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Environment Component

IMPACT OF BUILT STRUCTURES ON TROPICAL FLOODPLAINS WORLDWIDE

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ABBREVIATIONS

ADB	Asian Development Bank
IEE	Initial Environmental Examination
EIA	Environmental Impact Assessment
CIA	Cumulative Impact Assessment
SEA	Strategic Environmental Assessment
INPA	National Institute of Amazonian Research
IUCN	The World Conservation Union
MRC	Mekong River Commission
FAP	Flood Action Plan
WCD	World Commission Dam
PCB	Polychlorinated Biphenyls
DDT	Dichloro-diphenyl-trichloroethane
ICOLD	International Commission on Large Dams
WB	World Bank
WRI	World Resource Institute
MRAG	Marine Resource and Fisheries Consultants
SIA	Social Impact Assessment
IIRSA	Integración de la Infrastructura Regional Suramericana
SEMRY	Secteur Expérimental de Modernisation de la Riziculture de Yagoua (later renamed to Société d'Expansion et de Modernisation de la Riziculture de Yagoua)
BCAS	Bangladesh Centre for Advanced Studies
PIRDP	Pabna Irrigation and Rural Development Project
FCDI, FCD/I	Flood control, drainage and irrigation scheme
CPP	Compartmentalisation Pilot Project
IRN	International Rivers Network
SEARIN	Southeast Asia Rivers Network
SEI	Stockholm Environment Institute
CBD	Convention on Biological Diversity
NEPA	National Environmental Policy Act (USA)
EMS	Environmental Management System
FAO	The Food and Agriculture Organization of the United Nations
GEF	Global Environment Facility

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EXECUTIVE SUMMARY

This review discusses the recorded impacts of built structures on the environment and fisheries of tropical floodplains worldwide.

Riverine floodplains cover more than two million km^2 globally. The floodplains in various parts of the globe vary considerably in terms of their physical, chemical and biological characteristics. However, the majority of all floodplains share one quality; they are highly productive due to the exchange of energy and nutrients between different groups of organisms, terrestrial and aquatic. Moreover, all literature describing floodplains mentions their undisputable importance for fisheries.

Floodplains are among the most biodiverse environments known. Apart from being biodiverse, tropical areas also display a high percentage of endemism. Tropical riverine fauna generally include a large number of migratory species, which are highly vulnerable to human impact, including modifications of lateral or longitudinal connectivity to their habitat. Many of these species are both riverine and lacustrine, depending on the season, and therefore dependent on the availability of both habitats.

Floodplains are rapidly being destroyed through reclamation of the land for other purposes. Today, rivers and wetlands are valued with regard to all ecosystem goods and services they provide, and as such are estimated far higher in value than e.g. forests or grasslands. In Europe and the USA, where most floodplains have been lost, restoration of regulated wetlands is increasingly taking place, and at a great cost, to return these long-term benefits and ecosystem services provided by the wetlands.

One of the highest valued “direct use value ecosystem services” of floodplains is fish, while inputs to agriculture (nutrient rich deposits) and nursery functions of fish and other organisms, are considered the most important “indirect use value services”. Some, albeit few, studies concerning the value of specific ecosystem services in tropical floodplains have been carried out, and these studies make it clear, that the conservation of the flooded forest habitats is of critical importance, also financially, to ensure a sustainable future for local economies.

Predictions suggest that in the near future, the most threatened floodplains will be those in Southeast Asia, Sahelian Africa and North America. Without beginning to preserve existing floodplains and to restore hydrological dynamics, sediment transport and riparian vegetation to those rivers that retain some level of ecological integrity, dramatic extinctions of aquatic species and ecosystem services will be faced within the next few decades.

Hydrology is clearly the single most important driving variable in tropical floodplains, based on which the flood pulse concept defines the river and its floodplain as an indivisible unit. Any long-term change to the pulse affecting the hydrodynamics of the flood, such as timing, height, duration, amplitude, smoothness or the rapidity of change of the flood pulse, will result in fundamental ecological changes in the affected areas and also influence the living conditions of the local human population. It is now generally accepted that the conservation of most species in the aquatic system, as well as biodiversity in its broader sense, depends on the maintenance of the flood pulse.

Impacts of different types of built structures such as embankments, roads, canalization, and mining and fishing gears, is discussed in this review. Of these, dams and canalization have been discussed most in literature, due to their significant impacts on floodplain environments, fish and fisheries.

The main effects of dams include changes in discharge downstream, desiccation of floodplains, riverbank erosion, changes in water quality, and changes in flora and fauna.

The following effects of stress caused by built structures, such as dams or levees, on fish have been identified:

- Obligate migratory species will tend to disappear in systems where the main channels are locked by large dams.
- Floodplain spawners are selected by chanelisation or other stream regulation processes that reduce or eliminate the annual flood.
- Within modified channels there is a tendency to lose obligate migratory species although management is usually directed at their protection through installation of fish pass structures or through stocking.
- There is a tendency for dominance in fish assemblages to shift from floodplain spawners toward main channel spawners.

Because of the negative impacts, and the difficulty in finding effective mitigation measures, the environmental flow requirements methodology (which includes managed flood releases) is increasingly used to reduce the impacts of changed stream flow regimes on aquatic, floodplain and coastal ecosystems downstream.

Recorded impacts of built structures on floodplain environments have been reviewed based on case studies worldwide.

In the South American floodplains, deforestation has, and continues to be, the most severe and debated threat to the vast floodplains. Built structures are still relatively few, and the impacts thereof less discussed. However, large-scale infrastructure projects are increasingly planned, and feared to have major impacts on the floodplains. The most significant threats to the Amazon floodplains are summarised as 1. modification of the hydrological regime, 2. large-scale destruction of plant communities, 3. reduction of populations of plant and animal keystone species and 4. pollution. Examples of projects for which impacts have been recorded are discussed.

In Africa, water needs for irrigation, domestic and industrial uses have caused construction of numerous reservoirs affecting the downstream flow and floodplains. The changed hydrological regime of rivers has adversely affected floodplain agriculture, fisheries, pasture and forests that constituted the organising element of community livelihoods and culture. In many cases, the desiccation caused by dams has been enhanced by natural drought.

Impacts of flow alteration on fish species have been documented for numerous artificial reservoirs in Africa, which have replaced running water habitats resulting in the disappearance of lotic species and the proliferation of species adapted to lentic systems. Many of these species are exotic, which has had further impacts on the ecosystem.

The case of the Waza Logone floodplain is discussed in detail due to it being an important example of a successful initiative to restore the lost ecosystem services of a floodplain impacted by dams. The restoration was based on an ecosystem approach and carried out through planned releases of water. The return of the flood was of greatest value to pasture and fishing, while it has also significantly benefited agriculture, the state of other natural resources and surface water reserves.

In general, there are many lessons to be learnt with regard to the restoration of floodplains in Africa. Opening of structures unnecessary changing flooding patterns, as well as artificial flood releases, in connection with a participatory approach utilising local knowledge, have achieved successful results. Despite these experiences, it has been shown that it is extremely hard to recover the complete variety of ecosystem services, once lost.

In Australia, wetland habitats are decreasing mainly due to modified flood regimes, floodplain isolation and increasing salinization. The following factors have been listed as key pressures on the aquatic ecosystems:

- changes in natural flow regimes due to water extraction and supply
- direct modification or destruction of important habitats
- barriers to the movement of plants and animals upstream
- effects of poor water quality
- competition from introduced and exotic animal and plant species

Common built structures in Australia include dams, weirs, regulators, farm dams, floodgates, causeways, culverts, pipes, channelised streams, bridge footings, and erosion control works. These barriers have been observed to isolate fish communities, restrict passage and result in changes in the fish community structures as many native fish need to migrate up and down river systems to breed, disperse and travel to spawning grounds.

Bangladesh has one of the richest and largest floodplain systems in the world, floodplains constituting about 80% of the country. Because of the large damage to the human population caused by floods, many flood control programs have been built to mitigate the adverse impacts of flooding. These structures have affected the floodplain environment and fisheries, most strikingly through the drastic reduction of floodplain area by over 2 million hectares in the past 30 years, which has severely impacted floodplain dependent fish species.

Numerous studies carried out in Bangladesh point to decreasing inland fish catches due to water resources development projects, as well as decreasing fish diversity. In general, whenever flood control projects reduce the area of flooded land, there will be a loss of habitat for fish production and a subsequent loss in annual fish yields or catch per unit area. Flood control programmes have been found to affect reproduction and larval fish drift, block fish migration and dispersal routes, and reduce species diversity by up to 30%, most of which is due to the loss of the more valuable white fishes. Sluice gates have proven to be fatal for many fish species. Water control projects have substantially reduced fisheries on the floodplains. Flood control, drainage and irrigation schemes have been found to negatively affect fish species assemblages and stock values by reducing the accessibility of impounded floodplains to migratory fish. The fish production from inland capture fisheries has been in decline in Bangladesh for some time. A major reason is the flood control projects, while pesticides and industrial pollution are also mentioned as important factors impacting the fisheries. Flood control and drainage projects have been implemented partly to increase rice production, but it has turned out that they have been of little value for rice production, whereas their effects on fisheries have been devastating (in some cases reducing indigenous floodplain fisheries by over 70%).

In the Mekong area, several large dam projects have brought insights into their impacts on the environment. As in Africa, there are some encouraging examples of participatory approaches in connection with the rehabilitation of lost ecosystem services through managed releases of water. However, better management of environmental and social safeguard perspectives are commonly called upon to avoid impacts on the environment and fisheries. Suggested management practices are discussed based on the knowledge base collected through this review.

Final recommendations are as follows:

Modification of the hydrological regime has been found the first and foremost threat toward floodplain ecosystems, based on numerous experiences in tropical floodplains worldwide. Therefore, any structure affecting the all-important hydrology of a floodplain should be assumed to influence the environment, and treated with consequent caution. Most impacts are directly or indirectly combined with aspects of changing hydrological regimes, and cannot be separated from this. Any assessment must take into account impacts on integrative processes such as the flood pulse and alterations to any aspect of it; these include its **magnitude, timing, amplitude, duration, modality, smoothness and rapidity of change**. In general, the loss of flooded areas and hydrological connectivity should be minimized.

Another general recommendation concerns the importance of a systematic, professional and serious EIA process. This entails, among other things, to accommodate **adequate baseline collection** (to be extended over at least two years) and present a comprehensive collection of proposed **mitigation measures**, to ensure that these be taken into account in the design phase of the project, rather than later at a significantly greater expense. The incorporation of an **Environmental Management System** (EMS) is a central part of the EIA process and the resulting EMS must be adhered to throughout the project cycle, including setting of milestones, response plans to detected changes and an evaluation of the functioning of the EMS. Also, **Strategic Environmental Assessments** should be developed for relevant sectors.

The following recommendations have been drawn from the case studies considered in this review:

1. **Indirect impacts** of large-scale construction sites may be enormous in comparison to the actual structures. Land-use change, potentially induced by project activities in the area surrounding the project site, and their impact on the environment should be considered in EIAs.
2. Small-scale canals and natural water channel modifications are possibly the most common type of built structure and therefore lead to many **cumulative impacts**. Taking these into account in connection with new built structure assessments is of importance.

3. The main causes of freshwater aquatic **biodiversity loss** have been identified as flow modification, habitat alteration, water pollution, introduction of exotic species and over-exploitation of certain species. All these issues are, directly or indirectly, linked to built structures, and therefore EIAs relating to built structures should include a component considering biodiversity issues at as many levels of the ecosystem as possible.
4. In connection with river regulation such as dams, as well as other large structures blocking migration routes and causing fragmentation of habitats, **fish biodiversity** has decreased in most reported cases. In connection with new built structures it is therefore of importance to consider this probable impact at an early stage and prepare mitigation measures during the entire project cycle. Planning of structures should take into account the **movement of fish,** as well as securing the presence of **sanctuaries/protection times**. The design of sluice gates and other modified passages should take into account that for many fish an overshot mode regulator is less destructive than an undershot one, while e.g. various designs of turbines for hydropower differ with regard to the mortality of passing fish.
5. Lessons learnt have shown that the destruction of floodplains affects specialized artisanal-type fisheries, often operating on a small-scale. This type of **small-scale fisheries** livelihood is very hard to replace and it is therefore of importance to **assess and value** in the course of the EIA process. The spread of invasive plant and animal species (often occurring as a result of changed hydrology or intended introductions of e.g. fish to reservoirs) can lead to surprising and dramatic losses/changes and also affects local livelihoods that depend on other ecosystem goods than fish.
6. When assessing the impact of built structures on e.g. fish catches, it is of importance to **evaluate the distribution of the catches between subsistence fisheries and professional fisheries**. In many cases, it has been shown that e.g. flood control structures have benefited groups of people that have the ability to invest in fish farming, while the opportunities for natural open water fisheries have diminished, either through changes in species composition or fish production in the affected area. Unlike land, floodwater usually belongs to all. Therefore, **the risks connected to reduced floodwater availability are significant especially for non-land owners**, the poorest section of the rural population.
7. The **value of other ecosystem goods**, such as forest and plant resources, pasture, wildlife etc. are often underestimated until these are lost with degenerating floodplain conditions. Even though fisheries are indisputably the most significant resource of the floodplains, other natural resources are of great importance in view of **diversification of food resources and livelihoods**, and often play an important part especially for the poorest people. Also e.g. the value of wetlands as natural purification filters for water is surprisingly high. **The use of integrative approaches, such as the ecosystem approach, is highly recommended in complex environments such as floodplains.**
8. **Valuation of ecosystem services** should be developed and integrated into project planning and EIA procedures. This type of valuation yields figures and a numerical measure that can be integrated into more conventional economic cost benefit analyses of the proposed investment, and allows a more thorough economic analysis of the predicted returns for different investment options.
9. Lessons learnt have demonstrated **the sensitivity of tropical floodplain** environments to **increased nutrient runoff**. Recent research has illustrated the

importance of phytoplankton to tropical floodplains in Australia and South America. This has important implications for the management of floodplains. Attention should be directed to the control of water quality changes (nutrients, but also turbulence, herbicides, metals, etc.) influencing phytoplankton productivity and species composition of the floodplains, which could have a profound impact on the entire food chain including the species composition of fish.

10. In connection with road construction, it is of importance to assess how to reach a **compromise between construction costs** and the need for including e.g. culverts and other **means to facilitate floodwater flows and the passage of flora and fauna**. In many cases where the needs of the ecosystem functions have not been taken into account during the planning phase of the construction, fitting of culverts has been done at a later stage (and at a significantly higher cost) to e.g. enable fish passage.

11. In connection with any built structure in floodplain areas, the effects of **increased access to the wetlands** should also be assessed. It has been shown that improved access due to lessened flooding, improved road networks and consequent increased human habitation in the floodplain areas will inevitably lead to increased destruction of forest resources and habitats through increased commercial activities facilitated by road accessibility. Increased access has also had drastic effects on wildlife due to intensified poaching in areas previously less accessible. Similarly, the newly accessible areas will be subject to new agricultural activities or improved agricultural methods (including irrigation, flood control works, and other infrastructure, as well as new crops or varieties), which in turn will cause changes in the hydrology and increased runoff of pesticides and herbicides.

1. INTRODUCTION

This report forms part of the ADB TA 4669, "Study of the Influence of Built Structures on the Fisheries of the Tonle Sap" project, presenting part of the Environmental Component. The intention of this component is to assess the side-effects of built structures on the (aquatic) environment.

The key outputs of this component are:

1. Literature review (this product, references in Annex 1) including recommendations based on lessons learnt in tropical floodplains worldwide.
2. Table of data concerning recorded, and quantified, impacts (in the form of an Excel file with collected metadata on selected reference cases, Annex 2)
3. Review of IEEs and EIAs in the Tonle Sap Basin (to be produced by Sophie Nguyen Khoa, available in November 2006)
4. Synthesis report based on this review and the analysis of IEEs and EIAs on the Tonle Sap Basin.

This report reviews documented short-term and long-term influences of built structures on selected tropical floodplains worldwide, from an environmental and social safeguard perspective. It reviews mainly impacts recorded after a built structure project has been realised, while predictive information such as Environmental Impact Assessments (EIAs), Cumulative Impact Assessments (CIAs) and Strategic Environmental Assessments (SEAs) are only dealt with occasionally when information on post evaluations have not been found in the literature. Lessons learnt and recommendations based on this literature review will be combined with the second part of the environmental component, which aims to synthesize the findings and recommendations from EIA processes conducted for development projects in the Tonle Sap Basin. The final output will be a joint effort to produce a set of recommendations based on this literature review and the findings from the EIA analysis. These will feed into the policy briefs to be produced as part of the "Informing policy and decision makers" component.

2. METHODS AND SUMMARY OF MATERIAL

2.1. METHODS USED

The following approaches were used to identify literature and other materials concerning the impacts of built structures:

- Internet based search engines
- Library searches at the University of Turku, Finland, and especially in the Amazon library hosted at the same university
- A questionnaire (Annex 3) sent to experts identified during the preliminary literature review
- Correspondence with floodplain experts through the email, phone and other means (Annex 4, Persons Consulted)

2.1. Summary of information sources reviewed

Information on general aspects of floodplains is extensive and readily available. However, quantitative information is scarce. The review collected quantitative information (presented in Annex 2), but qualitative data has also been reviewed and summarised in this report. The review concentrates on selected, important and well-documented floodplains around the world.

- >300 journal articles/reports were reviewed
- 9 books were reviewed
- A number (>120) of web pages were reviewed

The questionnaire contained 10 questions (Annex 3 displaying questions and a summary of quantitative answers) regarding floodplains and observed impacts of built structures within them was sent to altogether 62 recipients, mainly scientists known (through the review process) to have worked in floodplain environments. Twenty-three replies were received (of which 19 answered most questions) out of the 62 recipients (31% response rate). The replies received considered floodplains on all continents and major river basins.

3. FLOODPLAINS – GENERAL ISSUES

3.1. Definition

The most common and referred to definition of floodplains is: “Areas of low lying land that are subject to inundation by lateral overflow water from rivers or lakes with which they are associated” (Junk and Welcomme 1990). The “Glossary of terms related to floodplain management” defines floodplains as “low lands adjoining the channel of a river, stream or watercourse, or ocean, lake or other body of water, which have been or may be inundated by flood water, and those other areas subject to flooding” (FMA website *http://www.floodplain.org/glossary_of_terms.htm*). In the literature, several more specific definitions are used for different types of floodplains. The terminology varies, including names such as floodplain, flooded forest / shrub land / savannah, inundated forests, *várzea* and *igapó*, seasonal floodplain and wetland, being used depending on flooding characteristics, geographical area, and vegetation of the floodplain or other characteristics of the environment. In the Amazon, the floodplains are defined according to the origin and type of the water flooding the forest; *várzea* forests are fed by sediment rich “white water” rivers, *igapó* forests border the blackwater (high humus content) and clearwater tributaries (Goulding *et al*. 1995). The *várzea* forests are the most common, the most nutrient rich, and have the tallest trees, and therefore are probably the ones that correspond the closest to the nutrient rich Asian monsoon-driven floodplains.

This review concentrates mainly on tropical riverine freshwater floodplains (thus excluding e.g. marine and brackish deltas and mangrove swamps) that are, or have been, regularly inundated by seasonal floods, and where development has taken place and the impacts thereof have been recorded. The review concentrates on some well studied and documented areas, and it does not by any means present an exhaustive inventory of floodplains or structures built on them.

3.2. STATUS OF KNOWLEDGE REGARDING TEMPERATE VERSUS TROPICAL FLOODPLAINS

Riverine floodplains cover more than two million km^2 globally (Tockner and Stanford 2002). The tropical floodplains of the world are scattered over all continents with tropical areas, occurring along numerous tropical rivers and lakes. The floodplains in various parts of the globe vary considerably in terms of their physical, chemical and biological characteristics. However, the majority of all floodplains share one quality; they are highly productive due to the exchange of energy and nutrients between different groups of organisms, terrestrial and aquatic (Junk 1997). Moreover, all literature describing floodplains mention their undisputable importance for fisheries.

Another trait shared by most floodplains is their rapid destruction through reclamation of land for other purposes. Due to the special features of the floodplains, oscillating between aquatic and terrestrial phases, they have proved difficult environments for human utilization, and for this reason they have been eliminated or strongly modified by human activities. In highly industrialised countries in North America, Australia and Europe, most floodplains have been lost to agriculture, industries, infrastructure and housing; all the while the understanding of the importance of floodplains and other wetlands has increased. Today, rivers and wetlands are valued with regard to all ecosystem goods and services they provide, and as such are estimated far higher in value than e.g. forests or grasslands. According to Constanza *et al*. (1997) the estimated average global value for ecosystem goods, services, biodiversity and cultural considerations of wetlands is US$14 785 million while forests are estimated at US$969 and grasslands at US$232 million respectively. In both the USA and Europe, restoration and recovery of regulated wetlands is increasingly taking place, and at a great cost, to return these long-term benefits and ecosystem services provided by wetlands. The restoration efforts have even included decommissioning of dams due to environmental concerns. Much of the restoration effort has concentrated on rehabilitation of wetland habitat and fish migration routes. A recent example is the restoration plan for the Everglades Wetlands in Florida. The documented negative impacts of water diversions through dikes and canals included diminished water retention capacity of the watershed, topsoil loss, runoff from developments leading to raised phosphorus levels, salinity intrusion, loss of biodiversity and proliferation of invasive species. The first phase of the restoration plan is estimated to cost US$7.8 billion, mainly due to the restoration of natural hydrological patterns to increase the capacity for storing water within the watershed. This includes the removal of long stretches of canals and levees, and the installation of gates and culverts to roads presently interrupting the ability of many animals to find suitable habitats timed to their lifecycle (WRI 2000).

In the near future, the most threatened flood plains will be those in SE Asia, Sahelian Africa and North America. There is an urgent need to preserve existing, intact flood plain rivers as strategic global resources and to begin to restore hydrological dynamics, sediment transport and riparian vegetation to those rivers that retain some level of ecological integrity. Otherwise, dramatic extinctions of the aquatic and riparian species and of ecosystem services and faced within the next few decades.

Tockner and Stanford 2002

Apart from restoration programs, research activities are also currently taking place in connection with e.g. flood control and its implications for fish and fisheries in temperate areas (e.g. the Living Murray initiative in Australia, the recent symposium in Austria on the topic “Hydropower, flood control and water abstraction: implications for fish and fisheries” held in June 2006). The abstracts submitted for presentations during this conference indicate that a clear majority of the work in temperate rivers and floodplains reports decreasing fish catches, increased larval mortality, reduced or strongly altered species diversity as common consequences of built structures on rivers and floodplains. To remedy these losses, fish passes, bypass channels, spawner transportation, flood simulation and weir operation have been studied in connection with migratory fish rehabilitation programmes.

Research concerning implications of flood control and other built structures on floodplains in tropical areas, mostly located in less developed countries, is in comparison with temperate floodplain research in short supply. In addition, given the differences between tropical and temperate riverine systems, theories and conservation strategies that have been developed based on studies in temperate environments may not be applicable or effective in tropical environments (Pringle 2000). For example fish ladders, which have been developed and used extensively in temperate regions to facilitate the migration of especially economically important fish species, have on many occasions proven to be a failure in tropical regions (Roggeri 1995 and references therein).

There are well-studied exceptions, however. The Amazon floodplains have long received much attention from both natural and social scientists. Research has been conducted especially in the areas of Manaus, Brazil, due to the presence of the National Institute of Amazonian Research (INPA), while other, more remote, parts of the basin remain largely unexplored. Extensive studies have been done by the tropical ecology group of the Max Planck Institute on the floodplains of Brazil, but also the Pantanal in the Paraguay River Basin. In Africa, floodplain related research is mostly quite recent, with the exception of some thorough studies carried out in the 1970s by e.g. Welcomme and colleagues, who demonstrated the relation between the fish catch per kilometre of river related to the floodplain area in km^2, and discussed the importance of floodplain development to the variation between catches (Welcomme 1975). Some recent and valuable efforts have been made by independent researchers as well as research organisations such as the IUCN (water and wetlands programme) in Africa. Environmental research including aspects of floodplains has been done extensively in the Senegal valley, Barotse floodplains in Zambesi, Tana River floodplains in Kenya, Waza Logone floodplains in the Niger Basin, and in Kenya and Tanzania on eastern African wetlands (Duvail 2004), while the Congo Basin is largely unexplored. In Asia, recent studies on floodplain ecosystems and their fisheries have been carried out for instance in Bangladesh (in connection with the Flood Action Plan studies) and the Greater Mekong region (MRC work, other ADB projects on the Tonle Sap / Mekong floodplains).
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3.3. TROPICAL FLOODPLAINS - HYDROLOGY AND PRODUCTION

Hydrology is clearly the single most important driving variable in tropical floodplains (Tockner and Stanford 2002), based on which the flood pulse concept defines the river and its floodplain as an indivisible unit (Junk 1997). Any long-term change to the pulse affecting the hydrodynamics of the flood, such as timing, height, duration, amplitude, smoothness or the rapidity of change of the flood pulse, will result in fundamental ecological changes in the affected areas and also influence the living conditions of the local human population (Junk and Cunha 2005).

A positive correlation between the height of flood pulse / inundated area of the flood and fish catches has been reported for a number of tropical floodplains (Welcomme 1979, de Graaf 2003a and de Graaf 2003b and references therein, Halls and Welcomme 2004, and Tockner and Stanford 2002). Studies in both the Amazon and Africa have shown that the growth of tropical floodplain fish is maximal in the high water season (Hoggarth *et al*. 1999). However, not only the height of the flood pulse (amplitude) is of importance, but also other flood pulse characteristics such as timing, continuity, rapidity of change and duration of flood, as well as dry season water levels, have been shown to be related to fish production (Welcomme and Halls 2004). The productivity of floodplain environments in indisputable in comparison to any other freshwater system: Jackson and Marmulla (2000) conclude that while shallow, managed reservoirs yield on average 30-150 kg/ha/year of fish, deep reservoirs 10-50 kg/ha/year, and slow flowing rivers 30-100 kg/ha/year, floodplains averaged 200-2000 kg/ha/year. Baran (2005) summarises the productivity of some known floodplains in Asia and South America, reporting yields varying between 25 and 230 kg/ha/year.

Much is still unknown concerning tropical floodplain ecosystems. The high biodiversity and intricacy of the environment leads to complex ecological interactions. For example, only recently has the evidence of the importance of autochtonous (produced within the system) carbon, and especially microalgae, in tropical riverine systems increased, as opposed to the earlier belief that allochtonous carbon was the driver of floodplain ecosystem functions (Douglas *et al*. 2005). In the Amazon, it has been shown that some plant groups contribute more to the primary production of a floodplain in comparison to others, which are more important as food resources for adult fish (Forsberg *et al*. 1993). Flooded forest trees, certain macrophyte leaves, periphyton and phytoplankton as a group produced only 48% of the organic matter of the floodplain, but accounted for 82-98% of the carbon in adult fish, due to selective feeding by the fish themselves, or by herbivores and detrivores lower in the food chain. In numerous other tropical rivers it has been shown that microalgae are the main driver of aquatic food chains (Douglas *et al*. 2005 and references therein). Therefore, algal production in floodplain lakes may play a critical role in sustaining commercial fish production (Forsberg *et al*. 1993). Algae are sensitive to even small changes in nutrient loads (Douglas *et al*. 2005). In case of high light and temperature conditions, increases in nutrients are likely to trigger rapid increases in primary production and lead to changes of species composition, thereby affecting the entire food web productivity. This means that attention should be directed to the control of water quality changes (nutrients, herbicides, some metals like copper especially) influencing phytoplankton productivity and the species composition of floodplains (especially in connection with structures involving aqueous effluents), which would have a profound impact on the entire food chain including the species composition of fish.

3.4. FLOODPLAIN BIODIVERSITY

Floodplains are among the most biodiverse environments known, due to the high level of spatiotemporal heterogeneity as well as the diversity of habitat types, representing a variety of successional stages (Ward *et al*. 1999). Junk *et al*. (2000) regard the floodplain forest to be the system with the highest biodiversity, since it consists of many endemic highly adapted tree species, which offer habitat and food for a highly diversified, but mostly unknown, community of invertebrates. This applies most probably to the Tonle

Sap area as well, not only regarding the fish diversity but also other floodplain organisms.

Apart from being biodiverse, tropical areas also display a high percentage of endemism. In the Amazon, 90% of the over 2000 known fish species are endemic, and in the Congo, 70% of the 700 species are endemic. The corresponding figures for temperate rivers are significantly lower; in the Mississippi River 30% out of 250 species are endemic, and in the Danube only 10% out of 70 species are endemic (Pringle 2000). This entails that even local disruption of a habitat in tropical rivers and floodplains can lead to devastating impacts for certain endemic populations. In the Amazon it is thought that damming of rivers has most likely resulted in numerous species extinctions, especially of highly confined endemic species (Goulding *et al*. 1995.

Tropical riverine fauna generally include a large number of migratory species, highly vulnerable to human impact including modifications of lateral or longitudinal connectivity to their habitat. Many of these species are both riverine and lacustrine, depending on the season, and therefore dependent on the availability of both habitats (Pringle 2000).

The ichtyofaunas of North America (about 1500 species), Europe (about 360), and Australia-New Guinea (about 500) are the most thoroughly documented, but new species continue to be described based on discovery of previously unseen forms and species-level taxonomic splits of known species. The ichtyofaunas of tropical Asia (perhaps >3000), Africa (perhaps >3000) and South and Central America (perhaps >>5000 species), are species-rich yet incompletely known. Tropical freshwaters are hot spots of recent and likely future ichtyological discoveries. Especially in the tropics, discoveries of species that signal new generic-level taxa are common, and new family-level groups are found occasionally. Everywhere ongoing phylogenetic studies often suggest or reveal unsuspected relationships. These are times of exciting discovery and advancement of knowledge in freshwater ichthyology. New discoveries beckon us to seek the many remaining unknowns in the diversity of life on our planet. These are also times of rapid and destructive change in freshwater habitats around the globe. These threats alert us to the increasing potential for permanent loss and ignorance of much of our planet's rich aquatic biota.

Lundberg *et al*. 2000

According to Bayley (1998), it is now generally accepted that the conservation of most species in the aquatic system, as well as biodiversity in its broader sense, depends on the maintenance of the flood pulse. It also depends on the maintenance of connectivity, both longitudinally within the river channels and laterally between the main river and the floodplains. Longitudinal connectivity is necessary to keep migratory pathways open for the long and medium distance migrants. Lateral connectivity is necessary so that the floodplain environments, including the associated higher vegetation, are sustained and fish can move from their dry season habitats to the wet season spawning and feeding areas. Generally, the effects of excessive fishing are insignificant relative to the damage that can be caused by changes in connectivity, and water quantity, quality and timing (Bayley 1998). Conservation of the biodiversity of floodplains is also of importance for retaining other ecosystem services. Recently, experimental research provided proof of the importance of one single migratory fish species to the carbon flow in a tropical river in South America (Taylor *et al*. 2006). The authors showed that *Prochilodus mariae* modulates the carbon flow and ecosystem metabolism of a river in the Orinoco Basin. Removal of the species decreased downstream transport of organic carbon and increased primary production and respiration. Therefore, besides being an important harvested species, *Prochilodus* is a critical ecological component of South American rivers, and dependent on both latitudinal and longitudinal access to floodplains (spawning during wet season) and the river (feeding in dry season).

It has been shown in temperate rivers and floodplains that the impoundment of river channels does not have a significant impact on the species richness of molluscs, crustaceans or insects, but the species composition changed. However, disconnecting the floodplain from the main river channel led to a severe impact on biodiversity, reducing the species richness in all studied groups from 494 species in a connected floodplain to 149 in a disconnected floodplain (Ward *et al*. 1999). Moyle and Leidy (1992), and later numerous other researchers (summarised in Dudgeon *et al*. 2006 categorised the causes of the loss of freshwater aquatic biodiversity into five broader units (built structures relating to these units in parenthesis):

1. Competition for water / flow modification (most built structures, dams, impoundments, dikes, levees, irrigation, canals),
2. Habitat alteration, destruction or degradation (impoundments, canals, irrigation),
3. Water pollution (all built structures with effluents, but also irrigation, dams),
4. Introduction of, and invasion by, exotic species (canals, dams, reservoirs) and
5. Commercial (over)exploitation (selective fishing gears).

Each of these five causes can be connected to built structures; thus built structures will impact biodiversity. The first three causes mentioned often act in concert, and are the principal causes of the loss of aquatic biodiversity, but are often exacerbated by the introduction of exotic species and overexploitation. The effects of all of these factors are also both additive and cumulative.

3.5. ECOSYSTEM VALUE OF FLOODPLAINS

Ecosystem valuation (as presented by Barbier *et al*. 1993 and Constanza *et al*. 1997) has fairly recently been introduced in connection with ecosystem services provided by wetlands, including some floodplains. According to Constanza *et al*. (1997) wetlands are one of the most valuable landscape types in the world. One of the highest valued “direct use value ecosystem services” of floodplains is fish, while inputs to agriculture (nutrient rich deposits) and nursery functions of fish and other organisms, are considered the most important “indirect use value services” (e.g. Turpie 2000). Destruction of floodplains has been found to lead to diminished water storage during floods (Junk 1997) and subsequently reduced release of stored water during the dry season, another important ecosystem service of all floodplains, which is hard to value without complicated hydrological models. Dudgeon *et al*. (2006) conclude that freshwater biodiversity in general provides a broad variety of valuable goods and services for human societies, some of which are irreplaceable. Nonetheless, there is a paucity of empirical data showing how the value of goods and services derived by retaining habitats in relatively natural conditions compares with that obtained when they are converted for human use. The uses of fresh water, including non-consumptive use, underscore the importance of considering the perspectives of a wide range of stakeholders in environmental valuation and in the development of effective conservation policies (Dudgeon *et al*. 2006).

> *African floodplains provide a host of goods and services; these include floodplain recession agriculture, fish production, wildlife services and goods, livestock grazing, ecotourism, biodiversity as well as natural products and medicine. Not one of these goods and services has been valued completely. Estimates abound for individual floodplains, but no systematic evaluation for the economic valuation of floodplain services has been carried out continent wide, nor has this been linked to floodplains resilience to stress. It is this lack of information on the economic value that has been a major contributory factor in the destruction of floodplains. Decision makers and politicians see floodplains, as areas without use, to be "developed".*
>
> Christopher Gordon, 2002

In the Amazon floodplains in Brazil the annual flooded forest revenue related to *Tambaqui* production has been estimated (Araujo-Lima *et al*. 1998) at US$13 million, of which US$8.2 million originated from floodplain areas. As such, the revenue from this one specific species of fish was larger than the concomitant poultry and rubber production in the Amazonas State, and close to the value recorded for the logging industry in 1992 (US$9 million). In Cambodia, a valuation of the flooded forests in Kandal Province (Navy *et al*. 2001) estimates that the flooded forest brings a 33% higher net income (predominantly through fishing, but also including fuel wood and vegetables) compared to converted land (mainly through rice and some other crops). In the Waza Logone floodplains in Nigeria, the economic loss of a decrease of 30% in flooding was estimated at US$2.4 million per year. These studies make it clear that the conservation of the flooded forest habitats is of critical importance also financially, to ensure a sustainable future for local economies.

This type of quantification of ecosystem services can contribute significantly to more accurate calculations of actual benefits created by a certain built structure, taking into account both losses and benefits of ecosystem services and natural resources resulting from the development.

4. IMPACTS OF BUILT STRUCTURES ON TROPICAL FLOODPLAINS

In this section, impacts recorded in connection with certain types of structures are briefly discussed. More specific impacts of certain selected structures are discussed in the following chapters dealing with specific floodplains.

Major human impacts on tropical floodplains are according to Tockner and Stanford (2002) caused by hydrological change and urbanisation.

Rosenberg *et al*. (2000) summarised the environmental effects of large-scale hydrological alterations in general as follows:

- habitat fragmentation within dammed rivers,
- downstream habitat changes, such as loss of floodplains, riparian zones and adjacent wetlands and deterioration and loss of river deltas and ocean estuaries,

- deterioration of irrigated terrestrial environments and associated surface waters and dewatering of rivers, leading to impaired water quality because pollution cannot be adequately diluted.

Furthermore, he mentions the following less conspicuous impacts:

- genetic isolation through habitat fragmentation,
- changes in processes such as nutrient cycling and primary productivity,
- impacts in biodiversity,
- methylmercury contamination of food webs and
- greenhouse gas emissions from reservoirs.

4.1. DAMS

The largest and most discussed and debated built structures affecting floodplains are indisputably large dams. Much has been said on the topic, while few quantified and objective studies have been made. According to an inventory made in 2002 there were over 45,000 large dams (dams over 15 m height, or with reservoirs containing 3 million m^3 of water), and total annual freshwater withdrawals were estimated at 3800 km^3, twice as much as 50 years earlier (de Sherbinin 2002). Existing dams retain approximately 10 000 km^3 of water, the equivalent of five times the volume of all the world's rivers (Dudgeon *et al*. 2006). Dams are constructed for hydroelectric power, flood control, irrigation, and water supply, and many dams serve multiple purposes. Even though dams *per se* make up only a small percentage of total land cover, these artificial water bodies often facilitate other forms of land cover change, such as development of large-scale irrigated areas and urbanization, which impact far larger areas.

4.1.1. Impacts of dams

Since the 1980s there has been a well-organised international movement opposing dam building which does not comply with the San Francisco Declaration of 1988[1], resulting in much discussion concerning the costs and benefits especially of larger dams. The World Commission on Dams (WCD) collated a significant pool of information on issues regarding dams during its activities since 1998 until the release of the WCD report in 2000. According to this report, large dams have numerous impacts on ecosystems. These include:

- the loss of forests and wildlife habitat, the loss of species populations and the degradation of upstream catchment areas due to inundation of the reservoir area;
- the loss of aquatic biodiversity, of upstream and downstream fisheries, and of the services of downstream floodplains, wetlands, and riverine, estuarine and adjacent marine ecosystems; and
- cumulative impacts on water quality, natural flooding and species composition where a number of dams are sited on the same river.

Furthermore, dams and reservoirs impact the hydrological cycle by increasing evaporation (dams in arid areas can lose 5% of total withdrawals to evaporation) and

[1] *In June 1988 the International Rivers Network sponsored an international conference in San Francisco for citizens organizations concerned with protecting rivers and water resources from their most immediate threat – construction of large dams. The position statement adopted by the conference and subsequently extended by network organizations forms the San Francisco Declaration, including 22 points which can be accessed at e.g. http://www.irn.org/basics/ard/index.php?id=sfdeclaration.html*

loss of downstream aquifers due to reduced replenishment (de Sherbinin 2002). The extension of irrigation systems has also been shown to lead to habitat fragmentation and destruction, e.g. in the Senegal valley floodplains and delta (Daffé web citation).

Bernacsek (1984) summarised the main effects of dams as changes in discharge downstream (volume, timing and amplitude), desiccation of floodplains, riverbank erosion, changes in water quality (especially low oxygen conditions), and changes in flora (including aquatic macrophytes) and fauna (especially changes in fish biodiversity and composition).

In a synthesis based on studies presented at the international symposium concerning large rivers, Welcomme *et al*. (1989) summarised the effects of stress caused by built structures, such as dams or levees, on fish:

- Obligate migratory species will tend to disappear in systems where the main channels are locked by large dams, while
- Floodplain spawners are selected against by chanellisation or other stream regulation processes which reduce or eliminate the annual flood.
- Within modified channels there is a tendency to lose obligate migratory species although management is usually directed at their protection through installation of fish pass structures or through stocking.
- There is a tendency for dominance in fish assemblages to shift from floodplain spawners (phytophilous species) toward main channel spawners (mainly litophils).

More recently, in a contributing paper to the World Commission on Dams, Bernacsek (2000) reviews the impacts of dams on fish and fisheries. He lists the following direct and indirect impacts:

- Clogging or creating hazards to migration in upstream and downstream directions, and by mortality or damage when fish pass through dam discharge structures.
- Indirect impacts on fish biodiversity, fish stocks and fisheries through modifying and/or degrading the upstream and downstream aquatic environments, such as floodplains, including: (i) thermal stratification of the reservoir and release of cool and anoxic hypolimnion water downstream; (ii) downstream flood alteration and termination of inundation of downstream floodplains; (iii) sediment and nutrient trapping in reservoirs; (iv) release of contaminants from trapped sediment into the reservoir food chain; (v) infestation of the reservoir with floating aquatic plants; (vi) ghost fishing by nets snagged on drowned trees in the reservoir; (vii) long distance recession of the shoreline during drawdown; and (viii) pesticide contamination arising from agriculture on the reservoir drawdown zone.

The potential of reservoir fisheries is often listed as one of the benefits of dam construction, creating new fisheries opportunities in the area affected. However, the yields obtained from reservoirs are very variable, and tend to be higher in smaller reservoirs than in larger impoundments. On average, reservoir fisheries are far less productive than river fisheries on a per unit area basis (Jackson and Marmulla 2000).

Petrere (1996) points out the potential benefits of dams with regard to water quality in the river, if constructed in a highly polluted river (example River Tietê in Brazil), where downstream dams can have a positive effect through deposition of dissolved solids in the reservoirs and forced water aeration through spillways. However, the author acknowledges the detrimental effects of large dams on floodplains both above and downstream of the dam. He also discusses fish ladders, lifts, canal locks, transportation of spawning schools and spawning channels as mitigation measures for the impacts of dams on fish migration. However, fish ladders have been shown to have a low efficiency even for the selected species that can, at all, use them. In addition, fishways designed to promote fish passage past dams are in many instances used by fishers to capture fish (Jackson and Marmulla 2000). Fish lifts are not very common as they are expensive to build and operate. Canal locks may have a marginal effect on assisting in fish movements. The transportation of spawning schools is comparatively inexpensive but requires short distances and efficient water oxygenation apparatus in the transporting vehicles. Spawning channels have been found to be effective but require much maintenance and care taking (Petrere 1996).

Because of the negative impacts recorded, and the difficulty in finding working mitigation measures, the environmental flow requirements methodology (which include managed flood releases) is increasingly used to reduce the impacts of changed stream flow regimes on aquatic, floodplain and coastal ecosystems downstream (de Sherbinin 2002).

There is a need for fundamental research linking abiotic processes to changes in ecology, particularly in tropical environments, where much of the remaining potential for "new" river regulation resides. For all new large dams pre and post construction studies should be conducted in order to assess the environmental impacts and to determine the effectiveness of mitigating measures.

McCartney *et al*. 2000

4.1.2. Impacts of dams on fisheries

In Africa, studies have been made on the sequence of events after damming. According to Lévêque (1997), the results of these studies conclude that in general, and in tropical areas (as opposed to temperate, where the consequences of dams can be quite different), the closure of the dam is followed by a marked increase in fish populations favored by the new lacustrine conditions. After some time, the fish biomass decreases sharply as predators reduce the inflated population. The change in species composition is marked, and hard to predict, but the obvious change is the disappearance of riverine fish in the reservoir, while species adapted to life in open waters, such as small clupeids, become abundant. Although the number of species in a reservoir may be equivalent to the number inhabiting the original river at the reservoir site, native forms often disappear (Lévêque 1997). Apart from changes in fish diversity, the reservoirs are often subject to a succession of increasing pollution, eutrophication, algal blooms, extensive growth of water weeds, deoxygenation of the water and subsequent fish kills.

4.1.3. Water-related diseases and chemical pollution

An important indirect effect of dams is the increase in water-related diseases through the creation of suitable habitats for vectors in reservoirs and irrigation schemes. Well documented examples include the Akosombo and Kainji dams, man-made lakes of the

Tana River, Lake Volta regions after the construction of the dam, and the Senegal River Delta after the construction of the Diama Dam (Roggeri 1995). Irrigated agriculture worldwide is by far the largest user of freshwater and, consequently, impacts on freshwater ecosystems and the fisheries they support are stronger than for most other human activities (Nguyen Khoa *et al*. 2005). Irrigation, in combination with the potential increase in the use of pesticides (such as PCBs, DDT, dieldrin, chlorodan) and other chemicals related to increased agricultural activity, can lead to indirect impacts on the environment and fisheries. The bioaccumulation of these compounds through the food chain and their persistence in nature also impacts people using fish as a resource.

4.1.4. Environmental standards for dam construction

Regarding dam construction, environmental standards have been set both by institutions related to the construction (such as ICOLD, International Commission on Large Dams) as well as those which facilitate funding for construction (e.g. World Bank). ICOLD calls for a "comprehensive EIA" to be standard procedure as part of dam construction (ICOLD web pages, accessed in June 2006) but guidance on what should be included in this is not provided, except mentioning that "special attention should be paid to any effects on biodiversity or the habitat of rare or endangered species". The WB applies the same environmental standards to any project, i.e. pre-project environmental assessments. The only specific guidelines applying to dams seem to relate to water quality standards, implying that releases from reservoirs must comply with acceptable water quality standards (McCartney *et al*. 2000).

4.1.5. EIA on dam construction

In connection with Environmental Impact Assessments related to dam construction, only recently has attention been drawn to the downstream impacts of dams (much as a result of the work done by the WCD, including the impact on floodplains), while most attention is still given to the direct impacts of dams and the reservoirs created upstream. Indirect impacts such as infrastructural works in connection with dam construction (such as clearance of forest for accommodating machinery, temporary or permanent roads to enable access to the building site, temporary housing for staff working on the building site, etc.), as well as the general development of socio-economic activities connected to dam construction that tends to attract people and industry, are still largely ignored, especially in connection with developments in tropical areas. Generally, river ecosystems containing dams and other built structures must contend with pollution and increased exploitation of their resources, pressures independent from, but adding to, the direct influence of dams and reservoirs (Jackson and Marmulla 2000). The same applies, even more so, to the assessment of cumulative impacts, even though in connection with impoundments it is generally agreed that several impoundments in the same river catchment can result in synergistic negative impacts on downstream fisheries. E.g. Roberts (1995, cited in Jackson and Marmulla 2000) discussed impacts from 12 hydropower projects in the mainstream of the Mekong River and stressed that the combined impact on fisheries from these dams is greater than the sum of the individual impacts.

4.2. EMBANKMENTS, ROADS

Embankments are, like dams, structures opposing water flow. Roggeri (1995) lists at least the following types of embankments: dikes (submersible or not, with water inlet and outlet, or without), river embankments (man-made levees along a watercourse, raising the riverbanks), water–body embankment (for flood-control, creation of a stable water-body), basin embankments (floodwater storage in an annual or seasonal, man-made lake), floodwater storage dikes (often built in a crescent-shape to increase the dry-season agricultural area by storing water when the flood recedes, common in west Africa), controlled flooding dikes (usually for shortening of the flood pulse through delaying the flood), horseshoe dikes (open embankments), polders (closed embankments protecting land against flooding altogether), groynes (stone or gabion dikes, decreasing flow velocity and increasing filtration into the soil and sedimentation), bunds (usually constructed of local materials such as earth or stones) to increase flood duration or spread floodwater, for irrigation or aquaculture basins, and for infiltration purposes, and contour bunds and water spreading bunds. All these structures affect the water flow in some way, and have been used for centuries to manage floodplain hydrology for human needs. Some embankments occur in most inhabited floodplain environments. The cumulative effects of these types of structures must be significant, but have not been studied much, based on the literature reviewed. However, embankment of long stretches of major rivers, such as the Senegal River, has been documented and the negative effects of drying out of agricultural and pastoral land noted (see details in chapter 5.2.3). Collectively, the impacts of drainage by various means, embankment and subsequent landfilling, often results in worsened flood problems due to reducing the volume of floodwater which can be stored and evenly released later on (Roggeri 1995). Another effect can be reduced filtering and natural water purification of the water due to reduced floodplain vegetation.

Roads crossing floodplains are typically built on an embankment, and hence they have a similar impact on the floodplain environment and fisheries. Roads, forming long and continuous barriers to the natural movement of aquatic organisms, lead to fragmentation of habitat. The construction of roads along embankments has been argued to be a cheaper alternative compared to alternation between roads and bridges, or including culverts in the road construction (Vaz 2000). Roads crossing floodplains have been recorded to disturb natural migration routes of floodplain organisms amongst other things in Florida, USA (WRI 2000), India (Mathur *et al*. web citation) and Mozambique (Vaz 2000). Little specific information is available on the impacts of roads in tropical floodplain environments, but potential impacts in Ireland have been listed as follows (O'Neill, J. web citation): increased sediment runoff or loading, interruption of (ground)water flow, channel straightening, deepening and widening, stream flow/water level changes, loss of riparian and wetland associated vegetation, severance of habitat, increased risk of toxic runoff, modification of faunal behavior, spread of alien species and loss of spawning habitat.

4.3. CANALIZATION

Canalization (also called, especially in connection with larger-capacity canals, channelization) typically involves the realignment, clearing, widening, and lining of the stream channel, usually for flood control through improvement of flows and drainage of land. When a river is channelized, it is usually also embanked (Roggeri 1995). Canalization can also entail the construction of completely new canals for bypass, water transfer, drainage, flood control and recession or inundation purposes (Roggeri 1995). Among other effects, canalization may reduce stream length, create uniform habitat conditions, modify the hydrological cycle, drain adjacent wetlands, eliminate instream cover and riparian vegetation, degrade water quality and alter trophic relationships

(Moyle and Leidy 1992). In the industrialised world, many temperate rivers have been canalized along vast stretches. For instance in the USA, the Minnesota and Missouri Rivers are channelized for much of their lengths, which has led to the elimination of shallow-water habitats as well as adjacent riparian habitats that flooded annually, resulting in agricultural, urban and industrial encroachment on wetland habitats on 95% of the former floodplains of the Missouri River, and shortening the river by at least 120 km. Construction of the floodplain and reservoir structures has reduced the input of organic matter by 65%. Channelized sections of river have fewer fish and lower species diversity. In general, habitat alteration encourages the invasion of “weedy” fish and exotic species, with high reproductive rates and aggressive behaviour which allows them to invade adjacent less disturbed habitats and displace native species (Moyle and Leidy 1992). In the Mississippi River floodplain 80% of the hardwood forests have declined and the land has been turned into farms. As a consequence, only 20% of the floodplains can sustain fish populations, and standing biomass within this area declined from 170-340 kg/ha in undisturbed streams to 13 kg/ha. The cumulative effects of channelization and forest or wetland clearing are a watershed-level phenomenon not limited to the immediately adjacent floodplain. Rather, such activities often negatively affect hydrology, deposition of sediments, water quality, productivity and biotic diversity of all downstream aquatic habitats. In the Mississippi River Basin, these activities have increased catastrophic flooding, silted reservoirs, and eroded coastal wetlands, often creating the perceived need for further canalization and levee construction (Moyle and Leidy 1992). Similar experiences have been reported from Australia (Ball 2001).

4.4. MINING, INDUSTRIAL PLANTS

Pollution in the form of chemical pollutants stemming from human constructions (in the form of effluents and sewage) is widespread and serious in all parts of the world. This type of impact is fairly well monitored in temperate regions, while information on the type and magnitude of aquatic pollution is in many tropical environments non-existent. In the Amazon, one of the main concerns with regard to fish populations, apart from habitat destruction and over exploitation of certain species, is the mercury pollution of rivers, caused by gold and tin mining. It is estimated that more than a thousand tons have been released in the Amazon in just two decades (Araujo-Lima and Rufino 2003). In Mexico, it has been shown that unique freshwater fishes and fisheries are in sharp decline due to environmental degradation caused by pollution from human settlements and water competition. Of 44 native fishes, 3 are extinct, and 23 greatly reduced in abundance or range. The fisheries for several valuable native species have declined or collapsed, and exotics constitute a major portion of the catch. In the Ayuquila River, several species have been locally eradicated, and major untreated industrial and municipal discharges, coupled with substantial water withdrawals for irrigation, preclude fish life during the dry season in 20 km of river that once supported an important subsistence fishery (Lyons *et al*. 1998). In the Everglades wetlands in Florida, increased runoff from agriculture and irrigation water, and effluents from industry and settlements have lead to serious eutrophication causing repeated algal blooms (and resulting fish kills), and *Typha* invasions in areas previously dominated by indigenous grasses (WRI 2000).

4.5. SMALL STRUCTURES, FISHING GEARS

Smaller built structures, such as small-scale irrigation channels, small dams and weirs, floodwater storage systems, waterspreading dams, and fishing weirs, have received little attention regarding their impacts on the environment and fisheries.

Research carried out regarding flood control and regulator structures (sluice gates, weirs) has shown the structures to have a lesser impact on larval fish mortality if operating in an overshot mode rather than in deeper layers (de Graaf *et al*. 1999). In cases where it is not possible in the short to medium term to modify weir height or flow regime, consideration should be given to installing regulators on important wetlands and operating these structures to mimic natural wet and dry regimes (Living Murray, web citation)

Fishing gears left permanently or semi-permanently (e.g. during a certain season) in the water, may be considered built structures, and naturally have a marked effect on fisheries. In many areas selective fishing has lead to a decrease in the most valuable (often also the largest) species, and a shift toward smaller species has occurred. Due to the natural variability of floodplains, the gear types used are also adapted to this variability and include numerous different types. Baran *et al*. (2005a) describe at least 41 types of fishing methods commonly used in Laos and Cambodia. According to a study done in Bangladesh, Indonesia and Thailand, twenty different gear types were observed within nine broader classes (namely: Static barriers/Fykes, Active Filters/Seines, Lift Nets, Gill Nets, Cast Nets, Portable Traps, Hoods, Dewatering and Spears), and used according to the flood cycle. Some of these gears form static filtering barriers, fykes, which can form barriers for long stretches at the floodplain-river margin, the catch representing up to 32% of the total fishery (MRAG 1994). In cases where the floodplain environment has been reduced due to impacts from structures altering the hydrology of the area, this type of intensive and targeted fishery may have destructive results on species migrating from the floodplain back into the main river channel.

4.6. IMPACTS OF BUILT STRUCTURES – RESULTS OF QUESTIONNAIRE

During this desk review, a questionnaire regarding impacts of built structures was sent to 62 recipients (details in Annex 3). The recipients were selected based on the review. Only 23 replies were received, of which 19 answered most questions (31% response rate). In some instances it was reported that no built structures were present on the floodplains the recipients were working on, and therefore they could not answer the questions. This concerned especially floodplains in Venezuela and Peru. However, based on the few replies received, some general conclusions can be drawn. The number of answers per question is very low and can therefore be considered of indicative value only.

- Replies considered floodplains on all continents, with a small majority from Brazil. Floodplains mentioned included Amazon, Pantanal, Orinoco and Rio Mapire in South America; Gagnes, Brahmaputra and Meghna, Bangladesh, Mekong and Tonle Sap in Asia; Senegal, Okavango and Kafue flats in Africa and several floodplains of Australian tropical rivers (4 responses).
- Most floodplains considered had seasonal flooding, and consisted of large river floodplains with slow, ample and predictable floods, or flooded forests.
- Concerning ecosystem goods in the floodplains considered, fish was reported very significant or significant in all cases. With regard to other ecosystem goods and services, most suggested options scored “significant” except for game, rubber and medicinal plants, which were mainly classified as “not significant”.
- Of ecosystem services, nutrients and fertile soils for agriculture were valued the most, followed by ecotourism potential and transport and navigation. Recreational and aesthetic value was considered less significant.

- The dispersal of answers regarding ecosystem goods and services illustrates the variety of ecosystem goods and services that different floodplains provide.
- Regarding built structures recorded in the floodplains, the following were listed: structures related to flood protection, mining, hydroelectric plants, chanellization, dikes, "*hydrovia*", large roads, dams, irrigation schemes, raised canals, gas storage facilities, levees, weirs, seasonal sand dams, bridges, culverts, and caseways.
- Regarding EIAs and SIAs most answers reported either no assessments made, or not in sufficient detail. Environmental Management Strategy was suggested to be incorporated into any built structure proposals. One reply indicated that a growing number of assessments are being done, but several pointed to weak implementation of the recommendations made during assessments.

All (12) respondents indicated that fish were impacted by structures, and 92% (11) noted that the environment had been impacted.

5. CASE STUDIES AND LESSONS LEARNT IN SPECIFIC FLOODPLAINS

This section gives an overview of some important tropical floodplains in South America, Africa, Australia and Asia.

A list of specific built structures and their environmental impacts, if quantified, is attached in Annex 2. This section discusses some of these cases in more detail, or other cases where only qualitative impacts have been recorded.

5.1. SOUTH AMERICA

5.1.1. Amazon floodplains

About 20% of tropical South America is wetlands (Junk 2002), including a great number of floodplains occurring in areas with low population and in remote areas where little human impact has taken place (Figure 1). In total, 6% of the entire basin area is periodically inundated. Flood control measures *per se* do not exist in the Amazon floodplains due to the high flood amplitude of the Amazon River (between 4 and 20 meters). Sometimes small, very local, flood protection measures are taken but they do not affect the ecosystem (Junk *et al*. 2000).

5.1.1.1. Large structures

Roads and other built structures are still scarce in large parts of the Amazonian floodplains. Despite this attempt to intensify the utilisation of natural resources have led to the construction of roads and other infrastructure to stimulate the agroindustrial development of the region. Operation Amazonia in Brazil (1966-1967) led to a significant increase in the road network in the Amazon to facilitate the occupation of northern parts of Brazil. These road constructions have been reported to have impacts on the floodplains through e.g. increased turbidity of rivers due to increased erosion from deforested areas. Waters of the previously Clearwater Rio Ji-Paraná became milky in colour after the construction and colonisation along the Cuiabá-Porto Velho Highway, which cut across its headwaters.

Many of these construction projects have demonstrated the vulnerability of the region especially to erosion and subsequent sediment loading of rivers and floodplains (Junk 2005). One of the major indirect impacts discussed in connection with e.g. road and gas pipe construction through remote and isolated floodplains is the introduction of the floodplains to human impact in general, introducing previously pristine areas to immigration and development of settlements, agricultural activities and ranching with livestock.

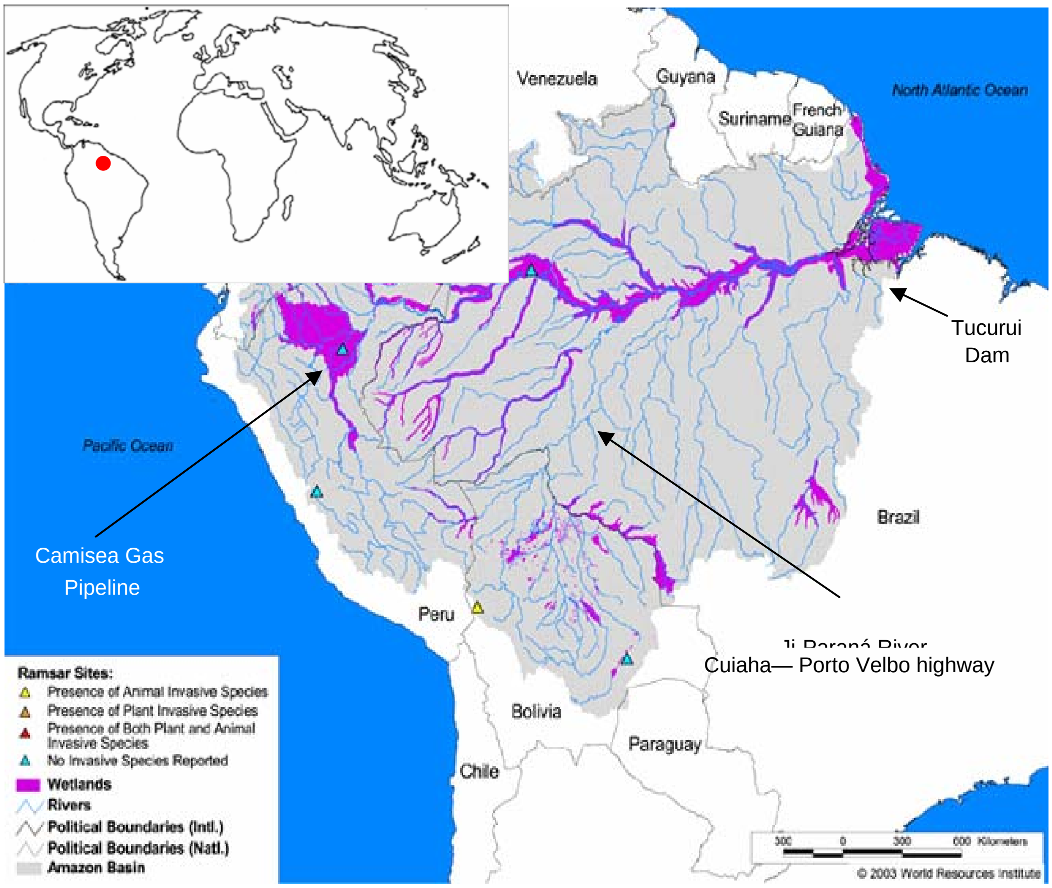

Figure 1. Map of the Amazon rivershed (grey area) showing wetlands in purple. Floodplains and built structures discussed are marked with arrows. Source of map: *www.iucn.org/themes/wani/eatlas/index.html*

Comparatively few hydropower plants have been built in the Amazon region, and even fewer have had complete pre- and post-filling evaluations done regarding their impact on the environment and fish. One of the most documented cases is the Tucurui Dam. Recorded impacts include a reduction in species richness of fish and catch per unit of effort both in the reservoir as well as downstream of the dam, an increase in the abundance of piscivorous species and a decrease in frugivorous and detrivorous species, while migratory species disappeared all together (Araujo-Lima and Ruffino 2003). The situation was unstable for a number of years after construction, improving somewhat in the reservoir, while downstream fisheries did not show a similar recovery. Anoxic environments were created through decaying vegetation left in the reservoir (Fearnside 2001). Assessing the impacts of the dam is made complicated due to the differing points of view and impacts reported by different authors (see Annex 2 with list of impacts recorded). Araujo-Lima and Ruffino (2003) conclude that the impacts of the reservoir on fish varies between fish species, some being negatively affected while others respond positively to the habitat change. However, a common trend observed was the reduction in fish diversity. The only mitigation measure that has been generally adopted seems to be the establishment of hatcheries to stock the reservoirs with native species, but little follow up has been done to monitor stock densities (Fearnside 2001).

One of the most controversial, discussed and disputed construction projects in South America, apart from large dams, has been the Camisea Gas Project in Peru. The 731 km-long Camisea pipeline runs from the Amazon, over the Andes, to the Pacific Coast. EIAs and independent reviews by local organisations point to massive erosion caused by the construction and operation. The erosion causes loss of topsoil, siltation pollution of the aquatic river systems and landslides on inclines. As of March 2006 there have already been 5 spills along the Camisea pipeline since it became operational in August 2004 (Wikipedia internet encyclopaedia[2]).

The experiences related to the gas pipe constructions in the Amazon has led to attention being directed toward the social and environmental impact assessments involved. The Bank Information Centre USA prepared (Hamerschlag 1999) a set of recommendations based on the experiences derived from a 3000 km gas pipe construction from Bolivia to Brazil. The recommendations point to emphasis of information, public consultations, environment and indigenous peoples, project monitoring and compliance. However, specific instructions for consideration of different ecosystems, such as floodplains, are not specified.

Despite difficult experiences during massive infrastructural construction projects, the future of the Amazon Basin will still include several extensive projects focussing on fluvial transportation and road construction, e.g. within the programme “Iniciativa para la Integración de la Infrastructura Regional Suramericana” (IIRSA web citation).

5.1.1.2. Identified threats to Amazon floodplains

According to Goulding *et al*. (1995) the main threat to the remaining floodplain forest in the Amazon is deforestation, which has already affected most areas of the floodplains. The area of flooded forests on the floodplain has decreased dramatically. Intensive logging of valuable species in the flooded forest, as well as clearing of land for cattle farming, are the main reasons for the deforestation. Clearing of trees is also the first step in agriculture and mining.

Bayley and Petrere (1989) consider that in the case of the Amazon *várzea*, hydrological alteration due to hydroelectric dams may lead to more severe impacts on fisheries than deforestation during the next 10-20 years. The well-documented cases in Africa (Bernacsek 1984), in particular the inability of reservoir production to replace losses of floodplain fisheries and agriculture production downstream, have according to Bayley and Petrere (1989) been largely ignored in connection with the planning of new reservoir developments in the Amazon.

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[2] *http://en.wikipedia.org/wiki/Camisea_Gas_Project* citing *El Comercio*, accessed March 6, 2006 - *http://www.elcomercioperu.com.pe/EdicionOnline/Html/2006-03-05/onlPortada0467113.html*).

Bayley (1998) summarises the major threats to Amazonian aquatic biodiversity as follows:

- The conversion of *várzea* floodplain to pasture and crop agriculture;
- Changes in flood regimes and system connectivity through hydropower dams and navigation channels (‘*hidrovias*’); and
- Deterioration of water quality through mercury used in gold mining, petrochemical effluents, drug processing wastes and sewage discharges.

Of these, Bayley (1998) considers *várzea* conversion to be the greatest short term threat, while the most fundamental long-term threat is unsustainable water-use, principally construction of navigation channels and dams, which reduces biological productivity by altering the floodplain inundation regime and curtails longitudinal and lateral connectivity. Junk *et al*. (2000) classifies (the same) human impacts on the *várzea* in different categories, with decreasing destructive effects: 1. modification of the hydrological regime, 2. large-scale destruction of plant communities, 3. reduction of populations of plant and animal keystone species, and 4. pollution.

5.1.1.3. Threats to Amazon fish and fisheries

Large-scale ranching with cattle and water buffalo is at the moment a serious threat to the primary economic resource of the floodplain: the abundant and diverse fish. The number of known fish species in the Amazon is around 2500 species (Araujo-Lima and Goulding 1997) of which only a fraction, mainly economically important species, have been studied. The impact of development on the Amazon fish fauna is therefore still poorly understood. The main impacts apart from over fishing (of certain high value species) are, according to Araujo-Lima and Ruffino (2003), mercury pollution and deforestation caused by gold and tin mining and habitat destruction including built structures such as dams and reservoirs. Although most of the Amazon fish catches are harvested in the main river channels and far downstream, they ultimately rely on the floodplain for spawning areas, food and cover (Goulding *et al*. 1995). The location of a built structure in the river channel is of importance, and can lead to a stronger impact on some species than others. For instance some larval fish species are predominantly transported into floodplains during rising waters, mostly along the riverbanks, in which case a structure changing riverbank attributes will affect migration patterns (e.g. canalization creating abrupt and steep riverbanks), while others are flushed out of floodplains more evenly during the water recession (Araujo-Lima and Oliveira 1998).

5.1.2. Floodplains of the Paraguay/Paraná River Basins

The “El Gran Pantanal” or the larger La Plata Basin is an expanse which encompasses more than 2 million km^2 and a population of more than 100 million inhabitants, and extends through Brazil, Bolivia, Paraguay, Argentina and Uruguay in the Paraguay River Basin (Swarts 2000). The Pantanal is the largest South American seasonally flooded land, composed of the floodplains of the Paraguay River and effluents (Figure 2). During the dry season, the Pantanal is covered by dense to open savannah and riparian forest at river edges, while during the flood, the plains are covered by water up to two meters deep that stays for several months (da Silva *et al*. 2000). The Pantanal is increasingly threatened by large development programs, including agroindustries and hydropower reservoirs, plans for canalization of the Paraguay River (hidrovia) and increasing industrial and livestock developments. These developments negatively affect habitat and species diversity, scenic beauty and also the hydrological buffer capacity of the Pantanal (Junk and Cunha 2005).

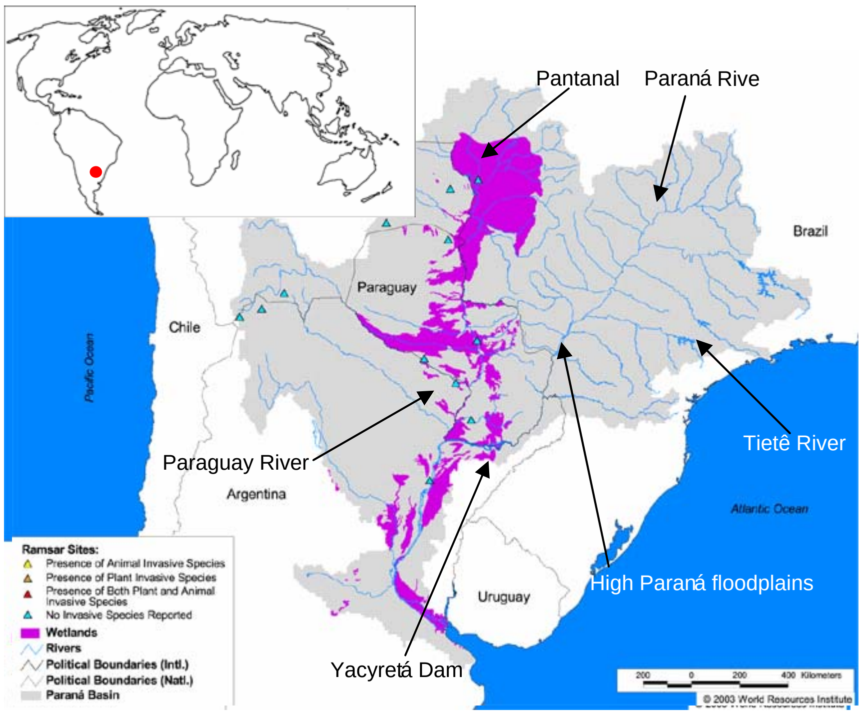

Figure 2. Map of the Paraná rivershed (grey area) showing wetlands in purple. Floodplains and built structures discussed are marked with arrows. Source of map: *www.iucn.org/themes/wani/eatlas/index.html*

The high Paraná floodplains in Brazil cover an area of 230 km between Itaipu and Porto Primavera reservoirs, with a width of about 20 km. The floodplain has been affected by intensive reservoir constructions (25 reservoirs larger than 100 km^2), but due to water from several unregulated tributaries, the flood regime still maintains and this remaining stretch of the high Paraná floodplain ecosystem still supports considerable biodiversity (Agostinho *et al*. 2000). This floodplain area is the last unimpounded section of the river within Brazilian territory. In Argentina, the Paraná River is highly regulated, the water in reservoirs of the Upper Paraná Basin currently comprising more than 70% of the mean annual discharge at its confluence with the Paraguay River (Quirós 2004). The expansion of hydroelectric generation in the Upper Basin has 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 (Quirós 2004). A study done by Terraes *et al*. (1999) in connection with the Yacyretá Dam, located in the Upper Paraná River, confirmed that the reproduction of many species of fish was negatively affected by the dam through a change in the male-female ratio, as well as a shortened reproductive period. The fisheries in the Paraná River Basin were traditionally based on large potamodromous fish caught from a fish community containing a relatively high frequency of the detritivorous *Prochilodus* (Quirós 2004). 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. Striking differences in the fish species structure of the catch are noticeable between reservoir and floodplain fisheries and among floodplain fisheries themselves. Quirós (2004) identified three main fishery states in the Plata Basin across broad temporal and spatial scales:

1. A relatively undisturbed state corresponds to the unregulated river, when fishing effort was relatively low to moderate, the catch being mainly dominated by high value large siluroids and characins. This state is represented by fisheries at the Pantanal floodplains and the Parana-Paraguay confluence and to a lesser extent by some of the remnant lotic reaches at the Upper Parana.

2. 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.

3. Fisheries in riverine reservoirs represent a third, relatively highly disturbed fishery state. The catch of potamodromous fish frequently descends well below 50% 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, and provide a unique opportunity to study different stages of disturbance and its effect on floodplain fisheries.

5.2. AFRICA

Nearly all African rivers are accompanied by large fringing floodplains and several internal deltas occur. Forty-three large floodplains have been reported and described to some extent (Junk 2002). In most parts of Africa, water availability is sufficient only in the moist equatorial belt. Therefore, water needs for irrigation, domestic and industrial uses have caused construction of numerous reservoirs affecting the downstream flow and floodplains (Junk 2002). Most large rivers of Africa have at least one main stem dam and some, such as the Nile and the Zambezi, have more. There are also a large number of medium-sized dams (reservoir sizes 10 -100 km^2) for irrigation, urban water supply and small-scale power generation. The larger dams are the major causes of degradation of the aquatic environment and disruption of the livelihoods of communities dependent upon farming, fishing and grazing along the river valley (Welcomme 2003). The changed hydrological regime of rivers has adversely affected floodplain agriculture, fisheries, pasture and forests that constituted the organising element of community livelihoods and culture (World Commission on Dams Report 2000). In many cases the desiccation caused by dams has been enhanced by natural drought.

Impacts of flow alteration on fish species have been documented for numerous artificial reservoirs in Africa, which have replaced running water habitats resulting in the disappearance of lotic species and the proliferation of species adapted to lentic systems. Many of these species are exotic, which has had a further impact on the ecosystem (Revenga and Kura 2003). Only in a few cases has remediation action taken place, e.g. in the Phongolo (South Africa), Senegal and Waza Logone (Cameroon) floodplains.

5.2.1. Congo River Basin

The Congo River Basin is the largest watershed in Africa, and the second largest (after the Amazon River Basin) in the world. Due to the unstable political situation that has prevailed in the area for a long time, little information is available on this vast floodplain area. Only minor infrastructure development is present and therefore it is probable that large parts of the wetlands are still intact (Junk 2002).

5.2.2. Niger River Basin

The Niger River traverses four countries, but the basin covers 9 countries of West Africa (Figure 3). The Niger has been comparatively well studied. Welcomme has conducted comprehensive studies in many African floodplains, including the Niger. Already in 1975 Welcomme published calculations showing the importance of floodplains for fish production in the Niger and Benue Rivers, indicating that the floodplain area of a river accounts for 72% of the variance of actual catch per km of river. This relationship has been improved and extended in newer literature (e.g. Laë 1992, Laë 1994). Differences in the yield within one river system can thus be attributed both to the development of the floodplain in the various river reaches and to differences in the water chemistry of the various tributaries (Welcomme 1975).

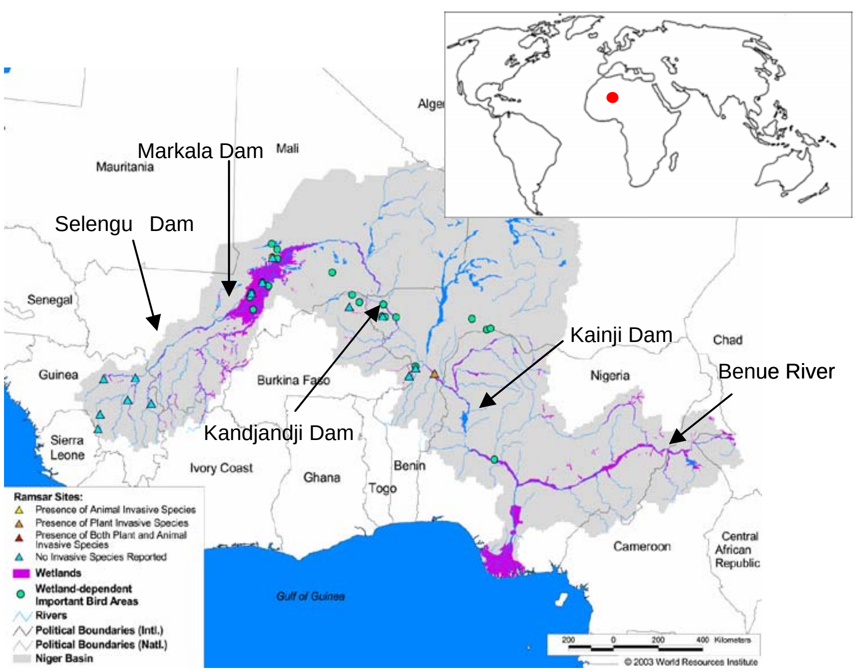

Figure 3. Map of the Niger rivershed (grey area) showing wetlands in purple. Floodplains and built structures discussed are marked with arrows. Source of map: *www.iucn.org/themes/wani/eatlas/index.html*

The floodplains along the Niger River have been much affected by built structures, especially the building of dams which has reduced the area of large floodplains and floodplain lakes. According to Laë *et al* (2003), there are four major dams built on the Niger, as follows:

- 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 $m^3 s^{-1}$.
- The Markala Dam was built in 1943 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.
- The only mainstream impoundment on the Niger River is Lake Kainji in Nigeria, located about 1200 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 1300 km^2.
- 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 (Laë *et al* 2003). According to Laë (1994) the effects of the dams is felt especially during highwater, when the filling up of especially the Selengue and Markala dams leads to a deterioration of the flooding through decreased expanse and duration of flooding. This in turn has lead to a decrease in recruitment and fish catches. The yearly production loss has been estimated at 5000 tons (10% of fished volume) of which 2000 are directly attributable to the Selengue dam.

A fairly well documented example of the impacts of dams on the Niger is the Kainji Dam. As a result of diminished downstream flows, the floodplain lake Ndakolowu, downstream of the dam, has been strongly reduced in area (Bernacsek 1984). The Kainji Dam has been reported to also have positive effects through changed fisheries opportunities in the reservoir of the dam, the Kainji Lake, second in size in West Africa to Lake Volta. A report on small-scale fishery studies done by a Nigerian-German project stated that "Although the lake's primary function is for hydroelectric generation, an important small-scale fishery has developed that in 1999 supported some 9502 fisherfolks using a wide range of gears including gill nets, cast nets, beach seines, fishing traps and longlines" (Alamu *et al*. 2003). However, earlier studies in the area pointed to the opposite. Welcomme (1985) reports a fish loss of 6000 tons per year due to the Kainji Dam. Later studies showed a 30% decrease in fish catches, and a reduction in commercially important *Mormyridae* species from an average of 20% of the catches to just 5% (Jackson and Marmulla 2000). It is not a simple task to weigh the gains and losses of a certain large project, even retrospectively. However, in the presence of floodplains downstream of a dam, losses in flooding will inevitably lead to major changes to the rich floodplain ecosystem, and the losses of these should be compared to the gains received from the artificial lacustrine environment created through the reservoir.

For many decades (especially between 1970 and 1985) the Sahelian drought has caused decreased annual inflows to many rivers in West Africa. EIA's prepared in connection with dam constructions in regions affected by this drought suggest that the dam, and possibilities for increased flows during at least part of the year, will counteract the impacts of the drought. For example, the EIA prepared for the proposed construction of the Kanjandji Dam in Niger suggests mostly positive impacts of the dam through rehabilitation of floodplains (that have decreased due to drought), including fish passes in the dam and creating new habitats (Kimba 2003, Lahmeyer Int 2002).

5.2.3. Chad River Basin

The Waza Logone floodplain in Cameroon is an exceptionally well-documented case, where promising experiences in the rehabilitation of the floodplain have been collected. The Waza Logone floodplain covers an area of about 8000 km^2 (5000 in dry season). It is located in the North Province of Cameroon (Figure 4), where the floodplain comprises about 10% of the total surface area of major riverine wetlands in the West African Sahel (Emerton 2005). It therefore represents a critical area of biodiversity and productivity in an otherwise arid area. Sixty percent of the inhabitants of the region rely on floodplain and wetland resources for their basic income and subsistence (Emerton 2005).

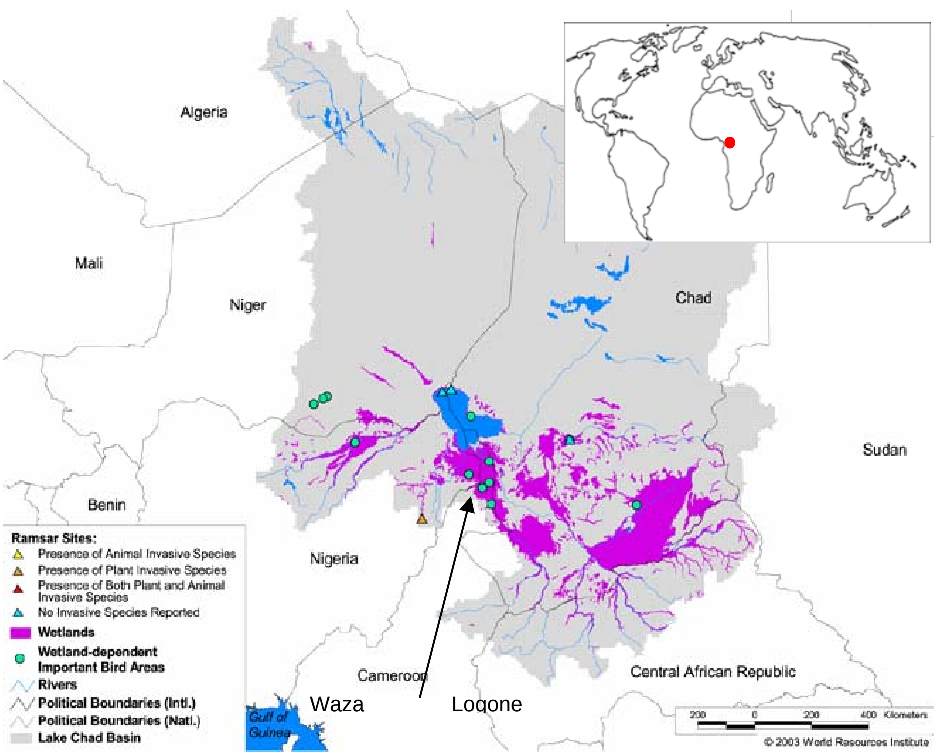

Figure 4. Map of the Chad rivershed (grey area) showing wetlands in purple. Floodplains and built structures discussed are marked with arrows. Source of map: *www.iucn.org/themes/wani/eatlas/index.html*

The high productivity of the Waza Logone region depends to a large extent on the overbank flooding of the Logone River (tributary of the Benue and Niger) and three seasonal rivers. Since 1979 the inundated area has been reduced by 964 km^2 representing almost 30% of the original flooded area, due in large part to the construction of a rice irrigation scheme (SEMRY) including a 30 km long dam creating a 400 km^2 reservoir (Maga Lake), as well as extensive embankments along the Logone River (Loth 2004). The construction works resulted in a 70% reduction of water supply to the floodplain from the Mandara Mountains, and an almost complete curtailment of the water supply from the Logone.

According to Loth (2004), the reduction in inundated area had a number of negative impacts on the ecology, biodiversity and socio-economy of the Waza Logone floodplain, including:

- Reduction in crop agriculture, mainly floating rice and floating sorghum, and flood recession sorghum.
- Loss of fisheries, including an estimated 90% decline in fish yields within flood-fed wetlands, and reduction of the capacity of the area to provide nursery for fish stocks in the wider river systems of the Logone and Chari. Decrease in dry season pasture: floodplain pastures (especially *bourgou* (*Echinochloa stagnina*), a high-quality floodplain grazing area in the dry-season, which has been replaced by expanding rice cultivation. However, rice crop residues are a poor substitute for the loss of *bourgou* pasture (Wagenaar *et al* 1986).
- Loss of plant resources, including grasses, shrubs and trees that were used for house construction, beekeeping, handicraft production, wood-fuel, wild foods and medicines. Grasses from the flooded areas were harvested and used for thatching houses and constructing fishing baskets.
- Decrease in wildlife populations, which has indirectly decreased economic activities within the tourism, sport and subsistence hunting sectors.
- Reduction in surface water availability, affecting water holes and water courses that are used for domestic and livestock water supplies and for water transport.

In response to the droughts which affected the Sahel in the 1960s and 1970s, many countries opted for large-scale, intensive irrigation schemes to meet their food security needs and to provide export opportunities. Unfortunately, until the early 1990s, these schemes were premised on overly optimistic economic forecasts and, even worse, implemented without any assessment of their impacts on downstream ecosystems and livelihoods. Today, a wealth of evidence demonstrates that, in many instances, these engineering projects … have not delivered the food increases anticipated during pre-commissioning phases. It has therefore become apparent that full floodplain conversion to irrigated agriculture is economically risky because the traditional farming, herding and fishing activities which such projects replace require no capital investments and often generate higher and more regular (and thus safer) returns per unit of water used.

Loth 2004: The Return of Water

Due to all these losses in the natural floodplain ecosystem services, it was decided to carry out restoration of the floodplains, which started in 1988 and continued until 2000. The restoration of the floodplain began with two pilot releases of water, which coincided with above average rainfall during the period 1994 to 1997. In these years a larger surface area was flooded than during the years immediately following the rice-irrigation interventions. The ecological monitoring programme initiated by the project showed that as a result of re-flooding, perennial grasses returned, and since grazers prefer perennial grasses, the number of wild herbivores increased. Socio-economic data showed improvements in fishing yields and livestock production as a result of increased flooding (Loth 2004). The restoration also led to a marked increase in the number of waterbirds, mammals, fish production, improvement and extension of pasture and changed agricultural opportunities (Emerton 2005). The return of the flood was of greatest value to pasture and fishing, while it also significantly benefited agriculture, the state of other natural resources (such as grass and *bourgou*) and surface water reserves (Loth 2004). The environmental, social and economic impact of the restoration project, as well as the methods used e.g. for the valuation of the re-inundation of the ecosystem, and the planning framework for managed flood releases etc. have been described in detail in Loth (2004).

5.2.4. Senegal River Basin

The Senegal River is accompanied by fringing floodplains along nearly its entire main course (Figure 5).

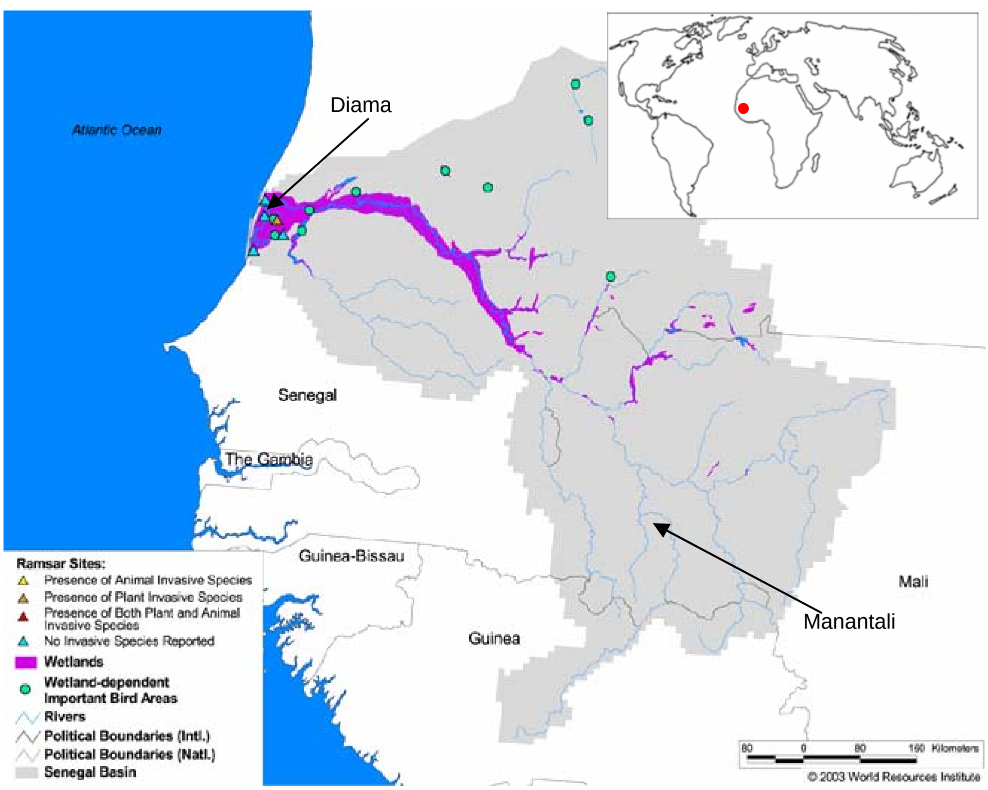

Figure 5. Map of the Senegal rivershed (grey area) showing wetlands in purple. Floodplains and built structures discussed are marked with arrows. Source of map: *www.iucn.org/themes/wani/eatlas/index.html*

The Senegal floodplain received, in a natural state, floods during the high-water period between June and October. During this high water period the river overflows its banks and floods the broad alluvial plain of the middle valley. This enables farmers to practice recession agriculture, growing crops during the dry season, after the waters have receded and the low-water period has started (Finger and Teodoru 2003).

In response to the droughts of the seventies, two major dams were built in the Senegal River, the Diama and Manantali dams. Water management policies were mainly dictated by the needs of new production systems, such as irrigated farming, hydropower and fluvial transport while traditional recession farming was considered old fashioned (Kloff and Pieterse, webcitation). The first dam to be completed (in 1986) was the Diama Dam, located 27 km upstream from St. Louis (Senegal). It was built to stop the dry-season intrusion of seawater. The impoundment reservoir became fully operational in 1992, after the completion of the embankment on the Mauritanian side. The second is the storage dam at Manantali in Mali (completed in 1990) on the Bafing, the main tributary of the Senegal River (delivering approximately 50% of the annual flow). The reservoir is theoretically capable of stocking 11 billion m^3 of runoff from the strongly seasonal rainfall in the mountains of northern Guinea. The water can then be gradually released over a longer period than the natural flood (Hamerlynck *et al*.web citation).

Most of the environmental and social impacts [of the Diama and Manantali dams] have stemmed from the physical separation of the river bed from the floodplains by the building of longitudinal embankments. The original ecosystems now either have too much water (the reservoir and the lowest lying parts of the floodplains) or too little water (the higher parts). Special impacts have occurred in the former estuarine part downstream of the Diama dam which became hypersaline, a common problem with dams in tropical areas. The changed hydrology in the regions has led to salinisation and loss of top soil, hampering the agricultural sector. Areas previously affected by floods and droughts, have now a stable water level which has led to the invasion of Typha domingensis*, a reed that has perfectly adapted to the new water management regime.*

In the agricultural sector, on top of the salinisation and loss of soil fertility mentioned previously, production has been hampered by the increase in the populations of granivorous (grain eating) birds. It is thought that this population explosion is linked to the permanent availability of fresh water which has eliminated the important dry season mortality. Another factor may have been the creation of inaccessible breeding and resting areas in the tens of thousands of hectares of former floodplain invaded by Typha domingensis*. Another major problem is that the land available for the previously largely practised recession agriculture, a sustainable type of agriculture, is now insufficient.*

The fish species living in the main rivers of the Sahel have a life cycle that is adapted to the characteristic seasonal flooding, migrating into the floodplain to spawn and returning to the river bed with the new generation at the water's retreat. Through history, the different communities of fishermen in the Sahel have learned to exploit this life cycle by allowing the spawning migration to go through virtually without intervention, and by concentrating their effort on the fish trying to regain the permanent waters of the river bed. Many techniques exist for the blocking of the return channels with different devices. There is a very clear relationship between flood extent and fish capture, estimated at around 50 kg per ha. Fish catches in the delta of the Senegal River were estimated to be around 30 000 tonnes in the pre-dam era and most of this production has been lost *subsequently. This loss has been very extreme in the formerly estuarine part downstream of Diama and probably this has also impacted on marine fisheries through the loss of nursery functions for mullets (*Mugilidae*), shrimp (*Penaeidae*), shad (*Ethmalosa fimbriata*) and other species having an obligatory estuarine life history stage.*

*Though catches in the Manantali reservoir have increased this is certainly not a compensation for the losses in the rest of the valley. It is likely that a change in species composition has occurred in the Diama reservoir, with a decrease of the typical migratory species and a relative increase of the more sedentary, opportunistic species (*Claridae, Cichlidae*) but no joint surveys have been done in the international waters of the river and no data have been made available from surveys carried out by Senegal. Fishing in the Diama reservoir is seriously hampered by the dense stands of* Typha*, and by the floating invasives,* Pistia stratiotes *and (since 1999)* Salvinia molesta *that are blocking the channels.*

The conversion of the floodplains of the Senegal valley for irrigated agriculture has considerably reduced the quality and quantity of dry season pasture. This loss is more extensive than the surface area actually converted to rice fields because of the hydraulic infrastructures used for the control of water supply to the paddy fields. The irrigation systems target paddy fields only, while the surrounding floodplains have dried out and been subjected to wind erosion removing the topsoil causing sedimentation problems in the tributaries, blocking water transport.

Floodplain forests, especially those of [the indigenous] Acacia nilotica *and* Borassus aethiopium*, are of great value. Most of the natural floodplain forests of the valley had already suffered from the drought and overexploitation but after the dams losses have been compounded. The forests have died because of lack of water (on the higher grounds) or waterlogging (in the low-lying areas. The impact on* Sporobolus robustus *stands, a perennial grass used in mat weaving, which incidentally was the main source of income of the local women, was also devastating. Another important species that used to occupy the seasonal pools in the floodplains is the water lily* Nymphea lotus*, which was used locally as a cereal substitute and for its pharmaceutical properties. Most of the original habitat is now covered with* Typha*.*

Summarised from Hamerlynck *et al*. 2000

These impacts, summarised above as presented in Hamerlynck *et al*. (2000), finally led to restoration projects, including the Diawling National Park projects. The construction of the Diama Dam in 1986 affected also the floodplain and estuarine areas on the Mauritanian bank by the absence of floods. In 1994, managed flood releases were initiated in the Bell Basin (4000 ha) of the Diawling National Park, as part of a rehabilitation effort. The basin was designated as a joint management area between traditional users and the Park authority and a revised management plan was developed through a participatory approach based on topographical, hydro-climatic, ecological and socio-economic data. Hydraulic modelling was developed as a tool to support stakeholder negotiations on the desired characteristics of the managed flood releases. The volume of flood release required to restore the delta did not affect hydropower generation, navigation or intensive irrigation, for which the dams in the basin were constructed. This project provides an example of implementation of the recommendations of the World Commission on Dams through ecologically and sociologically beneficial operation of a dam-based infrastructure within the basin, agreed through stakeholder participation (Duvail and Hamerlynck 2003).

5.2.5. Zambezi Basin

Compared to many other river basins in Africa, the Zambezi (Figure 6) is for much of its length relatively little affected by human activities.

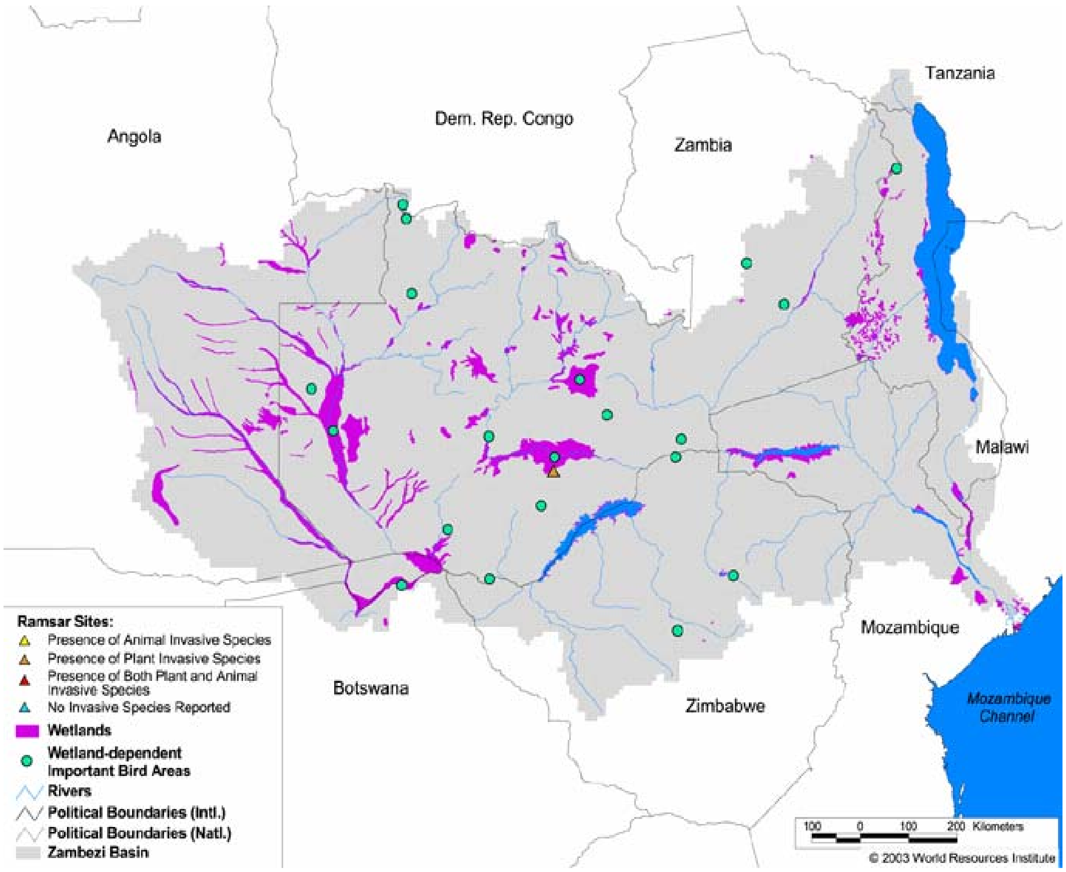

Figure 6. Map of the Zambezi rivershed (grey area) showing wetlands in purple. Floodplains and built structures discussed are marked with arrows. Source of map: *www.iucn.org/themes/wani/eatlas/index.html*

The major changes in land use affecting biodiversity in the Zambezi Basin over the last 100 years have been the construction of the two major dams at Kariba in 1958 to form the 5361 km² Lake Kariba and at Cabora Bassa in 1974 to form the 2665 km² Lake Cabora Bassa (Timberlake 1998). However, due to inadequate or non- existent baseline data, as well as the absence of EIAs on species composition and abundance, it is impossible to assess the change deriving from these major developments (Timberlake 2000). Prior to these impoundments a series of dikes was built to keep the Zambezi floodwaters out of the sugar plantations. This regulation of river flow and flooding events has almost certainly had a major impact on species abundance and distribution, but the extent of these changes, given a naturally variable and changing environment, is still not clear (Timberlake 2002). Lesser dams that have had major effects on biodiversity are

Itezhi-Tezhi and Kafue Gorge, both on the Kafue River in Zambia, situated at the upstream and downstream ends of the Kafue Flats floodplain, respectively (Timberlake 1998). These two dams have altered and now strongly regulate flooding patterns on the Kafue Flats. The area flooded during the rainy season is now smaller (4340 km^2) and more regular. Flood duration is longer and slightly delayed. During the dry season a larger area remains permanently flooded (about 1000 km^2). The amplitude of water level fluctuation has been reduced from a mean of 5.1 m to a new mean of 3.3 m (Bernacsek 1984). Other dams are much smaller and situated on the upper reaches of tributaries. Two further dams are planned for the Zambezi: at Batoka Gorge below Victoria Falls, and at Mepanda Uncua below Cabora Bassa (Timberlake 2002).

The construction of these dams has resulted in regulation of the previously-vast annual Zambezi floods below Victoria Falls. Kariba Dam reduced the flood magnitude of the Zambezi River by an average of 24% in eight out of ten years (1970–80 period), which in turn reduced flooding on the downstream Mana Pools floodplain (Bernacsek 1984). Cabora Bassa Dam prevents flooding of the Lower Zambezi floodplain, resulting in drying of floodplain lakes (Bernacsek 1984). The reduction in the flooding has caused radical changes in the fish fauna of the Middle and Lower Zambezi, e.g. a dramatic decline in two commercially important cyprinid fish species (*Labeo congoro* and *L. altivelis*), due to their spawning migration routes being blocked (Lévêque 1997). New fisheries opportunities were expected to be created in the reservoir of the dam, Lake Kariba, which however turned out to be unproductive. This caused the introduction of an endemic sardine-type fish from Lake Tanganyika, which now accounts for over 80% of the commercial catch of the lake (Revenga and Kura 2003 and references therein). The reduction in flooding has also led to the modification of riparian and wetland vegetation by encouraging woody growth at the expense of grassland and, obviously, the large-scale development of lacustrine environments and benthic fauna (Timberlake 1998). Unfortunately, owing to the lack of a good series of pre-impoundment data on biodiversity and ecology, it is difficult to reliably determine the magnitude and exact cause of these changes. However, already in 1970, Attwell reported that the Kariba Dam had both directly and indirectly a great influence on the ecological deterioration of the Mana floodplains, due to the alterations in the flood regime. He mentions effects of flood releases at abnormal seasons affecting the regeneration of vegetation due to the decrease in silt-load in the alluvium caused by the dam, as well as the reproduction of many animal species, such as frogs, crocodiles, water leguaans and terrapins that breed in backwaters and small pools, and several bird species nesting on the riverbanks, where the eggs and larvae are swept away. The lack of flooding during the wet season again has severely affected especially higher lying areas where the vegetation has changed markedly, and species adapted to standing water have become more common. Some of these species, such as water ferns and water lettuce, create considerable problems due to clogging of waterways, and consequent habitat alteration for several key species (e.g. hippopotamuses and crocodiles). In general, Attwell draws attention to the requirement of diversity rather than stability in environmental conditions to maintain a healthy floodplain ecosystem.

Further downstream along the Zambezi, Bento and Beilfuss (2004) have studied the environmental flows for the sustainable development of the Zambezi Delta and the Marromeu complex Ramsar site. They found that the construction of the Cabora Bassa Dam has led to a change in the magnitude of Zambezi flows, the timing of the annual peak to the discharges, and duration of the inundation of the Zambezi Delta, all of which has led to a marked change in vegetation cover in the pre- and post-dam conditions. The area covered by typical savannah species, such as *Acacia* sp. and certain types of palms had increased by up to 24%, while typical wetland species, such as certain types of grass and shrubs adapted to seasonal inundation had declined markedly. The density and distribution of larger wildlife, such as water buffalo and antelopes, had changed clearly, with a concentration of animals on isolated patches of wetlands left, while the areas left dry after the building of the dam had been abandoned. This leads to heavy grazing pressure and probable land degradation in the limited wetland areas preserved.

A number of mitigation measures have been proposed to ameliorate the changes in the flooding regime, mainly prescribed flood releases from Cabora Bassa, opening up by means of culverts or bridges the major distributor channels coming off the main Zambezi River that feed important floodplains and swamp areas, and ensuring that the forested areas important for the maintenance of the watershed functions are not further deforested (Timberlake 2000).

5.3. AUSTRALIA

In general, wetland habitats are decreasing in Australia mainly due to modified flood regimes, floodplain isolation and increasing salinisation (Ball 2001). Australia has at least 446 large dams (>10 m crest height), most of the stored water being diverted upstream of floodplain wetlands, while 50% of floodplain wetlands on developed rivers may no longer flood (Kingsford 2000). In the State of the Environment Report for Australia (Ball 2001), the following factors have been listed as key pressures on aquatic ecosystems:

- changes in natural flow regimes due to water extraction and supply
- direct modification or destruction of important habitats
- barriers to the movement of plants and animals upstream
- effects of poor water quality
- competition from introduced and exotic animal and plant species

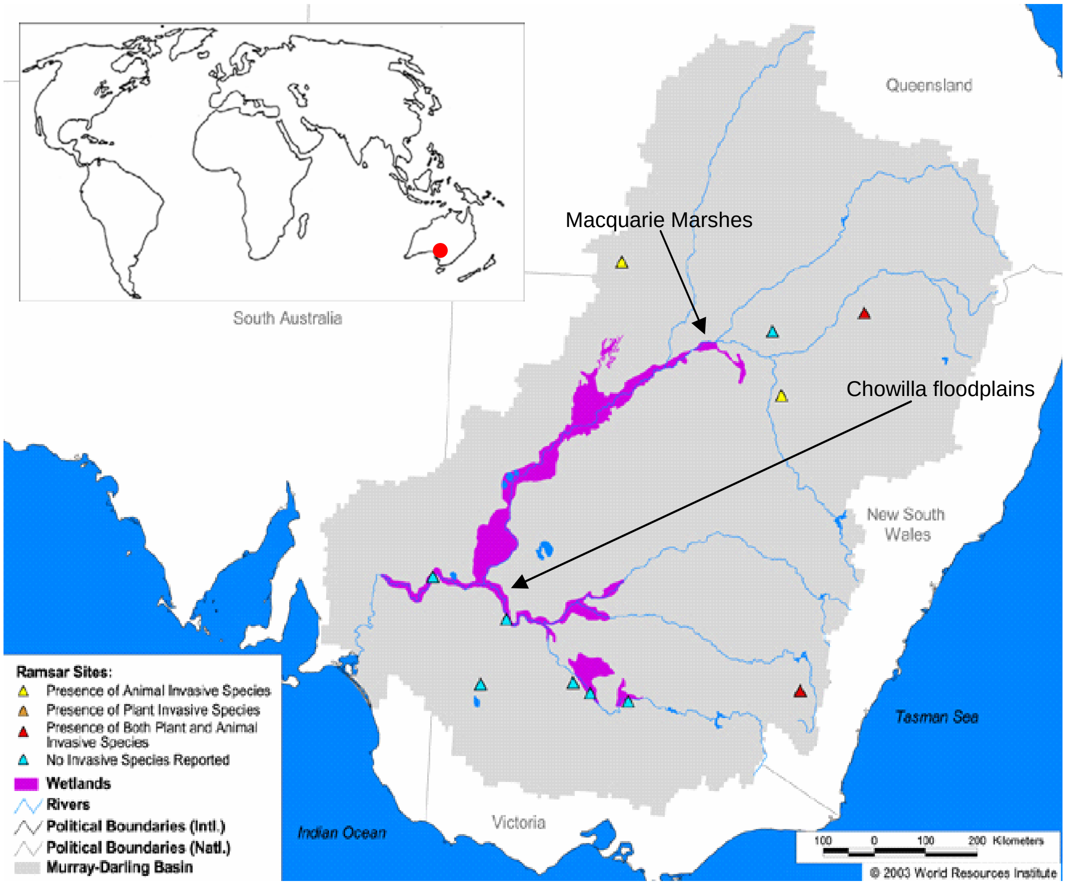

Figure 7. Map of the Murray-Darling rivershed (grey area) showing wetlands in purple. Floodplains and built structures discussed are marked with arrows. Source of map: *www.iucn.org/themes/wani/eatlas/index.html*

While figures concerning the construction of major dams and water storages since 1990 are not readily available, it is clear that the growth in total water storage has declined significantly since the mid-1980s. This is partly because the most economically efficient sites for water storage have already been developed and because attitudes have changed towards major storages and their potential effects on river flows and floodplain habitats (Ball 2001). The Murray-Darling Basin in the temperate South-East of Australia is highly developed, and the most studied floodplain in Australia (Figure 7). The Murray-Darling Basin has most of its annual runoff diverted and the second highest number of dams with storage capacity exceeding mean annual runoff, as well as 87% of divertible resources extracted (Kingsford 2000). Irrigation is a major water demand sector in Australia, and has led to severe water shortages in many parts of the country. Development of the Murray-Darling Basin has resulted in 9 801 000 million l/yr of water being used for irrigation, therefore reducing flows that would have naturally inundated floodplain wetlands. Floodwaters, which used to reach the Chowilla floodplain about every 1.2 years, now reach the floodplain every 2.5 years. Moderate flooding now only occurs every three years and lasts half as long. Large floods that previously inundated the floodplain every three years and lasted for three months now occur every 10 years and last for two months (Ball 2001 and references therein). This reduction in flood frequency has had a considerable impact on native floodplain plant and animal species in the Murray-Darling Basin floodplains. In the Chowilla floodplain, populations of 18 species of snails in the Lower Murray River have declined in the last 50 years. Snails are important foods for native fish species and waterbirds and therefore their decline in population may also affect these species. Reduced flows have allowed dense littoral plants, reeds (*Phragmites australis*) and cumbungi *(Tyhpa* spp.) to become established in weir pools, displacing other naturally occurring species (Ball 2001 and references therein).

The Macquarie Marshes are located on the Lower Macquarie River, also in the Murray-Darling Basin, and represent an area of approximately 130 000-200 000 ha, part of which (18 000 ha) is listed under the Ramsar Convention. The marshes contain a number of wetland types and their important ecological features include waterbird habitat, inland reed swamps and floodplain woodlands. Since the 1960s there has been a loss of over 50% of the original marsh area, the primary cause being a 30% reduction in annual river flows since the construction of Burrendong Dam in the late 1960s. These losses correspond to a decrease over the same period of 40-50% in the area inundated by large floods and have resulted in a decline in the waterbird population. Grazing and irrigated agriculture are common activities in the wetland catchment, and some reclamation of the marshes for farming has also taken place. Prolonged inundation and alienation of floodplain areas from the river by levees and erosion of river channels have also had significant impacts. The reduction in wetland area in the marshes has had additional downstream impacts including increasing salinity and erosion. The management of the Macquarie Marshes is focused on achieving a sustainable balance between water supply for irrigation, erosion control and environmental values (Ball 2001).

Also other artificial in-stream barriers have proved to have a significant impact on native fish populations. Common built structures in Australia, apart from dams, include weirs, regulators, farm dams, floodgates, causeways, culverts, pipes, channelised streams, bridge footings, and erosion control works (Ball 2001 and references therein). Major barriers isolate fish communities, restrict passage and result in changes in fish community structures, as many native fish need to migrate up and down river systems to breed, disperse and travel to spawning grounds. Of the 55 species of native freshwater fish in New South Wales, 32 are known to be migratory and require free passage to sustain populations (Ball 2001 and references therein). In Victoria, 2438 existing barriers to fish movement and migration have been identified, while there are over 1700 barriers to fish movements in New South Wales rivers systems of the Murray-Darling Basin, with three rivers having over 300 separate barriers to fish movement. Also floodplain isolation, due to flood mitigation through the construction of e.g. levees along the riverbanks is common in most large Australian rivers.

The greatest impacts of dams and other built structures on floodplain wetlands in Australia are predicted to continue within the Murray-Darling Basin, while in the tropical areas of Australia, the impacts of built structures on floodplain environments are less well known (Kingsford 2000). Recently, a review by Douglas *et al*. (2005) examined ecological functions of wetlands and rivers of tropical Australia, which have received international and national recognition for their high ecological and cultural values. Unlike many tropical systems elsewhere in the world and their temperate Australian counterparts, they have largely unmodified flow regimes and are comparatively free from the impacts associated with intensive land use, while plans exist for high investments in new dams, weirs, channels and potential areas for irrigation on many river systems in the northeast coast basin (Kingsford 2000). Also, the growing demand for agricultural development and existing pressures, such as invasive plants and feral animals, threaten their ecological integrity. According to Douglas *et al*. (2005), there are five general principles about food webs and related ecosystem processes that both characterise the tropical rivers of northern Australia and have important implications for their management. These are: (*1*) the seasonal hydrology is a strong driver of ecosystem processes and food-web structure; (*2*) hydrological connectivity is largely intact and underpins important terrestrial–aquatic food-web subsidies; (*3*) river and wetland food webs are strongly dependent on algal production; (*4*) a few common large species have a strong influence on benthic food webs; and (*5*) omnivory is widespread and food chains are short.

5.4. ASIA

Intensive seasonal flooding occurs in many parts of Asia, and despite natural flooding events being recognised as an important mechanism essential to maintain natural resources, the devastating effects of extreme floods also cause concern. Frequent flood and drought events continue to dominate the mindset of water resource managers, and engineering solutions are easily used as the tool for flood control (Gopal 2002). Non-structural approaches, such as flood forecasting and protection and restoration of floodplains, in comparison to structural approaches in general, are a good alternative to flood control through the use of large constructions (Gopal 2002) such as dams and extensive embankments, unless the construction can be justified due to other purposes (irrigation, water storage, hydropower). However, numerous large dams as well as other flood control structures have been built, their impacts being a subject of intensive debate.

5.4.1. Bangladesh

Bangladesh is one of the lowest lying countries in the world, and has historically been hard hit by flooding, while at the same time being much dependent on normal seasonal flood levels to sustain the fisheries and other natural resources that a large part of the population depends on. Bangladesh has one of the richest and largest floodplain systems in the world, floodplains constituting about 80% of the country (BCAS 2004, referring to several sources). Because of the large damage to the human population caused by floods, many flood control programs have been built to mitigate the adverse impacts of the flooding. These constructions have affected the floodplain environment and fisheries, most strikingly through the drastic reduction in floodplain area of over 2 million hectares in the past 30 years (Parveen and Faisal, 2003), which has severely impacted floodplain dependent fish species (constituting 60% of the 251 fish species found in Bangladesh).

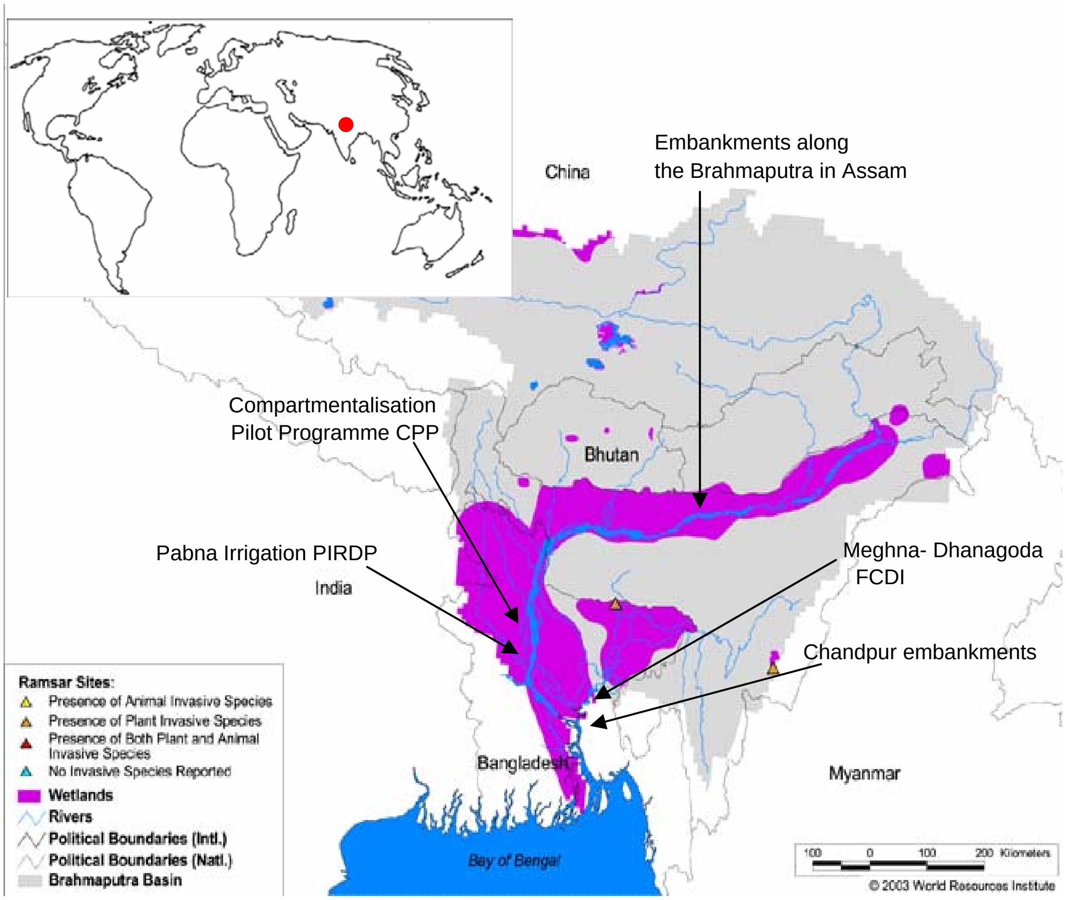

Figure 8. Map of the Brahmaputra rivershed (grey area) showing wetlands in purple. Floodplains and built structures discussed are marked with arrows. Source of map: *www.iucn.org/themes/wani/eatlas/index.html*

Numerous studies carried out in Bangladesh point to decreasing inland fish catches due to water resources development projects, as well as decreasing fish diversity (BCAS 2004). The Flood Action Plan was a collaborative international study comprising 26 components since 1990, developing long-term flood control policies and an action programme for Bangladesh (Figure 8). The results of these, as well as various other studies carried out on inland fish production in relation to the flood control, drainage, irrigation and compartmentalisation projects, indicate that fish catches and fish diversity are declining in inland water bodies of Bangladesh, while production has increased in culture fisheries (BCAS 2004). In general, whenever flood control projects reduce the area of flooded land, there will be a loss of habitat for fish production and a subsequent loss in annual fish yields or catch per unit area. Flood control programmes have been found to affect reproduction and larval fish drift (de Graaf *et al*. 1999, de Graaf 2003c), block fish migration and dispersal routes (Mirza and Ericksen 1996), reduce species diversity by up to 30%, most of which belong to the more valuable white fishes (BCAS 2004). Sluice gates have proven to be fatal for many fish species, e.g. carps (white fish) of which only small numbers can get through sluice gates (BCAS 2004) and fish larvae and hatchlings, of which 25% died when passing the sluice gates (Marttin and de Graaf 2002). The authors found that there was a difference between the mode of operation of the regulating sluice gate: when operating in an undershot mode (water passing underneath the gate door) up to 44% of released hatchlings died, while only 11% died when passing the regulator when operated in overshot mode (water flowing on top of the gate door).

Mirza and Ericksen (1996) report the impacts of one of the embankment projects, the Chandpur project. The project is one of the major water resource development projects of Bangladesh, and covers an empoldered area of 56 655 ha, designed to provide flood protection, drainage and irrigation to the empoldered area. It was found that the open-water fishery in the project area has undergone great losses (83%) while the closed-water culture fish farming has benefited from the project, creating suitable stable conditions for fish culturing. However, the benefits for fish culturing opportunities have not compensated for the loss in natural open-water fisheries, and the total fish production has decreased by nearly 30% as a consequence of the Chandpur project. These developments have indirectly led to another impact: the fish consumption per capita in the area has dropped markedly (to half of the national average in 15 years) as a result of lower fish production and catches, higher population numbers and higher cost of buying farmed fish (the production of which has increased, and which is being exported out of the local area to a large extent), affecting especially the poorest people. Mirza and Ericksen (1996) note that water control projects have substantially reduced fisheries from floodplains, recommend that environmental considerations be taken into account and suggest that all new projects should collect baseline data on all fishery related issues for the benefit of future impact assessments. Annual losses of between 300 and 3000 metric tonnes of net fish production was estimated in connection with another FCDI project in the Southeast region of Bangladesh, the Meghna-Dhanagoda FCDI. The losses were mainly due to drainage and loss of floodplains and *beels* in the area, as well as the closure of internal canals inside the project (BCAS 2004).

In the Pabna Irrigation and Rural Development Project (PIRDP) site in northwestern Bangladesh, studies were carried out by Halls *et al*. (1998) concerning fish migration and movement through sluice gates in a flood control, drainage and irrigation (FCDI) scheme. It was found that *Catla catla, Channa striata* and *Wallago attu* migrated through the sluice gates, both with and against prevailing currents in different seasons, while the smaller *Anabas testudineus, Glossogobius giuris* and *Puntius sophore* did not. Species assemblages were significantly different inside and outside the FCDI schemes, with up to 25 species absent or less abundant inside compared to outside. The majority of these species were large predators or conspicuous members of the highly prized migratory 'whitefish' category, including the silurid catfish, Indian major carps, mullets and clupeids. In their absence, species inside FCDI schemes were dominated by much smaller resident 'blackfish' species. Assemblages inside FCDI schemes thus had both a reduced species richness, and a unit value reduced by up to 25%. It was concluded that FCDI schemes such as the PIRDP negatively affect fish species assemblages and stock values by reducing the accessibility of impounded floodplains to migratory fish. Though some fish are capable of penetrating existing sluice gates, management measures are required to encourage the passage of more species (Halls *et al*. 1998).

FAP 20 was a study developing a compartmentalisation approach to flood hazard mitigation. The concept includes an embanked area that would provide a comprehensive water control system to allow controlled flooding without causing damage to crops, fisheries, infrastructure or urban land. Built structures include main river embankments, existing road and railway embankments, inlet and outlet control structures and improved waterways for controlled flooding, drainage and navigation. De Graaf (2003b) summarises the results of the Compartmentalisation Pilot Project (CPP), maintaining that no difference in fish catch before and after the CPP was noted, attributable to the project not significantly altering the average flooded area. De Graaf (2003c) concludes that this type of controlled flooding is a better option than complete flood control, from a fisheries perspective.

As a summary, evidence suggests that fish production from inland capture fisheries has been in decline in Bangladesh for some time. A major reason for this decline is the flood control projects, while pesticides and industrial pollution are also mentioned (BCAS 2004) as important factors impacting the fisheries. FCDI projects have been implemented partly to increase rice production, but it has turned out that they have been of little value for rice production, whereas their effects on fisheries have been devastating (reducing indigenous floodplain fisheries by over 70%), due to built structures such as embankments, sluice gates, and culverts preventing floodwater from entering the floodplains (BCAS 2004). The results of FAP-17, designed solely to address inland fisheries issues and the impact of different types of FCDI projects on fish resources, as well as mitigation measures to prevent harmful effects, listed the following impacts of flood control on fisheries in Bangladesh (Ali and Fisher 1997):

- Loss of fish catch through loss of habitat
- Reduction in catch per unit area
- Reduced fish density/abundance
- Increased fishing effort
- Reduced biodiversity
- Reduction in the numbers of migratory fish and the number of fish migrations
- Disruption of fish community structure
- Increased capture at regulators
- Reduced opportunity for mitigation measures and
- Reduced potential for stock enhancement.

The local people were found to be highly dependent on fisheries related activities, especially the small and landless farmers in agricultural communities. The flood season was especially important for the fisheries, and it was found that reduction in flooding and floodplain area led to significant losses in income, a cheap source of animal protein and employment opportunities.

5.4.2. India

The main rivers in India, Ganges, Brahmaputra and Indus, are extensively regulated for water diversion, flood control and hydropower by a series of dams, barrages and embankments. The Indo-Gangetic floodplain is the largest wetland regime in India, but up to 70-80% of individual fresh water marshes and lakes in the Gangetic floodplains have been lost to developments after the 1950s (Ramachandra 2001). According to Mathur *et al*. (web based reference) there are over 4000 big dams in India, submerging over 37 500 km^2 and having displaced at least 42 million people in India. High population density leading to high domestic and industrial pollution, and the numerous activities in the catchments, floodplains and within the river channels have seriously decreased the quality of water. Rehabilitation of the floodplains of India to remedy the grave pollution of the rivers has been suggested by Gopal (2003).

Development of the water resources of the Brahmaputra Basin has caused concern. Fazal (web based reference) points out that the raising of embankments in India without adequate measures for the restoration of ecological balance in the catchment areas has led to increased siltation of rivers and reservoirs. In several cases riverbeds are now higher than the ground level in their vicinity. Indiscriminate use of land along the river banks has also resulted in the formation of ravines and gullies. Ravine formations are estimated to have damaged about 3.67 million hectares in Uttar Pradesh, Madhya Pradesh, Rajasthan, Gujrat, Maharashtra, Punjab, Tamil Nadu and West Bengal. Nearly 2.3 million hectares have been rendered almost useless on the banks of the Chmnbal, the Yamna, the Mahi and some other rivers. Boruah *et al*. (2000) draw attention to the importance of *beel* (deeper parts of the floodplains where water is trapped when the flood recedes) fisheries and the ecological degradation of the *beels* in the Brahmaputra River Basin in Assam. Problems have been encountered due to eutrophication caused by the construction of embankments along almost the entire length of the Brahmaputra River and many of its tributaries in the 1950s. The establishment of embankments considerably reduced the flooding and the flushing of the *beels*, and the impact has since been aggravated by human activities such as buffalo and cattle grazing, agriculture and over fishing. Boruah and Biswas (2002) summarise the impacts of the Brahmaputra embankment and dike constructions, escalating the problems caused by deforestation and subsequent erosion of the riverbanks. The embankments trap the sediment load, which is now deposited on the riverbed, making the level rise on a daily basis while the land has remained the same, except for losing the natural manure normally received during floods. Furthermore, the embankments are responsible for the shrinkage of the spawning and feeding grounds of many riverine fishes, leading to a decline in e.g. major carp species.

Kaziranga National Park in the Brahmaputra River floodplains in Assam is a small national park with important biodiversity related to the floodplain environment. Management plans for the national park draw attention to the impacts of planned developments for the area, including suggested construction of highways and expressways, harnessing of water resources for hydroelectric potential through a series of dams on Brahmaputra River (with no large dams so far, but extensive embankments constructed for flood control, Mathur *et al*. web based reference), and developments in the fields of agriculture, and oil and gas production. Main threats identified include changes in the river flow and barrier effects created by the construction of roads through or along ecological corridors connecting other areas with the floodplains (Mathur *et al*. web based reference).

5.4.3. Mekong region

The impacts of dams have been debated for a long time in the Mekong region. The Mekong has been subject to intensive dam building, the effects of which in many cases have been little studied. Despite the impacts of dams being better known now, tens of new dams are either currently under construction or planned on the Mekong and its tributaries (MacLean *et al*. 2004). According to MacLean *et al*. (2004) nearly one-third of the river's total sediment load originates in the Chinese sections of the Lancang/Mekong (Figure 9). Numerous dams in the Upper Mekong are reported to have severe impacts on downstream environments, including floodplains. These include (according to IRN 2002)

- Agriculture: Greater regulation of the flood cycle means that there will be less frequent floods, which will decrease sediment and nutrient deposition and hence reduce soil fertility. Without a massive program of artificial fertilizer use, long-term agricultural yields will decline.
- Fish and fisheries: Spawning sites may be drastically reduced in the dry season and in the rainy season lower water levels in the flooded forests of southern Laos and Cambodia will affect important fish feeding, spawning and nursery grounds. This may result in a major decline in fisheries in the Mekong Basin, including possible extinction of some species.
- Erosion: Water released from the lowest dam in the scheme will have less sediment than before and will therefore scour and erode the bed of the river downstream. This erosion could alter the Mekong's course and width, weaken supports for buildings, piers and bridges, and cause financial loss to downstream areas.

Amornsakchai *et al*. (2000) prepared a case study on the impacts of the Pak Mun Dam. The dam is built on the Mun River, 5.5 km upstream from its confluence with the Mekong, in Northeast Thailand. The dam has a maximum height of 17 m and total length of 300 m. The reservoir has a surface area of 60 square km at normal high water level of 108 meters above the mean sea level and a capacity of 225 million cubic meters. None of the EIA studies performed predicted that fisheries issues would become problematic during construction or implementation. After the completion of Pak Mun Dam, however, the Lower Mun River experienced a decline in fishing yields with an estimated value of US$1.4 million per annum at 20 Baht/kg. In the post-dam period fishing communities located upstream and downstream of the dam reported a 50-100% decline in fish catch and the disappearance of many fish species. The dam has especially affected several migrating and rapid-dependent fish species. A fish pass was built but this has apparently not been functioning as anticipated. Assessment of project impacts, like the assessment practices in past dam projects, remained focused on inundated areas and resettlement issues. The Pak Mun project happened to be the first run-of-river type dam, with no reservoir and thus impacts due to flood and resettlement were not assumed to be as serious as those of other big dam projects in the region. Thus, fisheries impacts were overlooked.

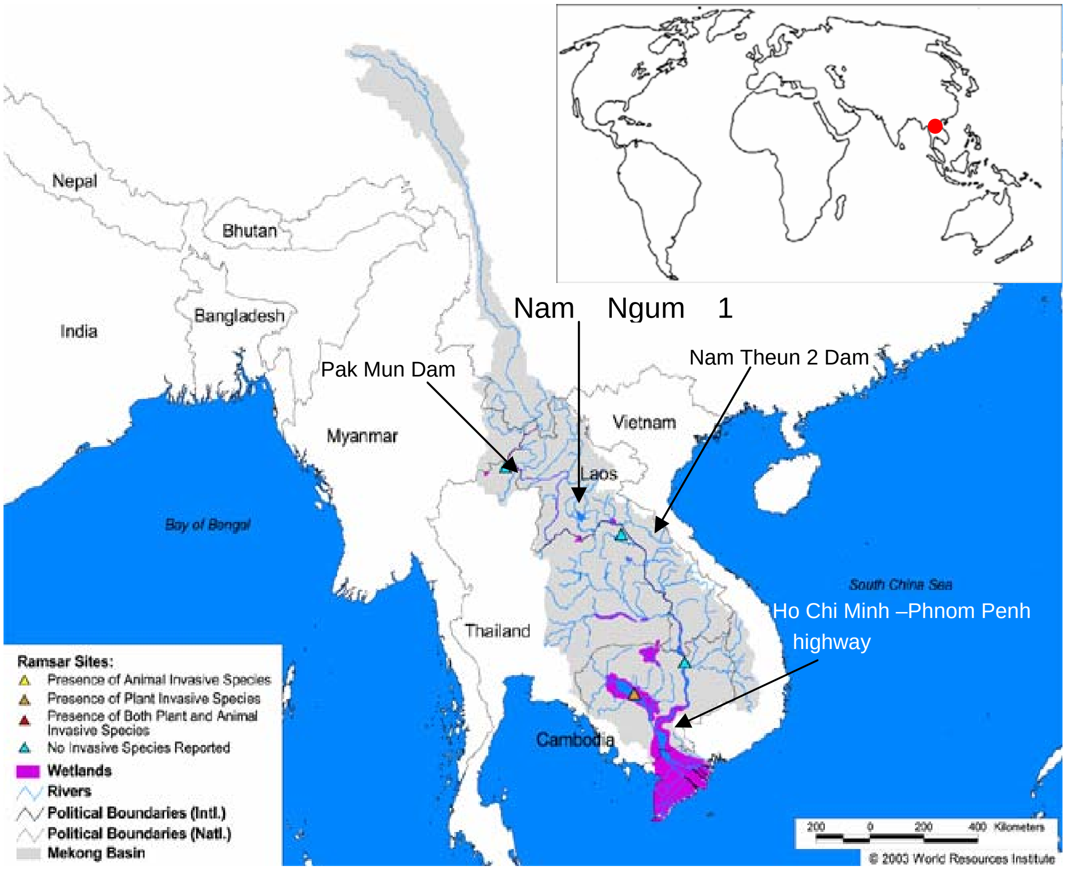

Figure 9. Map of the Mekong rivershed (grey area) showing wetlands in purple. Floodplains and built structures discussed are marked with arrows. Source of map: *www.iucn.org/themes/wani/eatlas/index.html*

In order to demonstrate the impacts of blocking the flow of the Mun River caused by the Pak Mun Dam, the local villagers requested the government to open the sluice gates for a year in order to assess the impacts on fisheries and their livelihoods from the dam. The Thai government agreed to open the dam gates on June 14, 2001 for four months to conduct studies on fisheries, social impacts and the impact of the dam on electricity supply. A participatory research project was carried out as a collaboration between Pak Mun villagers and researchers from South East Asia Rivers Network ("*Thai Baan* research"). Selected results from the report are presented below.

*When the Dam was built, villagers found that only 45 out of 265 fish species indigenous to the Mun and Mekong rivers remain in the Mun river in Pak Mun area. The reservoir submerged perennial plants that typically grew in the rapids, riverbanks and islands (*Don*) and allowed the invasive alien weed, giant mimosa, to thrive and dominate the riverbanks. The still water also created an environment where new types of aquatic weeds and microorganisms proliferated, such as hyacinth, "itchy snails" and the fish parasite* Mae Pla*.*

Villagers found that opening the dam gates for one year had dramatic impacts, bringing much of the fishery and associated ecosystem back to life. When the dam gates were opened, a large number of fish once again migrated from the Mekong to the Mun River, *laying eggs from the mouth of the river upstream to the river's tributaries. Village researchers found that 129 species of fish returned to the Mun River during the period between June 2001 to May 2002.*

The opening of the Pak Mun Dam gates restored the diversity of fish species in the Mun River. Among the native species of fish, village researchers documented that 104 species migrate from the Mekong River to the Mun River, and 25 species live and migrate within short distances within the Mun River. The migratory fish from Mekong to the Mun River include some endangered species, such as the Mekong giant catfish, or Pla Buek*,* Pla Dtong Grai Pla Kae Hin *and* Pla Eian Hu *or* Too Na Hoo Khao*.*

The opening of the dam gates has restored the fertile ecosystem near to its state before the dam was built. When sluice gates were open, the still body of water began running again, cleaning the river and sweeping away water hyacinth plants within the first month. Gradually, rapids began to reappear in the river, however, they were covered with sediment, or Aon*. After three months, the river washed away the* Aon *from the rapids. After five months, the populations of the* Mae Pla *fish parasite decreased and then disappeared. Eventually, the Mun River's fisheries, ecosystem, and vegetation returned to near to the normal state before the dam was built.*

SEARIN 2004

Riverbank vegetable gardens are a form of highly productive and important seasonal farming practised by tens of thousands of families from Yunnan down to the Mekong Delta region in Vietnam. It is an agro-ecosystem which has traditionally relied on the rich sediments carried down by the Mekong and its major tributaries, and deposited each year on the floodplain and banks to maintain soil fertility (Blake 2004). The growing of the numerous crops in riverbank vegetable gardens requires almost no fertilizers (Roberts 2001). In the northeast of Thailand large-scale dams, water extraction schemes and deforestation have radically altered the hydrology and geomorphology of the rivers draining the Khorat Plateau, resulting in mass abandonment of this sustainable farming system on a massive scale. According to Blake (2004), riverbank vegetable gardens are still relatively common in Laos and Cambodia, both along the mainstream Mekong and its many tributaries, providing vital nutrition and livelihood income to villagers and communities. Here too it is threatened by massive irrigation, flood management and hydroelectric schemes, like along the Sesan river in Northeast Cambodia and the Xe Bang Fai River, which would be impacted by the planned trans-basin diversion Nam Theun 2 Dam in central Laos (Blake 2004).

The planned Nam Theun 2 Hydropower Project is the largest infrastructure developments project in Lao Peoples Democratic Republic, including a 48 m high dam creating a reservoir covering an area of 450 km^2 in the wet season (Norplan and EcoLao 2004). A cumulative impact assessment was carried out regarding added and induced impacts. Regarding environmental impacts, the CIA pointed to possible indirect impacts regarding increased pressure on wildlife, migration of fish by the establishment of the reservoir, better protection, but also threats to biodiversity from extractive activities, hunting and general population increases, leading also to increased untreated wastewater possibly causing oxygen depletion, increased logging activities causing increased threats to biodiversity, agricultural activities causing eutrophication and higher levels of pesticides in the water (and consequently fewer fish), lowered biodiversity and fish production due to changes in flow regime, while an increase in back swamps may also increase floodplain area, reduced discharge in the flood season, negative impacts on fisheries in the Great Lake of the Tonle Sap, and positive impacts through dampening damaging flood incidents and reduced salt intrusion in the Mekong Delta.

Schouten (1998) has studied the downstream impacts of Nam Ngum 1 Dam in Laos. The dam has had positive impacts through increased fisheries in the reservoir; however, water quality downstream of the dam has deteriorated due to low levels of oxygen in the deeper layers of the stratified dam. The dam also blocks fish from upstream spawning areas and has hence impacted especially migratory fish.

A report by the Stockholm Environment Institute (SEI 2002) analyses five case studies in the Greater Mekong Sub-region dealing with various infrastructure projects (roads and dams). Out of five projects involving large-scale built structures, one had a cumulative assessment carried out (Theun-Hinboun hydropower project in Laos), while none had an economic evaluation of environmental impacts done. One of the analysed projects had no EIA process carried out whatsoever (Kinda Dam in Myanmar). The integration of social and environmental issues on a regional scale was found to be weakly carried out. The Theun-Hinboun hydropower project has been considered an environmentally friendly project due to its run-of-the-river design, absence of reservoir and hence absence of resettlement issues involved. However, the EIA process (which started too late to be able to change the design of the project) pointed to impacts on fish migration, but little consideration was given to downstream losses and potential mitigation measures to avoid these. Loss of fish biodiversity due to hydropower dams was found to be the single most important ecological issue in connection with the Theun-Hinboun hydropower project (SEI 2002), and loss in fish catch the single most important socio-economic issue. The cumulative assessment, which considered further ongoing and planned hydropower projects, indicated that these impacts would be exacerbated through further decreased flows downstream of the developments.

The SEI (2002) study also pointed to the Ho Chi Minh City – Phnom Penh highway, which in Cambodia separates the Mekong River from the Bassac Marshes, as a habitat for a diverse and abundant population of water birds. The road currently disrupts the flow of flood waters from the Mekong River to the Bassac Marshes due to the poor design of drainage structures. By improving the drainage structures, such as culverts, along this section of the road, the project will contribute to restoration of ecosystem functioning and productivity in adjacent areas (SEI 2002).

6. REVIEW OF GUIDELINES AND RECOMMENDATIONS FOR MANAGEMENT OF FLOODPLAINS

While this review did not specifically concentrate on EIA procedures in connection with the case studies, it was noted that guidelines for EIAs do not generally include instructions for how to consider specific floodplain variables and the interconnections between different environmental sectors. Therefore, few recommendations are available for how to assess the environmental impacts of a project on these integrated features of floodplain ecosystems, or how to include economic valuation of lost ecosystem services. The nature of various floodplain systems differs from river to river, and therefore the results of detailed studies done on one floodplain cannot be directly applied in another. This underscores the need for baseline information collection, even if this would be done immediately prior to project design while the site is still undisturbed. It is, however, important to make sure that the time available for data collection spans at least two years and analysis of data is given proper attention (SEI 2002). Similarly, the importance of designing and implementing environmental and social management plans and the regular monitoring of impacts and results of mitigation measures are emphasised.

Despite a general lack of guidelines with regard to floodplain environments, specific guidelines with regard to dam construction, design, and management of fisheries impacted by dams have been prepared. McCartney *et al*. (2000) and Ledec and Quintero (2003) propose a set of key indicators of likely environmental impacts of dams (see Table 1) in different situations. This should be noted as a guideline in connection with EIAs and could be developed to apply also when considering other built structures than dams.

Table 1. Indicators of likely environmental impacts in connection with the construction of dams and other impoundments (according to McCartney and references therein, 2000)

Indicator	**Comment**
Reservoir surface area	The area flooded by the reservoir is a strong proxy for many environmental and social impacts. A large reservoir area implies the loss of much natural habitat and wildlife, or the displacement of many people or both. Very large reservoirs are typically in the lowlands and often impound large rivers. Large rivers tend to be characterised by a greater range of habitats and food sources associated with greater fish diversity and a wide range of trophic adaptations.
Water retention time in reservoir	Mean water retention time (calculated as a function of reservoir volume and mean river flow) during normal operation is very useful in estimating the extent to which a reservoir will have long-term water quality problems.
Biomass flooded	The greater the amount of biomass flooded the greater the implications for reservoir water quality. Flooding native forests also harms biodiversity conservation and releases greenhouse gases (carbon-dioxide and methane) into the atmosphere.
Length of river impounded	To conserve aquatic and riparian biodiversity (including riverine forests), dam sites should minimise the length (kilometres) of river (main stem plus tributaries) impounded by the reservoir (measured during high flow periods).
Number of downstream tributaries	The greater the number of tributaries of the dam site, the better, in terms of maintaining a) accessible habitat for migratory fish, b) the natural flooding regime for river ecosystems and c) nutrients of sediment inputs needed for the high biological productivity of estuaries.
Access roads through forests	Where the risks of induced deforestation are high, project siting should minimise the kilometres of required new or upgraded access roads passing through or near natural forests.

Bernacsek (2000) specified a series of management procedures to facilitate sound management of fish biodiversity, fish stocks and fisheries in connection with all stages of dam construction (Table 2). The adoption of these procedures in the identification, design, appraisal, construction and operation phases of dams would facilitate a systematic approach to mitigation measures for fisheries management.

Table 2. Capacity and information base requirements for effective management of fish biodiversity, fish stocks and fisheries threatened or affected by dams during different phases of the project cycle, modified from Bernacsek (2000.)

Phase of project cycle	Requirements
Dam identification	Community-based or user group fisheries management systems should be put into place in the impacted area for commercial and recreational fisheries. An Initial Environmental Examination should be carried out. A data base should be assembled, providing detail on the aquatic environment, fish biodiversity, fish migration, existing fisheries upstream and downstream, likely impacts of the dams and possible mitigation measures
Dam design	Community-based fisheries management should be continued. An Environmental Impact Assessment should be carried out. The information base should be made more comprehensive. An assessment of the level of impacts on, and the risks for, fish and fisheries, and a statement with regard to the degree of suitability and acceptability or need for rejection, of the project from a fisheries point of view should be prepared. A set of mitigation measures and an environmental management plan should be prepared.
Dam project appraisal	CBM should be continued. The worth of the project should be examined. A set of questions and criteria concerning the fisheries impacts and mitigations should be satisfied before approval for dam construction is given.
Dam construction	Fisheries management activities need to be carried out which aim at preventing damage to fish biodiversity and fish stocks arising from construction activities, such as soil erosion and silt runoff, siltation of key fish habitats downstream, blast damage from explosives and blockage of fish migration. Real time data required. Management activities need to be rapidly responsive to the construction schedule. Special attention needs to be given to reservoir preparation with regard to clearing forests in a manner which will reduce problems of snagged nets and ghost fishing yet still allow sufficient surface area for periphyton growth for fish forage. Information needs focus on suspended solids, sediment transport, fish mortality, fish migration and fish biodiversity.
Dam operation	Needs for fisheries management in four impact areas must be addressed: 1) the reservoir and its affluent streams, 2) the fauna passage facilities, 3) the downstream river channel and floodplain and 4) the delta, estuary and adjacent sea. The downstream river fisheries management concerns focus on aeration of anoxic discharge water from the dam, provision of effective fish passes to allow broodstock and juveniles to migrate across the dam, reduction of turbulence in the stilling pool, and mitigation of fish losses on the floodplain. The release of artificial mini-floods and the provision of adequate dry season flow is crucial to maintaining a suitable environment for migratory fish species, especially endangered species.
Dam decommissioning	Fisheries management should focus on rapid recovery of fish stocks that have suffered impacts during dam operation. Measures should be implemented to prevent damage to fish stocks during dam demolition as well as enhancement measures, e.g. river rehabilitation, for the aquatic and related terrestrial environments. Fish biodiversity and migrations, as well as sediment loads, should be carefully monitored. CBM should be continued.

Some recommendations have been presented in the literature, based on lessons learnt in various tropical floodplains/wetlands. Lessons learnt in Senegal have shown that the combined use of modelling and thorough participatory methods involving local communities and stakeholders to explore various mitigation scenarios and options in a specific floodplain environment has led to successful results. In connection with the Waza Logone restoration project, the ecosystem approach was used extensively and throughout the project. The project provided an example of the sound practice of integrating ecosystem conservation and sustainable development, and the results from the project have been adopted by many international organisations including the World Bank and IUCN, as well as Multilateral Environmental Agreements such as the CBD.

Based on experiences from dams in Laos, Schouten (1998) recommends that feasibility and design studies for hydropower projects consider variable-level reservoir intakes that allow water to be taken continuously from the reservoir (better quality) surface water layer. Variable-level intakes avoid release of water from the (anoxic) hypolimnion and associated negative downstream effects. He also points to the importance of paying attention to downstream effects and the cumulative impacts of dams in the Mekong region. Schouten (1998) recommends hydrological and water quality monitoring and modelling, as well as fish surveys and fisheries monitoring, as a necessary baseline for hydropower development that should also lead to the formulation of mitigation measures and appropriate watershed management planning.

Lessons learnt in Australia (Douglas *et al*. 2005) have given rise to recommendations regarding management of tropical wetlands. According to these principles, one should avoid developments that would:

- Disrupt the flood pulse
- Reduce hydrological connectivity
- Impact factors influencing the production or composition of algae, such as turbidity and increased runoff of nutrients, herbicides, pesticides or metals into the water
- Disrupt the species composition and especially the occurrence of key species of the food webs.

As management options for Indian rivers and floodplains, Boruah and Biswas (2002) recommend the use of an integrated ecohydrological approach through e.g. modelling the impacts of anthropogenic activities on fish stocks (commercial and endangered species especially), emphasising mitigation measures such as control of riverbank erosion through phytoremediation, identifying the main factors impacting fish migration, and interaction between stakeholders.

The growing awareness of the cumulative negative impact on inland capture fisheries of the progression of flood control embankment and polder type projects throughout Bangladesh has led to management plans being developed (Hoggarth *et al*. 1999, Nishat 1997), suggesting e.g. the further study of the potential of closed water fisheries (resident black fish especially), as well as adapting hydraulic structures used in FCDI projects to fish-friendly models (overspill of sluice gates, fish passes, etc.) to enhance natural migration (Nishat 1997). Ali and Fisher (1997) recommend stock enhancement schemes, increased future research activities, as well as the following mitigation measures:

- Production of deep water *aman* (rice fields)
- Habitat rehabilitation and protection
- Increased fish migration across flood control structures

- Fisheries conservation: *Beel* management
- Fisheries conservation: Prohibited fishing zones at regulators
- Fisheries conservation: Protection of river fisheries
- Fisheries conservation: Establishment of fish sanctuaries
- Conversion of full flood control to partial control
- Provision of flood pathways in extensive areas protected by submersible embankments
- Increased fish migration across rural roads
- Strengthening of technical assessments and planning capabilities of concerned institutions
- Establishment of a national database on FCD/I projects
- Improvement in data collection by national monitoring agencies
- Establishment of water-user groups
- Institutional training
- Development of flood modelling techniques

Based on lessons learnt in Bangladesh (Ali and Fisher 1997, Hoggarth *et al*. 1999) especially in connection with flood protection schemes on floodplains, the following recommendations have been extracted:

- Ensure fish migration routes through structures
- Protect fisheries and habitats through protected areas/times
- Minimize loss and degradation of flooded areas
- Strengthen management institutions, and develop monitoring, forecasting and information dissemination.

Hoggarth *et al*. (1999) recommend the following management implications for floodplain river environments:

- Managers of fisheries and other resources must discuss their impacts on each other
- The impacts of floodplain modifications must be investigated and managed at both catchments and local levels
- Variability in habitats between localities necessitates local involvement in management
- Uncertainty in hydrological regimes necessitates local involvement in management
- Quantity and quality of flood water must be maintained for high fish productivity
- Diversity of floodplain habitats must be maintained for high fish biodiversity
- River channels must be maintained for fish migrations and access to spawning grounds.

Increasingly, CIAs and SEAs are called for with regard to developments involving large structures. There are few environments where a built structure will be an isolated structure impacting the environment, and the final consequences for the environment rarely add up to the simple additional value of each structure. To study the synergistic effect of many built structures, the cumulative impact, is naturally a complicated task. According to the Council on Environmental Quality regulations, cumulative effects are defined as “the impact on the environment which results from the incremental impact of the action when added to other past, present and reasonably foreseeable future actions regardless of what agency or person undertakes such other actions (40 CFR § 1508.7)" (NEPA 1997). A selection of studies including or referring to the cumulative impacts of dams has been listed on the WCD web pages (*http://www.dams.org/kbase/submissions/showsub.php?rec=ENV130*) some of which report promising approaches to the assessment of cumulative impacts in connection with e.g. impacts of dam tailings on dissolved oxygen levels downstream of dams. Modelling has been utilised in some of these studies and has shown encouraging results for assessing impacts as well as mapping potential mitigation measures.

SEI (2002) recommends that the need for Strategic Environmental Assessments be considered and developed for certain sectors, as stated in the Paris Declaration on Aid Effectiveness (OECD-DAC 2005) and recommended in the Strategic Environmental Framework for the Greater Mekong Sub-region, and a set of guidelines developed based on the results of these.

7. CONCLUSIONS AND LESSONS LEARNT

Information on floodplain ecology and functions in general is abundant, detailed studies on ecosystem functions having been conducted in the Amazon floodplains as well as the West African floodplains. However, studies concerning impacts of built structures are not as abundant, with the exception of large dams. A general conclusion is that there has been a marked increase in the awareness of the value of floodplains in past decades, as well as the impacts of constructions in these environments, but there is clearly a gap between this general awareness and the amount of research done on the type, magnitude and consequences of the impacts.

Tropical floodplains are diverse, complex and productive environments where hydrology and the flood pulse determine the seasonal succession. They support high numbers of endemic species. The high fisheries potential in these productive ecosystems is recognised in all tropical floodplains. Recently, other ecosystem services supplied by floodplains have been increasingly appreciated, with the decreasing state of remaining floodplains ones. Floodplains are now ranked amongst the highest valued landscapes in the world.

Increasing human impacts on floodplain areas, including various built structures, has led to flow modification, floodplain habitat alteration or destruction and water pollution, factors also defined as the three main causes for loss of freshwater biodiversity. A built structure rarely occurs in isolation, but rather attracts and induces developments beyond the control of the project developer, potentially causing additional impacts on the environment.

Most studies reviewed, regardless of location, emphasised the importance of the floodpulse and the protection of both lateral and longitudinal connectivity of floodplains. Isolation of the floodplain through e.g. embankments leads to a complete loss of floodplain ecosystem services.

In connection with pre- and post-valuation of tropical floodplain ecosystems, it has been shown that when a floodplain has been “reclaimed” for other uses, such as agriculture, the economic benefits gained rarely reach the same level as the ecosystem services provided by the floodplain when it was intact. Compensating for lost floodplain ecosystem services, such as recession and dry-season agriculture and natural pasture for livestock, is hard, if not impossible, to do through alternative land-uses.

Large dams have caused much discussion concerning their impacts on the environment, both upstream and downstream of the dam. However, any structure causing large-scale hydrological alteration will have many of the same impacts as dams, such as habitat fragmentation, change, deterioration and loss, as well as genetic isolation, changes in biogeochemical processes, impacts on biodiversity and pollution. The water quality changes caused by dams can strongly affect downstream floodplain environments, especially if acting in concert with other structures causing similar, or synergistic, effects. The construction of large dams or other large infrastructure usually attracts further developments, leading to higher pollution loads. The combination of the effect of the dam and the reservoir on the water quality being released downstream, and increased runoff from industry, agriculture and settlements possibly aggravated by erosion caused by these developments, can lead to severe cumulative impacts. These effects will be further exacerbated if the volume of released water is reduced.

Smaller, but numerous, built structures such as the various types of embankments, channels and dikes that are an integral part of most floodplain related livelihoods in tropical floodplains have similar, although more localised effects. The large number of this type of localised flood control construction, as well as canals, small dams and weirs built for irrigation purposes, most probably lead to significant cumulative impacts, which have not been studied to any large extent. Canalization (for e.g. improved navigation) of floodplain rivers is of concern due to the probability of cutting off the lateral connectivity to the adjacent floodplains, causing isolation and subsequent deterioration thereof. Pollution of the water caused by mines, industrial or urban structures can have long-term effects, as illustrated by the mercury pollution of Amazonian floodplains caused by mining activities.

In the Amazon floodplains built structures are still scarce, with the exception of large dams, road and gas pipe constructions. The major impacts of human activities on the *várzea* floodplain forests are classified, with decreasing destructive effects, as: 1. modification of the hydrological regime (e.g. by hydropower dams and navigation channels), 2. large-scale destruction of plant communities, 3. reduction of populations of plant and animal keystone species and 4. pollution. Decreases in fish catch and species richness, as well as significant changes in the species composition due to the disturbance of floodplains were often reported. Most of the documented cases concern very large size projects. The documentation is coloured by the strong opinions of different stakeholders and often refer to mere “enormous impacts” without specifying the type or magnitude of these said impacts. Much attention has been focussed on social impacts since these have, historically as well as presently, been significant and difficult in the case of Latin America.

In Africa less baseline information is available and much of the continent’s water resources have been little studied until the last few decades of the previous century. In most parts of Africa, water availability is sufficient only in the moist equatorial belt. Therefore, water needs for irrigation, domestic and industrial uses have caused the construction of numerous reservoirs affecting the downstream flow and floodplains. Changed hydrological regimes of rivers has adversely affected floodplain agriculture, fisheries, pasture, forests and plant resources that constituted the organising element of community livelihoods and culture. Deterioration of floodplains has in many cases also had a devastating impact on wildlife, which in turn has severely impacted the important tourism industry in Africa. Drought has often exacerbated the negative impacts of built structures affecting floodplains, and much attention has thus been directed toward rehabilitation of the impacted floodplains. Therefore, most of the limited number of projects dealing with the rehabilitation of floodplains to restore former floodplain ecosystem services stem from the African continent.

Positive results in efforts to rehabilitate floodplains through managed flood releases have also been achieved in Africa (e.g. Senegal, Waza Logone and Zambezi floodplains). These rehabilitation efforts have shown that through (artificially) reintroducing floods to a former floodplain environment, it is possible to partly recover ecosystem services lost, while the complete variety of floodplain ecosystem services may be hard to restore.

In Australia five principles concerning the ecosystem processes of tropical wetlands have been recommended to improve the management of floodplains and large river systems. These include avoiding developments that would 1. disrupt the flood pulse, 2. reduce hydrological connectivity, 3. increase the input of nutrients into the water, or 4. disrupt the species composition and 5. disrupt the occurrence of key species of the food webs. Increased use of hydrological models to include connectivity to floodplains, and generally increased collaboration between scientists and management to improve the integration of river, river basin and floodplain management is also recommended.

In Asia severe floods have created much damage to human populations living in very low lying areas, such as Bangladesh, which has prompted applied research into ways of mitigating the hazards of flooding, while simultaneously preserving the beneficial functions of flooding. In this respect there is a pool of experiences from e.g. the Flood Action Plan studies. Different types of flood control structures have repeatedly been proven to impact fish, both in terms of acting as barriers for normal fish movement and migration, as well as decreasing fish diversity. To remedy this situation, a number of specific management and mitigation measures have been formulated and proposed, as well as structural approaches allowing controlled flooding (see chapter 5.4.1.). In India, extensive embankments and dikes along major river channels have caused problems with sedimentation and elevation of river channels, erosion of the riverbanks, and deterioration of the water quality in the *beels*, affecting the important *beel* fisheries.

Guidelines and recommendations for management practices in floodplain environments have been collected from the literature reviewed and presented in chapter 6. Based on these, and on the general knowledge base collected through the literature reviewed, a set of recommendations has been prepared and is presented in Chapter 8.

8. RECOMMENDATIONS FOR ENVIRONMENTAL ASSESSMENT AND MANAGEMENT OF FLOODPLAIN ENVIRONMENTS

Modification of the hydrological regime has been found the first and foremost threat to floodplain ecosystems, based on numerous experiences in tropical floodplains worldwide. Therefore, any structure affecting the all-important hydrology of a floodplain should be assumed to influence the environment, and treated with consequent caution. Most impacts are directly or indirectly combined with aspects of changing hydrological regimes, and cannot be separated from this. Any assessment must take into account impacts on integrative processes such as the flood pulse and alterations to any aspect of it, including the **magnitude, timing, amplitude, duration, modality, smoothness and rapidity of change**. In general, the loss of flooded areas and hydrological connectivity should be minimized.

Another general recommendation concerns the importance of a systematic, professional and serious EIA processes. This entails, amongst other things, accommodating **adequate baseline collection** (to be extended over at least two years) and presenting a comprehensive collection of proposed **mitigation measures** to ensure that these be taken into account in the design phase of the project, rather than later at a significantly greater expense. The incorporation of an **Environmental Management System** (EMS) is a central part of the EIA process and the resulting EMS must be adhered to throughout the project cycle, including the setting of milestones, response plans to detected changes and an evaluation of the functioning of the EMS. Also, **Strategic Environmental Assessments** should be developed for relevant sectors.

The following recommendations have been drawn from the case studies considered in this review:

1. **Indirect impacts** of large-scale construction sites may be enormous in comparison to the actual structure. Land-use change, potentially induced by project activities in the area surrounding the project site, and their impact on the environment should be considered in EIAs.
2. Small-scale canals and natural water channel modifications are possibly the most common type of built structure, and therefore lead to many **cumulative impacts**. Taking these into account in connection with new built structure assessments is of importance.
3. The main causes of freshwater aquatic **biodiversity loss** have been identified as flow modification, habitat alteration, water pollution, introduction of exotic species and over-exploitation of certain species. All these issues are, directly or indirectly, linked to built structures, and therefore EIAs relating to built structures should include a component considering biodiversity issues at as many levels of the ecosystem as possible.
4. In connection with river regulation such as dams, as well as other large structures blocking migration routes and causing fragmentation of habitats, **fish biodiversity** has decreased in most reported cases. In connection with new built structures it is therefore of importance to consider this probable impact at an early stage and prepare mitigation measures during the entire project cycle. Planning of structures should take into account the **movement of fish,** as well as securing the presence of **sanctuaries/protection times**. The design of sluice

gates and other modified passages, should take into account that for many fish an overshot mode regulator is less destructive than an undershot one, while e.g. various designs of turbines for hydropower differ with regard to mortality of passing fish.

5. Lessons learnt have shown that the destruction of floodplains affects specialized artisanal-type fisheries, often operating on a small-scale. This type of **small-scale fisheries** livelihood is very hard to replace and it is therefore of importance to **assess and value** in the course of the EIA process. The spread of invasive plant and animal species (often occurring as a result of changed hydrology or intended introductions of e.g. fish to reservoirs) can lead to surprising and dramatic losses/changes and also affect local livelihoods that depend on other ecosystem goods than fish.
6. When assessing the impact of built structures on e.g. fish catches, it is of importance to **evaluate the distribution of the catches between subsistence fisheries and professional fisheries**. In many cases, it has been shown that e.g. flood control structures have benefited groups of people that have the ability to invest in fish farming, while the opportunities for natural open water fisheries have diminished, either through changes in species composition or fish production in the affected area. Unlike land, floodwater usually belongs to all. Therefore, **the risks connected to reduced floodwater availability are significant especially for non-land owners**, the poorest section of the rural population.
7. The **value of other ecosystem goods**, such as forest and plant resources, pasture, wildlife etc. are often underestimated until these are lost with degenerating floodplain conditions. Even though fisheries are indisputably the most significant resource of the floodplains, other natural resources are of great importance in view of **diversification of food resources and livelihoods**, and often play an important part especially for the poorest people. Also e.g. the value of wetlands as natural purification filters for water is surprisingly high. **The use of integrative approaches, such as the ecosystem approach, is highly recommended in complex environments such as floodplains.**
8. **Valuation of ecosystem services** should be developed and integrated into project planning and EIA procedures. This type of valuation yields figures and a numerical measure that can be integrated into more conventional economic cost benefit analyses of the proposed investment, and allows a more thorough economic analysis of the predicted returns for different investment options.
9. Lessons learnt have demonstrated **the sensitivity of tropical floodplain** environments to **increased nutrient runoff**. Recent research has illustrated the importance of phytoplankton to tropical floodplains in Australia and South America. This has important implications for the management of floodplains. Attention should be directed to the control of water quality changes (nutrients, but also turbulence, herbicides, metals etc.) influencing phytoplankton productivity and species composition of the floodplains, which could have a profound impact on the entire food chain including the species composition of fish.
10. In connection with road construction, it is of importance to assess how to reach a **compromise between construction costs** and the need for including e.g. culverts and other **means to facilitate floodwater flows and the passage of flora and fauna**. In many cases where the needs of the ecosystem functions have not been taken into account during the planning phase of the construction, fitting of culverts has been done at a later stage (and at a significantly higher cost) to e.g. enable fish passage.

11. In connection with any built structure in floodplain areas, the effects of **increased access to the wetlands** should also be assessed. It has been shown that improved access due to lessened flooding, improved road network and consequent increased human habitation in the floodplain areas will inevitably lead to increased destruction of forest resources and habitats through increased commercial activities facilitated by road accessibility. Increased access has also had drastic effects on wildlife due to intensified poaching in areas previously less accessible. Similarly, the newly accessible areas will be subject to new agricultural activities or improved agricultural methods (including irrigation, flood control works, and other infrastructure as well as new crops or varieties), which in turn will cause changes in the hydrology and increased runoff of pesticides and herbicides.

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ANNEX 2: STRUCTURES ANALYSED IN DETAIL

Structure type is classified roughly according to size:

1 = dams and reservoirs

2= irrigation related smaller structures, weirs, regulators, dykes, levees

3= roads, railways, gaspipes, canals, flood control, polders

4= mines and other structures impacting water quality

5= fishing gear

Structure type	Size	Built	Location	Continent	Type of Impact	Main findings	Social Impact	Economic impact	Recommendation	Time of study	Ref
1. 5 Hydropower reservoirs; Kindaruma, Kamburu, Gitaru, Masinga, Kiambere	Kamburu: Area: At upper storage level 15 km^2, cumulative surface area 40 215 km^2.	1968,75, 78, 81, 88	Kenya, Tana River	Africa	Downstream flow and physical characteristics, decreased frequency and magnitude of flooding.	Changes include reduction in area and composition of floodplain grasslands, currently much used for pasture, increasing grazing pressure. Lowering of surface and groundwater, loss of fertile riverbank sediment depositions, reduction in swamps and ox-bow lakes.	Increasing grazing pressure has lead to conflict beween pastoralist and floodplain agriculturalists over land and resource use.	The total costs of the existing dams estimated at nearly 27 mill US$, additional (proposed Mutonga Grand Falls) dam construction 19 mill US$ in flood loss related costs. Over 1 million people have been affected.	Further reservoir construction would lead to a cessation of bi-annual flooding, increasing the net cost of the dam building with 19 mill US$. Dam design options including e.g. constriction of the reservoir and dam to allow for bi-annual flood simulation would lead to a higher economic net value and rate or return.	1994	23
1. Aswan Dam	111 m high, 3600 m long, 43 million m^3, reservoir area 6000 km^2, volume 150-165 km^3.	1902	Nile River, Egypt	Africa	Change in hydrology	Prior to impoundment by the Aswan High Dam tilapia constituted 35% of the fish catch but rose to 75% afterwards, probably due to decrease in current velocity and increased macrophyte growth. Loss of floodplain habitat depresses recruitment of migratory taxa such as mormyrids, cyprinids, characoids, catfish and Nile perch. The number of fish species recorded from the lower Nile has decreased from more than 70 species to between 20 and 30.					81

1. Bakolori Dam		1970's	Nigeria	Africa	Reduction in extent, depth and duration of flooding	Reduction in the area of rice cultivation from 60 to 14% of plots in study area. Corresponding rise in amount of early millet and sorghum. Dryseason cultivation was reduced with up to 73%. Substantial decline in fishing in both dry and wet seasons.	In many villages fishing was stopped altogheter in the floodplain, and in others there was a shift to fishing in the main river channel. Five villages (24%) reported no fish catches at all, eleven reported fish to be of smaller size and twelve the absece of certain species, e.g. Nile Perch. The number of fishermen leaving the villages increased from 33% to 67% after dam closure.	Estimated loss of cropping in the Sokoto Valley in total for wet season - 0.74 and dry season - 3,06 million Naira. (Ref 18) or 7 million US$ (ref 86)	Since dam construction can have important effects on the viability of traditional floodplain livelihoods and bring considerable losses of agricultural and fishery procution downstream, effort should be put into predicting them in advance of dam construction. It is one problem to recognixe adverse enviromental and socio-economic effects, but another to get them taken into account in decision over the future of proposed porjects.		18, 86
1. Cahora Bassa Dam	Area: At upper storage level 2 665 km^2, cumulative surface area 27 675 km^2	1975	Mozambique	Africa	Elimination of flood cycles in the Zambezi River downstream of the dam	After the construction of the dam, the previous floodplains of the Marromeu have ceased nearly completely, and the complex is much drier at the end of the dry season than under natural conditions. The stagnant waterways are infested with exotic vegetation, and intrusion of saltwater. The dessiccation of the floodplain has opened the area to aggressive poaching of wildlife species and widespread frassland fires.					39

1. Construction of dams in northern Cameroon; also Sahelian drought		In past 30 years (1970 onward)	Lake Chad Basin, Nigeria	Africa	Reduction of riverine discharge and floodplain; major reduction in size of Lake Chad, but creation of fringing floodplain; change in species diversity; change in fish migrations & distribution; catch rates stable; increased demand/ prices from nonlocal markets;	The impact of environmental change has been widely characterized in the literature as a drastic decline of the fishery. In this study it is hypothesised that while the nature of the fishery has changed, the total economic value may have remained relatively stable.		No change			44
1. Construction of dams on headwaters; (ii) smaller irrigation dams elsewhere; (iii) Sahel drought (70s/80s)		In past 30 years (1970 onward)	Nguru-Gashua Wetlands, Nigeria	Africa	Reduction of riverine discharge and floodplain; reduction of fish stock size abundance and diversity; falling catch rates; increased regional demand and prices.	The study assumes that the relatively low reduction in economic value of the fishery (11%), in the face of drastic reduction in the aquatic environment, is only a temporary phase. It is anticipated that the fishery in the Nguru-Gashua Wetlands will not be able to sustain the present level of activity, and that it will become overexploited (biologically and economically) in the near future. The situation will be exacerbated by the inability of local authorities to manage water releases from the major headwater dams.		Estimated change in value of fishery -11%			44

1. Construction of Lagdo and Gongola River dam; also Sahelian drought		In past 30 years (1970 onward)	Upper River Benua, Nigeria	Africa	Reduction of riverine discharge, size of annual flood, less inundation of floodplains, reduction of fish biodiversity and stock size; falling catch rates; prices stable; stable local demand	The reduction in the size of the River Benue and its floodplain over 20 years since the construction of the Lagdo Dam upstream in Cameroon, coupled with low and only local demand for the available fish, has produced a fishery of low value to the local economy overall.		Estimated change in value of fishery -96%			44
1. Dam and irrigation constructions in Nigeria		In past 30 years (1970 onward)	Nigeria	Africa	Altered hydrological patterns and drying up of floodplains	Fisheries have been impacted by environmental change, mainly as a result of natural (e.g. Sahel drought) and manmade (e.g. dam construction) disturbance. The impact of change has in all cases led to a reduction in the aquatic environment – rivers and floodplains have been reduced in size, Lake Chad has shrunk and been replaced by a large swamp – and by and large, as a consequence, fish stocks have been reduced in size, diversity and distribution.					44
1. Dam construction for large-scale irrigation			Hadejia Jama-are River basin, Nigeria	Africa	Losses of benefits from intact floodplain system	Agricultural, fishing and fuelwood benefits lost through reduced flooding downstream against the gains from increased irrigation production upstream.		Irrigation benefits can only partially replace the lost benefits from reduced floodplain inundation	Regulated flood releases is the best hope of minimizing further losses of floodplain benefits. Further expansion of large-scale irrigation within the river basin should also be avoided.		24

1. Dam, Brokopondo Reservoir	1500 km^2 reservoir area	1964	Surinam	America	During dam building, vegetation was not cleared which led to deoxygenation of water, affecting the levels of oxygen 110 km downstream of the dam, causing massive fish kills	In tropical areas it may take many decades of even centuries for the organic matter to decay within impounded reservoirs due to the high amount of plant biomass (while in temperate areas this may take just one decade).			Clearing of vegetation in reservoir site in of importance in tropical areas.	1964-1970	76
1. Dams			Sokoto and Rima floodplains, Niger	Africa	Decrease in floodplain area from 100 000 ha in 1960 to 50 000 ha in 2020	Expected loss of production in fish, pasture and acgriculture 50%					72
1. Dams			Hadejia Komadugu, Nigeria	Africa	Decrease in floodplain area from 380 000 ha in 1960 to 38 000 ha in 2020	Expected loss of production in fish, pasture and acgriculture 90%					72
1. Kainji Dam		1968	Niger River	Africa	The flooding of the "fadamas" on either side of the Niger River has been reduced since the construction of the dam.	The fadamas are no longer suitable for fry-season cultivation because soil moisture is insufficient. 50-70% of the surface area of each fadama has been lost for agriculture. Natural soil fertilisation has been significantly reduced, leading to a 20% drop in the rice yields.					86
1. Kainji Dam		1968	Niger River	Africa	Decrease in fish catches after filling of dam	Fish catches from the system were reduced by 30%, and the commercially important Mormyridae were reduced from about 20% of the catch to around 5%.				1970s	107

1. Kainji, Bakolori and Tiga Dams	Kainji Dam: Area: At upper storage level 1 260 km^2, cumulative surface area 32 035 km^2.	1968	Niger River	Africa	Altered flow regime, stabilistation of flow in downstream area of dams, eliminating much of the seasonal inundation of the floodplains.	Fish catches declined to between 39 and 75% of their original values. Changes occurred in species composition, decline of swamp dwelling and herbivorous fish and increase in predators, finally reducing stock as a whole since not sustainable. (4) Productive pools and swamps, previously flooded in the downstream area, became dry (73). Dramatic change in species composition (78).					4, 73, 78
1. Kariba Dam	Area: At upper storage level 5550 km^2, cumulative surface area 20 670 km^2	1958	Zimbabwe/Zambia	Africa	Reduced flood magnitude of the Zambezi River by an average of 24 percent in eight out of ten years (1970–80 period)						
1. Kariba dam	Area: At upper storage level 5550 km^2, cumulative surface area 20 670 km^2	1958	Zimbabwe/Zambia	Africa	flooding of preferred habitat	Labea congoro and Labeo altivelis were important commercial fihses in the Zambezi and abundant in the Kariba area before the closure of the dam. They used to have well marked annual spawning migrations up the tributary rivers. The decline in the Labea stocks after closure of the dam was expected.				1958-1967	73
1. Kariba dam and Cabora Bassa dam	At upper storage level 5550 km^2, cumulative surface area 20 670 km^2 Cahora Bassa: At upper storage level 2	1958 and 1974	Zimbabwe/Mozambique	Africa	Changes in hydrology	"The effects of human activities on wetland and aquatic biodiversity across the Zambezi Basin are still rather speculative when it comes to detailed assessments. The major reason for this is the shamefully inadequate or non- existent baseline data on species composition and abundance; thus an assessment of change deriving from a major			(a) prescribed flood release from Cabora Bassa, (b) opening up by means of culverts or bridges the major channels coming off the main Zambezi River that feed the swamp areas, and (c) ensuring that the forested Cheringoma Plateau which is an		48

	665 km^2, cumulative surface area 27 675 km^2					development, such as a dam, is not possible."			important source of runoff for the southwestern parts of the delta wetlands is not deforested.		
1. Maga dam including 28 km of embankments creating a reservoir and 80 km of dykes along the Logone River to control the flooding of adjoining floodplains to allow rice cultivation and irrigation		1979	Logone River, Cameroon	Africa	These schemes seriously modified the floodplain regime leading to an acceleration of the degradation of the environment caused by drought. These modifications are also thought to have eliminated the flooding of some 59,000 ha of floodplain and seriously reduced another 150,000 ha which were important breeding and nursery areas for fishes.	IUCN Waza Logone restauration project started in 1993. The economic impact of pilot flood releases in 1994 and 1997 was an added value of over 800000$ a year through restoring floodplain goods and services. Relating these changes to further recovery of floodplain ecology and biolgogy showed an incremental economic benefit of between 1,1 million and 23 million US$.		Total catch reduction would be an estimated 6,700 t/yr, total direct lost of 120 US$ million over the 21 years during which the flooding pattern has been significantly affected (1979-2000) (ref 44). Economic costs of flood loss in the Waza Logone regione estimated as 1.31 mill US$/year in pasture losses, 0,47 mill US$/year in fisheries losses, 0,32 mill US$/year in agricluture losses, 0,29 mill US$/year in grass losses and 0,02 mill US$/year in surface supply losses (ref 71)			44. 71

1. Manantali and Diama dams			Senegal valley floodplains, Senegal	Africa	Decrease in floodplain area from 550 000 ha in 1960 to 55 000 ha in 2020	Expected loss of production in fish, pasture and acgriculture 90%. Filling of the reservoir behind the Manantali Dam has reduced the volume and duration of the annual floods, which in turn has diminished the inundation of the flood plain and resulted in weakened ecosystems depending on prolonged seasonal submersion, a reduced area suitable for flood-recession cropping and curtailed groundwater recharge. Diama Dam has been invaded by dense growth of aquatic plants which hamper fishing efforts and access to the water. Reference 107: There was a net loss of 11250 tons (representing approximately 50%) of fish from the system due to intrusion of salt waters and changes in hydrological regime.	The increase in aquatic plant species offer habitat for vectors of water-borne diseases. An explosion of mosquito and snail populations has brought malaria and bilharzial to epidemic proportions.				72, 74, 107
1. Pak Mun Dam	Max height 17 m, total length 300 m.	post 1981	Mekong River, Laos	Asia	Number of fish species declined from 121 fish species in 1967 to 66 species in 1981 and 31 in 1990.	EIA done in 1981 predicted that fish production from the reservoir would increase considerably, while the opposite has happened.	Livelihoods of fish dependent households affected. The number of households dependent on fisheries in the upstream regions declined from 95,6% to 66.7% , but no alternative viable means of livelihood has been identified, requiring financial compensation by the government.	Decline in fishing yields downstream estimated to USD 1,4 million per annum. Upstream losses due to cloosure of Tum Pla Yon traps estimad USD 212000 per annum.		2005	119

1. Reservoirs in the Amazon			Amazon floodplains	America	Migratory patterns of fish	Building of reservoir affected species differently: some seem to be negatively affected by habitat change, while others respons positively. However, a common trend is the decrease in species diversity and abundance of frugivorous species. The impact on the fish community in Tucurui was more severe for migratory species. Five years later the fisheries situation had improved and catches had increased to pre-filling levels, but downriver the fisheries did not show the same recovery probably due to recruitment failure in the absence of floodplain habitat.					40 and refe ren ces ther ein
1. Selenge and Markala Dams, Niver River	Selenge Dam: Area: At upper storage level 409 km^2, cumulativ e surface area 34 900 km^2.	1943 and 1980	Niger River, Mali	Africa	Decrease in highwater level, decrease in flow and duration of flooding, leading to a decrease in recruitment and fish catches	Loss in catches between 1600 to 4000 tons annually due to Markala, 5000 tons (10% of fished volume) since Selenge was built. However, only 2000 tons can be attributed to the dam, while 3000 ton losses are due to drought.	Fishermen have had to pursue complementary livelihood activities such as agriculture, and part of the family may have moved to other parts of Mali or to other countries				25
1. Several dams on the Niger and tributaries			Niger valley floodplains, Niger	Africa	Decrease in floodplain area from 300 000 ha in 1960 to 150 000 ha in 2020	Expected loss of production in fish, pasture and acgriculture 50%					72

1. Tucurui Dam			Brazil	America	Decrease in fish bidoversity in the reservoir, upstream and downstream of the dam	Fish diversity decreased between 30-50 species following impoundment. 11 species have dissappeared in total. Piscivorous species have increased instead of detrivorous species in the reservoir and to a lesser extent upstream of the reservoir.					11
1. Tucurui Dam			Brazil	America	Changes in fish catches	Increase in fish catch in reservoir (from 400 to 3200 tons annually) and upstream (from 400 to 1000 tons) of dam, decrease downstream (wih half, from 1000 to 500 tons annually)					11
1. Tucurui Dam		1984	Brazil	America	Blockage of fish migration, creation of anoxic environments due to decaying vegetation left in the reservoir.	Because of decomposing vegetation in the impoundment, both from remains of the forest left uncut when the lake was filled and from aquatic weeds that proliferated on the surface, the water become acid and anoxic, which rendered the water unsuitable for many fish species.The diversity of fish species declined drastically, with the communities becoming dominated by a few species. While primary consumers had been most abundant, the population of predators exploded immediately after closing: in the first					41 and references therein

						year piranhas (Serrasalmus spp.) made up 40%– 70% of fish caught. The dominance of predators was maintained during the three first years, although some primary and secondary consumers were able to make a partial recovery. The biomass of fish present fluctuated strongly in the first three years: by January 1986 fish biomass had increased to a level above that present prior to closing, followed by a crash in the third year. This is probably due to the predatory fish that made up much of the biomass starving for lack of prey.					
1.Dams			Logone floodplains, Cameroon		Decrease in floodplain area from 1 100 000 ha in 1960 to 660 000 ha in 2020	Expected loss of production in fish, pasture and acgriculture 60%					72
2. Dikes		?	Pantanal, Brazil	America	Attempts to enclose areas of the Pantanal in the Camargo de Correia Island with dikes led to a prolonged moisutre period within the dikes (rather than keeping the water out as expected).	Growth of woody weeds made the area unusable for cattle ranching.			"Floodplain-friendly" philosophies recommended: utilising the unique adaptations and life strategies of organisms originating from floodplain environments.		22

2. Flood control, drainage and irrigation schemes (FCDI)			Bangladesh	Asia	Control of water levels, avoiding rapid inundation and preventing extreme flood events	Benefits to agricultural sector can be significant, while fish production and species richness is lowered by the structures. Fish yields inside a flood control compartment can be 50% lower compared to outside, with up to 25 species of fish absent or less abundant. Biodiversity, measured in fish species richness, was 6-35% lower inside than outside of fully functional FCDI schemes. Lower rates of recruitment of migratory whitefish species whose lateral migrations are obstructed by the embankments is largely responsible for these changes.		Unit value of fish catches inside FCDI schemes dropped with 25% due to changes in stock species composition from white fish dominated to smaller, black fish dominated.	Mitigation measures for the combined impacts of FCDI and incrasing dry season irrigation on fish procuction and biodiversity suggested : 1) improving passage of migratory species, 2) improving production of resident fish species based upon improved sluice gate management and alternative cropping strategies.	1996 onward	27, 28, 32
2. Floodplain levees			River Murray, Australia	Australia	Reduced floodplain connection and area of floodplain inundated				An audit should be undertaken of all floodplain levees and other structures (block banks, roads) that alter the natural movement of water across the floodplain. Unnecessary and illegal levees should be removed as a matter of priority.	2002	31
2. Regulator		1992-1998?	Lohajang River, Bangladesh	Asia	Mortality of hatchlings	Hatchling densities highest in surface layer and near the embankment. Spawning of major carp during first 8-10 weeks of the flood. 44% of fish larvae passing a regulator operated in undershoot mode die within 2 hours, while only 11.8% die if passing in overshot mode.			Fish gates should be overflow and close to shore. Fish passes should be open during spawning time.	1992-1998	1,2, 3

2. Several, including rice irrigation scheme, establishment of embankments and the Maga Dam	30 km long dam, 400 km^2 reservoir (Maga Lake), as well as extensive embankments along the Logone River	1979 onwards	Waza Logone, Cameroon	Africa	Inundated area reduced by almost 30%	Reduction in crop agriculture (floating rice and sorghum, flood recession sorghum. Loss of fisheries, including an esitmated 90% decline in fish yields. Reduction of capacity of the floodplains to provide nursery for fish stocks in the river systems of Logone and Chari. Decrease in dry-season pasture by sedentary farmers and nomadic pastoralist from northern Cameroon as well as neighbouring countires. Loss of plant resources used for construction, beekeeping, handicraft production, woodfuel, wild foods and medicines. Decrease in wildlife populations impacting tourism and subsistence hunting. Reduction in surface water availablitity.	Many families have left the villages to settle in other areas where this influx of immigrants has lead to the over-ecploitation of resources. (Ref 86)	Original value contributed by the flooding (area 3383 ha) was over 19 mill US$, or 3000/km2 flooded area. Economic costs of flood loss of 30% was estimated at -2,4 million US$ per year, including losses in pasture (1.31), fisheries (0,47), agriculture (0,32), grass (9.29) and water supply (0,02). According to ref 86, the watering of wildlife of the Waza National Park amounted to 1.8 million US$ in 1983, fish catches in the surroundings of the park have fallen to less that 10% of former values, the loss of 900 km2 floodplain pasture represents a loss of 2,5 mill US$, and increased migrations by	Flood re-release was recommended and carried out in two pilot releases in 1994 and 1997, resulting in an annual increase in the flooded area of 200 km2 and led to recovery in the number o wildlife, increase in fish production, improvment and extension of pasture and changed agricultural opportunities.	2001	19, 86

								elephants due to vegetational changes has lead to major damages caused by the elephants to hundreds of hectares of agricultural land, amounting up to 850 US$ per farmer.			
2. sluice gates or pumps positioned along earth embankments or levees			Bangladesh	Asia	Dnnual inundation of approximately 2–3 million ha of floodplain in Bangladesh has been either prevented altogether, or controlled.	The reduction in floodplain area is one of the reasons for declining floodplain fisheries in Bangladesh but over-exploitation of inland fish stocks has also been reported					37
2. Small dams for irrigation		between 1965 and 1997	Khammouane, Savannakhet and Champassak provinces, Laos	Asia	Reduced water flow in wet season, increased dry season flows	Significant reduction in riverien habitat area, increased lacustrine and dry-season rice-field areas. Redistribution of catch and fishing effort from riverine to reservoir fisheries. No significant impact on species richness or relative abundance of functional feeding groups. Synthesis: Small to medium scale irrigation schemes in rain-fed rice-farming landscapes have only moderate impacts in fisheries. Changes in agrucultural practices in the wet season are likely to have greater effects on fisheries than dry-season irrigation.				1999-2001	53

2. Weirs			Murray Darling River, Australia	Australia	Mortality of fish larvae	The percentage of fish larvae dying while passing the weir was significantly higher in the undershot weir than in overshot. Both species were affected but golden perch had greater mortality rate while passing.			Based on this and other studies on the impact of different types of weirs it seems that overshot weirs have less damaging effects on fish larvae and hatchlings, compared to undershot weirs creating much turbulence and water velocities.	2004-2005	26
2. Weirs			River Murray, Australia	Australia	Unseasonal flooding, wetlands permanently drowned by weir-pools				In cases where it is not possible in the short to medium term to modify weir heights or flow regime, consideration should be given to installing regulators on important wetlands and operating these structures to mimic natural wetting and drying regimes.	2002	31
2. Weirs for irrigation	Irrigated land area average 155 ha, associated paddy area average 93 ha	between 1965 and 1997	Khammouane, Savannakhet and Champassak provinces, Laos	Asia	Diversion of water flow	Weir schemes had no significant impact on aquatic habitat, but caused significant decline (-36%) in fish catches that was partly explained by fishing effort. Weirs had no effect on species richness, but were associated with a significant increase (+17%) in the relative abundance of omnivores. Synthesis: Small to medium scale irrigation schemes in rain-fed rice-farming landscapes have only moderate impacts in fisheries. Changes in agricultural practices				1999-2001	53

						in the wet season are likely to have greater effects on fisheries than dry-season irrigation.					
3. Constructed canals to bypass the convoluted river channels to facilitate navigation			Barotse floodplain, Zambia	Africa	Vegetation changes, increase of throughflow of flood water reducing the extent of flooding	Reduced flooding significantly reduces breeding grounds for fish, since these are located in the shallowest areas.					14
3. Cuiaba-Porto Velho Highway		1970s	Rondonia, Brazil	America	Increased turbidity, milky color of water	Turbidity was mainly caused by erosion from agricultural activity along the new highway and its feeder roads in the watershed.					6
3. Dredging and excavation of river channel		?	Boro River, Okavango Delta, Botswana	Africa	Increased surface outflow to meet human needs	The dredgning led to significant encroachment of terrestrial plant species onto the floodplain					22
3. Empolderments for water control programs to mitigate flood hazard		after 1980	Chalan Beel Polder D project, NW Bangladesh	Asia	not known	Open water fisheries dropped in the project area from a pre-project 3300 tonnes/year (1980) to a post-project 786 tonnes/year (1992) (-76% in 12 years).				1992	54 and ref ere nce s the rein
3. Empolderments for water control programs to provide flood protection, drainage and irrigation	Empolder ed area 56655 ha, embankm ents for 30,4 km in north-south direction and 25,6 km across.	1978	Chandpur Irrigation Project between Meghna and Dakatia tivers	Asia	Restriction of floodplains, modification of timing and amplitude of flooding. Inhibits movement and migration of fish and prawns. Limits the availability of the floodplain area for grazing, feeding and growth of juveniles of riverine and	Production of floodplain fish was substantially reduced. Prawn species were affected variously, some benefiting form the regulated freshwater environment inside the project, others failed to disperse from inside of project area to outside through the regulator, possibly due to greater velocity of water during the period of operation. Some species received little adverse	Fish consumption has decreased from 36 g/person/day pre-project (1972) to 19g/person/day post-project (1992), and the increase in exported fish from closed water culturing has decreased the intake per capita even more. Especially the			1991	54

					estuarine breeding fish, reduction of the size and quantity of stocks. Destruction of riverine character inside embankments, restricting the passage of fry, juveniles and adults of migratory species. Blocked connection and passge to the Dakatia River.	effects while some riverine species have almost disappeared inside the project area. Also the sex rations of some prawn species have been affected with the ratio of male to female increased. Tidal and estuarine fish have been seriously impacted by blockage of migratory routes. Coastal plain species are favoured by the stable freshwater environment inside the project area. Carp species have decreased inside the project area and the number of carp fingerlings has decreased and become extremely rare in the Dakatia River. *Hilsa ilisha* was found to be able to migrate into the project area through the regulator during the early monsoon season. Closed water fisheries have been impacted favorably by the project, significantly decreasing the number of exodus of fish during high water. 9 out of 47 resident shallow water fish species were beneficially affected while the rest showed no effect. 9 out of 38 jag fish species were benefited. Open water fisheries experienced a net loss in the project area 5343 tonnes/year (-83%).	poorest people in the area have suffered from the decreased open-water fish population and fish catch. Access to flooded lands have been lost due to shrinkage of the floodplains, and much of the open waters have been leased by the government to influential fish farmers. The price of the fish has gone up and cannot be afforded by the poorer people. Decrease in number of fishers was also shown over a 13-year period after the constructions. Catch per fisher within and outside the project areas was 2.55 kg/day and 4,8 kg per day, respectively.				
3. Gas pipeline		2002-2003	Peru	America	Environmental	The construction of			Environmental		15

(720 km) from Amazon to Lima					degradation of pristine, high-biodiversity Amazon jungle area; resettlement and destruction of food and water supplies of indigenous peoples (some voluntarily isolated)	the gas pipe through very remote areas of the Amazon rainforest, including floodplains, has had severe impacts on local people and their livelihoods. The main problem has been the erosion that the clearing of vegetation has had, which has in turn polluted the water and decreased fishing possibilities.			impact mitigation measures are recommended.		
3. Hidrovia, canalization of the Paraguay River		Planned, but now officially cancelled by the Brazilian government but private companies continue building infrastructure for implementation of the hidrovia (Junk 2002)	Pantanal, Brazil	America	Building of the canal will require cutting off natural meanders, deepening of the river channel, buildings to be constructed along the shores and rocky outcrops to be removed.	Changes in the hydrology will be irreversible. Lowering of the river channel depth by 10 or 25 cm could reduce the flooded area by 12 or 32%. In Northern Pantanal there are areas of high fish species diversity which would be affected by this and 40-60% of the species could be eliminated.			Natural capital of the Pantanal should be weighed against the economic benefits derived from the hidrovia construction. The predicted modifications of the flooding regime caused by the construction would not fit within the concept of sustainable development		22
3. Polders protecting rice cultivation through flood control			Bangladesh	Asia	Control of water levels	Catch per unit area was 65-104% higher outside flood control area than inside			Integrated floodplain management options to be introduced to benefit both farmers and fishermen		29
4. Gold mining structures		Late 1970s	Amazon floodplains	America	Mercury pollution of water						9
No Structure, DROUGHT			Niger	Africa	Decrease in inundated surface of floodplain, lost water volumes	Landings of fish show a decrease in production from 87000 metric tons in 1969-79 to 37000 metric tons in 1984-85. Mostly caused by a natural drought, while increased fishing effort did not have an effect on the total of the catches.	Decline in individual catches from 1900kg in 1966 to 740 kg per year in 1989.			1989	62

No Structure, DROUGHT			Sahel	Africa	Pluriannual drought in 1980' affected the fisheries in the central delta of the Niger river	Fish catches declined from 90 000 t yr-1 to 45 000 t yr-1 because of poor rainfall					23

ANNEX 3: QUESTIONNAIRE AND SUMMARY OF REPLIES RECEIVED.

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2. Details

1. Name, contact details (email preferred) and position	
View **Total Respondents**	**23**
(skipped this question)	1

3. Geographic

2. Which floodplain areas are you working or living in/familiar with?	
View **Total Respondents**	**19**
(skipped this question)	5

3. In which country (countries) is the floodplain situated?

		Response Percent	Response Total

Australia	19%	4
Bangladesh	14.3%	3
Bolivia	0%	0
Botswana	4.8%	1
Brazil	**28.6**%	**6**
Cambodia	14.3%	3
Cameroon	0%	0
China (PRC)	0%	0
Dem. Rep. Congo	0%	0
India	9.5%	2
Laos	4.8%	1
Mali	0%	0
Mozambique	0%	0
Nigeria	0%	0
Peru	0%	0
Thailand	4.8%	1
Vietnam	9.5%	2
Zambia	4.8%	1
View **Other Country**	**28.6**%	**6**
	Total Respondents	**21**
	(skipped this question)	**3**

4. Description of floodplain

4. Which of the below illustrates the floodplain environment you are describing? Tick off as many as are appropriate.

		Response Percent	Response Total
Seasonal flooding		**68.4**%	**13**
Monomodal flooding (one time per year)		36.8%	7
Non-Seasonal, unpredictable flooding		5.3%	1
Flush floods of high amplitude		10.5%	2
Large river floodplains with slow, ample and predictable floods		52.6%	10
Várzea		31.6%	6
Igapó		36.8%	7
Flooded forest		52.6%	10
Flooded shrubland		26.3%	5
Flooded savannah (grassland)		15.8%	3
View Other (please specify)		21.1%	4
		Total Respondents	**19**
		(skipped this question)	**5**

5. What are the most significant goods and services provided by the floodplain?						
	Very significant	**Significant**	**Not very significant**	**Not significant at all**	**N/A**	**Response Average**
natural resources in general	47% (7)	**53% (8)**	0% (0)	0% (0)	0% (0)	**1.53**
fish	**78% (14)**	22% (4)	0% (0)	0% (0)	0% (0)	**1.22**
wild vegetables	7% (1)	20% (3)	**40% (6)**	27% (4)	7% (1)	**2.93**
fruit	13% (2)	13% (2)	**53% (8)**	20% (3)	0% (0)	**2.80**
game	0% (0)	15% (2)	31% (4)	**46% (6)**	8% (1)	**3.33**
rubber	0% (0)	0% (0)	15% (2)	**54% (7)**	31% (4)	**3.78**
wood	19% (3)	**31% (5)**	19% (3)	25% (4)	6% (1)	**2.53**
medicinal plants	0% (0)	23% (3)	23% (3)	**31% (4)**	23% (3)	**3.10**
Other ecosystem services such as	17% (1)	**50% (3)**	33% (2)	0% (0)	0% (0)	**2.17**
nutrients and fertile soils for agriculture	40% (6)	**47% (7)**	7% (1)	7% (1)	0% (0)	**1.80**
food for domestic animals	13% (2)	**47% (7)**	13% (2)	20% (3)	7% (1)	**2.43**
food for wild animals	7% (1)	**43% (6)**	29% (4)	14% (2)	7% (1)	**2.54**
transportation/navigation	25% (4)	**31% (5)**	19% (3)	25% (4)	0% (0)	**2.44**
recreational and aesthetic value	20% (3)	**40% (6)**	**40% (6)**	0% (0)	0% (0)	**2.20**
ecotourism potential	29% (4)	**50% (7)**	21% (3)	0% (0)	0% (0)	**1.93**
flood control	21% (3)	**57% (8)**	14% (2)	7% (1)	0% (0)	**2.07**
groundwater replenishment	15% (2)	**54% (7)**	15% (2)	0% (0)	15% (2)	**2.00**
					Total Respondents	**19**
					(skipped this question)	**5**

5. Built Structures

6. Have any structures been built in the floodplains? Which ones and when, and for what purpose?	
View **Total Respondents**	**15**
(skipped this question)	**9**

7. Has an Environmental and/or Social Impact Assessment been done before building? If so, do you think it has adequately addressed the potential or actual effects of the built structures on fisheries and floodplain ecosystems? If not, why? What improvement(s) would you suggest?	
View **Total Respondents**	**14**
(skipped this question)	**10**

8. Have you recorded or heard of any positive or negative impacts of these structures that have affected the

	Response Percent	Response Total
environment (e.g. flow of water, changes in water quality, silting or turbidity, changes in animal and plant species occurring)	91.7%	11
fish (species, numbers or areas of occurrence) and the fisheries (number or composition of catch, fishing areas) in the floodplain area	**100**%	**12**
livelihoods of local people in the floodplain area	83.3%	10
socio-economy of the area	58.3%	7
management of the fisheries	66.7%	8
View Other (please specify)	16.7%	2
Total Respondents		
(skipped this question)		

9. Please describe and, if possible, quantify the impact(s).	
View **Total Respondents**	**11**
(skipped this question)	**13**

10. Can you recommend a way or alternatives for the built structure mentioned, that would have less environmental or social impacts, but would still serve its purpose considering the special challenges of a floodplain environment? Please describe here. You can also point to documents recording these impacts, and recommendations, here.	
View **Total Respondents**	**11**
(skipped this question)	**13**

ANNEX 4 PERSONS CONTACTED FOR INFORMATION ON FLOODPLAIN RESEARCH

	Name	Date	Study area	Affiliation	Reply	Notes	Questionnaire link sent
1	Gertjan De Graaf	26.4	Bangladesh	Nefisco			X
2	Felix Marttin	26.4	Bangladesh	FAO	X	Sent articles	X
3	Professor Shinji Tsukawaki	2.5	Cambodia	Uni Kanazawa	X	Sent articles	X
4	Dr Klement Tockner	2.5	Global	EAWAG/ETH	X	Sent articles	X
5	Professor Robin Clarke	2.5	Brazil	Uni Rio Grande do sul, Brazil	X	Sent articles	X
6	Terry Boyle	2.5	Brazil (Plata basin)				X
7	Robert Naiman	2.5		Uni Washington	X	No work on floodplains	X
8	Professor Bill Adams	2.5	Nigeria	Uni Cambridge	X	Sent articles	X
9	Dr Wolfgang Junk	3.5	Amazon	Max-Planck Institute for Limnology	X	Sent articles	
10	David Dudgeon	3.5	Asia	Uni Hong Kong	X	Sent articles	X
11	Mauro Ruffino	3.5	Amazon	Coordinator of ”ProVárzea”	X	Sent articles	X
12	Virginia Dale	3.5	Americas	Oak Ridge National Laboratorium, USA	X	Sent articles	X
13	Jukka Käyhkö	5.5	Amazon, Africa	Uni Turku	X		X
14	Risto Kalliola	5.5	Amazon	Uni Turku	X		X
15	Petteri Alho	5.5	Global	Uni Turku			X
16	Roberta Lossio	8.5	Latin America	Independent consultant	X		X
17	Aarnyak project	9.5	India, Brhamaputra			Reply from Partha Yoti Das, busy but will contact later	X
18	Kaziranga Protected Forests Project	9.5.	India				X
19	Dr Paul Loth	12.5	Nigeria	Uni Leiden		Acquired elsewhere	X
20	Dr Lee Baumgartner	12.5	Australia	Dep of primary industried, Australia	X	Sent articles, would like to see report when finished	X
21	Professor Isaacman	15.5	Cahora Bassa, Mozambique	Uni Minnesota		Acquired elsewhere	X
22	Brian Marshall	15.5	Zambezi Basin				X
23	Jonathan Timberlake	15.5	Zambezi Basin	Kew Gardens, London	X	Sent CD ROM with Zambesi biodiversity book	X
24	R. Cunliffe	15.5	Zambezi				X

			Basin				
25	Olivier Hamerlynck	15.5	Senegal, Africa	IUCN	X	Sent links to articles	X
26	Madiodio Niasse	16.5	Senegal, Africa	Independent consultant	X		X
27	'Rafael Herrera Fernández'	16.5	Brazil, Venezuela				
28	Atossa Soltani	17.5	Camisea, Peru				X
29	Robert Montgomery Head	17.5	Americas	Environment and Social Unit , IADB, USA	X	Busy but will reply later	X
30	Mr Holt-Giménez	17.5	Amazon	BIC			X
31	Mr George Lukacs	17.5	Australia	Australian Centre for Tropical Freshwater Research	X	student Vern Veitch replied	X
32	Tonje Folkestad	17.5	Global dams	WWF			X
33	Mr Welcomme	19.5				Email not working	X
34	Dr Ashley S. Halls	22.5	Bangladesh	Aquae Sulis Ltd	X	Sent articles	X
35	Dr Sandra Kloff	24.5	Senegal, Mauritania	IUCN			X
36	Dr Shumway	5.6	Africa	Edgerton Research Laboratory New England	X	Will send publication	
37	Dr Frank Farqharson	15.6	global	Water Resources, CEH, UK	X		
38	Judith .Rosales	15.6	Orinoco, Venezuela	Uni Guyana	X		
39	Dr Maria Piedade	15.6	Amazon	INPA	X		
40	Karl Wantzen	16.6	Amazon Pantanal	Uni Konstanz	X		
41	Dr Kai Lorenzen	18.6	Amazon, Mekong	Imperial College London	X		
42	Ulrich Saint-Paul	18.6	Amazon, Vietnam	Center for Tropical Marine Ecology Bremen	X		
43	Dr. Michael Douglas	18.6	Australia	Charles Darwin University	X		

Additional information especially concerning the Mekong received from Matti Kummu (selected articles by Lamberts etc), Marko Keskinen (CD ROM with literature, plus fisheries database), Eric Baran, Sophie Nguyen Khoa and Yumiko Kura (World Fish Centre/Phnom Penh)