids or is rare in large rivers. All designations of habitat zone and dependency are specific to the reach of the Mississippi River where the species occurs; for example a shallow, riffle-dwelling species may occupy the main channel in the upper headwaters reach but may be restricted to the channel border in the UMR or open river reaches.

Excluding marine, diadromous and peripheral species and species not recently collected (hereafter, resident species), 140 species are resident in the Mississippi River; 4 of these species are introduced. Sixty-one species are resident in the Headwaters, 107 species in the UMR and 109 species in the open river. Sufficient evidence was available to consider 55 resident species backwater dependent and 17 resident species riverine dependent. Of the 137 resident species I was able to assign to habitat zones, none are expected to reside in main channel habitats throughout their life cycle, 24 are expected to occupy one or more channel border habitats throughout their life cycle and 50 species are expected to reside in one or more backwater habitats throughout their life cycle. A substantial number of fish were considered rare by Fremling *et al*. (1989) or Baker *et al*. (1991). Including fish not recently collected (Fremling *et al*. 1989), 23 resident species are rare in the Headwaters, 24 species are rare in the UMR and 24 species are rare in the open river.

Fish production has not been estimated and biomass estimates are limited. Individual estimates are highly variable but tend to range from 300-900 kg ha^{-1}

Table 1: Distribution and abundance of fishes in the headwaters (HW), upper (UMR), or open river (OR) segments of the Mississippi River. Fish are resident in the Mississippi River unless noted otherwise (Residence). Data were compiled from Fremling *et al*. (1989), Baker *et al*. (1991), Pitlo *et al*. (1995), and Warren *et al*. (2000). Fish categorized as strays by Fremling *et al*. (1989) and marine fishes collected only in the lower 150 km of the Mississippi River are excluded. Backwater dependent or riverine dependent indicates those taxa that are dependent on backwater or riverine conditions to complete their life cycle. Probable zone is the area of the river from which the fish have been or are likely to be collected.

Modified from Pitlo *et al*. 1995, Schlicht, Diederman, Bartels

Family species	Residence[1]	HW[2]	UMR[2]	OR[2]	Back water dependent	Riverine dependent	Probable zone[3]
Petromyzontidae							
Chestnut lamprey, *Ichthyomyzon castaneus* (Girard)			O/U	O/R			MC, CB
Silver lamprey, *Ichthyomyzon unicuspis* (Hubbs and Trautman)			O	R			MC, CB
American brook lamprey, *Lampetra appendix* (DeKay)			R				MC, CB, BW

[5] Main channel is the portion of the river that contains the thalweg and the navigation channel; water is relatively deep and the current, although varying temporally and spatially, is persistent and relatively strong.

[6] Channel border is the zone from the main channel to the riverbank. Current velocity and depth will vary, generally decreasing with distance from the main channel, but the channel border is a zone of slower current, shallower water, and greater habitat heterogeneity. Channel border includes secondary channels and sloughs, islands and their associated sandbars, dikes and dike pools, and natural and revetted banks of other authors.

[7] The backwater zone includes lentic habitats lateral to the channel border that are connected to the river at least for some time in most years. This zone includes abandoned channels (including floodplain lakes) severed from the river at the upstream or both ends, lakes lateral to the channel border, ephemeral floodplain ponds, borrow pits created when levees were built, and the floodplain itself during overbank stages.

Family species	**Resi-dence**[1]	**HW**[2]	**UMR**[2]	**OR**[2]	**Back water dependent**	**Riverine dependent**	**Probable zone**[3]
Ascipenseridae							
Lake sturgeon, *Acipenser fulvescens* (Rafinesque)			O[4]	R[4]		Yes	MC, CB
Atlantic sturgeon, *Acipenser oxyrhynchus* (*Mitchill*)	D			R[5]			MC, CB
Pallid sturgeon, *Scaphirhynchus albus* (Forbes and Richardson)			R	O		Yes	MC, CB
Shovelnose sturgeon, *Scaphirhynchus platorynchus* (Rafinesque)			O	O		Yes	MC, CB
Polyodontidae							
Paddlefish, *Polyodon spathula* (Walbaum)			O	O		Yes	MC, CB, BW
Lepisosteidae							
Alligator gar, *Atractosteus spatula* (Lacepede)				R	Yes		BW
Spotted gar, *Lepisosteus oculatus* (Winchell)			U	O	Yes		BW
Longnose gar, *Lepisosteus osseus* (Linnaeus)			O	C	Yes		MC, CB, BW
Shortnose gar, *Lepisosteus platostomus* (Rafinesque)		H1	C	C	Yes		MC, CB, BW
Amiidae							
Bowfin, *Amia calva* (Linnaeus)		R	C	O	Yes		BW
Anguillidae							
American eel, *Anguilla rostrata* (Lesueur)	D	R	O	U			CB
Hiodontidae							
Goldeye, *Hiodon alosoides* (Rafinesque)			U	O			CB
Mooneye, *Hiodon tergisus* (Lesueur)			O	U/R			CB
Clupeidae							
Alabama shad, *Alosa alabamae* (Jordan and Everman)	D			R			MC, CB
Skipjack herring, *Alosa chrysochloris* (Rafinesque)			O/R	C			MC, CB, BW
Gizzard shad, *Dorosoma cepedianum* (Lesueur)		A	A	A	Yes		MC, CB, BW
Threadfin shad, *Dorosoma petenense* (Günther)			U	A	Yes		CB, BW
Salmonidae							
Cisco, *Coregonus artedi* (Lesueur)		R	R				BW
Umbridae							
Central mudminnow, *Umbra limi* (Kirtland)		U	O		Yes		BW
Esocidae							
Grass pickerel, *Esox americanus vermiculatus* (Lesueur)			R	R	Yes		BW
Northern pike, *Esox lucius* (Linnaeus)		O	O		Yes		BW
Muskellunge, *Esox masquinongy* (Mitchill)		O/U			Yes		BW
Chain pickerel, *Esox niger* (Lesueur)				R[5]	Yes		BW
Cyprinidae							
Central stoneroller, *Campostoma anomalum* (Rafinesque)		R	R	H2[6]			MC, CB
Goldfish, *Carassius auratus* (Linnaeus)	I		U	R	Yes		BW

Family species	Residence[1]	HW[2]	UMR[2]	OR[2]	Back water dependent	Riverine dependent	Probable zone[3]
Grass carp, *Ctenopharyngodon idella* (Valenciennes)	I		U	U		Yes	MC, CB, BW
Bluntface shiner, *Cyprinella camura* (Jordan and Meek)	P			H2			CB
Red shiner, *Cyprinella lutrensis* (Baird and Girard)			O	C/O	Yes		CB, BW
Spotfin shiner, *Cyprinella spiloptera* (Cope)		C	C	R			CB, BW
Blacktail shiner, *Cyprinella venusta (*Girard)				O			CB, BW
Steelcolor shiner, *Cyprinella whipplei* (Girard)	P			R			CB, BW
Common carp, *Cyprinus carpio* (Linnaeus)	I	C	A	C	Yes		CB, BW
Gravel chub, *Erimystax x-punctatus* (Hubbs and Crowe)				R			CB, BW
Western silvery minnow, *Hybognathus argyritis* (Girard)				R			BW
Brassy minnow, *Hybognathus hankinsoni* (Hubbs)		U	R				CB
Cypress minnow, *Hybognathus hayi* (Jordan)				R	Yes		BW
Mississippi silvery minnow, *Hybognathus nuchalis* (Agassiz)			U/R	O	Yes		CB, BW
Plains minnow, *Hybognathus placitus* (Girard)				U/R		Yes	MC, CB
Clear chub, *Hybopsis winchelli* (Girard)				R[5]			CB
Silver carp, *Hypophthalmichthys molitrix* (Valenciennes)	I		C/O	C			CB
Bighead carp, *Hypophthalmichthys nobilis* (Richardson)	I		O	O			CB
Striped shiner, *Luxilus chrysocephalus (*Rafinesque)	P			R			CB
Common shiner, *Luxilus cornutus* (Mitchill)		C	O/R				MC, CB, BW
Ribbon shiner, *Lythrurus fumeus* (Evermann)	P			R			BW
Redfin shiner, *Lythrurus umbratilis* (Girard)	P		R	H2			CB, BW
Speckled chub, *Macrhybopsis aestivalis* (Girard)			O	C			CB
Sturgeon chub, *Macrhybopsis gelida* (Girard)				U/R			CB
Sicklefin chub, *Macrhybopsis meeki* (Jordan and Everman)				U/R			CB
Silver chub, *Macrhybopsis storeriana* (Kirtland)			C/O	C/O			CB, BW
Pearl dace, *Margariscus margarita* (Cope)		R					MC, CB, BW
Black carp, *Mylopharyngodom piceus* (Richardson)	I			R			CB, BW
Hornyhead chub, *Nocomis biguttatus* (Kirtland)		O	R				CB
Golden shiner, *Notemigonus crysoleucas* (Mitchill)		O	C/O	U	Yes		BW
Pallid shiner, *Notropis amnis* (Hubbs and Greene)			R				CB
Emerald shiner, *Notropis atherinoides* (Rafinesque)		A	A	A			CB, BW

Family species	**Residence[1]**	**HW[2]**	**UMR[2]**	**OR[2]**	**Back water dependent**	**Riverine dependent**	**Probable zone[3]**
River shiner, *Notropis blennius* (Girard)			C	C			CB, BW
Bigeye shiner, *Notropis boops* (Gilbert)	P			R			CB
Ghost shiner, *Notropis buchanani* (Meek)			R	U/R	Yes		CB, BW
Bigmouth shiner, *Notropis dorsalis* (Agassiz)		P	O	O/R	R		CB
Blackchin shiner, *Notropis heterodon* (Cope)		U	O/R		Yes		BW
Blacknose shiner, *Notropis heterolepis* (Eigenmann and Eigenmann)		U	R				BW
Spottail shiner, *Notropis hudsonius* (Clinton)		U	U	R			CB
Longnose shiner, *Notropis longirostris* (Hay)				U[5]		Yes	MC, CB
Ozark minnow, *Notropis nubilus* (Forbes)	P		R	R			CB
Chub shiner, *Notropis potteri* (Hubbs and Bonham)				R			CB
Rosyface shiner, *Notropis rubellus* (Agassiz)	P		R				CB
Silverband shiner, *Notropis shumardi* (Girard)			R	O			CB, BW
Sand shiner, *Notropis stramineus* (Cope)	P	R	O	U[5]			CB
Weed shiner, *Notropis texanus* (Girard)			O	U	Yes		BW
Mimic shiner, *Notropis volucellus* (Cope)		R	C	O			CB, BW
Channel shiner, *Notropis wickliffi* (Trautman)			C/O	O			MC, CB
Pugnose minnow, *Opsopoeodus emiliae* (Hay)			O	O	Yes		BW
Suckermouth minnow, *Phenacobius mirabilis* (Girard)			R	R			CB, BW
Northern redbelly dace, *Phoxinus eos* (Cope)		C					CB
Southern redbelly dace, *Phoxinus erythrogaster* (Rafinesque)		P		H1	H2		CB
Finescale dace, *Phoxinus neogaeus* (Cope)		R					CB, BW
Bluntnose minnow, *Pimephales notatus* (Rafinesque)		P	O	O	U		BW
Fathead minnow, *Pimephales promelas* Rafinesque		C/U	U	R	Yes		BW
Bullhead minnow, *Pimephales vigilax* (Baird and Girard)		R	O	O	Yes		BW
Flathead chub, *Platygobio gracilis gracilis* (Richardson)				R		Yes	CB
Eastern blacknose dace, *Rhinichthys atratulus* (Hermann)	P	U	R			Yes	CB
Longnose dace, *Rhinichthys cataractae* (Valenciennes)		C/O	R			Yes	CB
Creek chub, *Semotilus atromaculatus* (Mitchill)		O	R			Yes	MC, CB
Catostomidae							
River carpsucker, *Carpiodes carpio* (Rafinesque)			C	A		Yes	CB, BW
Quillback, *Carpiodes cyprinus* (Lesueur)		R	C	U			CB, BW
Highfin carpsucker, *Carpiodes velifer* (Rafinesque)			O/U	R			CB, BW
White sucker, *Catostomus commersoni* (Lacepü de)		C	C				MC, CB, BW

Family species	Resi-dence[1]	HW[2]	UMR[2]	OR[2]	Back water dependent	Riverine dependent	Probable zone[3]
Blue sucker, *Cycleptus elongatus* (Lesueur)			O	O		Yes	MC, CB
Creek chubsucker, *Erimyzon oblongus* (Mitchill)				U			BW
Lake chubsucker, *Erimyzon succetta* (Lacepü de)				U			BW
Northern hog sucker, *Hypentelium nigricans* (Lesueur)		O	R				CB
Smallmouth buffalo, *Ictiobus bubalus* (Rafinesque)			C/O	A/C	Yes		MC, CB, BW
Bigmouth buffalo, *Ictiobus cyprinellus* (Valenciennes)		O	C	C/O	Yes		CB, BW
Black buffalo, *Ictiobus niger* (Rafinesque)			U/R	U	Yes		CB, BW
Spotted sucker, *Minytrema melanops* (Rafinesque)			C/O	U/R[5]	Yes		CB, BW
Silver redhorse, *Moxostoma anisurum* (Rafinesque)		O	C/O	H2			CB, BW
River redhorse, *Moxostoma carinatum* (Cope)			O/R	R			CB
Golden redhorse, *Moxostoma erythrurum* (Rafinesque)			O				MC, CB
Shorthead redhorse, *Moxostoma macrole pidotum* (Lesueur)		C	C/O	U[7]			MC, CB
Greater redhorse, *Moxostoma valenciennesi* (Jordan)		O	R			Yes	MC, CB, BW
Ictaluridae							
White catfish, *Ameiurus catus* (Linnaeus)	P			H3			
Black bullhead, *Ameiurus melas* (Rafinesque)		R	O	U	Yes		BW
Yellow bullhead, *Ameiurus natalis* (Lesueur)		R	O	U	Yes		BW
Brown bullhead, *Ameiurus nebulosus* (Lesueur)		R	O		Yes		BW
Blue catfish, *Ictalurus furcatus* (Lesueur)			O	A			MC, CB
Channel catfish, *Ictalurus punctatus* (Rafinesque)		O	C	C			CB, BW
Mountain madtom, *Noturus eleutherus* (Jordan)				H1		Yes	CB
Stonecat, *Noturus flavus* (Rafinesque)		R	R	O		Yes	CB
Tadpole madtom, *Noturus gyrinus* (Mitchill)		R	O	U/R	Yes		BW
Freckled madtom, *Noturus nocturnus* (Jordan and Gilbert)			R	O/U			BW
Northern madtom, *Noturus stigmosus* (Taylor)				H2			CB, BW
Flathead catfish, *Pylodictis olivaris* (Rafinesque)		R	C/O	A			MC, CB
Aphredoderidae							
Western pirate perch, *Aphredoderus sayanus* (Gilliams)			R	R	Yes		BW
Percopsidae							
Trout-perch, *Percopsis omiscomaycus* (Walbaum)		O	O		Yes		BW
Gadidae							
Burbot, *Lota lota* (Linnaeus)		O	R				CB, BW

Family species	Residence[1]	HW[2]	UMR[2]	OR[2]	Back water dependent	Riverine dependent	Probable zone[3]
Fundulidae							
Golden topminnow, *Fundulus chrysotus* (Günther)	P			R	Yes		BW
Banded killifish, *Fundulus diaphanus* (Le Sueur)		R	H1				
Starhead topminnow, *Fundulus dispar* (Agassiz)	P		R	R			BW
Blackstripe topminnow, *Fundulus notatus* (Rafinesque)			O	O	Yes		BW
Blackspotted topminnow, *Fundulus olivaceus* (Storer)				O	Yes		BW
Poeciliidae							
Western mosquitofish, *Gambusia affinis* (Baird and Girard)			O	O	Yes		BW
Atherinidae							
Brook silverside, *Labidesthes sicculus* (Cope)		O	C/O	C/O			BW
Inland silverside, *Menidia beryllina* (Cope)				O			CB, BW
Gasterosteidae							
Brook stickleback, *Culaea inconstans* (Kirtland)		R	R				MC, CB
Cottidae							
Mottled sculpin, *Cottus bairdi* (Girard)		R					
Percichthyidae							
White bass, *Morone chrysops* (Rafinesque)		R	C	C			CB, BW
Yellow bass, *Morone mississippiensis* (Jordan and Everman)			R/O	O			BW
Striped bass, *Morone saxatilis* (Walbaum)[7]	D			O			MC, CB
Centrarchidae							
Rock bass, *Ambloplites rupestris* (Rafinesque)		C	C/O		Yes		BW
Shadow bass, *Ambloplites arriomus* (Viosca)	P			U[5]			BW
Flier, *Centrarchus macropterus* (Lacepüde)				O	Yes		BW
Banded pygmy sunfish, *Elassoma zonatum* (Jordan)				R[5]	Yes		BW
Green sunfish, *Lepomis cyanellus* (Rafinesque)		R	C/O	U	Yes		BW
Pumpkinseed, *Lepomis gibbosus* (Linnaeus)		R	C/O		Yes		BW
Warmouth, *Lepomis gulosus* (Cuvier)			O/U	C/O	Yes		BW
Orangespotted sunfish *Lepomis humilis* (Girard)			O	O	Yes		BW
Bluegill, *Lepomis macrochirus* (Rafinesque)		O	A	C	Yes		BW
Longear sunfish, *Lepomis megalotis* (Rafinesque)				U	Yes		BW
Redear sunfish, *Lepomis microlophus* (Günther)				U	Yes		BW
Bantam sunfish, *Lepomis symmetricus* (Forbes)				O[5]	Yes		BW
Smallmouth bass, *Micropterus dolomieu* (Lacepüde)		C	O				CB, BW
Spotted bass, *Micropterus punctulatus* (Rafinesque)	P			R			CB, BW
Largemouth bass, *Micropterus salmoides* (Lacepüde)		O	C	C	Yes		BW
White crappie, *Pomoxis annularis* (Rafinesque)		R	C	C	Yes		BW
Black crappie, *Pomoxis nigromaculatus* (Lesueur)		O	C	O/U	Yes		BW

Family species	Resi-dence[1]	HW[2]	UMR[2]	OR[2]	Back water dependent	Riverine dependent	Probable zone[3]
Percidae							
Western sand darter, *Ammocrypta clara* (Jordan and Meek)	P		O	R		Yes	CB, BW
Crystal darter, *Crystallaria asprella* (Jordan)	P		R	R		Yes	CB
Mud darter, *Etheostoma asprigene* (Forbes)			O/R	O			BW
Rainbow darter, *Etheostoma caeruleum* (Storer)	P		R	R			CB
Bluntnose darter, *Etheostoma chlorosoma* (Hay)			R	U			BW
Iowa darter, *Etheostoma exile*			R				
Fantail darter, *Etheostoma flabellare* (Rafinesque)	P		R			Yes	CB
Swamp darter, *Etheostoma fusiforme* (Girard)				U[5]	Yes		BW
Slough darter, *Etheostoma gracile* (Girard)				U			BW
Johnny darter, *Etheostoma nigrum* Rafinesque		O	O	R[5]			CB, BW
Cypress darter, *Etheostoma proeliare* (Hay)	P			O[5]			BW
Missouri saddled darter, *Etheostoma tetrazonum* (Hubbs and Black)	P			R[5]			
Banded darter, *Etheostoma zonale* (Cope)	P		R				
Yellow perch, *Perca flavescens* (Mitchill)		O	C/O		Yes		CB, BW
Log perch, *Percina caprodes* (Rafinesque)		O	C/O	R[5]	Yes		CB, BW
Gilt darter, *Percina evides* (Jordan and Copeland)	P		H1				CB
Blackside darter, *Percina maculata* (Girard)		C	R				
Saddleback darter, *Percina vigil* (Hay)				U			CB
Slenderhead darter, *Percina phoxocephala* (Nelson)			R	R[5]			CB
River darter, *Percina shumardi* (Girard)			O	O/U			CB
Sauger, *Stizostedion canadense* (Smith)		R	C	O			CB
Walleye, *Stizostedion vitreum* (Mitchill)		O	C	U/R			CB, BW
Sciaenidae							
Freshwater drum, *Aplodinotus grunniens* (Rafinesque)		R	A	A		Yes	CB, BW
Mugilidae							
Striped mullet, *Mugil cephalus* (Linnaeus)	M			O			CB

1 Db diadromous, Ib introduced, Mb marine, PB peripheral, typically occupies tributary streams and rivers but may temporarily enter the Mississippi River.

2 AB abundantly taken in all river surveys. CB commonly taken in most surveys. OB occasionally collected; not generally distributed but local concentrations may occur. UB Uncommon, does not usually appear in survey samples. RB Considered rare. H1B Taxon has been collected in the Mississippi River but no records of collection since 1978 (Fremling *et al*. 1989). H2B Taxon reported as present by Warren *et al*. (2000) but abundance not known. H3B Taxon presumed by Warren *et al*. (2000) to be present but not verified by collection records.

3 MCB main channel CBB channel border BWB backwater.

4 Occasional occurrence in UMR; rare occurrence in OR attributed to stocking.

5 Not listed as present in the open-river reach of the Mississippi River by Warren *et al*. 2000.

6 Warren *et al*. (2000) list Mississippi stoneroller (*C. a. pullum*) as present in the open-river reach of the Mississippi River.

7 Warren *et al*. (2000) list pealip redhorse (*M. m. pisolabrum*) as present in the open-river reach of the Mississippi River.

5 The Gulf Coast strain striped bass is native to the Mississippi River. Atlantic Coast strain striped bass have been introduced into numerous impoundments in the Mississippi River basin. Escapees from these introductions have colonized the Mississippi River and likely contribute to occasional collections of striped bass in the UMR and open river.

(Table 2). Standing stocks appear greater in the LMR than in the UMR, but comparability may be limited by habitat differences. Standing stock in UMR backwaters, sloughs and side channels was 38 percent commercial species (excluding catfishes), 30 percent gizzard shad, 14 percent panfish (white bass, sunfishes, crappies, yellow perch) and 5 percent catfishes (Pitlo 1987). Pitlo (1987) found no longitudinal or temporal trends in total fish biomass but noted decreases in catfish and predator fish and increases in shad and panfishes over time. In the LMR backwaters, gizzard shad were 44 percent of the biomass, common carp 15 percent, freshwater drum 7 percent, bigmouth buffalo 6 percent and threadfin shad 5 percent of the total biomass; collectively, commercial species were 34 percent of the biomass and sport fishes were 10 percent (Lowery *et al.* 1987). Levee borrow pits contained an average of 688 kg ha^{-1}; shads and buffalo fishes dominated the catch (Cobb *et al.*1984). Lentic dyke pools can contain over 3 800 kg ha^{-1} of fish and larger pools average over 2 000 kg ha^{-1} (Baker *et al*. 1991). The high biomass is primarily from abundant shads and occasionally large numbers of buffalo fishes, catfishes, crappies, gars and white bass (Nailon and Pennington 1984; Baker *et al*. 1991). Nailon and Pennington (1984) noted substantial differences between lentic and lotic dyke pools, the latter supporting more blue sucker, blue catfish and flathead catfish.

Fish biomass is usually estimated by recovery of fish after toxicant application; hence, biomass estimation is typically limited to lentic waters where toxicants can be confined. However, Rasmussen, Pitlo and van Vooren (1985) and Pitlo (1987) obtained high biomass in channel border habitats using primacord (explosives), suggesting promise for this method. If fish recovery from primacord sampling can be assumed equivalent to that from rotenone sampling, channel borders support fish biomasses similar to backwaters. Non-ictalurid commercial fishes averaged 73 percent, catfishes 20 percent and gizzard shad 6 percent of the biomass (Pitlo 1987). Dettmers *et al.* (2001) estimated biomass of benthic fishes in the main channel in the UMR (Pool 26) using trawls. Although the biomass estimates are low (and probably conservative), the trawl caught a wide variety of species and sizes. Hydroacoustic sampling indicated moderate to high densities of fish in LMR main channel and channel border habitats (Baker *et al.* 1988a, 1988b), with densities in the main channel lower than along banks or in dyke pools (Baker *et al.* 1987; Baker *et al*. 1988a, 1988b). Many of the main channel and channel border fish were small (3-30 cm) and the fish were distributed throughout the water column in some areas.

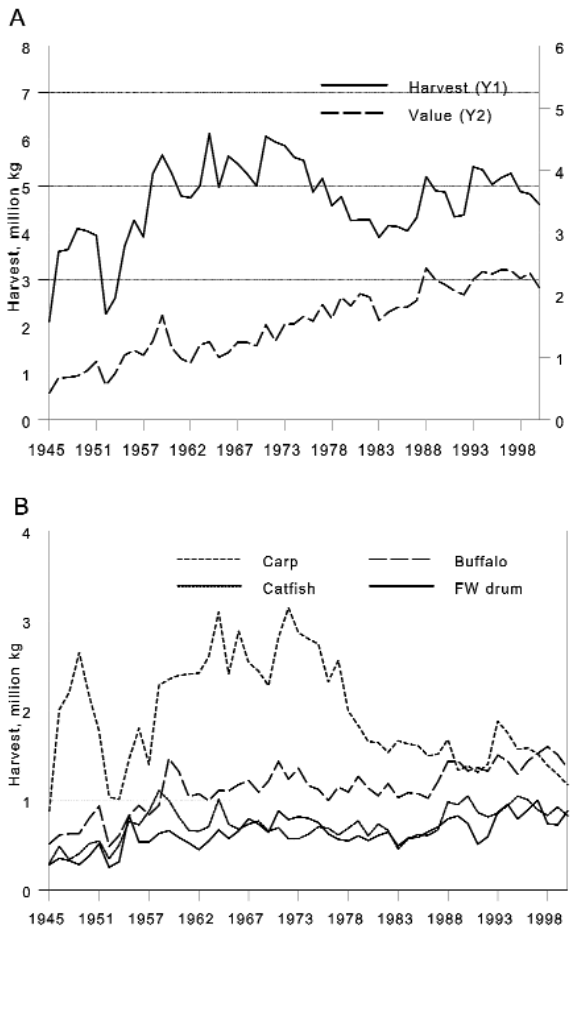
Table 2: Fish biomass estimates in Mississippi River habitats. Values in parentheses are standard error, sample size.

Reach	Habitat	Year	Method	Biomass (kg $ ha^{-1})	Reference
UMR	Backwater	1947-1952	Rotenone	361 (90, 8)	Pitlo 1987
UMR	Channel border (slough)	1946	Rotenone	333 (141, 2)	Pitlo 1987
UMR	Backwater	1977-1984	Rotenone	596 (171, 4)	Pitlo 1987
UMR	Channel border (slough)	1979-1984	Rotenone	327 (92, 8)	Pitlo 1987
UMR	Backwater (side channels)	1976-1981	Rotenone	558 (478, 2)	Pitlo 1987
UMR	Channel border	1983-1984	Primacord	748 (413, 6)	Pitlo 1987
UMR	Main channel	1996-1997	Benthic trawl	21 (3, 114)	Dettmers *et al*. 2001
LMR	Backwater (oxbow lakes)	1984	Rotenone	741 (263, 5)	Lowery *et al*. 1987
LMR	Backwater (abandoned channal connected to river)	1984	Rotenone	34 (B, 1)	Lowery *et al*. 1987
LMR	Backwater (abandoned channel not connected to river)	1984	Rotenone	911 (559, 2)	Lowery *et al*. 1987
LMR	Borrow pits	1981	Rotenone	687.9 (132.6, 25)	Cobb *et al*. 1984
LMR	Dyke pools, <0.5 ha		Rotenone	153	Baker *et al*. 1991
LMR	Dyke pools, 0.5-4.0 ha		Rotenone	2,065	Baker *et al*. 1991

Commercial Fisheries

There is no commercial fishing in the Headwaters. The National Marine Fisheries Service (NMFS) maintained commercial harvest statistics for the Mississippi River until 1977. Based on these records, annual catch in the UMR ranged from 12-16.5 million kg and followed a general downward trend (NMFS data presented in Risotto and Turner 1985). The Upper Mississippi River Conservation Committee (UMRCC) has compiled commercial harvest statistics for the UMR plus the reach of open river upstream of confluence with the Ohio River (i.e. the MMR) since 1945. In contrast to the NMFS landing statistics, the UMRCC data show wide fluctuations over time and a slight positive linear trend, despite the dominating influence of high common carp landings in 1958-1975 (Figure 5, Table 3). Highest harvest reported by the UMRCC is less than half the landings reported by the NMFS. Furthermore, the decline in catch during 1965-1973 evident in the NMFS statistics coincides with a period of peak catch in the UMRCC data. Although the statistics from both the NMFS and the UMRCC are based on self-reported data and may be biased, I consider the UMRCC data more reliable. The NMFS data are collected from diffuse sources. The UMRCC data are collected by each member-state fisheries agency. The combined catch of common carp, buffalo fishes, catfishes and freshwater drum is more than 90 percent of the total fish catch in the UMR. Catches of all these species or species groups except common carp have trended upward (Table 3). Catch of common carp was generally high during 1958-1975 and has decreased since; harvests have approximately doubled for buffalo fishes, catfishes and freshwater drum during 1945-1999 (Figure 5). Commercial harvest in the UMR likely is more driven by selling price and market demand than catch rate (J. Rasmussen and R. Maher pers. comm.).

In the LMR, NMFS statistics for 1954-1977 show catches of 6-12 million kg and increasing over time (Risotto and Turner 1985). No catch statistics comparable to those of the UMRCC exist. Self-reported commercial harvest statistics have been collected by the Tennessee Wildlife Resources Agency since 1990 and by the Kentucky Department of Fish and Wildlife Resources since 1999. Annual catch from the Mississippi River bordering Tennessee (river km [Rkm] 1 151-1 458, approximately 259 km^2) during 1991-2000 varied from 36-125 tonnes (Figure 6) but trended upward (Table 3). Landings of blue catfish and flathead catfish have increased substantially, while harvests of common carp, buffalo fishes, channel catfish and freshwater drum have been highly variable. In Kentucky waters of the Mississippi River (Rkm 1 458-1 534), catch ranged from 18-56 tonnes during 1999-2001. As in Tennessee, buffalo and catfishes predominated the catch. Commercial landings are measured in Louisiana but are not assigned to specific waters. The other states with jurisdiction over the LMR either do not measure commercial catch or do so sporadically.



■ **Figure 5.** Commercial fish harvest in the Upper Mississippi River. A. Total fish harvest and value. B. Harvests of common carp, buffalo fishes, catfishes, and freshwater drum.

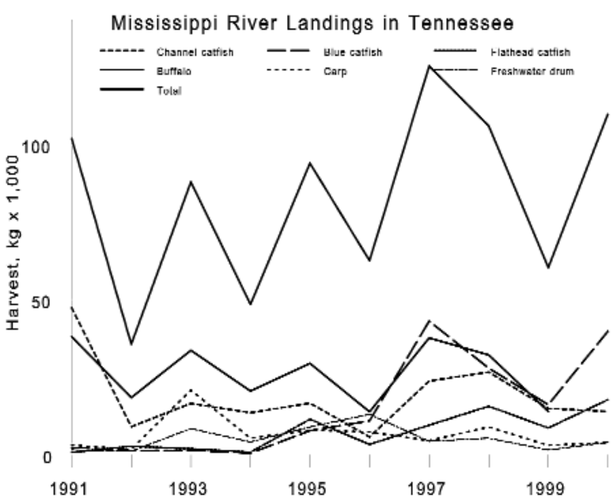
Table 3: Trends in commercial harvest (metric tons) of fish in the upper Mississippi River and Tennessee waters of the lower Mississippi River. *N* is sample size (number of years).

Location Species or species group	Linear trend	*N*	R^2	*P*
Upper Mississippi River				
Total fish	Harvest = -34927 + 20.066(year)	52	0.13	<0.01
Common carp	Harvest = 25227 - 11.801(year)	52	0.10	0.02
Buffalo fishes	Harvest = -25951 + 13.724(year)	52	0.63	<0.01
Catfishes	Harvest = -12111 + 6.503(year)	52	0.29	<0.01
Freshwater drum	Harvest = -14373 + 7.605(year)	52	0.46	<0.01
Paddlefish	Harvest = 78 - 0.021(year)	54	0.00	0.91
Shovelnose sturgeon	Harvest = -479 + 0.254(year)	55	0.11	0.01
Tennessee				
Total fish	Harvest = -6368 + 3.233(year)	10	0.11	0.35
Common carp	Harvest = 563 - 0.279(year)	10	0.02	0.67
Buffalo	Harvest = 992 - 0.484(year)	10	0.02	0.66
Channel catfish	Harvest = 2307 - 1.147(year)	10	0.09	0.41
Blue catfish	Harvest = -8492 + 4.263(year)	10	0.63	<0.01
Flathead catfish	Harvest = -3387 + 1.701(year)	10	0.68	<0.01
Freshwater drum	Harvest = -172 + 0.089(year)	10	0.01	0.85

Fluctuations in catch probably do not reflect variation in catch rate but, as in the UMR, are driven by price and market demand. However, LMR catches also vary as commercial fishers direct their fishing effort to other waters. For example, some fishers in the upper portion of the LMR will fish both the Mississippi and the Tennessee rivers and choice of fishing site is dictated by fishing conditions in both rivers.

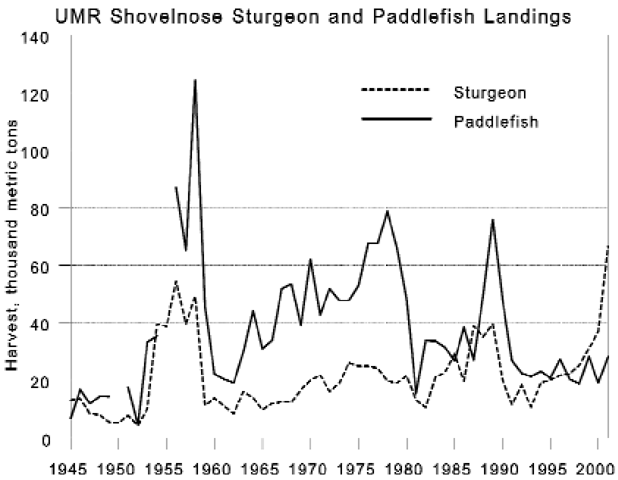
Although relatively minor components of the UMR commercial fishery, shovelnose sturgeon and paddlefish fisheries are significant management concerns. Substantial efforts are underway by State and Federal fisheries agencies to conserve or increase the stocks of paddlefish; yet, commercial fishing is still allowed in two of the five states. Paddlefish harvests have fluctuated widely, but without any long-term linear trend (Figure 7, Table 3). As observed by Rasmussen (in press), shovelnose sturgeon harvests have fluctuated but trended upward. Most noticeable is the sharp increase in 2000-2001. The upsurge is attributed to rapidly increasing value of the roe resulting from international declines in sturgeon roe harvest. Concern for these fish is warranted, because population information is limited and the long life and late maturity make these fish susceptible to recruitment overfishing. High mobility of the fish and the roe fishery mandates multi-jurisdictional management.

As in any fishery, appropriate harvest is an important fisheries management issue. Using NMFS commercial fishery statistics, Risotto and Turner



■ **Figure 6.** Commercial harvest in Tennessee waters of the Mississippi River.

(1985) found estimated fish harvests from the Mississippi River fell within the realm of expected harvests based on global harvest-drainage area and harvest-river length relationships developed for large rivers by Welcomme (1979). Further, small and trendless variations in catch over 25 years and stable catch at varying effort levels led Risotto and Turner to conclude the Mississippi River was harvested at near optimal levels. The average harvest for the LMR was 11 000 tonnes and average effort was 7 000-8 000 fishers per year during the 25 year period (Risotto and Turner 1985). However, the substantial differences in catch magnitude and trend between the UMR and NMFS data detract from the well-intentioned analyses by Risotto and Turner (1985). Pitlo (1997) demonstrated over harvest of high market-value channel catfish in Iowa waters of the UMR. Implementation of a 15-inch (38 cm) minimum size limit in 1985 increased both yields and recruitment index of the channel catfish; as of 1997 the population was continuing to expand. The



■ **Figure 7.** Commercial harvest of shovelnose sturgeon and paddlefish, Upper Mississippi River.

general trend of increasing harvest from the UMR suggests the stocks presently are not over harvested in the upper portion of the Mississippi River. The trend of increasing harvest of total fish and high-value catfishes in the Tennessee reach also suggests stocks are not over harvested in at least a portion of the LMR. Indeed, the commercial harvest from Tennessee waters of the Mississippi River is low compared to other Tennessee waters. During 1996-2001, the annual harvest of blue catfish from Tennessee waters of the Mississippi River averaged 1.1 kg ha^{-1} and harvest of flathead catfish averaged 0.4 kg ha^{-1}. In nearby Barkley Lake and Kentucky Lake, impoundments of the Cumberland and Tennessee rivers, respectively, annual harvest of blue catfish was 5.5-8.6 kg ha^{-1} and annual harvest of flathead catfish was 1.0-1.3 kg ha^{-1}. The catfish fisheries of Barkley and Kentucky lakes are not considered over harvested (R. Todd pers. comm.); thus the low harvest from the Mississippi River suggests its catfish stocks may support considerably greater harvest. The size and age structures of the commercial fisheries are not routinely monitored. However, beginning in 1988 a standardized fishery assessment program was implemented in the UMR. Evaluation of length frequency distributions of important sport and commercial fishes (Gutreuter *et al.* 1997; Gutreuter *et al.* 1998) indicates adequate recruitment and length distributions show no evidence of overfishing. UMR catch rate trends from the standardized assessment indicated one commercial species declined and two commercial species increased in abundance; overall, there was no evidence for a general decline in abundance (Gutreuter 1997). At this time, the commercial fish stocks in the Mississippi River appear stable and, at least in portions of the LMR, may support additional harvest. Shovelnose sturgeon stocks should be closely monitored.

Recreational Fisheries

The Mississippi River is a bountiful recreational fishing resource. The Headwaters is entirely within the state of Minnesota and the Minnesota Department of Natural Resources frequently conducts creel surveys on portions of the river and the river lakes. Fishing effort ranges from 13-47 hours ha^{-1} and harvest ranges from 5-16 kg ha^{-1} (Albert 1995; Bublitz 1996; Sledge 1998, 2000; Ekstrom 1999). Fishing effort, catch rate, harvest rate and mean size of fish caught have remained steady or trended upward over the past

20 or more years. Prevalent recreational species include northern pike, channel catfish, smallmouth bass, white crappie, black crappie and walleye.

In the UMR, recreational fishing effort and catch have been measured sporadically on several pools. Averaged for 7 of the 26 pools, annual harvest ranged from 8.1-9.4 kg ha^{-1} from 1962-1973. Throughout the UMR, annual recreational fishing effort was 4.6-5.2 million hours and harvest was 1.2-1.4 million kg during the 1962-1973 time frame. Catch and effort were stable over this brief time frame. More recent creel surveys estimated fishing effort of 18-64 hours ha^{-1} and catches of 13-100 fish ha^{-1} in four different UMR pools (Fleener 1975; Ackelson 1979; Watson and Hawkinson 1979; Farabee 1993). Recreational fishing effort and harvest are relatively low in the headwaters and UMR; for comparison, angler effort averages 88 h and harvest 13.3 kg ha^{-1} $year^{-1}$ in U.S. reservoirs (Miranda 1999), many of which are serial reservoirs on rivers (like the UMR) but have longer retention times (c.f. Jenkins 1967). Analysis of abundance trends in the UMR during 1990-1994 indicated that three sport species declined and two sport species increased; declining species were fishes associated with backwaters while species that increased were riverine (Gutreuter 1997).

The recreational fishery has not been measured in the MMR or LMR reaches of the open river. Personal observations on the LMR suggest that freshwater fishing catch rates are relatively high; but effort and thus catch and harvest, are extremely low. Because of the large size, swift and dangerous currents, the presence of large commercial craft and lack of public access, recreational fishing on these reaches has been largely discouraged. Providing access is difficult because of the large annual fluctuations in river level and separation of many of the remaining floodplain lakes from the river during low water stages (see below). Management agencies are only beginning to recognize the potential fisheries that the Mississippi River offers and measures are being initiated to improve access and public education regarding the fishing opportunities. Although catfishes are important to both recreational and commercial fisheries and channel catfish suffered overfishing before increasing the minimum length limit, recreational fish stocks do not presently appear overfished and, especially in the LMR, can withstand increased harvest.

MANAGEMENT OF THE MISSISSIPPI RIVER

Ten state agencies manage the Mississippi fisheries resources by establishing and enforcing harvest methods and limits and by providing boating and fishing access. The U.S. Fish and Wildlife Service and the five bordering states manage about 184 000 ha of lands and wetlands adjacent to portions of the UMR and MMR (Theiling et *al.* 2000). However, the U.S. Army Corps of Engineers (COE) is mandated by the Federal government to control flooding throughout the Mississippi basin and maintain commercial navigation on the Mississippi River from Minneapolis, Minnesota to the mouth. Up to the present, flood control and navigation have dominated management of the Mississippi River-floodplain ecosystem. Thus, the COE manages the habitat and, therefore, is the principal manager of the Mississippi River downstream of St. Anthony Falls. Most of the major fisheries management issues in the Mississippi River are related to flood control and navigation.

SEDIMENTATION

The Mississippi River has always carried sand and sediment to the Gulf of Mexico. Agricultural development of the Mississippi River basin has increased sediment inputs; however, for the LMR, some increases have been offset by impoundment of the UMR, the Ohio River and, principally, the middle Missouri River. Although most of the sediment originates in the watershed (a relatively small amount results from bank erosion and re-suspension related to navigation traffic [Bade 1980]), it is the management of the river for navigation (i.e. impoundment, channelization and dredged material disposal) and flood control that has resulted in rapid rates of sediment accumulation and habitat loss in off-channel and floodplain habitats. In the UMR, impoundment has slowed the water flow, causing navigation pools to become sediment traps. Directing flows through the navigation channel has reduced flows through side channels, increasing sedimentation during low flows and decreasing scouring during high flows. Thus side channels and backwaters are most impacted by sedimentation; the expected life of backwater habitats may be as short as 50 years (Simons, Schumm and Stevens 1974; Bade 1980; Breitenbach and Peterson 1980). These are productive habitats and essential for one or more life stages of many species (e.g. Christenson and Smith 1965; Schramm and Lewis 1974; Holland 1986; Shaeffer and Nickum 1986; Rasmussen 1979; Grubaugh and Anderson 1988). By providing warmer water and refuges from the current, they are especially important overwintering habitats (Pitlo 1992; Bodensteiner and Lewis 1992; Sheehan, Lewis and Bodensteiner 1990); but their value rapidly diminishes as sediment reduces water depth (McHenry *et al.* 1984; Bhowmik and Adams 1989; Gent, Pitlo and Boland 1995; Knights, Johnson and Sandheinrich 1995). Although the time to fill various habitats varies within and among pools, without continued regulation the river will restore its historic channel dimensions. For the pools of the UMR, this means continual sedimentation until the channel cross-sectional area equals the collective cross-sectional area of the pre-impoundment channel. Site-specific dredging is required annually to maintain the navigation channel. While the amount of sediment excavated may be small relative to the cumulative sediment load, this material may substantially affect biota depending on the disposal method. Disposal lateral to the navigation channel can alter channel border and backwater habitats. Some fishery benefits have been gained by using dredged materials to build islands in the channel border zone (Johnson and Jennings 1998).

In the open river reach flows remain essentially unchanged and the loss of habitat from sediment deposition probably resembles natural processes that occurred 10 000 years B.P. However, channelization, which not only maintains channel depth and width but also trains the channel course, prevents the river from carving new channels. Sediment deposition occurs in backwaters, both those on the floodplain and in abandoned channels confluent with the river. These backwaters appear to support the greatest biomass of fishes and provide important, if not essential, habitat for one or more life stages of most native Mississippi River species (Beckett and Pennington 1986; Baker *et al.* 1991; Table 1). In the LMR, Schramm *et al.* (1999a) estimated 8 400 ha of backwater habitat within the riverbanks and 53 300 ha on the floodplain. However, existing lakes are rapidly filling (Gagliano and Howard 1984; Cooper and McHenry 1989). Borrow pits created when soil was excavated from the batture lands (the floodplain from the levee to the river) to build the levees in the 1930s can provide important fish nursery areas (Sabo and Kelso 1991; Sabo *et al.* 1991). However, many of these borrow pits have filled during the 60-70 years since their construction. In the upper portion of the open river, abundance of several riverine species appears to be increasing while backwater species are decreasing (Bertrand 1997) although based on only 5 years of data, a similar trend was noted in the UMR (Gutreuter 1997).

Sediment deposition in the open river reaches also occurs in secondary channels, former main channels or new channels in the making that are separated from the present main channel by large sandbars or islands. The secondary channels are usually 5 km or longer. Dyke fields that divert water to align and hydraulically dredge the navigation channel reduce flows through many of these secondary channels. Dyke placement initially increases habitat diversity by the addition of hard bottom substrate (rock riprap), by creating deep scours at the tip and immediately downstream of the dykes and by providing reduced or zero current pools further downstream of the dykes. These areas temporarily harbour high diversity, density and biomass of fish (e.g. Pennington, Baker and Bond 1983a; Nailon and Pennington 1984; Beckett and Pennington 1986; Baker *et al*. 1987, 1988a) and are inhabited by different fish assemblages than open side channels (Barko and Herzog in press). However, the dykes slow the flow through the secondary channel; the water-borne sediment is deposited downstream of the dykes, filling the scours and pools, eventually covering much of the rock riprap dyke and resulting in net loss of both aquatic area and habitat diversity. In an effort to conserve aquatic habitat and diversity, the COE is evaluating the benefits of large (15-30 m wide) notches in dykes to allow more water to flow through the secondary channel, thereby reducing sedimentation. This technique has been used successfully on the UMR and Missouri rivers. Elevation of the bottom of the notch is usually at or below the Low Water Reference Plane to ensure some flow through the secondary channel during low water stages. During low flow, catch rates of lentic fishes (e.g. shads, white bass) are higher downstream of un-notched dykes, whereas catch rates of rheophilic catfishes are greater downstream of notched dykes (Schramm *et al*. 1998, 1999b). Steep natural banks support relatively high densities of fish (Pennington, Baker and Potter 1983b; Baker *et al*. 1988b; Driscoll 1997; Driscoll, Schramm and Davis 1999). These productive banks with irregular current-washed walls of clay and clay-sand substrate, deep holes, variable currents and concentrations of large woody debris are essentially unique to secondary channels; such a bank in the main channel would be armoured with articulated concrete mattress and rock riprap to prevent erosion. Filling of LMR secondary channels will eliminate steep natural banks.

THE FLOODPLAIN, CONNECTIVITY AND THE FLOOD-PULSE CONCEPT

Current thinking about floodplain-river ecosystems predicts fish production is a function of floodplain inundation (Junk, Bayley and Sparks 1989; Bayley 1995). The floodplain provides energy that is consumed directly (e.g. plant or animal material produced on the floodplain between floods) or indirectly (e.g. through trophic webs) by fishes colonizing the floodplain during the flood pulse. The floodplain also provides essential or desirable spawning and nursery habitat for many native fishes. Further, the floodplain contributes to riverine fish production when terrestrial plant and animal material and fish produced on the floodplain are flushed into the river with flood flows or drain into the river with receding water levels. In keeping with the flood-pulse concept, fisheries production should show some relation to the amount of food, spawning, or rearing resources available; thus, fish production would be related to the area of floodplain inundated. Levees isolate the river from much of the historic floodplain beginning at Pool 15 in the UMR and throughout the open river reach. Flood proofing at the Mississippi River valley, particularly the open river where vast areas of the floodplain have been reclaimed for agricultural and related developments, is a polarized issue. One alternative favours protecting personal property and agricultural production and the economy (local, regional and national) associated with it. Another option proposes minimizing economic loss resulting from repeated disaster recovery payments and crop and flood insurance payouts by the Federal government and achieving the fish, wildlife and economic (e.g. hardwood timber) benefits expected from a larger and presumably more functional floodplain. Proponents of this non-structural alternative advocate levee removal, notching, or relocation further from the river to reconnect at least portions of the floodplain to the river. Such an action would necessitate Federal government purchase of private lands or flood easements from willing sellers and even relocating some towns that would be impacted by floodwaters. Advocates argue that costs would be lower than repetitive emergency relief and flood insurance payments.

Economic value of personal property and commodities lost and gained on the restored floodplain can be estimated, but the effect on fish and wildlife and the subsequent value gained or lost is unknown. Despite this, evaluations of the relationship between fish production and floodplain inundation in the Mississippi River are few. Results in the UMR lend support to the applicability of the flood-pulse concept to the Mississippi River. Growth of littoral zone (floodplain-dependent) fishes was higher during a year of protracted flooding than in other years, but growth of a riverine species did not differ over the same time frame (Gutreuter *et al.* 1999). Studies in the LMR failed to find expected relationships between growth and abundance of age-0 and 1 Mississippi River fishes and measures of floodplain inundation (Rutherford *et al.* 1994; Rutherford *et al.* 1995). Risotto and Turner (1984) found no relationship between commercial harvests and area of floodplain inundated. These LMR evaluations suggested that failure to find expected positive relations between fish growth or abundance and floodplain inundation may be related to the reduction of active floodplain area. Employing a bioenergetic approach, Eggleton (2001) failed to find a clear linkage between catfish growth and floodplain inundation. The evidence in support of the floodplain as a primary determinant of fish production in the Mississippi River is far from compelling; but, as discussed below, floodplain function may have been compromised by the interaction of several alterations to the river and its floodplain.

In the LMR, catfish growth was not significantly related to area or duration of floodplain inundation; however, a strong positive relationship emerged between catfish growth and extent of inundation when water temperature exceeded 15C, a threshold temperature for active feeding and growth by catfishes (Mayo 1999; Schramm, Eggleton and Mayo 2000). These results need validation with a longer time series. However, in support of the importance of temperature, the increased growth of littoral zone fishes observed by Gutreuter *et al*. (1999) occurred during an unusually late summer flood when water temperatures were conducive to active feeding and rapid growth.

Considering the flood-pulse concept is largely based on and supported by studies of rivers in tropical and subtropical climates (Junk *et al.* 1989), consideration of a thermo-temporal component (Schramm *et al.* 2000) or the coupling of temperature and flooding (Junk *et al.* 1989) may be appropriate for the temperate Mississippi River with warm water fish assemblages. Although water temperature data are not available, the thermal conditions of the current flood pulse probably are quite different from historical conditions. During 1928 to 1942, two coincidental changes dramatically affected hydrology in the LMR. The first is the aforementioned levees. Although numerous small levees have existed since the mid 1800s (Baker *et al.* 1991) the river still remained connected to much of the floodplain until the continuous mainline levees were built during 1928-1937. The other change was cut-offs. During 1929-1942, 16 meander loops were bypassed by constructing cut-off channels (Baker *et al.* 1991). These cut-off channels shortened the river by 245 km and subsequently increased the slope. The hydrologic consequences of the cut-offs were less frequent, lower and shorter duration flood pulses (Figure 4). Presently, the floodwaters inundate the floodplain relatively briefly and subside earlier in the year; consequently, the water is colder. Schramm *et al.* (2000) found thermal conditions on the floodplain suitable for spawning and growth of warm water fishes occurred only twice in six years during 1993-1998. Before levees were constructed, floodwaters spread over a broad, flat floodplain; the waters likely warmed quickly and receded slowly as flood discharges subsided. Conversely, the same discharges confined by levees into a narrower floodplain produced deeper inundation, shorter retention time and substantial current in many areas (Welcomme 1985; Satterlund and Adams 1992). These waters warm slowly (Schramm *et al.* 1999; Schramm *et al.* 2000; Eggleton 2001) and probably recede quickly. From this reasoning, the net result of the cut-offs and levees is a greatly reduced floodplain of only infrequent value for feeding or reproduction of warm water fishes. The inconsistent recruitment of several floodplain-dependent fishes sampled in LMR floodplain ponds (levee borrow pits Cobb *et al.* 1984) lends support to this contention. The role of the floodplain and the effect of the current hydrologic regime on Mississippi River fisheries require further evaluation.

The LMR continues to adjust to the change in slope that resulted from the cut-offs. To regain its original slope the channel is degrading (incising) upstream of Rkm 700 and aggrading downstream. Channel degradation results in a lower elevation for a given discharge. This in turn results in lower summer and fall water levels in some floodplain lakes and severs their connection with the river.

In the impounded UMR, a flood pulse still occurs (Figure 5) and both the timing and the duration of the flood pulse are similar to pre-impoundment conditions. Although the area seasonally inundated by the flood pulse may be less than before impoundment, except during years of exceptionally high precipitation, there is no evidence to suspect that thermal conditions of the flood pulse differ from historic conditions. However, dams and regulation of minimum water levels necessary for navigation have eliminated the flood-drought pulse, a summer dewatering of the historic floodplain and the fall rise. The summer drawdown would benefit consolidation and aeration of the sediments and growth of terrestrial vegetation. Fisheries managers have recommended summer pool drawdowns to improve habitat and benefit UMR fish populations (J. Rasmussen pers. comm.). Obviously, a major summer drawdown to mimic natural conditions is incompatible with navigation. Although brief, the fall-rise may have substantially contributed to fisheries production. Peak plant senescence occurs in autumn and coincides with substantial elaboration of benthic macroinvertebrate biomass (Anderson and Day 1986). The fall-rise probably flushed the plant material into the river where it could be used by the benthos (Grubaugh and Anderson 1988).

NAVIGATION

In addition to the habitat alteration from creating and maintaining a navigable channel, navigation and directly related activities affect fish populations. Commercial navigation upstream of Baton Rouge consists of barges pushed by towboats. The greatest economy is achieved by a single, powerful towboat pushing the largest number of barges. Although fish mortality is difficult to quantify, entrainment of larval and juvenile fishes by towboat propellers is significant (Bartell and Campbell 2000). Additional mortality results from stranding associated with wakes from the tows or when approaching barges cause temporary drawdown (Adams *et al.* 1999). In the UMR, Gutreuter, Dettmers and Wahl (in press) estimated adult fish losses from entrainment at 2.65 clupeids, 0.53 shovelnose sturgeon and 0.53 smallmouth buffalo per km for each towboat. Use of the UMR by recreational powerboats is relatively high (e.g. Watson and Hawkinson 1979; Farabee 1993; Carlson, Propst, Stynes *et al.* 1995; Gutreuter *et al.* 1999) and likely also contributes to fish mortality from wave action and stranding. However, because recreational vessels are shallower draft and have smaller propellers, losses from entrainment would be expected to be lower.

Driven by local economies and competition from agricultural production in other countries, commercial river traffic is forecast to increase. Bartell and Campbell (2000) estimated recruitment losses in four pools of the UMR from a 25 percent increase in traffic ranged from 1 420 fish for walleye to 88 million fish for emerald shiner. Linear increases in losses were predicted for further increases in traffic. However, the predictions do not include the effects of cumulative stress to the fish from increased frequency of entrainment, increased habitat disturbance (e.g. increased sediment suspension, more bank erosion), loss of habitat from activities and development associated with increased commerce (e.g. barge staging areas, docking areas) and elevated probabilities of toxic spills (Breitenbach and Peterson 1980), all of which may adversely affect fish survival and may operate in a synergistic, multiplicative fashion. Furthermore, entrainment losses probably are site specific; entrainment is expected to be higher in a narrow, shallow channel where a larger portion of the water column passes through the propellers than in a wider and deeper channel. In the latter case fish can more easily escape entrainment. Present traffic levels kill fish, but catch and harvest data indicate the various populations are able to support existing fisheries. Whether navigation-related mortality acts in a compensatory or additive fashion with natural mortality (i.e. whether the estimated foregone production actually reduces population size and, in turn, catch and harvest) awaits resolution.

Water Quality

The Mississippi River flows through a sea of intensive agriculture dotted with islands of urban development. As such, the river is the inland sink for fertilizers, pesticides and domestic and industrial wastes. During the 1940s-1960s the river and its aquatic life were severely impacted by pollution. Segments of the river downstream of Minneapolis and St. Paul, Minnesota suffered severe oxygen depletion (Fremling 1964, 1989). Improved wastewater treatment and agricultural practices have reduced nutrient and toxic chemical loads. Although the river still shows the effects of agriculture, industry and urban development and persistent toxicants remain in the sediments, water quality is improved (Meade 1995; Fremling and Drazkowski 2000; Sullivan *et al.* 2002) and the river supports fish throughout its length that generally are safe for human consumption. Yet, fish health remains impacted by various contaminants, in particular bioaccumulative organic compounds, throughout the river (Schmitt 2002). Nutrient dynamics have undoubtedly been changed by habitat alterations. The UMR pools are sediment traps and, thus, remove nutrients and toxins associated with sediment. Impoundment also likely contributes to biological processing of nitrogen and phosphorus. Conversely, biological filtration may be reduced in the MMR and LMR, where the spatially reduced floodplain and the briefer, colder and faster-flowing flood pulse likely results in less assimilation of nutrients. These conditions may, in turn, contribute to downstream problems, such as nutrient accumulations and hypoxic conditions in the Gulf of Mexico (Rabelais *et al.* 1996; Rabelais, Turner and Wiseman 2002). Comprehensive assessments of contemporary water quality are given by Meade (1995), Schmitt (2002) and Sullivan *et al*. (2002).

Introduced Species

Confluence with waters draining 3.25 million km^2 and connection to international commerce via the Gulf of Mexico and the Great Lakes makes the Mississippi River highly vulnerable to invasion by non-native aquatic species. Non-native animal species presently established in the Mississippi River include the common carp, grass carp, silver carp, bighead carp and zebra mussel (*Dreissena polymorpha* Pallas). Except for the common carp, the impacts of these species in the Mississippi River are not known. However, populations are expanding and competition with native fauna is likely. A comprehensive assessment of potential Mississippi River invaders and their impacts is available in Rasmussen, Pitlo and Steingraeber (in press).

Sustaining Future Fisheries

At present, the River's native fish assemblage appears intact (Fremling *et al*. 1989; Gutreuter 1997; Weiner *et al*. 1998), but a substantial number of species are considered rare and I found no information to elevate their abundance status. With the exception of sturgeons, sport and commercial fisheries show no signs of overfishing and may even support increased effort and harvest. However this level of apparent abundance may be short lived as additional backwater habitat disappears, the remnant active floodplain only intermittently contributes to fish production and non-native species invasions take their toll. Water quality is improved but fish are still stressed by contaminant burdens. While the river has been managed to achieve maximum economic benefit for man, fisheries resources have been largely ignored.

The UMRCC has identified strategies to sustain UMR fisheries and other natural resources (Duyvejonck 2002). These include: improve water quality, reduce erosion and sedimentation, reclaim the floodplain to allow channel meanders and to increase habitat diversity, provide for an effective flood pulse and periodic low flows, connect backwaters to the main channel, manage the channel and dredge material to improve habitat, prevent the spread of non-native species and provide native fish passage at dams. With minor exceptions, these strategies are also applicable to the open river. Engineering technologies are available to accomplish these strategies and some restoration has been done (e.g. Bade 1980; Knights *et al*. 1995; Johnson and Jennings 1998). However, fundamental to these strategies and the general conservation and management of the fishery resources of the Mississippi River are (1) implementation of a system-wide assessment program and (2) societal recognition of the multiple values of the Mississippi River.

A system-wide assessment program is essential to comprehensively assess the status of the fish assemblage and individual populations, identify management needs, provide essential biological and ecological information to guide management and restoration efforts and evaluate the progress of management and restoration activities. A resource assessment program (Long-Term Resource Monitoring Program), initiated on the UMR in 1988, has implemented a systematic assessment of UMR fisheries and aquatic resources that provides information useful for management decisions. This program should be expanded to the entire navigation reach of the river. Advances in sampling methodology, such as benthic trawling (Gutreuter, Dettmars and Wahl 1999; Dettmers *et al*. 2001) and electrofishing (Burkardt and Gutreuter 1995; Pugh and Schramm 1998; Schramm and Pugh 2000), increase sampling efficiency, expand the range of habitats that can be sampled, allow better comparability among habitats and likely will contribute to a better understanding of the system as a whole. A comprehensive, long-term assessment program is expected to stimulate further development and refinement of sampling methodologies. Application of geospatial technologies will help monitor system changes and contribute to more effective assessment. Advances in remote sensing technologies may be especially applicable to monitoring and managing sedimentation, measuring fish abundance and measuring physical conditions where the fish live (in contrast to surface measurements). Advances in analytical (statistical) procedures may help assess trends and evaluate habitat suitability and requirements. Fisheries assessment has been confounded by the dynamic nature of the river and interpretation of fisheries data has been hampered by high variability. Habitats and the physical and biotic conditions that create them are not discrete; they are continua in space and in time. Statistical procedures that evaluate multiple variables (e.g. Johnson and Jennings 1998) or gradients (e.g. Brown and Coon 1994; Eggleton 2001; Barko and Herzog in press) are less encumbered by variation (which may be inherent to the system) and may prove efficient tools for evaluating habitat change and management efforts.

The second fundamental need is to change social perception of the river, especially the MMR and LMR and to establish value for the natural resources of the Mississippi River. There is much to be done to restore the Mississippi River and the technologies are available. Projected changes in the river-floodplain ecosystem foretell increasing management and restoration needs. The Federal government spends several hundred million U.S. dollars annually to maintain navigation and flood control in the LMR. Less than 1 percent of this amount is spent for assessment and management of fisheries resources. Recreational use of the Headwaters is substantial. Recreational use of the UMR is valued at US$1.2 billion per year (Carlson *et al*. 1995); of the estimated 12 million annual visits to the river, 49 percent were for fishing. Our society, including lawmakers, needs to be aware of the changes in this vast system that are adversely affecting its ecological function and value to man. Without societal support, management and restoration of the Mississippi River to achieve fishery and other natural resource benefits will not be a priority. Achieving societal support is difficult in the UMR, but will be even more difficult in the LMR where the river is largely inaccessible and where recreational use is probably three orders of magnitude lower.

ACKNOWLEDGMENTS

Hydrographic data used in this report were provided by Richard Engstrom, Allen Phillips, Tim Rodgers, U.S. Army Corps of Engineers. James Rogala, U.S. Geological Survey, provided spatial data for the Upper Mississippi River floodplain-river ecosystem. Commercial fisheries data were provided by Jon Duyvejonck, Upper Mississippi River Conservation Committee, Karen Hukill, Kentucky Department of Fish and Wildlife Resources, Michelle Marron, Wisconsin Department of Natural Resources and Robb Todd, Tennessee Wildlife Resources Agency. Steve Ellis and Wayland Hill, U.S. Army Corps of Engineers provided valuable information about levee construction and river hydrology. Jon Duyvejonck, Steve Gutreuter, U.S. Geological Survey, Bob Hrabik, Missouri Department of Conservation and Ron Nassar and Jerry Rasmussen, U.S. Fish and Wildlife Service, provided useful reviews of earlier versions of this manuscript. Andy Bartels, Wisconsin Department of Natural Resources, Melvin Bowler, Iowa Department of Natural Resources, Daniel Dieterman and Konrad Schmidt, Minnesota Department of Natural Resources, Robert Hrabik, Jerry Rasmussen and Stephen Ross, University of Southern Mississippi provided input on the status and distribution of Mississippi River fishes (Table 1).

REFERENCES

Ackelson M.C. 1979. Recreational use survey. Pool 9 Mississippi River. Rock Island, Illinois: Upper Mississippi River Conservation Committee. 36 pp.

Adams S.R., Keevin T.M., Kilgore K.J., & Hoover J.J. 1999. Stranding potential of young fishes subjected to simulated vessel-induced drawdown. *Transactions of the American Fisheries Society.* 128: 1230-1234.

Albert G.E. 1995. *1994 creel survey: Lake Winnibigoshish and connected waters. Completion report, F-29-RP-14*. St. Paul, Minnesota, Department of Natural Resources. 56 pp.

Anderson R.V. & Day D.M. 1986. Predictive quality of macroinvertebrate-habitat associations in lower navigation pools of the Mississippi River. *Hydrobiologia*, 36: 101-112.

Bade G. 1980. Great River Environmental Action Team: Side channel work group appendix. Rock Island, Illinois, USA, Fish and Wildlife Service. 211 pp.

Baker J.A., Kasul R.L., Winfield L.E. Bingham C.R., Pennington C.H. & Coleman R.E. 1988a. An ecological investigation of the Baleshed Landing Ben Lomond and Ajax Bar dyke systems in the Lower Mississippi River, river miles 481-494. Lower Mississippi River Environmental Program Report 12. Vicksburg, Mississippi, Mississippi River Commission. 85 pp.

Baker J.A., Kasul R.L., Winfield L.E. Bingham C.R., Pennington C.H. & Coleman R.E. 1988b. *An ecological evaluation of three revetted and two natural banks in the Lower Mississippi River. Lower Mississippi River Environmental Program Report 9.* Vicksburg, Mississippi, Mississippi River Commission. 81 pp.

Baker J.A., Killgore K.J. & Kasul R.L. 1991. Aquatic habitats and fish communities in the lower Mississippi River. *Reviews in Aquatic Sciences,* 3: 313-356.

Baker J.A., Pennington C.H., Bingham C.R. & Winfield L.E. 1987. An ecological evaluation of five secondary channel habitats in the Lower Mississippi River. Lower Mississippi River Environmental Program Report 7. Vicksburg, Mississippi, Mississippi River Commission. 86 pp.

Bartell S.M. & Campbell K.R. 2000. Ecological risk assessment of the effects of the incremental increase of commercial navigation traffic 25, 50, 75, and 100 percent increase of 1992 baseline traffic on fish. Interim Report for the Upper Mississippi River, Illinois Waterway System Navigation Study. Vicksburg, Mississippi, USA Army Engineers. 113 pp.

Bayley P.B. 1995. Understanding large river-floodplain ecosystems. *BioScience*, 45: 153-158.

Becker G.C. 1983. *Fishes of Wisconsin*. Madison, University of Wisconsin Press. 1052 pp.

Beckett D.C. & Pennington C.H. 1986. Water quality, macroinvertebrates, larval fishes, and fishes of the Lower Mississippi River: A synthesis. *Technical Report E-86-12*. Vicksburg, Mississippi, Waterways Experiment Station. 136 pp.

Bertrand B.A. 1997. Changes in the Mississippi River fishery along Illinois, 1976-1996. *Journal of Freshwater Ecology,* 12: 585-597.

Bhowmik N.G. & Adams J.R. 1989. Successional changes in habitat caused by sedimentation in navigation pools. *Hydrobiologia*, 176/177: 17-27.

Bodensteiner L.R. & W.M. Lewis 1992. Role of temperature, dissolved oxygen, and backwaters in the winter survival of freshwater drum *Aplodinotus grunniens* in the Mississippi River. *Canadian Journal of Fisheries and Aquatic Sciences*, 49: 173-184.

Breitenbach R. & Peterson G., eds. 1980. *Great River environmental action team. GREAT II. Upper Mississippi River. Fish and wildlife management work group appendix*. Rock Island, Illinois: USA Fish and Wildlife Service. 298 pp.

Brown D.J. & Coon T.G. 1994. Abundance and assemblage structure of fish larvae in the lower Missouri River and its tributaries. *Transactions of the American Fisheries Society*, 123: 718-732.

Bublitz C.J. 1996. *Mississippi River recreational use survey: Potlatch Dam Brainerd to Little Falls Dam. June 1 to October 31, 1995. Completion report*. Project F-29-RP-15. St. Paul, Minnesota Department of Natural Resources. 15 pp.

Burkardt R.W. & Gutreuter S. 1995. Improving electrofishing catch consistency by standardizing power. *North American Journal of Fisheries Management*, 15: 375-381.

Carlander K.D. 1969. *Handbook of freshwater fishery biology. Volume 1*. Ames, Iowa State University Press. 752 pp.

Carlander K.D. 1977. *Handbook of freshwater fishery biology. Volume 2*. Ames, Iowa State University Press. 431 pp.

Carlander K.D. 1997. *Handbook of freshwater fishery biology. Volume 3*. Ames, Iowa State University Press. 397 pp.

Carlson B.D., Propst D.B., Stynes D.J. & Jackson R.S. 1995. *Economic impact of recreation on the upper Mississippi River system. Technical Report EL-95-16.* Vicksburg, Mississippi, U.S. Army Engineer Waterways Experiment Station. 45 pp.

Christenson L.M. & Smith L.L. 1965. *Characteristics of fish populations in Upper Mississippi River backwater areas. Circular 212.* Washington, Fish and Wildlife Service. 53 pp.

Cobb S.P. & Clark J.R. 1981. *Aquatic habitat studies on the Lower Mississippi River, river mile 480 to 530. Report 2, Aquatic habitat mapping.* Miscellaneous Paper E-80-1. Vicksburg, Mississippi, U.S. Army Engineer Waterways Experiment Station. 23 pp.

Cobb S.P., Pennington C.H., Baker J.A. & Scott J.E. 1984. *Fishery and ecological investigations of main stem levee borrow pits along the lower Mississippi River.* U.S. Army Corps of Engineers, Mississippi River Commission. 120 pp.

Cooper C.M. & McHenry J.R. 1989. Sediment accumulation and its effects on a Mississippi River oxbow lake. *Environmental Geology and Water Sciences,* 13: 33-37.

Dettmers J.M., Gutreuter S., Wahl D.H. & Soluk D.A. 2001. Patterns in abundance of fishes in main channels of the upper Mississippi River system. *Canadian Journal of Fisheries and Aquatic Sciences*, 58: 933-942.

Driscoll M.T. 1997. Influences of channel and habitat types on fish assemblages in the lower Mississippi River. Starkville, Mississippi State University. 173 pp. Masters thesis

Driscoll M.T., Schramm H.L. Jr. & Davis W.R. 1999. Relative abundance of catfishes in main channel and secondary channel habitats in the lower Mississippi River. *In* E.R. Irwin, W.A. Hubert, C.F. Rabeni, H.L. Schramm Jr. & T. Coon, eds. *Catfish 2000: Proceedings of the International Ictalurid Symposium.* Bethesda, Maryland, American Fisheries Society. pp. 231-237.

Duyvejonck J. 2002. A preliminary description of measures and estimated costs needed to achieve a desired level of ecosystem integrity on the Upper Mississippi River system. Rock Island, Illinois, Upper Mississippi River Conservation Committee. 21 pp.

Eggleton M.A. 2001. Catfish feeding ecology and bioenergetics in a large river-floodplain ecosystem. Starkville, Mississippi State University. 204 pp. (Doctoral dissertation)

Ekstrom R.R. 1999. 1997 Cass Lake summer creel survey. Completion Report. Project F-29-RP-17. St. Paul, Minnesota Department of Natural Resources. 37 pp.

Etnier D.A. & Starnes W.C. 1993. *The fishes of Tennessee*. Knoxville, The University of Tennessee Press. 681 pp.

Farabee G.B. 1993. *Recreational use of Pool 24, Upper Mississippi River*. Jefferson City, Missouri Department of Conservation. 22 pp.

Fleener G.G. 1975. *Recreational use of Pool 21, Mississippi River*. Jefferson City, Missouri Department of Conservation. 21 pp.

Fremling C.R. 1964. Mayfly distribution indicates water quality on the Upper Mississippi River. *Science*, 146, 1164-1166.

Fremling C.R. 1989. *Hexagenia* mayflies: Biological monitors of water quality in the Upper Mississippi River. *Journal of the Minnesota Academy of Science,* 55: 139-143.

Fremling C.R. & Drazkowski B. 2000. *Ecological, institutional and economic history of the upper Mississippi River.* Winona, St. Mary's University of Minnesota. 44 pp. (http://www.umbsn.org/news/documents/UMR_Ecological_History.htm)

Fremling C.R., Rasmussen J.L., Sparks R.E., Cobb S.P., Bryan C.F. & Claflin T.O. 1989. Mississippi River fisheries: A case history. *In* D.P. Dodge, ed. *Proceedings of the international large rivers symposium*. Ottawa, Department of Fisheries and Oceans. pp. 309-351.

Gagilano S.M. & Howard P.C. 1984. The neck cut-off oxbow lake cycle along the Lower Mississippi River. *In* C.M. Elliott ed. *River Meandering.* New York, American Society of Civil Engineers. pp. 147-158.

Gent, R., Pitlo J. Jr. & Boland T. 1995. Largemouth bass response to habitat and water quality rehabilitation in a backwater of the upper Mississippi River. *North American Journal of Fisheries Management*, 15: 784-793.

Grubaugh J.W. & Anderson R.V. 1988. Spatial and temporal availability of floodplain habitat: Long-term changes at Pool 19, Mississippi River. *The American Midland Naturalist*, 119: 402-411.

Gutreuter S. 1997. *Fish monitoring by the long-term resource-monitoring program on the upper Mississippi River system: 1990-1994*. Onalaska, Wisconsin, U.S. Fish and Wildlife Service, Environmental Management Technical Center. 122 pp.

Gutreuter S., Bartels A.D., Irons K. & Sandheinrich M.B. 1999. Evaluation of the flood-pulse concept based on statistical models of growth of selected fishes of the upper Mississippi River system. *Canadian Journal of Fisheries and Aquatic Sciences*, 56: 2282-2291.

Gutreuter S., Burkhardt R.W., Stopyro M., Bartels A., Kramer E., Bowler M.C., Cronin F.A., Soergel D.W., Petersen M.D., Herzog D.P., Raibley P.T., Irons K.S. & O'Hara T.M. 1997. *Annual status report 1993: A summary of fish data in six reaches of the upper Mississippi River system*. LaCrosse, Wisconsin, U.S. Geological Survey. 206 pp.

Gutreuter S., Burkhardt R.W., Stopyro M., Bartels A., Kramer E., Bowler M.C., Cronin F.A., Soergel D.W., Petersen M.D., Herzog D.P., Irons K.S., O'Hara T.M., Blodgett K.D. & Raibley P.T. 1998. *Annual status report 1991: A summary of fish data in six reaches of the upper Mississippi River system*. LaCrosse, Wisconsin, U.S. Geological Survey. 206 pp.

Gutreuter S., Dettmers J.M. & Wahl D.H. 1999. *Abundance of fishes in the navigation channels of the Mississippi and Illinois rivers and entrainment mortality of adult fish caused by towboats. Interim Report for the Upper Mississippi River: Illinois Waterway System Navigation Study.* Vicksburg, Mississippi, U.S. Army Corps of Engineers. 156 pp.

Gutreuter S., Dettmers J.M. & Wahl D.H. Estimating mortality rates of adult fishes from entrainment through the propellers of river towboats. *Transactions of the American Fisheries Society*. (forthcoming)

Holland L.E. 1986. Distribution of early life history stages of fishes in selected pools of the upper Mississippi River. *Hydrobiologia*, 136: 121-130.

Jenkins R.M. 1967. The influence of some environmental factors on standing crop and harvest of fishes in U.S. reservoirs. *In Reservoir Fishery Resources Symposium.* Bethesda, Maryland, American Fisheries Society. pp. 298-321.

Johnson B.L. & Jennings C.A. 1998. Habitat associations of small fishes around islands in the upper Mississippi River. *North American Journal of Fisheries Management*, 18: 327-336.

Junk W.J., Bayley P.B. & Sparks R.E. 1989. The flood pulse concept in river-floodplain ecosystems. *In* D.P. Dodge, ed. *Proceedings of the international large rivers symposium. Can. J. Fish. Aquat. Sci. Special Pub.*, 106: 110-127.

Knights B.C., Johnson B.L. & Sandheinrich M.B. 1995. Responses of bluegills and black crappies to dissolved oxygen, temperature, and current in backwater lakes of the upper Mississippi River during winter. *North American Journal of Fisheries Management*, 15: 390-399.

Lowery D.R., Taylor M.P., Warden R.L. & Taylor F.H. 1987. Fish and benthic communities of eight lower Mississippi River floodplain lakes. Lower Mississippi River Environmental Progaram Report 6. Vicksburg, Mississippi, The Mississippi River Commission. 222 pp.

Mayo R.M. 1999. Growth of blue catfish, channel catfish, and flathead catfish relative to latitude and physical characteristics of the lower Mississippi River. Starkville, Mississippi State University. 77 pp. (Masters thesis)

McHenry J.R., Ritchie J.C., Cooper C.M. & Verdon J. 1984. Recent rates of sedimentation in the Mississippi River. *In* J.G. Weiner, R.V. Anderson & D.R. McConville, eds. *Contaminants in the Upper Mississippi River*. Stoneham, Massachusetts, Butterworth Publishers. pp. 99-117.

Meade R.H. 1995. Geology, hydrology, sediments, and engineering of the Mississippi River. *In* R.H. Meade, eds. *Contaminants in the Mississippi River, 1987-1992. U.S. Geological Survey Circular 1133*. Washington, U.S. Government Printing Office. pp. 13-30.

Mettee M.F., O'Neil P.E. & Pierson M.J. 1996. *Fishes of Alabama and the Mobile Basin*. Birmingham, Alabama, Oxmoor House. 819 pp.

Miranda L.E. 1999. A typology of fisheries in large reservoirs of the United States. *North American Journal of Fisheries Management*, 19: 536-550.

Nailon R.W. & Pennington C.H. 1984. *Fishes of two dyke pools in the lower Mississippi River. Technical Report E-84-3*. Vicksburg, Mississippi, U.S. Army Engineer Waterways Experiment Station. 77 pp.

Pennington C.H., Baker J.A. & Bond 1983a. *Fishes of selected aquatic habitats on the Lower Mississippi River. Technical Report E-83-2*. Vicksburg, Mississippi, Waterways Experiment Station. 96 pp.

Pennington C.H., Baker J.A. & Potter M.E. 1983b. Fish populations along natural and revetted banks on the lower Mississippi River. *North American Journal of Fisheries Management*, 3: 204-211.

Pflieger W.L. 1975. *The fishes of Missouri*. Jefferson City, Missouri Department of Conservation, Jeferson City. 343 pp.

Pitlo J. Jr. 1987. Standing stock of fishes in the upper Mississippi River. Rock Island, Illinois, Fish Technical Section, Upper Mississippi River Conservation Committee. 28 pp.

Pitlo J. Jr. 1992. *Mississippi River investigations. Federal Aid in Sport Fish Restoration, Project F-109-R-4, Final Report*. Des Moines, Iowa Department of Natural Resources. 129 pp.

Pitlo J. Jr. 1997. Response of upper Mississippi River channel catfish populations to changes in commercial harvest regulations. *North American Journal of Fisheries Management*, 17: 848-589.

Pitlo J. Jr., van Vooren A. & Rasmussen J.L. 1995. *Distribution and relative abundance of upper Mississippi River fishes*. Rock Island, Illinois, Upper Mississippi River Conservation Committee, Fish Technical Section. 20 pp.

Pugh L.L. & Schramm H.L. Jr. 1998. Comparison of electrofishing and hoopnetting in lotic habitats of the lower Mississippi River. *North American Journal of Fisheries Management,* 18: 646-656.

Rabelais N.N., Turner R.E., Justi D, Dortch Q., Wiseman W.J. Jr., and Sen Gupta B.K. 1996. Nutrient changes in the Mississippi River and system responses on the adjacent continental shelf. *Estuaries*, 19: 386-407.

Rabelais N.N., Turner R.E., Wiseman W.J. Jr. 2002. Gulf of Mexico hypoxia, a.k.a. The dead zone. *Annual Review of Ecology and Systematics*, 33: 235-263.

Rasmussen J.L. 1979. *UMRCC fisheries compendium. second edition*. Rock Island, Illinois, Upper Mississippi River Conservation Committee. 259 pp.

Rasmussen J.L. 1994. Management of the Upper Mississippi River. *In* P. Calow & J.E. Petts, eds. *The Rivers Handbook*. Oxford, UK, Blackwell Scientific Publications. pp. 441-445.

Rasmussen, J.L. Shovelnose sturgeon *Scaphirhynchus platorynchus*. *In* J. Pitlo Jr. & J.L. Rasmussen, eds. *UMRCC Fisheries Compendium. 3rd edition.* Rock Island, Illinois, Upper Mississippi River Conservation Committee. (forthcoming)

Rasmussen J.L., Pitlo J.M. Jr. & Steingraeber M.T. Upper Mississippi River resource management issues. *In* J. Pitlo Jr. & J.L. Rasmussen, eds. *UMRCC Fisheries Compendium, 3rd edition*. Rock Island, Illinois, Upper Mississippi River Conservation Committee. (forthcoming)

Rasmussen J.L., Pitlo J. and van Vooren A. 1985. *Use of primacord to sample fish populations of Upper Mississippi River UMR main channel border habitat.* Contract Report prepared for U.S. Army Corps of Engineers, Rock Island District, Rock Island, Illinois. 35 pp.

Risotto S.P. & Turner R.E. 1985. Annual fluctuations in abundance of the commercial fisheries of the Mississippi River and tributaries. *North American Journal of Fisheries Management,* 5: 557-574.

Robison H.W. & Buchanan T.M. 1988. *Fishes of Arkansas*. Fayetteville, University of Arkansas Press. 536 pp.

Ross S.T. 2001. *The inland fishes of Mississippi*. Jackson, University Press of Mississippi. 624 pp.

Rutherford D.A., Kelso W.E., Bryan C.F. & Constant G.C. 1995. Influence of physicochemical characteristics on annual growth increments of four fishes from the lower Mississippi River. *Transactions of the American Fisheries Society*, 124: 687-697.

Rutherford D.A., Kelso W.E., Constant G.C., Bryan C.F. & Cobb S.P. 1994. Growth rates and year-class strength of selected fishes as related to stage and discharge of the lower Mississippi River. Vicksburg, Mississippi, Mississippi River Commission. 44 pp.

Sabo M.J. & Kelso W.E. 1991. Relationship between morphometry of excavated floodplain ponds along the Mississippi River and their use as fish nurseries. *Transactions of the American Fisheries Society.* 120: 552-561.

Sabo M.J., Kelso W.E., Bryan C.F. & Rutherford D.A. 1991. Physicochemical factors affecting larval fish densities in Mississippi River floodplain ponds. Louisiana, USA. *Regulated Rivers: Research and Management,* 6: 109-116.

Satterlund D.R. & Adams P.W. 1992. *Wildland watershed management*. New York, John Wiley and Sons. 536 pp.

Scarpino P. 1985. *Great River: An environmental history of the Upper Mississippi River*. Columbia, University of Missouri Press. 219 pp.

Schmitt C.J. 2002. Biomonitoring of environmental status and trends BEST program: Environmental contaminants and their effects on fish in the Mississippi River Basin. Biological Science Report, USGS.BRD/BSRB2002-0004. Reston, Virginia, U.S. Geological Survey. 241 pp.

Schramm H.L. Jr. & Lewis W.M. 1974. *Study of the importance of backwater chutes to a riverine fishery. Contract Report Y-74-4*. Vicksburg, Mississippi, U.S. Army Engineer Waterways Experiment Station. 144 pp.

Schramm H.L. Jr., Eggleton M.A. & Mayo R.M. 2000. Habitat conservation and creation: invoking the flood-pulse concept to enhance fisheries in the lower Mississippi River. *Polski Archiwum Hydrobiologii*, 47: 45-62.

Schramm H.L. Jr., Eggleton M.A. & Minnis R.B. 1999. *Spatial analysis of floodplain habitat critical to lower Mississippi River fishes*. Starkville, Mississippi, Mississippi Cooperative Fish and Wildlife Research Unit.

Schramm H.L. Jr., Eggleton M.A., Pugh L.L. & Mayo R.M. 1999. Lower Mississippi River Fisheries Investigations 1996. Annual Report. Vicksburg, Mississippi, U.S. Army Engineers Mississippi Valley Division. 58 pp.

Schramm H.L. Jr. & Pugh L.L. 2000. Relative selectivity of hoopnetting and electric fishing in the Lower Mississippi River. *In* I.G. Cowx, ed. *Management and Ecology of River Fisheries*. Oxford, UK, Fishing News Books. pp. 40-52.

Schramm H.L. Jr., Pugh L.L., Eggleton M.A. & Mayo R.M. 1998. Lower Mississippi River Fisheries Investigations 1996. Annual Report. Vicksburg, Mississippi, U.S. Army Engineers Mississippi Valley Division. 80 pp.

Sheaffer W.A. & Nickum J.G. 1986. Backwater areas as nursery habitats for fishes in Pool 13 of the upper Mississippi River. *Hydrobiologia*, 136: 131-140.

Sheehan R.J., Lewis W.L. & Bodensteiner L.R. 1990. *Winter habitat requirements and overwintering of riverine fishes. Federal Aid Project F-79-R Completion Report*. Carbondale, Fisheries Research Laboratory, Southern Illinois University. 86 pp.

Simons D.B., Schumm S.A. & Stevens M.A. 1974. *Geomorphology of the middle Mississippi River. Contract Report Y-74-2*. Vicksburg, Mississippi, U.S. Army Engineer Waterways Experiment Station. 110 pp.

Sledge T.J. 2000. *Leech Lake creel survey, May 15 to September 30, 1999. Completion report. Project F-29-RP-19*. St. Paul, Minnesota Department of Natural Resources. 52 pp.

Sledge T. 1998. *Mississippi River creel survey from St. Cloud to Dayton, May 10 to September 30, 1997. Completion report. Project F-29-RP-17*. St. Paul, Minnesota Department of Natural Resources. 70 pp.

Sternberg R.B. 1971. *Upper Mississippi River habitat classification survey. Fish Technical Section Special Report*. Rock Island, Illinois, Upper Mississippi River Conservation Committee. 5 pp.

Strahler A.N. 1952. Hypsometric area-altitude analysis of erosional topography. *Bulletin of the Geographical Society of America*, 63: 1117-1142.

Sullivan J., Stoltenberg D., Manoyan S., Huang J., Zdanowicz D. & Redmon W. 2002. *Upper Mississippi River water quality assessment*. Rock Island, Illinois, Upper Mississippi River Conservation Committee, Water Quality Technical Committee. 184 pp.

Theiling, C.H., Korschgen C., de Haan H., Fox T., Rohweder J., & Robinson L. 2000. *Habitat needs assessment for the Upper Mississippi River System: Technical report*. La Crosse, Wisconsin, U.S. Geological Survey, Upper Midwest Environmental Sciences Center. 248 pp.

U.S. Geological Survey. 1999. *Ecological status and trends of the Upper Mississippi River System 1998: A report of the long-term resource-monitoring program*. La Crosse, Wisconsin, U.S. Geological Survey, Upper Midwest Environmental Sciences Center. 236 pp.

Warren M.L. Jr., Burr B.M., Walsh S.J., Bart H.L. Jr., Cashner R.C., Etnier D.A., Freeman B.J., Kuhajada B.R., Mayden R.L., Robison H.W., Ross S.T. & Starnes W.C. 2000. Diversity, distribution, and conservation status of the native freshwater fishes of the southern United States. *Fisheries*, 2510: 7-28.

Watson L.D. & Hawkinson B.W. 1979. *Recreational use of Pool 5, Mississippi River. Investigational Report No. 362*. St. Paul, Minnesota Department of Natural Resources. 23 pp.

Weiner J.G., Fremling C.R., Korschgen C.E., Kenow K.P., Kirsch E.M., Rogers S.J., Yin Y, & Sauer J.S. 1998. Mississippi River. *In* M.J. Mac, P.A. Opler, C.E. Puckett Haecker & P.D. Doran, eds. *Status and trends of the nations biological resources*. Reston, Virginia, U.S. Department of the Interior, U.S. Geological Survey. pp. 351-384.

Welcomme R.L. 1979. *Fisheries ecology of floodplain rivers*. London, Longman. 317 pp.

Welcomme R.L. 1985. *River fisheries*. Rome, Food and Agriculture Organization of the United Nations. 330 pp.

Wilcox D.B. 1993. An aquatic habitat classification system for the Upper Mississippi River System. EMTC93-T003. Onalaska, Wisconsin, U.S. Fish and Wildlife Service, Environmental Management Technical Center. 9 pp.

THE MEKONG RIVER SYSTEM

N. van Zalinge[1] P. Degen[1] C. Pongsri[1] S. Nuov[2] J.G. Jensen[3] V.H. Nguyen[4] X. Choulamany[5]

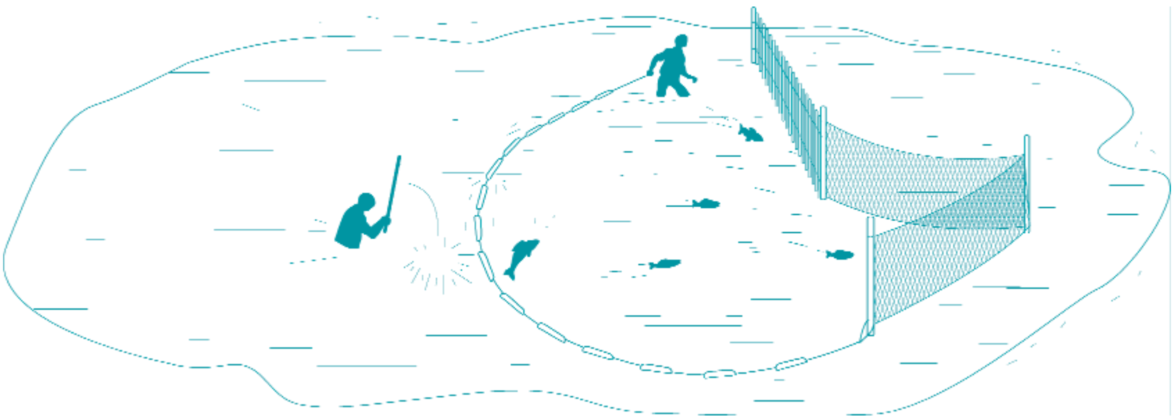
[1] Mekong River Commission Fisheries Program

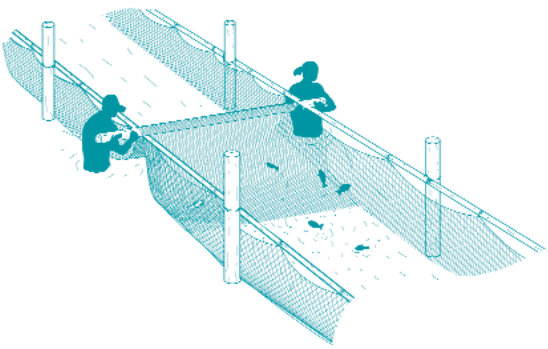
[2] Department of Fisheries and Inland Fisheries Research and Development Institute, Phnom Penh, Cambodia

[3] DANIDA, Copenhagen, Denmark

[4] Research Institute for Aquaculture No.2, Ho Chi Minh City, Viet Nam

[5] Living Aquatic Resources Research Center, Vientiane, Lao PDR





ABSTRACT

The Mekong is the longest river in Southeast Asia. From its source on the Tibetan plateau it runs for 4 800 km through China, Myanmar, Lao PDR, Thailand, Cambodia and Viet Nam to the South China Sea, where it discharges on average 475 000 million m^3 per year. The total Mekong Basin (MB) catchment area covers 795 000 km^2 and has 73 million inhabitants. The Lower Mekong Basin (LMB) comprises four countries, i.e. Cambodia, Lao PDR, Thailand and Viet Nam, which signed the 1995 river development agreement and cover 77 percent of the total basin with 55 million people. The degree of inundation of the 70 000 km^2 flood-

plains depends on the strength of the monsoon, as 85-90 percent of the discharge is generated during the wet season from May to October. Although far from pristine, the river still is in a relatively good condition. Only two mainstream dams have been built (in China), but there are many more on the tributaries. The number of fish species that has been found in the MB exceeds 2 000. Many migrate across international borders, thus constituting trans-boundary resources. The largest fisheries are found in the extensive floodplains in central Cambodia and the delta. A huge variety of fishing gear is used, from the most simple traps to kilometres-long fence systems. Catch levels of the capture fisheries in the LMB are estimated to top 2.6 million tonnes annually with a value exceeding US$1.7 billion. In Cambodia fisheries contribute 16 percent to the GDP. Strong increases in human population are matched by equal increases in fishing effort resulting in catch levels that are probably higher than ever. Major declines in stock sizes of the larger later-in-life spawning species have been witnessed. Catches are now dominated by smaller rapidly reproducing species.

Aquaculture is widespread in the Thai and Vietnamese parts of the LMB; production is estimated at 260 000 tonnes. In addition, 240 000 tonnes are captured in reservoirs. In rural areas most people engage in fishing to generate part of their income and food supply. The basin-wide consumption of fish and other aquatic animals ranges from 42 to 66 kg caput^{-1} year^{-1}. The Mekong River Commission came into being with the signing of the 1995 agreement by Cambodia, Lao PDR, Thailand and Viet Nam. It focuses on the need for cooperation in the sustainable development of the LMB. China and Myanmar have not joined yet. The member nations have agreed to prior consultation on proposed river water usage. The most important interventions required to sustain the fisheries are: (1) strengthening of the capacity of riparian governments in coordination and balanced decision-making on water resources development; (2) setting up of consultation procedures on water resources and fisheries management with resource users, decision makers, researchers and donors; (3) collection of data clarifying the contribution of fisheries to the national economy, food security and livelihoods; (4) participation of resource users in fisheries management; (5) protection of floodplain habitats; (6) maintenance of highest possible flood levels and a free flowing mainstream with as many free tributaries as possible.

DESCRIPTION OF THE RIVER SYTEM

The Mekong River Basin has a very diverse fish fauna that provides the basis for a large variety of fisheries, some with very impressive yields, especially in the lowlands of Cambodia and Viet Nam.

■ **Figure 1.** The lower Mekong Basin

Geography

With a total length of about 4 800 km the Mekong is one of the longer rivers in this world (Figure 1). Its source is on the north-eastern rim of the Tibetan plateau (Qinghai Province) at an elevation of more 5 000 m from where it flows through six countries: People's Republic of China, Myanmar, the Lao PDR, Thailand, Cambodia and the southern end of Viet Nam before it reaches the South China Sea, where it discharges on average 475 000 million m^3 per year (15 062 m^3 per second). The contribution of each country to the average river flow is as follows: China 16 percent, Myanmar 2 percent, Lao PDR 35 percent, Thailand 17 percent, Cambodia 19 percent and Viet Nam 11 percent (MRC 1998). The Mekong has 249 major tributaries.

The upper part of the river is called Lancang Jiang (in China) for about 2 400 km and is characterized by deep gorges and steep declines. Having fallen to about 360 m, it passes the Golden Triangle, where the borders of Lao PDR, Myanmar and Thailand meet. This is where the Lower Mekong Basin (LMB) starts and the river runs for another 2 400 km to the sea. For a stretch of about 900 km it forms the common border of the Lao PDR and Thailand. There is an inland delta at the geological fault line forming also the 21 m high Khone Falls on the Lao-Cambodian border. At Kratie about 545 km from the sea it becomes a lowland river. Then at Phnom Penh some 330 km from the sea, it is joined by the Tonle Sap River, which connects the Great Lake of Cambodia with the Mekong. There, the river splits into the Mekong proper and the much smaller Bassac to form a large estuarine delta, called the Nine Dragons in Viet Nam, before it empties in the South China Sea.

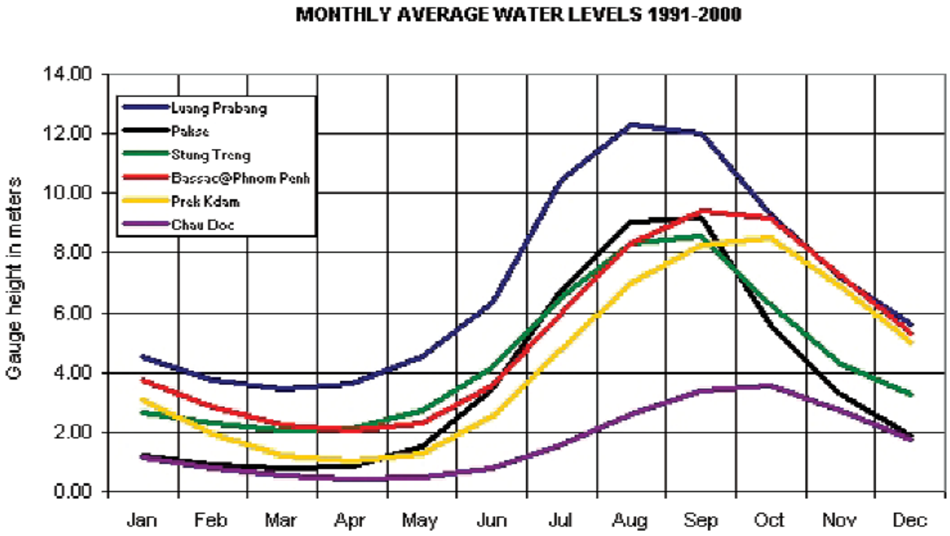
Basin size and population

The total Mekong Basin catchment area covers some 795 000 km^2 and has over 60 million inhabitants (Kristensen and Lien 2000). The Lower Mekong Basin comprises the four countries, Cambodia, Lao PDR, Thailand and Viet Nam that signed the 1995 river development agreement, which established the Mekong River Commission (MRC). The LMB covers 609 000 km^2 (77 percent of the total) and harbours 55.3 million people, of which ca. 50 percent is below 15 years of age. Population densities are lowest in the Lao PDR and Myanmar followed by Cambodia and Yunnan (China). Densities are much higher in north-east Thailand and highest in the delta of Viet Nam. Average population growth is 2 percent. The LMB countries are classified as low-income nations with GDPs of less than US$300 per capita per year, except for Thailand, which is a middle-income country. With growing populations, urbanization and industrialization, water demands will increase.

Flood regime

The river has one flood pulse a year. During the wet season (May-November) the discharge is 30 times greater than in the dry season (December-April) at Pakse (southern Lao PDR) and 53 times at Kratie (Cambodia). Floodplains cover some 70 000 km^2. The degree of inundation depends on the strength of the monsoon, as 85-90 percent of the discharge is generated during wet season. The Tonle Sap Great Lake floodplains in the heart of Cambodia contain the largest continuous areas of natural wetland habitats remaining in the Mekong system. One of the striking characteristics of the Mekong's hydrologic regime is the flow regulation by the Great Lake in Cambodia, the largest permanent freshwater body in Southeast Asia. The Tonle Sap River at Phnom Penh connects the lake to the Mekong. During most of the wet season the Mekong pushes the Tonle Sap River flow toward the lake. This expands it 3 to 6 times from 2 700 km^2 to 9 000-16 000 km^2. In the dry season the flow direction is reversed. Then the lake supplies water to the Mekong and thereby raises the dry season water levels in the delta for some 5-6 months.

The hydrological cycle is shown in Figure 2. The recording stations shown are all in the LMB with



■ **Figure 2.** Hydrologic cycle of the Mekong river at selected stations

Luang Prabang being the farthest upstream and Chau Doc in the delta in Viet Nam. Prek Kdam is on the Tonle Sap River. Flood levels peak at Luang Prabang in August, but at Prek Kdam and Chau Doc in October.

Hydrographic data are available from Pakse and a few other places along the Mekong River since 1924. They show a considerable inter-annual variation in wet season river discharge (by a factor of two), which affects the extent of floodplain inundation. Weather patterns associated with the El-Niño phenomenon are thought to be partly causing these variations. However, the average wet season discharge in the last twenty years (1979-98) appears to be at least 10 percent lower than in 1924-56 (34 years), while the inter-annual variations have become more extreme. The downward trend seems to be independent of fluctuations in rainfall and has been linked to building of weirs and dams that started in the late 1950s (Nam Sokleang 2000).

Flood controls and mitigation

Flood controls (dykes) are widely applied in the Vietnamese part of the delta for irrigated rice growing. In the dry season saltwater intrusion in the Vietnamese delta can occur as far inland as 40 km from the sea (ESCAP 1998) posing a major problem for irrigation practices at this time of the year.

The Mekong River Commission Secretariat operates a flood forecasting system (www.mrcmekong.org). It is presently being expanded in Cambodia to help vulnerable communities to cope with the floods.

Hydropower

Demand for energy comes mainly from Thailand and increasingly Viet Nam, whereas the Chinese province of Yunnan and the Lao PDR have the greatest hydropower potential. Hydropower development in the LMB has so far only taken place in the tributaries (11 dams, totalling 1 600 MW or 9 percent of the estimated potential), mainly in Thailand, but also in the Lao PDR, resulting in several large reservoirs. However, in Yunnan one mainstream dam has been completed, a second one is under construction and three more are planned by 2020 (Lukang 2001). By that time there will be a decrease in wet season flows and increase in dry season flows. There are also undeveloped plans for several mainstream dams in the Lao PDR and one in Cambodia (at Sambor), but greater public scrutiny and increasing regulatory procedures, including requirements for detailed Environmental Impact Assessments and resettlement plans, are likely to influence their future unfavourably (Hill and Hill 1994; Gleick 1998; Ringler 2000) and financing is likely to be difficult.

Irrigation

There are thousands of reservoirs in the LMB largely concentrated in northeast Thailand, which are mainly used for irrigation and most are less than 100 ha in size (Virapat, Phimonbutra and Chantarawaratid 1999). They significantly contribute to the breaking up of the river system and hamper fish migrations. In the LMB a total of over 2 million ha was irrigated in the late nineties (Ringler 2000). Expansion plans include Mekong water diversion projects to alleviate dry season water shortages in Thailand. Northeast Thailand and the Vietnamese delta are largely deforested and are major rice producing areas with the largest water consumption. Dry season flow levels are of extreme importance to the delta. Water needs in irrigation and hydropower usage clash strongly with the water needs in fisheries and other wetland resource usage. The poor, who comprise the great majority of the Mekong basin’s people, disproportionately rely on the latter resources (Ringler 2000; Sverdrup-Jensen 2002).

Forest cover and sedimentation

Forest cover is still about 36 percent of LMB and mostly found in Cambodia and the Lao PDR. Deforestation is rampant: in Cambodia 1.4 percent is lost every year, in the Lao PDR 0.9 percent and in Viet Nam 0.8 percent (MRC/GTZ 1999).

Natural floodplain habitats consist of forests with plant species that can withstand seasonal inundation, as well as lakes and extensive grasslands, where deep-water rice farming takes place. Riverine forest is found along the lake and stream borders. It acts as an important trap of the sediments brought in with the Mekong water during the rising flood phase (van Zalinge *et al.* 2003). The average rate of sedimentation in the Great Lake itself is estimated to be 0.08 mm per year since the lake was formed 5 000-5 600 years ago (Tsukawaki 1997). The lake is on average a little over 1 m deep in the dry season and will eventually silt up, but the process is expected to take thousands of years, except if rampant deforestation and erosion in the Tonle Sap watershed would speed it up. The mainstream dams already built or planned in Yunnan, China, will trap the sediments brought down by the river from the Tibetan plateau. After the Manwan dam was closed in 1993, the average level of downstream total suspended solids in the river water nearly halved at Chiang Saen (north Thailand) compared to the average level before the closure, thereby lowering the fertility of the Mekong water (MRC 2002). The effect was still noticeable at Pakse in the southern Lao PDR, but had disappeared in Cambodia.

The natural floodplain habitats are in a much better condition around the Great Lake than in the floodplains south of Phnom Penh, which have largely been turned into rice fields by removing the flooded forest vegetation.

Navigation

Only limited parts of the river are navigable for small ships all year round: mainly from Yunnan to Luang Prabang and from Phnom Penh to the sea. The main obstacles are the extreme difference in wet and dry season flow, as well as the rapids of the upper Mekong, the Khone Falls and the Stung Treng-Kratie river stretch.

Channel modifications for navigation of ships up to 200 tons have taken place in Yunnan, China. Proposals have been made by China for blasting of the rapids in the part of the Mekong from the Yunnan border to Luang Prabang in the Lao PDR, which is now suitable for vessels up to 80 tons. China is likely to push for further channelization of the river.

Water laws and pollution

Water laws are quite new to countries of the region. Lao PDR and Viet Nam had framework laws coming into effect respectively in 1997 and 1999. Cambodia and Thailand still have draft laws only. Thailand and Viet Nam have the "polluter-pays" principle incorporated in their legislation, although little monitoring and enforcement take place (Ringler 2000).

In Yunnan a major source of pollution are the paper mills. Domestic wastewater is the major source of river pollution in northeast Thailand, as it is generally discharged without treatment (ESCAP 1998). Industrial pollution and agricultural run-off are also major problems, in particular for the Mun River. Phnom Penh city mostly discharges its raw sewage into the nearby rivers. Agro-pollutants have been found in fish, but dietary intake of PCBs and DDT from fish was lower in Cambodia than in other Asian countries (JSRC 1996; In Nakata, Tanabe *et al*. 1999).

FISH DIVERSITY AND MIGRATIONS IN THE MEKONG BASIN

Fish diversity

According to Rainboth (pers. comm.) the number of species occurring in the Mekong Basin may exceed 1 100. This includes nearly 900 freshwater species and some 200 estuarine species. In addition, there is likely also a high degree of genetic variation within species. Endemicity is fairly high, especially in the upper catchments and will probably grow in line with in-depth taxonomic studies. The high species diversity is a product of the geological history of the area, whereby different drainage systems each with their own set of species have joined to form the modern Mekong (Rainboth 1996). It also reflects a great diversity in habitat types. In fact, per unit area the Mekong basin has more species than the Amazon basin.

Coates (2001) has argued that human interferences (dams, habitat destruction, pollution) work to undermine ecosystem integrity and this may be a greater threat to diversity than over-exploitation by fisheries. Currently the state of the environment is still in reasonably good shape, especially in Cambodia and the Lao PDR, mainly because of slow development due to the regional conflicts in the recent past. Rainboth (pers. comm.) believes that there may have been a few extinctions, i.e. of *Puntioplites bulu* and others, but is not certain, as detailed surveys have not taken place.

Main groups of fish

Following Welcomme (1985) the river fish species are broadly classified by life cycle strategy into black fishes and white fishes. Black fish species like the snakeheads (*Channa* spp), gouramis (*Trichogaster* spp) and the catfishes (Clariidae) undertake relatively short migrations between the flooded areas in the rainy season and permanent waterbodies in or close to the floodplain in the dry season. They are adapted to withstand adverse environmental conditions (e.g. low dissolved oxygen) often prevailing on the floodplains. During the wet season the fish go back to the floodplains for feeding and spawning. In particular, the Channidae support large fisheries and are regarded as a valuable food resource fetching high prices.

The large group of "white fish species" carries out considerably longer migrations. At the beginning of the dry season most species move from the floodplains via the tributaries to the Mekong main stream. Their migrations may extend to several hundred kilometres. In the main stream they use the deeper parts of the river as refuges for the rest of the dry season. At the onset of the rains spawning takes place near these areas before the adult fish move back again for feeding to the floodplains again for feeding. In Cambodia the fish larvae drift downstream with the river current to the floodplains.

Well known white fish species are the river catfish, *Pangasianodon hypophthalmus* and two giant fishes: the giant Mekong catfish, *Pangasianodon gigas* a Mekong endemic of truly gigantic proportions (individuals exceeding 300 kg have been caught) and the beautiful giant carp, *Catlocarpio siamensis,* which can exceed 100 kg. The giant catfish is very rare nowadays. In Cambodia known catches were in the order of 6–11 fish annually in 2000-2002 (Hogan, Ngor and van Zalinge 2001; Mattson *et al.* 2002).

Among the white fish species group, there are a number of species with a short life span and a fast rate of reproduction. They mature and reproduce within the first year of their life. They are sometimes called “opportunists”, because each year their abundance in the catch appears to follow the level of the floods. The dominant species is the cyprinid, *Henicorhynchus siamensis,* which is an important food fish, as it forms the basis for a large production of traditional fermented fish products. Throughout the LMB these migrations support large fisheries, such as the *Dai* (bagnet) fishery in Cambodia. In Cambodia the fish and the national currency bear the same name: riel.

The bulk of the migrating riel (*Henicorhynchus* spp) tends to move out of the floodplains in January and in smaller quantities in February and March. Curiously they migrate en mass in a time window of 6-1 days before the full moon. More than half of the season’s catch is taken in the January peak period, when close to 1.5 million riel are taken per hour in the *Da*i fishery (that is ca. 36 percent of the catch). The catch estimates for this particular fishery are quite accurate and range from 9 000 - 16 000 tonnes annually.

Fish migrations

Much of what is known about the fish migrations in the Mekong River basin has been gained by tapping the local knowledge that is held by the fisher communities along the rivers (Bao *et al*. 2001; Poulsen *et al*. 2002) and through monitoring of selected landing sites in Cambodia (Srun and Ngor 2000; Kong, Ngor and Deap 2001).

Typically, most migrations in the Mekong River take place during the rising flood and the drawdown period. Based on different migration patterns Poulsen *et al*. (2002) distinguish three major systems in the lower Mekong in which white fish species participate. The systems are interconnected to some extent and have many species in common. The migration patterns are shown in Figure 3.

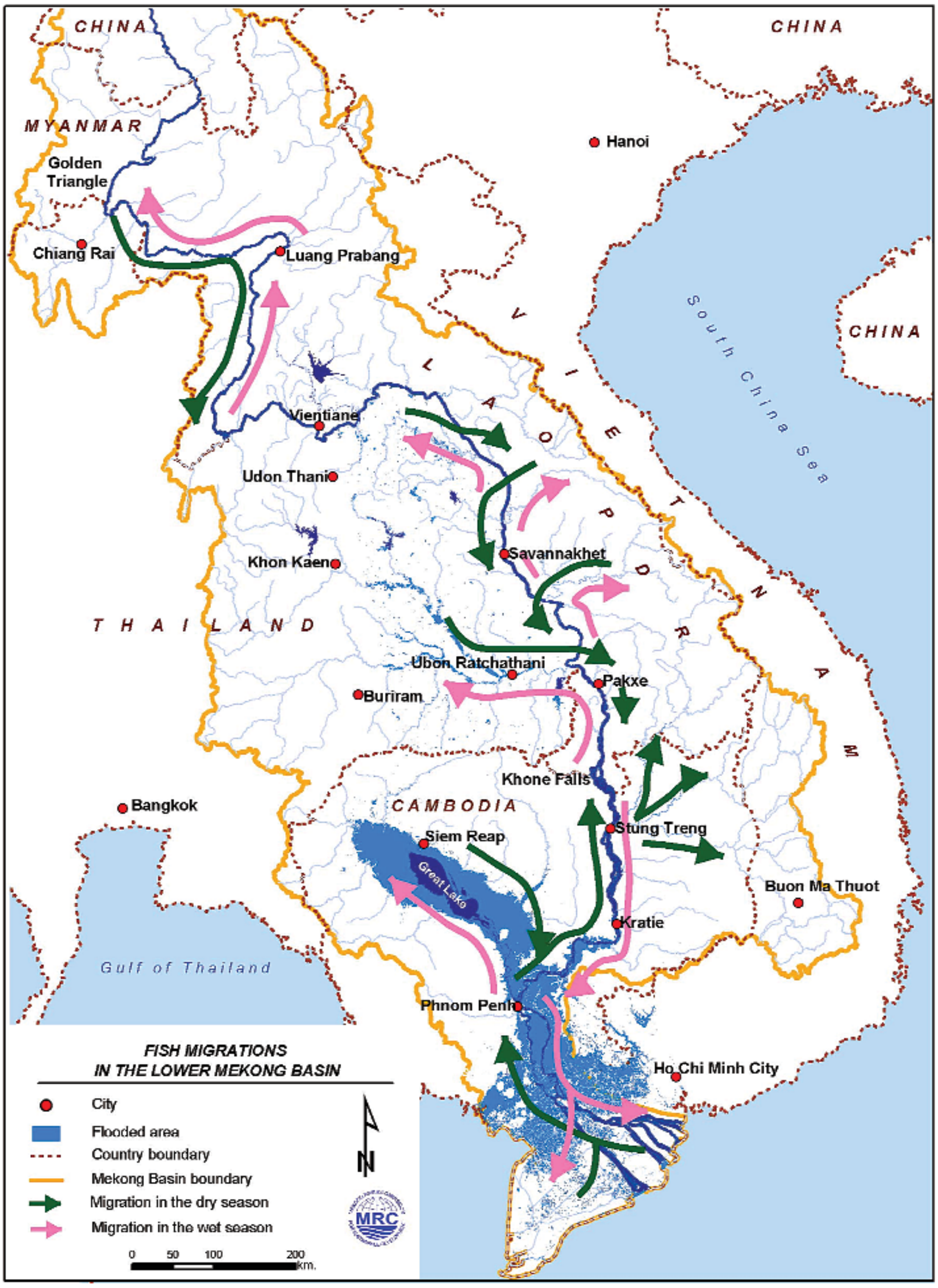
The lower Mekong migration system (altitudinal range 0 - 150 m)

This system covers the migrations taking place in Cambodia and Viet Nam. The upstream limit is the Khone Falls, although Baird *et al.* (2000a, 2000b) report that many species are able to cross this barrier, but possibly in small numbers only. The migrations are basically movements out of the floodplains and tributaries, including the Tonle Sap, to and up the Mekong at drawdown, where a number of species spawn around their dry season refuges usually at the onset of the monsoon. The return migration is made to the floodplains with the rising flood. The fish larvae generally drift downstream during the rising flood and pangasiid larvae are fished for stocking fish forms (van Zalinge, Lieng, Ngor *et al.* 2002). However, the large seasonal fisheries target only the drawdown migrations.

In the dry season the Sekong, Srepok and Sesan tributaries act as an extension of the Mekong for some species, such as *Henicorhynchus* spp and *Probarbus jullieni*, a large cyprinid (Poulsen *et al*. 2002), while other species, such as *Mekongina erythrospila* and *Bangana behri*, visit these tributaries mainly during the wet season.

The middle Mekong migration system (altitudinal range 150-200 m)

The system covers migrations from the Khone Falls upstream to approximately the level of Vientiane. Contrary to the lower system, in the middle system the fish move upstream in the Mekong during the wet sea-



■ **Figure 3.** Fish migrations in the Lower Mekong Basin (adapted from Poulsen et al. 2002)

son and enter the tributaries and their associated flooded areas for feeding. Some species spawn in the floodplains, while others spawn around the dry season refuges. During drawdown they leave the tributaries and return to dry season refuges downstream in the Mekong (Figure 3). These migrations tend to be shorter than in the lower system. Both systems have many of the species in common that may or may not form genetically distinct populations.

Interestingly Poulsen *et al*. (2002) report that some species, such as *Cyclocheilichthys enoplos* and *Cirrhinus microlepis* are mainly caught as juveniles and sub-adults in the lower system and as adults in the middle system. They speculate that this may be also true for other species, such as giant Mekong catfish (*Pangasianodon gigas*).

The upper Mekong migration system (altitudinal range 200 - 500 m)

This system is relatively isolated from the middle system possibly by a lack of dry season refuges in the section between the two. It stretches from the mouth of the Loei River in north Thailand (ca. 150 km upstream of Vientiane) to Chiang Rai and probably beyond into China. This section of the river has relatively few floodplains and major tributaries. In the wet season fish migrate upstream to spawning habitats in the Mekong to return later to their dry season habitats also in the main river. Spawning habitats are to be found in river stretches with alternating rapids and deeper channels.

Again this system has some species in common with the downstream systems, such as the giant Mekong catfish. In addition, there is also a *Henicorhynchus* species, which is also important for the fisheries here. It may be genetically distinct from the stock(s) downstream.

Management of migratory fish stocks

Poulsen *et al*. (2002) have pointed out that all six Mekong riparian states are signatories to the Convention on Biological Diversity, which commits these states to the conservation of biodiversity, their sustainable use, etc. In addition, the nations sharing the LMB signed the 1995 Agreement establishing the Mekong River Commission, which provides the framework for management of transboundary fish resources. This would involve the maintenance of habitats critical to the survival of migratory stocks and includes maintenance of connectivity (i.e. migration corridors) between these habitats (Poulsen *et al*. 2002). The types of habitats that are of critical importance have been mentioned briefly in the section above.

THE STATE OF FISHERIES

The size of the fisheries in the LMB appears to be related to the extent and inundation of the floodplains. Thus, the largest fisheries are found in the lowest parts of the river system in central Cambodia and the delta. More upstream floodplains are less extensive, the major ones being associated with the Songkram, the only un-dammed Thai tributary. As the floodplains are only temporarily covered with water, fish are forced to migrate to and from them. This necessity makes the fish vulnerable to interception by a large variety of fishing gears. “Black” fish species tend to move short distances from the nearest permanent water to the floodplain and back. “White” fish species cover much longer distances, as has been described above. The sum of these movements can result in an almost complete seasonal species turnover at a specific location. Hence, most fisheries are strongly seasonal.

Types of fishery

A huge variety of fishing gear is found in the LMB reflecting the diversity of the fish stocks and the complexity of their relationship to the different habitats at different stages of their life cycles and different times of the season.

Around 200 fishing gears and methods have been recorded in the extensive Cambodian floodplains and river systems, ranging from the mere use of the hands for collecting living aquatic products, simple basket traps and hook and lines to larger seines, trawl nets and lift nets to yet larger fishing operations like barrages, bag nets (*Dais*) and fishing weirs with kilometre long lead fences and intricate labyrinth constructions guiding the fish into big traps or even pens. The large-scale fishing activities commonly combine a series of successive fishing strategies, which complement each other into a highly efficient operation. Most of the gears and in particular the large-scale gears operate during the drawdown phase of the flooding season working on the principle that fish will have to move to deeper water when water levels are falling.

Large-scale inland fisheries are now limited to Cambodia, where they are managed as government concessions, the fishing lots. Their main purpose is to raise a rent on these rich resources. The system predates the French colonial occupation of Cambodia. Since 1919 the area covered by the lots has been reduced by ca. 70 percent. The largest reduction took place in 2001 apparently as a reaction to the mounting conflicts over access to fishing grounds between lot managers and fisher communities. The “freed” areas were placed under community fisheries management. The results so far are not encouraging, as the communities are not experienced in handling management and moreover appropriate laws have not been adopted yet. Detailed descriptions can be found in Lieng, Yim and van Zalinge (1995); van Zalinge *et al*. 2000; Degen *et al*. (2000); Degen *et al.* (2000, 2002); and Sverdrup-Jensen (2002).

Horizontal and vertical basket traps made of widely available natural raw materials, such as bamboo, rattan and vines reveal the biggest variety. Basket traps are passive fishing gears and as such well adapted to the needs of fishing/farming households. In all four countries of the LMB monofilament gillnets with their different ways of operation (floating, set, bottom, surface or mid-water) is the most popular gear. Descriptions of the gears found in Lao PDR and Cambodia are given in Claridge, Thanongsi Sorangkhoun and Baird (1997) and Deap *et al.* (2003), respectively.

In floodplain environments in Cambodia, the Mekong Delta of Viet Nam, the Khone Falls and the Songkram River the variety of gears seems to be bigger than in upland areas where fishing is carried out mainly during the rainy season.

In the floodplains fishing intensity is the highest during the recession period (October to April). In the uplands of the Lao PDR, northern Thailand, northeastern Cambodia and the central highlands in Viet Nam mainly small-scale fishing gear including fishing by hand is used to retrieve aquatic animals from the wetlands, including rice fields. In addition, there are important fisheries for freshwater shrimps (Caridea, in particular *Macrobrachium* spp) and mollusks. The fishing principles are the same, the shape of the traps may vary considerably and mark local traditions and customs, including beliefs.

Though legally forbidden everywhere destructive fishing practices such as the use of explosives, electric shock, as well as chemical and natural fish poisons still constitute a threat to fish stocks, habitats and to consumers (in the case of poisons).

Exploitation levels

Estimates of the total catch made by the fisheries in the LMB have increased dramatically in recent years and are presently topping 2.6 million tonnes annually (see Table 1) with a value exceeding US$1.7 billion (Jensen 1996; Sjorslev 2001; Sverdrup-Jensen 2002; Hortle and Bush 2003). These figures are based on per capita consumption of all freshwater fish and other aquatic animal products and exclude the fish produced in aquaculture and in reservoirs, respectively 260 000 and 240 000 tonnes. In northeastern Thailand aquaculture and reservoir fisheries are relatively important, as is aquaculture in the Vietnamese Mekong Delta. Estuarine fish production in Viet Nam is excluded from these figures.

The capture fisheries estimates are nearly nine times higher than the figures routinely used in FAO world fisheries statistics in the past. Closer examination of other tropical river systems is likely to lead to similar increases in the estimation of fish catches. Data collection by standard statistical methods is often greatly hampered by the dispersed small-scale nature of fresh water fisheries and therefore an approach using fish consumption information, as applied in the LMB, can be revealing.

The levels of the exploitation of the resources in the LMB are likely to be high to very high every-

Table 1: Estimated annual consumption of freshwater fish products, including other aquatic animals in the lower Mekong basin by country and by source, in 2000, expressed in whole fresh weight equivalents (as recalculated by Hortle & Bush 2003)

Country	Population (million)	Average per capita consumption (kg)	Total[1] fish consumption (tonnes)	Capture[2] fisheries catch (tonnes)	Reservoirs[3] fish catch (tonnes)	Aquaculture[4] production (tonnes)
Cambodia	11.0	65.5	719 000	682 150	22 750	14 100
Lao PDR	4.9	42.2	204 800	182 700	16 700	5 400
Thailand	22.5	52.7	1 187 900	932 300[5]	187 500	68 100
Viet Nam	17.0	60.2	1 021 700	844 850	5 250	171 600
Total LMB	55.3	56.6	3 133 400	2 642 000	232 200	259 200

1 Sjorslev (2001) recalculated by Hortle & Bush (2003)
2 Total consumption minus Reservoir catch and Aquaculture production
3 MRC Management of Reservoir Fisheries data
4 Phillips (2002)
5 Includes a large part of the probably more than 50,000 tons of freshwater fish products exported from Cambodia to Thailand (van Zalinge *et al.* 2001)

where and related to the presence of a large low-income rural population. However, despite a much higher population in the Mekong Delta of Viet Nam compared to Cambodia per capita consumption does not differ much (Table 1). Coates (2001) has suggested that this could mean there still is potential for increases in fish production in more lightly populated areas. As the flooding regime and the state of the natural environment are the most critical factors in the survival of the fish resources of the LMB, the situation in some countries may be deteriorating. In Thailand, large-scale alterations of the river system have taken place. Also in the Mekong Delta in Viet Nam widespread irrigation works are preventing fish to access large areas of floodplain, while in the central Vietnamese highlands reservoirs are being established on most rivers. To a lesser degree this is also the case in the Lao PDR. Only in Cambodia are the river systems still largely free flowing and fish are able to utilize the floodplains.

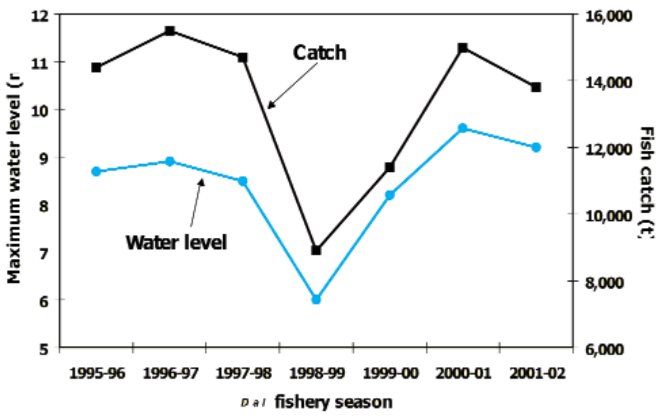
Cambodia

Within the MB fisheries are economically most significant in Cambodia, where they presently contribute 16 percent to the GDP (Zia Abbasi, pers. comm.; van Zalinge 2003). As in the Angkorian period (802-1432 A.D.), today fish and rice production are the basis of the food security in the country. Export of fish and fish products to the neighbouring countries is important, especially to Thailand. The seasonal inundation of the extensive floodplains, such as around the Tonle Sap Great Lake, is the reason for the wealth of fish. Fish yields in the Tonle Sap floodplain area range from 139-190 kg/ha per year (Lieng and van Zalinge 2002). Overall about 700 000 tonnes are caught in the country annually (van Zalinge *et al.* 2000; Sjorslev 2001; Hortle and Bush 2003). Limited historic information on catches is available; see e.g. Chevey and Le Poulain (1940), Fily and d’Aubenton (1965). However, because the human population in Cambodia has increased considerably (3-fold since 1940) and lives mainly (85 percent) in rural areas, full and part-time employment in fishing is very high (ca. 6 million or over 50 percent of the population), fishing effort must have increased equally strongly, probably resulting in catch levels that are higher than ever. Catch rates of individual fishers must have gone down a lot. Strong declines in stock sizes have been witnessed in the larger, later-in-life spawning, species. Catches are now dominated by smaller short-lived and rapidly reproducing species, the so-called opportunists, whose abundance seems to be directly related to the maximum flood level attained by the Mekong River during the wet season. This shift to smaller and cheaper species has reduced the average per-kg value of the catch.

It was found that the higher the Mekong flood and its sediment load are, the higher the catch of opportunist species in the Dai (bagnet) fishery (van Zalinge *et al.* 2003). The Dai fishery targets fish migrating out of the Great Lake area to the Mekong River during the drawdown of the floods. Among the ca. 100 fish species caught the genus *Henicorhynchus*, small cyprinids, is by far the most prominent (van Zalinge *et al.* 2003). Higher floods also favor better growth of these species.

The effect on the catch of longer-lived species is probably delayed, as for snakehead species (*Channa* spp) the best correlation was found with the catch in the following year. Degradation of the natural habitats in the floodplains, such as conversion of flooded forest to rice fields, leads to a significant decline in the value of the fish yield per ha of inundated area mainly as a result of changes in the species composition of the catch. For instance, the share of the valuable snakehead species decreases proportionally when rice fields replace flooded forest habitats (Troeung *et al.* 2002). On the other hand it is likely that the value of the rice crop compensates for this loss.

The flood-yield relationship (Figure 4) also implies that fish catches will be lower if upstream river interventions result in lower average flood levels and sediment loads, as seems to have happened already in the past 30-40 years (Nam Sokleang 2000; MRC 2002). This will be particularly harmful to Cambodia, where so many people depend on fish and fisheries for food and employment. Cambodia would be well



■ **Figure 4** or bagnet fishery in the Tonle Sap River. This is a small fishery of 60-63 bagnet units targeting white fish migrating out of the floodplains around the Great Lake to the Mekong River.

advised to continue assessing its fisheries output and to monitor upstream developments carefully.

Lao PDR

Fish consumption is estimated to be 204 800 tonnes (Sjorslev 2001; Hortle and Bush 2003), mainly from small-scale river fisheries, but also from reservoirs and aquaculture. Although fish is a significant part of the animal protein intake, it is not as important as in Cambodia, because Laotians rely also on hunting and trapping of forest animals to make up for the shortfall in their diet. Nevertheless, a fishery survey carried out in Luang Prabang found that 83 percent of households reported to fish and collect aquatic animals (Sjorslev 2000). Total production was estimated at 10 000-15 000 tons per year. A large variety of mainly small gears were used.

Fairly large fisheries exist in the Khone Falls area, where migratory fish are intercepted in the falls with many special gears (Roberts and Baird 1995). Baird *et al.* (1998) infer that annually some 4 000 tonnes are caught in the Khong district alone.

As the Lao PDR has adopted a policy favoring the use of hydropower, the number of reservoirs and related fisheries will increase. Mainstream dams have so far not been constructed in the Lao PDR still leaving the Mekong open to fish migrations. Fisheries for native species in the Nam Ngum hydropower reservoir have developed well since its closure in 1972 yielding 173 kg ha^{-1} $year^{-1}$ in 1998. The catch is dominated by *Clupeichthys aesarnensis*, a small pelagic clupeid, which contributed 24 percent (Mattson *et al.* 2000). However, the importance of the Nam Ngum catchment for fisheries was not assessed before the closure of the dam and at least ten migratory species are not found anymore upstream of the dam (Schouten 1998).

Viet Nam

The parts of Viet Nam that are in the LMB are a section of the central highlands and the Mekong Delta. Fishing activities are largely small-scale. Fishery surveys carried out in the delta provinces of An Giang and Tra Vinh show that 66 percent and 58 percent of households were part-time and 7 percent and 4 percent full-time involved in fishing in 1999 and 2000 (Sjorslev 2001a; AMF 2002). Most of the catch is for home consumption. Overall fish consumption in the Vietnamese parts of the LMB was estimated to be 1 021 700 tonnes annually (Sjorslev 2001; Hortle and Bush 2003) and also includes other aquatic animals and fish from aquaculture, but excludes sea fish. In 2000 a ban was declared on the *Dai* fishing for fry in the Mekong and the Bassac.

Viet Nam has an active hydropower program in its highlands. The resulting reservoirs are often partly stocked with exotics.

Thailand

Thailand largely removed the forests in its part of the LMB at around the time of the Second Indochina War, converting them to large-scale irrigation schemes for rice production. Its rivers were harnessed with thousands of dams - mostly small ones - for irrigation purposes and some large ones with huge reservoirs for hydropower (Virapat *et al.* 1999). The losses in fish catches must have been considerable and affected many rural people, even though the government adopted the policy of stimulating aquaculture and reservoir stocking to make up for these shortfalls. After years of protest the Pak Mun dam that was closed in 1994, was recently re-opened, allowing migratory fish to re-enter from the Mekong. Statistics on river fisheries are weak or not collected and consequently fish consumption rates have been used to gauge catch levels. Overall freshwater fish consumption in northeast Thailand stands at 1 187 900 tonnes annually (Sjorslev 2001; Hortle and Bush 2003). This figure includes fish and aquatic animals from inland fisheries, aquaculture and reservoir fisheries, as well as imports from Cambodia.

FISHERIES AND AQUACULTURE

Fish fry are caught for stocking purposes in all four countries of the LMB. The main species are snakehead (*Channa*) and pangasiid catfish. Cheap fish are often used as fish feed. It is argued that aquaculture production based on wild resources should also be included in capture fisheries.

Among the riparian countries there are no agreed policies for regulations on introductions of exotic species into the basin, nor on movements of genetic strains within the basin. According to Welcomme and Chavalit (2003), 17 species have been introduced successfully into the LMB, but their impact appears to be relatively minor so far. The lack of impact is thought to be due to the relatively good condition of the environment and this supports the native species.

Cambodia

Due to the large output of the capture fisheries and the low price levels, aquaculture development has been very slow. Hatchery production is low, as most culture establishments stock wild caught fry, mainly snakeheads (*Channa spp*) and pangasiid catfishes.

Cheap fish is generally used as feed. Mainly due to flooding of aquaculture ponds escapes of tilapias and carps have occurred and very small quantities are regularly caught in the wild. There is a large clandestine fishery for pangasiid fry (*Pangasianodon hypophthalmus* and *Pangasius bocourti*) in the Cambodian Mekong in the rising flood period. The fry is mainly exported to Viet Nam for culture (van Zalinge *et al.* 2002).

Lao PDR

Due to a large increase in irrigation schemes during the past few years, the potential for aquaculture, including rice-fish culture, has grown. However, fish seed production still does not meet the demand. Quite a few exotic species have been introduced, mainly tilapias and carps. The Lao government has made a policy towards banning the practice of stocking of certain exotic fish species in natural bodies. Cage culture of snakehead (*Channa* spp), such as practiced in the Nam Ngum reservoir, depends on fry and feed collected in the wild.

Thailand

Freshwater aquaculture has been developed mainly for domestic consumption and fish seed is commonly supplied by hatcheries. Higher-priced indigenous species, such as catfish, snakehead and freshwater prawn, are raised in commercial freshwater ponds. About 62 percent of farms are integrated, primarily with chicken farming and tree crops. More than 115 freshwater species have been introduced in Thailand, most of them through the ornamental fish trade. To enhance fish production the Department of Fisheries has long been stocking exotic species, such as tilapias, Chinese carps, major Indian carps and common carp, in public water bodies all over the country, but only tilapias, in particular *Oreochromis niloticus*, are commonly found in major reservoirs and lakes. The African catfish, *Clarias gariepinus*, was introduced by the private sector some 20 years ago. Although the Department of Fisheries has tried to minimise the possible impact of this species by hybridisation, this aggressive species has been able to spread and is found in open waters occasionally. The Department of Fisheries has developed regulations regarding introductions of exotic species into the country, but is not monitoring the level of infiltration.

Viet Nam

The Mekong Delta has the largest aquaculture output in the basin: 171 600 tonnes in 1999. Integrated cultures are quite common, as is rice-fish farming. In these farming systems are stocked both indigenous and exotic fish seeds mainly from hatcheries.

Snakehead is grown in cages, but pond culture is now also developing. Both completely depend on seed collected in the wild. Cage and pond culture of pangasiid catfish has relied heavily on stocking with wild caught fry in the past, most of which was coming from Cambodia, even though the fishery was declared illegal in 1994. In recent years hatchery output of fry has increased and is overtaking wild fry in importance. Most catfish is exported to overseas markets (van Zalinge *et al.* 2002).

Stock enhancement with exotic fish is mainly taking place in reservoirs and lakes. Tilapias have been used a lot with the result that populations have established themselves in brackish water bodies. Traditional extensive shrimp farming in the brackish waters of the Mekong Delta completely depends on wild seed, while in intensive farming only hatchery seed is used. In mud crab and bivalve farming mainly wild seed is stocked.

IMPORTANCE OF FISHERIES FOR LIVELIHOOD, EMPLOYMENT, FOOD SECURITY AND RECREATION

LIVELIHOOD AND EMPLOYMENT

The large majority of rural dwellers in the LMB are engaged in a wide range of production and income generating activities. These activities are integrated with all aspects of people's livelihood strategies and many of them exploit common property resources such as fish, aquatic products and water. Since products obtained for household consumption do not go through market chains and the cash economy, these activities have largely remained unnoticed or undervalued by policy planners. Farming, especially of rice and other related land based activities, is generally the most important source of employment. Depending on the proximity and the duration of access to water bodies, fishing is the second or third most important activity.

With the absence of comprehensive data and of total figures for the riparian countries, some targeted case studies may give indications of the importance of fishing activities for livelihoods and employment. In the provinces around the Great Lake Tonle Sap in Cambodia more than a million people generate income from fisheries (Ahmed *et al.* 1998). In Luang Prabang province in Lao PDR 83 percent of all the households in all surveyed villages are engaged in fishing and collection of aquatic animals, which is the third most important economic activity (after rice farming and livestock rearing) (Sjorslev 2000). Access to fish and aquatic resources is crucial for the most vulnerable strata of the rural populations. Their ability to access fish and collect other kinds of common property resources from their immediate natural surroundings serves them as an important sometimes last resort safety net of subsistence. It allows them to produce valuable proteins and nutrients for their household consumption and to market the surplus in order to cover the expenses of other basic needs of living. Results from a fishery survey in Luang Prabang show that 91 percent of people catch for home consumption, although 79 percent of the total catch was sold to middlemen (Sjorslev 2000). A recent survey of fisheries communities in a limited area in the Tonle Sap flood plains in Cambodia reveals that 31 percent of the households derive their main income from fishing, however 98 percent of all households report being involved in some kind of fishing activity throughout the year (Degen *et al*. in preparation).

In mountainous areas in the northern Lao PDR an important fishery for tadpoles in rice fields was observed at the beginning of the rainy season. There, tadpoles are collected mainly for income generation through export to lucrative Thai markets.

FOOD SECURITY

Although overlooked in the past, it does not come as a surprise that fish and other aquatic animals are the most important sources of animal protein and thus, a major support to food security, in particular of the rural population in the LMB. Apart from fish, frogs, tadpoles, snails, mollusks, shrimps, crabs, snakes and other reptiles and water birds from wetland habitats are considered "aquatic animals". Average basin-wide consumption of fish and other aquatic animals is estimated at 56 kg capita^{-1} year^{-1} (Hortle and Bush 2003). In high-yielding fishing areas such as in rural communities of the floodplains around the Great Lake Tonle Sap in Cambodia fish consumption is as high as 71 kg capita^{-1} year^{-1} (Ahmed *et al.* 1998). Even in mountainous regions like Luang Prabang in the Lao PDR, which present similar physical-geographic conditions as the central highlands in Viet Nam or northern Thailand or north-eastern Cambodia, fish and other aquatic animals account for 55 percent (29 kg capita^{-1} year^{-1}) of the total animal protein intake of the human population in rural areas (Sjorslev 2000). In An Giang province in the Vietnamese Mekong Delta consumption of fish, aquatic animals and processed products is reported as high as 58 kg capita^{-1} year^{-1} (Sjorslev 2001).

Recreation and eco-tourism

Compared to other inland fisheries in the world sport fishing for recreation occurs on a very limited scale in the LMB. In Thailand weekend tourism for fishing in the reservoirs enjoys a certain popularity.

Eco-tourism is starting in such obvious areas as the inundated forests around the Great Lake in Cambodia with its unique and rare bird colonies. Likewise the Khone Falls in the southern Lao PDR and more recently the undisturbed tributaries like the Srepok River in Ratanakiri and Mondulkiri provinces in Cambodia are attracting eco-tourists.

FISHERIES MANAGEMENT

Existing management and the way forward

Management measures and the registration of fish production have traditionally concentrated on the larger water bodies. All the four countries conduct management in relation to larger reservoirs, either through exclusive fishing rights, as in many Vietnamese reservoirs, or closed seasons and gear regulations as in many Thai reservoirs. A complex system for the management of the large scale fishery is in operation only in Cambodia, where it is based on licences to fish sections of the floodplains (the so-called fishing lots) and for major gears, like arrow-shaped traps, seines, trawls, barrages and bagnets (*Dais*). However, this system is not based on integrated plans for managing the fishery in a sustainable way, but rather on maximizing profits or, at best, maintaining catch levels in certain water bodies by habitat protection (Degen *et al.* 2000). Because it is very effective in controlling "open access", the fishing lot system would have been termed "best management practice" by Coates (2001), if the social problems caused by it could be addressed. Management experiments involving communities in operating fishing lots have not been tried so far.

Recent research (see above) has demonstrated how most fish species in the Mekong depend on annually repeated migrations for their survival. These migrations will often cross borders and may in all cases depend on the water quality and quantity in the mainstream and the tributaries. Dams and weirs may directly obstruct the migrations. Pollution may affect the stocks and reduce the survival and growth of larvae and fry, while alternative land use, alterations of wetlands and rock clearing for navigation may destroy the crucially important habitats, just to mention a few dangers emanating from other sectors. Present national laws are generally too limited to deal with these situations (Sverdrup-Jensen 2002).

It is therefore obvious that cooperation among several countries will be needed in order to manage these resources and secure their sustainability. And it is necessary to realize that fisheries management is not confined to the fisheries agencies and the fishers, but fisheries management includes habitat management and thereby the effects caused by other sectors. The Mekong River Commission seems at the moment to offer the best framework for such cooperation. Considerable information on the fish resources has been created in a close cooperation among the line agencies for fisheries of the four MRC countries and the corresponding National Mekong Committees. A Technical Advisory Body has been established with members from the top of the four national line agencies for fisheries, where issues of joint interest regarding regional fisheries management are being discussed and advice is being given to the National Mekong Committees and the national agencies responsible for fisheries management.

Hand in hand with the strengthened cooperation a viable strategy must be established to manage the resources jointly. And it will not be sufficient to do this country by country. Fish do not respect national borders, but do respect catchment (watershed) borders. For this reason, a "catchment approach" to fisheries management will be the most natural strategy to apply. Fish migrations can be seen as species migrating from one tributary catchment area where it spawns, entering the mainstream and exiting it into another tributary catchment area where it feeds, etc. The mainstream becomes the "highway" connecting tributary catchment areas. Everything, which goes in or out passes the "gate", where the tributary meets the mainstream.

The model is simple and functional. Water management measures, e.g. dam projects, may be examined through their potential effect at the building site, on the particular tributary catchment area and on distant tributary catchment areas sharing the same fish resources. Effects of aquaculture on the wild fish resources may be evaluated in the same way and catchment-specific regulations made for introduction of exotic species. A fish health management system, comprising temporary closure of trade in live fish and disease treatment, may be based on tributary catchments or clusters of catchments as well.

This will to some extent require working across the administrative borders and give rise to some headaches for a few administrators, but fortunately the administrative borders follow to a large extent the watersheds in the Mekong basin. To coordinate basin-wide management exchanges of research information, regular meetings among the fisheries managers of the participating countries are needed.

Co-Management

De facto co-management arrangements have been in use for a long time in the LMB. In all four riparian countries basic legal conditions (an enabling framework) for involving communities in natural resource management are in place (Hartmann *et al.* 1999). However, in practice the implementation of this enabling framework differs from country to country and from case to case and comprises a continuum of forms that range from more government-directed approaches at one extreme to community-based initiatives at the other. Rights and obligations of state and community differ accordingly. Since in all riparian countries stewardship of natural resources is vested in the state, governments have established more or less detailed legislations on fisheries management. Thus, consciously or unconsciously, resource users are ultimately implementing (or not!) these rules and regulations (Sverdrup-Jensen 2002).

In legislating fisheries, governments face the difficulty of addressing the specific requirements of a multitude of fisheries situations and conditions. In order to solve this problem and in line with the overall tendency of strengthening democratic governance structures, all governments in the LMB are decentralizing fisheries management decision-making to administrative levels closer to the fishers. The degree of decentralization differs in the four countries.

The dispersed settlement structure and remoteness of villages in some areas of the Lao PDR (Claridge *et al.* 1997; Sjorslev 2000) and north-eastern Cambodia has given rise to localized fisheries management regulations including permanently or seasonally closed fishing grounds, restrictions on specific fishing methods and protection of particular fish species or groups. These management initiatives, many of them focusing on migratory fish species, have evolved empirically and are embedded in local cultural institutions and reflect a deep knowledge of environmental conditions held by resource users. Frequently, such community-based management systems focus mainly on conflict management through managing fishing effort, including gear use regulations, conservation zones, seasonal fishing restrictions and procedures for handling cases of contention (Baird 2001). The dispersed nature of rural communities, their fragmented organization and the difficulties of communication have prevented effective socio-political representation of fishing communities.

In Thailand the existence of traditional forms of user organizations at village level is in decline and NGOs addressing issues of fisheries and natural resource use management have emerged more prominently than in other riparian countries. In Viet Nam co-management initiatives are embedded into the established politico-administrative system. Local authorities, in principle, follow the regulations on management and protection of natural fish resources stipulated by the Ministry of Fisheries. The degree of compliance, however, is reported to be less than satisfactory.

In Cambodia, the Government has drafted a special legal instrument (a decree) for the development of “community fisheries”, through which small-scale fishers obtain the right to use and manage fishing grounds that were formerly exploited by private large-scale fishing concessionaires. The implementation of this important change in the management regime, though, is hampered by still weak organizational capacities at village levels and the traditional focus on production with a view to maximize income for the privileged rather than protection of stocks and habitats and equitable sharing of the benefits from the fisheries resources. However, the reform process towards community fisheries has initiated a potentially powerful platform for creating transparency and awareness on the need for responsible participation of resource users at community level (Degen *et al.* 2002).

In Cambodia, attempts are undertaken to anchor local fisheries management efforts within the context of an integrated natural resource management approach at community level. A broader scope of management tries to “internalize” the effects of agricultural practices, forest use and other forms of exploitation of locally available natural resources. This for example includes linkages to water use for irrigation, the use of flooded forest for fish habitat, firewood and the forest soil for agricultural land. However, it is difficult for local communities to influence development measures, such as agro-business developments, deforestation and dam building, which may occur outside their limited boundaries, but have a large impact on local fisheries.

Unless community-based fisheries management initiatives are integrated into a functioning co-management set-up that involves, in addition to the local level, also national and regional levels, through which their members can exert influence on constraining external factors such as environmental degradation or decrease in water quality and quantity, decentralized management approaches will fail to achieve sustainability in fisheries resource management.

HOW TO SUSTAIN THE FISHERIES OF THE MEKONG BASIN?

Due to the inherent incompatibility of the various sectors with interests in water resources management and development, it will ultimately be necessary to make hard choices on how to develop the Mekong basin. To assist in the decision-making process and have proper representation of fisheries interests, it is felt that the most important interventions required to sustain the fisheries are:

1) Strengthening of the capacity of riparian governments in coordinating decision-making on water resources development plans that have been based on objective research;
2) Setting up of consultation procedures on water resource usage and fisheries management with resource users, decision makers, researchers and donors;
3) Collection of data clarifying the contribution of fisheries to the national economy, food security and livelihoods;
4) Participation of resource users in fisheries management; and
5) Clarifying the basic principles of fish productivity and lifecycles, such as the need for the protection of floodplain habitats, for maintaining high flood levels with a sufficient sediment load and minimally a free flowing mainstream.

REFERENCES

Ahmed M., Hap N., Ly V. & Tiongco M. 1998. *Socioeconomic assessment of freshwater capture fisheries of Cambodia. A report on a household survey. MRC/DoF/Danida Project for the Management of the Freshwater Capture Fisheries of Cambodia*. Phnom Penh, Cambodia, Mekong River Commission. 186 pp.

AMF. 2002. *Tra Vinh Viet Nam fisheries survey. AMFC/MRC and RIA2*. Ho Chi Minh City. 68 pp.

Baird I.G., Vixay I., Bounpheng P. & Phongsavath K. 1998. *A rapid fishery survey in Khong District, Champasak Province, Southern Lao PDR*. Department of Forestry, Champasak Province. Environmental Protection and Community Development in the Siphandone Wetland Project. 31pp.

Baird I.G., Flaherty M.S. & Bounpheng P. 2000a. *Mekong river Pangasiidae catfish migrations and the Khone falls wing trap fishery in southern Laos.* Environmental Protection and Community Development in the Siphandone Wetland Project. Champasak Province, Lao PDR.

Baird I.G., Flaherty M.S. & Phylaivanh B. 2000b. *Rhythms of the river: Lunar phases and small Cyprinid migrations in the Mekong river.* Environmental Protection and Community Development in the Siphandone Wetland Project. Champasak Province, Lao PDR. 21 pp.

Baird I.G. 2001. Towards sustainable co-management of Mekong river aquatic resources: the experience in Siphandone wetlands. *In* G. Daconto ed. *Siphandone Wetlands.* CESVI, Bergamo. pp. 89-111.

Bao T.Q., Bouakhamvongsa K., Chan S., Chhuon K.C., Phommavong T., Poulsen A.F., Rukawoma P., Suntornratana U., Tien D.V., Tuan T.T., Tung N.T., Valbo-Jorgensen J., Viravong S. & Yoorong N. 2001. *Local knowledge in the study of river fish biology: Experiences in the Mekong. MRC Development Series No. 1*. Phnom Penh, Cambodia, Mekong River Commission. 22 pp.

Chevey P. & Le Poulain F. 1940. *La pêche dans les eaux douces du Cambodge. Travaux de L'institut Océanographique de l'Indochine*. 5e Mémoire, Gouvernement Générale de l'Indochine. Saigon. 241 pp.

Claridge G.F., Thanongsi Sorangkhoun & Baird I.G. 1997. *Community fisheries in Lao PDR: a survey of Techniques and Issues*. IUCN-The World Conservation Union. Vientiane, Lao PDR. 69 pp.

Coates D. 2001. *Biodiversity and fisheries management opportunities in the Mekong River Basin. Contribution to the Blue Millenium Conference*. MRC Technical Paper. Phnom Penh, Cambodia, Mekong River Commission. (forthcoming)

Deap L., Degen P. & van Zalinge N. 2003. Fishing Gears of the Combodian Mekong. Inland Fisheries Research and Development Institute of Combodia, Phnom Penh. Combodia Fisheries Technical Paper Series, Volume IV, 269 pp.

Degen P., van Acker F., van Zalinge N.P., Nao T. & Deap L. 2000. *Taken for granted. Conflicts over Cambodia's freshwater fish resources*. Prepared for the IASCP Conference, Bloomington, Indiana, USA, 31 May - 4 June 2000.

Degen P., Vuthy L., Thyda P.C., Dara Y., Piseth C. & Saroeun L. 2002. People, power and fishery policy. Fisheries management reform addressing community fisheries in Cambodia. *Proceedings 4th technical symposium on Mekong fisheries.* 10-11 December 2001. *MRC Conference Series No. 2*. Phnom Penh, Cambodia, Mekong River Commission. pp. 11-28.

Degen P., Yin D., Chap P. & Lieng S., eds. *A self-review of Community Fisheries development in ex-fishing lots No. 13, 14 and 15, Kampong Chhnang Province, March 2002. Crafting monitoring tools by those who need them.* MRC/DoF/Danida. Cambodian Capture Fisheries Component. (forthcoming)

ESCAP. 1998. *Sources and nature of water quality problems in Asia and the Pacific*. Economic and Social Commission for Asia and the Pacific. ST/ESCAP/1874. New York, UN.

Fily M. & d'Aubenton F. 1965. *Cambodia: Report on fisheries technology in the Great Lake and the Tonle Sap, 1962-63*. National Museum of Natural History, Paris. 509 pp.

Gleick P.H. 1998. *The world's water 1998-1999: The biennial report on freshwater resources*. Washington, DC, Island Press.

Hartmann W., Degen P., Logarta M., Phounsavath S. & Nao T. 1999. Are state-user relations conducive to fisheries co-management in the Lower Mekong Basin? *Proceedings 2nd technical symposium on Mekong fisheries.* 13-14 December 1999.

Hill M.T. & Hill S.A. 1994. Fisheries ecology and hydropower in the Mekong River: An evaluation of run-of-the-river projects. Mekong Secretariat, Bangkok.

Hogan Z., Ngor P.B. & van Zalinge N.P. 2001. Status and Conservation of two Endangered Fish Species, the Mekong Giant Catfish *Pangasianodon gigas* and the Giant Carp *Catlocarpio siamensis* in Cambodia's Tonle Sap River. *Natural History Bulletin of the Siam Society,* 49: 269-282.

Hortle K.G. & Bush S.R. 2003. *Consumption of fish and other aquatic animals in the Lower Mekong Basin. MRC Technical Series.* (forthcoming)

M., Nakata H., Tanabe S. & Touch S.T. 1999. Persistent organochlorine residues in marine and freshwater fish in Cambodia. *Marine Pollution Bulletin,* 38: 604-612.

Jensen J.G. 1996. 1,000,000 tons of fish from the Mekong? *Mekong Fish Catch and Culture,* 21.

JSRC. 1996. *Basic study of the environment of Cambodia*. Japan Sotoshu Relief Committee JSRC Research Group for Cambodian Environment. 26 pp.

Kristensen J. & Lien N.D. 2000. Experience in international cooperation for planning and sustainable development of the Mekong River Basin. Contribution to the 4th Regional Consultation of the World Commission on Dams, Ha Noi, Viet Nam, 26-27 February 2000. 6 pp.

Kong H., Ngor P.B. & Deap L. 2001. The dry season migration pattern of five Mekong fish species: Trey Chhpin *Barbodes gonionotus*, Trey Kaek *Morulius chrysophekadion*, Trey Sloeuk Russey *Paralaubuca typus*, Trey Klang Hay *Belodontichthys dinema*, and Trey Po *Pangasius larnaudiei*. Inland Fisheries Research and Development Institute of Cambodia, *Fisheries Technical Paper Series III*: 73-87.

Lieng S., Yim C. & van Zalinge N.P. 1995. Freshwater fisheries of Cambodia: The bagnet dai fishery in the Tonle Sap River. *Asian Fisheries Science,* 8: 255 - 262.

Lieng S. and van Zalinge N.P. 2002. Fish yield estimation in the floodplains of the Tonle Sap Great Lake and River, Cambodia. Inland Fisheries Research and Development Institute of Cambodia, *Fisheries Technical Paper Series III,* 23-26.

Lukang Li. 2001. The perspectives of the Lancang Jiang River Basin. Wetlands International China Program, Beijing. (available at http://www.ecolife.ru/jornal/ereg/2001-2-1eng.shtml)

Mattson N.S., Bouakhamvongsa K., Sukumasavin N., Tuan N. & Ouk V. 2002. Mekong giant fish species: On their management and biology. *MRC Technical Paper No. 3,* Phnom Penh, Cambodia, Mekong River Commission. 29pp.

Mattson N.S., Balavong V., Nilsson H., Phounsavath S. & Hartmann W. 2000. *Changes in fisheries yield and catch composition at the Nam Ngum reservoir, Lao PDR*. MRC Reservoir Project Report. 11 pp.

Mekong River Commission. 1998. *Conceptual framework report: Water utilization programme*. Prepared by SMEC and Funded by Global Environmental Facility.

MRC/GTZ. 1999. *Forest-cover monitoring project. Final report 1998*. Phnom Penh, Cambodia, Mekong River Commission.

Mekong River Commission. 2002. *Report on informal donor meeting. Phnom Penh, 28 May 2002*. 40 pp.

Nam Sokleang. 2000. Mekong River flow data analysis. *In* N.P. van Zalinge, T. Nao and S. Lieng, eds. *Management aspects of Cambodia's freshwater capture fisheries: Eleven presentations given at the annual meeting of the Department of Fisheries, 27 - 28 January 2000*. Cambodia, Mekong River Commission and Cambodian Department of Fisheries. 170 pp.

Poulsen A.F., Poeu O., Viravong S., Suntornratana U. & Tung N.T. 2002. Deep pools as dry season fish habitats in the Mekong River Basin. *MRC Technical Paper No. 4*. Penom Penh, Cambodia, Mekong River Commission. 22 pp.

Poulsen A.F., Poeu O., Viravong S., Suntornratana U. & Tung N.T. 2002. Fish migrations of the Lower Mekong Basin: Implications for development, planning and environmental management. *MRC Technical Paper No. 8*. Phnom Penh, Cambodia, Mekong River Commission. 62 pp.

Phillips M.J. 2002. Freshwater aquaculture in the Lower Mekong Basin. *MRC Technical Paper 7*. Phnom Penh, Cambodia, Mekong River Commission. 62 pp.

Rainboth W.J. 1996. *Fishes of the Cambodian Mekong. FAO Species identification sheets for fishery purposes*. Rome, Food and Agriculture Organization. 265 pp.

Ringler C. 2000. *Optimal allocation and use of water resources in the Mekong River Basin: Multi-country and intersectoral analyses*. Bonn, Rheinischen Friedrich-Wilhelm's Universität. 119 pp. Doctoral dissertation

Roberts T.R. 1993. Artisanal fisheries and fish ecology below the great waterfalls of the Mekong river in southern Laos. *Nat. Hist. Bull. Siam Soc.,* 41: 31-62.

Roberts T.R. & Baird I.G. 1995. Traditional fisheries and fish ecology on the Mekong river at Khone waterfalls in southern Laos. *Nat. Hist. Bull. Siam Soc.*, 43: 219-262.

Schouten R. 1998. Effects of dams on downstream fisheries, the case of the Nam Ngum reservoir. *Mekong Fish Catch and Culture*, 4: 1-5.

Sjorslev J.G. ed. 2000. *Luang Prabang Fisheries Survey. LARReC research report no. 0001*. Vientiane, Living Aquatic Resources Research Center. 45 pp.

Sjorslev J.G. 2001. *Assessment of consumption of fish and aquatic animals in the Lower Mekong Basin. Draft report for the Mekong Development Series*. 35 pp.

Sjorslev J.G. eds. 2001a. *An Giang Viet Nam fishery survey. AMFC/MRC and RIA2*. Vientiane. Living Aquatic Resources Research Center. 70 pp.

Srun P. & Ngor P.B. 2000. Migration study of some Mekong fishes in Cambodia. *In* N.P. van Zalinge N.P., Nao T. & Lieng S. eds. 2000. pp. 61-76. *Management aspects of Cambodia's Freshwater Capture Fisheries: Eleven presentations given at the Annual Meeting of the Department of Fisheries of the Ministry of Agriculture, Forestry and Fisheries, 27-28 January 2000*. Phnom Penh, Cambodia, Mekong River Commission and Department of Fisheries. 170 pp.

Sverdrup-Jensen S. 2002. *Fisheries in the Lower Mekong Basin: Status and perspectives. MRC Technical Paper No. 6*. Phnom Penh, Cambodia, Mekong River Commission. 103 pp.

Troeung R., Aun S., Lieng S., Deap L. & van Zalinge N.P. 2002. *A comparison of fish yields per unit area between flooded forest habitats in Battambang provincial Lot 2 and deforested habitats in Prey Veng provincial Lots 14 and 18*. Fifth MRC Symposium on Mekong Fisheries, Khon Kaen, 11-13 December 2002.

Tsukawaki S. 1997. *Lithological features of cored sediments from the northern part of Lake Tonle Sap, Cambodia*. International Conference on Stratigraphy and Tectonic Evolution of southeast Asia and the south Pacific, Bangkok, Thailand, 19-24 August 1997. pp. 232-239.

Van Zalinge, N.P. 2003. Data requirements for fisheries management in the Tonle Sap. *In New approaches for the improvement of inland capture fishery statistics in the Mekong Basin*. Bangkok, FAO Regional Asia & Pacific Office, 2003/01. pp. 68-75.

Van Zalinge N.P., Nao T., Touch T.S. & Deap L. 2000. Where there is water, there is fish. Cambodian fisheries issues in a Lower Mekong Basin perspective. pp. 37-48 *In* M. Ahmed and P. Hirsch, eds. *Common property in the Mekong: Issues of sustainability and subsistence. ICLARM Studies and Reviews*, 26. 67 pp.

Van Zalinge N.P., Nao Thuok & Sam Nuov. 2001. *Status of the Cambodian inland capture fisheries sector with special reference to the Tonle Sap Great Lake*. Inland Fisheries Research and Development Institute of Cambodia, *Fisheries Technical Paper Series, Volume III*. pp. 10-17.

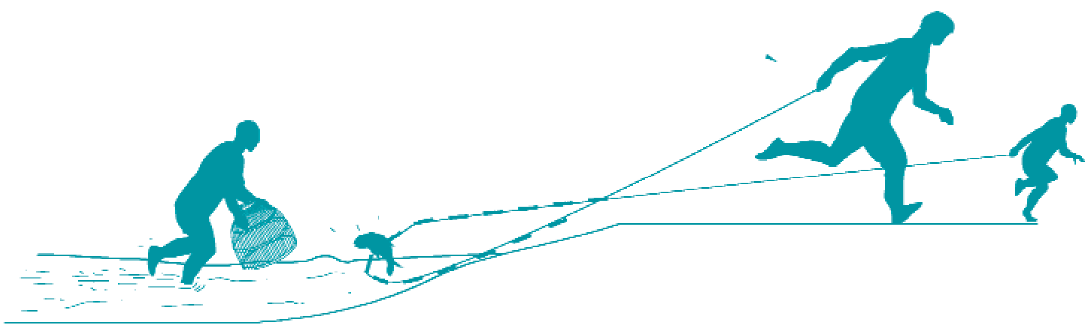
Van Zalinge N.P., Lieng S., Ngor P.B., Heng K. & Valbo-Jørgensen J. 2002. Status of the Mekong *Pangasianodon hypophthalmus* resources with special reference to the stock shared between Cambodia and Viet Nam. *MRC Technical Paper No. 1*. Phnom Penh, Cambodia, Mekong River Commission. 29 pp.

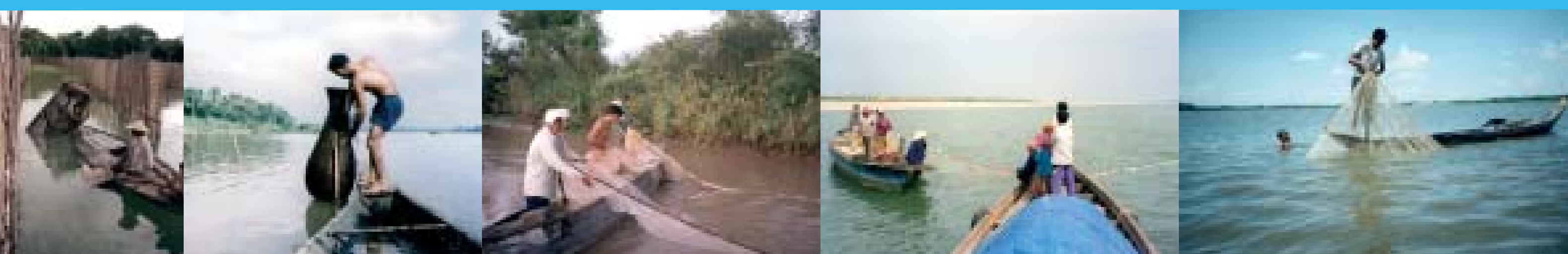
Van Zalinge N.P., Deap Loeung, Ngor Pengbun, Juha Sarkkula, Jorma Koponen & Huon Rath. 2003. Mekong flood levels and Tonle Sap fish catches. Abstract submitted to the Second International Symposium on the Management of Large Rivers for Fisheries. Phnom Penh, Mekong River Commission.

Virapat C., Phimonbutra U. & Chantarawaratid C. 1999. *Fishery and fisheries management in Thai Reservoirs: Review and assessment. Management of the Reservoir Fisheries in the Mekong Basin*. Phnom Penh, Cambodia, Mekong River Commission. 45 pp.

Welcomme R.L 1985. River fisheries. *FAO Fisheries Technical Paper No. 262*. 330 pp.

Welcomme R.L. & Chavalit V. 2003 The impacts of introductions and stocking of exotic species in the Mekong Basin and policies for their control. MRC Technical Paper No.9, Mekong River Commission, Phnom Penh. 38 pp.





HOSTS

MAJOR SPONSORS

SPONSORS