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Inland fisheries evolution and management

Case studies from four continents

***Cover photos*:**
Clockwise from top left: Dai fishery on the Tonle Sap (courtesy of the MRC Fisheries Programme); Lake Victoria (courtesy of Ashley S. Halls); Amazon fishing boat (provided by Robin Welcomme); Lake Constance (courtesy of Roland Roesch).

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579

Edited by

Robin L. Welcomme
Independent Consultant and Visiting Scientist
Imperial College Conservation Science Long Barn
Stoke by Clare, United Kingdom

John Valbo-Jorgensen
Fishery and Aquaculture Officer
FAO Subregional Office for Mesoamerica
Panama City, Panama

and

Ashley S. Halls
Director
Aquae Sulis Ltd
Bath, United Kingdom

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Preparation of this document

This document is one of a series prepared by the FAO Fisheries and Aquaculture Department examining some of the best-studied inland fisheries. It was prepared as four chapters:

- Status and trends of the fishery resources of the Amazon Basin in Brazil, by Mauro Luis Ruffino;
- Lake Constance fish and fisheries, by Roland Roesch;
- The stationary trawl (dai) fishery of the Tonle Sap – Great Lake System, Cambodia, by Ashley S. Halls and Bruce Paxton;
- Status, trends and management of the Lake Victoria Fisheries, by Jeppe Kolding, Modesta Medard, Oliva Mkumbo and Paul van Zwieten.

These case studies are used to illustrate some of the most pressing issues faced by inland fisheries in a concluding section prepared by the editors.

Abstract

In 2009, inland fisheries produced some 10 million tonnes of fish. Despite their importance to rural communities, especially in the least-developed countries, little attention has been paid to this sector in recent years. As a result, there is a deficit in management of the fisheries and also an increasing threat to freshwater by a number of non-fishery users of the aquatic resource. As part of an effort to raise awareness of the problems facing inland fisheries and to examine more closely the various issues, this document reviews four of the world's best-documented inland fisheries: the Amazon, Lake Constance, the Mekong and Lake Victoria. These represent two lake fisheries and two river fisheries drawn from a wide geographical sample – Africa, Asia, South America and Europe.

This technical paper draws conclusions from the four case studies and more general experience as to some of the main issues facing inland fisheries. Inland fishery statistics are generally are very poor, so knowledge of the actual contribution of the sector to food security is not known. Nevertheless, inland fisheries employ about 56 million people directly and indirectly. The state of the stocks of fish in many fisheries is not known because of the low level of research across the many rivers and lakes. However, it is understood that, in many cases, the main driver of the fish assemblages is not the way in which the fishery is managed but rather the state of the environment as acted upon by other human uses. This means that mechanisms are needed to improve both management of fisheries through forms of comanagement and collaboration at the national and international level between agencies responsible for the management of the aquatic resource in general.

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Abbreviations and acronyms

BMU	beach management unit
CAS	catch assessment survey
CPUE	catch per unit of effort
EAFFRO	East African Freshwater Fisheries Research Organisation
FiA	Fisheries Administration (Cambodia)
IBGE	Geography and Statistics Institute
IFMP	Implementation of a Fisheries Management Plan (Lake Victoria project)
INPA	Institute for Research on the Amazon
IUU	illegal, unregulated and unreported fishing
LVFO	Lake Victoria Fisheries Organization
MCS	monitoring, control, and surveillance
MPEG	Emilio Goeldi Museum
MRC	Mekong River Commission
MSDR	Mamirauá Sustainable Development Reserve
NGO	non-governmental organization
TS–GL	Tonle Sap – Great Lake (system)
UFAM	Federal University of Amazonas

1. Status and trends of the fishery resources of the Amazon Basin in Brazil

Mauro Luis Ruffino
President of the Brazilian Association for Fisheries Sciences – ABCPesca
Brasilia, Brazil

INTRODUCTION

In Brazil, fisheries are important economically at the national and local level because of their social and economic contribution to income for rural communities. Annual production is about 1 million tonnes, half of which is of marine and estuarine origin, one-quarter from inland capture and one-quarter from marine and inland aquaculture (IBAMA, 2008). These resources are exploited along 4 590 nautical miles of coastline to depths of about 100 m and from different inland habitats.

Inland fisheries are mainly artisanal in scale, while estuarine and marine fishing are both artisanal and industrial and are characterized by the use of larger vessels equipped for trawl net operation and navigation. Industrial vessels in particular are large, mostly made of iron, with higher cargo capacity. Recent statistics show that the annual production (506 000 tonnes) of industrial marine/estuarine fisheries is almost double that of artisanal fisheries (272 000 tonnes) (IBAMA, 2008).

In the Amazon, people fish intensively, not just as full-time professionals or for sport but also as part-time employment or to supplement their diet. One reason for this is their proximity to large waterbodies with abundant fish. Many farmers living on river banks, for example, have properties that include lakes or share floodplain lakes, so fresh fish can be caught only a few metres away from home.

Fish consumption in northern Brazil is higher than in other regions of the country, and in certain communities in inner Amazonia daily fish consumption reaches almost 500 g/person (Cerdeira, Ruffino and Isaac, 1997; Batista *et al.*, 1998). In the coastal region, consumption is slightly lower. Estimates carried out in the coastal communities of the State of Amapá indicate daily values of 150 g/person (Isaac, Araujo and Santana, 1998) and, judging from the volume of catches being sold in markets and supermarkets (Souza, 1995), it should be more than 50 g/person in the city of Belém.

The dynamics of the fishery are strongly related to seasonal rainfall patterns. The rainy season occurs in the first half of the year, particularly in March and April, followed by the dry season, which usually begins in September. Levels of annual rainfall of up to 3 500 mm are no exception.

This chapter presents an analysis and synthesis of the available information on inland fishing in the Brazilian Amazon and of efforts to promote sustainable management in the region.

THE STRUCTURE OR CLASSIFICATION OF AMAZONIAN FISHERIES

Amazonian fisheries are divided into four different subsectors, each of which has distinct socio-economic characteristics and requires different approaches to management for sustainability.

Subsistence fishing. Fish is the main source of protein for floodplain communities. It is estimated that subsistence fishing represents as much as 60 percent of the whole production of fish in the Amazon (Bayley and Petrere, 1989). Subsistence fishers consume a great diversity of species, although lake species are preferred over those from the river (Bayley and Petrere, 1989).

Commercial fishing. Catches from commercial fishing mainly supply local and national markets. Commercial fisheries are practised by part-time or seasonal fishers for whom it usually provides their main source of income. They can be divided into monospecific and multispecific fisheries. Monospecific fisheries are industrial-scale operations at the mouth of the Amazon River as well as some artisanal fishing in the interior along the Amazon and Solimões Rivers. Target species are mainly siluriforms such as dourada (*Brachyplatystoma rousseauxii* [Castelnau]), piramutaba (*B. vaillanti*i [Valenciennes]), piraíba (*B. filamentosum* Lichtenstein), the surubims and caparari (*Pseudoplatystoma tigrinum* Valenciennes and *P. fasciatum* Linnaeus), pirarara (*Phractocephalus hemiliopterus* Bloch & Schneider) and the mapará (*Hypophthalmus marginatus* Valenciennes). Multispecific fisheries mainly exploit migrating species such as jaraquis (*Semaprochilodus insignis* Jardine) and (*S. taenirus* Valenciennes), pacus (*Myleus sp., Metynnis sp.* and *Mylossoma sp*.), tambaqui (*Colossoma macropomum* [Cuvier]), matrinxã (*Brycon amazonicus* Spix & Agassiz) and curimatá (*Prochilodus nigricans* Spix & Agassiz). Reproductive and migratory behaviour of the majority of these species is largely determined by the hydrological cycle, which is the main regulator of the whole ecosystem.

Sport fishery. Sport fisheries are mainly practised by tourists coming from urban centres or other countries and do not necessarily involve consumption of the catch. Sport fishing is usually practised between June and October. The beginning of the season coincides with the low-water season and continues until the end of the dry season – a total of six months per year. The main target of sport fishing in Amazon State is the tucunaré (*Cichla* spp.) and the main area fished is the middle River Negro Basin.

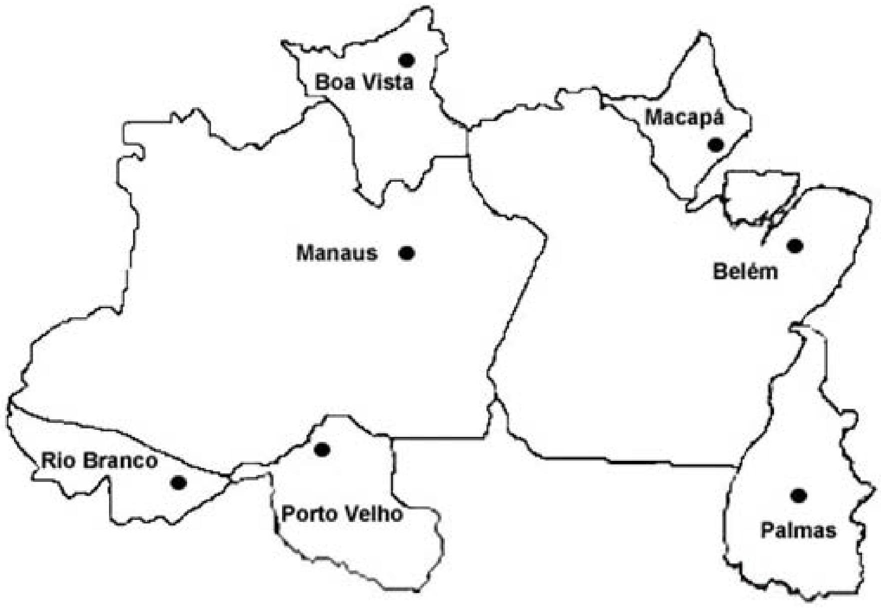
Ornamental fishery. The fishery for ornamental species catches small fish that are popular in the aquarium trade. According to Chao (2001), there are 800 registered species in the Negro River, of which only about 60 are traded for ornamental purposes. The cardinal tetra (*Paracheirodon axelrodi* Schultz) represents 76–89 percent of all exported ornamental fishes (Chao, 2001). Other important species include the neon verde (*Paracheirodon simulans* Géry), rodóstomos (*Hemigrammus bleheri* Géry & Mahnart), rosaceu (*Hyphessobrycon* spp.), borboletas (*Carnegiella* spp.) and apistogramas (*Apistogramma* spp.). Stingrays (*Potamotrygon* spp.) were caught for export until permission was suspended in December 2005.

STATISTICS USED FOR EVALUATING LANDINGS

Collection of fisheries statistics in the Amazon has been irregular. The Institute for Research on the Amazon (INPA) collected statistics on landings in Manaus from the mid-1970s to the mid-1980s, but sampling was interrupted from the mid-1980s to the early 1990s. Landings in Manaus were monitored by the Federal University of Amazonas (UFAM) (Batista, 1998). Landings were monitored in Belém from 1993 to 1997 (Barthem, 2003) by research groups from Emilio Goeldi Museum (MPEG), and Santarém from 1991 to 2005 by Projeto IARA/IBAMA (Ruffino and Isaac, 1995, Isaac, Ruffino and Melo, 2000) and by the Mamirauá Institute since 1991 and still ongoing (Barthem, 1999). Other cities, such as Porto Velho in Rondônia State and Itacoatiara in Amazonas State were sampled for short periods in the 1970s and 1980s, and monitoring has now recommenced. Another source of landing statistics, used mainly in Acre and Roraima, are the reports of the Fisher Unions (Colônias de Pesca).

The following analyses are based on landing statistics collected in seven states of the Brazilian Amazon by different institutions and compiled by the federal environment agency (IBAMA) (Figure 1). There are some limitations in the data that affect the

FIGURE 1
Brazilian states where landings are monitored by IBAMA



interpretation of the results. First, the fish landed are classified and recorded using common, commercial or generic names, which makes it difficult to identify the fish to the species level. Hence, the collected data are of limited use for stock assessment, which requires identification to the lowest taxonomic level.

A second factor influencing the quality of the fisheries statistics is the lack of agreement among states on a standardized methodology for data collection. The Geography and Statistics Institute (IBGE), which is responsible for the collection and dissemination of statistics in general, interrupted collection of fishery statistics in 1990. To fill this gap, IBAMA started (in 1995) to compile and disseminate data produced by different institutions, including the Estatpesca Project and the Floodplain Natural Resources Management Project (ProVárzea), which between 2000 and 2004 collected statistics in the 17 most important cities along the Solimões and Amazon Rivers (Ruffino, 2008). Landings were reported as fisheries products that may combine several species of the same genus or related groups, or may cover only one species. This hindered comparison of fishery yield data between states, although it still allows for the evaluations of trends in landings.

INLAND CAPTURE COMMERCIAL FISHERY PRODUCTION

The inland commercial fisheries of the Amazon are the most productive in the country. They contribute significantly to the production of aquatic animals in Brazil, representing an average of 17 percent of the total production (marine, inland and aquaculture) and 69.7 percent of the inland capture fisheries production of Brazil between 1996 and 2006 (Table 1). Figure 2 presents the evolution of inland commercial fishery production in the Amazon Basin during the last 10 years, showing an increase of more than 37.2 percent from 1996 to 2006.

TABLE 1
Brazilian Amazon fisheries and aquaculture production

	1996	1997	1998	1999	2000	2001
	(tonnes)					
Brazil total capture	646 51	732 090	727 833	744 598	842 377	939 756
Brazil inland capture	193 845	178 871	173 680	185 472	199 159	220 432
Amazon inland						
Capture	107 789	97 965	92 101	102 003	112 429	133 306
Aquaculture	2 079	3 447	6 580	5 987	8 196	13 682
Total inland	109 868	101 412	98 681	107 990	120 625	146 988
Amazon marine						
Capture	43 977	38 204	38 667	98 702	105 147	102 480
Aquaculture	0	30	30	130	140	150
Total marine	43 977	38 234	38 697	98 832	105 287	102 630
Total capture	**151 76**	**136 168**	**130 767**	**200 705**	**217 575**	**235 785**
Total aquaculture	**2 079**	**3 477**	**6 610**	**6 117**	**8 336**	**13 832**
Total production	**153 84**	**139 645**	**137 377**	**206 822**	**225 911**	**249 617**

TABLE 1 (*cont.*)
Brazilian Amazon fisheries and aquaculture production

	2002	2003	2004	2005	2006
	(tonnes)				
Brazil total capture	1 006 869	990 272	1 015 914	1 009 073	1 049 539
Brazil inland capture	239 416	227 551	246 101	243 435	251 241
Amazon inland					
Capture	148 302	133 377	140 963	135 596	147 931
Aquaculture	15 719	14 085	17 532	19 707	22 100
Total inland	164 021	147 462	158 494	155 303	170 031
Amazon marine					
Capture	108 882	97 273	93 625	89 683	84 335
Aquaculture	78	324	242	278	250
Total marine	108 960	97 597	93 867	89 961	84 585
Total capture	**257 183**	**230 649**	**234 588**	**225 279**	**232 266**
Total aquaculture	**15 797**	**14 409**	**17 774**	**19 985**	**22 350**
Total production	**272 980**	**245 058**	**252 361**	**245 264**	**254 616**

In 2006, it was estimated that of the 26 406 inland fishing vessels in the Amazon region (Ministério da Integração Nacional, 2006), 80 percent were registered in the State of Pará, or an increase of 70.3 percent over those registered in 1985 (SUDEPE, 1986). The State of Amazonas was second with 2 616 vessels, a figure very close to the 2 500 vessels estimated by Batista (1998). The vessels change their mode of operation during the year, according to the target species, fishing gear and physical characteristics of the fishing grounds.

In 2006, the total commercial fishery production in the Brazilian Amazon was 147 931 tonnes. Pará State was the largest producer in the region with 48.6 percent, followed by Amazonas with 38.7 percent (Table 2). The average catch over the last ten years was 122 614 tonnes/year, of which Amazonas State produced 45.4 percent and Pará State 42.4 percent.

FIGURE 2
Total, marine and inland capture commercial fishery production in Brazil and the Amazon Basin, 1996–2006

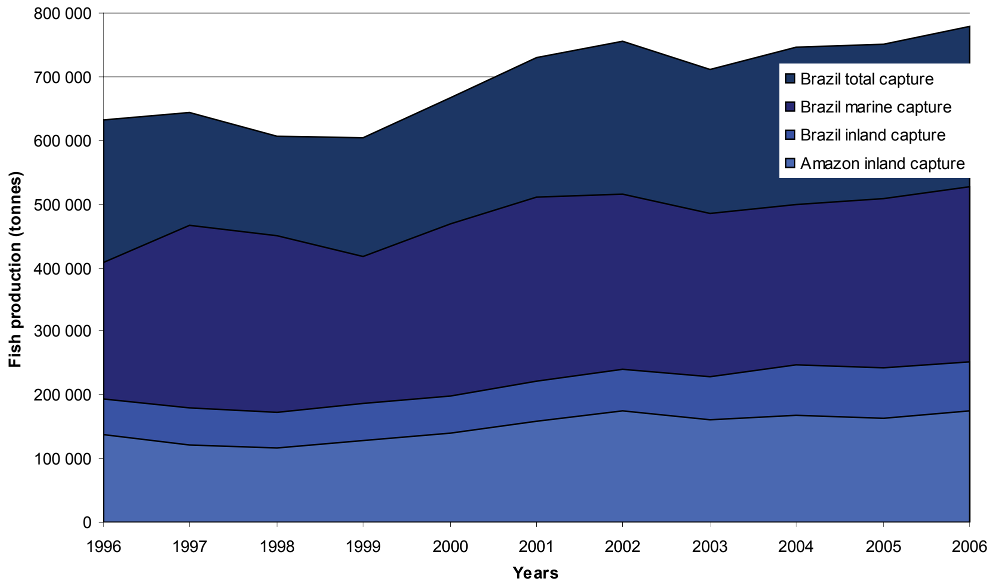


TABLE 2
Inland capture commercial fishery in the Brazilian Amazon Basin, by producer state

	1996	1997	1998	1999	2000	2001
	(tonnes)					
Rondônia	2 053	4 450	3 937	4 469	4 285	4 432
Acre	3 829	1 314	2 397	1 514	1 699	1 662
Amazonas	57 314	48 270	45 621	48 423	55 726	60 528
Roraima	144	119	118	121	201	250
Pará	40 357	36 485	33 567	38 307	42 901	58 225
Amapá	3 283	5 652	5 088	7 770	6 146	6 681
Tocantins	809	1 675	1 374	1 399	1 471	1 528
Total	**107 789**	**97 965**	**92 101**	**102 003**	**112 429**	**133 306**

TABLE 2 (*cont.*)
Inland capture commercial fishery in the Brazilian Amazon Basin, by producer state

	2002	2003	2004	2005	2006	Average
	(tonnes)					
Rondônia	4 396	4 352	3 854	2 329	2 241	3 709
Acre	1 537	1 633	1 610	1 488	1 413	1 827
Amazonas	66 581	59 926	56 696	55 413	57 316	55 619
Roraima	262	349	420	783	721	317
Pará	67 199	59 079	62 543	6 853	71 950	51 951
Amapá	6 712	6 376	11 146	13 009	12 664	7 684
Tocantins	1 615	1 663	1 696	1 722	1 626	1 507
Total	**148 302**	**133 377**	**137 963**	**135 596**	**147 931**	**122 614**

SPECIES CONTRIBUTING TO AMAZON FISHERIES

The Federal Environment Agency (IBAMA) reported the following as the main species captured from 1996–2006: piramutaba (*Brachyplatystoma vaillantii*); jaraqui (*Semaprochilodus* spp.); dourada (*Brachyplatystoma rousseauxii*); curimatã (*Prochilodus nigricans*); mapará (*Hypophthalmus* spp.); pescada (*Plagioscion* spp.); pacu (*Mylossoma* spp. and *Myleus* spp.); tucunaré (*Cichla* spp.); surubim (*Pseudoplatystoma* spp.); aracu (Anostomidae); matrinchã (*Brycon* spp.); tambaqui (*Colossoma macropomum*); filhote (*Brachyplatystoma filamentosum*); sardinha (*Triporteus* spp.); and pirapitinga (*Piaractus brachypomus*). Several other species or species groups contributed to the catches (Table 3). The same species were listed as forming the highest catches since the early 1970s, although with some change in ranking (SUDEPE, 1986). Most of these species are migratory, carrying out reproductive migrations in the Solimões and Amazon Rivers or their nutrient-rich tributaries and having larvae or juveniles that drift downstream and onto nursery grounds in the estuary or floodplain. Yield from both habitats is strongly influenced by the high nutrient load coming from the Andean headwaters.

The species composition of catches in the two most-productive states (Amazonas and Pará) differ considerably (Table 3). Fishers in Amazonas tend to catch more characids, whereas those of Pará concentrate on catfish. The emphasis on catfish is related to market preferences – people in Amazonas State tend to believe that eating catfish is unhealthy, an opinion not shared by people in Pará.

The total catch from the Amazon may be several times greater than the values reported by IBAMA. Catches of subsistence fisheries in rural areas of Amazonas State remain unrecorded and may total about 113 000 tonnes/year, which, if added to the reported landings would triple the total catch of this state. This would then rank among the highest fisheries producing states in Brazil.[1] Isaac and Almeida (2011) estimated that total fish consumption in the Brazilian Amazon could be as high as 575 678 tonnes/year, which does not include the significant export to large Brazilian cities outside the basin.

The composition of catches by subsistence fisheries is comparable with that of the commercial artisanal fisheries near Manaus, Pará and Acre. In neither fishery do the reported catches reflect the natural relative fish abundance in the floodplains.

THE STATUS OF INLAND FISHERIES RESOURCES

The available information on the fisheries and from stock assessments indicates that most inland stocks of the top 20 species or species groups in the Amazon region are underexploited. However, 30 percent of the stocks are overexploited or recovering and cannot be expected to produce major increases in catches (Figure 3). This is the case for tambaqui (*Colossoma macropomum*), surubims (*Pseudoplatystoma* spp.), jaraquis (*Semaprochilodus* spp.) and curimatá (*Prochilodus nigricans*). However, the stocks of pirarucu (*Arapaima gigas*) are recovering and as are to a lesser extent those of piramutaba (*Brachyplatystoma vaillantii*) of the Amazon.

Catfishes (Siluriformes)

Dourada (*Brachyplatystoma rousseauxii*) and piramutaba (*B. vaillantii*) make extensive reproductive migrations from the estuary to the headwaters of the Amazon-Solimões River and its tributaries. Genetic population analysis of dourada and piramutaba suggests that there is only one population of each species (Batista *et al*., 2005). Both species undertake large-scale reproductive migrations along all the channels and tributaries of the Amazon River. The tributaries should be seen as the critical environments for

[1] The unreported catch from Amazonas State was calculated by using the average daily fish consumption of 300 g per day for a rural population of 1.03 million people.

these species, not only because they are spawning sites but also because the various subcatchments are a source of genetic diversity for the whole group.

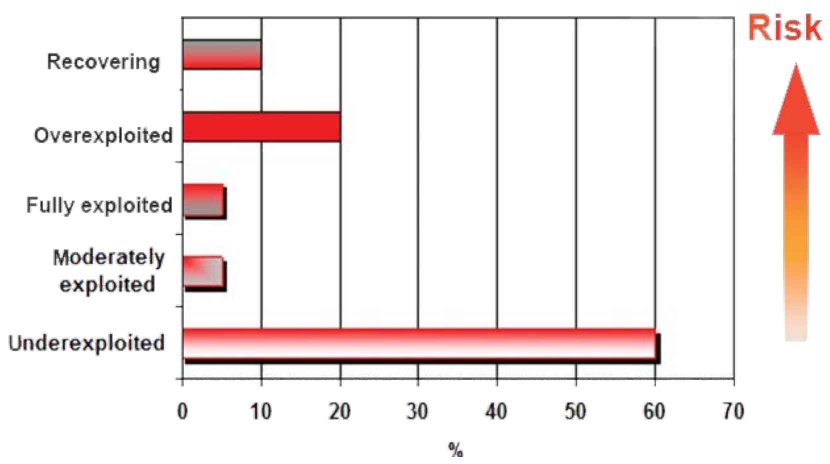
Fishing for catfishes along the channel of the Solimões and Amazon Rivers is mainly industrial, based on storage of fish in cold-storage containers. The gross profit from the catfish fisheries in the Amazon Basin was about USD72 million in 2002–03 (Parente *et al*., 2005), and they employed about 16 000 fishers in the same period. The main trade centres for Amazonian catfish are: (i) the State of Pará, which has 8 fishing companies that are associated with the labour union and 20 federally inspected cold-storage units with a storage capacity of 7 852 tonnes of fish and 6 832 tonnes of ice; and (ii) Leticia, in Colombia, which records landings of about 10 000 tonnes/year. Its landings are mostly destined for Bogotá, Cali and Medellin. The great majority of the catch commercialized by the cold-storage units in Leticia comes from the part of the Amazon Basin between Tefé and Tabatinga in Amazonas State.

TABLE 3
Landings by species groups in the states of the Brazilian Amazon Basin in 200

Species	Total	AM	RO	AC	RR	PA	AM
	Catch (t)						
Piramutaba – *Brachyplatystoma vaillantii*	28 196	3 415	17	0	0	24 701	63
Jaraqui – *Semaprochilodus* spp.	15 844	14 624	254	52	44	740	130
Dourada – *Brachyplatystoma rouseauxii*	14 559	2 891	298	87	48	9 080	2 155
Curimatã - *Prochilodus nigricans*	9 993	6 313	638	99	59	2 533	351
Mapará- *Hypophthalmus* spp.	8 237	2 012	9	79	25	5 926	186
Pescada – *Plagioscion* spp.	7 857	895	17	2	31	6 582	330
Pacu – *Mylossoma* spp.	7 552	6 073	413	54	50	304	658
Tucunaré – *Cichla* spp.	4 957	2 212	29	58	60	2 291	307
Surubim – *Pseudoplatystoma* spp.	4 716	1 797	67	149	28	2 013	662
Aracu – Anostomidae	4 575	666	0	52	0	3 499	358
Matrinxã – *Brycon* spp.	4 419	2 093	6	38	42	295	1 945
Tambaqui – *Colossoma macropomum*	4 315	2558	13	61	16	1 358	309
Filhote - *Brachyplatystoma filamentosum*	3 349	587	65	118	90	1 699	790
Sardinha – *Triportheus* spp.	2 702	2 093	21	1	11	576	0
Pirapitinga – Piaractus brachypomus	2 118	1 792	10	10	10	197	99
Traíra – *Hoplias malabaricus*	2 011	37	3	40	12	1 027	892
Aruanã – *Osteoglossum bicirrhosum*	1 680	1 548	3	9	6	58	56
Acará - Cichlidae	1 587	884	0	0	0	384	319
Mandubé – *Ageneiosus inermis*	1 297	7	0	0	0	585	705
Charuto - Anostomidae	1 295	1 178	0	0	0	117	0
Pirarucu – *Arapaima gigas*	1 121	961	19	24	10	76	31
Mandi – Pimelodidae	1 023	433	38	197	0	143	212
Bodó – Loricariidae	987	165	5	13	12	759	33
Acará-açu – *Astronotus ocelatus*	906	176	15	39	18	658	0
Branquinha – Curimatidae	834	560	49	111	23	40	51
Piranha - Characidae	825	141	2	43	11	481	147
Pirarara – *P. hemioliopterus*	743	2 24	43	0	13	463	0
Camarão – *Macrobrachium amazonicus*	729	0	0	0	0	143	586
Other species	9 504	1 768	986	101	111	4 805	1 733
Total	**147 931**	**58 103**	**3 020**	**1 437**	**730**	**7 1533**	**13 108**

[1] AM = Amazonas, AC = Acre, RO = Rondônia, RR = Roraima, AP = Amapá, PA = Pará, TO = Tocantins.
Source: IBAMA (2008).

FIGURE 3
Status of the main stocks in the commercial inland fisheries of the Amazon Basin



Brachyplatystoma vaillantii
This fish is known as piramutaba, pira-botão, and mulher ingrata in Brazil, pirabutón in Colombia and manitoa in Peru. It is a medium-sized riverine piscivore (maximum length of 100 cm SL) that rarely visits the floodplain, preferring the main channels of the rivers (Barthem and Goulding, 1997). Its migration has been studied by tagging, field observation and fishery studies that suggest that it migrates 3 500 km upriver between May and October from the mouth of the Amazonas River to spawn in Andean tributaries, such as the Ucayali and Japurá Rivers (Barthem and Goulding, 1997).

B. vaillantii occupies the estuary when adult, but avoids saltwater, and the fish move to the upper estuary during the low-water season when the freshwater recedes. All life stages of piramutaba live primarily near the river bed.

The time series for landings of *B. vaillantii*, are the longest in the Amazon Basin, and have been measured by SUDEPE since the early 1970s. Currently, different institutions in Pará collect the data, which are then compiled by IBAMA. Statistics in Pará State (> 70 percent of the catch) are relatively easy to collect because the fishery is carried out by a fairly small fleet of large boats using only a few landing sites. The situation in other areas of the basin is less organized and landings have begun to be monitored only recently.

Piramutaba has been the main fish caught by weight in the Amazon since the 1970s. Landings increased after 1972, peaking at about 29 000 tonnes in 1977. Catches then decreased until 1992, but have since recovered to about 20 000 tonnes/year. However, effort has increased, and catch per unit of effort (CPUE) has decreased correspondingly.

The species was considered to be overexploited at the end of 1980s as indicated by the high catch-to-biomass ratio of trawls in the estuary and the decreasing size of landed fish. The maximum sustainable yields calculated using the Schaeffer model from two sources were 19 929 tonnes/year and 20 900 tonnes/year at a maximum effort of 48 boats and 5 900 days, respectively (IBAMA, 1997).

Figure 4 shows the annual landings of piramutaba for the period 1996–2006. They varied from 10 000 tonnes to 28 195 tonnes, with an average of 21 157 tonnes/year, with a trend towards equilibrium and/or a possible recuperation of the stock.

Brachyplatystoma rousseauxii
Brachyplatystoma rousseauxii is known as dourada in Brazil, zúngaro dourado in Peru, and dorado or plateado in Colombia. It is a large riverine piscivore (maximum

length 180 cm SL) that occurs in the Solimões/Amazonas River from its estuary to its headwaters, including the Negro, Madeira and Tocantins Rivers and other Amazonian tributaries (Barthem and Goulding, 1997).

Barthem and Goulding (1997) hypothesized that schools of juveniles leave the nursery grounds in the estuary and disperse for two years throughout the Central Amazon, where they feed and grow. After this period in the main river channels, the fish migrate upstream to spawn in the headwaters of the Solimões/Amazonas River and its tributaries. The larvae drift downriver to the estuary.

Dourada is important in the Amazonian fisheries. Its landings increased in recent years to reach 21 329 tonnes in 2004 (Figure 4). The species is landed mainly in Pará State, where 15 425 tonnes were landed in 2004, with 3 138 tonnes being landed in Manaus in the same year. In Amazonas State, Resende (1998) registered total landings at six fish-packing plants of 798, 929 and 1 155 tonnes in 1995, 1996 and 1997, respectively. This suggests a slight increase over the period. Catch per unit effort varied from 9 to 64 kg/fisher/y-. Alonso and Piker (2005) suggest that stocks of this species are fully exploited.

Hypophthalmus *species*

Popular names for *Hypophthalmus* spp. are mapará and mapará bico de pena in Brazil, and refer to at least three species: *Hypophthalmus edentatus*, *H. marginatus* and *H. fimbriatus*. The three species are medium sized planktivores (maximum length about 40 cm SL).

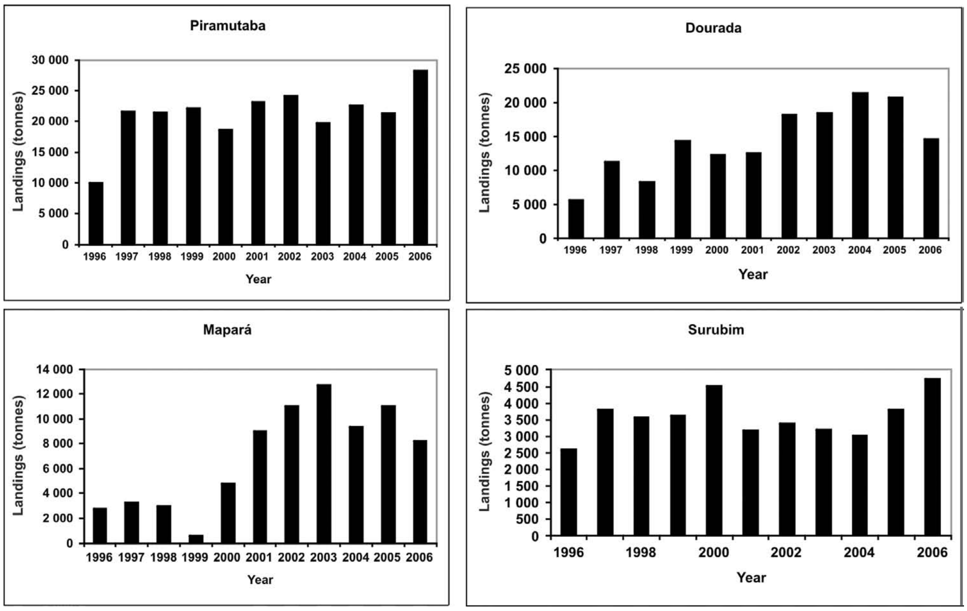
Carvalho and Merona (1986) studied the size distribution and movements of *H. marginatus* in the Lower Tocantins River before the filling phase of the Tucuruí Reservoir and made inferences about its migration. They found young fish in the mouth and adults in the middle Tocantins River in January and February, in relatively homogeneous schools. Between March and October (the low-water period), the schools of young fish swam upstream to the middle Tocantins River where they dispersed. In November, maturing fish migrated upstream from the middle Tocantins River and spawned near the rapids in January and February. The eggs and larvae were believed to drift downriver to the mouth of the Tocantins River.

Mapará landings have only recently been recorded. The fishery for this species in the Tocantins River accounts for 29 percent of the catch of the species from the whole basin (Isaac *et al*., 2008), although with the closure of the Tucurui dam, the catch of mapará declined (Merona *et al*, 2010). Landings at seven fish-packing plants near Manaus averaged 400 tonnes/year between 1995 and 1997 (Resende, 1998). In Santarém, Pará State, landings were 810 tonnes in 1993 (Ruffino, Isaac and Milstein, 1998). The reported landings for the period 1996–2006, showed an increase in the catches of these species, ranging from 610 to 12 722 tonnes in 2003 and declining to about 8 000 tonnes in 2006 (Figure 4), with an average of 6 889 tonnes/year.

Pseudoplatystoma *species*

The two species of *Pseudoplatystoma* – surubim (*Pseudoplatystoma fasciatum*, maximum length 110 cm SL) and caparari (*P. tigrinum*, maximum length 130 cm SL) – are usually grouped in the landing reports as surubim and are considered together here for convenience. Other names are surubim lenha or surubim tigre in Brazil, pintado, rayadao, pintadillo or bagre tigre in Colombia, and zúngaro doncella or zúngaro tigre in Peru. Both species are piscivores and are widely distributed in the Amazon Basin, excluding the estuary. *P. tigrinum* seems to be more concentrated in the lower reaches. There are few accounts of larval distribution and juveniles. Adults have been found in the floodplains and in the main stem of the Solimões/Amazonas River and tributaries. The migration pattern of both species is unknown.

FIGURE 4
Annual landings of main catfish species groups, 1996–2006



Sources: IBAMA (1997, 1999, 2006, 2007, 2008).

Pseudoplatystoma is an important catfish in the fish landings of Amazonas State. The landings of surubim in Manaus market averaged less than 100 tonnes/year between 1986 and 1996. Resende (1998) reported mean landing of 700 tonnes/year of surubim in seven fish-packing plants near Manaus, suggesting that Manaus harbour took only 10 percent of the total landings in 1995 and 1996. However, figures from the packing plants have only recently been sampled and no reliable time series is available. In Tefé, surubim landings averaged 18 tonnes/year between 1991 and 1994.

In Santarém, surubim reached 500 tonnes/year in 1993 (Ruffino, Isaac and Milstein, 1998). The fish is relatively less important in Pará, where the average landings of *P. tigrinum*, which represents 6 percent of the total landing in Santarém, was 215 tonnes between 1992 and 1996 (Ruffino and Isaac, 1999). The average daily CPUE was 3.7 kg/fisher. The same authors, considered this species to be overexploited on the basis of a yield-per-recruit model.

The reported landings of surubim from 1996 to 2006 ranged from 2 559 tonnes in 1996 to 4 510 tonnes in 2000; after, there was a reduction in 2004 to 3 028 tonnes and finally an increase in landings in 2006 to 4 715 tonnes (Figure 4).

Characids

Brycon *species*

Brycon species are called matrinxã, matrinchã, matrinchão, jatuarana and piracanjuba in Brazil, and sábalo in Peru.

The migration of *Brycon cephalus* is complex, resembling that of *Semaprochilodus* spp. The migratory movements of other *Brycon* species are less well known. Borges (1986) suggests that *B. melanopterus* does not migrate downriver to spawn.

Matrinxã are important in landings in Manaus, varying from 3 317 to 5 021 tonnes/year in recent years (Figure 5). In Tefé, landings of matrinxã averaged 26 tonnes/year in 1992, 1993 and 1994 (Barthem, 1999). In 1997, landings of matrinxã in three cities (Manacapuru, Itacoatiara and Parintins) totalled 60 tonnes (Bittencourt, 1999).

Colossoma macropomum

Colossoma macropomum is known as tambaqui in Brazil, gamitana in Peru, pacu in Bolivia (Plurinational State of), and cachama or cachama negra in Colombia. It is widely distributed throughout the Brazilian Amazon, and is most abundant west of the Xingú River. It is found up to the headwaters of the nutrient-rich Madeira, Juruá, Purus and Içá Rivers, but seems restricted to the lower 300 km in nutrient-poor rivers (Araújo-Lima and Goulding, 1997). It is a large omnivorous/frugivorous fish (maximum length about 110 cm SL).

Schools of tambaqui are now hard to find in the river. The tambaqui fishery was very important in the 1970s, but landings in Manaus have decreased markedly from a peak of 15 000 tonnes/year in 1972. Since 1996, catches have fluctuated considerably from year-to-year (Figure 5).

There is no doubt that stocks of tambaqui have been overexploited. Using different methods, Petrere (1983), Merona and Bittencourt (1988), Isaac and Ruffino (1996) and Freitas, Nascimento and Souza (2007) reached similar conclusions. Most fish currently landed are juveniles (Araujo-Lima and Goulding, 1997). Fishing effort has not been reduced, although catches were already low in 1997 and CPUE has continued to fall.

Piaractus brachypomus

Piaractus brachypomus (formerly *Colossoma brachypomum*) is known as pirapitinga in Brazil, paco in Peru and cachama blanca in Colombia. The migration of this species is not well known, although Goulding (1979) suggests that it is similar to that of other migratory characins.

Pirapitinga landings varied from 1 927 to 2 714 tonnes/year between 1996 and 2006, but with no clear trend (Figure 5), and it is possible that the fishery for this species is underexploited.

Mylossoma *spp. and* Myleus *spp.*

Mylossoma are known as pacu, pacu comum, pacu caranha, pacu manteiga and pacu branco in Brazil. In Venezuela (Bolivarian Republic of), the fish is called palometa. There are actually two species: *Mylossoma duriventre* and *M. aureum*. Other species, such as *Myleus schomburgki*, *Myleus torquatus* and *Myleus rubripinnis* are occasionally marketed under this name, but in small quantities. *Myleus schomburgki* is also known as pacu mula. The other species are normally referred to as just pacu.

Mylossoma duriventre (maximum length 25 cm) and *M. aureum* (maximum length 20 cm) are omnivores that are distributed throughout the Amazon Basin, including the Solimões/Amazonas River, its main nutrient-rich tributaries, and the Tocantins/Araguaia Rivers. *Myleus* spp. is common in nutrient-poor tributaries, and less frequent in whitewater rivers.

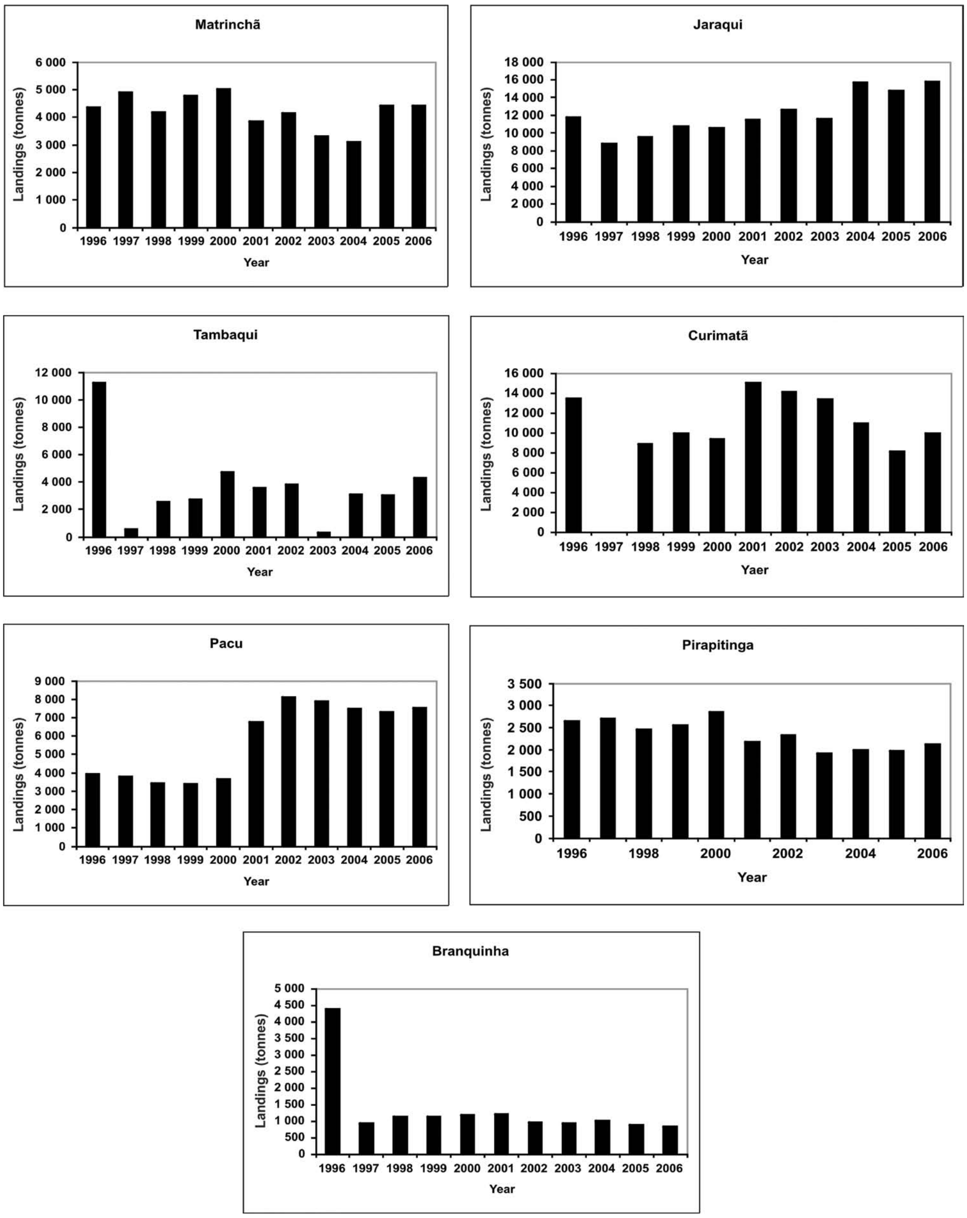
The mean catch in Tefé (1992–94) was 73 tonnes/year (Barthem, 1990). In 1997, landings of pacu in three cities (Manacapuru, Itacoatiara and Parintins) totalled 360 tonnes (Bittencourt, 1999). Data for Santarém in Pará State from 1993 show landings of 102 tonnes (Isaac and Ruffino, 1996). Recent pacu landings averaged 5 700 tonnes/year in the period 1996–2006, but an average of 3 647 tonnes/year was recorded from 1996 to 2000 and 7 518 tonnes/year from 2000 to 2006 (Figure 5). The information available indicates that this fishery is moderately exploited.

Semaprochilodus *spp.*

Semaprochilodus species are known as jaraqui in Brazil, and yarachi in Peru and Colombia. Three species occur in the Brazilian Amazon: *Semaprochilodus insignis*, *S. taeniurus* and *S. brama*.

Jaraqui (*Semaprochilodus taeniurus* and *S. insignis*) have been the second-most-frequently captured fish in the Amazon in the last decade. In 2006, their total catch

FIGURE 5
Annual landings of representative fisheries products, 1996–2006



Sources: IBAMA (1997, 1999, 2006, 2007, 2008).

was estimated at 15 843 tonnes/year (Figure 5). The maximum landings in Manaus Central Harbour, the largest port of Amazonas State, was about 13 000 tonnes/year in the mid-1980s. If one assumes landings at this harbour represent about 50 percent of the total Amazonian landings, then the maximum catch in this period would be 26 000 tonnes/year. Landings have been decreasing in Manaus since then, and by 1996 they had dropped to about 7 000 tonnes/year (Batista, 1998) and 10 247 tonnes/year in the whole Amazon (IBAMA, 1997). Since 1997, landings have increased (Figure 5).

Merona and Bittencourt (1988) applied the Schaeffer model to jaraqui data and estimated a maximum sustainable yield of 11 000 tonnes/year for a daily effort of 84.4 kg/fisher, a yield reached only in 1985. Their estimation must be considered carefully because it was based on the yield of only part of the fishing fleet.

Average landings in other cities of Amazonas State were 250 tonnes/year in Tefé (1991–94) (Barthem, 1999), 500 tonnes/year in Itacoatiara (1996–97), and 150 tonnes/year in Parintins and Manacapuru (1996–97) (Bittencourt, 1999). In Santarém, Pará State, the landings in 1993 were 185 tonnes (Ruffino, Isaac and Milstein, 1998), and recent studies suggest that these species are overexploited (Freitas, Nascimento and Souza, 2007).

Prochilodus ***species***

Popular names for these detritivore species are curimatã in Brazil, boquichico in Peru, sábalo in Bolivia (Plurinational State of) and bocachico in Colombia. Three species occur in the Amazon: *Prochilodus nigricans*, *P. rubrotaeniatus* and a third undescribed *Prochilodus* sp.

Two species have a very restricted distribution: *Prochilodus rubrotaeniatus* occurs only in the headwaters of the Negro River and in the Branco and Trombetas Rivers, and the undescribed *Prochilodus* sp. has been reported in the headwaters of the Tapajós River. Therefore, most of the landings in the Amazon are probably of *P. nigricans*.

In Tefé, landings in 1992, 1993 and 1994 averaged 232 tonnes/year of curimatá (Barthem, 1990). In 1997, landings of curimatá in three cities (Manacapuru, Itacoatiara and Parintins) were 434 tonnes (Bittencourt, 1999). Data for Santarém in Pará State from 1992, 1993 and 1994 revealed landings of 391, 185 and 962 tonnes (Mota and Ruffino, 1997) with an average daily CPUE of 6.8 kg/fisher. Landings are very high in Manaus, exceeding 5 000 tonnes/year in 1996 (Batista, 1998). In the last five years, curimatá landings decreased from 15 061 tonnes in 2001 to 9 991 tonnes in 2006 (Figure 5). Freitas, Nascimento and Souza (2007) suggest that this stock is overexploited.

Potamorhina, curimata ***and related species***

The category marketed as branquinha is made up of many relatively small detritivore species (maximum length < 25 cm) within several genera. Fish from the genera *Potamorhina* and *Curimata* dominate landings, but *Psectrogaster* and *Curimatella* are also harvested occasionally.

Three species of *Potamorhina* (*P. latior*, *P. altamazonica* and *P. pristigaster*), six species of *Curimata* (*C. ocellata*, *C. vittata*, *C. kneri*, *C. inornata*, *C. incompta* and *C. cisandina*), two species of *Psectrogaster* (*P. rutiloides* and *P. amazonica*) and at least three species of *Curimatella* (*C. dorsalis*, *C. meyeri* and *C. immaculata*) are found in the Central Amazon and in the headwaters of nutrient-rich rivers. *C. cyprinoides* was found only in the Tocahavebe and decreased in abundance in the last ten years, but with no clear trend (Figure 5) and this stock may be is underexploited.

Arapaima gigas

The pirarucu (*Arapaima gigas*) is one of the largest freshwater scaled fish in the world reaching as much as 3 m in length and weighing more than 200 kg (Saint-Paul, 1986; Nelson, 1994). It has been exploited since the nineteenth century (Veríssimo, 1895; Menezes, 1951), and was the first commercial fish species of the Amazon to show signs of overfishing. A significant decrease in catches began to be noticed in the 1970s, when it became commercially extinct near large cities, and completely disappeared from some areas (Goulding, 1980). In 1975, pirarucu was included in Appendix II of the Convention on International Trade in Endangered Species of Fauna and Flora (CITES).

Queiroz and Sardinha (1999) identified the pirarucu as the fish species of greatest economic importance for the residents and users of the Mamirauá Sustainable Development Reserve (MSDR). They recorded an average annual catch ranging from 1.4 to 1.6 tonnes in six local communities studied between 1993 and 1995 and estimated that the average annual catch in the focal area of the MSDR could be up to

110–150 tonnes. Pirarucu production was not uniformly distributed throughout the year, but was concentrated in the dry season months (September–December).

In 1996, these studies led to the development of the management plan, which included regulations for the pirarucu fisheries in the MSDR. In 2000, an innovative tool became available for monitoring pirarucu stocks and managing their fishery – a counting method based on the knowledge of pirarucu fishers – which assesses the number of fish in their natural environment (Castello, 2004).

Table 4 shows that the gross average income of fishers has increased over the years. The expectation was that it would practically double in 2003. However, marketing of pirarucu in that year faced difficulties in accessing buyers' markets and the average gross income of the fishers was actually lower than that of the previous year, despite the fact that production practically doubled in comparison with the previous year (Viana *et al*., 2007).

The response of the arapaima stocks to fishery management has been astonishing. Neither the fishers nor the technical staff expected it would be so fast or of such a magnitude. Between 1999 and 2006, the numbers of arapaima increased by more than eightfold in the Jarauá Sector area, going from 2 507 (2 149 juveniles and 358 adults) to 20 648 (12 052 juveniles and 8 596 adults) (Viana *et al.*, 2007). Based on the success of the Mamirauá experience, the approach is being extended to other regions including Fonte Boa, Silves, Itacoativa, Juruá in Amazonas State and Santarém in Pará State, and the results are excellent, showing astonishing stock recoveries.

INLAND CAPTURE FISHERY OF ORNAMENTAL FISHES

The cardinal tetra (*Paracheirodon axelrodi*) is the main target species of the fishery for ornamental fish and represents 76–89 percent of all exports each year (Chao, 2001). Other important exported species include the neon verde (*Paracheirodon simulans*), rodóstomos (*Hemigrammus bleheri*), rosaceu (*Hyphessobrycon* spp.), borboletas (*Carnegiella* spp.) and apistogramas (*Apistogramma* spp.). Arraias (*Potamotrygon* spp.) represent a potential ornamental resource, which was exported under the regulation of a Normative Instruction until December 2005 but whose exports are suspended at present. The middle Negro River – more specifically the municipalities of Barcelos and Santa Isabel do Rio Negro – can be considered the main region for fisheries for ornamental fishes in Brazil.

The fishery is mostly artisanal, based on the fishers' empirical knowledge of the use of the rapiché,[2] cacurí[3] and other types of traps (Leite and Zuanon, 1991). The export of ornamental fishes is an important source of income in the region, generating more than USD2 million and employing more than 10 000 people (Chao, 1993). The main exports are from the Amazon region, representing about 81.5 percent of the total production; the State of Amazonas representing 52.5 percent and the State of Pará the remaining 28.5 percent (Table 5). Twenty million fish were exported in 1979, 13–17 million/year in the 1980s and about 26 million/year in the mid-2000s (IBAMA, 2007). The United States of America, Europe and Asia are the main markets for ornamental fishes, where rare species and those difficult to reproduce in captivity are most in demand.

[2] Rapiché is an artisanal indigenous trap (puçá) made of a wooden frame measuring 1 m long by 0.5 m wide to which is attached a 1-mm nylon grid woven in opposing knots.

[3] Cacurí consists of a cylindrical trap with a very small longitudinal side opening, which allows small fish to enter. This device is made of 1-mm nylon canvas woven in opposing knots. The top is made of iron and the base is made of wood. Both rapiché and cacurí are baited to attract fish.

TABLE 4
Indicators of the community-based management system of Arapaoma in the Jarauá Sector, 1999–2005

Indicators	1999	2000	2001	2002	2003	2004	2005
Number of fishers	42	46	67	65	69	70	74
Total production (tonnes)[1]	3.0	3.5	5.2	18.2	34.9	26.7	51.4
Weighted average price (kg manta)	3.42	6.00	8.00	8.00	–	4.55	3.74
Weighted average price (kg charuto)	–	–	–	4.00	3.00	–	3.00
Gross turnover (BRL1 000)	10.8	20.3	42.0	87.2	85.8	126.3	162.5
Gross income (for 3 months) per fisher (BRL)[2]	257	440	628	1 340	1 244	1 804	2 196
Net income (for 3 months) per fisher (BRL)[2, 3]	208	395	496	1 000	–	–	–

[1] Up to 2011 total production refers only to mantas (fish filets. After 2002, total production refers to the sum of the mantas and "charutos" (charuto is the name for a whole gutted fish with or without the head).
[2] Arapaima fishery management activities are concentrated in 3 months of the year, from September to November.
[3] Starting from 2003 it has not been possible to estimate the net income per fishery as they began to make a variety of deals with buyers and an intermediary who advanced amounts to the fishers (or groups of fishers) to finance their fishing activities.
Source: Extracted from Viana *et al*. (2007).

EMPLOYMENT AND INCOME

There are about 175 803 fishers in the Brazilian Amazon Basin, representing 30.8 percent of the total number of fishers in Brazil. Figure 6 shows the number of fishers by state of the Amazon region. The State of Pará has more than 110 000 fishers, followed by Amazonas State with more than 37 000.

Local and regional economies are partly or fully dependent on commercial fishing. Ruffino (2001) estimated that this type of fishing generates about USD100 million per year – based on the average first sale price of about USD0.50/kg and a catch of about 200 000 tonnes per year. More recently, Almeida (2004), studying 15 cities along of the Solimões/Amazon River, estimated that about USD278 million is yielded by the fishery sector, of which 48 percent comes from fish-processing plants, 18 percent from small-scale fishers and 16 percent from commercial fishers. The same author estimates that the fishery sector provides more than 155 000 jobs. Of this total, most are subsistence fishers (72 percent), followed by jobs in commercial fishing with 23 percent and the fish-processing plants with only 3 percent. Official statistics published by the IBGE (1992) differ widely from these estimates, reporting 17 000 people as working in fisheries out of the 1.2 million persons employed in the primary sector.

TABLE 5
Value of exports of ornamental fishes by state in Brazil

States	2003	2004	2005	2006	Mean	%	% accumulated
	US$						
Amazonas	2 525 721	2 785 376	2 395 980	2 402 735	2 527 453	52.5	52.5
Para	984 031	1 511 306	1 572 615	1 435 694	1 375 912	28.6	81.1
Ceara	311 466	372 425	366 176	438 020	372 022	7.7	88.8
Sao Paulo	92 293	276 655	299 165	102 086	192 550	4.0	92.8
Pernambuco	113 783	148 588	202 193	126 845	147 852	3.1	95.9
Rio de Janeiro	58 763	55 595	34 349	109 292	64 500	1.3	97.2
Others	173 559	159 559	109 945	90 333	133 349	2.8	100.00
Total	**4 259 616**	**5 309 504**	**4 980 423**	**4 705 005**	**4 813 637**	**100.0**	–

The annual commercial value of ornamental fish from the Amazon is estimated at USD2–3 million, making it the third-largest extractive product in the State of Amazonas. It is estimated that more than 1 000 families are actively involved in the capture, transport and marketing of ornamental fishes, and possibly 80 percent (Eisenstadt, 1992) of the riverside population of the municipalities of Barcelos, Saint Isabel do Rio Negro and São Gabriel da Cachoeira has some financial relationship with this trade (Prang, 2004).

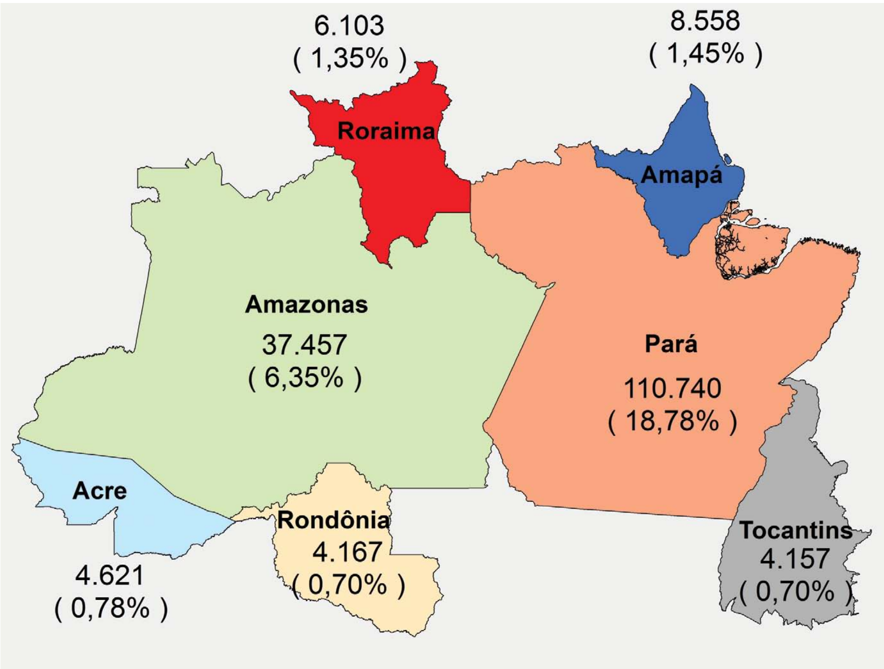
Sport fishing is currently one of the most important touristic industries in Amazonas State. Some 10 000 tourists fish recreationally, and the industry employs directly about 1 000 people per season. According to FAO (1998), the income derived from sport fishing in the Brazilian Amazon could amount to more than USD400 million (including direct and indirect costs).

STATUS OF MANAGEMENT OF FISHERIES IN THE REGION AND THE MANAGEMENT SCHEME/MEASURES IN PLACE

Conventional single-stock assessment has been undertaken in recent years for some commercially important fish species, mostly using length-based methods and growth and mortality parameters. Results indicate that large, slow-growing species such as the tambaqui (*Colossoma macropomum*), surubim (*Pseudoplatystoma tigrinum* and *P. fasciatum*) (Isaac, Ruffino and McGrath, 1998), dourada (*Brachyplatystoma rousseauxii*) and piramutaba (*Brachyplatystoma vaillantii*) (Fabré and Barthem, 2005) are overexploited. The curimatá (*Prochilodus nigricans*) stocks are still not overexploited, but the fishery for this species must be monitored because of the intensification of its exploitation throughout the basin, as indicated by the analysis of landings data by Freitas, Nascimento and Souza (2007).

Stock assessments of species with more opportunistic (“r”) life strategies, such as the pescada, (*Plagioscion* spp.) need to take into account environmental factors, such as the velocity and intensity of floods, as they explain better the success or failure of

FIGURE 6
Number of fishers by state and respective percentage in relation to the total number of fishers in Brazil



Source: SEAP (2008).

recruitment, and, consequently, the total catch, than does the intensity of fishing effort (Annibal, 1982; Merona, 1993).

The analyses for two species of jaraqui (*Semaprochilodus* spp.) should be more cautious because, although these species can be characterized as r-strategists, the current levels of exploitation are so high that the stocks may collapse if recruitment fails in a year (Freitas, Nascimento and Souza, 2007).

Management strategies applied

Efforts to mitigate impacts of fishing on fish stocks have largely consisted of implementation of regulations, of which the most common measures relate to: (i) the type of fishing gear; (ii) the time and period of the year that fishing is allowed; (iii) restriction of access; and (iv) the number of licences granted.

In the past, the first two measures were used intensively to regulate fishing in the Amazon River, while fishing in the coastal areas was regulated more through limiting the number of licences granted, for example, for the industrial fishing of piramutaba in the estuary and for the pink shrimp and pargo fisheries on the Atlantic coast.

At the time of writing, legislation regulating the minimum size of capture exists for *Arapaima gigas*, *Pseudoplatystoma tigrinus*, *P. fasciatus*, *Semaprochilodus* spp. and *Colossoma macropomum*. In addition, fishing for certain species of characins is prohibited during the period of upstream reproductive migration (from December until February–March). There are also restrictions on the number of vessels and the mesh size used in the trawl fishery for piramutaba (*Brachyplatystoma vaillantii*) in the Amazon River estuary. Despite these regulations, enforcement remains difficult and most of these norms are not respected.

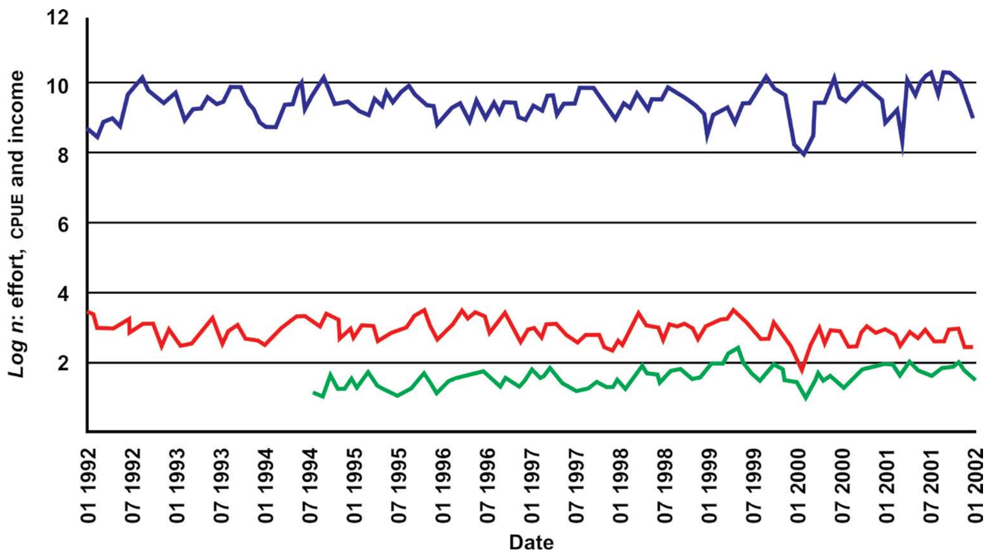
Community-based management has evolved into fishing accords based on the interests of communities and the protection of the exploitation rights of the members of the community. Fishing accords establish rules with respect to access, the type of gear and the time of year that fishing is allowed based on the needs of community members and on the requirements for stock maintenance. Several such agreements are supported by projects, non-governmental organizations (NGOs) or governmental agencies.

According to Castro and McGrath (2001), fishing agreements are a set of rules established by riverine communities that define the rights of access and use of the fisheries resource within a determined geographic area. The rules are strongly founded in local ecological knowledge and monitoring is based on the local social ethics. Thus, this type of community-based management is a form of comanagement with many partnerships, power-sharing arrangements and integration between local management and government-centred systems.

In their analysis of fish landing data in Santarém for the decade 1992–2001, Almeida *et al.* (2009) concluded that the levels of capture and total effort of the commercial fishery in the Lower Amazon did not show any trend in this period. There is some evidence of seasonal variation in which no significant trends can be observed. Analyses for each of the most important species did not show any trends either in total catch or CPUE. Thus, it may be concluded that commercial fishing in the Santarém region is in equilibrium (Figure 7). Almeida *et al.* (2009) calculated the CPUE in managed and non-managed lakes, and showed that the productivity was significantly and consistently higher in communities that established agreements than in those without agreements (Figure 8).

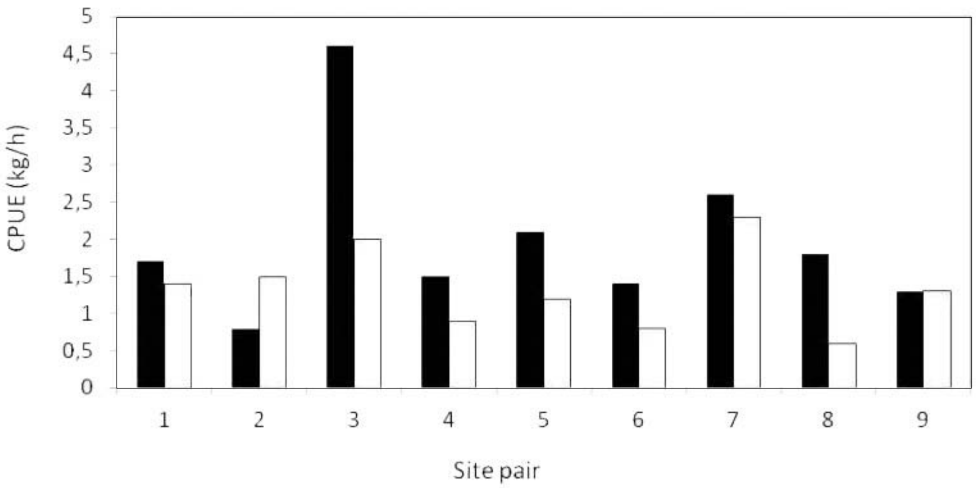
Intensification of the fishery and local organizational development processes are leading to a new model of community management. However, the establishment of fishing agreements not only gives a solution to changes in fishing patterns (through effort restriction and increase in lake productivity), but also to the demand for rights to access common resources. It also shows that the performance of such models depends on the accord between local laws and social and ecological systems, as well as on the ability of the organization to identify any continuous environmental changes (Ostrom, 1999).

FIGURE 7
Commercial fishing in Santarém 1992–2002: fishery effort (number of fishers/day) (blue line), capture per unit of effort (kg/fisher/day) (red line) and income (US$/month) (green line)



Source: Almeida *et al*., 2003.

FIGURE 8
Comparison of the fishery productivity (catch per unit of effort, CPUE) in communities with and without fishery agreements



Note: Communities with management are those with black bars.
Source: Almeida *et al*., 2003.

Management policies and the promoting of sustainable fisheries

Fish resources are important to the inhabitants of the Amazon region as a source of food and income. From the 1990s onwards, demands by local communities, often with the support of civil society, have changed the management of natural resources and, in particular, of fisheries. Fishing accords and their recognition by the responsible government agencies have led to the decentralization of management and the institutionalization of participatory approaches (Raseira, Câmara, and Ruffino, 2006).

This alternative management system has become a model that is being replicated in other regions of the country. The Amazon region is considered a great laboratory of social and environmental experiments and alternative actions for sustainable development. However, experience has shown that this system should be adaptable, whereby changes are monitored and deviations are corrected in an interactive dynamic between society, scientists and decision-makers. These experiences still need to be perfected and extended to a continental scale, particularly with regard to international agreements for the management of migratory species.

The complexity and dynamics of the Amazon region require the capacity of the State to be enhanced to coordinate and monitor complex processes. The government approach should be multidisciplinary – which means a change from the paradigm of centralized and "definite" management hitherto dominant in government institutions towards more flexible and democratic approaches.

2. Lake Constance fish and fisheries

Roland Roesch
LAZBW, Fisheries Research Station Baden-Wuerttemberg
Langenargen, Germany

INTRODUCTION

Fisheries management and the fisheries yield of lakes depend on a number of factors, of which one of the most important is its trophic state. Many lakes have experienced intensive changes in nutrient concentrations over the years with effects on the nutrient cycle. These have led to changes in fish community composition and fisheries yield, which may be influenced by changes in species composition. A few lakes, including Lake Constance, have undergone limnological changes from oligotrophic to eutrophic and back to oligotrophic status.

The following gives an overview of the Lake Constance fish and fisheries over the past 100 years.

THE LAKE

Lake Constance is situated between Austria, Germany and Switzerland (Figure 9). It has a total surface area of 536 km². It is divided into a larger and deeper Upper Lake and a smaller and shallower Lower Lake. Lake level is not regulated so it fluctuates by about 1.5 m from low water in late winter to high water in summer. Only the Upper Lake is considered in this paper. The Upper Lake has a maximum depth of 254 m and an average depth of 100 m (www.IGKB.org). Originally oligotrophic, it has undergone dramatic changes in nutrient content in recent years (Figure 10) (Güde, Rossknecht and Wagner, 1998; www.IGKB.org). Until the 1950s, it was oligotrophic, with a very low nutrient concentration and low productivity. Thereafter, owing to increases in human population density, intensification of agriculture, and industrialization along the lake shore as well as changes to the drainage system, the lake underwent intensive eutrophication. As soon as the effects of eutrophication became obvious, measures were put in place to reduce the nutrient load to the lake (for details, see Güde, Rossknecht and Wagner [1998]). These were primarily the installation of sewage treatment plants including phosphorus retention and regulation of industry, not only on the shore area but in the entire drainage system (Zintz, Löffler and Schröder, 2010). The increase in nutrient content stopped in the 1980s and since then nutrient concentration has decreased (re-oligotrophication) to the point at which the phosphorus concentration is back to the level it was before eutrophication started.

The lake area is a hot spot for tourism. It also serves as a drinking-water reservoir for more than 4 million people. There is intensive agriculture along the northern shoreline.

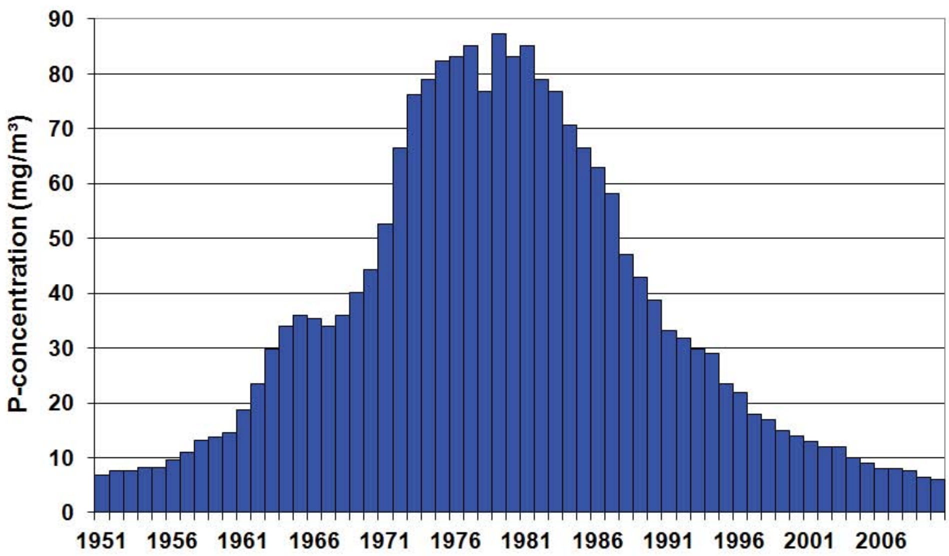
THE FISH COMMUNITY

More than 30 fish species occur in the lake (Table 6). Originally, four whitefish (*Coregonus lavaretus*) forms were found in the lake: a pelagic spawning form (locally called Blaufelchen), a nearshore spawning form (locally called Gangfisch), a fast-growing form (locally called Sandfelchen) and a deep-water form (locally called

Kilch) (Nümann, 1972). During the mesotrophic/eutrophic phase of the lake, the Kilch disappeared (Eckmann and Roesch, 1998). Presumably, the conditions for the survival of the eggs on the surface of the bottom sediment were unsuitable. Arctic charr (*Salvelinus alpinus*) and brown trout (*Salmo trutta*) almost became extinct in the 1970s (Hartmann, 1984; Ruhlé *et al.*, 2005). The populations of both species then stabilized owing to the measures taken to control eutrophication within the lake and/or in the tributaries.

FIGURE 9
Map of Lake Constance

FIGURE 10
Annual mean phosphorus concentration in Lake Constance



Source: www.igkb.org

Since 1880, five new species have become established in the lake. Rainbow trout (*Oncorhynchus mykiss*) and pike perch (*Sander lucioperca*) were introduced about 100 years ago (www.IBKF.org), whereas ruffe (*Gymnocephalus cernuus*), bluegill sunfish (*Lepomis gibbosus*) and three-spined stickleback (*Gasterosteus aculeatus*) arrived in the lake in an unknown manner. Ruffe was detected for the first time in 1987 and spread over the whole lake within a few years (Hartmann, 1993, Roesch and Schmid, 1996).

TABLE 6
List of fish species occurring in Lake Constance

Species	Before 1880	Today
Anguilla anguilla (L.)	X	X
Salmo trutta L.	X	X
Salvelinus alpinus (L.)	X	X
Coregonus lavaretus L.:		
Blaufelchen	X	X
Gangfisch	X	X
Sandfelchen	X	X
Kilch	X	
Thymallus thymallus (L.)	X	X
Esox lucius L.	X	X
Rutilus rutilus L.	X	X
Leucaspius delineatus (Heckel)	X	X
Leuciscus leuciscus (L.)	X	X
Leuciscus cephalus (L.)	X	X
Phoxinus phoxinus (l.)	X	X
Scardinius erythrophthalmus (L.)	X	X
Tinca tinca (L.)	X	X
Chondrostoma nasus (L.)	X	X
Gobio gobio (L.)	X	X
Barbus barbus (L.)	X	X
Alburnus alburnus (L.)	X	X
Blicca bjoerkna (L.)	X	X
Abramis brama (L.)	X	X
Rhodeus sericeus amarus (Bloch)	X	X
Carassius carassius (L.)	X	X
Cyprinus carpio L.	X	X
Barbatula barbatula (L.)	X	X
Silurus glanis L.	X	X
Perca fluviatilis L.	X	X
Cottus gobio L.	X	X
Lota lota (L.)	X	X
Stizostedion lucioperca (L.)		X
Oncorhynchus mykiss (Walbaum)		X
Gasterosteus aculeatus L.		X
Gymnocephalus cernuus (L.)		X
Lepomis gibbosus (L.)		X

FISHERIES MANAGEMENT

Governance

An agreement (the Bregenzer Übereinkunft) signed by all adjacent countries in 1893 harmonized fisheries regulations for the whole lake. The regulations concern fishing gear (dimensions and numbers of nets, minimum mesh size or range of mesh sizes allowed for the respective gear, days of the week, when a specific gear can be used, closed season). Adjustment of the rules is discussed in a group of experts (the Sachverständigenausschuss), which may suggest any changes to the political board (the Internationale Bevollmächtigtenkonferenz für die Bodenseefischerei [International Conference of Plenipotentiaries for Fishery in Lake Constance]) on the basis of regular monitoring data. The board meets once a year, whereas the group of experts meets at least twice a year. The current regulations for the economically most important species (whitefish and perch) are given in Table 7. As the lake is a condominium, i.e. no borders exist on the lake, the total lake surface (except those areas with a water depth of less than 25 m) is open for all fishers independent of their nationality.

Rules are also set for anglers concerning minimum size, gear allowed, fishing season and, in the case of perch, a limit of 50 fish per day.

The fisheries regulations are controlled by fishery wardens and are based on regular monitoring of whitefish and perch. Monthly samples are taken using gillnets of different mesh sizes.

Stocking

Blaufelchen, Gangfisch and Arctic charr are stocked regularly into the lake, whereas juveniles of brown trout are stocked into the tributaries. The eggs of whitefish and Arctic charr are derived exclusively from specific fisheries for spawners in the lake, whereas in the case of brown trout spawners, which are raised from wild fish, are held in captivity. The effect of stocking into Lake Constance is unknown, as there has been no research on stocking efficiency.

FISHERIES

Professional fisheries

There are currently about 140 professional fishers on the lake (www.ibkf.org). Formerly, fish were marketed wholesale, but now almost all fish are marketed directly. A small number are marketed as gutted fish, but most of the fish are sold as fillets, smoked or in the form of other products.

Fisheries statistics

The total yield (i.e. the yield of all species combined), the yield of commercially important species and the relative composition of the catch are available from the professional fisheries yield statistics, which are available continuously since 1910. This is one of the longest time series of catch statistics worldwide. Statistics on recreational fisheries yield begin in 1993.

Each professional fisher is obliged to record catches separately for each species on a daily basis. These records have to be provided monthly to the regional fishery wardens. The fishery wardens transfer the data anonymously to the fisheries research

TABLE 7
Closed season and gear allowed for the whitefish (*Coregonus lavaretus*) and perch (*Perca fluviatilis*) fisheries on Lake Constance in 2011

Species	Closed season	Mesh size *(knot to knot)*	Net size *(height × length)*	Number of nets allowed
Whitefish (pelagic spawning)	16 October – 10 January	38–44 mm	7 m × 120 m	4
Whitefish (nearshore spawning)		38–42 mm	2 m × 100 m	In total: 6
Perch	1–20 May	28–32 mm	2 m × 100 m	

station of Baden-Wuerttemberg, where all data are combined to provide the yearly statistics for the lake. Anglers also have to record their catches and provide them annually to the local authorities.

The data are published in an annual report (www.IBKF.org).

Total yield

The total yield for 1910–2010 is shown in Figure 11 together with the phosphorus concentration. The time series of total yield can be divided into three main periods: 1910–1955, 1956–2005, and 2006–10. In the period 1910–1955, the fisheries yield fluctuated widely from year to year with a median of 421 tonnes. In 1956, more than 1 000 tonnes of fish was caught for the first time, and then until 2005 only fell below 800 tonnes in very few years. The median for this period is 1 088 tonnes. The maximum yield of 1 897 tonnes was reached in 1977. Since that time, the annual yield has gradually decreased and, since the 1990s, year-to-year fluctuations have also decreased. In 2006 and 2007, the fisheries yield was as low as that 50 years earlier in the oligotrophic phase of the lake. It increased in 2008–10 to a slightly higher level with a median of 725 tonnes. Even if the yield of the years 2008–10 suggests stabilization, the long-term trend predicts a further decrease. This view is supported by the fact that, prior to eutrophication in the 1950s, the fisheries yield was lower than it is at present.

*Whitefish (*Coregonus lavaretus*) yield*

Until 1955, the annual whitefish yield was below 400 tonnes (Figure 12). For the period 1956–1961, it increased to more than 600 tonnes. In the following years, the yield underwent drastic fluctuations from year to year, with some years of very low yield, although the maximum whitefish yield recorded so far of 1 218 tonnes occurred in 1976. From about 1990, the whitefish yield stabilized at a high level and the fluctuations from year to year were lower than in previous years. For most of this time, the annual yield exceeded 500 tonnes although a decrease in yield is visible. Whitefish growth and age at catch underwent drastic changes, as described below.

FIGURE 11
Total yield of professional fisheries in Lake Constance

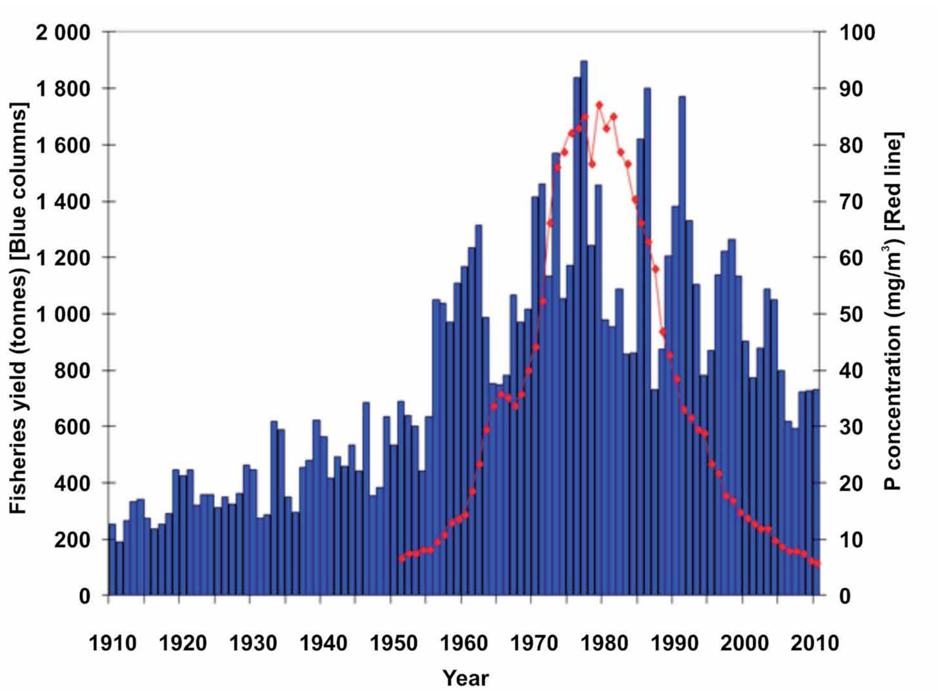
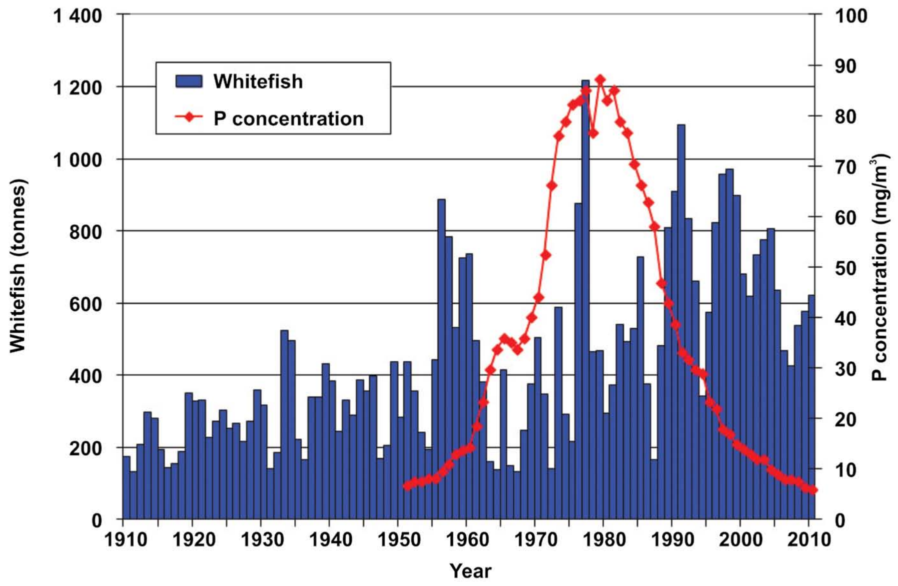


FIGURE 12
Yield of whitefish in Lake Constance



*Perch (***Perca fluviatilis***) yield*

Until recently, the second-most important fish species for the Lake Constance professional fisheries was perch. Up to the 1950s, the perch yield was less than 200 tonnes (Figure 13) (Hartmann and Nümann, 1977). In 1958, the annual yield exceeded 200 tonnes for the first time and in the following 20 years the perch yield generally exceeded 400 tonnes. The perch yield has decreased since the 1980s, with the lowest yield of 34 tonnes in 2010. Such a low yield had not been recorded since 1955. Perch have changed their diet and behaviour during eutrophication and re-oligotrophication. Originally, perch were predatory fish, but with eutrophication perch changed their diet and switched almost completely to the abundantly available zooplankton. With re-oligotrophication, perch became predatory again. An overview is given in Eckmann, Gerster and Kraemer (2006).

*Arctic charr (***Salvelinus alpinus***)*

In Lake Constance, Arctic charr is at the most southerly part of its natural distribution in Europe. For most of the time its yield has not exceeded 2 000 kg (Figure 14). With increasing nutrient content, its yield decreased dramatically to only 34 kg in 1975. At that time Arctic charr was on the verge of disappearance (Hartmann 1984). However, with decreasing nutrient concentration coupled with stocking, the Arctic charr population recovered, and with up to 12 tonnes in recent years the annual yield is by far the highest since the beginning of the fisheries statistics.

Arctic charr has changed over the years. Originally, two populations were found in the lake: a deep-water form and the “normal” form, which were distinguished mainly by the number of gill rakers (Dörfel, 1974; Hartmann, 1984). In recent years, according to gill raker numbers, only the deep-water form has remained in the lake and the “normal” form has disappeared (Bader and Roesch, 2008). The reasons for this change are unknown. The Arctic charr population has also changed its behaviour. Originally, Arctic charr was a slow-growing, deep-water form present mainly in the western areas of the lake, but now Arctic charr are caught in the whole lake as bycatch in whitefish and perch gillnets. They aggregate in the western part of the lake only during spawning in November–December when they are found over the traditional spawning areas.

FIGURE 13
Yield of perch in Lake Constance

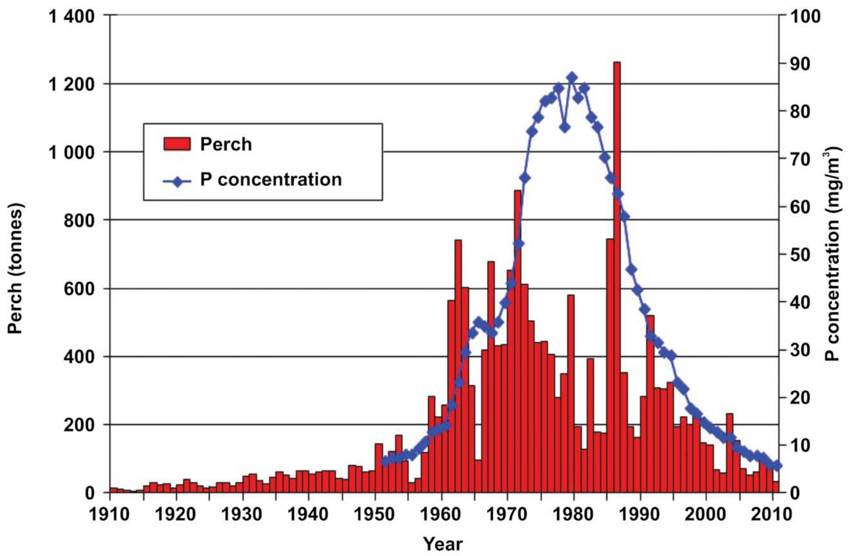
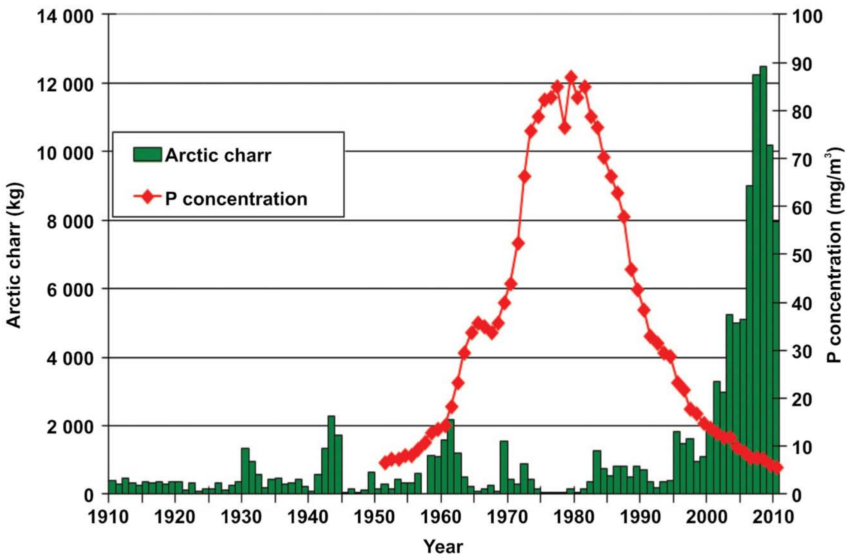


FIGURE 14
Yield of Arctic charr in Lake Constance



*Common carp (*Cyprinus carpio*)*

Until 2003, the professional catch of carp was low and the maximum yield was 7 tonnes in 1951 (Figure 15). However, from 2003 onwards, the carp yield increased to a maximum of 17 tonnes in 2007. The main reason for this increase was the strong 2003 year-class. In Lake Constance, carp do not spawn successfully every year. Since 1999, carp juveniles have only been found in the lake in 2003, 2006 and 2011 (Roesch, 2008). The weather in 2003 was unusual, as an extremely mild spring was followed by a very hot summer. This combination provided optimal conditions for carp larvae to grow and a large year-class developed. The growth rate of carp of the 2003 year-class was high and was comparable with the growth rate of carp that cultivated in carp ponds (Roesch, 2008).

Relative catch composition

The relative composition of yield from the Lake Constance professional fishery is shown in Figure 16. Until 1960, the yield was composed of about 70 percent whitefish, 10–20 percent perch and 10–20 percent "others" (the yield of all species except whitefish and perch). Such a catch composition is typical for an oligotrophic whitefish lake. With increasing eutrophication, the relative contribution of whitefish to the total yield decreased and the contribution of perch to the catch also increased. In certain years, whitefish composed less than 20 percent of the total catch. Since the 1980s, the relative contribution of whitefish to the catch has increased again and is now about 80 percent of the annual catch. This means that the relative catch composition is about the same as before eutrophication.

FIGURE 15
Yield of common carp in Lake Constance

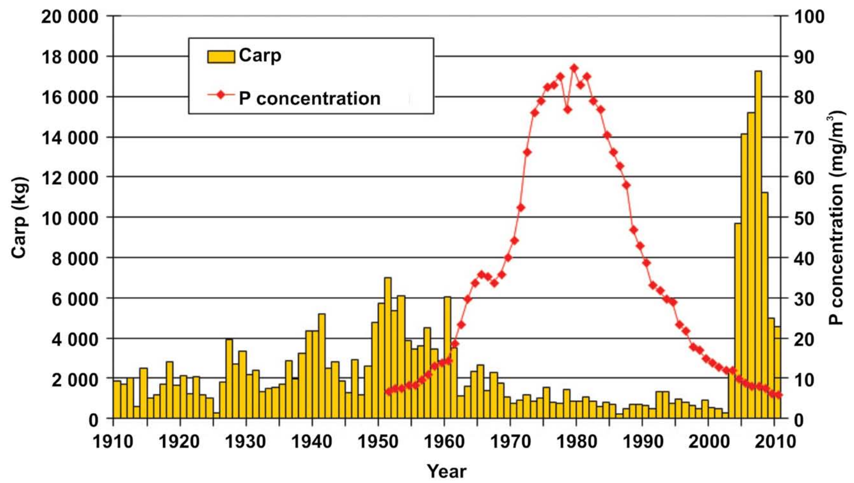
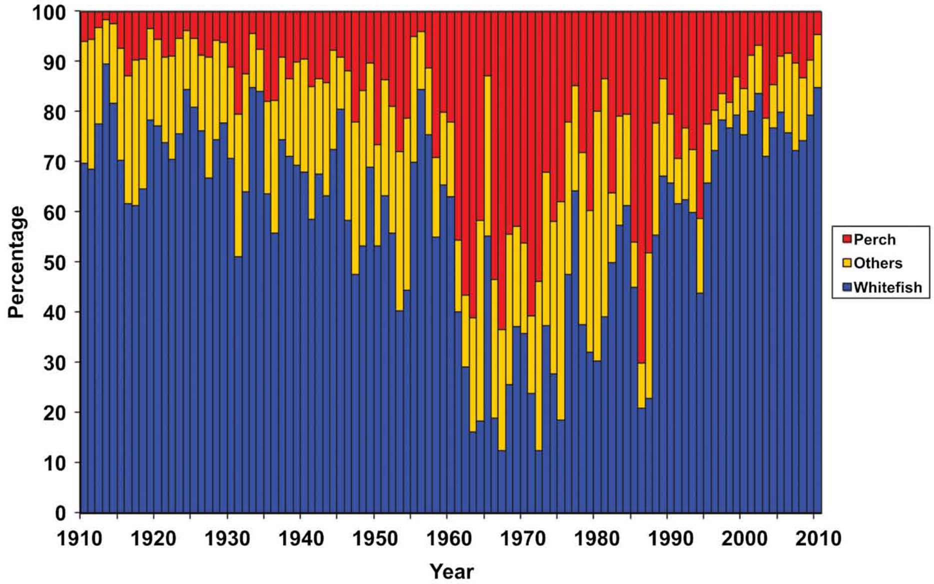


FIGURE 16
Relative catch composition of professional fisheries in Lake Constance, 1910–2010



Age at catch of whitefish

Whitefish have been routinely monitored since 1952. Figure 17 shows age at catch. Before eutrophication, the catch consisted mainly of 3-year-old whitefish, but with increasing eutrophication in the 1950s age at catch decreased until the beginning of the 1960s when the whitefish catch consisted mainly of 1+ and 2+ fish. As such young fish were mainly juveniles, there was a danger of recruitment overfishing. Therefore, in 1963 the minimum mesh size for whitefish gillnets was changed from 38 mm (knot to knot) to 44 mm and catching whitefish was banned for this year (Nümann, 1972). Subsequently, the age composition in the catch changed to slightly older fish. A major change occurred with the beginning of re-oligotrophication. From here on, age at catch has increased and since the 1990s it has mainly consisted of 3–4-year-old fish with a certain percentage of older ones.

In the last 20 years, at least two year-classes contributed to the catch in each year – which is one of the reasons that the yearly fluctuations of yield have become much smaller than during the meso-eutrophic phase of the lake.

Anglers yield

The anglers yield for the period 1993–2010 is shown in Figure 18 (www.IBKF.org). The total yield decreased from about 100 tonnes in 1993 to 40 tonnes in 2010. In 1993, perch was the main target with 75 percent of the catch (weight), whereas in 2010 perch comprised only 18 percent of the catch and the percentage of whitefish increased from 2 to 22 percent. A main reason for this change is that perch changed its behaviour and diet (see above). With re-oligotrophication, perch changed from planktivory to piscivory and the population size decreased. Because of these changes the accessibility of perch to the anglers deteriorated and the majority of Lake Constance anglers switched to other species. Predatory species such as pike and brown trout are highly welcomed by the anglers, but their yield is low compared with the yield of whitefish and perch.

In total, the anglers yield is in a range of about 7–10 percent of the commercial yield.

FIGURE 17
Age at catch of whitefish in Lake Constance, 1952–2010

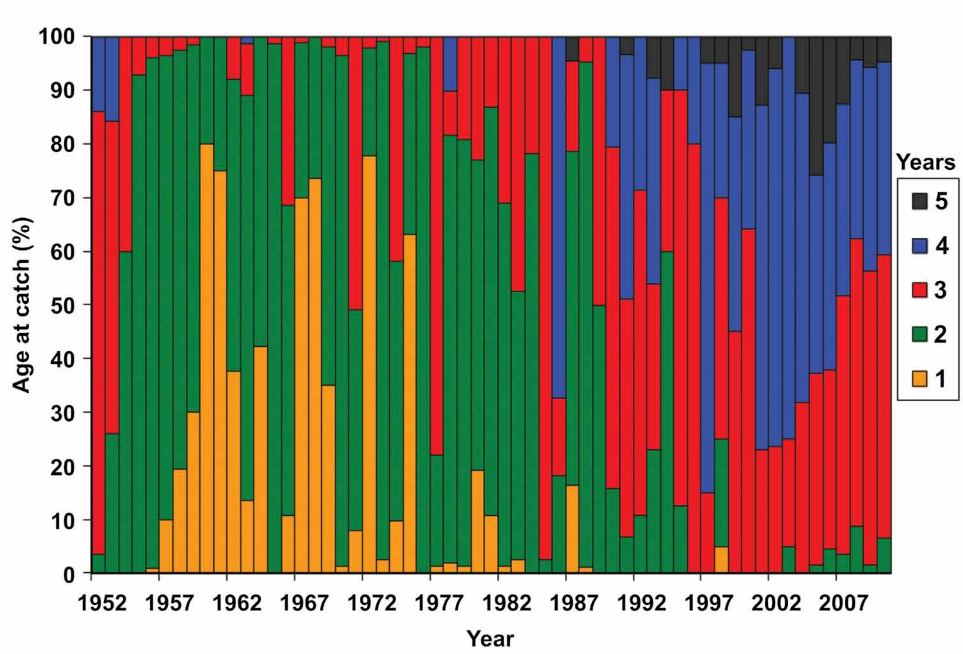
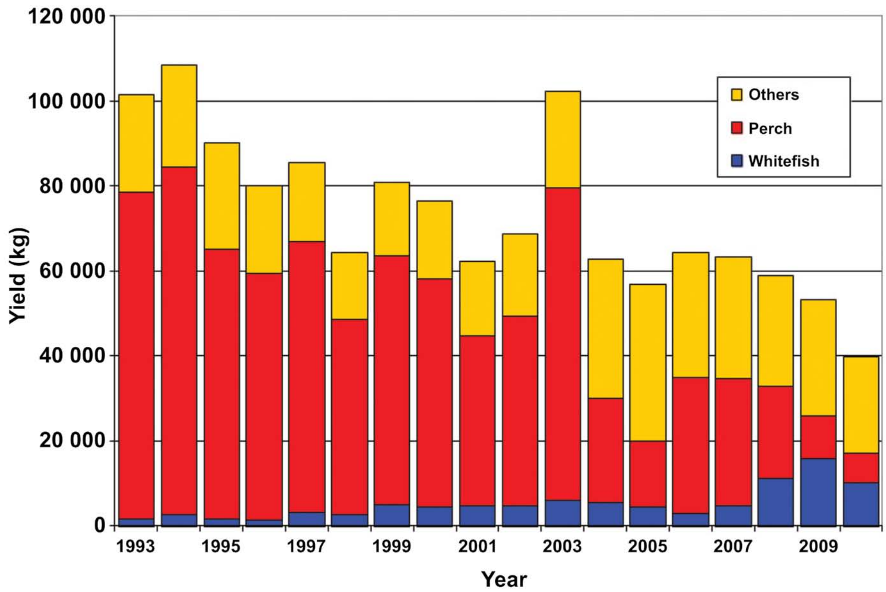


FIGURE 18
Total yield of recreational fishery in Lake Constance, 1993–2010



DISCUSSION

Lake Constance has undergone intensive eutrophication and re-oligotrophication in the last 100 years (www.IBKF.com; Zintz, Löffler and Schröder, 2010). However, because phosphorus concentration is only one component of the trophic status, the present status of the lake is not directly comparable with that of 60 years ago. The lake itself differs in many aspects from the lake in the 1950s, for example, in the intensity of agriculture in the surrounding land, the intensity of touristic use and the water management in the catchment area. Global warming also is a major issue for Lake Constance as its surface temperature has increased by a value of 0.03 °C per year in recent years (www.kliwa.de, Straile, Jöhnk and Rossknecht, 2003).

Statistics on professional fisheries yield go back to 1910. Long-term trends concerning total yield as well as species composition of the catch are evident; although their accuracy may be doubtful. Limnological data, i.e. data on nutrient content, are also available since the beginning of eutrophication in the 1950s. In the case of Lake Constance, the effects of eutrophication and re-oligotrophication are well documented (Zintz, Löffler and Schröder, 2010; Güde, Rossknecht and Wagner, 1998). Short-term studies could not provide such information. In addition, an almost 20-year series of statistics of anglers yields is available, which enables yield from the professional fishery to be compared with those of the recreational fishery.

Thus far, the professional fisheries yield is higher than before eutrophication in the 1950s, although it is probable that yields will decrease to this former low level over time. Predictions of a further decrease in nutrient concentration corroborate this assumption. Thus, it is highly improbable that adapted fisheries management will be able to keep the fisheries yield at the current level and any increase in yield is even more unlikely. The relationship between phosphorus concentration and annual yield shows that in years when the P concentration was below 10 mg/m^3 fisheries yield is correlated with the P concentration. This finding does not exclude fluctuations in annual yield, but the trend is apparent. In conclusion, the economic basis for professional fishers will decrease further and it is safe to predict that the number of professional fishers on Lake Constance will decline further in the future.

Currently, the lake serves as a drinking-water reservoir for more than 4 million people and the lake region is a hotspot for tourism (Zintz, Löffler and Schröder, 2010). Therefore, any discussion about enhancement of the economic basis of the professional fishers has to be seen in this context. Even a slight increase in nutrient content by technical means is out of the question. The economic importance of professional fisheries is much too low compared with the interests of other sectors.

Statistics of fisheries yield do not necessarily reflect the fish biomass and species composition in a lake because only species of commercial or recreational value are exploited intensively. In Lake Constance, these are mainly whitefish (*Coregonus lavaretus*) and perch (*Perca fluviatilis*) and to a lesser degree eel (*Anguilla anguilla*), brown trout (*Salmo trutt*a), pike (*Esox lucius*), pike perch (*Sander lucioperca*), burbot (*Lota lota*) and carp (*Cyprinus carpio*) (www.ibkf.org). Other species, such as the cyprinids, roach (*Rutilus rutilus*) and bream (*Abramis brama*), have only become of interest in recent years because of the reduced availability of the other species.

The yield increase in the 1950s, which included nearly all species, may have occurred for several reasons. The most obvious is the beginning of eutrophication in that decade. However, in this period, two parallel developments took place: (i) a change in fishing gear; and (ii) a change in the marketing of the fish (Eckmann and Roesch, 1998). The change in fishing gear was primarily characterized by the introduction of nylon gillnets instead of ones made from cotton. This new material resulted in a much higher fishing efficiency compared with the traditional material used, which may have led to a higher yield. Whitefish fisheries changed to being a year-round gillnet fishery. Traditionally, during spring and summer whitefish were caught using a purse seine (locally called Klusgarn), and gillnets were used only during autumn and winter (Elster, 1944).

Up to the 1950s, perch was economically unimportant because its market value had been very low. However, since the beginning of direct marketing, the fishers have learned to produce perch fillets, which are a highly prized product.

Typical whitefish lakes are oligotrophic. With eutrophication, whitefish yield decreases and the whitefish population may even disappear. Favourable periods for whitefish yield can also be seen in Lake Constance where those years with a phosphorus concentration between 10 and 25 mg/m^3 were optimal – whitefish yield was generally high and fluctuations from year to year were low. When the P concentration was higher, the fluctuation was much higher. Here, years with very high, but also very low, yield were recorded. On the other hand, with a P concentration below 10 mg/m^3, fisheries yield decreased drastically with decreasing P concentration.

In many lakes, invasive introduced species are a major threat, as their occurrence may change the nutrient cycle and fish community. For example, the Laurentian Great Lakes fish community changed drastically with the introduction of several fish species, one of the most important being the sea lamprey (*Petromyzon marinus*) (Mills *et al*., 1993; Ricciardi, 2006). It is unusual, therefore, that the present Lake Constance fish species composition is almost the same as that of 100 years ago (Eckmann and Roesch, 1998). By the beginning of the twentieth century, several fish species had been introduced into the lake (Löffler, 1998). Of these early introductions, only rainbow trout and pike perch have established successfully. Three further fish species have been established in the lake more recently. In case of ruffe (*Gymnocephalus cernuus*), it was expected that a population expansion would change the littoral fish community (Hartmann, 1993; Roesch and Schmid, 1996). However, ruffe has integrated into the littoral fish community with no major effects. During the eutrophic phase of the lake, two species were at the edge of extinction: Arctic charr (Hartmann, 1983, 1984) and brown trout (Ruhlé *et al*., 2005). The Kilch, a slow-growing, deep-water whitefish form, disappeared during that time (Eckmann and Roesch, 1998).

In Lake Constance, the most recent introductions of invertebrates have been *Limnomysis benedeni* (first detected in 2006), *Dikerogammarus villosus* (first detected in 2003) and *Katamysis warpachowski* (www.neozoen-bodensee.de). The possible impacts of these species are being investigated.

The fisheries management of Lake Constance is an example of successful international cooperation over more than 100 years (www.IBKF.org). From the beginning, its aim was to obtain maximum sustainable yield. This has been reached, especially under the conditions of changing nutrient content, i.e. eutrophication and, in recent years, re-oligotrophication. All the decisions are based on a routine monitoring of whitefish and perch as well as the fisheries statistics.

In recent years, fisheries management has been especially influenced by re-oligotrophication. It is hoped that a higher yield than that obtained before eutrophication may be sustained by adapted fisheries management. To date, the management has proved effective. The income of professional fishers depends on their catch. Fisheries enterprises would not be economically feasible on the basis of selling the catch to wholesalers. Therefore, most fishers have started direct marketing of their fish. In addition to being gutted and scaled, most of the fish are processed by filleting, smoking, etc. In this respect a good example is perch (*Perca fluviatilis*), which was unwanted until the 1950s. With the beginning of direct marketing, the fishers learned to prepare perch fillets. With this new product, the price for perch increased and the fishers started fishing especially for perch. Perch yield increased in this period – a trend encouraged by the transition from cotton to nylon as a netting material.

Another aspect is that, from time to time, professional fishers apply to increase fishing intensity in order to enhance fisheries yield. This possibility has been discussed several times, but there are no scientific data available on positive effects. On the contrary, fishing intensity is so high that almost every whitefish and perch specimen that reaches a size to be caught in the respective gillnet is caught. The proof is that in those nets used during monitoring, of which the mesh size is larger than the size allowed for the professional fishers, only very few fish are caught. This result shows that the current fishing intensity for the target species is so high that almost all fish of a given year-class are caught, and an increase of fishing intensity would not increase fisheries yield substantially.

The anglers yield is in a range of 7–10 percent of the professional fisheries yield. This relationship is true for the total yield, but for some of the most desirable species the anglers share of the total yield is much higher. For example, in the case of brown trout, which is a highly valued species among anglers, the yield is between 13 and 34 percent of the total brown trout yield.

CONCLUSION

In conclusion, the long-term series of fisheries yield and limnological data of Lake Constance provide a good example of recovery of a lake ecosystem from cultural eutrophication.

3. The stationary trawl (dai) fishery of the Tonle Sap – Great Lake system, Cambodia

Ashley S. Halls
Aquae Sulis Ltd
Bath, United Kingdom

and

Bruce Paxton
Murdoch University
Perth, Australia

INTRODUCTION

Rising in the east of Tibet Autonomous Region of China and discharging into the South China Sea, the Mekong River is one of the world's largest rivers with a catchment area of 795 000 km^2 and a length of about 4 900 km. The upper Mekong Basin lies within Myanmar and China. The lower part of the basin lies within Cambodia, the Lao People's Democratic Republic, Thailand and Viet Nam. Here, the river and its floodplains and wetlands support highly productive fisheries landing in the order of 2 million tonnes of wild fish per year comprising hundreds of species. A range of other aquatic animals including shrimps, crabs and molluscs contribute a further 0.5 million tonnes to landings. These resources are a major source of protein and essential elements in the region and support the livelihoods of millions of people (Hortle, 2007).

Situated in northwest Cambodia, the Great Lake is the largest wetland in Southeast Asia (Kummu *et al.*, 2008). It is a major hydrogeomorphic feature and an integral part of the hydrology of the Mekong River system to which it is connected via the Tonle Sap River (about 130 km long) near the city of Phnom Penh. The Tonle Sap River and the Great Lake together form the unique Tonle Sap – Great Lake (TS–GL) system, one of the most productive ecosystems on earth (MRC, 2005).

Flows in the Mekong River are primarily driven by the strongly seasonal southwest monsoon, resulting in a single annual flood pulse. This flood pulse, together with the flat nature of the terrain and extensive flooding over the Cambodian plain, gives rise to a unique hydrological phenomenon that is primarily responsible for the unusually high biological productivity of the TS–GL system.

In the dry season (October–May) water drains from the Great Lake into the Mekong River via the Tonle Sap River. As the wet season advances from June/July onwards, however, flooding in the delta downstream of Phnom Penh causes water levels in the Mekong River to rise higher than those in the Great Lake. This causes flow in the Tonle Sap to reverse, and instead of draining into the Mekong, the waters are pushed upstream towards the Great Lake, inundating its extensive floodplains and flooded forests. At the peak of the flood, the dry season aerial extent of the lake will increase between three and six times from about 3 500 km^2 to about 14 500 km^2 (Kummu *et al.*, 2008). Towards the end of the flood, backed-up waters in the lake and concurrently subsiding water levels in the Mekong River, cause the flow in the Tonle Sap River to change direction once more. The waters are then carried out of the lake via the Tonle Sap, back into the Mekong River and towards the delta.

The stationary trawl (Loh dai trey, dai trey, or Kanlaang dai) fishery of the TS–GL system was established in the late nineteenth century to target the migrations of fish from the Great Lake to the main channel of the Mekong River with the receding floodwaters each year. The fishery is located in the lower section of the Tonle Sap River spanning more than 30 km across the municipality of Phnom Penh and Kandal Province (Figure 19). Dai nets are arranged in up to 15 separate rows of between one and seven nets anchored perpendicularly to the channel, with the net mouths facing upstream. The most-upstream row (Row 15) is located about 35 km from Phnom Penh. These positions have remained largely unchanged for more than a century and may have been chosen to maximize catch rates determined by river morphology and hydrology.

The fishery contributes up to 33 000 tonnes (7 percent) of Cambodia's total annual landings of fish each year, excluding other aquatic animals, estimated to be in the region of 480 000 tonnes/year[4] (Hortle, 2007), for a value of at least USD3–6 million in 2006. The remaining proportion of the country's total catch is taken using large-scale fence and barrage traps, and by small and middle-scale fisheries employing seines, gillnets, small trawls, bamboo traps, cast nets and hook and line (Baran, 2005). It is estimated that about 25 percent of the fish consumed in the lower Mekong Basin is landed in Cambodia.

The dai fishery provides important seasonal employment for more than 2 000 rural people and supplies the essential ingredient for prahok, a fermented paste that is an important protein source for many, particularly towards the end of the dry season when fish is scarce (Halls, Lieng and Ngor, 2007; Lieng, Yim and van Zalinge, 1995).

The fishery has been monitored intermittently since the 1930s, and continuously and intensively in the last decade, thus providing the main source of data and information to monitor the health and guide the management of the country's fisheries resources. The fishery has also provided important insights into how fish populations respond to environmental variation, particularly flooding patterns. Models describing these responses are being utilized in the region to guide the integrated development of the lower Mekong Basin and to forecast the probable impacts of climate change (Halls, 2008a; Halls *et al.* 2008; Mainuddin *et al*., 2010; Halls *et al*., 2013a).

TARGET SPECIES, GEAR AND FISH DISPOSAL

Species caught

The dai fishery primarily targets small cyprinids of the *Henicorhynchus* genus, collectively known as trey riel in Khmer. Other species making an important contribution to landings are pelagic river carp (*Paralaubuca typus*), Nilem carp (*Osteochilus hasseltii*) and various species of *Labiobarbus* cyprinids and *Botia* loaches. The families Cyprinidae and Cobitidae dominate the landings. Their species are targeted as they migrate from the TS–GL system and surrounding floodplains to dry-season refuge habitat (e.g. deep pools) in the main channel as water levels fall from October to March. As water levels begin to rise at the start of the next wet season (June), adults migrate upstream to spawn and then return back downstream to the TS–GL system and other floodplain feeding habitat.

In the 2008–09 fishing season, a total of 125 individual species in 34 families were reported to have been landed. Thirty-eight families are reported as having been caught by the fishery since 1994, of which 15 constitute 99 percent of the catch (Table 8).

[4] Estimated from per capita consumption and population size in 2000. The consumption-based estimate of fish yield including other aquatic animals was 587 000 tonnes in 2000. Official landings of fish and other aquatic animals reported to FAO ranged from 250 000 to 422 000 tonnes between 2001 and 2010. Hortle (2007) suggests that the discrepancy between the two sets of estimates reflects the exclusion or under-reporting of artisanal and subsistence fisheries in the official statistics.

FIGURE 19
Map of the Great Lake – Tonle Sap system showing the stationary trawl (dai) fishery, Cambodia

Ngor (2000) notes that species composition varies during the six months of the fishing season. He reports that large and medium-sized fish species such as *Pangasianodon gigas*, *Catlocarpio siamensis*, *Probarbus jullieni*, *Cirrhinus microlepis*, *Pangasius* spp. and *Cyclocheilichthys enoplos* are caught in larger numbers at the start of the season (October and November) compared with later in the season. Inter- and intra-specific differences in the timing of migrations conditioned primarily by fish size have been described in the Mekong since the mid 1950s (Welcomme, 1985).

Gear – the dai

Long, cone-shaped nets are suspended from two anchored bamboo rafts or (sampans), and a floating work platform (or a movable floating house) is positioned at the codend of the net. According to Cambodian law, the maximum permissible size of the net is 27 m by 120 m, but the Fisheries Administration have found nets up to 30 m wide and 180 m long being used (Table 9). A small boat or floating platform is secured between the two anchored rafts by bamboo poles that serve as a gangway and help to keep the net mouth open. The distance between the two anchored rafts (25–27 m) and the depth of the water determine the net mouth area. In all, up to 30 anchors attached to steel cables may be required to secure the dai in position. Another raft is positioned above the entrance of the net mouth. This holds a winch for raising and lowering the chain "footrope", thereby opening and closing the net mouth. The bag net is kept open by the force of the current and with help of anchors (Figure 20).

TABLE 8
Principal families and species making up 99 percent of the dai catches, in descending order of total percentage contribution

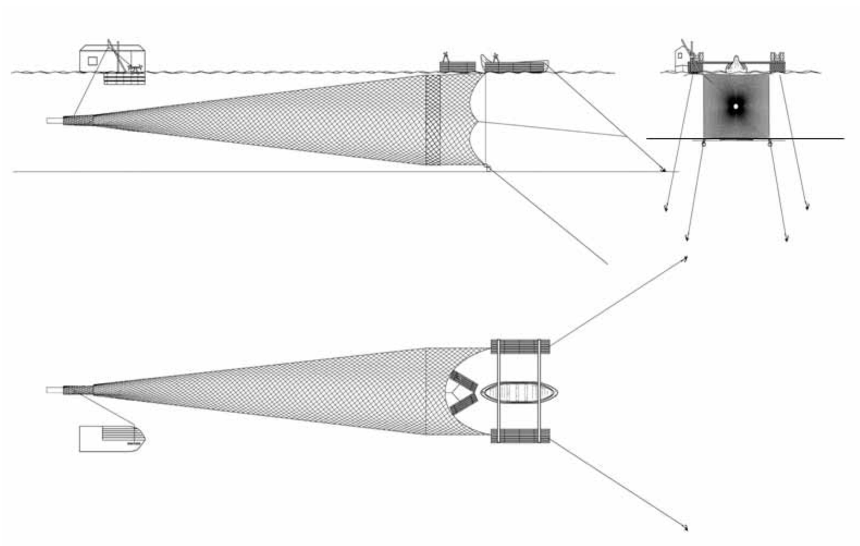
Family	No. of species	Species
Cyprinidae	53	*Henicorhynchus lobatus*
		Paralaubuca barroni
		Henicorhynchus cryptopogon
Pangasiidae	9	*Pangasius larnaudii*
		Pangasius pleurotaenia
		Pangasianodon hypophthalmus
Cobitidae	5	*Botia modesta*
		Botia morleti
		Botia helodes
Siluridae	8	*Belodontichthys truncatus*
		Kryptopterus micronema
		Wallago attu
Gyrinocheilidae	1	*Gyrinocheilus aymonieri*
Soleidae	1	*Synaptura marginata*
Bagridae	8	*Mystus nemurus*
		Mystus singaringan
		Hemibagrus wyckii
Clupeidae	4	*Clupeichthys aesarnensis*
		Tenualosa thibaudeaui
		Anodontostoma chacunda
Engraulidae	3	*Coilia lindmani*
		Setipinna melanochir
		Lycothrissa crocodilus
Cynoglossidae	1	*Cynoglossus feldmanni*
Sciaenidae	1	*Boesemania microlepis*
Belonidae	1	*Xenentodon cancila*
Notopteridae	2	*Chitala ornata*
		Notopterus notopterus
Polynemidae	3	*Polynemus multifilis*
		Polynemus dubius
		Polynemus borneensis
Bagriichthidae	1	*Bagrichthys macracanthus*

Note: The number of species in each family is reported together with the three dominant species by weight in each family, also in descending order of their percentage contribution.

Three types of net, varying according to mesh size and shape, are used by dai operators during the course of the fishing season according to the prevailing hydrological conditions and the mean size of migrating fish (Table 9). All three nets are conical in shape, but the Yor net has a much smaller top panel and longer U-shaped top rope to maintain net buoyancy during low-flow conditions towards the end of the season (January–March) when lift forces exerted on the net generated by the flow are much lower. With a much reduced top-panel area, fishers must first drive fish towards the codend before hauling it.

In the first 3–4 months of the open season (October–January), the dai chieu net is used to target medium- and large-sized fish species, which fishers believe migrate from the Great Lake first. They are followed by smaller-sized species and individuals later in the season. Strong water currents in this later period exert significant drag forces on the dai net, which limit the minimum net mesh sizes that can be used. In the first two months, when haul weights are low but fish sizes are relatively large, an open-weave basket made of bamboo and rattan is often attached to the codend. The dai nheuk net is used between December and February to target smaller species including *Henichorynchus* species (trey riel), *Paralaubuca* spp. (trey slak russy) and *Labiobarbus lineatus* (trey khnawng veng). The mesh sizes of all three nets decrease from the net

FIGURE 20
Main structures of the dai fishery in the Tonle Sap River



Source: Deap, Degen and van Zalinge (2003).

TABLE 9
Mean (and range) dimensions, mesh sizes, and periods of operation of each dai net type

Net type	Length	Width	Depth	Minimum mesh	Maximum mesh
		(m)		*(mm)*	
Dai Chieu	157 (110–180)	29 (27–30)	21 (10–32)	24 (13–50)	182 (100–250)
Dai Nheuk	157 (110–180)	29 (27–30)	17 (8–28)	16 (15–25)	118 (80–220)
Dai Yor	158 (110–180)	29 (27–30)	14 (6–26)	15 (15–20)	70 (20–200)

Net type	Period of operation					
	Oct	Nov	Dec	Jan	Feb	March
Dai Chieu	■	■	■	■		
Dai Nheuk			■	■	■	
Dai Yor				■	■	■

mouth to the codend. To empty the net of fish, the net mouth is first closed by raising the foot rope. The codend of the net is then winched aboard the working platform and emptied into sorting compartments or directly into boats belonging to fish buyers during peak landing periods. Since 1999, diesel engines have begun to replace the traditional hand-powered wooden winches used to raise the foot rope to close the net mouth and to raise the codend during net hauling.

Disposal of the catch

Small, low-value species that form the majority of the catch by weight are typically sold to fish traders either on the floating dai platform or on the nearest riverbank. In periods of high catch rates, the entire haul may be landed directly into traders' boats. Sy Vann and Yumiko (2007) report that fresh fish are also exported to Viet Nam by boat or road for human consumption, as well as for fish and animal feed. This practice was prohibited by the Government in 1990 to control prices and ensure adequate supply for rural farmers and households (Touch, 1998). Valuable medium and large-size fish species, including *Osteochilus melanopleurus*, *Pangasius larnaudii*, *Cyclocheilichthys* *enoplos* and *Pangasianodon hypophthalmus*, are often kept alive in bamboo cages suspended below the working platform of the dai. A single cage can contain up to 20 tonnes of live fish (Lieng, Yim and van Zalinge, 1995). These fish are sometimes sold during the closed season (March–September), when fish supply is low and prices are high. High-value species are also sold during the fishing season to fish traders to supply nearby markets or for export.

Using data on costs and revenue reported by So, Sy Vann and Yumiko (2007), the annual profit of dai units tends to decline from the most-upstream dai Row 15 to Row 2. Equipment, labour and fuel costs are all higher upstream and unit fish prices are lower, but these differences are more than compensated for by the disproportionately larger landings made by the upstream dai units. The licence fees paid by dai operators (both official and unofficial combined) appear to be independent of their reported operating profit.

MANAGEMENT

The fishery is administered by the Fisheries Administration (FiA) of the Government of Cambodia using input (effort) controls and technical measures (gear and minimum size restrictions, and closed seasons) according to the Law on Fisheries (KoC, 2006).

Fishing effort is primarily controlled by means of licensing. Fishing licences are either auctioned by the Government to the highest bidder for exclusive exploitation for a two-year period (Deap, Degen and van Zalinge, 2003) or are allocated by the FiA for research purposes. In 1938–39, 108 dai units were permitted to fish in 23 rows (Chevey and Le Poulain, 1940), but by 1962–63 the number had been reduced to 61 units in 15 rows (Fily and D'Aubenton, 1995). The mid-1980s saw an increase to 86 units followed by a decline to present-day numbers (Figure 21). There are currently 64 dais in 15 rows on the Tonle Sap.

Fishing effort (mortality) is also controlled by means of a closed season between 1 April and 30 September. The closed season, corresponding to the spawning period for the majority of target species, is also a technical measure designed to protect the reproductive potential of the resources.

Gear dimensions, mesh sizes as well as the period of operation of the dai fishery are determined by a "burden book". The burden book states the maximum gear dimensions and minimum mesh sizes for the three types of nets that can be used in the dai fishery (Table 10).

TABLE 10

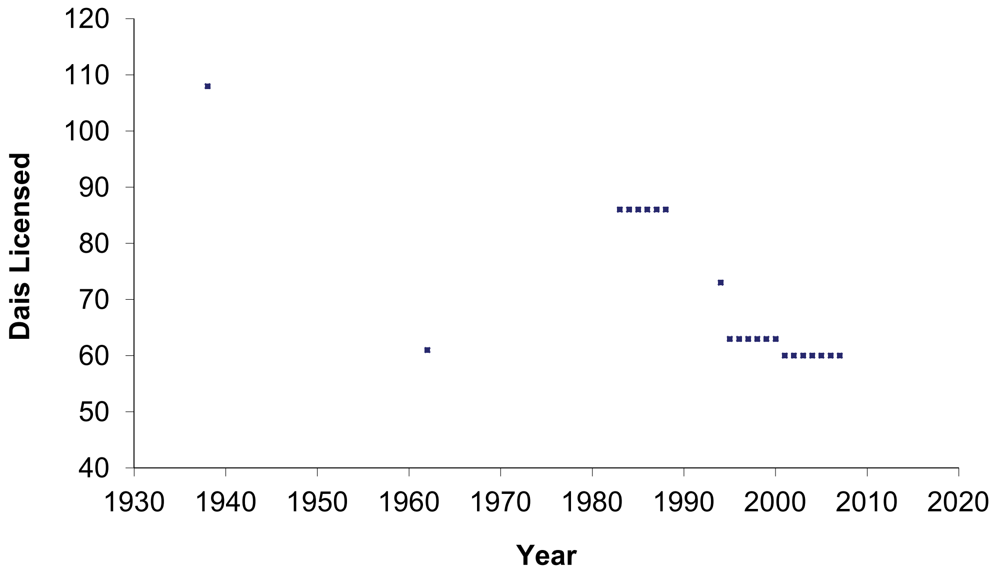
Maximum gear dimensions and minimum mesh sizes for the three types of dai nets

Types and size of dai gear	Period of operation	
	Start	*End*[1]
Dai Chieu Net dimension: – Size: 120 m (Length) × 27 m (width) – Mesh size : 20–220 mm	1 October	1 January
Dai Nheuk Net dimension: – Size: 120 m (Length) × 27 m (width) – Mesh size: 15–220 mm	2 January	28 February
Dai Yor Net dimension: – Size: 120 m (Length) × 27 m (width) – Mesh size: 15–30 mm	1 March	15 March

[1] After 30 March, all the dai structure must be removed from the river.
Source: Dai fishery's burden book 2005–07.

FIGURE 21

Number of licensed dais, 1938–2007



Sources: Chevey and Le Poulain (1940); Nguyen and Nguyen (1991); Lieng, Yim and van Zalinge (1995); Ngor (2000); Ngor and van Zalinge (2001).

Monitoring and evaluation

The first surveys of the dai fishery were undertaken in the late 1930s, generating estimates of landings of the order of 13 500 tonnes (Chevey and Le Poulain, 1940). Fily and D'Aubenton (1965) monitored the dai fishery from 1962 to 1963 and estimated much lower catches (Table 11). Regular monitoring by the FiA (formerly the Department of Fisheries) using logbooks began in the 1980s, supplemented by ad hoc surveys described by Nguyen and Nguyen (1991). Logbook monitoring was regarded as unreliable because fishers under-reported their catch in order to influence licence costs.

Since 1994, catch and effort variables and length-frequency data have been sampled daily by the FiA using direct observation (enumerator) methods with the support of the Fisheries Programme of the Mekong River Commission (MRC) to provide species-wise estimates of: (i) total annual catch; (ii) indices of abundance and biomass (CPUE), (iii) mean weight; and (iv) population size (age) structure. The catch assessment survey (CAS) samples randomly selected dai units for CPUE and effort data, stratified by municipality (Khandal and Phnom Penh), lunar phase (peak- and low-catch phase) and dai type (high catch and low catch). Catches are then estimated as the product of the mean catch rate (catch per dai unit per day) and the total fishing effort (dai fishing

TABLE 11

Estimates of total annual catch in the Tonle Sap – Great Lake fishery, 1938–1995

Season	Total catch *(tonnes)*	No. of dais	Reference
1938–39	13 568	106	Chevey and Le Poulain (1940)
1962–63	2 135	61	Fily and d'Aubenton (1965)
1981–93	5 000–12 839	35–97	Department of Fisheries statistics
1986–88	7 413–18 026	86	Nguyen and Nguyen (1991)

Source: Lieng, Yim and van Zalinge (1995).

days), before summing across strata to give estimates for the whole fishery (Ngor and van Zalinge 2001). Catches are subsampled for species composition data to provide estimates of catch by species.

Catch, effort and CPUE trends

Effort data are regarded as reliable only from 1997/98 onwards (P. Ngor, personal communication, 2010) and, therefore, data only from this season onwards are presented. In the 12-year period for which reliable data could be assembled, total catch (aggregated across species) by season has varied from between about 8 000 and 33 000 tonnes, with a mean of about 15 000 tonnes but with no obvious trend (Figure 22a). Very high catches were observed in 2004/5 and 2005/06. Effort has ranged from 60 to 68 dai units, again with no obvious trend (Figure 22b). Catch per dai per season – a crude index of fish biomass (Figure 22c) exhibits a similar coefficient of variation as catch per season (about 46 percent) and there is also no obvious trend through time. However, with the exception of the estimates for 2004/5 and 2005/06, variations in this simple biomass index appear to track the variation in the flood extent and duration of the TS–GL system very closely.

Trends in species diversity and catch composition

Any consideration of the diversity and identity of species in dai catches over the 14-year period that the fishery has been monitored needs to account for the interannual variation in sampling effort, the skill of the data collectors, as well as the number of species that have been targeted over the years, which has varied from 31 at the commencement of sampling (1994) to 125 currently (2009). However, in the period for which a species-wise analysis of the fishery can be considered reliable (1997–98 onwards), more than 70 species have been monitored. Therefore, bearing these factors in mind, caution should be exercised with regard to attributing any biological significance to interannual trends in species diversity or composition.

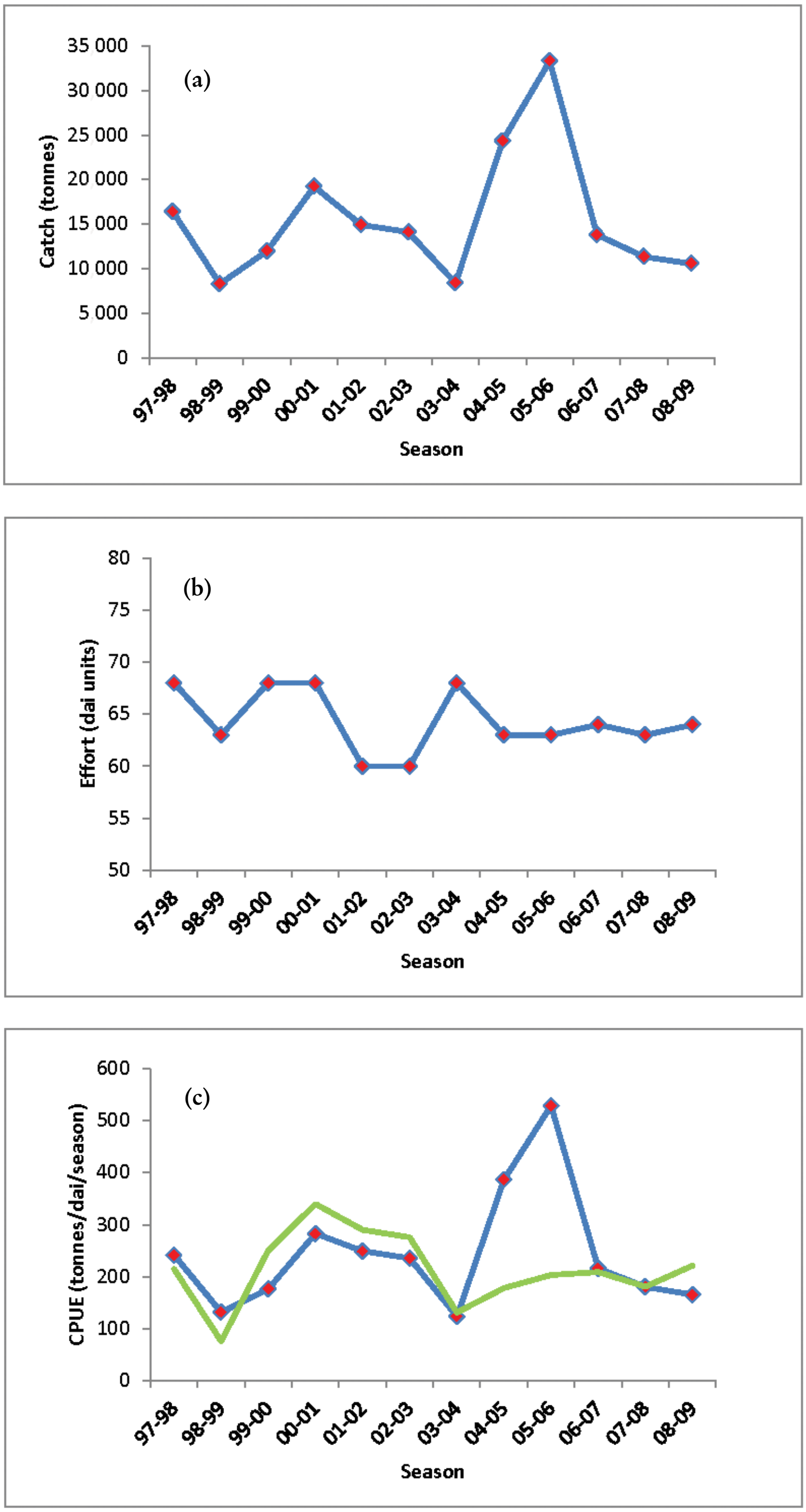
The largest number of species that has been recorded as having been caught by a single dai on a day is 80, with the mean being 22.8. However, both the species richness (S) and diversity as measured by the Shannon diversity index (H) of the dai catches have exhibited considerable interannual variability since the 1997–98 season (Figure 23).

Between 1998–99 and 2002–03, the mean number and diversity of species caught by the dai in a day show a steady increase. Thereafter, aside from a peak in 2006–07, the values decline and then stabilize with a daily mean of about 26 species/dai. Thus, the trends suggest an overall increase in the number and diversity of species has occurred over the 12-year period. However, strong parallels with the number of hauls sampled in each season (Figure 24) suggest that the patterns in diversity caught may reflect changes in sampling effort rather than changes in the fish community itself. Sampling effort in terms of the total number of hauls sampled in each season has varied considerably since the start of the monitoring period (Figure 24). A total of 435 hauls were sampled in 1997–98, with this number increasing to 2 426 in 2001–02. Sampling effort then declined after 2002–03 and this is paralleled by the sharp drop in species numbers and diversity over this season. The only inconsistency in the parallels between species diversity and effort is that the former peaked in 2006–07, whereas the latter peaked in 2007–08. On the whole, however, these patterns, when combined with the evidence for increasing species resolution in the database, suggest that the data should be treated with circumspection with regard to detecting diversity changes in the fish community itself.

Records of the species composition of the dai catches date to the 1930s and suggest that the dominant species in the catches have remained largely unchanged since this period. Lieng, Yim and van Zalinge (1995) compared catches in the 1994–95 season with those reported for the 1938–39 (Chevey and Le Poulain, 1940) and 1962–63 surveys (Fily and D'Aubenton, 1965) (Table 12). In both these earlier seasons, catches were dominated by *Henicorhynchus* spp. (25.4 percent in 1962–63), and in the 1962–63 season, *Cirrhinus microlepis* (18.6 percent) and *Thynnichthys thynnoides* (14.9 percent) were the second- and third-most dominant by weight respectively. In the 1994–95 and

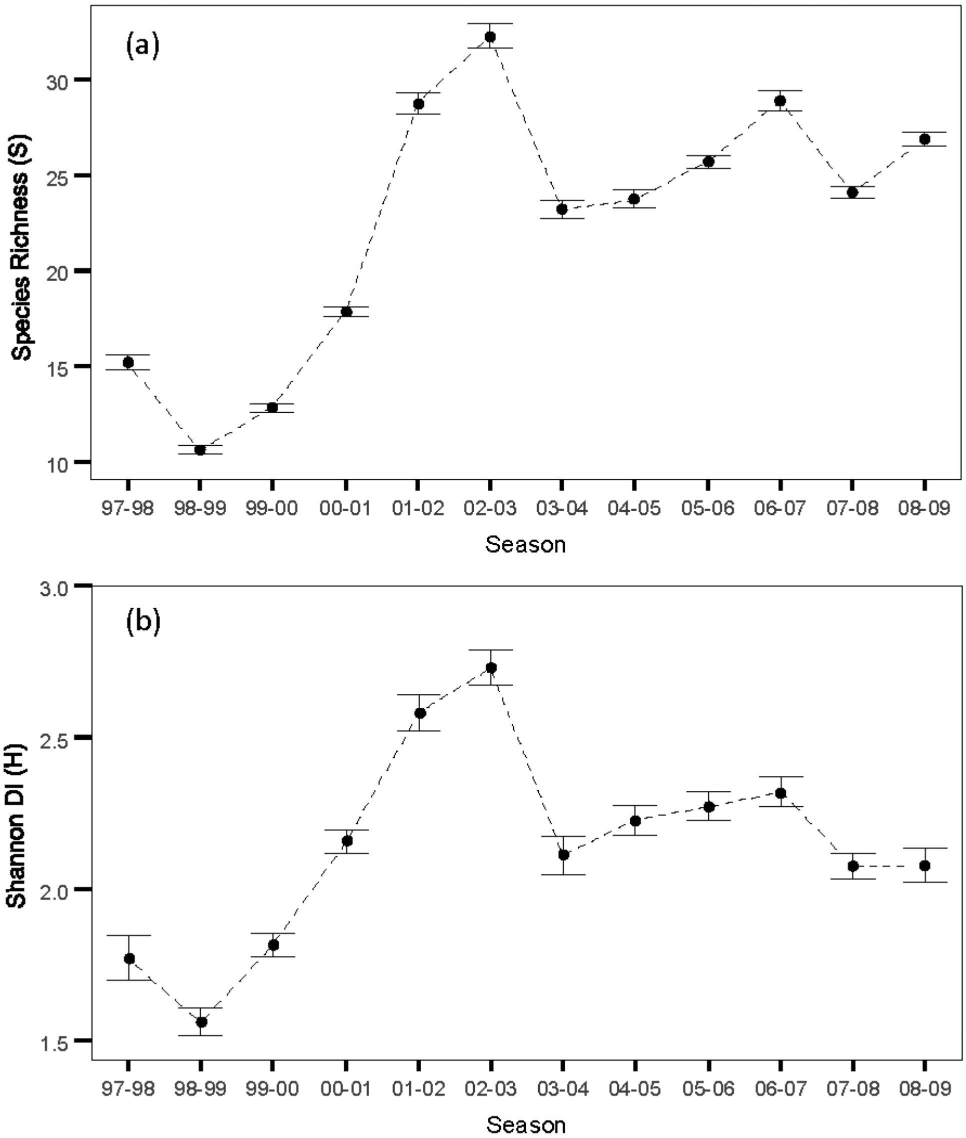
FIGURE 22

Total catch, effort and CPUE in the Tonle Sap – Great Lake system, 1997/98–2008/09



Note: The green line in the CPUE figure illustrates seasonal variation in an index combining flood extent and duration in the Tonle Sap – Great Lake system described by Halls *et al*. (2008, 2013a).

FIGURE 23
Species richness and diversity of fish species caught by a dai



Note: (a) Species richness (S) (mean ± 95% CI) and (b) Shannon diversity index (H) (mean ±95% CI) of species caught by a dai on a day for the seasons from 1997-98 to 2008-09 averaged across all sampling months in each season.
Source: Halls *et al.* (2013a).

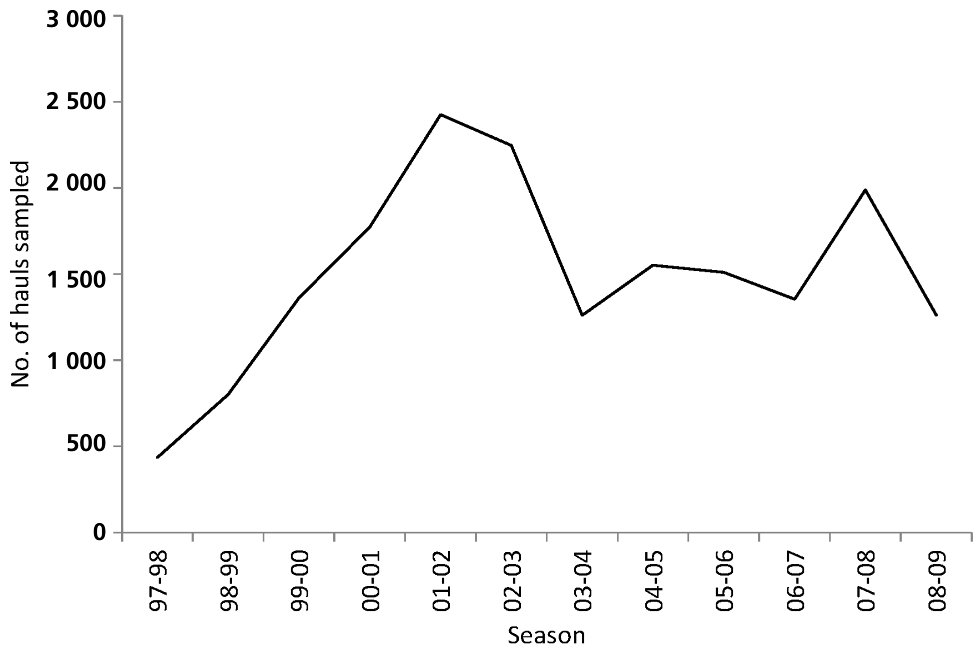
2008–08 seasons, *Henicorhyncus* spp. (67.5 percent and 50.3 percent, respectively) and *Paralaubuca typus* (13.4 percent and 10.6 percent, respectively) dominated catches. The relative contributions of *T. thynnoides* and *C. microlepis* to the total catch appear to have declined in these later seasons, whereas the contribution of *Paralaubuca typus* (currently *P. barroni* in the database) appears to have increased.

Focusing on the 35 most significant species in the dai catches, Baran, Van Zalinge and Ngor (2001) analysed the species composition between the 1995 and 2000 by means of principal component analysis. They concluded that, although the relative abundance of certain species changed between years, there appeared to be no significant interannual variability in catch composition for the bulk of the species.

Figure 25 shows the contribution to the total catch of the six most abundant species between 1997–98 and 2008–09. Consistent with the historical record, the *Henicorhynchus* group is the single-most dominant genus in the catch. The species complement of dominant species appears not to have changed either, with *P. barroni* (formerly listed as *P. typus*), *L. lineata* (formerly listed in the database as *O. hasseltii* or *Dangila* spp.), *T. thynnoides* and *L. chrysophekadion* (formerly listed as *M. chrysophekadion*). Figure 25 also supports the suggestion of an increasing contribution of the two most

FIGURE 24

Change in sampling effort represented as the total number of hauls sampled in each season between 1994–95 and 2007–08



Source: Halls *et al*. (2013a).

TABLE 12

Estimated catches of the most abundant species reported for the Tonle Sap – Great Lake system

Species	1938–39	1962–63	1994–95		2008–09	
	Relative abundance	Total catch	Total catch		Total catch	
		(%)	*(tonnes)*	*(%)*	*(tonnes)*	*(%)*
Henicorhynchus spp.		25.4	12 432	67.5	5 126	50.3
Paralaubuca typus[1]		0.30	2 460	13.4	1 081	10.6
Osteochilus hasseltii[2] *Dangila* spp.[3]		–	979	5.3	1 327	13.0
Thynnichthys thynnoides		14.9	515	2.8	245	2.4
Morulius chrysophekadion[4]		2.0	471	2.6	235	2.3
Cirrhinus mocrolepis		18.6	398	2.2	76	0.8
Botia spp.[5]		0.2	270	1.5	215	2.1

[1] *Paralaubuca typus* (Bleeker 1864) (Sloeuk Russey) is currently listed in the Dai Database as *Paralaubuca barroni* (Fowler 1934).

[2] Lieng, Yim and van Zalinge (1995) and Baran, Van Zalinge and Ngor (2001) list *Osteochilus hasseltii* (Valenciennes 1842) as "kros". In the current database, "kros" is listed as *Osteochilus lini*.

[3] *Dangila* sp. is a synonym for a Labiobarbus sp. Lieng, Yim and van Zalinge (1995) list this species as "khnong veng". In the current database, "khnang veng" is listed as *L. lineata* (Sauvage 1881).

[4] *Morulius chrysophekadion* (Bleeker 1850) is a synonym for *Labeo chrysophekadion* (Bleeker 1850) as it is currently listed in the database.

[5] For the purposes of comparison, the three *Botia* spp. were combined in the 2008–09 catch estimation.

Note: Catch for 1994–95 estimated as a sum of the catches for December, January and February 1994; present day total catch estimated for the 2008–09 season for the months from October 2008 to March 2009.

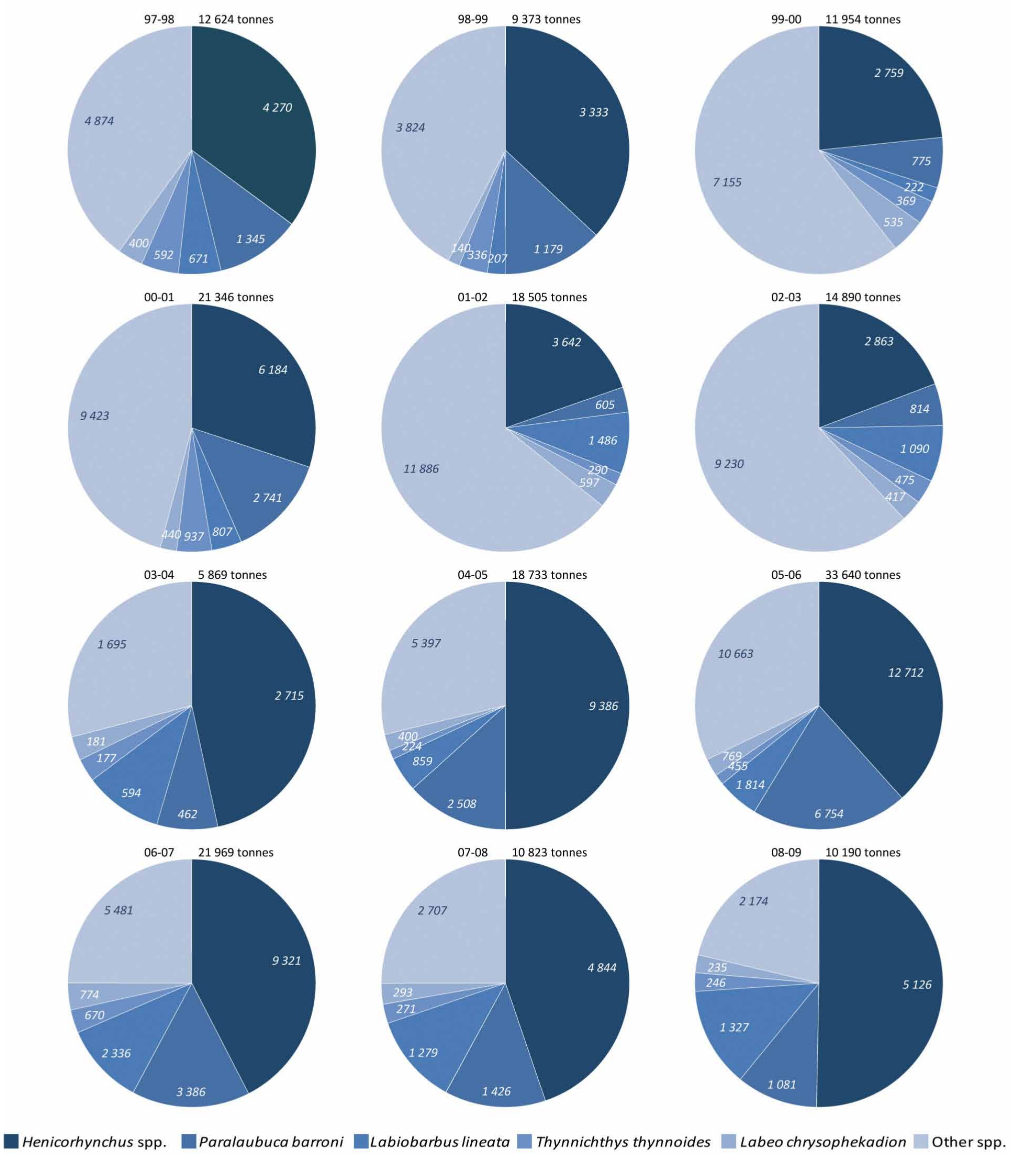
Sources: Chevey and Le Poulain (1940), Fily and D'Aubenton (1965), Lieng, Yim and van Zalinge (1995).

dominant taxa, i.e. the *Henicorhynchus* group and *P. barroni*, to the total catch with the other species contributing an ever-smaller proportion from the 1997–98 season to the present. There is considerable interannual variation of the contribution of other species (“Other spp.”) to the catch in the earlier seasons (1997–2003). However, as with the diversity indices, preliminary investigations appear to support the conclusion that these trends may be an artefact of changes to the survey techniques, i.e. sample stratification and/or species identification, and, therefore, may not be biologically significant.

Further research is under way to examine whether the contribution of larger, less-abundant species to the overall catch each year has changed through time. Some preliminary results of this work indicate that the relative abundance of large pangasiid catfish species has not changed.

FIGURE 25

Estimated catch composition of the most abundant species in the dai catches of the Tonle Sap – Great Lake system for the seasons from 1997–98 to 2008–09



Note: The season with the estimated total catch for that season is shown above each figure.
Source: Halls *et al*. (2013a).

Trends in fish size (mean weight)

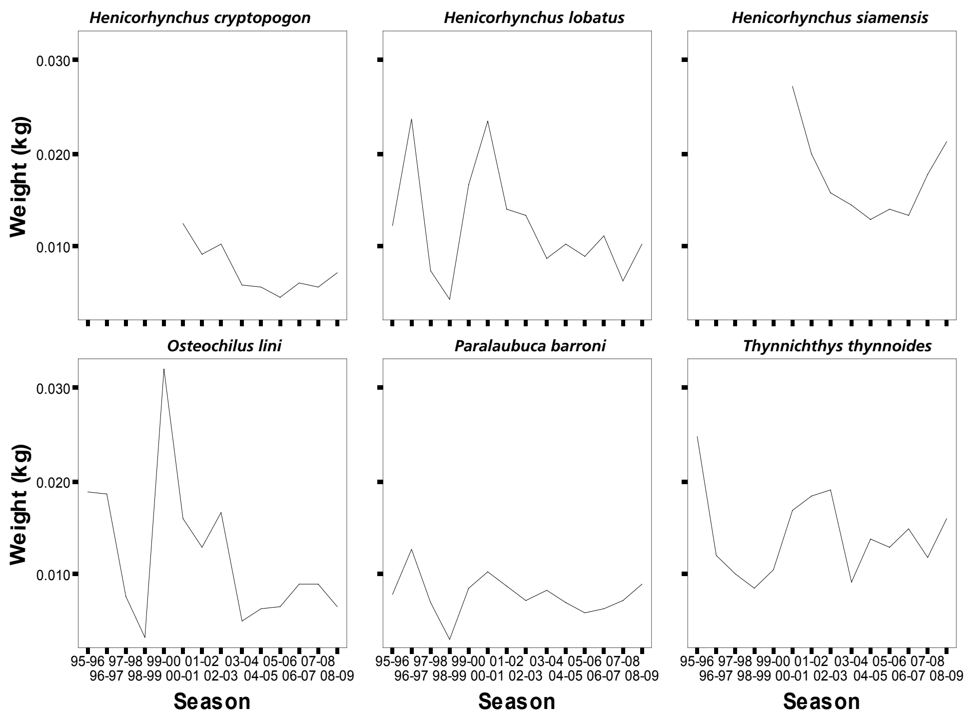
Assuming that recruitment is constant, a decline in the mean weight of individuals in a population through time is indicative of increasing rates of exploitation as fewer large (older) individuals survive with time (Sparre and Venema, 1992). Estimates of mean weight for those species that contribute to the majority of the catch by weight have shown considerable variation during the 15-year monitoring period but with no evidence of a continuous monotonic decline (Figure 26).

However, the majority (64 percent) of this variation can be explained by the covariation in the flood index each year, which is a proxy of feeding opportunities in the system (Figure 27). An analysis of variance (ANOVA) revealed that when variation in the flood index is accounted for, mean weight remains unchanged through time. The relatively low mean weights observed in the last six years correspond to below average flood conditions. Significantly, the mean weight of the entire multispecies assemblage (weighted by the catch weight of each species) also exhibits the same response (Figure 28).

CONCLUSIONS

The Cambodian stationary trawl or dai fishery of the TS–GL system contributes significantly to the country's economy, food security and fishery-dependent livelihoods. It is the most intensively monitored inland fishery in Southeast Asia providing important indicators of the status of floodplain-dependent fisheries resources in Cambodia and their response to flow. The effectiveness of management interventions implemented by the FiA remains uncertain, but there is no obvious evidence of declines in biomass indices, mean weight and species composition through time that could be attributable to increasing fishing pressure in response to a growing population. Rather, it appears that the species that form the basis of the fishery respond strongly and rapidly to changes in flood intensity and duration measured by the flood index.

FIGURE 26
Mean weight of the six most abundant species in the Tonle Sap – Great Lake fishery estimated for December each year, 1995/96–2008/09



Source: Halls *et al*. (2013a).

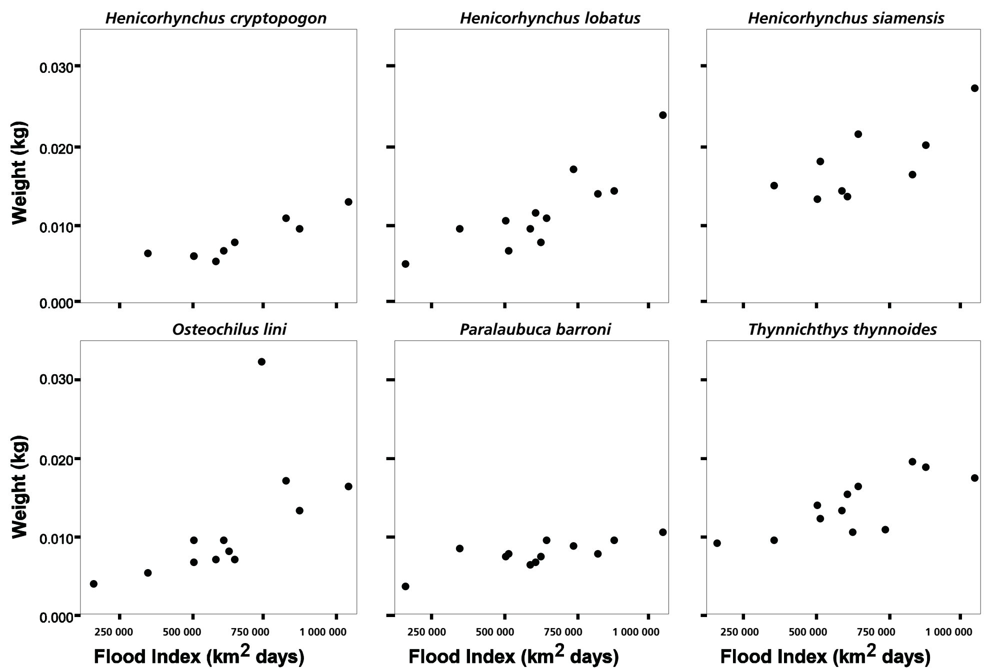
Biomass responses appear to be mediated through variations in growth (mean weight) possibly in response to feeding opportunities dictated by flood extent and duration (Welcomme, 1985). Mean fish weights for 2004/05 and 2005/06 were consistent with the flood index. Therefore, above average levels of recruitment were responsible for the very high catches observed during these two seasons. Factors responsible for these high levels of recruitment remain uncertain. Hortle *et al.* (2005) proposed that a campaign by the FiA to confiscate illegal gear, particularly in 2003 and 2004, might have been influential. However, a recent analysis of fisheries and recruitment survey data rejected this hypothesis in favour of environmental influences on spawning success and egg survival (Halls *et al.*, 2013b).

These findings provide valuable insights into how the fisheries resources of Cambodia and those of the other riparian countries with significant floodplains (i.e. Thailand and Viet Nam) are likely to respond to future flow changes arising from climate change and development pressure (particularly from the hydropower sector) in the lower Mekong Basin. They suggest that fisheries management and climate change adaptation efforts might be most effectively geared towards maintaining natural flooding conditions in the system to sustain exploitable biomass and maintain stock resilience (spawning stock biomass). These results also urge caution when monitoring mean fish size as a proxy for rates of exploitation in highly fluctuating environments.

Establishing the migratory range of the target species would determine whether the dai fishery could provide a means to monitor the status of migratory fish resources in the lower Mekong Basin. While correlations have been found between the catch rates observed for the dai fishery and those for fisheries routinely monitored at other locations in the lower Mekong Basin by the MRC (Halls, 2008b; Halls *et al.*, 2013b), these may simply reflect environmental responses of separate stocks. Mark-recapture or genetic-based approaches could provide an effective means of study.

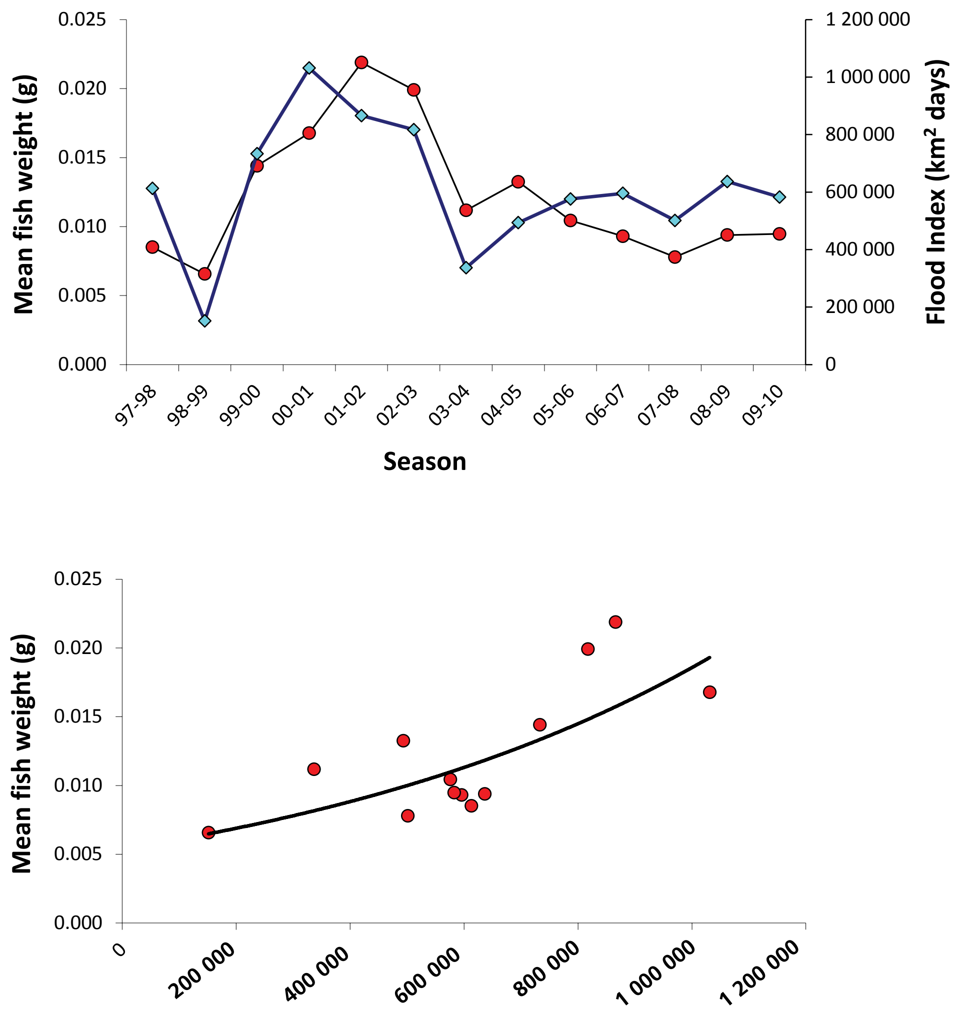
FIGURE 27

Mean weight estimates for the six most abundant species in the Tonle Sap – Great Lake fishery in December each year (end of the flood season) as a function of the flood index



Source: Halls *et al.* (2013a).

FIGURE 28
Mean fish weight (all species combined) and the flood index (blue line) for the Tonle Sap – Great Lake system (top), and mean fish weight as an exponential function of the flood index (bottom)



Source: Halls *et al.* (2013b).

ACKNOWLEDGEMENT

The case study presented in Section 3 (pp. 33–47) is a summary of a technical report published by the Mekong River Commission in 2013. The report is based on the long-term fisheries monitoring work of the Fisheries Programme of the MRC. Policy recommendations of the report were published in Catch and Culture, Vol. 20, No 1 in 2014. The citation for the original MRC Technical Paper is: Halls, A.S.; Paxton, B.R.; Hall, N.; Peng Bun, N.; Lieng, S.; Pengby, N.; and So, N (2013). The Stationary Trawl (Dai) Fishery of the Tonle Sap-Great Lake, Cambodia. MRC Technical Paper No. 32, Mekong River Commission, Phnom Penh, Cambodia, 142pp. ISSN: 1683-1489.

4. Status, trends and management of the Lake Victoria Fisheries

Jeppe Kolding
University of Bergen
Bergen, Norway

Medard Modesta
Wageningen University
Wageningen, the Netherlands

Oliva Mkumbo
Lake Victoria Fisheries Organization
Jinja, Uganda

Paul van Zwieten
Wageningen University
Wageningen, the Netherlands

INTRODUCTION

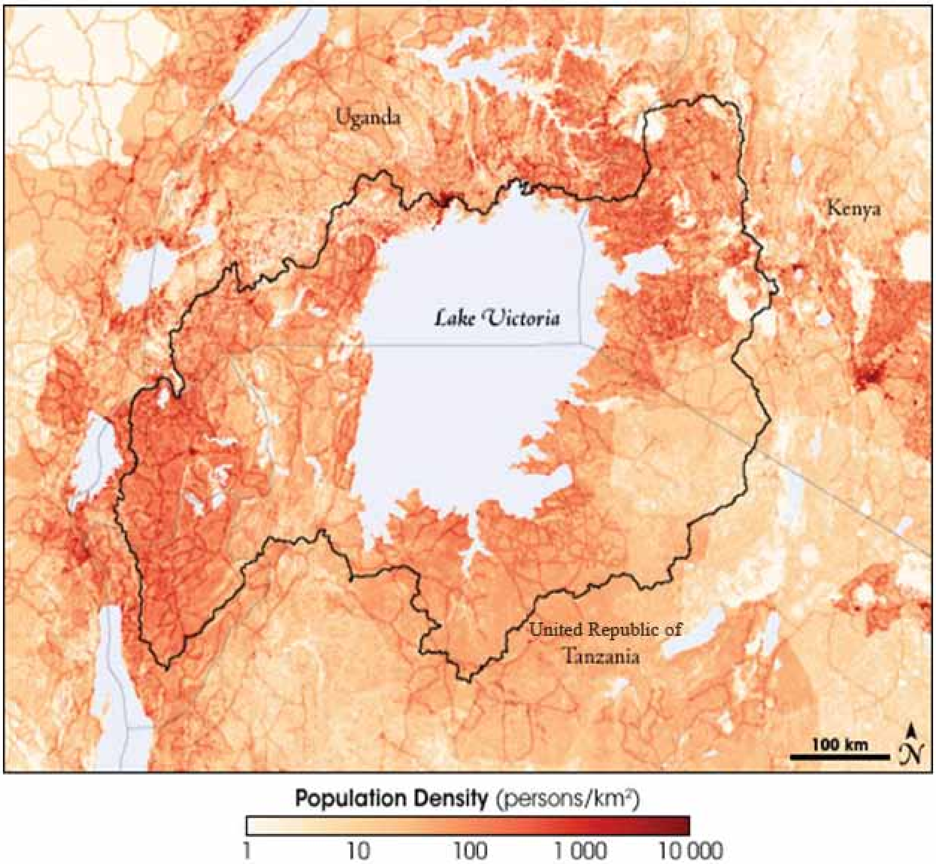
Equatorial Lake Victoria in East Africa (Figure 29) is the second-largest lake in the world, covering an area of 68 000 km^2 and surrounded by a dense and fast-growing human population of at least 25 million people. In addition to its size, the lake is unique in several ways. It supports one of the world's largest inland fisheries aimed at both domestic consumption and international export, and it has experienced some of the most extreme ecological perturbations ever observed in a large freshwater environment.

Biologically, Lake Victoria is best known for one of the greatest mass extinctions of fish species in modern times – a drastic depletion of biodiversity that has unanimously been associated with the deliberate introduction in the mid-1950s of the predatory Nile perch (*Lates niloticus*). These events have caused the Nile perch to be considered both an asset,[5] in terms of its thriving export fishery since the 1980s, and a menace, being rated among the world's 100 most dangerous invasive species (see Reynolds and Greboval [1989] for a review of the controversy). Less well known, but of increasing importance, are the environmental bottom-up changes in water quality resulting from accelerating discharges of nutrients into the lake that have also caused significant changes to the biological communities and the overall productivity of the lake (Hecky *et al.*, 2010).

In terms of its fish community, and in common with neighbouring Lakes Tanganyika and Malawi, Lake Victoria was originally considered a cichlid lake. This was because of the very high abundance and diversity (about 500–1 000 species [Seehausen, 1996; Turner *et al.*, 2001]) of small endemic haplochromine cichlids and its traditional artisanal fishery targeting larger endemic tilapia species. However, the catch rates of the endemic tilapias declined in the first half of the twentieth century, and in the mid-1950s four exotic species of medium-sized tilapiine cichlids, as well as the large Nile perch (which occurs naturally in several other lakes of the region), were introduced to boost the fishery. Concurrently, the artisanal fishery developed rapidly in terms of technological efficiency with the introduction of synthetic gillnets and outboard

[5] One local name is mkombozi, which means "the saviour".

FIGURE 29
Lake Victoria, East Africa



Note: The black line indicates the watershed of the lake. The grey lines indicate international boundaries. The lake is share by Kenya (6 percent by area), Uganda (43 percent) and the United Republic of Tanzania (51 percent). The lake has a mean depth of 40 m, a maximum depth of 84 m, a shoreline of 3 450 km, a water retention time of 140 years and a catchment area of 193 000 km^2, which extends into Rwanda and Burundi.
Source: http://infranetlab.org/blog/wet-borders-microslums-and-meanders

engines resulting in a doubling of fishing effort (Kudhongania and Chitamwebwa, 1995). At present, the commercially most important fishery is for Nile perch, which started with its sudden rapid expansion in the mid-1980s and the associated changes in the fauna and ecology of the whole lake that occurred over only a few years. Ever since then, the vast literature on its fish and fisheries has been strongly focused on understanding the changes in the lake's biodiversity and their causes. These have primarily been attributed to the large top-down changes to the food web instigated both by the Nile perch introduction and by (local) overfishing, as well as to bottom-up environmental changes (see references in Kolding *et al.*, 2008).

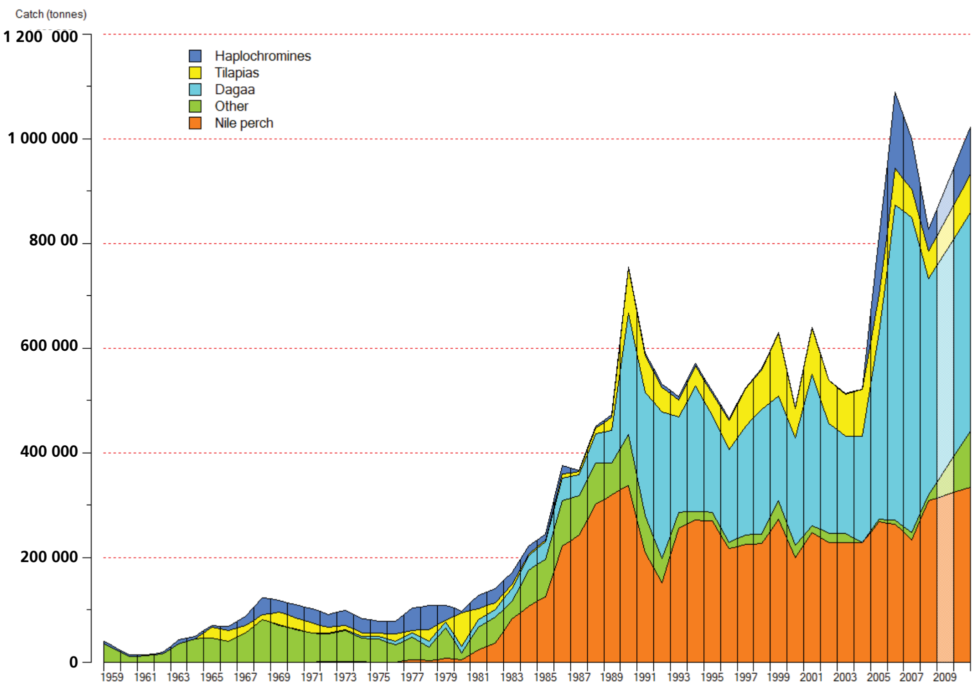
As a result, Lake Victoria is also unique in being one of the most studied freshwater systems in the tropics. These studies extend to its fisheries, yet there are huge gaps in the time series of important fisheries and ecological indicators, and there are different opinions on the status of the fishery and the importance of different system drivers. Moreover, the vast majority of studies give isolated short-term results from different disciplines, while the long-term trends are rarely updated and very few studies give a holistic perspective on the status of the stocks, the fishery and the lake ecosystem (Kolding *et al.*, 2005).The aim of this synopsis is to describe the overall trends and events that characterize the fishery, and the main management activities that have been initiated in the known history of the lake.

TRENDS IN CATCH

Lake Victoria's ecological changes have been highly dynamic, both before and after the dramatic shift in the 1980s, and developments in the fisheries have been associated with these changes. Historical documents and combined annual catch statistics from 1959 onwards (Figures 30 and 31) indicate a number of distinctive periods in the development of the fishery:

- Prior to the arrival of the railway in Kisumu, Kenya, in 1908, only traditional fishing methods (basket traps, hooks and papyrus seines) were employed and these probably had little impact on the stocks.
- The railway opened new markets, and between 1910 and the 1950s the inshore gillnet fishery for endemic tilapias (*Oreochromis esculentus* and *O. variabilis*) gradually increased with a corresponding decrease in individual catch rates reported from the Winam Gulf (Kenya) from 25 fish/net (1910) to about 2 fish/net in 1940 (Graham, 1929; Beverton, 1959; Fryer, 1973). However, the decrease was localized to inside the Winam Gulf, and Beverton (1959) found no indications of a similar decrease in Ugandan or Tanzanian waters. Some potamodromous cyprinid species, notably *Labeo victorianus*, also became commercially extinct during this period, probably as a result of overfishing.
- From about 1960 to the early 1980s, both a multispecies fishery consisting of artisanal inshore gillnets for tilapias and others, and a commercial offshore trawl fishery for haplochromines developed. Catches increased and stabilized at about 100 000 tonnes from the end of the 1960s. Despite its introduction in the 1950s, the Nile perch fishery did not take off until the early 1980s, when it expanded rapidly with an almost linear annual growth rate of about 35 000 tonnes/year in that decade.

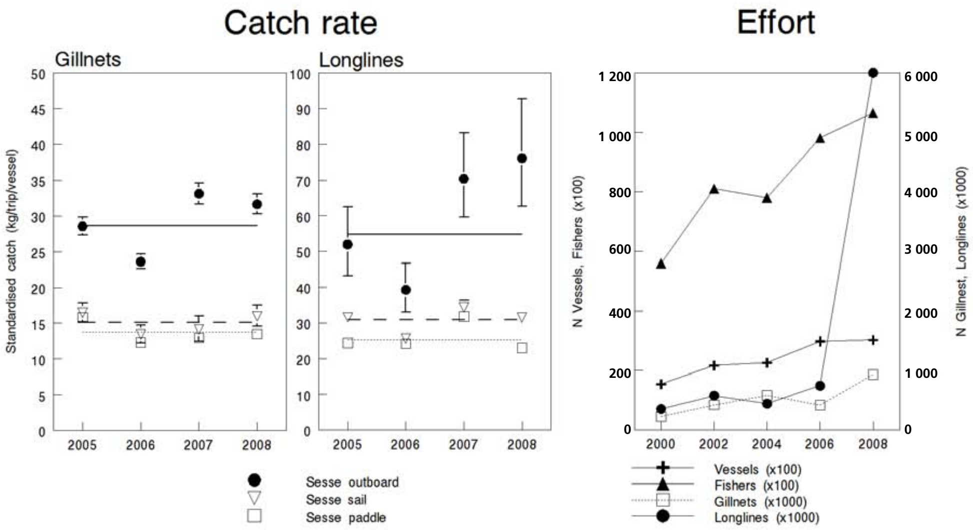
FIGURE 30
Total annual catches in Lake Victoria by main group, 1959–2010



Source: Based on Kolding, Haug and Stefansson (2008) and LVFO (unpublished data).

FIGURE 31

Catch rates of Nile perch and effort development in the Tanzanian artisanal fishery



Note: Since 1990, there have been no detectable changes in Nile perch landings, which have fluctuated around a mean of 235 tonnes (r^2=0,07, p=0.26, N=20).

Sources: Based on Kolding, Haug and Stefansson (2008) and LVFO (unpublished data).

- Nile perch soon became the commercially most important fishery on the lake and it has now developed into a multimillion-dollar export industry.[6] The fishery of the small pelagic cyprinid *Rastrineobola argentea* (commonly known as dagaa, omena or mukene) also expanded during this period with about 6 000 tonnes/year, while the exotic Nile tilapia (*Oreochromis niloticus*), also introduced in the 1950s, replaced the indigenous tilapia species. Simultaneously, most of the endemic haplochromines disappeared and the relatively small trawl fishery was subsequently banned in order to protect the stocks and accommodate the growing number of local artisanal fishers.
- The period from 1991 to 2003 can again be characterized as stable with total catches of about 500 000 tonnes/year. The fishery is now basically reduced to three species, consisting of Nile perch, dagaa (each about 42 percent in terms of volume) and Nile tilapia (15 percent). Since 2004, a rapidly expanding dagaa/omena fishery has developed, partly because of overcapacity in the Nile perch fishery, and it has become the most important in overall weight, while some of the haplochromines have started reappearing, predominantly as bycatch to the dagaa fishery.
- Since 2006, the total catch from the fishery reaches a new level of about 1 million tonnes/year.

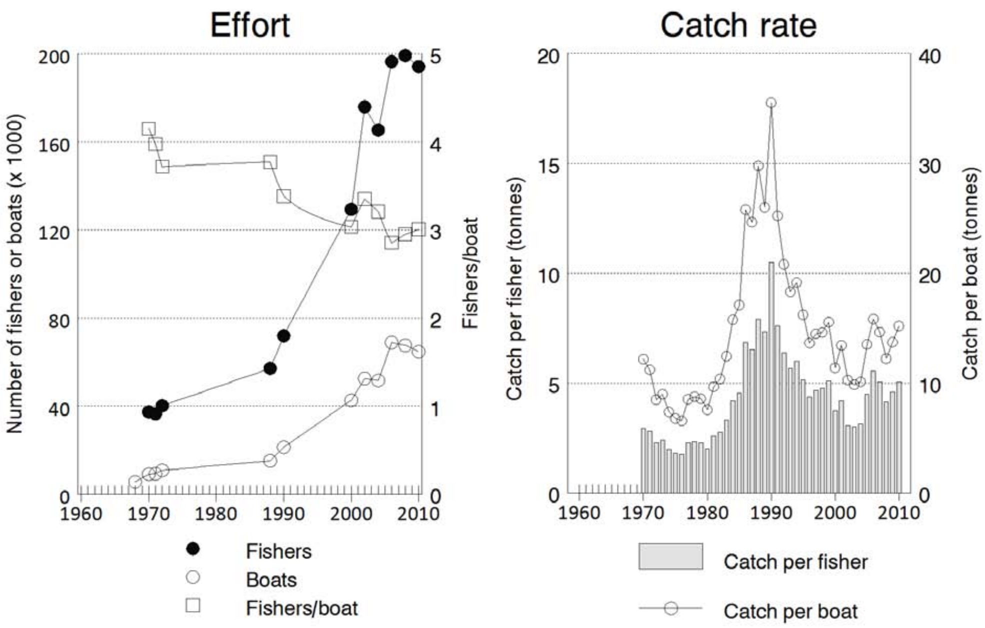
Trends in effort and estimated total catch rates

Effort statistics prior to 2000 (Figure 32) are less reliable than the catch statistics, but the overall pattern largely mirrors the changes in overall catches.

While the national effort statistics are considered incomplete and partly unreliable from the end of the 1970s, when the East African Community broke up (Reynolds, Wadanya and Nyeko, 1989), until the coordinated lake-wide frame surveys that started in 2000 (Table 13), the bonanza period of the fishery, lasting from the mid-1980s to the end of 1990s, is still reflected in the overall CPUE trends. As a result of the corresponding development of effort and catches, the overall average annual catch

[6] The export value of fresh and frozen fillets of Nile perch in 2008 was USD240 million.

FIGURE 32
Overall effort and annual catch rates in Lake Victoria, 1968–2010



Sources: from Kolding *et al*. (2008) and LVFO (2010).

TABLE 13
Indicators of fishing effort in the Lake Victoria fishery, 2000–2010

Indicator	2000	2002	2004	2006	2008	2010
Landing sites	1 492	1 452	1 433	1 431	1 327	1 443
No. of fishers	129 305	175 890	167 466	196 426	199 242	194 172
No. of boats	42 519	52 476	51 592	68 836	67 513	64 595
Outboard motors	4 108	6 552	9 609	12 765	13 721	16 188
Sails	6 304	9 620	8 672	10 310	9 811	8 424
Paddles	32 032	35 720	33 405	45 753	43 553	39 771
Gillnets < 5″*	113 177	178 205	142 618	215 049	207 954	159 013
Gillnets > 5″	537 475	724 879	1 090 434	1 007 258	805 678	708 292
Hand lines	53 205	58 123	40 953	71 636	65 717	48 681
Longline hooks	3 496 247	8 098 023	6 096 338	9 044 550	11 267 606	11 472 068
Dagaa: small seines	3 588	7 795	8 601	9 632	10 276	13 514
Beach seines*	7 613	3 491	3 355	3 653	4 187	3 743
Cast nets*	5 887	1 095	803	775	1 174	1 282
Monofilament nets*	0	0	5 944	2 293	20 194	16 488

* Illegal gear type.
Source: LVFO (2010).

rates was stable at about 2.3 tonnes/fisher ± 0.75 tonnes/fisher[7] prior to the Nile perch boom, when it rapidly increased to an all-time high of 10.5 tonnes/fisher in 1990. Since then, catch rates decreased to about 3.6 tonnes/fisher in the early 2000s. From 2005 onwards, catch rates have increased again to 4.9 ± 1.1 tonnes/fisher. The increased variability in annual catch rates reflects the highly dynamic state of the fish stocks, which most probably result from fluctuations in the dagaa fishery. The number of

[7] Indicates two standard deviations.

fishers per boat, has decreased from about four in the 1960s to three in recent years, and the catch rates expressed as tonnes per boat largely follow the same pattern. The annual catch per individual fisher of about 4 tonnes in the last decade is slightly higher than the overall inland African average of 3 tonnes (Kolding and Zwieten, 2011).

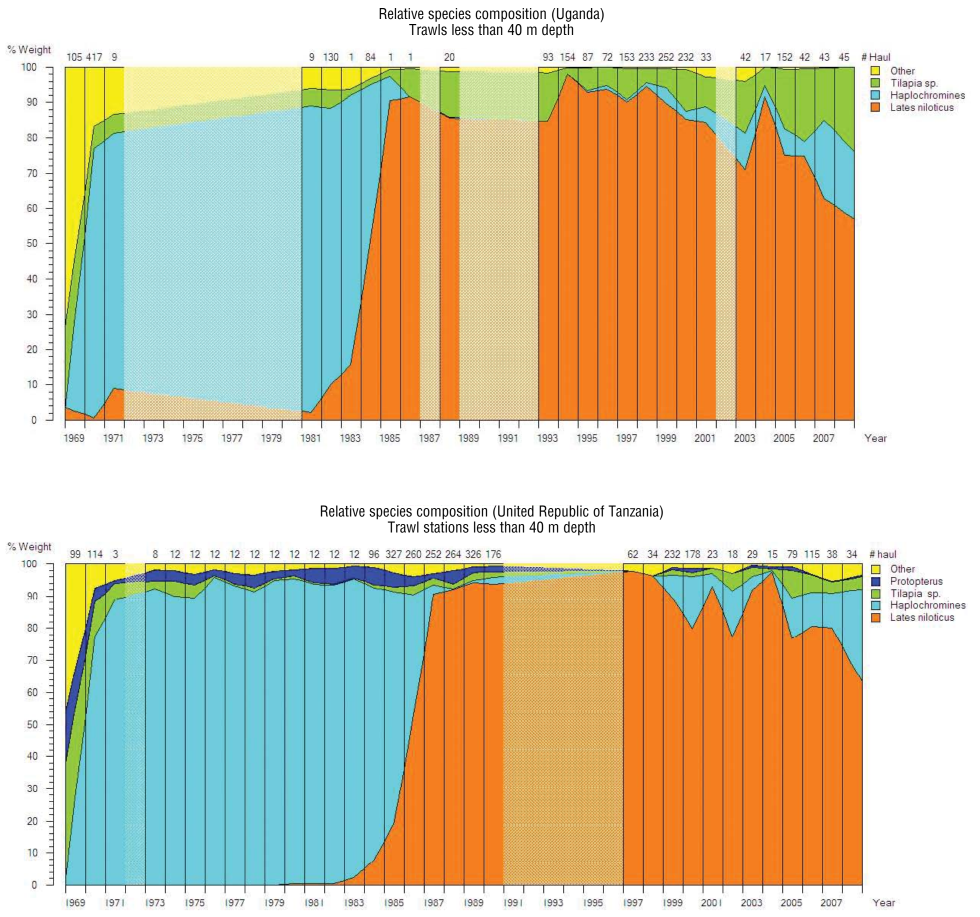
Trends in the most important fish stocks

The most notable change in the demersal Lake Victoria fish community and fishery is the fundamental metamorphosis in the mid-1980s when it suddenly changed from being dominated by the diverse species flock of endemic haplochromines (contributing about 90 percent of the demersal biomass) to a much simpler fauna consisting of three primary species: Nile perch, dagaa in the open waters and the introduced Nile tilapia along the shores (Figures 33 and 34).

Haplochromines: The stocks of this endemic species flock of more than 500 predominantly small and a few medium-sized cichlids apparently had its own short boom just prior to the Nile perch in the 1970s (Figure 34), where it peaked in about 1975, but then rapidly diminished and almost completely vanished in the mid-1980s. This decline has almost unanimously been attributed to the coinciding expansion of the Nile perch, but there are indications that it started before the Nile perch population exploded

FIGURE 33

Relative species composition in standardized experimental trawl surveys in Uganda and the United Republic of Tanzania, 1969–2008



Note: Years with no surveys are interpolated (light colours). Dagaa is not represented in the demersal trawl catches.
Source: Updated from Kolding *et al*. (2008)

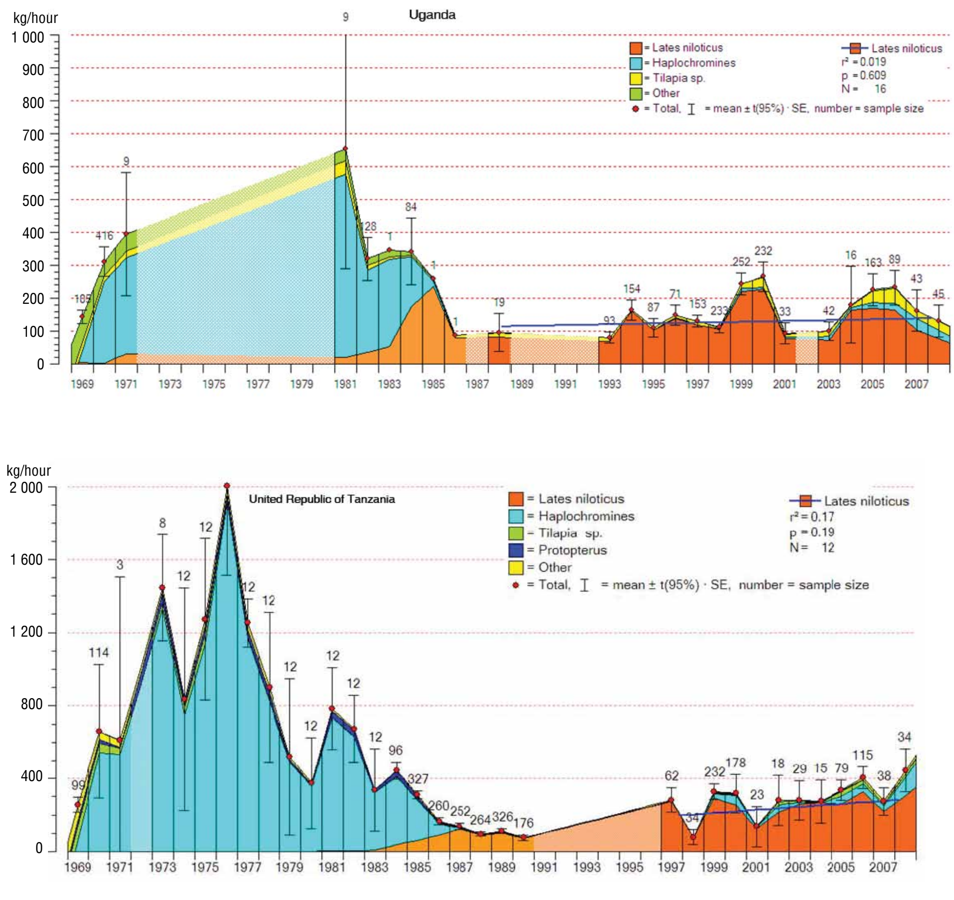
(Figure 34). From around the turn of the twenty-first century, some haplochromine species started reappearing in the catches of the dagaa fishery and in experimental lake-wide trawl surveys. Some species are now recovering rapidly (Witte *et al.*, 2007, 2008).

Inshore demersal species: Before the mid-1980s, this group consisted mainly of endemic tilapias (*Oreochromis esculentus* and *O. variabilis*), Nile catfish (*Bagrus docmak*), lungfish (*Protopterus aethiopicus*), elephant snout-fish (*Mormyrus kanume*) and ningu (*Labeo victorianus*). All of these are considered commercially depleted. After 1990, the nearshore fishery became dominated by the exotic Nile tilapia (*Oreochromis niloticus*) and there is also an ongoing fishery for African catfish (*Clarias gariepinus*). The state of these stocks is not regularly assessed, but the abundance of Nile tilapia in demersal trawl surveys is slowly increasing so it could possibly be labelled moderately exploited.

Dagaa (silver cyprinid): The dagaa stocks have increased steadily, along with the catches since the mid-1980s. Since 2005, it has become the largest fishery in the lake by weight and there are no signs of overexploitation. As the stock size, based on hydroacoustic surveys, still appears to be increasing, this would indicate that there is still room for expansion of this fishery.

Nile perch. This is economically by far the most important stock in the lake supporting an export industry worth some USD250 million/year. It is the most intensively targeted stock in the lake and receives the highest management attention,

FIGURE 34
Abundance of the major demersal stocks in standardized experimental surveys in Uganda and the United Republic of Tanzania, 1969–2008



Note: Years with no data are interpolated (light colours).
Source: Updated from Kolding *et al*. (2008).

as it is widely believed to be overfished. Nevertheless, there have been no significant trends in the catches (Figure 31) or the relative biomass (Figure 33) in recent decades, an indication that it can sustain the fishing pressure. Demographic changes in this stock have been investigated in detail by Kolding *et al.* (2008) who found no significant changes in experimental catches using the usual indicators of fishing pressure, such as mean size or abundance of adult fish, but there had been a strong statistically significant increase in the abundance of juveniles (recruitment) since the mid-1980s. There are some emerging signs of the decline or disappearance of Nile perch from sheltered eutrophic bays with high human populations, such as the Winam, Napoleon and Speke Gulfs. While most managers believe Nile perch stocks to be overfished (i.e. fishing takes place beyond the maximum sustainable yield), the trawl surveys (Figure 34) and CAS data from the United Republic of Tanzania do not support this claim at the regional level. Nevertheless, there are signs that the expanding industry is entering a phase of overcapacity as several processing factories are having supply problems, and some have closed or are diversifying into other economic activities (Sitoki *et al*., 2010).

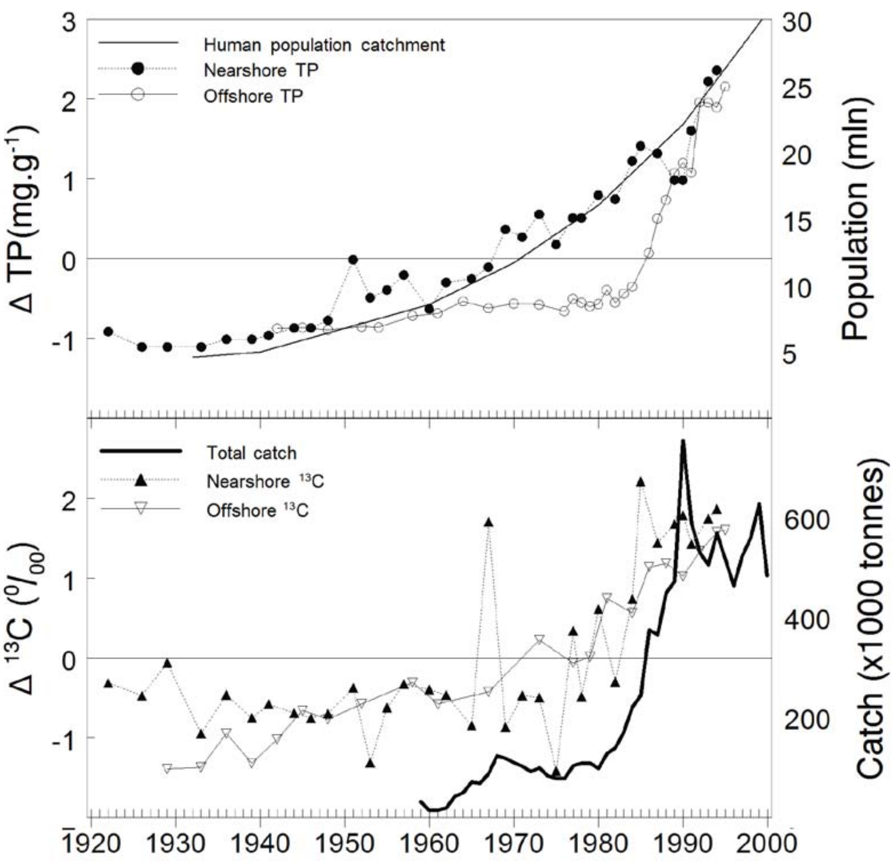
STOCK ASSESSMENT AND DRIVERS OF THE FISHERY

Most, if not all, stock assessments and fishery modelling in Lake Victoria has been performed using standard steady-state models where fishing mortality, expressed as effort, is considered the only driver in an otherwise assumed constant environment. However, Lake Victoria is also influenced by bottom-up processes in the form of steadily increased eutrophication and primary productivity (Figure 35). Between 1969 and 1993, nutrient loadings to the lake from the surrounding catchment area and the primary productivity in the lake increased by a factor of two along with a sixfold–tenfold increase in algal biomass in both nearshore and offshore environments (Hecky, 1993; Mugidde, 1993; Silsbe *et al.*, 2006). More-recent data suggest that the rate of deterioration has slowed since the 1980s and that the water quality of the lake has improved (Sitoki *et al.*, 2010). The analysis by Kolding *et al.* (2008) indicates that the dynamics of fish production in Lake Victoria are environmentally driven to a large extent. As a consequence, fishing is not the sole driver of stock dynamics. The changing indicators of water quality (algal biomass, composition and chemical nutrients, [Figure 35]) show that Lake Victoria is not in a steady state. Therefore, the interpretation of trends and the use of fishery assessment or ecosystem models that assume environmental constancy can be highly misleading if eutrophication is not taken into account. The debate as to whether the stocks are mainly driven by top-down (the fishery) or bottom-up (nutrients) processes is not settled yet and is under ongoing investigation (Sitoki *et al.* 2010). However, from the trends in catches, the abundance of the stocks, and the lack of evidence from other size-based or catch-rate-based indicators (Kolding *et al.*, 2008), it is difficult to state that the fishery shows any immediate signs of being biologically overexploited. A decrease in length at maturity has been reported and could indeed be a sign of heavy exploitation but it could also be caused by environmental changes (Kolding, Haug and Stefansson, 2008b), so here again the cause and effect are not clear. The current average length at maturity of Nile perch in Lake Victoria is now the same as in its native habitats (Loubens, 1974; Lévêque, 1997). Fish species have highly plastic life-history traits including growth, age at maturity and fecundity during and after successful invasion (Bøhn *et al.*, 2004).

In summary, it is impossible to explain the development in the fishery without taking bottom-up processes into account, as well as the reorganization of the fish community owing to the various species introductions. In the United Republic of Tanzania, for example, the number of fishers and boats almost doubled between 2000 and 2008 (Figure 32). Still, the development in catch rates of Nile perch from the fishery, showed no decrease as would have been expected under steady state conditions. These data again suggest that the stock can sustain, and even compensate for, the increased fishing

FIGURE 35

Eutrophication of Lake Victoria: trends in total phosphorus, riparian population, carbon13 stable isotope signature in sedimentary organic matter, and total landings



Sources: Verschuren *et al*. (2002); Hecky *et al.* (2010).

pressure. All trends indicate that factors other than effort drive the productivity of fish stocks and that the usual assumptions of steady-state or equilibrium conditions are hard to defend. To assess the state of the stocks, fishery and ecosystem, regular updating of time series of important indicators is necessary.

THE HISTORY AND INSTITUTIONAL STRUCTURES FOR THE MANAGEMENT OF THE FISHERIES

The first assessment of the Lake Victoria fish stock was carried out in the 1920s (Graham, 1929), when signs of inshore overfishing were already identified. Recommendations for gillnet mesh size restrictions were made and implemented in 1931 in Uganda (Kyangwa and Geheb, 2000). A second stock assessment was carried out in 1957 (Beverton, 1959), which recommended that the existing mesh and gear regulations (minimum 5” [127 mm] gillnets and prohibition of seines) should be maintained. However, mesh-size limitations were relaxed in Uganda and the United Republic of Tanzania in 1957, and from 1961 in Kenya. Mesh-size and gear restrictions have since been reintroduced and amended in all three countries several times, and they are still the main technical measure for fisheries management in the lake. In 1947, the first regional management institution, the Lake Victoria Fisheries Service, was established under the East African High Commission, and shortly after in 1949 the East African Fisheries Research Organisation (after 1960 this became the East African Freshwater Fisheries Research Organisation [EAFFRO]) was formed and based in Jinja, Uganda. The Lake Victoria Fisheries Service, together with the EAFFRO, combined both administration and research. The Lake Victoria Fisheries Service had the responsibility for the collection of statistics around the whole of the lake until 1960, when its role was taken over by the governments of the three riparian countries. The EAFFRO was strengthened by the formation of the East African Community in 1967, but its activities ceased with the sudden collapse of the latter in 1977, when the lake was monitored and managed by separate fisheries departments in each country. A Sub-Committee for Lake Victoria of the Committee for Inland Fisheries of Africa continued to ensure international collaboration and eventually gave rise to the Lake Victoria Fisheries Organization (LVFO).

In 1994, following the expansion and booming fishing industry of Nile perch and the recognition that management should again be coordinated, the intergovernmental LVFO was formed by Kenya, Uganda and the United Republic of Tanzania through a signed convention. The main aim was to foster cooperation and collaboration in the management, development and utilization of the fisheries of the lake, as well as to coordinate research and harmonize management regulations. Around the same time, it became internationally recognized that the traditional top-down command-and-control approaches to fisheries management were not particularly well suited to the highly dispersed small-scale fishery activities, and a comanagement approach involving all stakeholders was globally promoted as a better way of organizing the management. The structure of the LVFO (Figure 36) was therefore designed for allowing a bottom-up management decision and implementation process through the establishment of decentralized beach management units (BMUs) in the three partner States (LVFO, 2001).

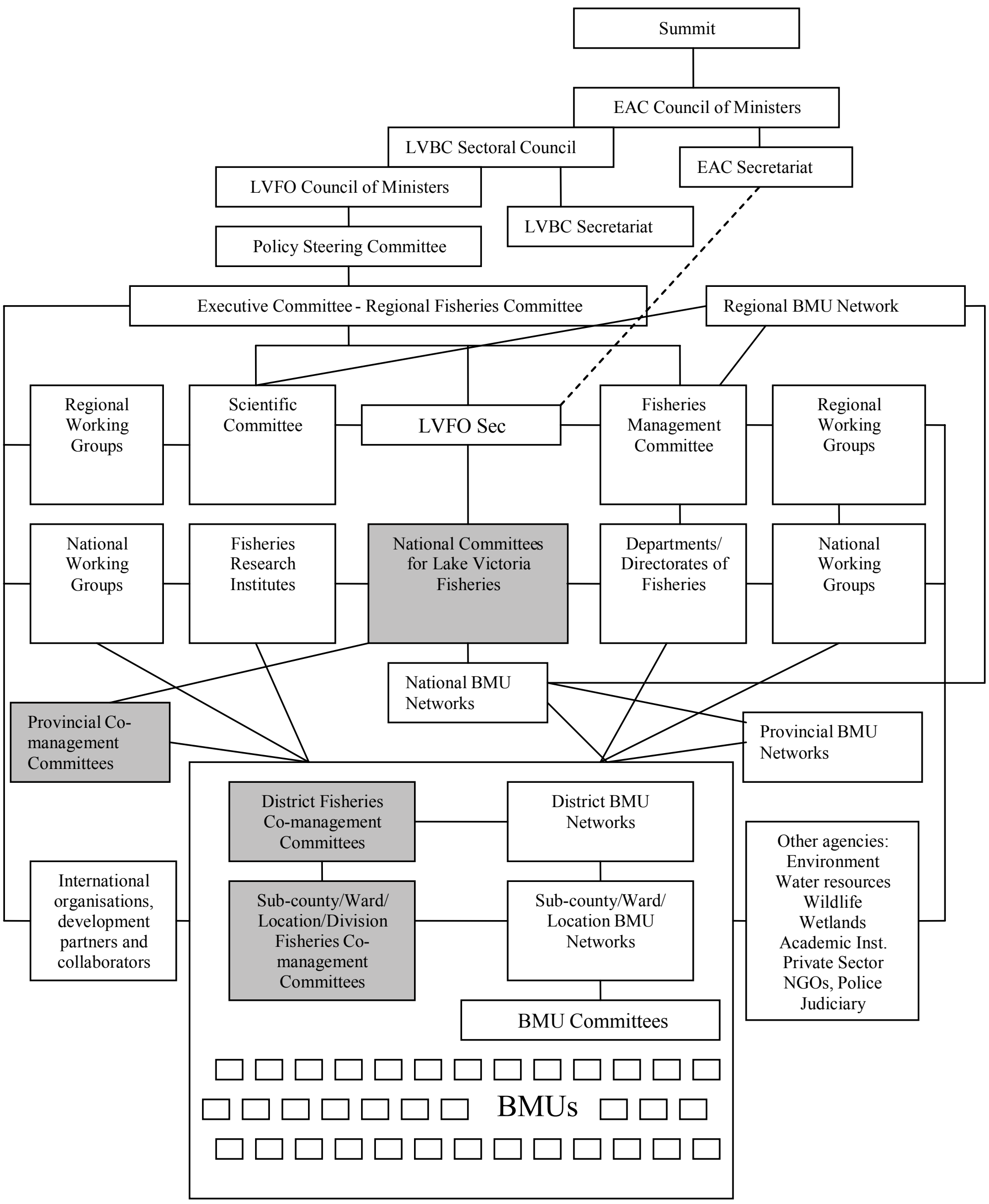
According to the structural flowchart (Figure 36), the BMUs are supposed to be connected and function upwards in a hierarchical national and regional network through District and Provincial Co-management Committees with membership from various public and private sectors and NGOs. At the national level, the Fisheries Research and Fisheries Management Institutions in the form of National Working Groups and Committees – also including membership from district-level NGOs and the private sector – provide a forum to discuss and propose national policies and measures, which in turn are harmonized and processed further at the regional level by Regional Working Groups. The outputs of the Working Groups are then digested by the technical Fisheries Management and Scientific Committees of the organization. Recommended measures are forwarded by the Secretariat to the statutory organs of the organization: the Executive Committee, the Policy Steering Committee and the LVFO Council of Ministers constituted by the Ministers of the national ministries responsible for natural resources and fisheries from the partner States. The role of these organs is to approve regulations and make policies to be implemented by the three countries coordinated by the East African Community Secretariat. Since its creation, the LVFO has played a vital role in coordination, fund raising and promotion of measures for the sustainable utilization of the resource, bringing together all the institutions and stakeholders. Therefore, the LVFO is central to the development of coordinated activities, instruments and policies, which include various regional plans such as:

- **Fisheries Management Plan.** Developed in 2001, the plan includes strategic programmes for: regulating fishing pressure; harmonization of activities; establishment of institutional environment to manage a modified access right regime; adoption of FAO Code of Conduct for Responsible Fisheries; strengthening institutional capacity and developing proper handling, preservation, processing and storage for fish and fish products. In addition, the current escalating concerns, especially for the sustainability of the Nile perch fishery, as well as a wish for its certification (ecolabelling), have highlighted the need to conduct regular fish stock assessments and monitoring surveys.

- **Regional Plan of Action to prevent and eliminate illegal, unregulated and unreported (IUU) fishing.** Adopted in 2004, the plan contains measures to prevent, deter and eliminate IUU fishing (Box 1). In 2008, the Council of Ministers of the LVFO issued a joint statement requiring partner States to implement zero-tolerance measure to eradicate illegal fishing gear and the capture and trading in immature fish (Okware, 2009).
- **Regional Plan of Action on fishing capacity.** Lake Victoria always has been an open-access fishery, but this plan was adopted in 2007 to encourage sustainably exploited fisheries that accrue optimal socio-economic benefits through an efficient, equitable and transparent system for the management of fishing capacity. However, specific restrictions have yet to be implemented.

FIGURE 36

Lake Victoria Fisheries Organization – institutional structure and comanagement arrangement with linkages to other partners



Note: Grey boxes indicate envisaged structures not yet implemented.

BOX 1

Measures taken as a result of the Regional Plan of Action to prevent and eliminate illegal, unregulated and unreported fishing in Lake Victoria

- Ensure and continue with collection of fisheries statistics, socio-economic data and monitoring/studies on, in particular, the important commercial species – Lates niloticus (Nile perch); Oreochromis niloticus (Tilapia); and Rastrineobola argentea (Dagaa/Omena/Mukene). The monitoring activities are to gather data and information to allow for review of management measures. The monitoring is harmonized and conducted following Standard Operating Procedures (SOPs) developed regionally through the Lake Victoria Fisheries Organization (LVFO).
- Slot size landings regulation of 50–85 cm TL aiming at protecting the juvenile and spawning stocks of Nile perch.
- Minimum sizes for tilapia to be landed of not less than 25 cm to protect juvenile stocks of tilapia.
- Minimum legal gillnet mesh size of 127 mm (5 inches) for Nile perch to protect juveniles/immature fishes.
- Closed seasons and closed/protected areas in all three countries to protect spawning stocks and species diversity.
- Ban on beach seines, cast nests, weirs and trawling to protect breeding and nursery grounds and the ecological integrity through conservation of biodiversity.
- Ban on "tycoon methods" by forcing fish into the nets by beating the water.
- Ban on chemicals, herbicides, dynamites or explosives for fishing.
- Development of harmonized licensing mechanisms for the fishers from the three partner States. This is currently piloted through the beach management units (BMUs) after approval of the guidelines.
- Ensure fish quality assurance and promote international fish trade. A code of practice for fishing, fish handling and processing for Lake Victoria has been prepared, and ecolabelling pre-assessment studies are ongoing to ecolabel the fisheries of Lake Victoria through the Marine Stewardship Council.
- Conduct monitoring, control, and surveillance (MCS) operations to ensure compliance. The States have quarterly MCS operations and these are coordinated and reported regionally. The LVFO has prepared MCS operational manuals and guidelines to ensure harmonized procedures. Industrial fish processors are involved in control through self-monitoring to ensure no undersized fish is processed in their factories. Surveillance is done at all levels: beach, local markets, regional markets at cross-border points, and fish-processing factories. The BMUs and all stakeholders take an active role in the self-monitoring activities.

Source: LVFO/FAO (2004).

Ongoing efforts under the comanagement approach

The comanagement approach was initiated in about 1997 during the first phase of the Lake Victoria Environmental Management Project. This was the time when a donor-driven need to involve the communities in fisheries management was being promoted all over the world. Local management bodies, known as local enforcement units, were initiated in the Mwanza Gulf, the United Republic of Tanzania (Hoza and Mahatane, 1998), but the name was later changed to beach management units (BMUs). From around 2000, under the Lake Victoria Fisheries Research Project, the BMU initiative was introduced all over the lake (Geheb, 2000a, 2000b; Medard, 2002), and operational guidelines were developed (Ogwang, Medard and Ikwaput-Nyeko, 2004). These initial initiatives were further consolidated under the Implementation of a Fisheries Management Plan (IFMP) Project from 2005 to 2008 through mentoring, training and networking processes. To date, a total of 1 067 BMUs have been formed, mostly supported by the IFMP project (281 in Kenya, 355 in Uganda, and 433 in the United Republic of Tanzania).

The BMUs are technically responsible for ensuring that no fishing illegalities take place in their areas of jurisdiction and that breeding areas are protected (Ogwang, Medard and Ikwaput-Nyeko, 2004). Their role, as outlined in the guidelines, includes:

- to ensure the beach environment is kept clean;
- to assist in the collection of data and document fisheries information;
- to inspect and record visiting boats and ensure that newcomers report to relevant local authorities;
- to mobilize and ensure financial sustainability to enable execution of various activities, including to conduct and facilitate monthly meetings;
- to propose fisheries by-laws for endorsement by district authorities, and enforce them;
- to undertake MCS in collaboration with the relevant authorities.

To date, the establishment of BMUs has delivered a considerable return in areas of raising awareness, training, lesson-learning (cross-border) and networking, as well as in repositioning and restructuring the role and scope of the various management institutions within the existing national and regional structures. However, in terms of comanagement, many challenges still exist as the priorities of the communities are to solve their day-to-day problems including poverty, livelihoods and health-related issues and not only to address top-down-decided control measures in the fishery that they do not necessarily believe in or agree with (Kateka, 2010). While the national or regional management institutions see the BMUs primarily as their new implementation tools for centrally decided harmonized regulations (Box 1) adopted from elsewhere (Kolding and Zwieten, 2011), the fishers see them as fora for solving local problems and conflicts, and particularly as instruments for reducing theft and piracy (which is accelerating around the lake), for securing access to shared fishing grounds, for ensuring fair and transparent price and enumeration systems, for facilitating access to markets and government financing and lending schemes, and, not least, for curbing corruption (Medard, 2010).

As in many other African inland fisheries (Nielsen and Hara, 2003; Nielsen *et al.*, 2004), the ongoing conflicts between the harmonized gazetted regulations on fishing gear and legal fish sizes, which have been a key area of the LVFO activities (Box 1), and fisher compliance have, until now, not been solved by the introduction of comanagement. The use of illegal fishing methods such as monofilament gillnets, beach seines, under-sized mesh nets and fish driving are still very common (Table 13). These methods are efficient and widely accepted by fishers (Medard and Ngupula, 2007; Okware, 2009; Kateka, 2010) and the implied negative effects causing their prohibition have never been empirically documented (Misund, Kolding and Fréon, 2002). The persistent resistance among fishers to curb illegal activities, combined with increasing media-reported fears of imminent stock collapses, is increasing frustration among the managers. The ensuing demands for increased government enforcement is a strong indication of the void that still exists between the top and the bottom in the envisaged comanagement structure (Figure 36). There is currently a high risk that the mutual trust and belief initiatives, on which comanagement hinges, may deteriorate if top-down regulations and enforcement are not understood and supported by the fishers. Notwithstanding its achievements, the comanagement process in Lake Victoria is still a centrally controlled exercise where local communities are not involved in co-determining the objectives of the fishery but are essentially expected to implement the existing regulations by self-policing (Abila *et al.*, 2000; Geheb, 2000a; Medard and Geheb, 2000). It appears that the underlying assumptions for implementing comanagement – a mutual common comprehension of problems and measures – may not have been properly tested from the outset. According to Kateka (2010), the State has never tried to understand why illegal fishing is protected instead of being fought at community level. Instead, management has continued to be formulated at the national level and is heavily influenced by the markets, the international development agenda, and the global management discourses.

CONCLUDING REMARKS

In principle, fisheries comanagement is an arrangement in which responsibilities and obligations for sustainable fisheries management are negotiated, shared and delegated among government, fishers, and other interest groups and stakeholders (Pomeroy and Rivera-Guieb, 2006). However, many fisheries comanagement arrangements in Africa are mainly consultative, which means that mechanisms exist for government to consult with fishers (Figure 36), but all decisions are taken by government, and partnerships therefore tend to be unequal (Njaya, 2007). This is also the situation in Lake Victoria, and it is questionable as to whether a consultative partnership can expect the consulted party to implement non-negotiated decisions voluntarily when these are not agreed upon.

The management institutions around Lake Victoria have called for drastic interventions to ensure that the current gear and mesh regulations are enforced under the recently initiated "Operation Save the Nile Perch" coordinated by the LVFO. The question is, however, whether the stocks are currently in such a bad state that time has run out for negotiations on management issues instead of top-down enforcement. While a number of fish-processing factories have closed and some Nile perch fishers have left the fishery owing to low catches, the classical biological indicators of overfishing cannot be detected from the data available (Kolding *et al.*, 2008). The biodiversity seems to be improving as the reappearance of the haplochromines indicate, and perhaps the rate of environmental degradation has also decreased lately (Sitoki *et al*., 2010). The overall trends presented here would indicate that the situation is not yet alarming from an overall biological point of view.

Most of the science-based evidence for the general perception of overfishing is a result of steady-state stock assessment applications, with only fishing effort as a driver, while ignoring that the environment of the lake is constantly changing with steadily increasing nutrient levels and sudden switches. The result of this incongruity is that the theoretical-model-based perceptions of the state of the stocks are based on wrong assumptions and will probably become incompatible with the empirical observations. Under steady-state assumptions, it is not possible to have increased catch and effort without a simultaneous decrease in the stock sizes and catch rates. Thus, when the map and the landscape no longer correspond, as seems to be the case in Lake Victoria, it is time to analyse the causes.

This review recommends a more in-depth analysis of all existing data to provide a reconciled understanding on the status of the fisheries of the lake and, in particular, the Nile perch fishery.

5. Review of the case studies

THE CASE STUDIES

The four case studies presented in this technical paper raise many of the questions that are common to inland fisheries across the world. They cover systems from four continents: Asia, Africa, Europe and South America, and together they, or the larger systems from which they are drawn, contribute about 30 percent of the 10 million tonnes of the annual freshwater fisheries landings as reported to FAO by its Members (FAO, 2011). The case studies deal either with whole fisheries, as in the case of Lake Victoria and Lake Constance, or with individual fisheries forming part of the larger set of fisheries, as with the large-boat commercial fisheries of the Amazon and the dai fisheries of the Tonle Sap. They cover both fisheries in rivers (Tonle Sap – Mekong and Amazon) and in lakes (Victoria and Constance). This chapter reviews the issues raised by the case studies, and by the global inland fishery situation generally, in order to propose measures to sustain the contribution of fisheries to global food security and environmental sustainability.

FISHERY STATISTICS

National catch statistics

At the national level, good fishery statistics are necessary to ensure that the sector is placed in its correct social, financial and environmental context in relation to other sectors involved with the aquatic resource. This is important for the allocation of government resources to fisheries for research, monitoring and enforcement. It is also important for environmental regulations and for planning decisions for significant infrastructure such as dams, irrigation perimeters and urban waste disposal. At present, there is much doubt as to the quality of national statistics as reported to FAO for publication under its FishStat database (Welcomme, 2011). Such is the uncertainty of the current estimates that the Large Numbers Project (de Graaf, 2011) estimated that inland fishery catches were about 14 million tonnes – rather than the 10 million tonnes reported to FAO by its Members. Many sources of possible error have been identified in the way inland water fish catch statistics are collected and reported. This uncertainty is reflected in the catch statistics for Lake Victoria, where the LVFO reports catches of 900 000 tonnes for 2009 whereas the three riparian countries (Kenya, Uganda and the United Republic of Tanzania) record only 802 688 tonnes from all the inland waters in their territories, some of which are quite considerable sources of inland fish on their own. Similarly, the MRC has estimated catches from the Mekong River at about 2 million tonnes, whereas the Governments of Cambodia, the Lao People's Democratic Republic, Thailand and Viet Nam report only 810 300 tonnes from all their inland waters, which include several lakes, reservoirs and rivers lying outside the Mekong Basin.

These differences in estimates suggest a lack of communication between the organization responsible for managing the river or lake and the office responsible for statistics in the governments concerned. This means that management decisions seem to be being taken on the basis of inadequate and inconsistent information. One particularly serious problem here is that the subsistence and non-industrial artisanal fisheries that are so common in tropical lakes and rivers often go unreported and have to be estimated from unreliable information. Typical of this is the situation in the Amazon, where the reported catches derive from landings by large commercial boats at the major landings. Catches by the huge riparian rural sector remain largely unrecorded although some attempts are now being made to estimate these directly by CASs and indirectly by means such as consumption surveys.

The trends in the fisheries reviewed are of interest in the larger context of global inland fisheries. The inland water catches reported to FAO have risen steadily since 1950, particularly in Africa and Asia. However, the catches in the Tonle Sap have not shown any distinct trend over the years of operation, despite the fact that the number of nets has decreased. Catches in Lake Victoria have contributed very significantly to the rising catches of that continent, especially in the periods 1980–1991 (coincident with the expansion of the Nile perch fishery) and 2004–2007 (with the development of the *Rastrineobola* fishery). Catches in the Amazon have also risen in the last decade despite much more sluggish growth in inland fish catches for South America as a whole. The current level of catch from the Amazon of 147 931 tonnes is about 41 percent of the 359 947 tonnes reported from South America in 2009. There is considerable speculation as to why catches for South America should be so low compared with Africa and Asia. This issue is unresolved although South American fisheries still depend on the larger species and are nowhere near the level of intensive exploitation that has caused the fishing-down of the communities in the other two tropical continents. Catches from Lake Constance follow a trajectory similar to the rest of Europe, where catches have generally declined since 1989. This has usually been attributed to the falling numbers of fishers and the changing financial situation following the political upheavals of the 1980s, but it may also be due, in part, to the trends towards cleaner water throughout the continent in recent years.

EMPLOYMENT

The BNP (2009) estimates that the inland fisheries sector employs about 56 million people either directly as fishers or indirectly as processors and marketers. Of the areas studied here, there are about 175 803 fishers in the Brazilian Amazon Basin, distributed between the commercial (large boat) fishery and the artisanal fishery. In Lake Victoria, the numbers of fishers rose from 129 305 in 2000 to 194 172 in 2010. The MRC reports that up to 65 million people are directly or indirectly dependent on the fisheries resources of the lower Mekong Basin, but many of these are dependent mainly for food and not employment. The dai fishery described in the case study provides important seasonal employment opportunities for about 2 000 rural people. In common with many countries, the Mekong States have no realistic estimate of the numbers directly involved in the fishery because of the difficulties in gathering such information from extremely diffuse populations. The lack of precise data on the numbers involved with fishing, processing and marketing inland fish makes it extremely difficult for countries to evaluate the impacts on incomes and food security of riparian communities throughout the tropics. Even in the temperate zone, where the prime use of inland fish resources has tended towards recreational use, small numbers of commercial fishers persist, for example, 140 on Lake Constance (although here numbers have declined in recent years).

RESEARCH

Two main approaches to the estimation of the size and health of stocks are adopted in the case studies. Direct counting at markets, landings or individual gears is a feature of the Amazonian fishery, the dai fishery of the Tonle Sap and both the commercial and recreational fisheries of Lake Constance. Some landing statistics are also used in Lake Victoria in the form of returns from the various fish-processing plants. While such direct sampling should give reliable results of the amount of fish being landed, this method is less practical in estimating yields from the diffuse landings and informal commerce in the wider fishery, particularly in rivers. It is also of limited use in relating the landings to the general health of the stocks from which they are being drawn. However, judgements on whether or not stocks of individual species are overexploited are made on the basis of trends in the mean length of fish caught and in

CPUE, although the dai fishery case study demonstrates that this can be misleading in the short term in rivers because fish growth is strongly influenced by the extent and duration of flooding each year. Research institutes on Lake Victoria, the Amazon and Lake Constance and in Cambodia have all conducted more-detailed science-based assessments of individual species with variable results. These are often based on classic estimates of growth, mortality and recruitment, as in the case of whitefish in Lake Constance, Nile perch in Lake Victoria and *Colossoma macropomum* in the Amazon. Species have also been studied by experimental trawl surveys and acoustic surveys in Lake Victoria. Such studies are relatively rare outside of major fisheries such as Lake Victoria and the Amazon, and most countries depend on general impressions gathered from more-general indices such as relative abundance and length of fish caught.

Another major field of research is the biology and ecology of individual species. This is needed both for regulation of the fishery, where closed seasons such as those imposed in lake Constance depend on an adequate knowledge of breeding behaviour, and for conservation of critical habitats and migratory pathways. All four of the case studies describe fisheries that have extensive research capacity, both through local institutions and external project support. As such, knowledge of the species of importance to the fishery is often good; however, each of the tropical systems contains several hundred species, with new ones being described frequently. In fact, many of the haplochromines of Lake Victoria have never been formally described and their definitive numbers are still unknown. Most countries, however, lack these facilities and the cost of research is often excessive. These then depend on extrapolations of accumulated knowledge from elsewhere. Increasingly, the grouping of species that behave in similar ways into functional guilds is used, enabling the requirements of many species to be satisfied together.

Items of information needed for the management of the fishery and the environment to favour fish are the habitats occupied by a species during its lifetime and the migratory pathways by which the species moves between them. In rivers, including the Amazon and the Mekong Rivers, these include not only the pathways used by adult fish to arrive at spawning sites, but also the conditions that favour the drift of the larvae and juveniles from spawning sites to downstream nurseries.

DRIVERS

One of the main issues in inland fisheries management is the relative degree to which the fishery responds to fishing pressures as opposed to environmental pressures.

Fishing

Fish stocks respond to fishing by characteristic changes known as the fishing-down process (Welcomme, 1999). This predicts that, with increasing effort, multispecies fisheries will respond by the successive elimination from the fishery of the largest species, producing a gradual decline in the mean length of the species caught. This is illustrated in the Amazon by the decline in catches of *Colossoma macropomum* and the increase in catches of *Semaprochilodus* spp.

The history of Lake Victoria is confused because of the introduction of the large Nile perch in the 1950s. However, prior to the effects of this introduction having been felt, several of the native fishes showed signs of fishing-down, including the mainstay of the fishery *Oreochromis esculentus.* That fishing pressure can exert this effect justifies the continuation of traditional fisheries management practices to control the amount and minimum length of a species that can be taken from the fishery. This practice is extremely difficult to apply in the majority of multispecies fisheries where many species are targeted, but it still appears to be practicable in single-species fisheries such as those of Lake Victoria. That such management works is indicated by the recovery of *Arapaima gigas* stocks in the Jarauá Sector of the Amazon following improved practice (Viana *et al.*, 2007).

Environmental drivers

Two main environmental variables have been implicated in the fisheries presented in the case studies: river flow (flooding), and nutrient enrichment (eutrophication).

The correlation between better flooding conditions and improved catches in rivers, and river-driven lakes and reservoirs, is now well established. In rivers, this arises mainly because the increased area of floodplain made available to fish in years of higher and more sustained flooding leads to better survival and growth of young fish – as demonstrated here for species seasonally inhabiting the Tonle Sap – Great Lake system. In river-driven lakes and reservoirs, greater quantities of nutrients are washed into lakes and reservoirs by the inflowing tributaries in years of elevated flows, so productivity is raised. Typically, examples of this effect are cited for the Tonle Sap, where the seasonal flooding of the forests around the Great Lake margins varies from year to year, and for the Amazon for the floodplain-dependent species. Flow is also important in regulating the distribution of downstream drifting larvae and juveniles that is so common in the Amazonian catfishes and Mekong species.

Nutrient enrichment is more important in lakes, and both Lake Victoria and Lake Constance provide examples of the impact of raised nutrient levels on the fishery. Eutrophication not only raises the productivity of the waterbody, and thereby the yield of the fishery, it also conditions the species of fish in the community. Thus, in Lake Constance, there was a marked swing from the whitefish that thrive under oligotrophic conditions to perch and carp, which prefer the more eutrophicated ones. This swing was reversed as more oligotrophic conditions were re-established following a campaign to clean up the lake water. In Lake Victoria, the situation is more difficult to interpret, although there is sufficient evidence to indicate that the increased eutrophication of the lake has favoured the current high yields from the fishery. It is possible, in fact, that many of the species extinctions from this lake, including that of *O. esculentus* and certain planktonophage haplochromines were caused by the shift from a diatom lake to one dominated by blue-green algae. Several of these species were highly adapted to filter out and digest diatoms, but were ill adapted to digest the blue-greens. The replacement species *O. niloticus*, on the other hand, is capable of exploiting this food source. In addition, shifts in the nutrient status of the lake, together with the disappearance of predatory haplochromines, allowed the development of *Caridina* shrimps and *Chaoborus*, which have been targeted by juvenile Nile perch and *Rastrineobola*, respectively.

A further driver that is particularly significant in the case of rivers is the morphology of the river channel and its associated wetlands and floodplains. Most river species are adapted to particular types of habitat within a system, and changes to this by channelization of the main river in the interests of navigation, and draining of the floodable wetlands for agriculture produce significant changes to the composition and abundance of the fish stocks. In systems that have been substantially altered by such interventions, methods have to be found to mitigate or reverse such degradation.

RECREATIONAL AND ORNAMENTAL FISHERIES

Two of the case studies underline the role of fishing activities other than for food. In Western Europe, it has long been established that the major use for inland fish resources is sport fishing or angling. This is reflected in Lake Constance, where about 10 000 anglers were recorded in 2006. In much of Western Europe, the fish caught is usually returned to the water unharmed, but in other areas and in most of Eastern Europe the recreational fishery is to be regarded as a type of support to family diets. The daily bag limit of 50 perch per day for Lake Constance indicates, that such fish are taken for consumption, it indicates also, that this species is highly valued. The anglers are not allowed to sell their catch. In this lake, the recreational fishery contributes about 68 tonnes of fish a year, representing about 10 percent of the commercial catch.

The trend from commercial food fisheries to recreational use as national economies develop has been remarked upon by Cooke and Cowx (2004), and this process is now advancing rapidly in many tropical countries, both for local sports fishers and for visiting tourists. Indeed, in many countries, tourism associated with sport fishing is now an important source of revenue. This situation is exemplified in the Amazon, where some 10 000 tourists fish recreationally and the industry directly employs about 1 000 people per season. According to FAO (1998), the direct and indirect income derived from sport fishing here could amount to more than US$400 million. This contrasts with the US$278 million estimated by Almeida (2004) for the Amazon food fisheries sector, of which 48 percent comes from fish-processing plants, 18 percent from small-scale fishers and 16 percent from commercial fishers. The same author estimates that the fishery sector provides more than 155 000 jobs.

Another fishing activity that is common in Africa, Asia and South America is the collection of ornamental fishes for the aquarium fish trade. There are no exact figures on the magnitude of the trade, although Oliver (2003) places the value of all aquatic ornamental organisms traded worldwide at more than US$1 000 million USD (this includes finfish, crustacea and molluscs from marine and inland habitats). The annual commercial value of ornamental fish from the Amazon is estimated at US$4.8 million, employing more than 1 000 families.

MANAGEMENT

National

Management of inland fisheries is often extremely difficult owing to the spatially dispersed nature of the fishery, the large number of persons involved and the distance from major urban centres. As a result, fisheries regulations are often poorly enforced. Even where enforced, their success may also be questionable, because they are usually established by central authorities and do not cater for the needs of individual waterbodies and their fisher populations. Moreover, the drivers of change and productivity in many fish populations arise from outside the fishery, usually in the form of environmental impacts arising from other users of the aquatic resource.

The authorities in the four case studies have adopted traditional approaches to management including limitations on access, closed seasons, minimum sizes of landed fish and limitations on the type and mesh size of the gear to be used. Such centrally imposed limitations have been unsuccessful in the larger systems, although they appear to work well in the case of a smaller lake such as Lake Constance, individual gear such as the dai of the Tonle Sap or a single species such as *Arapaima gigas*.

Comanagement systems are now being used in an effort to overcome the limitations imposed by central government agencies. These attempt to involve local fishers in the decision-making and enforcement of fisheries in local waterbodies. In Lake Victoria, a great deal of attention has been paid to setting up comanagement systems in the form of BMUs. These have enjoyed varying degrees of success and illustrate the problems of initiating new systems of governance. For example, the national or regional institutions see the BMUs as tools to implement top-down regulations, whereas the fishers see them as fora for solving local problems and conflicts. In the Amazon Basin, the fishers themselves request that locally agreed fishing accords be recognized by the responsible government agencies. This has led to the decentralization of management and the formalization of participatory approaches. In both Lake Victoria and the Amazon, comanagement systems of this type are still being modified to respond better to the needs of the fisher communities and the fishers by introducing more flexible approaches to the regulation and enforcement of local stocks.

Traditional management of the fishery is not the only approach to the management of fisheries resources. It is commonly accepted that modern fisheries management has three distinct aspects: (i) management of the fishery; (ii) management of the fish; and (iii) management of the environment. Management of the fishery involves those traditional practices such as input and output controls that operate through the practices of fishing. Management of the fish consists of those activities involving stocking, introductions and culling of unwanted species that constitute fisheries enhancement. Management of the environment involves measures to control the quality of the environment for fish, e.g. flows, water quality and habitat structure. None of the four examples given here involves management of the fish, although this practice is increasingly widespread as a method of increasing yield of a heavily exploited waterbody over and above that attained though natural recruitment.

Management of the environment is also not explicit in the case studies despite the fact that environmental drivers are affecting fish population in all systems. The one example where environmental management has had an effect is Lake Constance, where the trend to eutrophication was reversed by measures to reduce nutrient inputs, supposedly to improve water quality of drinking-water and not for fisheries motives. In extremely large systems, such as Lake Victoria, the Mekong and the Amazon, environmental management is much more difficult owing to the scale of the problem. In Lake Victoria, the trend towards eutrophication was relatively rapid until the 1980s, but has subsequently stabilized. The motives for the slowing of nutrient enrichment are not clear and are undoubtedly not associated with the needs of the fishery. Indeed, it is not evident what mechanisms exist to take environmental considerations into account in the various organizational processes associated with the management of this important fishery.

In the two river cases studies, it is clear that the main environmental driver is the year-on-year differences in flow. The relationship between flow and fish production is well established for most rivers as it conditions breeding success and the amount of fish available to the fishery in following years. This relationship can be altered by dams, water abstractions and other human activities, as well as possibly by climate change. For this reason, it is important that mechanisms be established to include the flow requirement of fish and associated organisms (environmental flows) in all future projects on rivers. This situation is especially important on systems such as the Mekong and Amazon where existing and planned dams may have severe effects of the downstream flood regimes to the detriment of the fishery.

International

With the exception of the Tonle Sap in Cambodia (which forms part of the larger international Mekong Basin), the case studies deal with fisheries on international waterbodies. In three of the cases, formal international mechanisms are in place to harmonize approaches to fisheries management in their basins. This is particularly important in view of the transnational nature of many of the stocks, particularly long-distance migrants such as the Amazonian catfishes or the Mekong cyprinids. Lake Constance is treated as a condominium by the riparian States and the environment and fisheries are managed through bodies such as the Internationale Bevollmächtigtenkonferenz für die Bodenseefischerei – one of the oldest international fishery bodies (dating from 1893) – together with other bodies including the Lake Constance Environmental Council and the International Commission for the Protection of Lake Constance. The MRC concerns itself with fisheries issues in the Mekong River, and the LVFO fosters collaboration between the national fisheries organizations of Lake Victoria with respect to research and regulation. The Amazon, uniquely, does not have an international body responsible for its fisheries although the Amazon Cooperation Treaty Organization does take responsibility for some aspects of aquatic biodiversity.

Globally, there are about 80 bodies responsible for international waterbodies, although not all of these play a significant role in fisheries matters. With growing pressures on inland waters through the need to generate power (dams) and provide water for irrigation and urban consumption (abstractions), there is a growing need for riparian nations to collaborate in the research and regulation of the aquatic environment and fisheries.

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