

Blue Harvest

Inland Fisheries as an Ecosystem Service

UNEP 2010. **Blue Harvest: Inland Fisheries as an Ecosystem Service.** WorldFish Center, Penang, Malaysia

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Programme 2010

ISBN: **978-92-807-3112-5**

Job Number: **DEP/1316/NA**

Printed by UNON, Publishing Services Section,
Nairobi , ISO 14001:2004-certified

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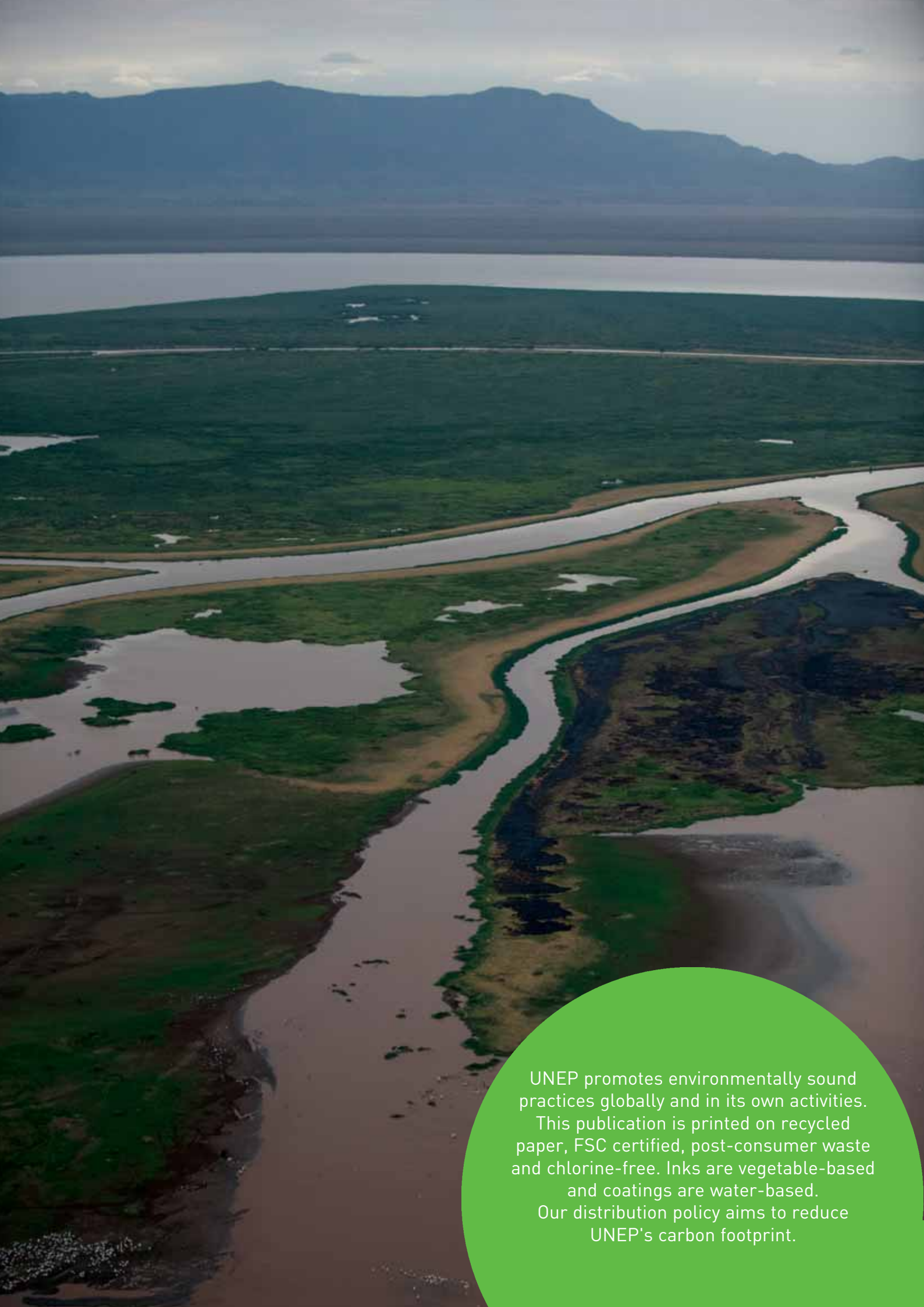




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Inland Fisheries as an Ecosystem Service





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Foreword



Discussions surrounding the future of fisheries invariably focus on marine catches from the world's seas and oceans.

Here, UNEP and the WorldFish Center are spotlighting the significant contribution of inland fisheries to diet, health and economies. The future of these fisheries is intimately linked with the way humanity manages or mismanages its rivers and lakes and their surrounding basins.

Marine fisheries are being over-fished, mainly as a result of over-exploitation fuelled in large part by global subsidies totalling somewhere under US\$30 billion.

Freshwater stocks, especially in developing countries, face a series of additional challenges, from dam construction and low river flows to run-off of chemicals from the land and the impact of alien invasive species. Managing healthy fisheries must focus on managing the health of the ecosystems that create the conditions for fish in the first place.

Loss of species and the rapid erosion of nearly all types of ecosystems worldwide are accelerating: freshwater fisheries are part of this unsustainable trend.

The missing link, in terms of a decisive response, is perhaps the economics: in the past the multi-trillion dollar services provided by nature have been all but invisible in national and global accounts.

The Economics of Ecosystems and Biodiversity (TEEB), a partnership hosted by UNEP, is now bringing the true value of the world's nature-based assets from the invisible into the visible spectrum.

This report, *Blue Harvest: Inland Fisheries as an Ecosystem Service*, contributes to the TEEB process. For example, researchers estimate that around a third of global, small-scale fish catch comes from freshwater, inland fisheries.

The catch from the Mekong River is worth over US\$2 billion annually. Globally, over 60 million people are employed, of which over half are women. Meanwhile, these stocks are a key source of the protein and micronutrients essential for a healthy diet.

Thus these fisheries are making an important contribution in developing countries to achieving the poverty-related Millennium Development Goals.

This report, commissioned as a contribution to the 10th Conference of the Parties to the Convention on Biological Diversity taking place in Nagoya, Japan, not only underlines the value of freshwater fisheries but provides guidance on how the ecosystem approach can be applied in order to sustain future harvests.

The world is facing a suite of persistent and emerging challenges, from climate change and food insecurity to loss of biodiversity: these are set against the backdrop of a global population rise to over nine billion by 2050.

These challenges can only be met by a transition to a low-carbon, far more resource-efficient, and employment-generating Green Economy. Investing and re-investing in the planet's ecological infrastructure, including freshwater ecosystems and the fisheries and other services they provide, will in large part define whether that urgent and fundamental transition can be fully realized.

Achim Steiner

UN Under-Secretary General and
UN Environment Programme Executive Director



Executive Summary

Global food production has increased greatly in recent years and rural livelihoods are much improved in many regions. Yet, despite this clear progress rural poverty and food insecurity remain deeply entrenched in many areas, especially in South Asia and sub-Saharan Africa. In response the international community has renewed calls for increased commitment to meeting the needs of the world's poor.

Simply producing more food however is not enough. Rather this needs to happen in ways that sustain the ecosystem services that support rural livelihoods and provide wider benefits to rural and urban communities. This is a particular challenge for management of the world's freshwaters and for the ecosystems that depend upon these. To help inform future approaches to conservation and management of freshwater ecosystems the present assessment reviews the importance of inland fisheries as an ecosystem service, the pressures upon them, and management approaches to sustain them.

The world's rivers and lakes support globally important inland fisheries. In Europe, North America and Australia these are today mainly used for recreation, but in Africa, Asia and Latin America their primary value is in providing food and employment for tens of millions of people. They provide 33% of the world's small scale fish catch and employ over 60 million people, of whom 33 million are women. China, Bangladesh, India and Myanmar are the four largest producers with a total harvest of 5.1 million tonnes. Another 16 countries (Uganda, Cambodia, Indonesia, Nigeria, Tanzania, Brazil, Egypt, Thailand, Democratic Republic of Congo, Russia, Philippines, Vietnam, Kenya, Mexico, Pakistan and Mali) produce over 100,000 tonnes each. Some river basins are especially important with the lower Mekong producing 2.1 million tonnes of wild fish. This catch is worth over US\$2.1 billion at first sale and over US\$4.2 billion on retail markets, and supports millions of livelihoods throughout the basin.

The supply of fish from inland waters is critically important for human nutrition, especially in Africa and parts of Asia. Over 200 million of Africa's 1 billion people regularly consume fish and nearly half of this

comes from inland fisheries. In the countries of the Lower Mekong Basin freshwater fish provide the main source of protein and micro-nutrients for 60 million people.

The continued supply of benefits from inland fisheries is dependent on the health of the ecosystems upon which they depend. As rivers have been dammed and lakes and waterways polluted, inland fisheries have declined, yet growing demand for the world's freshwater resources will increase these pressures further in coming years. There is therefore an urgent need for major investment in policy and management approaches that address the direct and indirect drivers of aquatic ecosystem degradation and loss of inland fisheries taking into account their role in sustainable development and human well being.

The UNEP Ecosystem Management Programme (UNEP-EMP) provides an effective framework for pursuing this challenge. It does so by incorporating the principles of the ecosystem approach presented in the Convention on Biological Diversity and providing a framework for the holistic management of ecosystems. It gives particular attention to the links between ecosystems and human well being and the need for proper ecosystem functioning to allow for the delivery of ecosystem services. The UNEP-EMP uses a participatory diagnosis as the entry point followed by adaptive management as the focus for investment, and provides a path to sustained delivery of provisioning services such as fisheries. More specifically the FAO Code of Conduct for Responsible Fisheries also promotes an ecosystems approach that complements the UNEP-EMP. The policy implications of this integrative ecosystem approach to inland fisheries include the need to:

- **Ensure participation.** Effective engagement of key stakeholders is essential for success. All constituencies that impact on fisheries need to be engaged, especially those concerned with land and water management, and economic development such as energy, trade and agriculture. Similarly coalitions of interest should be developed with stakeholders in other sectors that draw upon other services provided by aquatic ecosys-

tems, including water supply, conservation and tourism.

- **Agree future scenarios.** Stakeholders need to agree upon future scenarios and management objectives for each fishery and the ecosystems that sustain them. Unless this happens it is unlikely that there will be any real progress towards sustaining these resources, regardless of how well the drivers of change are understood. This stage of the diagnosis needs to embrace the social and political dimensions of fishery and ecosystem management, and bring together different social, economic, and institutional perspectives. In doing so it needs to confront the power relations between and within stakeholder groups and work to develop scenarios that recognise the costs and benefits to different stakeholders of different management options.
- **Manage for resilience.** The ecosystem approach recognises the limits to proactive management. Because multiple drivers impact inland fisheries and there are complex interactions between these, it is rarely possible to identify all drivers and tease out multiple impact pathways for each fishery. As a result managing these systems can be a very uncertain 'science', and one that requires investment to maintain resilience and multiple options for future use of these ecosystems. Underlying this approach is explicit recognition that resilience is fostered by investments that maintain ecosystem functioning, reduce vulnerability, and build adaptive capacity in the face of unforeseen and unforeseeable threats.
- **Pursue adaptive learning.** The complexity and variability of ecosystem processes is added to by the often complex social and institutional environ-

ments within which management processes take place. Successful management of inland fisheries needs to embrace this complexity and adopt an effective process of adaptive learning that adjusts management practices and policies in response to the results achieved.

- **Plan and manage catchments for inland fisheries.** The ecosystem approach highlights the importance of sustaining ecological processes that sustain fisheries productivity. This means investing in maintaining healthy catchments with appropriate land use and coverage of natural forest and wetland ecosystems, and sustaining the quality and quantity of water flow into lakes and rivers. Doing so requires engaging with land and water management processes at multiple scales within these lake and river basins. A number of approaches are available to assist with this engagement, but three of the most valuable are strategic environmental assessment; integrated planning at the basin scale; and design of environmental flow regimes for fisheries.

In support of this approach, five investments are recommended:

- Improve understanding of inland fisheries' vulnerability to environmental change
- Develop viable options for addressing the threats posed to inland fisheries by environmental change
- Build adaptive capacity among key stakeholder groups to increase resilience of inland fisheries at local, national and regional scales
- Improve governance of inland fisheries and their ecosystems
- Develop capacity to sustain and enhance social benefits from these resources.



Contents

- 3 Foreword
- 5 Executive Summary
- 8 Introduction
- 13 Chapter 1: Inland Fisheries: Ecosystem Services and Human Well-being
- 24 Chapter 2: Environmental Change and Inland Fisheries
- 44 Chapter 3: Managing for Sustainability of Inland Fisheries
- 52 Chapter 4: Investing in the Ecosystem Approach to Inland Fisheries
- 54 Glossary
- 56 Acronyms
- 57 References
- 63 Acknowledgements



Introduction

Global food production has increased greatly in recent decades and rural livelihoods are much improved in many regions. Despite this clear progress rural poverty and food insecurity remain deeply entrenched in many areas, especially in South Asia and sub-Saharan Africa, and there is growing recognition that new impetus is needed to meet this challenge (Lele et al., 2010). Doing so effectively will require not just providing more food, but doing so in ways that sustain the natural resource base upon which people depend for their livelihoods, while maintaining the ecosystem services that provide additional benefits to rural and urban communities. This is a particular challenge for the world's freshwaters that are in great demand for agricultural, domestic and industrial uses, and for the inland fisheries that depend upon a sustained supply of freshwater. To help inform future approaches to conservation and management of freshwater ecosystems the present assessment reviews the importance of inland fisheries as an ecosystem service, the pressures upon them, and management approaches to sustain them.

Ecosystem services

Human well-being depends on healthy ecosystems. We rely upon them for the air we breathe, the food we eat, the water we drink, and many other dimensions of life as we know it (Daily, 1997). We call these benefits 'ecosystem services' and their continued provision for the benefit of humanity is a growing concern for UNEP, national governments and the wider international community.

In 2005 the Millennium Ecosystem Assessment (MA, 2005a,b) analysed 24 ecosystem services and concluded that 15 were degraded or used unsustainably. This decline in services affects the world's disadvantaged people most strongly, presents a considerable barrier to reducing poverty and hunger, and impedes sustainable development globally (*ibid.*).

The Millennium Ecosystem Assessment grouped ecosystem services into four categories:

- **Provisioning services** such as the supply of food and water;
- **Regulating services**, which help to stabilize ecosystem processes such as climate and water storage and purification;
- **Supporting services**, including solid formation and nutrient cycling; and
- **Cultural services**, such as recreational, spiritual, religious and other non material benefits.

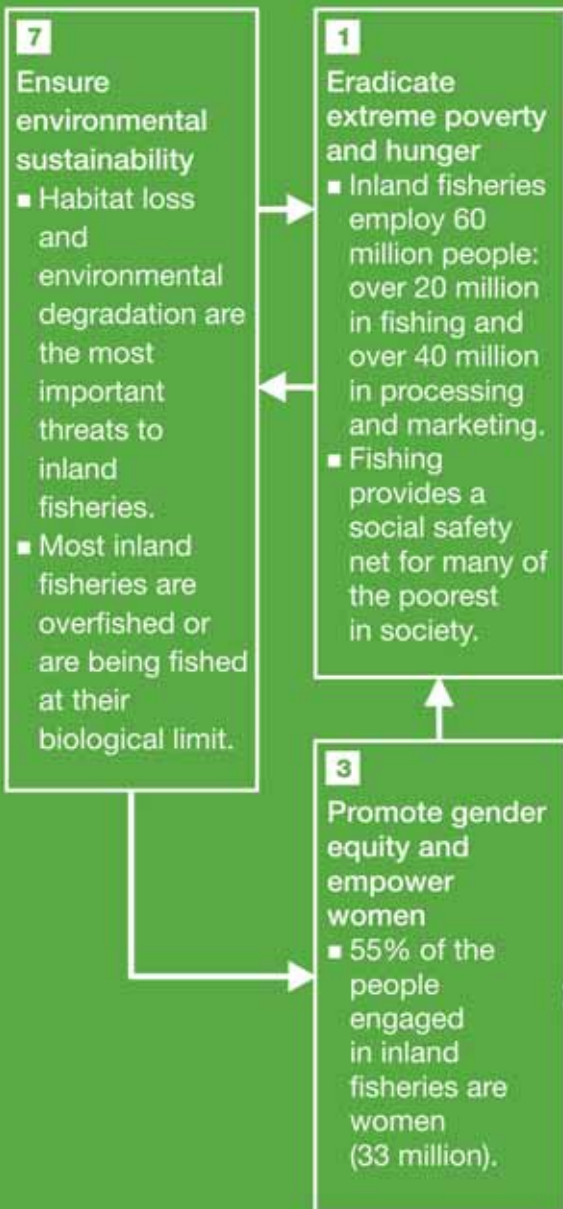
Many of these services have been degraded over the past 50 years, and business as usual will see this continuing with enormous social and environmental costs (MA, 2005a,b; Daily, 1997). To help redress this current trend towards decline of ecosystem services UNEP is focusing growing attention upon building awareness of the importance of ecosystem services and upon developing the ecosystem management capacity required to sustain them (UNEP, 2009). The present assessment contributes to this work by examining inland fisheries as an example of a provisioning service, the threats they face, and the actions required to sustain them. In this International Year of Biodiversity, the assessment illustrates the importance of biodiversity in supporting ecosystem services. It also highlights the many ways through which inland fisheries contribute to improving people's well-being and to achieving the Millennium Development Goals (Fig. 1).

Inland fisheries as a provisioning service

Provisioning services are the products ecosystems provide, of which freshwater and food are two of the most important (Fig. 2). Fish are in turn one of the most valuable wild foods provided by ecosystems and for many communities are a key component of both diet and income. For example, in Cambodia 80% of the 1.2 million people living around Tonle Sap use the lake and its rivers for fishing, and fish consumption in Cambodia is approximately 32 kg per person per annum (Hortle, 2007), compared to a global average of 16 kg (FAO, 2006).

In recent years marine fisheries have received great international attention because of widespread over-fishing and severe declines in stocks (Pauly et al., 2005). In comparison inland fisheries have received little attention, in part because their total harvest is lower than for marine fisheries, but also because they

Direct linkages



Indirect linkages



Figure 1. The role of inland fisheries in improving human well-being and achieving the MDGs (numbered 1-8) (after Heck et al., 2007). Investments in management of inland fisheries can yield direct positive impacts on poverty and hunger, on environmental sustainability, on gender equity, and empowerment of women; these can also in turn contribute to achieving improved primary education, maternal health, reduced child mortality, and reduced impacts of HIV/AIDS, while also building global partnerships for development.

are more dispersed, less easily monitored, and generally less well documented. Today however, this is changing with growing understanding of the local, national and regional importance of many inland fisheries, and improved recognition of the rising environmental challenges they face. In contrast to marine fisheries where overfishing is generally the primary concern for the future of fish stocks, environmental pressures are generally the most critical threats facing inland fisheries (FAO, 1999, 2003; Welcomme and Petr, 2003). This is especially so for rivers which contribute more than half the total catch for inland fisheries, yet are highly vulnerable to changes in land and water management in their catchment. The present assessment examines both the value of these fisheries and the threats they face.

The assessment focuses on rivers, lakes and their associated wetland ecosystems, as these provide the majority of inland fish catch (see for example Welcomme, 2001). In doing so, the assessment pays particular attention to natural rivers largely unimpeded by dams and natural lakes, and has not focused on artificial reservoirs or hydrodam impoundments. These are highly modified aquatic environments and their creation normally leads to the degradation and loss of the fisheries that depended upon the natural freshwater systems before

impoundment. An overview of reservoir fisheries is provided by Cowx (2002). Similarly aquaculture has not been dealt with here as this is dependent on extensive modification of natural ecosystems and generally places demands on ecosystem services, rather than providing them. A detailed analysis of the environmental footprint of aquaculture is to be provided by Hall et al. (in prep.).

The primary geographical focus of the assessment is Africa and Asia which together account for over 90% of the inland fish catch worldwide (calculated from FishStat plus, 2010), and where the direct dependence on inland fisheries and human well-being is highest. It is also in these regions that the threats to inland fisheries are greatest and where the largest losses are likely to occur in future decades if effective environmental management is not pursued. Comparative information is provided for other regions where available and appropriate.

As with many other ecosystem services, information on inland fisheries is very variable in quantity and quality. For example, while information on total inland fish catch is available for most countries, these official data often represent only a small percentage of the catches that have been recorded through more detailed studies. Because much of the inland catch

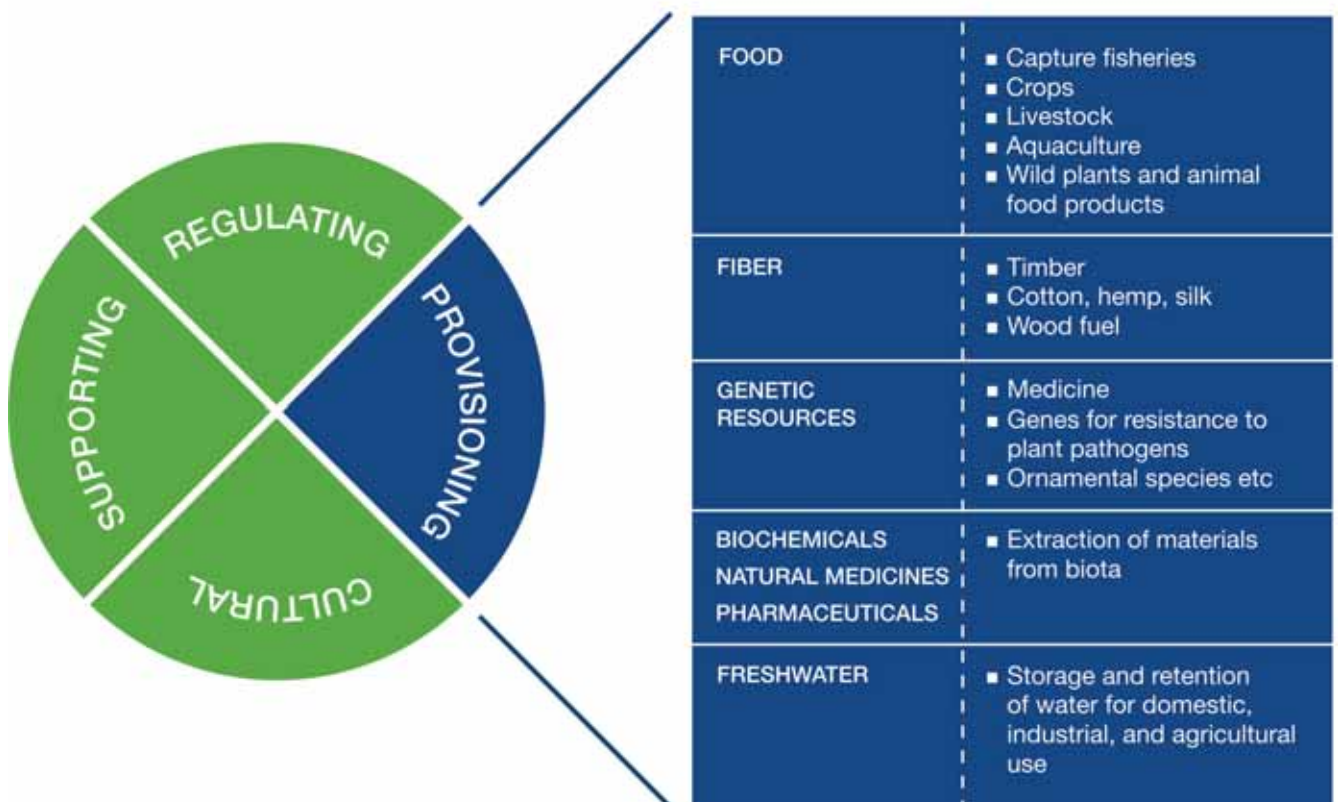


Figure 2. **The four categories of ecosystem services, and examples of provisioning services** (after MA, 2005a).

includes artisanal and illegal fisheries, and because landings are dispersed, actual catches are believed to be some 2-3 times larger than official statistics indicate (FAO, 1999, 2003; Allan et al., 2005, Welcomme et al., 2010). The present analysis has therefore limited use of national data to providing an initial global overview of inland fisheries, and more emphasis is instead placed on case studies from individual fisheries, where detailed studies over several years have provided better quality data.

Ecosystem services, human well-being and drivers of change

The current contribution of ecosystem services to human well-being, and future changes in benefits derived from these ecosystem services, is influenced by a series of direct and indirect drivers (Fig. 3). To examine these drivers of change in inland fisheries the

assessment draws on recent analyses of some key drivers of freshwater ecosystem health and, by extrapolation, of inland fisheries. Building upon this, case studies illustrate key drivers in selected fisheries.

Ecosystem management to sustain inland fisheries

The assessment concludes with an analysis of innovations required to sustain aquatic ecosystems health and the fisheries they support. In doing so, it draws from the ecosystem management approach promoted by UNEP, the Convention on Biological Diversity, FAO and other international bodies, and complements this with new information where appropriate. It concludes with a set of recommendations on policy and management investments that can help sustain inland fisheries and enhance the lives of the people who depend upon them.

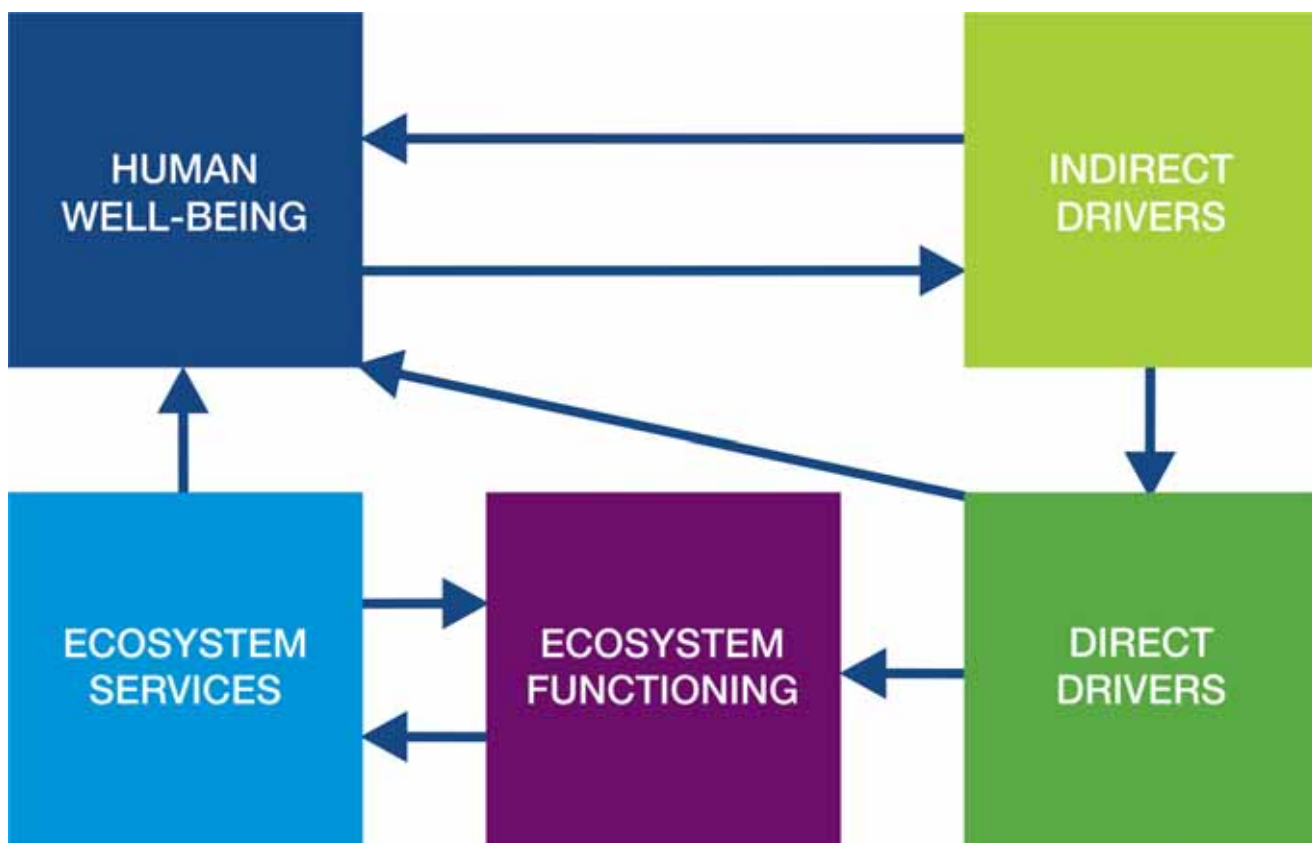


Figure 3. **Human well-being and ecosystem services framework** (source: MA, 2005; UNEP, 2009). Direct drivers enhance or diminish ecosystem services by altering ecosystem functioning and consequently the quantity and/or quality of services that these ecosystems provide. For example, abstraction of water for industrial, domestic or agricultural uses diminishes instream water flow. This in turn reduces the productivity of wetland ecosystems downstream and so diminishes the production and catch of fish dependent upon this. Indirect drivers include the demographic, economic, socio-political and technological changes that in turn increase or decrease direct drivers. So increases in population within a river basin leading to increase in water demand will impact river fisheries downstream. In the same way, the absence of effective participatory governance and consequent omission of downstream communities from decision-making regarding water allocation can lead to increased withdrawals upstream and consequent impacts on fisheries downstream.



Chapter 1:

Inland Fisheries: Ecosystem Services and Human Well-being

A globally important resource

All of the world's major rivers and lakes support important fisheries, or have done so in the recent past. In Europe, North America and Australia these are today primarily of importance for recreation. This generates direct income through the sale of national fishing licenses and permits for the right to fish in specific sites, and substantial secondary income through production and sale of fishing equipment, bait supply, boat rental, guiding, accommodation, travel and many other services. For example in 1996 35 million people in the US (18% of the US population 16 years of age and older) spent US\$38 billion on fishing in freshwaters or 0.5% of GDP (US department of the Interior, Fish and Wildlife Service, 1997). In the European Union there are an estimated 25 million anglers, many of whom fish in freshwaters. Their

direct and indirect expenditure on recreational fishing is estimated to exceed US\$8 billion (EAA, 2004).

In Africa, Asia and Latin America however the primary value of inland fisheries is in providing food and employment to tens of millions of people. A recent assessment of small scale fisheries (BNP, 2008) has documented this importance and shown how inland fisheries play a disproportionately large role in providing employment, especially for women. Thus, while inland fisheries in developing countries provide only 33% of the world's small scale fishery catch according to existing FAO statistics (FishStat plus, 2010), they provide employment to 60.4 million people, 56% of all people and 55% (approximately 33 million) of women in developing countries who work in small scale fisheries (Table 1).

Table 1. **Production, utilisation and employment estimates for small-scale fisheries for developing countries** (adapted from Mills et al., 2010).

Benefits from small-scale fisheries	Marine	Inland	Total
Production and utilisation			
Total annual catch (million tonnes)	28	14	42
Annual catch for domestic human consumption (million tonnes)	23	13	36
Annual catch for domestic consumption as share of total catch	83%	94%	87%
Annual catch per fisher (tonnes)	2.3	0.7	1.3
Employment			
Number of fishers* (million)	12.4	20.7	33.1
Number of post-harvest jobs** (million)	34.6	40.7	75.3
Total employment (million)	47	60.4	108.4
% of women in total workforce**	36%	55%	47%

* Full-time and part-time only (i.e. not occasional/subsistence and short-term seasonal).

** Includes full-time and part-time employment in the post-harvest sector.

The scale and value of inland fisheries

FAO data show the officially recorded inland fish catch to be 10 million tonnes globally (FAO, 2009), although detailed analysis from a few countries raises this to 13 million tonnes (BNP, 2008), and FAO's estimates of under-reporting (FAO, 1999, 2003) suggest that a more accurate figure is 20-30 million. The official global catch has grown steadily since 1950 but is now levelling off (Fig. 4). Asia produced 66% in 2008, Africa 25% and Latin America 4%. China, Bangladesh, India and Myanmar are the largest producers (Fig. 5a) with a total harvest of 5.1 million tonnes. Another 16 countries (Uganda, Cambodia, Indonesia, Nigeria, Tanzania, Brazil, Egypt, Thailand, Democratic Republic of Congo, Russia, Philippines, Vietnam, Kenya, Mexico, Pakistan and Mali) all report catches over 100,000 tonnes each; together these top twenty countries produce over 8.7 million tonnes, representing 85% of officially recorded global production.

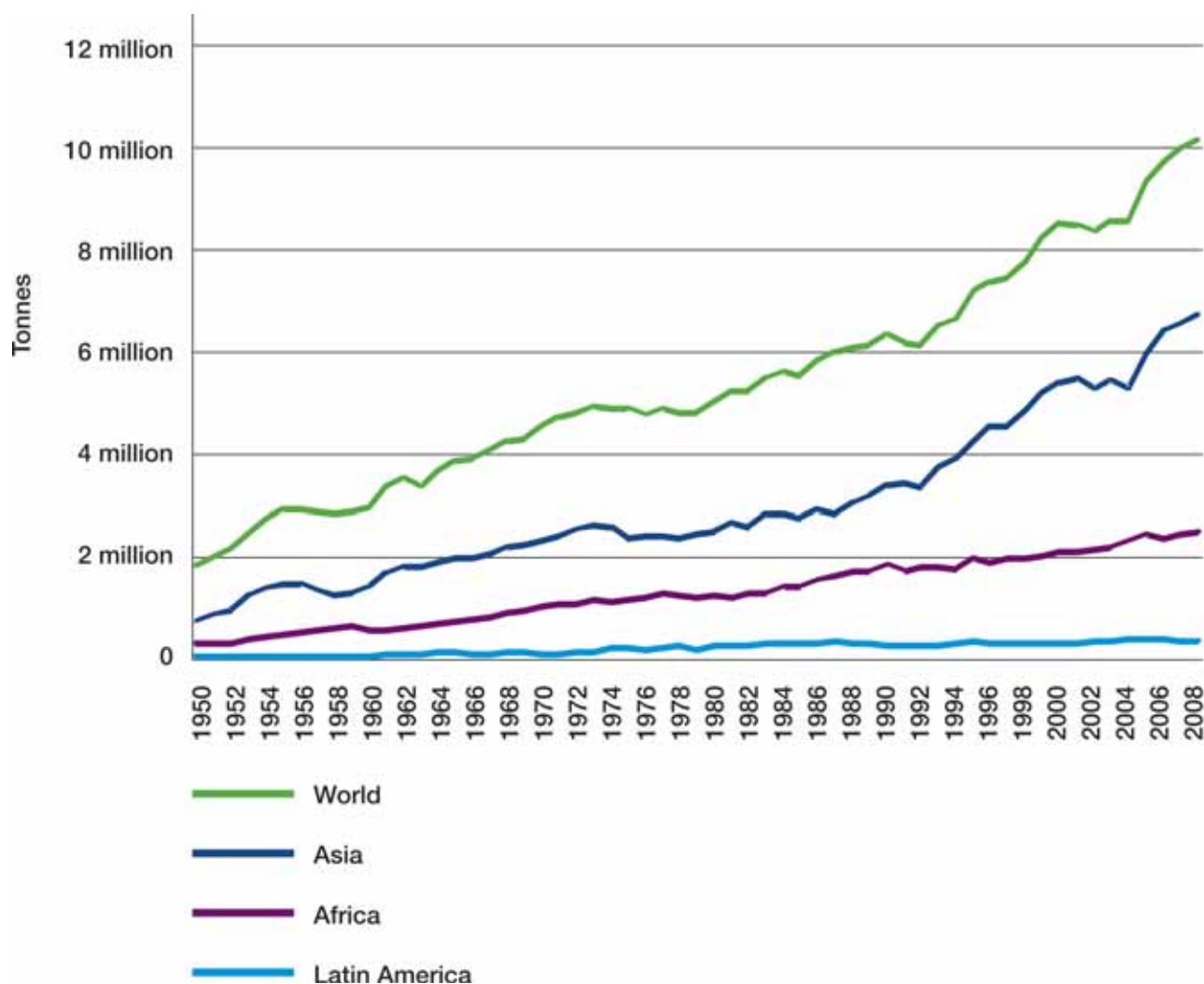
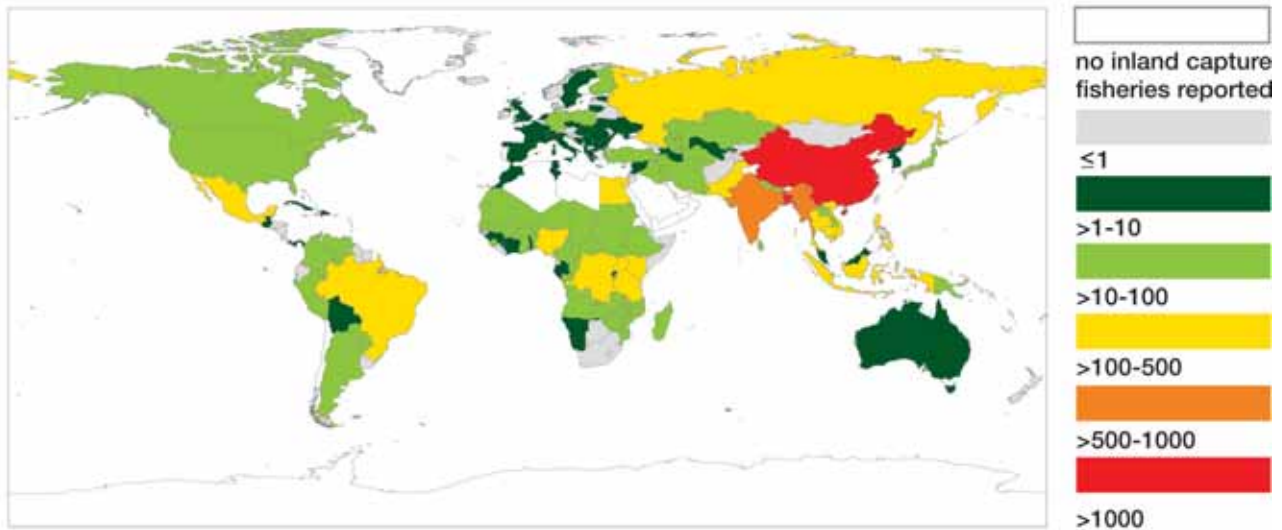
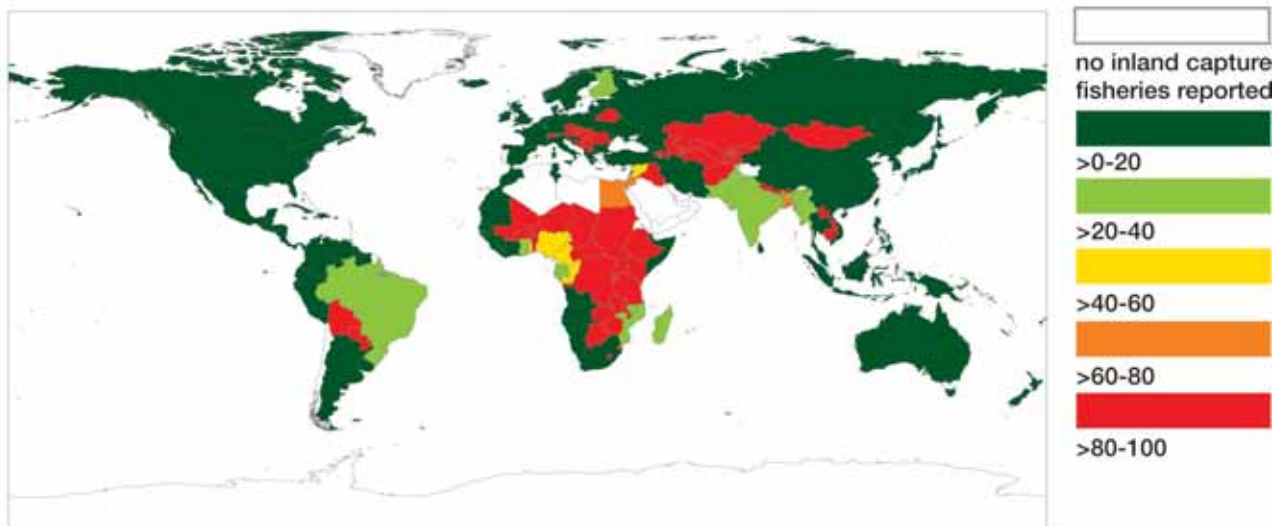


Figure 4. **Inland fisheries production 1950-2008** (source: FishStat plus; data include artificial lakes).

(a) Total inland capture production (thousand tonnes)



(b) Inland capture production as a proportion of total capture (%)



(c) Production (kg per capita)

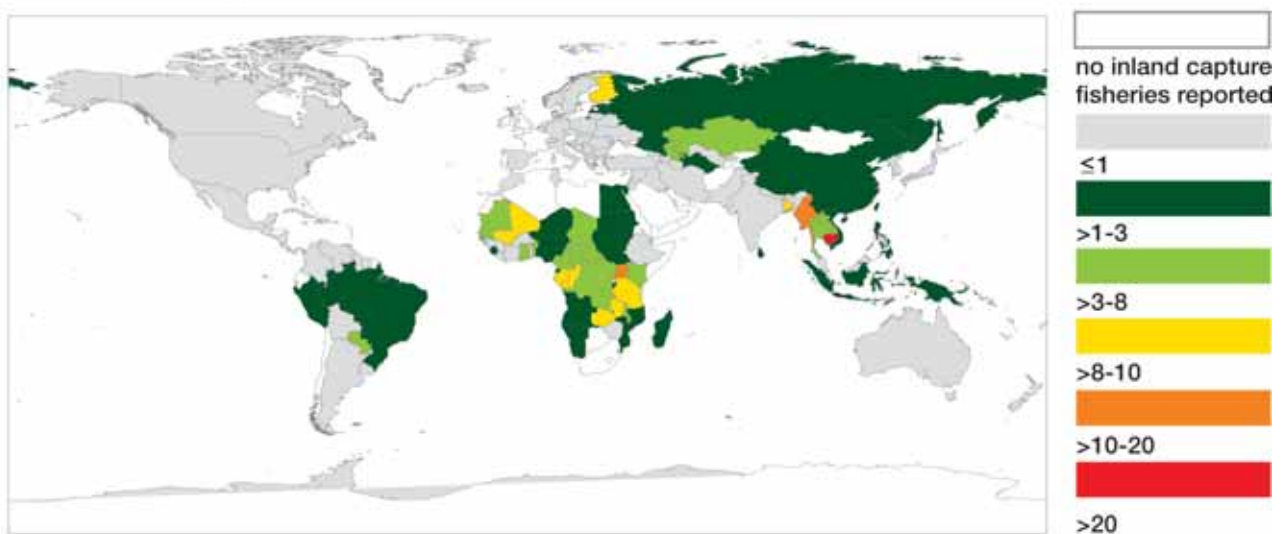


Figure 5. (a) Annual harvest from inland fisheries; (b) Proportion of total catch from wild fisheries that comes from inland systems; (c) Inland capture production per capita (data from FishStat plus, 2010).

Inland fisheries are especially important in land-locked countries in the developing world where they can provide an important source of protein, but even some countries with significant coastlines e.g. Kenya, Tanzania, Bangladesh, Cambodia and Nigeria are highly dependent on large inland systems for their fish supply (Fig. 5b). The importance of wild fisheries in these countries is also reflected in the analysis of capture production per capita (Fig. 5c).

The monetary value of this inland fish catch is large. In the Lower Mekong Basin the estimated fish catch

of 2.1 million tonnes is worth US\$2.1-3.8 billion at first sale and between US\$4.2 and US\$7.6 billion on retail markets (Hortle, 2009) (Box 1). In Africa the Lake Victoria Basin is the largest producer with just over 1 million tonnes harvested each year (Balirwa et al., 2007). The beach value of this catch is estimated at US\$350 million each year and the annual export earnings of Nile perch exceeded US\$300 million in 2007 (LVFO, 2008). Africa's river fisheries are also extremely important for fish production, as illustrated by the river basins of West and Central Africa (Table 2).

Box 1: The Mekong: the world's largest inland fishery

The Mekong is the world's 10th longest river, and the longest in South-east Asia (Liu et al., 2009). It flows over 4,909 km from the Tibetan Plateau in China to its mouth in Vietnam and drains a catchment of 795,000 km². Every year 475 km³ of water is carried by the Mekong into the South China Sea, with a flood season peak in September and dry season low in April. This seasonal flooding drives the annual cycle of fish and fisheries production along the river. Over 850 fish species are recorded from the Mekong, 135 of which migrate within the river to complete their life cycle. These include mega species such as the Mekong giant catfish (*Pangasianodon gigas*) which grows to over 3 metres in length and 300 kg in weight, and migrates annually to and from breeding grounds in northern Thailand and Lao PDR.

The Mekong's biodiversity and productivity supports the world's largest inland fishery. With an estimated annual harvest of 2.1 million tonnes of wild fish, the Mekong's fishery is worth US\$2.1-3.8 billion at first sale and between US\$4.2 and US\$7.6 billion on retail markets (Hortle, 2009). This catch is essential for livelihoods, nutrition and food security, and fish from the Mekong River provide the main source of protein and micro-nutrients (including amino acids, vitamins, and calcium) for 22 million people in Cambodia and Laos. The large volume of small fish that are eaten whole are particularly important as their bones provide an important source of calcium in a region where dairy foods are rare, and their internal organs provide iron and vitamin A. Annual fish consumption in the lower basin is between 29-39 kg per person, or twice as much as the average global consumption, and these are amongst the highest levels of fish consumption in the world. In comparison other animal food sources are of minor importance; for example, in Lao PDR consumption of freshwater fisheries products is 29 kg per person per year (48% of dietary animal protein intake), compared with 5, 6 and 5 kg per person per year for beef, pork and chicken respectively. In Cambodia, annual consumption of freshwater fisheries products is 37 kg per person (79% of dietary protein intake), compared with 2, 3 and 2 for beef, pork and chicken, respectively (ICEM, 2010).

The Mekong's fisheries are also a major source of household income. In Lao PDR more than 3 million people fish, mainly from the Mekong and its tributaries, and fishing provides 20% of household income. In Cambodia 80% of the 1.2 million people living around Tonle Sap use the lake and its rivers for fishing (Ahmed et al., 1998). Further downstream in Vietnam's Mekong Delta, capture fisheries are also crucial to livelihoods. For example, in An Giang province 60% of the people are part-time fishers (Sjorlev, 2001), and in Tay Ninh province 88% of 'very poor' households and 44% of 'high income' households depend on fisheries (Nho and Guttman, 1999).

In addition to this direct contribution of fisheries to people's livelihoods there are many additional economic benefits from engaging in fish processing and marketing, as well as in supplying boats and other materials essential for fishing. There are an estimated 5-6 thousand fish markets throughout the lower Mekong basin, and much of this trade is conducted by women. Likewise, there are estimated to be several million small boats used in the Mekong basin with a combined value of several billion US\$ (Hortle, 2009). This illustrates the important role played by fisheries in driving the rural economy.

Table 2. Production and value of river fisheries in West and Central Africa (where possible reservoir catches have been excluded from these figures) (source: Neiland and Béné, 2004).

River basins	Fishery Production (t/yr)	Value of Production (US\$ million/yr)	Potential Production (t/yr)	Potential Value of Production (US\$ million/yr)
Senegal-Gambia	30,500	16.78	112,000	61.60
Volta (rivers)	13,700	7.12	16,000	8.32
Niger-Benue	236,500	94.60	205,610	82.24
Logone-Chari	32,200	17.71	130,250	71.64
Congo-Zaire	119,500	47.80	520,000	208.00
Atlantic coastal*	30,700	46.66	118,000	179.30
Total	569,100	295.37	1,334,860	749.17

* The Atlantic coastal river basins are those smaller rivers systems that flow into the Atlantic Ocean.

Inland fisheries also provide employment to several million people. While fishing itself provides millions of jobs, processing, trading and other support services provide many more. For example, in both India and Nigeria the number of those employed in these fishery-related jobs is some four times the number of those who fish (Table 3). These country level figures

also highlight the importance of inland fisheries as a provider of jobs for women. In Cambodia, China, India and Nigeria more than 50% of those employed in inland fisheries are women, who generally spend more of their income on family needs, including providing food and medicine (Weeratunge and Snyder, 2010).

Table 3. Estimated number of people employed in inland fisheries in selected countries (derived from BNP, 2008).

Country	No. of Fishers (million)	No. of Other Jobs (million)	Total Jobs (million)	Percentage Men Employed	Percentage Women Employed
Bangladesh	1.0	1.2	2.2	97	23
Brazil	0.15	0.05	0.2	88	12
Cambodia	0.6	0.96	1.6	43	58
China	0.75	0.48	1.2	48	52
Ghana	0.07	0.04	0.1	67	33
India	1.10	4.4	5.5	28	72
Mozambique	0.07	0.02	0.09	95	5
Nigeria	0.32	1.4	1.7	27	73
Senegal	0.04	0.002	0.04	96	4

Monetary values and estimates of employment provide a useful insight into the importance of these fisheries, but these need to be complemented by wider assessments of their development significance. Over much of Asia and Africa fish are harvested as part of integrated rural livelihoods where fishing is combined with farming, herding, and other activities at either the household or community level (Table 4).

While some families are specialist fishers devoting the majority of their time to fishing and earning most of their income from catching and trading, the majority of fishers are farmer-fishers who fish part-time and have a more diverse income and greater assets. Some households do not fish directly but share in nets or boats, while others may work as crew in boats owned by neighbours or relatives.

Table 4. Contribution of fisheries to households' cash income (US\$ per household per year) in different parts of the Zambezi Basin, together with other activities (source: Turpie et al., 1999).

Income source	Barotse Floodplain	Caprivi-Chobe Wetlands	Lower Shire Wetlands	Zambezi Delta
Cattle	120	422	31	0
Crops	91	219	298	121
Fish (value & %)	180 (43%)	324 (28%)	56 (13%)	100 (39%)
Fish (ranking)	1st	2nd	2nd	2nd
Wild animals	6	49	1	0.4
Wild plants	24	121	48	29
Wild foods	0	11	7	4
Clay	2	0	8	0.1



Box 2: Congo River fisheries: the bank in the water

The Congo basin supports the richest fish biodiversity of any African river; 690 species have been described and 80% of these are endemic (Lowe-McConnell, 1987). This species diversity is the result of the river's particular geological history and the consequent complexity of rapids, pools, runs and floodplains along its length (Lévêque et al., 2008). As with the Amazon and other tropical rivers flowing through heavily forested regions, the Congo's fisheries are also dependent on the seasonal flood cycle that floods the rainforest. This allows many species to spawn and feed in this flooded land and brings nutrients from the forest into the aquatic food chain.

Along the Congo, rural communities harvest the benefits of this diversity and productivity. In the Salonga area of the central basin both men and women fish. However, men use mainly hooks and gillnets to fish the main river channel and women use basket traps to fish the floodplain and river margins. This gendered difference is important for food security. Men sell most of their catch, while more than 60% of the (mostly small) fish caught by women using basket traps are kept for home consumption.

The sale of fish is however crucial for other dimensions of these rural livelihoods. Revenues from fishing account for 61% of cash income in the Salonga river system and, although fishing has seasonal peaks, it is practised all year round. This is a major advantage over the farming of manioc, maize, rice, plantain and other crops that generate cash only when crops are harvested. Other traditional activities such as harvest of non-timber forest products generate only small amounts of cash. In this context fishing plays a critical role as a 'bank in the water' for the local population that allows them to access cash quickly and pay for basic necessities, manufactured goods, children's education, and inputs for farming and fishing.

Source: Béné et al., 2009.

This complex integration of fisheries into rural economies highlights the far reaching importance of inland fisheries as an ecosystem service and the potential impacts of their loss. This is especially so for remote rural populations who lack access to formal financial systems. For many of these, fisheries serve as a 'bank in the water' from which they 'withdraw' fish to sell or barter when cash or other productive inputs are required. In this way fish harvests are frequently used to pay for medicine, education, or for seeds or fertilizer (Béné et al., 2009) (Box 2). Freshwater fisheries also provide an economic 'safety net' for people at times of hardship (Jul Larsen et al., 2003; McKenney and Tola, 2002). For example, many traders and industrial workers turn to fishing during periods of economic downturn, and subsistence farmers do so in times of drought or crop failure (Jul Larsen et al., 2003). The importance of fisheries at these times is not reflected in fisheries statistics.

Inland fisheries and food security

Global fish consumption has increased from an average of 10.1 kg per capita per year in 1965 to 16.4 kg in 2005 (Kawarazuka, 2010). While historically most fish production has come from marine stocks, aquaculture has grown rapidly and is now responsible for almost 50% of fish used for human consumption.

While production from inland fisheries has grown in recent decades its contribution to all fish produced (including from aquaculture) has remained stable from 6.8% in 1970 to 6.4% in 2008 but has increased from 7.2% in 1970 to 11.2% in 2008 as a proportion of yield from capture fisheries (excluding aquaculture) (all figures derived from FishStat plus, 2010).

This supply of fish from inland waters is critically important for human nutrition, especially in Africa and parts of Asia. Over 200 million of Africa's 1 billion people regularly consume fish (Heck et al, 2007), and nearly half of officially recorded supply comes from inland fisheries (FAO, 1997; Neiland, 2005). Similarly in the countries of the Lower Mekong Basin freshwater fish are a crucially important source of animal protein, with Cambodia and Laos having amongst the highest fish protein consumption of non-island states (Fig. 6). In Bangladesh fish contributes 55% of animal protein and is especially important in the diet of poor households who can afford fish more easily than other more expensive forms of animal protein (Bose and Dey, 2007) (Box 3).

Their role in providing protein is however only one dimension of the importance of inland fisheries in supporting food and nutritional security. Even more

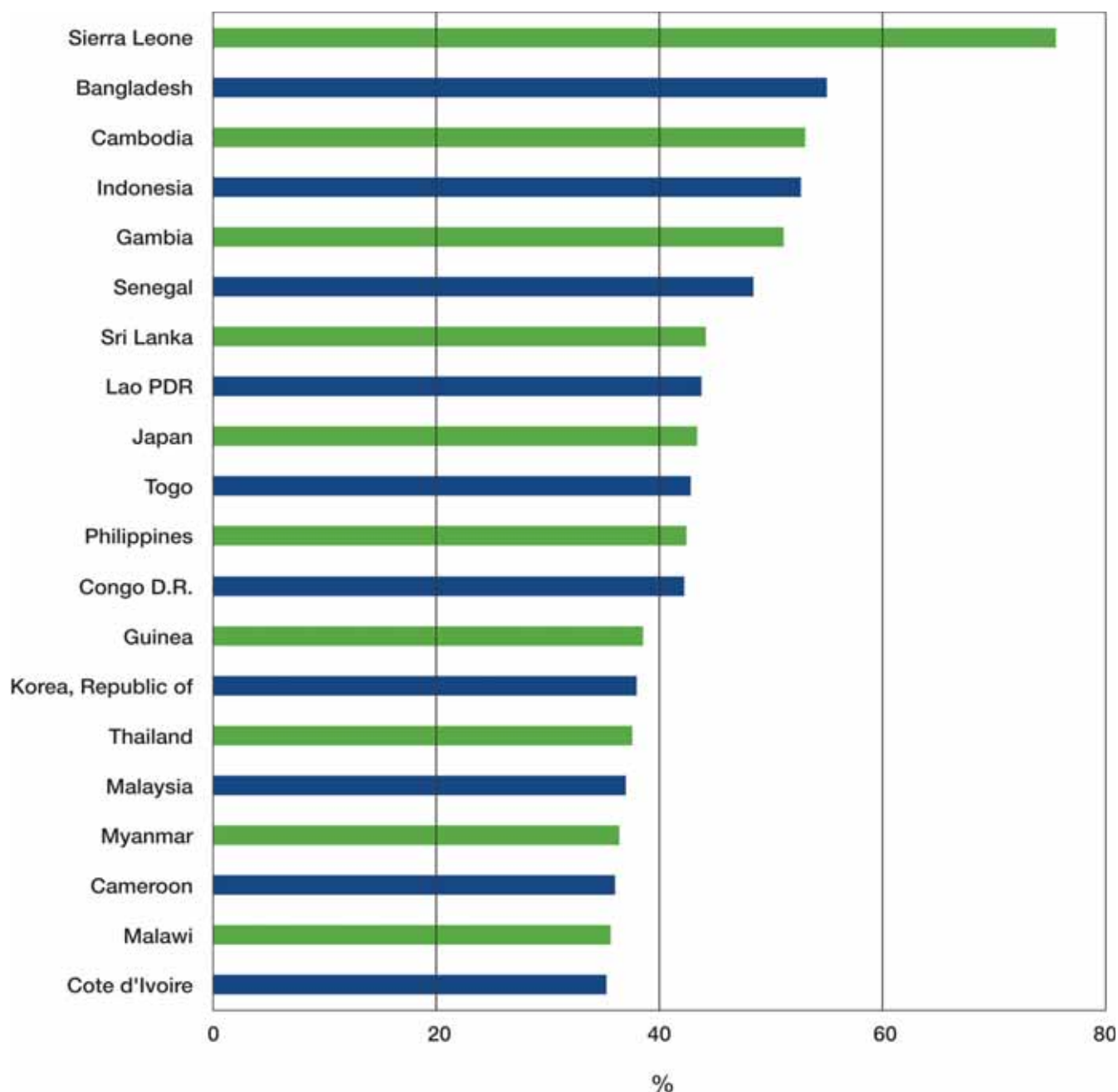


Figure 6. **Fish protein intake as a percentage of the total animal protein intake** (adapted from Kawarazuka, 2010). The twenty countries with the highest levels of intake are presented (excluding small island states).

important in many countries is the role of inland fisheries in supplying micronutrients, especially vitamin A, calcium, iron and zinc. Small freshwater fish are especially rich in these micronutrients and when consumed frequently in everyday diets contribute substantially to nutrition and health and mental development of children. For example, detailed studies in Bangladesh have shown that daily consumption of small fish contributes 40% of the total daily household requirement of vitamin A, and 31% of calcium (Roos et al., 2007). In Cambodia, fish and other aquatic animals contribute 51% of calcium, 39% of zinc, and 33% of iron intake for women (Chamnan et al., 2009).

Similarly in Malawi a serving of just 48 g of small dried fish (*Engraulicypris sardella* known as usipa) has been shown to increase iron, zinc and calcium intake (Gibson and Hotz, 2001).

These small fish are consumed in large quantities in many inland regions. In rural areas of Bangladesh 50-80% of fish consumption is made up of small indigenous species (Roos et al., 2003; Faruk-Ul-Islam, 2007), and in Cambodia small fish predominate in the diet of poor consumers who cannot afford medium-sized species (Chamnan et al., 2009). Similarly in East Africa the small pelagic cyprinid

Box 3: Bangladesh: floodplain fisheries of the Ganges, Brahmaputra and Megna rivers

Bangladesh comprises the delta of a vast river basin carrying the outflow from the Ganges-Brahmaputra-Megna river system. Some 80% of the country sits within floodplain agro-ecosystems, with over half the landmass inundated annually during the monsoon season. Within Bangladesh, land and water productivity, connectivity, and even the landmass itself are sustained by this pattern of seasonal inundation and retreat. Many of the 278 fish species recorded from this inland aquatic ecosystem depend on seasonal migrations into food rich habitats as feeding and nursery areas.

Fisheries play a critical role in Bangladesh's economy, by providing employment and food, and ultimately in poverty alleviation. An estimated 97% of the fish captured is consumed domestically; annual fish consumption per person (excluding infants) is in the order of 19 kg, providing over 50% of animal protein intake. Inland capture fisheries provide 70% of capture fishery harvest and over 40% of total fish production (the remainder coming from marine fisheries and from aquaculture). Small indigenous species captured by subsistence fishers play a particularly critical role in the provision of essential and hard-to-obtain micro-nutrients to the rural poor. Smaller fish are nutritionally richer than large fish and more easily shared among family members than larger fish or meat products (Roos et al., 2003a,b). Larger carp species increasingly produced through aquaculture systems and enhanced fisheries, and often proposed to replace declining wild fisheries, do not fulfil this role; their heads and frames are discarded and with them much of this nutritional value.

Some 10 million people fish and support a total of 50 million household members. In many rural communities, up to 80% of households fish to feed the family; others fish commercially, selling their fish directly to traders. For many of these people fishing plugs a critical livelihood and food supply gap as the peak season for fishing coincides with the lean pre-harvest period in agricultural systems. For others, in particular the landless poor, fishing is the sole source of income for much of the year. This complex pattern of use and dependency on inland fisheries highlights the importance of the fishery resource but also the challenges in establishing effective management systems to sustain these wetland systems and the multiple benefits they provide.

Source: BNP, 2008.



Rastrineobola argentea (known locally as dagaa, omena and mukene) that is caught in Lake Victoria provides an extremely important cheap source of fish for poor communities living around the lake and further afield in eastern, central and southern Africa (FAO, 2008b; Geheb et al., 2008).

Figure 7 summarizes the ways through which inland capture fisheries can contribute to improved nutritional status, including the importance of women's participation in fishing. Women play an especially important role in processing and trading of fish and predominate in fish marketing in many regions (see Table 3); for example 80% of workers in Cambodian fish sauce factories are women (Rab et al., 2006), while in India 72% of people employed in small scale inland fisheries are women, 90% of them engaged in

processing and marketing (BNP, 2008). As small scale processing and/or trading at local markets requires relatively few investments, has generally low operational costs, does not require a great deal of physical strength and can be undertaken by unskilled labour, these activities provide opportunities for a large number of women. Many of them lack education, literacy skills and the financial capital to engage in other activities and fish therefore represent the primary – and sometimes the only – source of income. This independent income for women contributes to securing children's nutritional needs (Heck et al., 2007). Similarly where women are actively engaged in fishing these fish are generally used for household consumption while fish caught by men are more often sold at market (Kawarazuka, 2010; Béné et al., 2009).

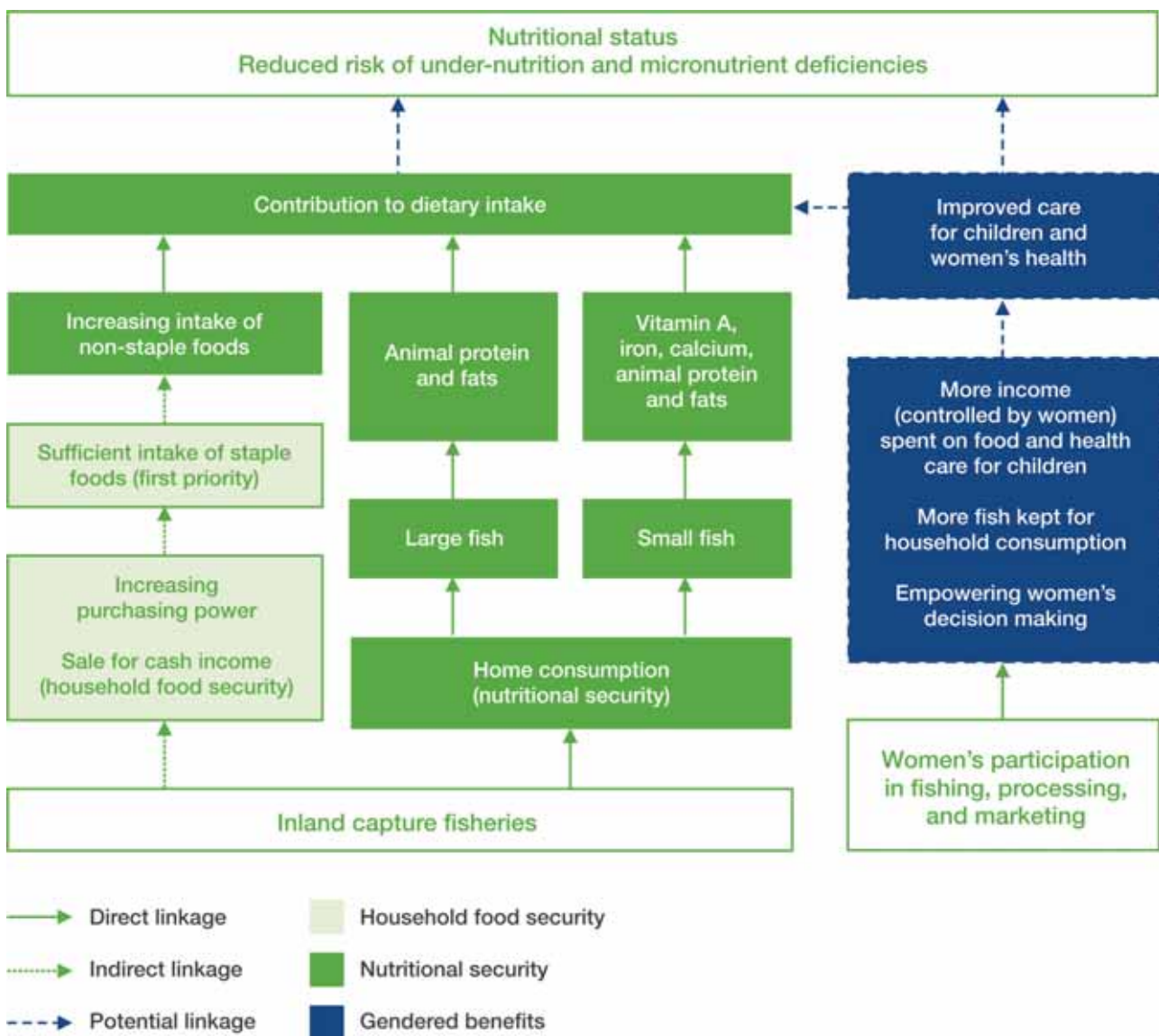


Figure 7. **Contribution from inland fisheries to nutritional well-being** (adapted from Karawazuka, 2010).



Chapter 2:

Environmental Change and Inland Fisheries

Change in inland fisheries

The steady increase in global production from inland fisheries over the course of the past 40 years hides a more complex pattern of change at regional level and in specific fisheries. While fish production has grown steadily in both Asia and Africa – the two regions with the largest production – catch in other regions has levelled off and reduced in some cases (Fig. 4). This is due in part to the switch from production fisheries to recreational fisheries in Europe and North America, but also to environmental change. For example, the fisheries of the Volga River in Europe have reduced substantially as a result of dams. Similarly in Africa, some fisheries have declined as a result of overfishing and environmental degradation, for example Lake Malawi and Lake Malombe (Kasulo and Perrings, 2005; Donda and Njaya, 2007), while others such as the fisheries of the Niger river have been reduced as a result of dam construction and climate change (Laë, 1994). This more complex pattern of change in inland fisheries reflects the diverse ways through which different sets of drivers alter the status of inland fisheries and their contribution to human well-being.

Ecological processes and the value of inland fisheries

The amount of fish present in different freshwater ecosystems is dependent on five principal factors: the success of reproduction and recruitment; the quantity and quality of the food supply and the growth dependent upon this; migration into or out of the system; mortality due to natural or human induced causes; and the fish harvest. Ecosystem health and functioning drive the first four of these, and degradation of aquatic ecosystems reduces their capacity to support fisheries. The quantity and value of fish harvested from these systems is in turn driven by the interaction between accessibility of the fishery, demand for fish, and governance arrangements.

Reproductive success and recruitment is dependent upon the condition of the breeding adults, the availability of suitable spawning habitat, and the proportion of larvae that can access appropriate nursery areas. Reproduction is generally timed to occur when food resources are abundant, and other conditions

are most favourable. In temperate regions these periods occur during the warmer seasons while in the tropics suitable environmental conditions are much more dependent on rainfall and water level. Many species in equatorial lakes breed throughout the year, but river species generally spawn just prior to, or during, the flood season, so allowing the young fish to benefit from the abundant food resources and shelter from predation on the floodplain (Welcomme, 1985; Wootton, 1990). Some species of long distance migrants time their upstream spawning so that their fry arrive at the downstream floodplains as the flood arrives. Should adult fish be unable to achieve breeding condition or access spawning grounds, or if larvae are unable to access suitable nursery and feeding areas, reproductive success will be low. This can occur naturally during time of severe drought when for example lake or river levels fall and breeding areas are inaccessible. In general however, such reductions in reproductive success are more frequently the result of human actions, especially in river systems where dams and other changes to water flow and floodplain areas reduce access to breeding and nursery areas, or cause mortality of spawning fish, eggs and larvae (Box 4).

While there can be some degree of seasonal variation in food supply and fish production in tropical lakes, these are relatively stable environments compared to tropical rivers. Here food availability changes dramatically with the annual flood cycle which drives the greater productivity of tropical floodplains (Junk et al., 1989). For example the mean catch from Latin American floodplains is 28 kg/ha, from Africa 60 kg/ha, and from Asia 100 kg/ha (Welcomme, 2001).

Total annual fish production from these floodplains is dependent upon the river flood, with years of high flow producing more fish and years of lower flow producing less fish. Where fisheries are heavily dependent upon harvesting the young of the year, there is a direct correlation between flood levels and harvest in that year. Where fisheries are more heavily dependent upon older fish the correlation is stronger with the flood level in earlier years. Analyses of river fisheries harvests in the 1960s and 1970s showed that catch in any year during that period was dependent on

Box 4: The ecological importance of migration and movements for river fish populations

The fish communities of tropical river floodplains are composed of numerous species that can be assigned to three major behavioural guilds (Welcomme et al., 2006). Whitefish are strongly migratory species and move large distances within the river channel between feeding and breeding habitats. While some fish move onto the floodplains to feed, they are generally intolerant of low dissolved oxygen concentrations, and return to the main channel to escape adverse conditions. Blackfish, in contrast are adapted to the low oxygen conditions of the floodplain pools during the dry season and so can remain on the floodplain at all times. They move only locally from floodplain waterbodies to the surrounding plain when flooded and return to pools during the dry season. Greyfish are intermediate between the floodplain-resident and long-distance migrants. They are generally not capable of surviving extremely low oxygen levels but do use the floodplain for breeding. They migrate short distances to breed and feed on the floodplain at high water, but return to the main channel in the dry season where they shelter in marginal vegetation or in the deeper pools.

The largest migrations are those that move along the main channel of the river; Amazonian catfishes cover up to 3000 km on these migrations, and the Mekong Giant Catfish may travel 2000 km. In the Mekong, 135 species are long distance migrants and make up 40-70% of the fish catch (Baran, 2006). These migrations allow fish to access suitable spawning habitats which do not exist in the feeding areas downstream. For some species with semi-pelagic eggs, placing eggs upstream compensates for downstream drift of larvae.

The shortest movements are those from the main river channel or floodplain lakes to breeding and feeding habitats in temporarily inundated floodplains. These movements allow the fish to harness the productivity of the floodplain ecosystems and are the main reason for fisheries' productivity in tropical floodplain rivers. For example the Inner Niger delta lies along a 600 km stretch of the Niger River in Mali. This is only 14% of the river's 4180 km mainstream (Welcomme, 1985), but its floodplain extends over 3987 km² and contributes up to 100,000 tonnes, around 80% of the basin's recorded fish catch (Maiga et al., 2007).



the flood level 2-5 years previously, reflecting the time taken for the large fish forming the bulk of the catch to enter the fishery. Analyses from more recent years show the best correlations to be with floods in the same or previous year, reflecting the fact that in heavily exploited fisheries there are now few large fish, and the fishery is much more heavily dependent upon fish in their first year of life (Welcomme et al., 2006).

These studies highlight both the changes that human exploitation has brought to these fisheries, and the underlying importance of river flow on fish production. By decreasing the availability of floodplain habitats, reductions in river flow, whether caused by climate change or by dams and water abstraction, can lead to rapid decline in fisheries.

Fish are removed from the population through fishing and natural mortality. In lakes natural mortality is due mainly to predation by fish, birds and mammals, but may also be caused by diseases, high temperature and low dissolved oxygen. Rapid changes in oxygen levels can cause sudden 'fish kills'. In rivers the major causes of mortality vary in intensity with the flood cycle, being highest at low flow levels. During the flood season the floodplain provides abundant food resources, greater shelter from predators, lower temperatures and higher oxygen levels. At these times fish densities are also lower and mortality is greatly reduced. By changing the quality and quantity of water in lakes and rivers human activities can greatly increase natural mortality. Human activities in river and lake catchments can lead to reduced inflow and eutrophication in many lakes and rivers,

which in turn can lead to changes in both fish populations and in production levels (Box 5).

Direct and indirect drivers of change

Direct drivers. The human well-being and ecosystems services framework (Fig. 3) highlights how direct and indirect drivers interact to alter ecosystem functioning and consequently enhance or diminish the quantity and or quality of services that these ecosystems provide. A range of processes drive such direct changes in inland aquatic ecosystems (Table 5). Dam construction in the catchment interrupts the connectivity of river systems, erects barriers to fish migration, and reduces the availability of breeding and feeding habitat. By retaining water, dams with large reservoirs alter seasonal flood regimes and retain sediments that underpin the productivity of downstream floodplains. This in turn diminishes the production and catch of fish dependent upon this wetland productivity. River channelization and dredging both remove riverine habitats directly and alter flow and flood patterns, hence reducing the availability of floodplain habitats. Construction of roads and other infrastructure have similar impacts, reducing wetland connectivity, and diminishing the capacity of aquatic ecosystems to absorb floodwaters and remove pollutants. Water abstraction for irrigation and urban-industrial uses also reduces downstream flows, so diminishing the availability of feeding and breeding habitats, and exacerbating problems of water quality in many locations.

Expansion of agriculture often involves the conversion of freshwater habitats – especially floodplains –

Box 5: Ecological diversity of freshwater fish

Freshwater fish are extremely diverse in their feeding habits ranging from mud and detritus feeding demersal fish to phytoplankton filter feeders and grazers, and other herbivorous fish feeding on higher plants, fruit, seeds and even nuts. Predators include zooplankton feeders, insectivores, and larger fish feeding on crustaceans, molluscs and fish. There are also omnivorous species, as well as a range of parasites feeding on fins, scales and other body parts.

This diversity of specialisation contributes to the diversity of freshwater fish species and the food webs found in freshwater systems, especially in lakes. However, heavy specialisation can also make species vulnerable to changing ecological conditions. For example one of the factors contributing to the disappearance of the indigenous species *Oreochromis esculentus* from Lake Victoria is thought to have been an environmentally driven change in food supply. Eutrophication is believed to have resulted in a change in the lake's plankton from diatoms to blue-green algae. *O. esculentus* was specialised to feed on a diet of diatoms whereas the introduced *O. niloticus* was better able to digest the blue-green algae.

Source: Welcomme, 2001.

Table 5. **Direct drivers of change in inland fisheries** (adapted from Postel and Richter, 2003).

Driver	Impact on Ecosystems and Fisheries
Dam construction	<ul style="list-style-type: none"> ● Alters timing and quantity of river flows, leading to loss of breeding and feeding habitats ● Alters water temperature, nutrient and sediment transport, leading to mortality of fish and fry ● Results in loss of floodplain and other wetlands ● Blocks fish migrations, preventing access to breeding and feeding areas and in time reduces population levels
Dike and levee construction	<ul style="list-style-type: none"> ● Destroys hydrologic connection between river and floodplain habitat, so reducing breeding and feeding habitat
Diversions	<ul style="list-style-type: none"> ● Reduce river flow leading to loss of breeding and feeding habitat
Draining of wetlands	<ul style="list-style-type: none"> ● Loss of key aquatic ecosystems and breeding and feeding habitats for fish
Deforestation/ land use changes	<ul style="list-style-type: none"> ● Alters runoff patterns and increases sedimentation leading to loss of fish habitats and mortality of eggs and larvae
Urbanisation	<ul style="list-style-type: none"> ● Reduces habitat and water quality and quantity
Navigation	<ul style="list-style-type: none"> ● Straightening and dredging of channels resulting in loss of channel length and habitat diversity ● Separation of floodplain from channel
Release of polluted water effluents	<ul style="list-style-type: none"> ● Diminishes water quality, leading to fish mortality ● Leads to changes in composition of plankton and other organisms: alters food chains and changes composition of fish communities
Overharvesting	<ul style="list-style-type: none"> ● Depletes fish populations ● Alters food chains and biodiversity ● Shifts fish catch to smaller species and individuals
Introduction of exotic species	<ul style="list-style-type: none"> ● Eliminates native species, alters biodiversity, food chains, production and nutrient cycling
Acid deposition	<ul style="list-style-type: none"> ● Alters chemistry of rivers and lakes leading to loss of fish habitat and decline in populations
Climate change	<ul style="list-style-type: none"> ● Changes in runoff patterns from increase in temperature and changes in rain fall, leading to changes in flow regimes i.e. flooding and low flows, as well as in breeding and feeding habitats

and therefore contributes to a loss of biodiversity and aquatic productivity (MA, 2005b). Change in land use and vegetation cover due to deforestation also changes patterns of water flow and reduces water quality, in some cases leading to siltation of important habitats for fish and other species. Similarly pollution, salinization and eutrophication can all have major impacts on aquatic ecosystems and result in

the eradication of native faunas. The introduction and spread of alien invasive species has also brought substantial ecological change in many freshwater systems, and are of particular concern in systems with high numbers of endemic species. Similarly overfishing can lead to the fishing down of foodwebs, loss of top predators and ecological change (Allan et al., 2005).

Indirect drivers. The processes of change that lead to ecosystem degradation and loss are similarly driven by a set of indirect drivers, including demographic, economic, socio-political and technological changes. Increases in population within a river basin, leading to increase in water demand, will impact river fisheries downstream. The development of water resources for human use has been a response to the need to provide expanding populations and growing economies with food, energy and domestic and industrial water supplies, and to provide transport. The degree and distribution of the impacts arising from this growing demand for water resources is however dependent on the institutional arrangements that govern the production, allocation, distribution and consumption of freshwater services (Aylward et al., 2005). For example the absence of effective participatory governance and consequent omission of downstream communities from decision-making regarding water allocation can lead to decisions to increase withdrawals upstream that ignore the consequent impacts on fisheries downstream.

Effective governance arrangements – including good quality information on the benefits of ecosystems services, and appropriate economic incentives – are therefore positive indirect drivers. Conversely the absence of effective governance leads to loss of ecosystem services, and the generally poor governance of water resource development has led to significant social and environmental impacts. This was highlighted by the World Commission on Dams which

criticised the narrow economic perspectives and engineering approaches that have historically dominated dam construction and caused significant negative impacts for the rural poor who rely on the natural functioning of inland water ecosystems (WCD, 2000). More broadly the role of policies in other sectors such as power, navigation, water supply and agriculture can all have substantial indirect impacts on inland fisheries, and their importance highlights the need for more effectively integrated policies for water management and river basin development.

Dams

Of the many direct drivers impacting inland fisheries, dams and their impact on the hydrological regimes of rivers are the most important. The number of large dams (>15m in height) has grown rapidly in the past 60 years, from 5,000 in 1949 to over 50,000 by 2006 (WCD, 2000; Berga et al., 2006), and there are also now an estimated 800,000 smaller dams. Worldwide there were 400 dams over 60 meters in height under construction in 2005 as well as many smaller ones, and current indications are that this number will increase by over 160 large dams annually in future (WWF, 2005). More than 50% of the world's large rivers have been fragmented by dams on their main channel, and 59% have fragmented tributaries. In only 12% of large European rivers is water flow unaffected by dams, while in Asia, Africa and South America the corresponding figures are 37%, 38% and 53% respectively. This has transformed rivers and their aquatic ecosystems (MA, 2005a,b), with many

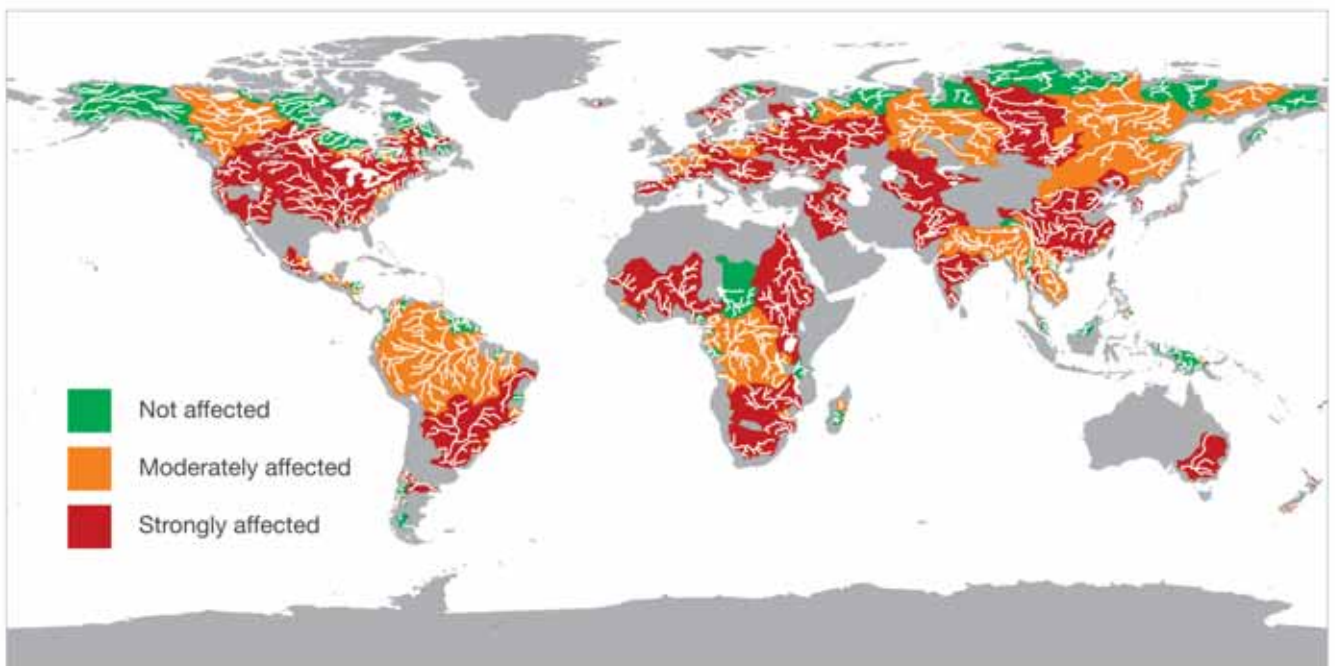


Figure 8. **Map of river fragmentation** (source: Nilsson et al., 2005).



rivers fragmented and large amounts of water impounded (Revenga et al., 2000; Vörösmarty et al., 2005, 2010; Nilsson et al., 2005) (Fig. 8).

Dams impact fish communities and the fisheries dependent upon them by changing the ecological functioning of the river ecosystems that sustain these communities and their fisheries. These changes are of five main types. First, dams replace the flowing river and its associated riverine habitats with more static reservoirs whose fisheries are generally less productive than the river fisheries they have replaced, and which benefit different sectors of society (Jackson and Marmulla, 2000; Hoeinghaus et al., 2009). In some rivers such as the Columbia in the north-western USA or the Parana River in Brazil the river has been turned into a cascade of reservoirs with little of the original free-flowing river remaining (see Box 6). Second, dams alter the annual flow regime of the river downstream of the dam and change the pattern of flooding along the river margins and floodplains. Fish production is higher in

both tropical and temperate rivers that have a strong and predictable flood pulse than in those without (Junk et al., 1989). Where dams remove this flood pulse, or reduce its amplitude, duration, and predictability, fisheries decline.

Third, in those rivers with important populations of migratory fish species, dams form a barrier to adults moving upstream to spawn, and both adults and juveniles moving downstream to feeding and nursery grounds (Marmulla, 2001; Antonio et al., 2007). This is an especially important concern for the Mekong (Box 7). Fourth, by reducing downstream flooding dams and levees reduce the availability of floodplain habitats that are important for fish as breeding, feeding and nursery sites. Finally, by retaining sediment in reservoir impoundments dams reduce the sediment loads carried by rivers and so their capacity to continue building riverine habitats downstream. This can lead to erosion and loss of riverine habitats and to the consequent decline in fish production dependent upon these.

Box 6: The Fraser and Columbia Rivers

The Fraser River is the longest on Canada's west coast and its watershed encompasses over 234,000 km². The Columbia River is even longer and larger, flowing over 2,000 km and draining an area of 567,000 km². The flow of both rivers is dominated by seasonal melting of snow in the mountains, with the Columbia's mean annual discharge rate of 7,800 m³s⁻¹, twice that of the Fraser.

The two rivers are similar in their location, flow regimes, and levels of biodiversity (Froese and Pauly, 2010), but have had very different histories of water resource development. The Fraser River is free flowing and the watershed has few dams located in tributaries. The Columbia River, and its main tributary the Snake River, have 15 mainstream dams and more than 130 dams in total (Fig. 9).



Figure 9. Location of dams in the Fraser and Columbia River Basins (source: Ferguson and Healey, 2009).

Box 6 continued...

Both rivers contain a rich diversity of salmon populations, whose juvenile and adult migrations are timed to the natural hydrological cycles. These Pacific salmon species spawn in freshwater but migrate to sea as juveniles and grow to adulthood in the sea. Spawning migration routes can be up to 1,300 km for Sockeye and Chinook salmon.

The Fraser River is recognised as the largest salmon producing system in the world (Northcote and Larkin, 1989). Seven species of salmon live in the basin; five of these are harvested in the ocean, and two are harvested by recreational fishers in the river. Native societies in the basin also depend on the fisheries for religious and cultural ceremonies and harvest some for subsistence and income.

Although plans for hydroelectric power generation on the Fraser River were developed in the 1900s, these did not materialise and the river has remained largely free from dams and with none on the mainstream. The absence of dams is widely recognised to have maintained the fisheries productivity of the river and sustained salmon populations at high levels. This is in contrast with the Columbia where 13 of 16 salmon groups are under Federal protection to enhance their recovery from depressed levels, and extensive use of hatcheries has been adopted to supplement wild production and sustain harvest. Currently, wild salmon make up as little as 20% of the total salmon production upstream of the lowest mainstem dam (Ferguson et al., in press).

Harvest of salmon in the Columbia started to decline in the early 1900s due to overfishing, habitat degradation, water withdrawal, and from the construction of mainstem dams beginning in 1932. These measures together were largely responsible for the long-term loss of wild salmon in the basin. In view of the cultural importance of salmon runs on the Columbia for native Indians, and in recognition of its recreational importance, a suite of mitigation measures have been taken to keep mainstem migration routes open to salmon. Dams have been engineered to include fish ladders, and juvenile salmon are routed past turbines on their way downstream. Major programmes have focused on collecting juvenile fish at upper dams and transporting them to release sites downstream, identifying an appropriate amount of water to be released during salmon migrations to aid their downstream migration rate, building systems that direct juvenile fish around turbines and dams, and developing turbines that pass salmon more effectively. These measures have helped maintain salmon runs, but at greatly reduced levels of wild fish, and at an estimated cost of US\$1 billion per year (Ferguson and Healey, 2009).

The social and environmental impacts of dams have attracted considerable concern, with 40-80 million people worldwide displaced by dams and 472 million impacted by changes in flow downstream (Richter et al., 2010). In response, the World Commission on Dams has produced policy principles and guidelines, the hydropower industry has developed sustainability guidelines, and dams have been decommissioned and removed in some countries, notably in the USA where some 500 dams have already been removed (Gleick, 2000; Doyle et al., 2003). Although these changes have been accompanied by a global decline in the number of new dams built each year, many dams still continue to be built in Africa, Asia and Latin America in response to demographic and economic growth, and rising demand for energy. For example the International Commission on Large Dams (ICOLD) reports that only 8% of Africa's hydropower potential has been utilised, 24% of Asia's, and 38% of Latin

America's. While much of this may not be technically feasible or economically viable, current indicators are that the hydropower industry will continue to pursue the potential that can be developed.

Water abstraction

Most large dams are built to produce hydropower, but many are also used to divert water for irrigated agriculture, and domestic and industrial use. Conversely many small dams are designed primarily to store water and manage its supply for multiple non-hydropower purposes. In addition, in many river systems water is removed for agriculture using pumping systems of various sizes. The combined effect of these water management schemes is that large volumes of water are removed from many large river systems. In several of these, including the Yellow River (China), Colorado (United States), Indus (India and Pakistan), Murray-Darling (Australia), Chao

Box 7: The Mekong

The continued focus on hydropower investment is clearly evident in Southeast Asia and especially in the Mekong River basin. China completed the first dam across the mainstem of the Mekong in 1995; a further three have now been completed, one is under construction, and three more are planned (MRC, 2010). Further downstream in the lower basin that lies within Cambodia, Laos, Thailand and Vietnam, nearly 200 dams are completed, under construction or planned (Baran et al., 2009; MRC, 2010). Of these, eleven are scheduled to be installed on the mainstem of the river within the next decade. Seven of these are located in Laos, two in Cambodia and two will be shared between Laos and Thailand (Fig. 10).

Plans for hydropower development in the Mekong have led to growing concern over the potential environmental, economic and social costs, and there is acute concern over the impact on the basin's fisheries. In the Lower Mekong Basin 40-70% of the fish catch is dependent on long-distance migrant species (Barlow et al., 2008), and these fish stocks will be especially vulnerable to dams built on the mainstem. While these 11 dams would convert 55% of the mainstem into a reservoir, altering water flows and so degrading the feeding and breeding habitats of fish along the river, the role of dams in blocking fish migration is believed to be the single most critical threat that dams pose for the fishery (Dugan, 2008; Baran and Myschowoda, 2008). In other river systems with fewer migratory species, developing fish passage facilities has taken decades, and these have had only limited success (Ferguson et al., in press) (see Box 6). In view of this international experience recent reviews of the impact of dams on the Mekong have called for action by governments to site dams as high as possible upstream and on tributaries so that they minimise impact on the fisheries.

Basin wide concern for the Mekong's fisheries is rising because of growing understanding of the importance of these fisheries, and the experience to date with dams in the Mekong basin. One of these, Pak Mun, was built on Thailand's largest Mekong tributary in the early 1990s. Even though a fish ladder was built with a view to allowing fish migration to continue, the Mun River above the dam experienced a 60-80% decline in fish catches representing a loss estimated at US\$1.4 million per annum. Only 96 out of the 265 fish species (a 64% decline) remained in the Mun River after operation of the dam. The fish production in the reservoir was hoped to amount to 220 kg/ha but actually reached only 10 kg/ha. The impact of the dam was particularly serious for 17 migratory fish species whose migration routes were blocked off, and spawning grounds were inundated. In response to intense pressure from local communities and NGOs, the dam gates were opened in 2001 for one year and this has had very positive effects, bringing back much of the fishery resources (129 species of fish returning to the Mun River). This has now been continued with a four month seasonal opening policy that has helped to reduce the impacts of the dam on the river's fisheries.

A second recent dam on a tributary of the Mekong, the Yali Falls Dam, is located on the Sesan River in Vietnam. Closed in 1996 the dam has caused major changes in hydrology and water quality downstream, with important subsequent impacts on fish populations. Flow releases from the dam are very different from the natural flood regime and these have altered migration triggers and reduced habitat availability for migratory species. Sediment retention by the dam and emergency flood releases from the dam have also combined to increase erosion downstream and this has resulted in siltation of fish breeding and feeding habitats further downstream. In addition to the impacts that these changes in river ecology have on fish migration and production, the fluctuating water levels in the post dam river also make fishing more difficult. Together these changes have resulted in important impacts on downstream fisheries in Cambodia where a 73% decline in fish catch has been reported in this section of the river. This resulted in US\$2.5 million in lost income in 1999 for 3434 households in Ratanakiri Province, or an average of about 58% of livelihood income per household.

Source: ICEM, 2010.

Box 7 continued...

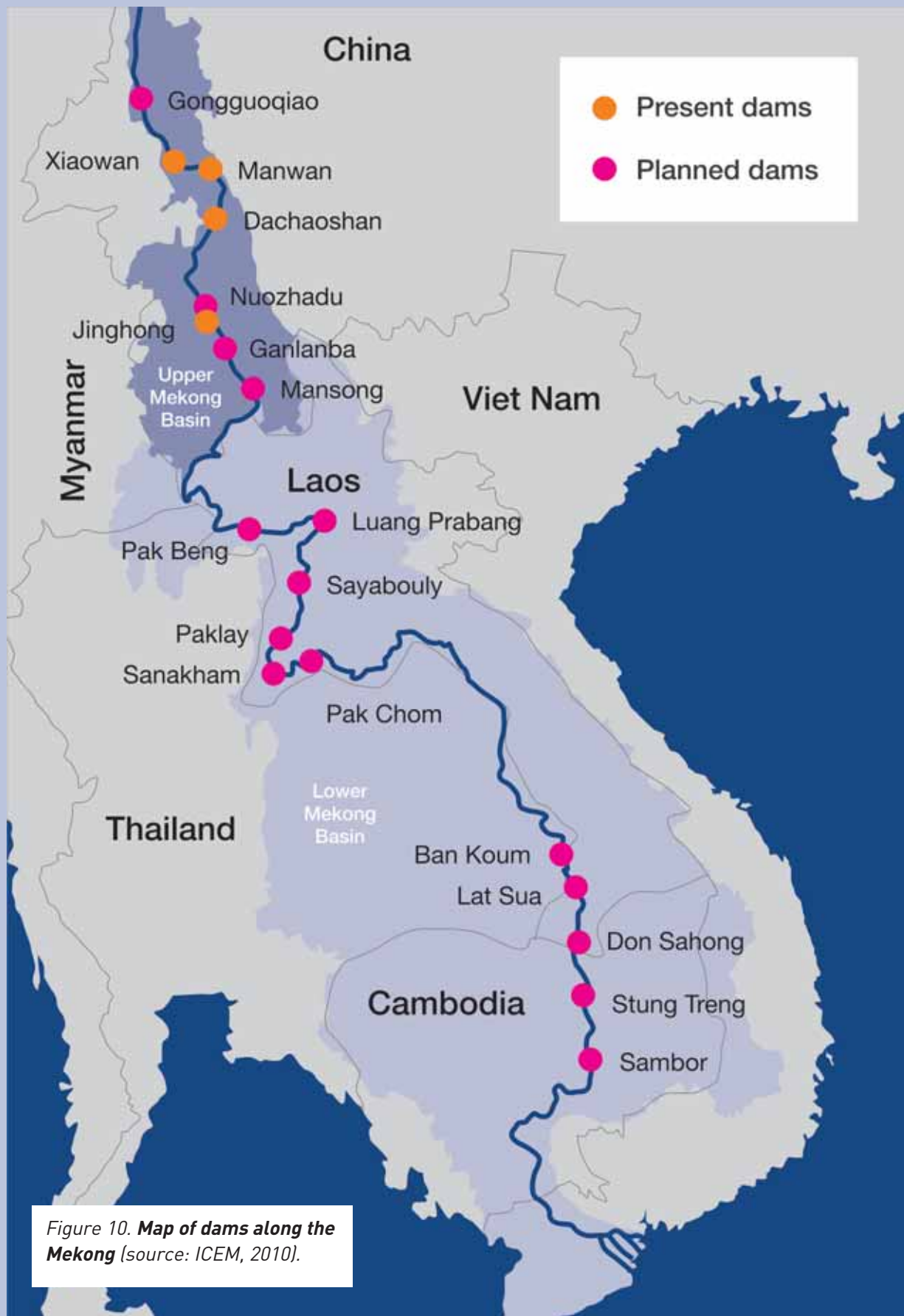


Figure 10. **Map of dams along the Mekong** (source: ICEM, 2010).

Phraya (Thailand) and Cauvery (India), water abstraction is now so large that downstream requirements can no longer be met, including diluting pollution and sustaining estuarine and coastal ecosystems (Molle et al., 2007).

Yet demand for water for industrial, municipal and agricultural uses (Fig. 11) continues to increase and the pressure for further abstraction from rivers is growing. Industrial and municipal uses have expanded most rapidly in recent years and there is widespread recognition that agricultural use of water needs to be more efficient, so continuing to increase food production while reducing water use (Abdullah, 2006). In this context the potential for increased impact on river fisheries is large.

Pollution

Freshwaters are exposed to both pollution and eutrophication. Pollution arises from the discharge of toxic materials such as industrial and mining wastes into the water, and is usually directly lethal to fish or serves to discourage them from living in

affected habitats. Eutrophication is primarily caused by the discharge of nutrients into the water either by natural processes or human activities, including agriculture and domestic waste disposal. Minor increases in eutrophying nutrients can be beneficial in many systems, especially those whose waters derive from poor soils. Excessive build up of nutrients however, especially in lakes, can change the nature of the phytoplankton, reduce dissolved oxygen concentrations and eventually render the environment unsuitable for many species of fish.

In the industrialised countries there has been a long history of increasing urban and industrial pollution during times when rivers and some lakes were used as open sewers. Growing awareness of these impacts was one of the drivers behind the environmental movement of the 20th century and the reduction of point source pollution has become an important success story. Combating the diffuse nutrient loads and pollution that comes from agriculture is a much bigger challenge however and has led to major initiatives to address the problem in Europe and

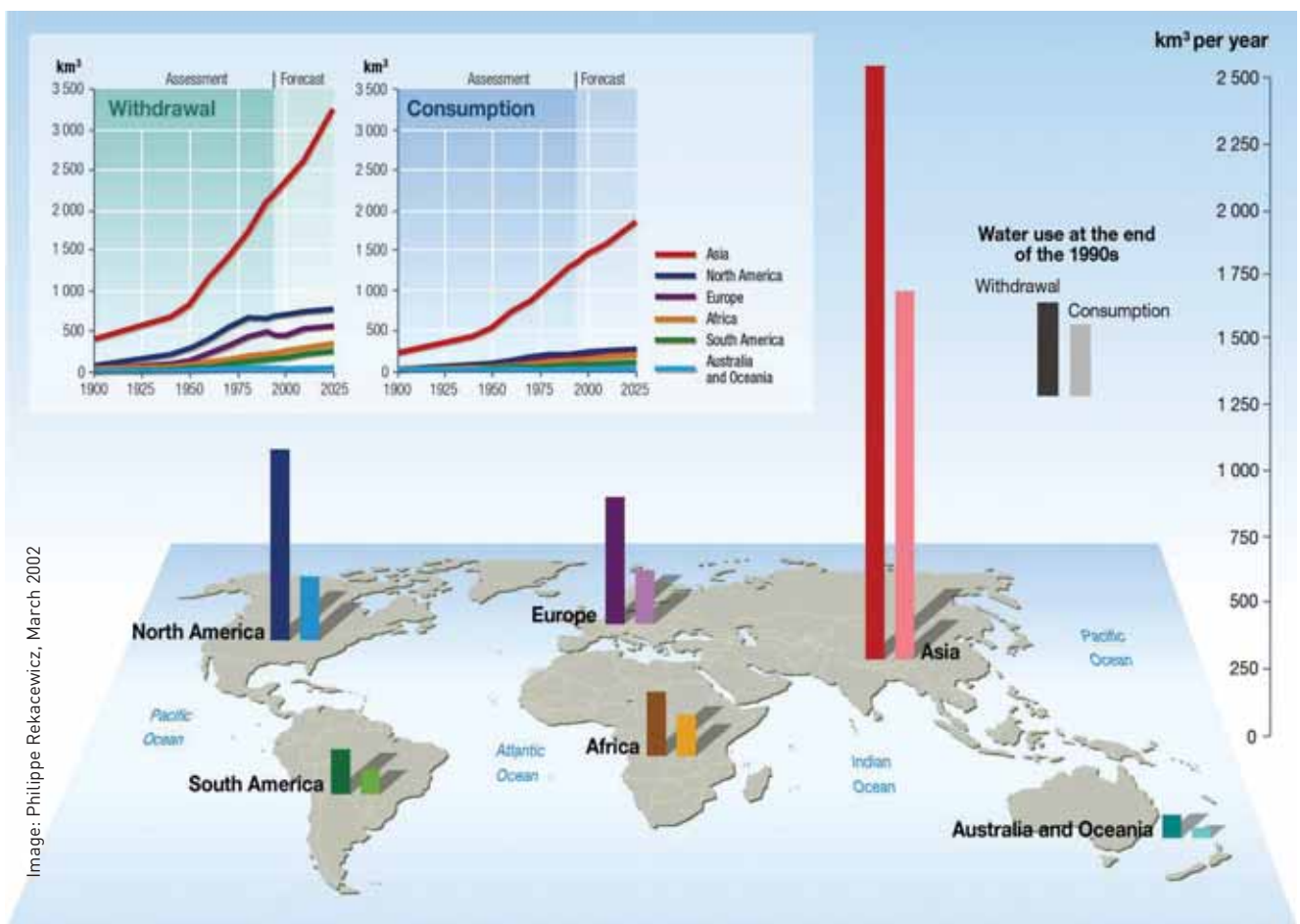


Figure 11. **Freshwater use from 1900 to 2000 for the world's major regions, and projected freshwater use for 2000 to 2025** (source: UNEP vital graphics, 2008b). Freshwater use is partly based on several socio-economic development factors, including population, physiography, and climatic characteristics.



North America. Similarly, increased awareness of acid rain and its impacts on freshwater lakes and streams has resulted in a range of measures to reduce sulphur emissions and depositions in both North America and Europe. In parts of the USA for example sulphur deposition decreased by up to 44% between 1990 and 2007 (EPA, 2009). However such reductions do not necessarily or rapidly translate into recovery of freshwater biodiversity in these systems, and still other sources of acidification need to be addressed. Nevertheless, reducing sulphur deposition is a key first step and demonstrates that change is possible when the political will and economic incentives exist.

Pollution has historically been less of an issue in developing countries, but is now an increasing challenge. Wastewater treatment systems are relatively rare in these economies and about 90% of wastewater is discharged directly into rivers and streams without any treatment. As a result freshwater ecosystems near most tropical cities have become polluted and this trend is likely to continue (Vörösmarty et al., 2010). Even in countries with very high economic growth, investments to prevent or

reduce water pollution are relatively low. For example the cities of Chongqing, Yichang, Wuhan, Nanjing and Shanghai in the Yangtze Valley have a combined population of over 70 million people and add 25 billion tonnes of wastewater to the river each year; much of this waste is untreated. Similarly, diffuse pollution with nitrogen, phosphorus and pesticides from agricultural land is also very high; the loss of nitrogen from agricultural land, for example, is almost four times the global average (Dudgeon, 2010).

It is rarely possible to clearly distinguish the effects of eutrophication and pollution from those of other changes in the freshwater systems. In the case of the Yangtze, pollution adds to the impacts of dams and water abstraction, as well as changing land use in the catchment and along the floodplain. However it is clear that the stress caused by pollution adds one more challenge to biodiversity that is already impacted by other factors. As a result of these pressures the fish populations of the Yangtze are in decline, catches are now maintained by stocking, and the Chinese sturgeon (*Acipenser sinensis*) and Chinese paddlefish (*Psephurus gladius*) are critically endangered (Dudgeon, 2010).

Climate change

Higher temperatures will bring a range of physiological challenges for fish species. Increased metabolic rate will raise oxygen and food requirements, raised gill ventilation can lead to increased uptake of aquatic pollutants, and higher temperatures can also improve survival of parasites and bacteria. This situ-

ation is aggravated by the fact that water retains less oxygen at higher temperatures. However while this combination of challenges may reduce fish survival, growth and reproductive success (Halls, 2009; Welcomme et al., 2010), the precise impacts on individual fisheries are difficult to predict at this time.

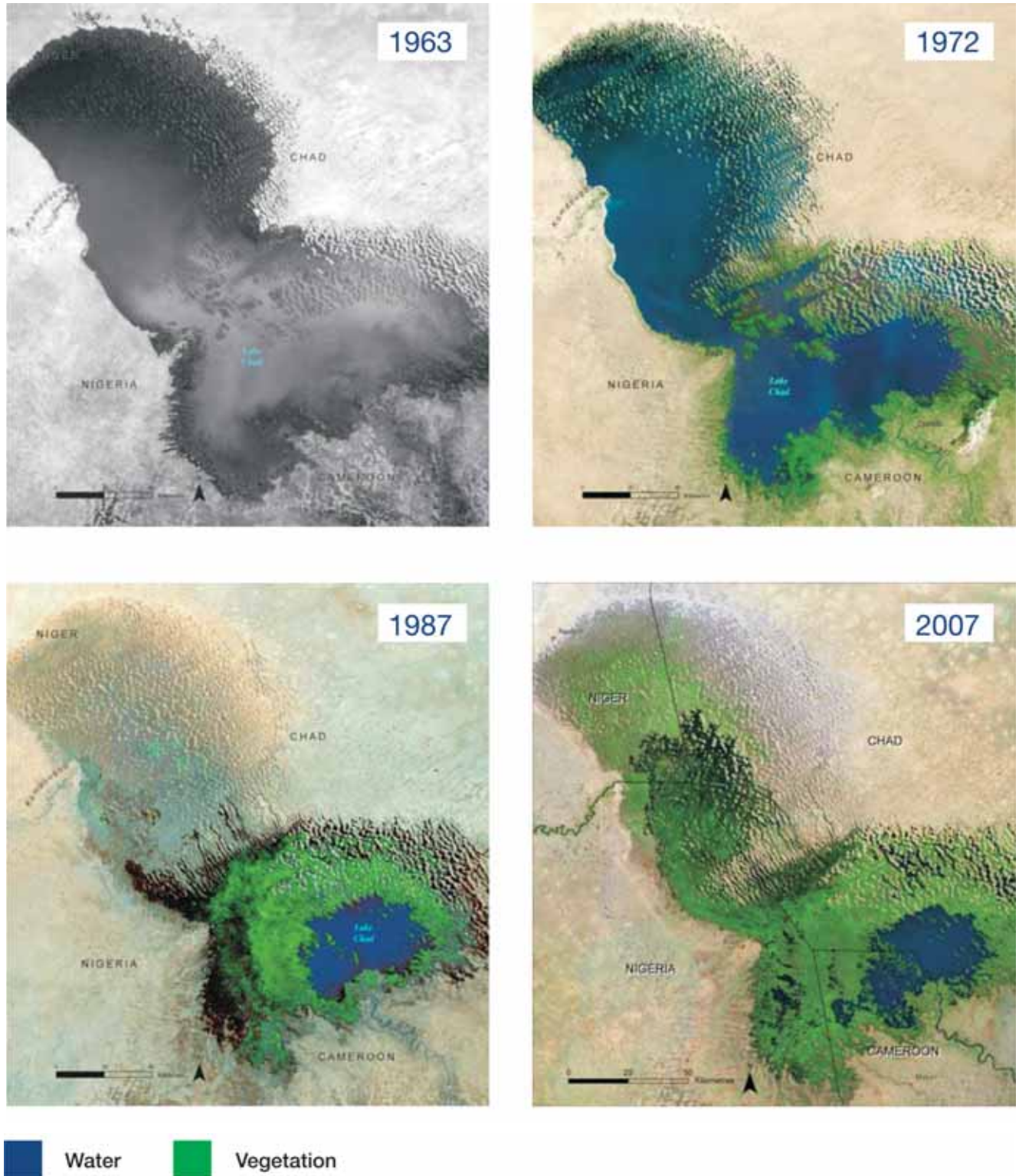


Figure 12a. **The disappearance of Lake Chad** (adapted from UNEP, 2008a).

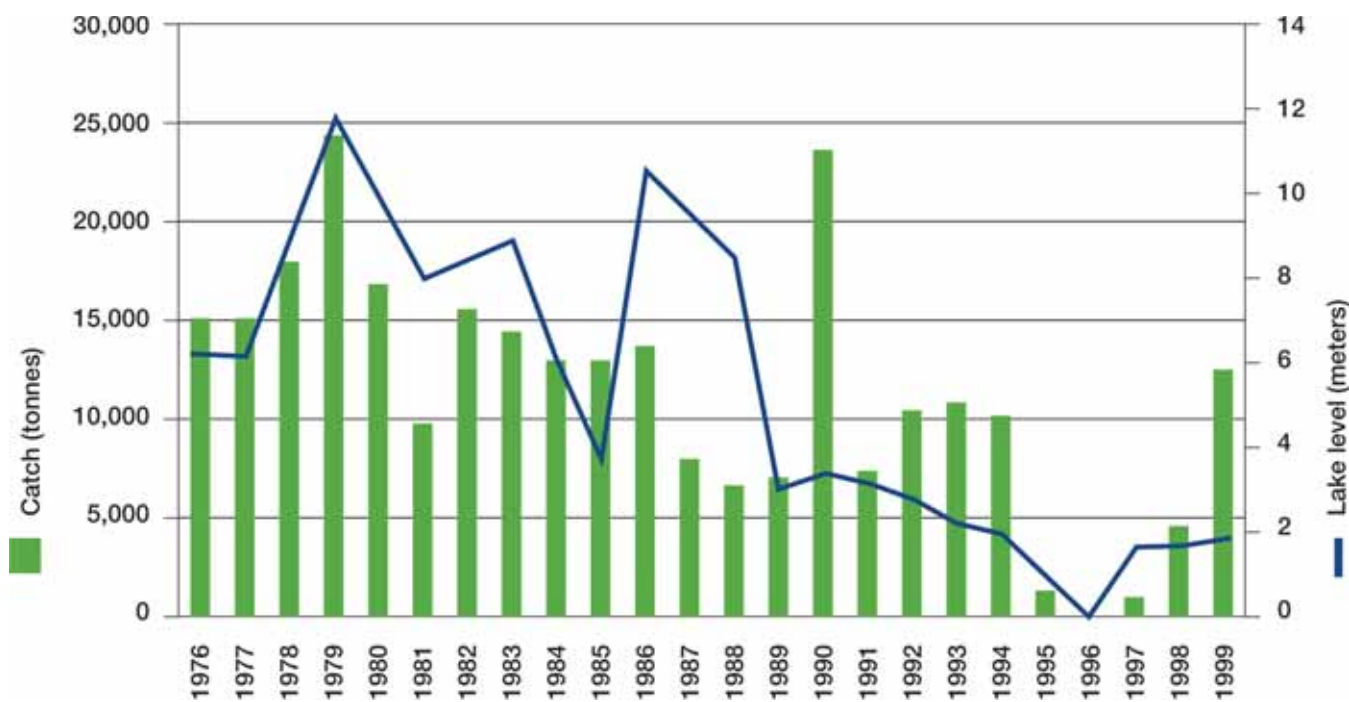


Figure 12b. **Catch fluctuations and water level in Lake Chilwa, Malawi 1976-1999** (source: Njaya, 2002; Allison et al., 2007).

In contrast, the potential consequences of hydrological alterations caused by climate change are relatively clear, in part because the effects of climate variability on river fisheries have already been documented, and also because the reductions in water flow caused by climate change are likely to parallel those caused by water abstraction for human use. For example, the Sahelian drought of the 1980s is estimated to have reduced the fish catch in the Inner Niger Delta by 50% (from 90,000 tonnes per year to 45,000 tonnes), while the Markala and Selingué dams reduced catch by 5000 tonnes (Laë, 1992). The most striking example of natural change in freshwater ecosystems and their fisheries has been in Lake Chad, where the lake fell from a high water level in 1963 to 10% of that surface area by 2007 (Fig. 12a).

Fish catches fell in parallel with this decline in river inflow and lake levels. Similarly Lake Chilwa in southern Africa is well known for fluctuating water levels and associated changes in fish populations (Fig. 12b). Should climate change lead to similar changes in water flow there will be significant changes in inland fisheries, especially in the drier regions. Recent analysis of the vulnerability of freshwater fisheries to climate change has highlighted the negative impact of decreased run off, drought, and diversion to crops. Central, eastern, and West African countries have been shown to be highly vulnerable to

potential impacts of climate change on freshwater fisheries, as are several countries in Asia (Fig. 13).

Invasive species

The introduction of non-native (alien) invasive species can result in major ecological changes in freshwater systems, including the extinction of native species. This has become a particular concern for fisheries with the expansion of aquaculture and the stocking of waterbodies with alien species. For example, introduced fish account for 96% of fish production in South America (Garibaldi and Bartley, 1998). The introduction of salmonid species is of particular concern as this has not only impacted other species but also reduced the genetic diversity of wild salmon stocks (Finlayson et al., 2005).

Alien species can impact natural fisheries in several ways, including through environmental disturbance, predation, competition, introduction of disease, and genetic contamination or hybridisation (Welcomme, 2001). For example, by rooting for food in the muddy bottom of lakes and rivers the common carp remobilises sediment and increases biochemical oxygen demand (BOD), while the turbid conditions reduce light penetration and plankton production (Welcomme, 2001). The introduction of predator species brings more direct impacts. The introduction of Nile perch into Lake Victoria is widely believed to

have reduced the cichlid flock there (Box 8), while introduction of trout into many areas has led to loss of many native species. As a result of these impacts there is today strong international pressure to regu-

late the movement of species to reduce the risks of damage to the environment, to native fish stocks and to the genetic make-up of resident fish populations (Welcomme, 2001).

Vulnerability rank

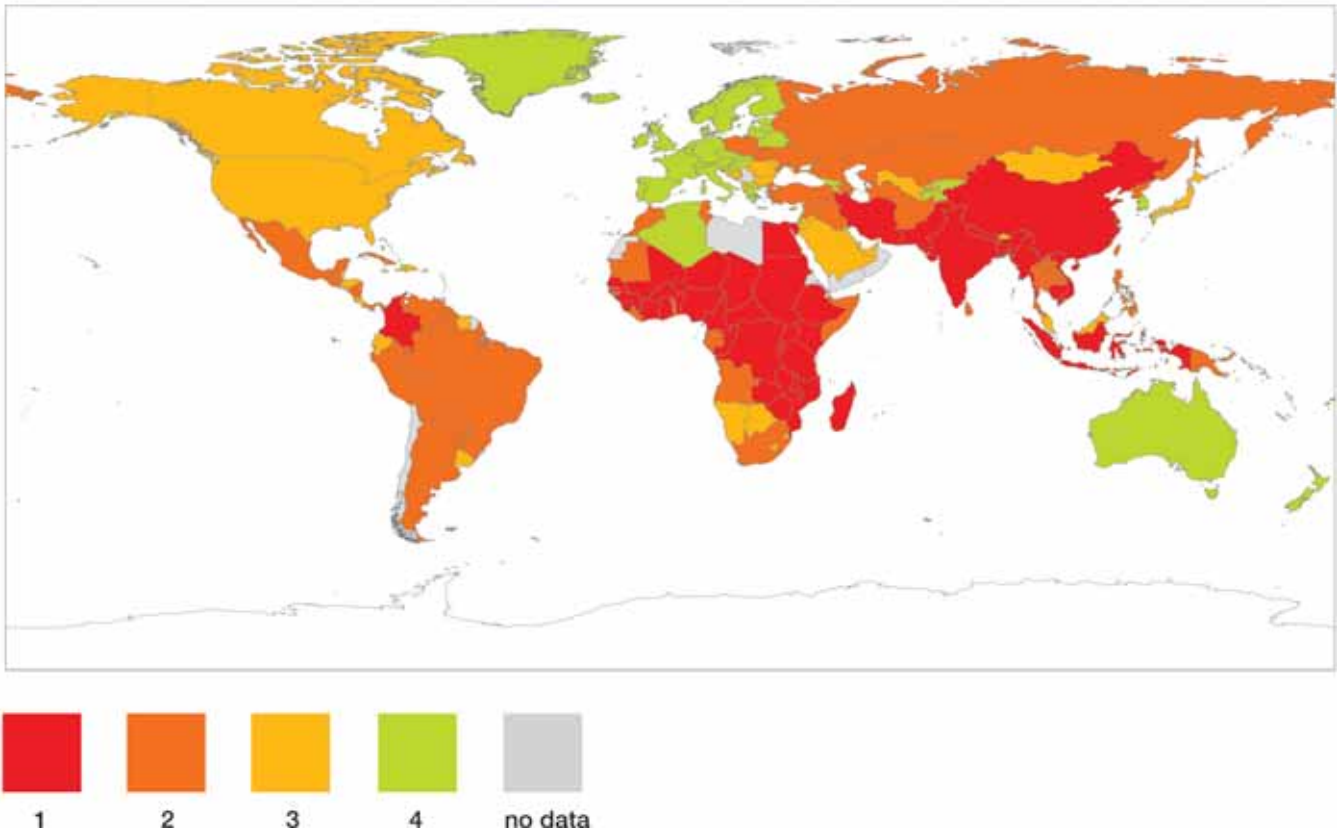


Figure 13. **Impact of climate change on inland fisheries.** Those countries whose inland fisheries are most vulnerable to drought and increased water abstraction are shown in red (source: Scutt Phillips et al., 2010).

Box 8: Recent history of the fishery in Lake Victoria

Lake Victoria is the largest freshwater lake in Africa and the continent's largest inland fishery. It not only exemplifies the importance of these resources, but also the ways through which economic drivers can bring about ecological change. In the mid 1970s the recorded fish catch from Lake Victoria was only 100,000 tonnes. Today it has increased to approximately 1 million tonnes (Fig. 14) following a period of intense exploitation and substantial change in both fish communities and the wider lake ecosystem. The beach value of the catch now exceeds US\$350 million per annum, while the total annual export earnings of Nile perch exceeded US\$300 million in 2007 (LVFO, 2008).

The lake's fishery was originally dependent on two species of tilapias (*Oreochromis esculentus* and *O. variabilis*), non commercial harvest of haplochromine cichlids, and more than 20 genera of non-cichlid fish, including mormyrids, catfishes, cyprinids, and lungfish (Muhoozi, 2003). The gradual expansion of the commercial fishery led to progressive pressure on these species and to collapse of stocks of *O. esculentus* by the 1940s. In an effort to replenish stocks, four species of tilapias were introduced (Welcomme,

Box 8 continued...

1967) followed by Nile perch *Lates niloticus* between 1955 and 1963 (Pringle, 2005). As a result of these introductions, the populations of Nile tilapia *Oreochromis niloticus* and Nile perch have grown to become the most important large fish species harvested in the lake. Nile perch has become especially important; it began to dominate fish catches in the mid 1970s, and harvest peaked in 1990 as fishing effort increased. The Nile perch has been blamed for a parallel decline in abundance of haplochromines, but it is now recognized that eutrophication of the lake as a result of land use change in the catchment has almost certainly also played a part (Balirwa, 2007; Welcomme, 2001).

Since 1990 the catch of Nile perch has declined, and that of the small pelagic cyprinid *Rastrineobola argentea* (known locally as dagaa, omena and mukene) has increased rapidly. This small species is now the most important catch from the lake in terms of weight, peaking at 650,000 tonnes in 2006. Dagaa owes its success to its adaptability. Although primarily a zooplanktivorous species it is able to utilize other food sources, while morphological changes to its gill rakes allow it to utilize the smaller plankton that now predominate in the lake (Wanink et al., 2000). Figure 15 summarizes the changes that have occurred to the food web in Lake Victoria.

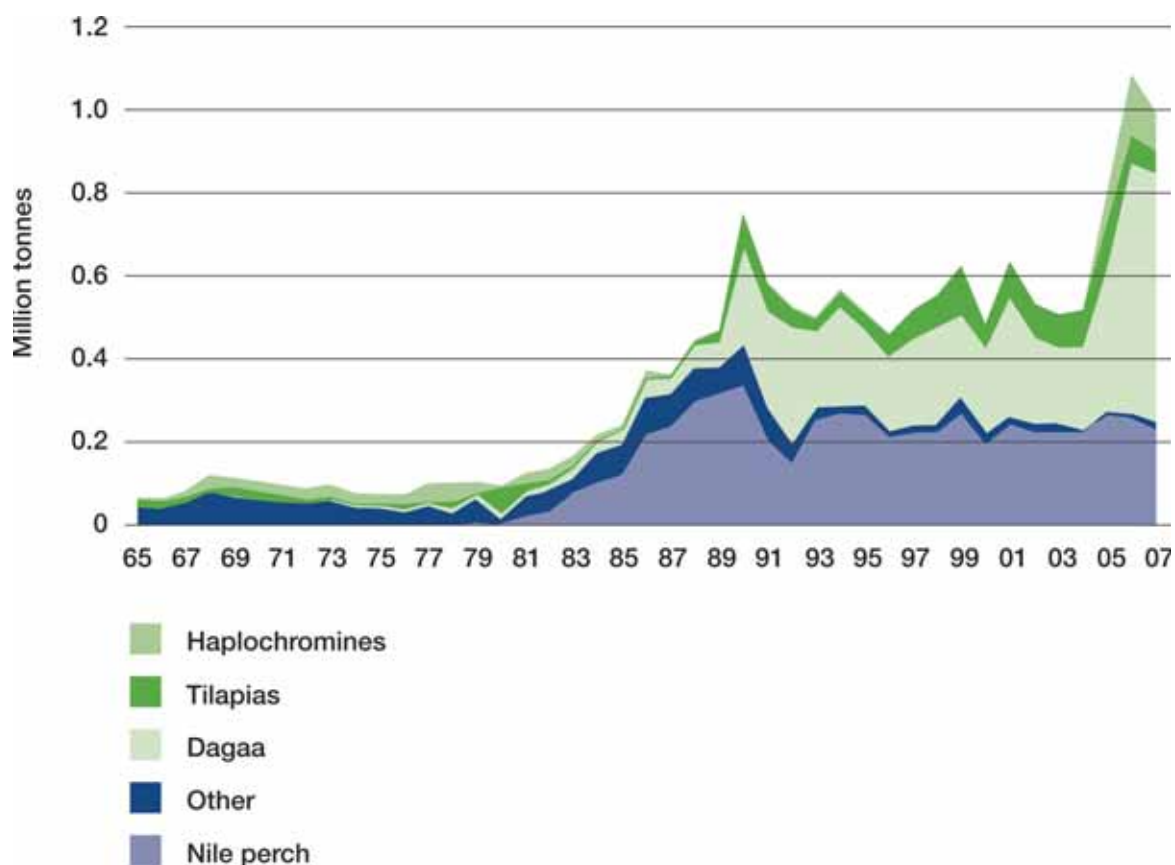


Figure 14. Evolution in species composition of fish catches from Lake Victoria 1965-2007 (source: FAO, 2009).

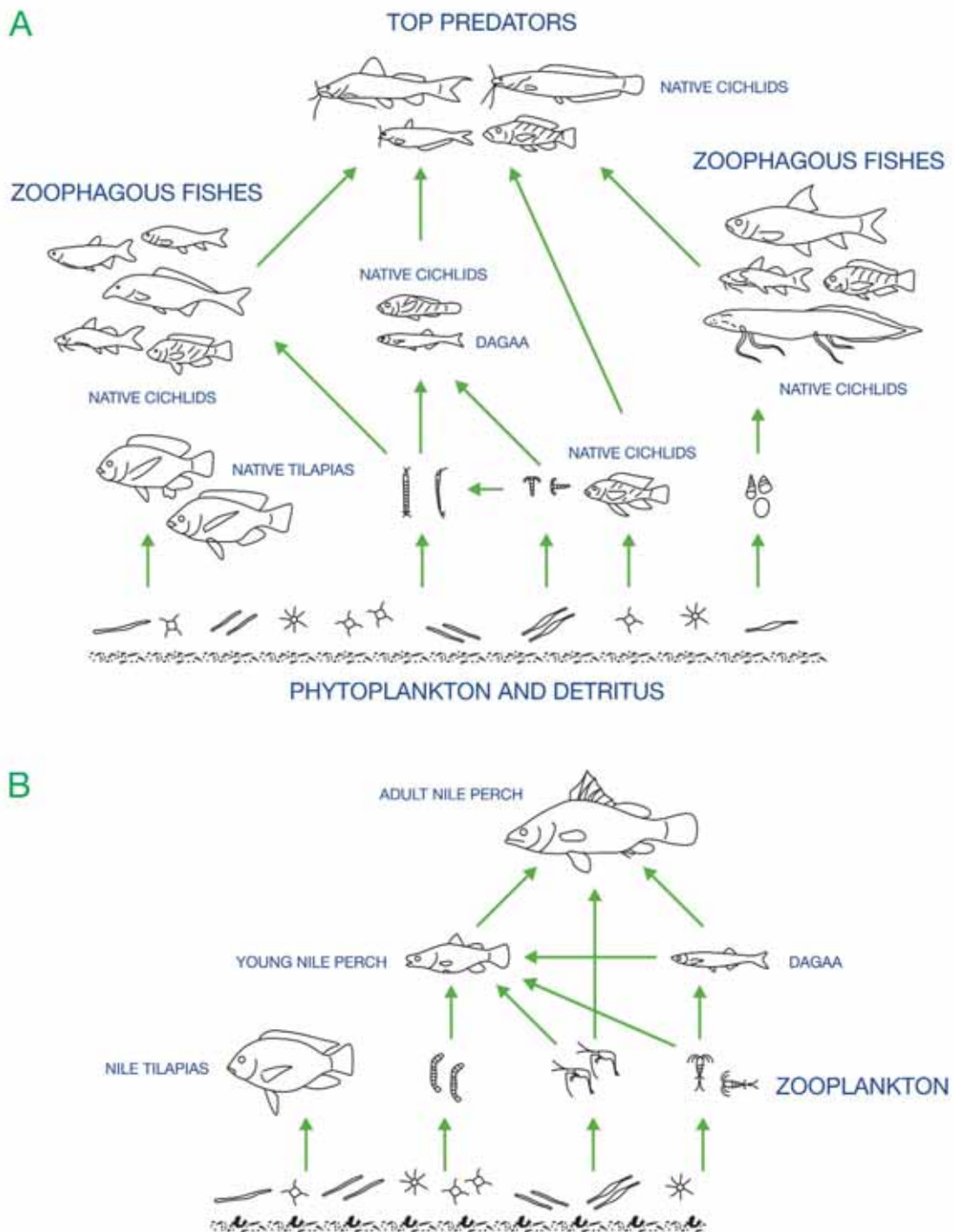


Figure 15. **Changes in the food web of Lake Victoria following fish introductions** (source: Moreau, 1997). Before introduction of Nile perch and Nile tilapia the lake supported a complex food web (A). This is now much simpler (B), and has greatly reduced biodiversity. While the fish catch from this simpler system has increased greatly, there is concern that it may be less resilient and more vulnerable to future shocks.

Overfishing

While FAO has concluded that the principal factors threatening inland fisheries are habitat loss and environmental degradation, they have also highlighted that most inland capture fisheries (that are not stocked) are overfished or are being fished at their biological limit (FAO, 2003). This has led to substantial change in the fish populations inhabiting rivers

and lakes and to changes in fish catch. As in most animal communities, inland fisheries are characterised by large numbers of small species and small individuals, and small numbers of large species and large individuals (McDowall, 1994). Because of their small numbers and lower growth rates these large fish are more prone to depletion (Allan et al., 2005), especially where they are the focus of targeted fish-

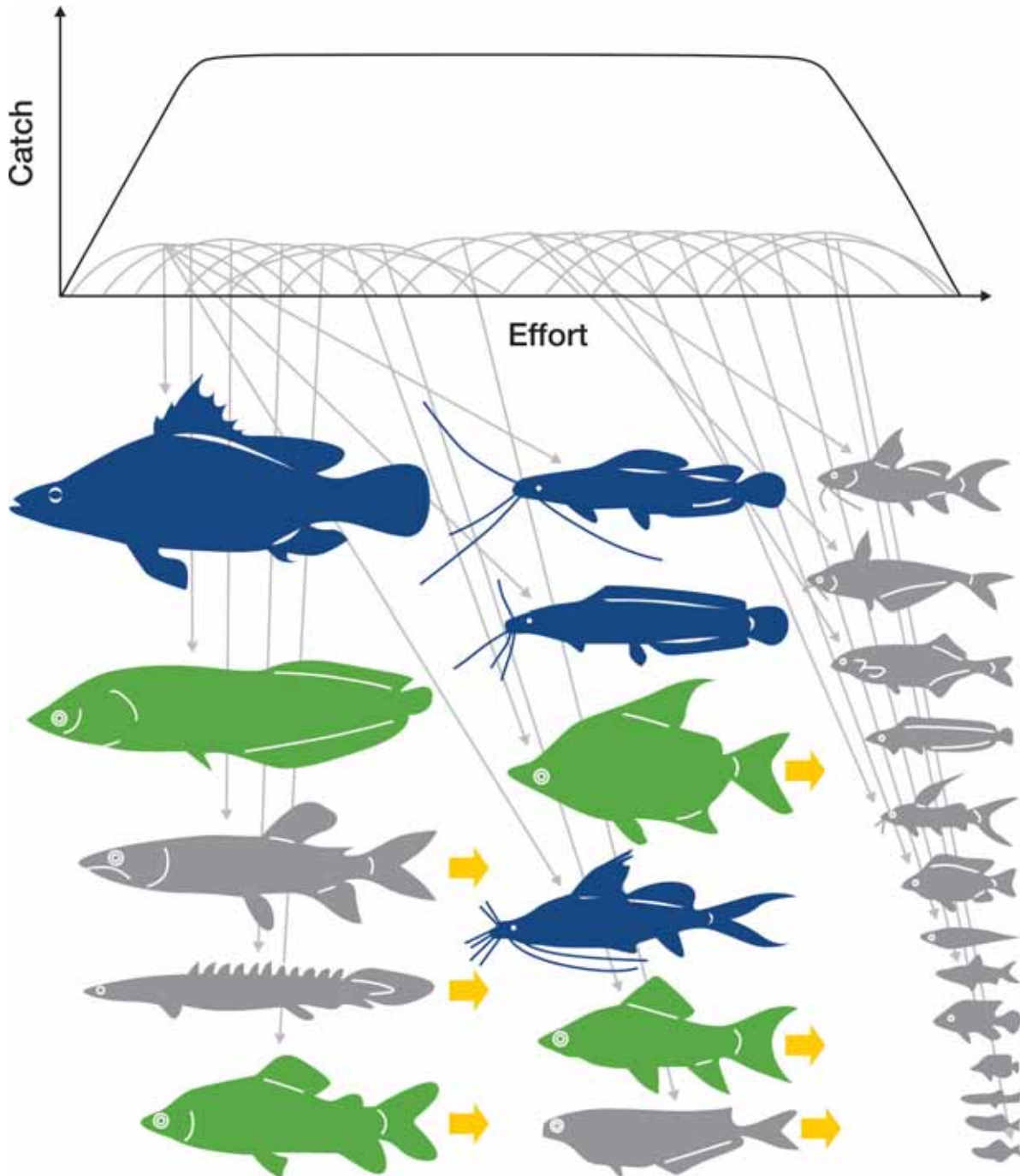


Figure 16. **Illustration of fishing down using the Ouémé River in West Africa.** As the fishing effort increased, catch switched from larger to smaller species and individuals. Species shown in blue disappeared from the fishery and the population sizes of species shown in green were severely reduced. Yellow arrows show species that now breed at smaller size. (Source: Welcomme, 2001).

eries. For example, several large fish species in the Mekong are endangered and the Mekong Giant Catfish is close to extinction in the wild (Hogan et al., 2004).

The progressive removal of larger species (mainly predators) in inland waters has led to the phenomenon called 'fishing down', where the small numbers of large species are replaced by larger numbers of small species (Fig. 16) (Welcomme, 1999). While this process generally leads to loss of species from the fishery it does not necessarily lead to a reduction in total fish catch. Instead the catch of large fish is replaced by an equal (and sometimes greater) volume of small fish. For example in the Tonle Sap fishery of Cambodia the number of fishers has increase from 360,000 in the 1940s to some 1.2 million in 1998.

While catch per fisher has decreased by 50%, overall catch has nearly doubled.

However large and medium sized fish dominated the 1940s catch, whilst the current catch is dominated by small fish (Allan et al., 2005). Similar phenomena have been documented in Bangladesh (Halls et al., 1998) and for Africa's floodplains fisheries, especially the Ouémé in Benin (Welcomme, 1971) and Niger in Mali (Laë, 1995), and the fish catch from Lake Victoria is now dominated by small pelagic cyprinids (see Box 8). While these changes in fish composition may not impact total fish catch or value of the fishery, they can contribute to significant ecological change (Box 9). These changes can reduce resilience and make the ecosystem more vulnerable to external shocks (Holmlund and Hammer, 1999).

Box 9: Fish and ecosystem functioning

The present study focuses on inland fisheries as a provisioning ecosystem service. However fish also play a key role in the functioning of aquatic ecosystems and so also provide important regulating and supporting services. Fish consumption of plankton, plants, insects, and other fish impacts upon the trophic structure of aquatic ecosystems and so can influence their stability, resilience and food web dynamics. Removal of top predators and herbivores in particular can lead to significant changes in species composition and to ecosystem change. For example large mortality of the zooplankton feeding *Coregonus artedii* from Lake Mendota in the USA led to changes in the plankton composition of the lake, decreased availability of nutrients in the water column and decline in biomass of algae (Vanni et al., 1990).

Similarly fish can change the physical structure of aquatic ecosystems as a result of their foraging and spawning activities. The spawning behaviour of salmon for example removes aquatic macrophytes, and fine sediment, and can displace invertebrates. Similarly, spawning beds of the cichlid fish *Sarotherodon aurea* disturbed over 10% of the littoral habitat of Lake Thonotosassa, USA, and modified benthic community organization (Fuller and Cowell, 1985).

Fish also provide important links between ecosystems. In North American rivers, marine-derived carbon and nutrients are provided by migrating salmonids through excretion, spawning and carcasses, and help support the production of algae, insect larvae, young salmon and other fish in these rivers (Larkin and Slaney, 1997). Nutrients and organic matter from salmon eggs and carcasses have been reported to stimulate biomass production up to 50 km downstream (Bilby et al., 1996; Larkin and Slaney, 1997). Similarly in Lakes Dalnee and Blizhnee, in the Kamchatka region of northern Russia, 20-40% of the total annual phosphorus impact was supplied by sockeye salmon carcasses (Krokhin, 1975).

Source: Holmlund and Hammer, 1999.



Chapter 3:

Managing for Sustainability of Inland Fisheries

The ecosystem approach to managing inland fisheries

Awareness of the importance of natural ecosystems, of the services they provide and the threats they face, has grown over the past few decades. This in turn has led to greater understanding of the need for a more holistic approach to conservation and use of these ecosystems and their resources. The ecosystem approach, which according to the Convention on Biological Diversity (CBD) is *"a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way ..."* (UNEP, 2009; Smith and Maltby, 2003), is the corner stone of the UNEP Ecosystem Management Programme (UNEP-EMP). The Convention further specifies that the ecosystem approach *"requires adaptive management to deal with the complex and dynamic nature of ecosystems and the absence of complete knowledge or understanding of their functioning, and that measures may need to be taken even when some cause and effect relationships are not yet fully established scientifically"* (UNEP, 2009).

The UNEP-EMP considers ecosystems as holistic living systems and recognizes that they provide a host of different interconnected services, rather than just a resource base to be exploited. The UNEP-EMP promotes environmental policies that recognize biodiversity as an integral component of ecosystem functioning and therefore to the delivery of ecosystem services. Such policies should be integrated into development planning and environmental management planning, including into fisheries management. Given the interconnectivity of ecosystem services, it is also important to recognize the need for 'trade-offs' that help achieve the optimal mix and equitable distribution of these services. In parallel with the emergence of the ecosystem approach of UNEP and the CBD, FAO has built on the Code of Conduct for Responsible Fisheries (FAO, 1995) to promote the Ecosystem Approach to Fisheries (EAF) (Garcia, 2003). The EAF and the Code of Conduct have considerable legal and policy status in many jurisdictions and are now enshrined in the national laws of many countries. As a consequence the EAF provides a widely accepted approach to small scale fisheries

management in the developing world. As defined by FAO (2003) the EAF *"... strives to balance diverse societal objectives, by taking account of the knowledge and uncertainties about biotic, abiotic and human components of ecosystems and their interactions, and applying an integrated approach to fisheries with ecologically meaningful boundaries"*.

This international consensus on the importance of comprehensive ecosystem-based approaches provides an unprecedented opportunity to improve management of freshwater ecosystems, and the fisheries they support. By placing emphasis on the external nature of the most important drivers, the ecosystem approach shifts our focus from inside to outside the fishery, and to the development of multi-sectoral management that engages effectively with this wider context. At its fullest interpretation, the ecosystem approach goes well beyond the traditional domain of the fisheries sector to reap the benefits of proactive dialogue with institutions and individuals involved in energy, water, health, urban development, forestry, and other aspects of natural resource management. For example, while some forms of hydro-power development can have a catastrophic impact on fisheries, early dialogue can influence the location, design and management of dams in ways that can greatly reduce impacts on fisheries (ICEM, 2010). Similarly sustaining inland fisheries in the face of wider rural and urban development requires early engagement with these processes, and a perspective that considers fisheries within a wider view of people's needs.

The multi-sectoral engagement of the ecosystem approach extends to other sectors that benefit from healthy aquatic ecosystems. For example water quality, flood regulation and biodiversity are other services provided by freshwater ecosystems. While inland fisheries may be the most important resource in some of these systems (Table 4) management approaches that seek to sustain and harness the full range of ecosystem services will not only build a stronger constituency in support of ecosystem management, but also help build understanding of the wider importance of these systems and secure their full value to society.

Table 6. *The 12 principles of the ecosystem approach and their rationale* (source: UNEP and CBD, 2000).

The following 12 principles are complementary and interlinked:
1. The objectives of management of land, water and living resources are a matter of societal choice.
2. Management should be decentralised to the lowest appropriate level.
3. Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems.
4. Recognising potential gains from management, there is usually a need to understand and manage the ecosystem in an economic context. Any such ecosystem-management programme should: (a) Reduce those market distortions that adversely affect biological diversity; (b) Align incentives to promote biodiversity conservation and sustainable use; (c) Internalise costs and benefits in the given ecosystem to the extent feasible.
5. Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the ecosystem approach.
6. Ecosystems must be managed within the limits of their functioning.
7. The ecosystem approach should be undertaken at the appropriate spatial and temporal scales.
8. Recognising the varying temporal scales and lag-effects that characterise ecosystem processes, objectives for ecosystem management should be set for the long term.
9. Management must recognise that change is inevitable.
10. The ecosystem approach should seek the appropriate balance between, and integration of, conservation and use of biological diversity.
11. The ecosystem approach should consider all forms of relevant information, including scientific and indigenous and local knowledge, innovations and practices.
12. The ecosystem approach should involve all relevant sectors of society and scientific disciplines.

In addition to looking beyond the fishery in this way, the ecosystem approach recognises the limits to proactive management. Because of the multiple drivers that impact inland fisheries (Table 5) and the complex interactions between these, it is rarely possible to identify all drivers and tease out multiple impact pathways for each fishery. This means that managing these systems can be a very uncertain 'science' and argues for investing to maintain resilience and with it multiple options for future use of these ecosystems. Underlying this approach is explicit recognition that resilience is fostered by investments that maintain ecosystem functioning, reduce vulnerability, and build adaptive capacity in the face of unforeseen and unforeseeable threats.

Taking up this challenge will require drawing upon the approaches set out by UNEP's Ecosystem

Management Programme, the CBD, and FAO, and identifying specific pathways to sustainability that are adapted to the specific challenges of different aquatic ecosystems and the fisheries they support. Applying the twelve principles of the ecosystem approach of the CBD (Table 6) and EAF, this diagnosis and management needs to be participatory and adaptive, and needs to look both within the fishery and its ecosystem, and the wider environment of the river or lake basin, as well as the larger development context. A number of frameworks have been developed to pursue this approach (Andrew and Evans, 2009), of which the framework for Participatory Diagnosis, Assessment and Management of small scale fisheries is the most recent (Andrew et al., 2007) (Fig. 17). This sets out participatory diagnosis as the entry point, including careful identification of stakeholders, followed by adaptive management as the focus for investment.

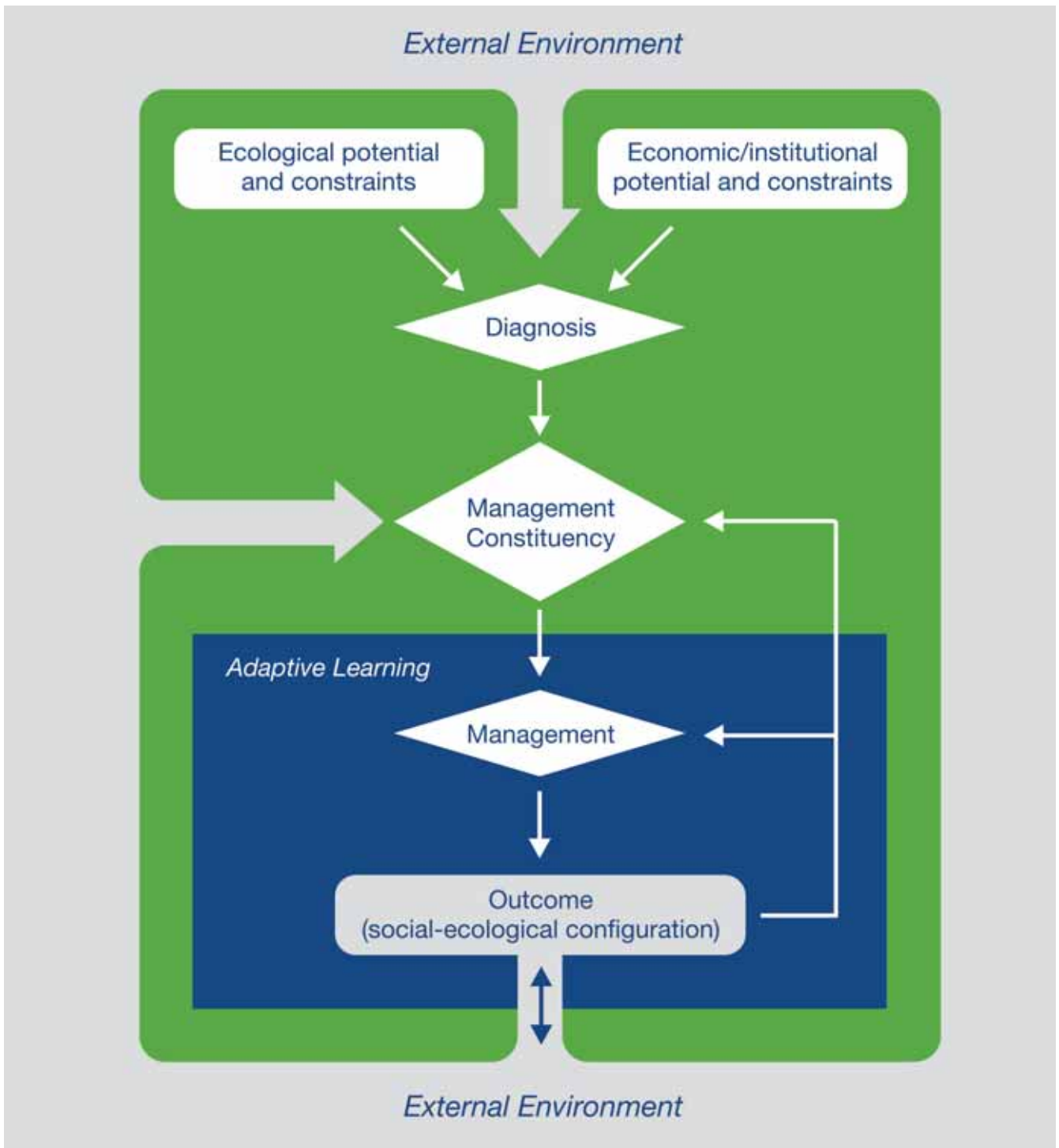


Figure 17. **Participatory diagnosis and management** (source: Andrew et al., 2007).

Participatory diagnosis

There are three main elements in participatory diagnosis:

Defining the fishery. Inland fisheries are characterised by complexity. Many cover large geographical scales and contain multiple species; the people who fish may be difficult to identify and may change over the course of a year, and for many the

fishery is only one dimension of diversified livelihoods. The Lake Chilwa fishery of southern Malawi and Mozambique provides one example of this complexity (Box 10). If we are to focus effectively on the drivers that impact the fishery and its benefits to people, we need first to understand its scale and scope. Open participatory processes that engage all key stakeholders within and outside the fishery are needed.

Identifying drivers of change. Once the fishery has been defined, the assessment needs to continue to work with stakeholders to identify and quantify the constraints and opportunities faced. This analysis of positive and negative drivers can be strengthened, whenever possible, with historical information on the fishery. For example, the historical information available for Lake Victoria, the Inner Niger Delta, the Mekong and Lake Chilwa, allows current discussion of the impacts of climate, dam development and fishing pressure, to draw on understanding of how the fishery has evolved over time and responded to different types of natural and human induced change.

Identifying future scenarios. Future scenarios and management objectives for the fishery need to be agreed upon by stakeholders. Unless this happens it is unlikely that there will be any real progress towards sustaining these resources, regardless of how well the drivers of change are understood. This stage of the diagnosis needs to embrace the social and political dimensions of the fishery and ecosystem management, and bring together different social, economic, and institutional perspectives and imperatives. In doing so it needs to confront the power relations between and within stakeholder groups and work to develop scenarios that recognise the costs and benefits to different stakeholders of different management options.

Scenarios map out divergent perspectives within a system and allow open and honest debate and learning, including identifying competing ecosystem services and the trade-offs that may be necessary (Bailey and Jentoft, 1990). Activities taking place within ecosystems can impact on each other, often in unforeseen ways. Some of these activities may have quick gains in the delivery of one particular ecosystem service, while resulting in a negative impact on overall ecosystem functioning and so limiting the delivery of another service. For example, overexploitation of fish populations in a given system may increase the growth of aquatic vegetation impacting negatively on navigation or freshwater intakes for municipal or industrial uses.

Because of these interactions, stakeholders should undertake a trade-off analysis on the services desired in an ecosystem and prioritize them for the purposes of management planning and implementation. For inland fisheries and aquatic ecosystems key questions include the following:

Is the ecosystem and its fishery to be managed primarily for human well-being, or biodiversity conservation? Is the fishery to be managed to develop its potential as an economic resource, or sustained as a social safety net? Does the cost of sustaining the ecosystem and managing the fishery greatly outweigh the benefit obtained, or might some degree of ecosystem degradation and fishery decline be accepted? Discussion of potential small scale fishery trajectories within the context of global scenarios, such as those developed for climate change (IPCC, 2000), can add extra dimensions to the debate.

The MA used scenario planning to look at global futures with different degrees of ecosystem loss and degradation. These should now be developed for specific inland fisheries to compare for example: i) management of the ecosystem and fishery for national or local development; ii) various forms of governance and their likely outcomes; iii) protection of traditional authority and management structures versus modernisation of fishing technology and governance structures; and iv) the outcomes of managing for different sets of drivers (internal/external).

Adaptive management

The ecosystem approach embraces the importance of building on the participatory analyses to pursue adaptive management. This approach has three key steps:

Identifying who needs to be involved and how.

Just as quality diagnosis requires effective participation of stakeholders, so ecosystem management needs this stakeholder engagement to be sustained. This requires careful stakeholder analysis followed by thoughtful design and management of the stakeholder interactions and management structures. This analysis and design needs to be guided by the drivers of change identified through the participatory diagnosis. It needs to reach out to those constituencies outside the fisheries sector that impact on fisheries, in particular those concerned with wider land and water management and economic development such as energy, trade and agriculture. Similarly it needs to engage with those sectors that draw on other services provided by aquatic ecosystems, including water supply, conservation and tourism.

Adaptive learning. The complexity and variability of the ecosystem processes that sustain inland fisheries, and the drivers that influence these, brings with it great uncertainty (see example of

Box 10: Lake Chilwa fishery: an example of complexity

In the Lake Chilwa fishery of southern Malawi and Mozambique fishers use a range of gear (including traps, fine-mesh seines and long lines), to target a variety of fish primarily *Barbus*, *Clarias* and *Oreochromis* species. There are as many as 5000 specialist and part-time fishers who also derive their income from farming and petty trading, and who enter and leave the fishery as catches and economic opportunities rise and fall. The fishery is co-managed by the Fisheries Department, and the Lake Chilwa Fisheries Management Association, which is composed of 43 Beach Village Committees. Management focuses on controlling access through the issuing of licenses and enforcement of fines for violating the closed season or for using inappropriate gear. Chilwa is an endorheic lake that recedes and expands with rainfall patterns in the basin (see Fig. 12b). Catches fluctuate with lake level and in good years account for almost half the total fish production in Malawi. The integrity of the lake system is dependent on the extensive wetlands that surround the lake and on ecological processes in the catchment. Some fish migrate up the rivers to spawn, so further enlarging the scale of the fishery and the scope of management.

Source: Andrew and Evans (2009).

Lake Chilwa in Box 10). This is increased by the often complex social and institutional environments within which management processes take place. Successful management of inland fisheries needs to embrace this complexity and adopt an effective process of adaptive learning that adjusts management practices and policies in response to the results achieved. The participatory diagnoses advocated here lay the basis for adaptive management. By engaging stakeholders and focusing on adaptive learning these management processes provide the flexibility that is needed to deal with the complex realities of natural ecosystems. Adopting these adaptive management approaches for complex, and relatively poorly understood, ecosystems and processes, is gaining wide acceptance. Yet there are still relatively few cases where these have been pursued effectively, and in particular in the developing world where their importance for human well-being is greatest. Major investment is needed to correct this if freshwater ecosystems and the inland fisheries they sustain are to be managed effectively in the coming decades.

Monitoring and evaluation. This flexible ecosystem approach to managing inland fisheries requires an effective system of monitoring and evaluation that guides subsequent adjustments in management and policy. This in turn requires indicators that simplify, quantify and communicate information regarding progress against the agreed management objectives. In most developing country contexts an ideal set of data intensive

indicators is unlikely to be feasible. More appropriate indicators are those that can trace progress in status of the fishery (improving, stable, degrading), those that reflect perceptions of change using local ecological knowledge and participatory science, and those that reflect socially relevant impacts of change such as income from fish catch.

Planning and managing catchments for inland fisheries

The ecosystem approach highlights the importance of sustaining ecological processes that sustain fisheries productivity. This means investing in maintaining healthy catchments with appropriate land use and coverage of natural forest and wetland ecosystems, and sustaining the quality and quantity of water flow into lakes and rivers. Doing so requires engaging with land and water management processes at multiple scales within these lake and river basins. A number of approaches are available to assist with this engagement, but three of the most valuable are strategic environmental assessment, integrated planning at the basin scale, and design of environmental flow regimes for fisheries.

Strategic Environmental Assessment. Sustaining the productivity of freshwater ecosystems in the face of multiple drivers of change requires a comprehensive assessment of these drivers and their impacts. Strategic Environmental Assessment (SEA) is one approach that is being used increasingly to engage with these issues in river basins. By assessing cumulative impacts and addressing broader strategic issues relating to multiple driv-

ers, SEA provides a powerful tool for understanding these drivers and developing approaches for managing them. For example SEA has been used effectively in the Vu Gia Thu Bon river basin in Vietnam to review the potential impacts of hydropower development and identify sub-basins that could be kept free from dams in order to sustain natural ecosystems and their services (Fig. 18). A similar approach is now being used in the Mekong (ICEM, 2010).

Integrated planning. When SEA and other analyses contribute to effective dialogue with key basin stakeholders, it is possible to plan river basin development so that impacts on fisheries are min-

imised (Fig. 19). Such integrated planning is still rare but the example of the Vu Gia Thu Bon basin in Vietnam (Fig. 18) shows what is possible. Similarly on the Penobscot River in the USA a dam re-licensing agreement between a power company and local stakeholders includes the removal of two main-stem dams and improved fish passage at the dams that will remain. Power production will be increased at the remaining dams through various management and technology improvements, so that total hydropower from the basin will be maintained. Removal of the dams is however expected to lead to an increase in the proportion of the basin accessible to migratory fish and so will contribute to increased fish populations (Richter et al., 2010).

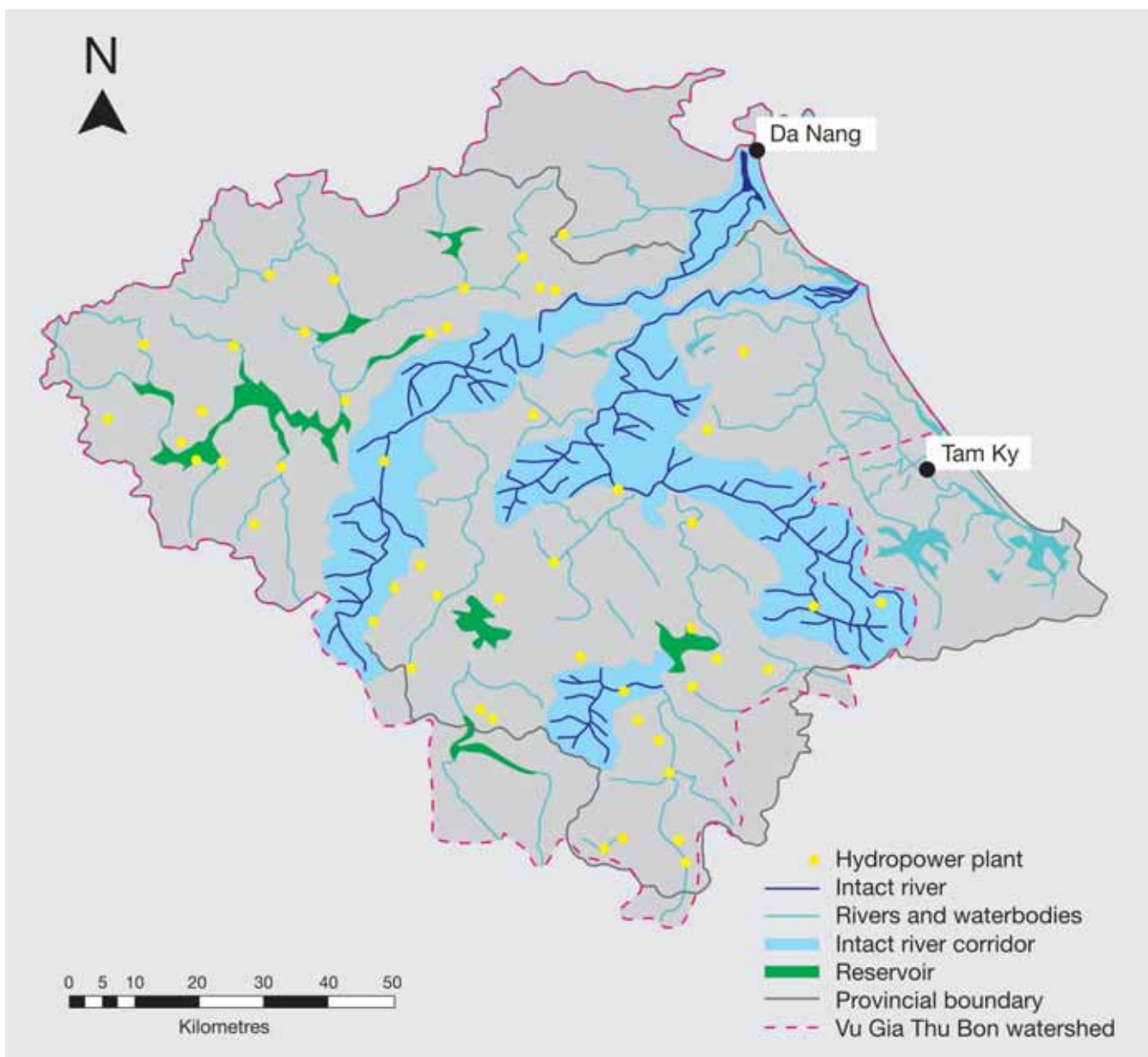


Figure 18. **Strategic Environmental Assessment in the Vu Gia Thu Bon river basin.** The SEA identified intact river corridors to be maintained. This proposal has now been adopted by government (source: ICEM, 2008).

Environmental flows for fisheries. When dams are built, careful design can still reduce impacts on fisheries. Historically such efforts have focused on the design of fish passages to allow spawning migrations upstream and feeding migrations downstream. Although these investments have had varied success and some are extremely costly, they need to be continued and improved. However it is now widely recognised that they need to be accompanied by a range of other measures to sustain the natural environment downstream of the dam, and the fisheries that depend upon this. These measures include the installation of sluice gates that allow sediment outflow from below the dam wall, but the most important are the design and management of environmental water flows (Arthington et al., 2007). While a regulated river cannot reproduce all aspects of the natural flow at the same time as providing for competing uses, well designed envi-

ronmental flows can maintain the river ecosystem at a level required to sustain fisheries at an acceptable level. The success of such approaches has been demonstrated on the Pongolo River in South Africa where controlled releases from an upstream dam were sufficient to flood the Pongolo Flats downstream and rehabilitate the fisheries of the floodplain (Weldrick, 1996). In future however, these measures need to be integrated into dam design from the outset and to do so the environmental flow requirements for fisheries need to be determined. As yet however, environmental flows have not been determined in any large river systems and attempts to incorporate fishery needs into existing tools (largely developed for small temperate rivers) are in their infancy (Arthington et al., 2007). Environmental flows also need to take explicit account of water quality requirements for fisheries, and tools to help do so developed.

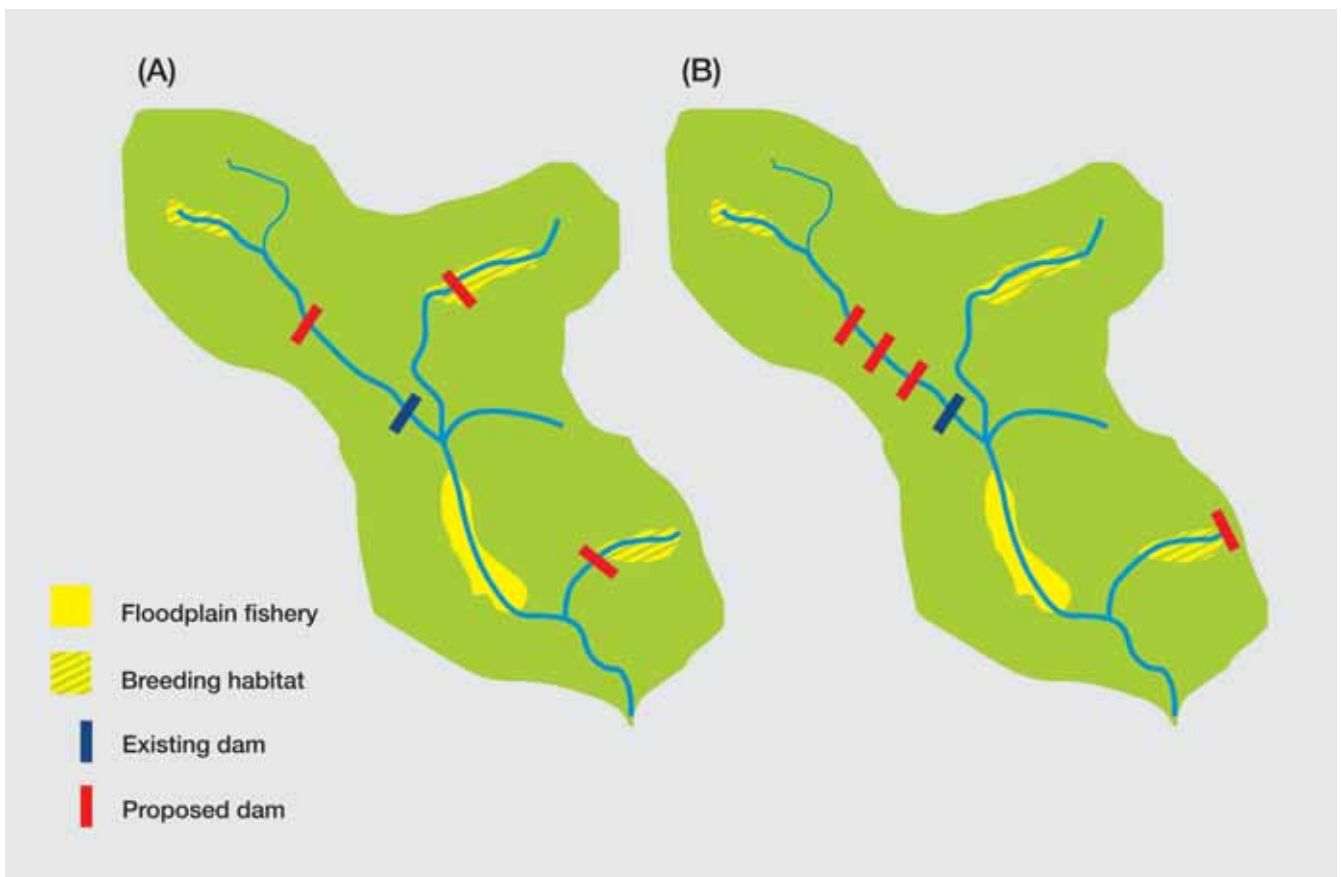


Figure 19. **Integrated planning for dams and river fisheries** (after Richter et al., 2010). Without integrated planning (A), new dams are likely to be built on all major tributaries, including those with important fish breeding and feeding habitats. Building the dams low in the tributaries prevents migration to the breeding habitats. In this scenario no options for environmental flow regimes are integrated into dam design. With integrated planning (B), new dams are built only on some tributaries, and a cascade of dams is built on the tributary with an already existing dam. Where dams are built on new tributaries, these are sited upstream of fish breeding habitats so allowing access to migratory fish populations. Environmental flow regimes are also developed for all dams.



Chapter 4:

Investing in the Ecosystem Approach to Inland Fisheries

This review highlights both the importance of inland fisheries and the threats they face. Sustaining this ecosystem service in the face of multiple external pressures, and the absence of social institutions required to foster robust management, presents a major challenge. It is one that needs to be met however if the hundreds of millions of people who depend on inland fisheries are to avoid traumatic decline in their well-being. UNEP's Ecosystem Management Programme is working to achieve this by fostering application of the ecosystem approach to management of inland fisheries and the ecosystems they depend upon. In support of this approach five investments in improved policy and management are recommended:

- a) Improve understanding of inland fisheries' vulnerability to environmental change
- b) Develop viable options for addressing the threats posed to inland fisheries by environmental change
- c) Build adaptive capacity among key stakeholder groups to increase resilience of inland fisheries at local, national and regional scales
- d) Improve governance of inland fisheries and their ecosystems
- e) Develop capacity to sustain and enhance social benefits from these resources.

Each of these investments is summarised below. In taking these steps the ecosystem approach advocates reaching out to other sectors that impact on inland fisheries and those that depend on other services provided by freshwater ecosystems. This cross-sectoral perspective will be central to success.

a) Improve understanding of inland fisheries' vulnerability to environmental change. If future investments in environmental management are to support the long-term maintenance of the ecosystem services provided by inland fisheries, the current pressures upon these fisheries and future trends need to be better understood. Systematic analyses of the vulnerability of these fishery systems are needed, combining assessments of the risk to different fisheries and

their dependent communities as well as of their capacity to mitigate and adapt. Drawing upon this information, future scenarios for major inland fisheries can be developed and advice provided to governments and regional bodies regarding future investments in management taken to address these. Analyses of the value and future scenarios for inland fisheries should take the form of participatory diagnoses (Andrew et al., 2007; Evans and Andrew, 2009), in which key stakeholders are recognised and brought together to define the fishery and assess its value, identify drivers of change, and agree future scenarios. These analyses can lay the foundation for innovation in management and governance, and provide a framework for long-term investment.

b) Develop viable options for addressing the threats posed to inland fisheries by environmental change.

While the full effects on inland fisheries of some types of environmental drivers, notably climate change, are still being understood, the potential impacts of many are clearer. This provides an opportunity to develop management approaches that can help sustain fisheries in the face of these changes. In doing so, specific attention needs to be given to sustaining the water flow required to maintain river fisheries. In some cases this will be achieved by keeping rivers free from dams and other infrastructure, but in others it will mean developing environmental flows for fish as part of the design of new dams. The key ecological principles required to do this are well understood (Arthington et al., 2007), but need to be adapted to the specific requirements of individual rivers, dams and fisheries. Similarly approaches to maintaining water quality need to be developed for specific fisheries.

c) Build adaptive capacity among key stakeholder groups to increase resilience of inland fisheries at local, national and regional scales.

Given the scale of the environmental pressures confronting inland fisheries it is very likely that the future will bring change to many of these. In the face of this probable change investments are needed to increase resilience and improve adaptive capacity at regional,



national and local scales. These investments may include:

- Supporting local or community-based fishery management institutions to become flexible, adaptive, 'learning organisations' that are able to respond to change. Management at the scale of the community, as with any form of institution, will need to 'fit' the ecological and social processes that envelop it. Community-based management will not be appropriate in all cases and where it is appropriate it will not take the same form.
- Providing them with information on projected environmental change and likely impacts on fisheries, and supporting them to engage in processes that can design future investments in land and water management and mitigation of the negative impacts of such investments.
- Strengthening the capacity of fishery-dependent people to diversify their livelihoods, and so adapt their dependence on inland fisheries to the size of the resource. This may include providing access to appropriate literacy and technical training, or to improved micro-financial services (saving and insurance, as well as credit).

d) Improve governance of inland fisheries and their ecosystems. Fisheries governance remains one of the most difficult arenas in natural resource management. If interpreted broadly as required by the ecosystem approach, reform should be integrated into a wider development agenda that can include trade, agriculture, and water policy, as well as social reforms that include decentralisation and human rights (Allison, in press). These opportunities need to be taken up and the specific needs of inland fisheries well explained, justified and followed-through with effective implementation. Investments should focus on providing knowledge and science-based evidence for policy debates at all stages, in particular by supporting civil society at national and basin levels.

e) Develop capacity to sustain and enhance social benefits from these resources. Ability to maintain and sustain the development benefits of inland fisheries in the face of environmental change is seriously constrained by limited capacity at all levels. Specifically, these constraints include the ineffectiveness of leadership in many key agencies, the absence of effectively integrated policies and management, and inadequate information and communication systems. To address these capacity gaps, significant investment is needed, with an initial focus on highest priority inland fisheries, notably those of the larger rivers and lake basins.

Glossary

Adaptation

Adjustment in natural or human systems to a new or changing environment, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation.

Adaptive capacity

The potential or ability of a system, region or community to adapt to the effects or impacts of a particular set of changes. Enhancement of adaptive capacity represents a practical means of coping with changes and uncertainties, reducing vulnerabilities and promoting sustainable development.

Adaptive management

Systematic process of continually improving management policies and practices (www.environment.fi).

Aquaculture

The farming of aquatic organisms in inland and coastal areas, involving intervention in the rearing process to enhance production and the individual or corporate ownership of the stock being cultivated.

Biodiversity

The variety of life on Earth, including diversity at the genetic level, among species and among ecosystems and habitats. It includes diversity in abundance, distribution and in behaviour. Biodiversity also incorporates human cultural diversity, which can both be affected by the same drivers as biodiversity, and itself has impacts on the diversity of genes, other species and ecosystems.

Biochemical oxygen demand (BOD)

The amount of dissolved oxygen, in milligrams per litre, necessary for the decomposition of organic matter by micro-organisms, such as bacteria. Measurement of BOD is used to determine the level of organic pollution of a stream or lake. The greater the BOD, the greater the degree of water pollution.

Catchment area

The area of land bounded by watersheds draining into a river, basin or reservoir.

Driver

Any natural or human-induced factor that directly or indirectly causes a change in an ecosystem.

Ecosystem

A dynamic complex of plant, animal and micro-organism communities and their non-living environment, interacting as a functional unit.

Ecosystem approach

A strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. An ecosystem approach is based on the application of appropriate scientific methods, focused on levels of biological organization, which encompass the essential structure, processes, functions and interactions among organisms and their environment. It recognizes that humans, with their cultural diversity, are an integral component of many ecosystems.

Ecosystem function

An intrinsic ecosystem characteristic related to the set of conditions and processes whereby an ecosystem maintains its integrity (such as primary productivity, food chain and biogeochemical cycles). Ecosystem functions include such processes as decomposition, production, nutrient cycling, and fluxes of nutrients and energy.

Ecosystem management

An approach to maintaining or restoring the composition, structure, function and delivery of services of natural and modified ecosystems for the goal of achieving sustainability. It is based on an adaptive, collaboratively developed vision of desired future conditions that integrates ecological, socio-economic, and institutional perspectives, applied within a geographic framework, and defined primarily by natural ecological boundaries.

Ecosystem process

An intrinsic ecosystem characteristic whereby an ecosystem maintains its integrity. Ecosystem processes include decomposition, production, nutrient cycling, and fluxes of nutrients and energy.

Ecosystem services

The benefits people obtain from ecosystems. These include provisioning services, such as food and water, regulating services, such as flood and disease control, cultural services, such as spiritual, recreational and cultural benefits, and supporting services, such as nutrient cycling, that maintain the conditions for life on Earth. Sometimes called ecosystem goods-and-services.

Eutrophication

The degradation of water quality due to enrichment by nutrients, primarily nitrogen and phosphorus, which results in excessive plant (principally algae) growth and decay. Eutrophication may be accelerated by human activities that speed up the ageing process.

Freshwater ecosystem

According to Ramsar, wetlands cover lakes, rivers and all freshwater habitats, including peatland areas, such as fens, bogs and mires.

Human well-being

The extent to which individuals have the ability to live the kinds of lives they have reason to value; the opportunities people have to achieve their aspirations. Basic components of human well-being include: security, material needs, health and social relations.

Invasive species

An alien species whose establishment and spread modifies ecosystems, habitats or species.

Monitoring

Continuous or regular standardized measurement and observation of the environment (air, water, soil, land use, biota).

Overexploitation

The excessive use of raw materials without considering the long-term ecological impacts of such use.

Pollution

The presence of minerals, chemicals or physical properties at levels that exceed the values deemed to define a boundary between 'good or acceptable' and 'poor or unacceptable' quality, which is a function of the specific pollutant.

Resilience

The capacity of a system, community or society potentially exposed to hazards to adapt by resisting or changing in order to reach and maintain an acceptable level of functioning and structure.

Siltation

The process by which silt or mud is deposited in a reservoir, lake, seabed, river, or overflow area.

Strategic Environmental Assessment (SEA)

SEA is undertaken for plans, programmes and policies. It helps decision makers reach a better understanding of how environmental, social and economic considerations fit together. SEA has been described as a range of "analytical and participatory approaches that aim to integrate environmental considerations into policies, plans and programmes and evaluate the interlinkages with economic and social considerations".

Water quality

The chemical, physical and biological characteristics of water, usually in respect to its suitability for a particular purpose.

All definitions come from

<http://www.unep.org/geo/geo4/report/Glossary.pdf>

Acronyms

BNP	Big Numbers Project
CBD	Convention on Biological Diversity
EA	Ecosystem Approach
EAA	European Anglers Alliance
EAF	Ecosystem Approach to Fisheries
EPA	United States Environmental Protection Agency
FAO	Food and Agriculture Organization
ICEM	International Centre for Environmental Management
ICOLD	International Commission on Large Dams
LVFO	Lake Victoria Fisheries Organization
MA	Millennium Ecosystem Assessment
MDG	Millennium Development Goal
MRC	Mekong River Commission
SEA	Strategic Environmental Assessment
SSF	Small-Scale Fishery
TEEB	The Economics of Ecosystems and Biodiversity
UNEP	United Nations Environment Programme
UNEP-EMP	UNEP Ecosystem Management Programme
WCD	World Commission on Dams
WWF	World Wildlife Fund/World Wide Fund for Nature

References

- Abdullah, K. B. (2006). Use of water and land for food security and environmental sustainability. *Irrigation and Drainage* 55(3): 219-222.
- Ahmed, M., Navy, H., Vuthy, L. and Tiongco, M. (1998). Socioeconomic assessment of freshwater capture fisheries in Cambodia: a report on a household survey. Mekong River Commission. 186 pp. Phnom Penh, Cambodia.
- Allan, J., Abell, R., Hogan, Z. and Revenga, C. (2005). Overfishing of inland waters. *BioScience* 55(12): 1041-1051.
- Allison, E.H., C. Béné and N.L. Andrew (in press). Poverty reduction as a means to enhance resilience, in *Small-scale fisheries management frameworks and approaches for the developing world*. Pomeroy, R. and Andrew, N. (Eds). London, CABI.
- Andrew, N. and Evans, L. (2009). Approaches and Frameworks for Management and Research in Small-scale Fisheries. WorldFish Center Working Paper 1914. WorldFish Center. Penang, Malaysia.
- Andrew, N. L., Béné, C., Hall, S. J., Allison, E. H., Heck, S. and Ratner, B. D. (2007). Diagnosis and management of small-scale fisheries in developing countries. *Fish and Fisheries* 8(3): 227-240.
- Antonio, R. R., Agostinho, A. A., Pelicice, F. M., Bailly, D., Okada, E. K. and Dias, J. H. (2007). Blockage of migration routes by dam construction: can migratory fish find alternative routes? *Neotropical Ichthyology* 5(2): 177-184.
- Arthington, A. H., Baran, E., Brown, C. A., Dugan, P., Halls, A. S., King, J. M., Minte-Vera, C. V., Tharme, R. E. and Welcomme, R. L. (2007). Water requirements of floodplain rivers and fisheries: existing decision support tools and pathways for development. *Comprehensive Assessment of Water Management in Agriculture Research Report*. International Water Management Institute: 74 pp. Colombo, Sri Lanka.
- Aylward, B., Bandyopadhyay, J. and Belausteguigotia, J. (2005). Freshwater Ecosystem Services, in *Ecosystems and Human Well-being: Policy Responses, Volume 3. Findings of the Responses Working Group of the Millennium Ecosystem Assessment*. K Chopra, R Leemans, P Kumar and H Simons (Eds). Washington DC, Island Press.
- Bailey, C. and Jentoft, S. (1990). Hard choices in fisheries development. *Marine Policy* 14(4): 333-344.
- Balirwa, J. (2007). Ecological, environmental and socioeconomic aspects of the Lake Victoria's introduced Nile perch fishery in relation to the native fisheries and the species culture potential: lessons to learn. *African Journal of Ecology* 45(2): 120-129.
- Baran, E. (2006). Fish migration triggers in the Lower Mekong Basin and other freshwater tropical systems. MRC Technical Paper 14. MRC: 56 pp. Vientiane, Lao PDR.
- Baran, E., Meynell, P., Kura, Y., Agostinho, A. A., Cada, G., Hamerlynck, T. N. and Winemiller, K. O. (2009). Dams and fish: impacts and mitigation; methods and guidelines to forecast, assess and mitigate the impacts of hydropower dams on fish resources in the Mekong Basin. WorldFish Center: 127 pp. Phnom Penh, Cambodia.
- Baran, E. and Myschowoda, C. (2008). Have fish catches been declining in the Mekong River Basin? In *Modern Myths of the Mekong*. M. Kumm, M Keskinen and O. Varis (eds). Helsinki University of Technology: 55-64. Helsinki, Finland.
- Barlow, C., Baran, E., Halls, A. S. and Kshatriya, M. (2008). How much of the Mekong fish catch is at risk from mainstream dam development? *Catch and Culture* 14(3).
- Béné, C., Steel, E., Luadia, B. K. and Gordon, A. (2009). Fish as the "bank in the water" - Evidence from chronic-poor communities in Congo. *Food Policy* 34(1): 108-118.
- Berga, L., Buil, J. M., Bofill, E., De Cea, J. C., Garcia Perez, J. A., Manueco, G., Polimon, J., Soriano, A. and Yague, J. (2006). Dams and reservoirs, societies and environment in the 21st century. *Proceedings of the International Symposium on Dams in Societies of the 21st Century*, Barcelona, Spain, 18 June 2006.
- Bilby, R.E., Fransen, B.R., Bisson, P.A. (1996). Incorporation of nitrogen and carbon from spawning coho salmon into the trophic system of small streams: evidence from stable isotopes. *Canadian Journal of Fisheries and Aquatic Sciences* 53: 164-173.

- BNP (2008). Small-scale capture fisheries. A global overview with emphasis on developing countries. Interim report of the Big Numbers Project. World Bank, FAO, WorldFish Center: 62 pp.
- Bose, M. and Dey, M. (2007). Food and nutritional security in Bangladesh: Going beyond carbohydrate counts. *Agricultural Economics Research Review* 20(2): 203-225.
- Chamnan, C., Thilsted, S. H., Rottana, B., Sopha, L., Gerpacio, R. V. and Roos, N. (2009). The role of fisheries resources in rural Cambodia: combating micronutrient deficiencies in women and children. Department of fisheries post-harvest technologies and quality control: 106 pp. Phnom Penh, Cambodia.
- Cowx, I. G. (Ed.) (2002). *Management and Ecology of Lake and Reservoir Fisheries*. London, Blackwell. 416 pp.
- Daily, G. C. (1997). Introduction: What are ecosystem services? In *Nature's Services: Societal Dependence on Natural Ecosystems*. G.C. Daily (Ed.). Washington DC, Island Press.
- Donda, S. and Njaya, F. (2007). Fisheries co-management in Malawi: an analysis of the underlying policy process. Food security and poverty alleviation through improved valuation and governance of river fisheries in Africa. WorldFish Center: 41 pp.
- Doyle, M. W., Stanley, E. H., Harbor, J. M. and Grant, G. S. (2003). Dam removal in the United States: emerging needs for science and policy. *Eos* 84(4): 29-36.
- Dudgeon, D. (2010). Requiem for a river: extinctions, climate change and the last of the Yangtze. *Aquatic Conservation: Marine and Freshwater Ecosystems* 20: 127-131.
- Dugan, P. (2008). Mainstream dams as barriers to fish migration: international learning and implications for the Mekong. *Catch and Culture* 14(3): 9-15.
- EAA and EFTTA (2004). "The Socio-Economic Value of Recreational Angling in Europe". From http://www.eaa-europe.org/fileadmin/templates/eea/docs/EAA_EFTTA_25_March_2004_FINAL.pdf.
- EPA (2009) <http://cfpub.epa.gov/eroe/index.cfm?fuseaction=detail.viewInd&lv=list.listByAlpha&r=216610&subtop=341>.
- Evans, L. and Andrew, N. (2009). Diagnosis and the Management Constituency of Small-scale Fisheries. The WorldFish Center Working Paper 1941. The WorldFish Center. Penang, Malaysia.
- FAO (1995). Code of conduct for responsible fisheries. FAO. 41 pp. Rome, Italy.
- FAO (1997). Inland fisheries. FAO Technical Guidelines for Responsible Fisheries 6. FAO Fisheries department: 36 pp. Rome, Italy.
- FAO (1999). Review of the state of world fishery resources: inland fisheries. FAO Fisheries Circular 942. Fishery Resources Division Inland Water Resources and Aquaculture Service. FAO: 58 pp. Rome, Italy.
- FAO (2003). Review of the state of world fishery resources: inland fisheries. FAO Fisheries Circular 942 Rev.1. Fishery Resources Division Inland Water Resources and Aquaculture Service. FAO: 60 pp. Rome, Italy.
- FAO (2006). FACT SHEET: The international fish trade and world fisheries. 2 pp.
- FAO (2008a). Inland fisheries 1. Rehabilitation of inland waters for fish. FAO technical guidelines for responsible fisheries n.6 suppl.1. FAO fisheries department: 36 pp. Rome, Italy.
- FAO (2008b). Present and future markets for fish and fish products from small-scale fisheries - case studies from Asia, Africa and Latin America. FAO Fisheries Circular 1033. FAO: 87 pp. Rome, Italy.
- FAO (2009). The state of world fisheries and aquaculture (SOFIA) - 2008. FAO: 196 pp. Rome, Italy.
- Faruk-Ul-Islam, A. T. M. (2007). Self-recruiting species (SRS) in aquaculture: their role in rural livelihoods in two areas of Bangladesh. Institute of Aquaculture. University of Stirling. PhD: 306 pp. Stirling, UK.
- Ferguson, J. W. and Healey, M. (2009). Hydropower in the Fraser and Columbia Rivers: a contrast in approaches to fisheries protection. *Catch and Culture* 15(1).
- Ferguson, J. W., Healey, M., Dugan, P. and Barlow, C. (in press). Potential effects of dams on migratory fish in the Mekong River: lessons from the Fraser and Columbia Rivers.
- Finlayson, C. M., D'Cruz, R., Aladin, N., Barker, D. R., Beltram, G., Brouwer, J., Davidson, N., Duker, L., Junk, W., Kaplowitz, M. D., Ketelaars, H., Kreuzberg-Mukhina, E., de la Lanza Espino, G., Léveque, C., Lopez, A., Milton, R. G., Mirabzadeh, P., Pritchard, D., Revenga, C., Rivera, M., Shah Hussainy, A., Silviu, M. and M, S. (2005). Inland water systems, in *Ecosystems and human well-being: current state and trends*. R Hassan, R Scholes and N Ash (Eds). Island Press. 1: 551-583.
- FishStat (2010). FishStat Plus <http://www.fao.org/fishery/statistics/software/fishstat/en>.

- Fuller, A. and Cowell, B.C. (1985). Seasonal variation in benthic invertebrate recolonization of small-scale disturbance in a subtropical Florida lake. *Hydrobiologia* 124: 211-221.
- Garcia, J. M. (2003). The ecosystem approach to fisheries: issues, terminology, principles, institutional foundations, implementation and outlook. FAO Fisheries Technical Paper 443. FAO: 74 pp. Rome, Italy.
- Garibaldi, L. and Bartley, D. M. (1998). The database on introductions of aquatic species (DIAS). *Aquaculture Newsletter (FAN)* 20. FAO.
- Geheb, K., Kalloch, S., Medard, M., Nyapendi, A.-T., Lwenya, C. and Kyangwa, M. (2008). Nile perch and the hungry of Lake Victoria: Gender, status and food in an East African fishery. *Food Policy* 33(1): 85-98.
- Gibson, R. S. and Hotz, C. (2001). Dietary diversification/modification strategies to enhance micronutrient content and bioavailability of diets in developing countries. *British Journal of Nutrition* 85(2): 159-166.
- Gleick, P. H. (2000). The world's water 2000-2001: the biennial report on freshwater resources. Washington DC, Island Press.
- Hall, S. et al. (in prep.) Global food production and the ecological footprint of aquaculture: trends and future prospects (interim title).
- Halls, A. (2009). Climate change and Mekong fisheries. *Catch and Culture* 15: 12-16.
- Halls, A., Hoggarth, D. and Debnah, K. (1998). Impact of flood control schemes on river fish migrations and species assemblages in Bangladesh. *Journal of Fisheries Biology* 53: 358-380.
- Heck, S., Béné, C. and Reyes-Gaskin, R. (2007). Investing in African fisheries: building links to the Millennium Development Goals. *Fish and Fisheries* 8(3): 211-226.
- Hoeinghaus, D., Agostinho, A., Gomes, L., Pelicice, F., Okada, E., Latini, J., Kashiwaqui, E. and Winemiller, K. (2009). Effects of river impoundment on ecosystem services of large tropical rivers: embodied energy and market value of artisanal fisheries. *Conservation Biology* 23: 1222-1231.
- Hogan, Z., Moyle, P. B., May, B., Vander Zanden, M. J. and Baird, I. G. (2004). The imperiled giants of the Mekong River. *American Scientist* 92: 228-237.
- Holmlund, C.M. and Hammer, M. (1999). Ecosystem services generated by fish populations. *Ecological Economics* 29: 253-268.
- Hortle, K. G. (2007). Consumption and the yield of fish and other aquatic animals from the Lower Mekong Basin. MRC Technical Report 16. Mekong River Commission: 87 pp. Vientiane, Lao PDR.
- Hortle, K. G. (2009). Fisheries of the Mekong River Basin, in *The Mekong. Biophysical environment of a transboundary river*. I.C Campbell (Ed.). New York, Elsevier: 199-253.
- ICEM (2008). Strategic Environmental Assessment of the Quang Nam Province Hydropower Plan for the Vu Gia-Thu Bon River Basin. Prepared for the ADB, MONRE, MOITT & EVN. Hanoi, Vietnam.
- ICEM (2010). Draft final report of the Strategic Environmental Assessment of hydropower on the Mekong mainstream. International Centre for Environmental Management, Hanoi, Vietnam and Mekong River Commission, Vientiane, Lao PDR.
- IPCC (2000). Special report on emissions scenarios. N. Nakicenovic, Swart, R. (eds). Cambridge, Cambridge University Press.
- Jackson, D. and Marmulla, G. (2000). The influence of dams on river fisheries in Dams, ecosystem functions and environmental restoration. Berkamp G., McCartney, M., Dugan, P., McNeely, J. and Acreman, M. (Eds). Cape Town, South Africa, World Commission on Dams.
- Jul-Larsen, E., Kolding, J., Overa, R., Raakjaer Nielsen, J. and van Zweiten, P. A. M. (2003). Management, co-management or no management? Major dilemmas in southern African freshwater fisheries. 1. Synthesis report. FAO Fisheries Technical Paper 426/1. FAO: 127 pp. Rome, Italy.
- Junk, W. J., Bayley, P. B. and Sparks, R. E. (1989). The flood pulse concept in river-floodplain systems. *Canadian Special Publication of Fisheries and Aquatic Sciences* 106: 110-127.
- Kasulo, V. and Perrings, C. (2005). Fishing down the value chain: biodiversity and access regimes in freshwater fisheries - the case of Malawi. *Ecological Economics* 59(1): 106-114.
- Kawarazuka, N. (2010). The contribution of fish intake, aquaculture, and small-scale fisheries to improving nutrition: A literature review. WorldFish Center Working Paper 2106. 44 pp. Penang, Malaysia.
- Krokhin, E.M. (1975). Transport of nutrients by salmon migrating from the sea into lakes, in *Coupling of Land and Water Systems*. A.D. Hasler (Ed.). New York, Springer: 153-156.
- Laë, R. (1992). Influence de l'hydrologie sur l'évolution des pêcheries du Delta central du Niger de 1966 à 1989. *Aquatic Living Resources* 5(2): 115-126.
- Laë, R. (1994). Effects of drought, dams and fishing pressure on the fisheries of the central delta on

- the Niger River. *International Journal of Ecology and Environmental Sciences* 20: 119-128.
- Laë, R. (1995). Climatic and anthropogenic effects on fish diversity and fish yields in the central delta of the Niger River. *Aquatic Living Resources* 8: 43-58.
- Larkin, G.A. and Slaney, P.A. (1997). Linking species and ecosystems: organisms as ecosystem engineers, in *Linking Species and Ecosystems*. C.G. Jones and J.H. Lawton (Eds). London, Chapman and Hall: 141-150.
- Lele, Ú., Pretty, J., Terry, E. and Trigo, E. (2010). Transforming agricultural research for development (Draft 11.0). The Global Forum for Agricultural Research (GFAR), Montpellier, France. Report for the Global Conference on Agricultural Research (GCARD) 2010.
- Lévêque, C., Oberdorff, T., Paugy, D., M.L.J. S. and Tedesco, P. A. (2008). Global diversity of fish (Pisces) in freshwater. *Developments in Hydrobiology* 210 198: 545-567.
- Liu, S., Lu, P., Liu, D., Jin, P. and Wang, W. (2009). Pinpointing the sources and measuring the lengths of the principal rivers of the world. *International Journal of Digital Earth* 2(1): 80-87.
- Lowe-McConnell, R. H. (1987). *Ecological studies in tropical fish communities*. Cambridge, University Press: 382 pp.
- LVFO (2008). "State of fish stocks." from <http://lvfo.org/index.php?option=displaypage&Itemid=103&op=page>.
- MA (2005). *Ecosystems and human well-being: current state and trends*. Volume 1. R Hassan, R Scholes and N Ash (eds). Washington DC, Island Press.
- MA (2005). *Ecosystems and Human Well-Being: Synthesis*. R Hassan, R Scholes and N Ash (Eds). Washington DC, Island Press.
- Maiga, H., Marie, J., Morand, P., N'Djim, H. and Orange, D. (2007). *Présentation du fleuve Niger in Avenir du fleuve Niger*. IRD (Eds): 103 pp.
- Marmulla, G. (2001). *Dams, fish and fisheries: opportunities, challenges and conflict resolution*. FAO Fisheries Technical Paper No. 419. FAO. Rome, Italy.
- McDowall, R. M. (1994). On size and growth in fresh water fish. *Ecology of Freshwater Fish* 3(2): 67-79.
- McKenney, B. and Tola, P. (2002). *Natural resources and rural livelihoods in Cambodia: a baseline assessment*. Cambodia Development Resource Institute, Working Paper 23. 116 pp.
- Mills, D. J., Westlund, L., de Graaf, G., Kura, Y., Willman, R. and Kelleher, K. (2010). Underreported and undervalued: Small-scale fisheries in the developing world in Small-scale fisheries management frameworks and approaches for the developing world. R.S. Pomeroy and N. Andrew (Eds). London, CABI.
- Molle, F., Wester, P. and Hirsch, P. (2007). River basin development and management, in *Water for food, water for life. A comprehensive assessment of water management in agriculture*. David Molden (Ed.). Earthscan and International Water Management Institute: 585-625. London and Colombo, Sri Lanka.
- Moreau, J. (1997). Impact of fish introductions in African aquatic ecosystems: an evaluation by using ECOPATH II, in *African Inland Fisheries, Aquaculture and the Environment*. K Remane (Ed.), Rome, FAO and London, Blackwell: 326-350.
- MRC (2010). *State of the Basin report 2010*. Mekong River Commission (MRC) 232 pp. Vientiane, Lao PDR.
- Muhoozi, L. (2003). *Aspects of the commercial exploitation of fish stocks in Lake Victoria*. University of Hull. PhD dissertation. United Kingdom.
- Neiland, A. E. (2005). *Inland Fisheries in Africa. Key Issues and Future Investment Opportunities for Sustainable Development*. Technical Review Paper - Inland Fisheries. NEPAD-Fish for All Summit. Abuja, Nigeria.
- Neiland, A. E. and Béné, C. (Ed.) (2004). *Poverty and small-scale fisheries in West Africa*. 253 pp.
- Nho, P. V. and Guttman, H. (1999). *Aquatic resources use assessment in Tay Ninh Province, Vietnam (results from 1997 survey)*. AIT Aqua Outreach Working Paper No. SV-51. Asian Institute of Technology. Bangkok, Thailand.
- Nilsson, C., Reidy, C. A., Dynesius, M. and Revenga, C. (2005). Fragmentation and flow regulation of the world's large river systems. *Science* 308(5720): 405-408.
- Njaya, F. (2002). *Fisheries co-management in Malawi: implementation arrangements for Lakes Malombe, Chilwa and Chiuta in Africa's Inland Fisheries: The Management Challenge*. K Geheb and M-T Sarch (Eds). Kampala, Uganda, Fountain Books: 9-30.
- Northcote, T. and Larkin, P. (1989). *The Fraser River: A major salmonine productive system*. Proceedings of the International Large River Symposium. D Dodge (Ed.): 174-204.
- Pauly, D., Watson, R. and Alder, J. (2005). Global trends in world fisheries: impacts on marine ecosystems and food security. *Philosophical Transactions of the Royal Society B* 29(360 [1453]): 5-12.

- Postel, S. and Richter, B. (2003). Rivers for life: managing water for people and nature. Washington, DC, Island Press.
- Pringle, R. M. (2005). The Origins of the Nile Perch in Lake Victoria. *BioScience* 55(9): 780-787.
- Rab, M. A., Hap, N., Ahmed, M., Kean, S. and Viner, K. (2006). Socioeconomics and values of resources in Great Lake, Tonle Sap and Mekong Bassac area: results from a sample survey in Kampong Chnang. *WorldFish Center Discussion Series 44*. 98 pp. Siem Reap and Kandal provinces, Cambodia.
- Revenga, C., Brunner, J., Henninger, N., Kassem, K. and Payne, R. (2000). Pilot analysis of global ecosystems: freshwater systems. Washington, DC, World Resources Institute.
- Richter, B. D., Postel, S., Revenga, C., Scudder, T., Lehner, B., Churchill, A. and Chow, M. (2010). Lost in Development's shadow: the downstream human consequences of dams. *Water Alternatives* 3(2): 14-42.
- Roos, N., Islam, M. M. and Thilsted, S. H. (2003a). Small fish is an important dietary source of vitamins and calcium in rural Bangladesh. *Journal of Food Sciences and Nutrition* 54(5): 329-339.
- Roos, N., Islam, M. M. and Thilsted, S. H. (2003b). Small indigenous fish species in Bangladesh: Contribution to vitamin A, calcium and iron intakes. *Journal of Nutrition* 133(11): 4021S-4026.
- Roos, N., Wahab, M., Hossain, M. and Thilsted, S. H. (2007). Linking human nutrition and fisheries: Incorporating micronutrient-dense, small indigenous fish species in carp polyculture production in Bangladesh. *Food and Nutrition Bulletin* 28(2): S280-S293.
- Scutt Phillips, J., Pilling, G. M., Cheung, W. W. L., Gosling, S. N., Pinnegar, J. K. and Dulvy, N. K. (2010). Do we know the vulnerability of fishing nations to global climate change? CEFAS. Lowestoft, UK.
- Sjorlev, J. G. (2001). An Giang fisheries survey. Report for the Component Assessment of Mekong Fisheries AMFC/RIA2. Sjorlev, J. G. (Ed.). Mekong River Commission Phnom Penh, Cambodia.
- Smith, R. D. and Maltby, E. (2003). Using the ecosystem approach to implement the convention on biological diversity: key issues and case studies. *Ecosystem Management Series 2*. IUCN.
- Turpie, J., Smith, B., Emerton, L. and Barnes, J. (1999). Economic value of the Zambezi basin wetlands. IUCN: 346 pp.
- U.S. Department of the Interior, Fish and Wildlife Service and U.S. Department of Commerce, Bureau of the Census. (1997). 1996 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation. 176 pp.
- UNEP (2008a). Africa: Atlas of Our Changing Environment. Nairobi, Kenya.
- UNEP (2008b). Vital Water Graphics - An Overview of the State of the World's Fresh and Marine Waters. 2nd Edition. Nairobi, Kenya.
- UNEP (2009). Ecosystem management programme. DEPI. 21 pp.
- UNEP and CBD (2000). Decisions adopted by the conference of the parties to the convention on biological diversity at its fifth meeting - Annex III. COP 5. Nairobi, Kenya.
- Vanni, M.J., Luecke, C., Kitchell, J.F., Allen, Y., Temte, J. and Magnusson, J.J. (1990). Effects on lower trophic levels of massive fish mortality. *Ecology* 78: 21-40.
- Vörösmarty, C. J., Douglas, E. M., Green, P. A. and Revenga, C. (2005). Geospatial indicators of emerging water stress: An application to Africa. *AMBIO: A Journal of the Human Environment* 34(3): 230-236.
- Vörösmarty, C. J., McIntyre, P. B., Gessner, M. O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S. E., Sullivan, C. A., Reidy Liermann, C. and Davies, P. M. (2010). Global threats to human water security and river biodiversity. *Nature* 467: 555-561.
- Wanink, J. H., Witte, F. and A. Rossiter, H. K. (2000). The use of perturbation as a natural experiment: Effects of predator introduction on the community structure of zooplanktivorous fish in Lake Victoria. *Advances in Ecological Research* 31: 553-570.
- WCD (2000). Dams and development. A new framework for decision-making. The World Commission on Dams. 438 pp.
- Weeratunge, N. and Snyder, K. A. (2010). Gleaner, fisher, trader, processor: understanding gendered employment in fisheries and aquaculture. *Fish and Fisheries* (in press).
- Welcomme, R. L. (1967). Observations on the biology of the introduced species of Tilapia in Lake Victoria. *Reviews in Zoology and Botany of Africa* 76: 249-279.
- Welcomme, R. L. (1971). Evolution de la peche interieure, son état actuel et ses possibilités. Technical Assistance Report 2989. FAO and UNDP: 97 pp.
- Welcomme, R. L. (1985). River fisheries. FAO Technical Paper 262. FAO: 330 pp. Rome, Italy.
- Welcomme, R. L. (1999). A review of a model for qualitative evaluation of exploitation levels in

- multi-species fisheries. *Fisheries Ecology and Management* 6: 1-20.
- Welcomme, R. L. (2001). *Inland fisheries. Ecology and management*. Oxford, Fishing News Books, Blackwell Science.
- Welcomme, R. L. and Petr, T. (2003). Proceedings of the second international symposium on the management of large rivers for fisheries, FAO Regional Office for Asia and the Pacific, Bangkok, Thailand.
- Welcomme, R. L., Winemiller, K. O. and Cowx, I. G. (2006). Fish environmental guilds as a tool for assessment of ecological condition of rivers. *River Research and Applications* 22: 377-396.
- Welcomme, R. L., Cowx, I. G., Coates, D., Béné, C., Funge-Smith, S., Halls, A. and Lorenzen, K. (2010). Inland capture fisheries. *Philosophical Transactions of the Royal Society* (in press).
- Weldrick, S. K. (1996). The development of an ecological model to determine flood release options for the management of the Phongolo floodplain in Kwazulu/Natal South Africa. Rhodes University. Masters thesis: 81 pp. Grahamstown, SA.
- Wootton, R. J. (1990). *Ecology of teleost fishes*. London, Chapman and Hall.
- WWF (2005). *To dam or not to dam? Five years on from the World Commission on Dams*. WWF: 16 pp.

Acknowledgements

Contributors and reviewers

We are grateful to the following contributors: **Eric Baran** for information on the Mekong River, **Christophe Béné** for material on the Congo River, **David Mills** for the case study on Bangladesh, **John Ferguson** and **Michael Healey** for information on the Columbia and Fraser Rivers, and **Nozomi Karawazuka** for information on nutrition.

We also thank the following reviewers for their helpful comments: **Ellik Adler**, UNEP-COB-SEA, Bangkok, Thailand; **Eric Baran**, WorldFish Center, Phnom Penh, Cambodia; **Thomas Chiramba**, UNEP-DEPI, Nairobi, Kenya; **David Coates**, CBD, Montreal, Canada; **Salif Diop**, UNEP-DEWA, Nairobi, Kenya; **Ryuichi Fukuhara**, UNEP-IETC, Osaka, Japan; **John Jorgensen**, FAO-FIMF, Rome, Italy; **Tim Kasten**, UNEP-DEPI, Nairobi, Kenya; **Elizabeth Khaka**, UNEP-DEPI, Nairobi, Kenya; **Razi Latif**, UNEP-MCEB, Nairobi, Kenya; **Janet Macharia**, UNEP, Nairobi, Kenya; **Daniele Perrot-Maitre**, UNEP, Nairobi, Kenya.

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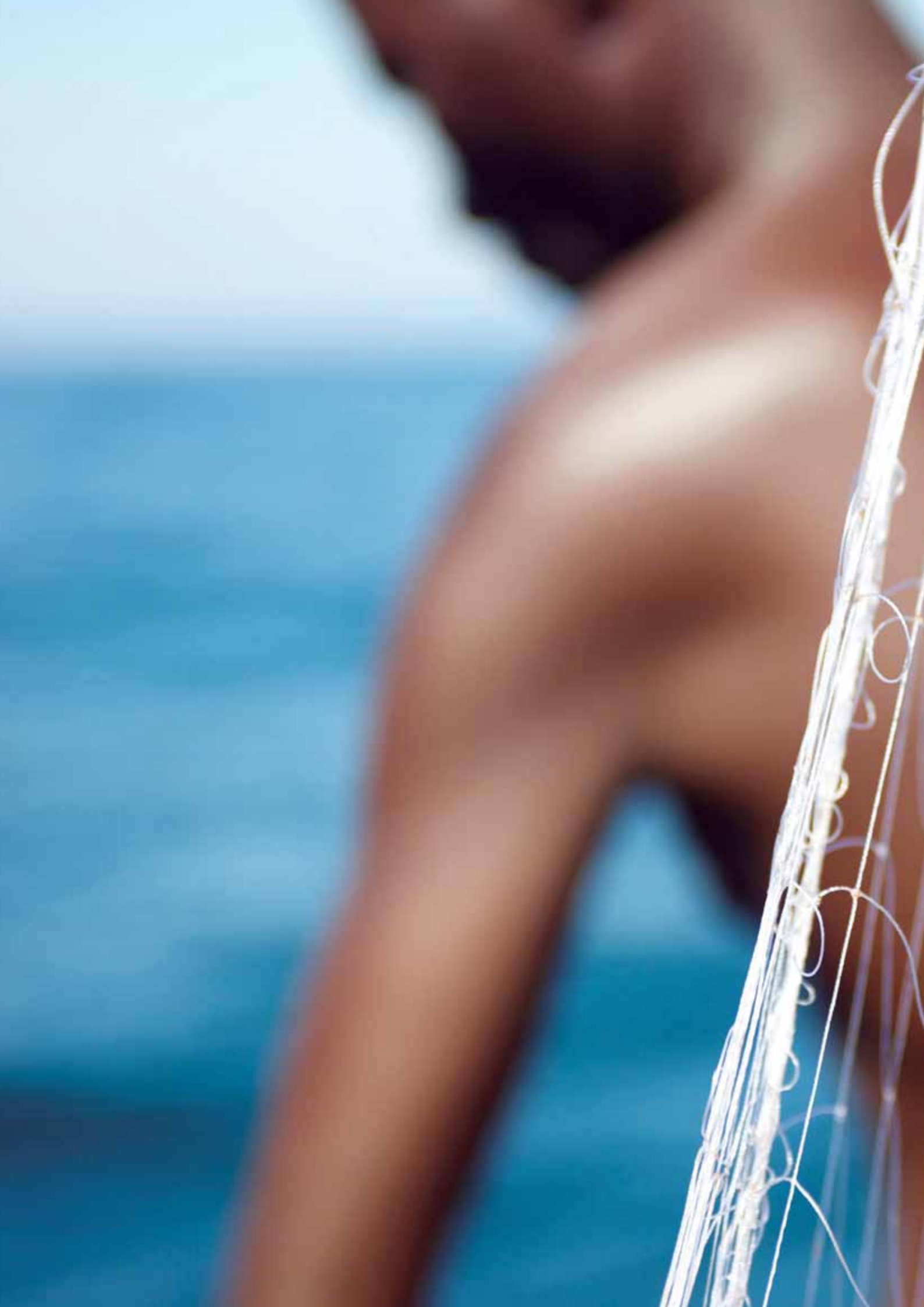
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Layout

Scriptoria Communications, www.scriptoria.co.uk







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ISBN: 978-92-807-3112-5
Job Number: DEP/1316/NA



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