Impacts of human activities

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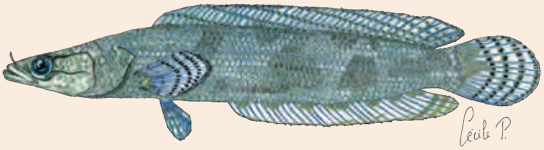


Continental aquatic ecosystems are particularly affected by human activities including the modification or elimination of habitats because of territorial planning works, pollution from different sources, and overfishing. The consequences of these activities, now amplified by population growth and increasingly heavy pressure on natural resources, endanger ichthyological fauna the world over. Long spared these impacts, Africa is now feeling their effects even though pollution, for instance, is still relatively limited in extent.

A number of anthropogenic threats to freshwater ecosystems are recognized to operate at the continental scale, including habitat loss or transformation, water extraction and hydrological disruption, invasive alien species, pollution, and overexploitation (Dudgeon *et al.*, 2006).

Given the unpredictable rainfall, very high evaporation rate (around 65% of rainfall), and low conversion of rainfall to runoff, it is clear that large areas in Africa face water management difficulties. In an effort to meet the increasing demand for water and power, many large wetlands have been affected by developments such as dams, flood control measures, or direct abstraction, and their ecological function has been impaired (Postel & Richter, 2003; Richter *et al.*, 2003). Groundwaters are also being used, most often to provide irrigation for agriculture, at a faster rate than they can be replenished such that the water table is being lowered and wetland areas are disappearing (Darwall *et al.*, 2009; Garcia *et al.*, 2010). Abstraction for agriculture or industry accounts for a large part of the total water consumption from rivers, lakes and aquifers such that an estimated 85% of Africa's total water withdrawals are directed toward agriculture (Aquastat, 2010) with about one-third of its surface area estimated to be under agricultural land use in 2000 (FAOStat, 2010). Such measures impaired the effective functioning of wetlands and floodplains with consequences on their associated biodiversity. Moreover, water runoff from agricultural lands brings sediments, nutrients and pesticides into aquatic systems. Pollution from domestic sewage and industrial facilities is also a large problem in many parts of Africa, where the infrastructure required for water purification is often inadequate or non-existent (Saad *et al.*, 1994; Lévêque, 1997a, UNEP, 2004b).

Changes in habitats

Habitat degradation is one of the greatest threats to aquatic fauna. Changes that can occur have two very distinct origins that nonetheless often act concomitantly:

- climate change and its effect on the water balance and the hydrological function of hydrosystems;
- anthropogenic changes at the level of both the aquatic system and its watershed.

Climate change and water abstraction

We know that at the geological scale, climate has never been stable and that aquatic systems have always fluctuated without humans bearing responsibility for such fluctuations (e.g. the "El Niño" phenomenon). Yet we also know that humans can affect the climate indirectly, either locally through deforestation or on a planetary level through the emission of so-called "greenhouse gases". In recent years, global opinion has been alerted of the possible warming of the planet that may be due to higher atmospheric concentrations of carbon dioxide, methane, and chlorofluorocarbons (CFC), the massive emissions of which are tied to industrial activity. Although we do not know the scope and speed at which this warming will occur, we can nonetheless fear that these changes to the climate will take place in coming decades, leading to a shift in the rainfall regimes of certain parts of the world. In addition to still hard-to-predict consequences on the hydrological front (local increase or decrease of rainfall), we can also expect an increase in insolation and temperature, changes in plant distribution, and a rise in sea water levels. These somewhat catastrophic scenarios will have long-term effects if they become a reality. While it is still impossible at the local level to evaluate the consequences of these expected changes, it seems obvious that regardless of the extent of the phenomenon, aquatic fauna as a whole will be the first to be affected.

Anthropogenic climate change and increasing human water use are widely expected to place great stress on available water resources across Africa (Thieme *et al.*, 2005), but their expected effects on freshwater biodiversity have only just begun to be considered (see www.freshwaterbiodiversity.eu). According to the global hydrologic model, by the 2050s, ecoregions containing over 80% of freshwater fish species and several outstanding ecological and evolutionary phenomena are likely to experience hydrologic conditions substantially different from the present, with alterations in annual discharge or runoff of more than 10% (Thieme *et al.*, 2010).

However, in the Sahelo-Sudanese area, fish populations have long been subjected to long-term climate changes. A typical example is Lake Chad. The levels of the lake have fluctuated over decades, centuries and millennia, responding to changes in the global temperature and regional precipitation. There was a time in history when Lake Chad was so huge that contemporary historians refer to it as Mega-Chad. At other times it may have even come close to disappearing. For instance when it was discovered at the beginning of the 20th century, the lake level was so low that the northern basin was dry.

These long term changes were clearly driven by natural climatic changes. That was also the case for the recent drying out of the lake which started at the beginning of the 1970s and has continued for almost two decades. This drying out was the result of a severe meteorological drought (reduced rainfall for well over a decade) in the Sahelian zone. A recent report on climate change and the hydrologic cycle suggested, that "of all the major basins in the world, probably Lake Chad has been affected most by climate change" (see www.fao.org/docrep/W5183E/w5183e04.htm).

Actually, diversion of streamflow for irrigation remained low until the 1980s when Lake Chad basin countries began to intensify their food production efforts. However, by the 1980s and 1990s, water from the inflowing rivers was increasingly diverted for irrigation purposes. It is estimated that about one-third of the streamflow today is diverted from the Chari River before its flow reaches Lake Chad. According to UNEP GRID about 50% of the decrease in the lake's size since the 1960s is attributed to human water use, with the remainder attributed to shifting climate patterns. (Glantz, 2004; http://www.fragilecologies.com/sep09_04.html). (figure 24.1). In such a situation, the recovery of Lake Chad is becoming difficult.

Virtually all wetlands in the region are either dried up or on the verge of drying up and planned irrigation development of 213,400 ha has been stopped at 33,824 ha (Musa *et al.* 2008). More than 20 million people, most of whom are

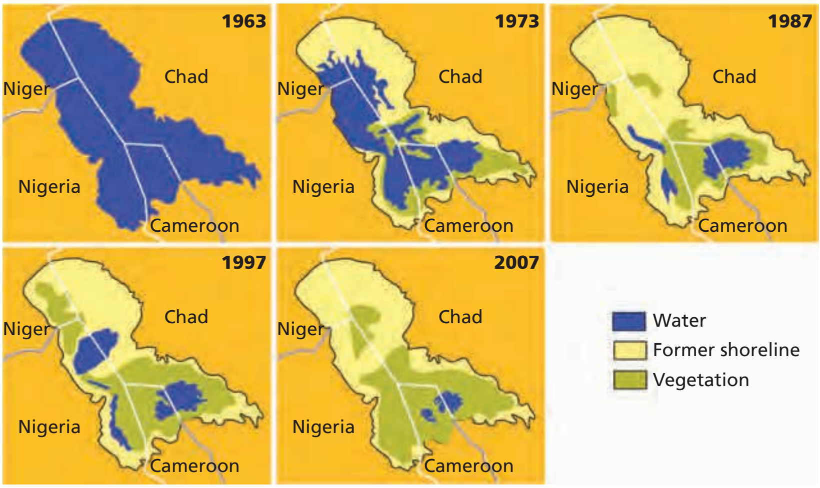


FIGURE 24.1.
Reduction in the size of Lake Chad over the period 1963-2007 (redrawn from Musa *et al.*, 2008).

farmers, fishermen and livestock breeders are dependent upon the lake and its surrounding wetlands for their livelihood (fishery and agriculture). This is so serious that plans are being tabled to transfer water from other rivers in the region.

System managements

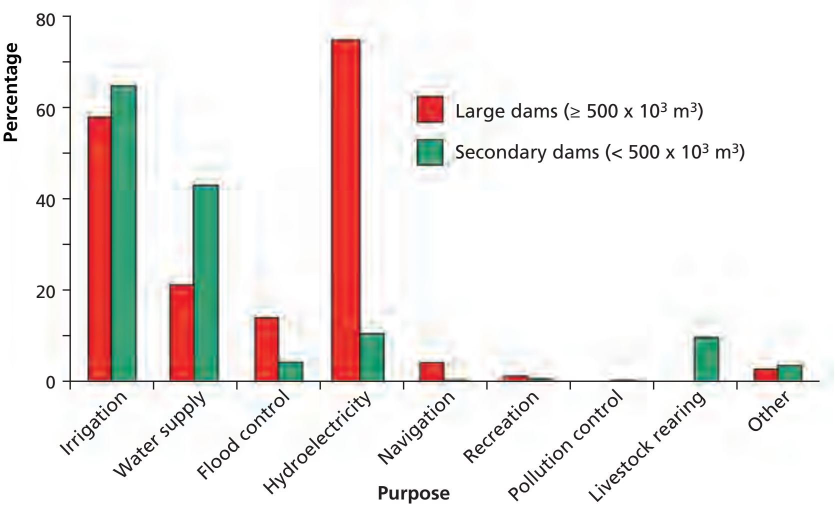
The various uses of water for agriculture, power generation, transport, and domestic use lead to structural adjustments of hydrosystems. These constraints modify the water balance but also directly or indirectly change the original aquatic habitats.

Man-made lakes (water fragmentation)

Africa has a large number of dams, particularly in the Maghreb and southern and western Africa (figure 24.2). Most of the largest dams were built after the mid-1950s on large rivers to supply electricity. More recently, probably thousands of smaller reservoirs have been established to meet other water demands including irrigation, pastoralism, water supply (domestic use) or fish production (figure 24.3).

FIGURE 24.2.
Location of 135 large dams (≥ 500,000 m^3) and 1,072 secondary dams (< 500,000 m^3) in Africa (data from Aquastat, 2010).

FIGURE 24.3.
Main purposes of dams in Africa (data from Aquastat, 2010).



The impacts of large dams on ecosystem functions and biodiversity are well documented (e.g. McAllister *et al.*, 2001; McCartney *et al.*, 2001; Nilsson *et al.*, 2005). They constitute obstacles for longitudinal exchange of organisms, and nutrient and sediment flows along rivers. They permanently destroy upstream submerged habitats, and block the migration pathways for some aquatic species. Downstream impacts include changes to the flow regime, water temperature and quality. The ecosystem impacts from dams should therefore be treated as costs to society and be considered in decisions taken before building a dam and in the subsequent design of its implementation. The nature of impact is summed up in one of the main conclusions of the Report of the World Commission on Dams (2001) as "On balance, the ecosystem impacts are more negative than positive and they have led, in many cases, to significant and irreversible loss of species and ecosystems. In some cases, however, enhancement of ecosystem values does occur, through the creation of new wetland habitat and the fishing and recreational opportunities provided by new reservoirs… Efforts to date to counter the ecosystem impacts of large dams have met with limited success due to the lack of attention to anticipating and avoiding such impacts, the poor quality and uncertainty of predictions, and the difficulty of coping with all impacts…"

For a few major impoundments in Africa, the sequence after damming has been studied (e.g. Jackson *et al.*, 1988) and, in general, the impacts are important (figure 24.4), but different from those observed in north temperate man-made lakes.

When a watercourse is blocked to create a reservoir, this triggers several modifications to habitats and fish communities (Jackson *et al.*, 1988) which, broadly speaking, can be summed up as follows:

- the new reservoir lake upstream eliminates species that are restricted to running waters. That said, owing to the development of plankton, there is generally an explosion of growth in planktophagic species, closely followed by significant development of pelagic piscivorous fishes. Because of water

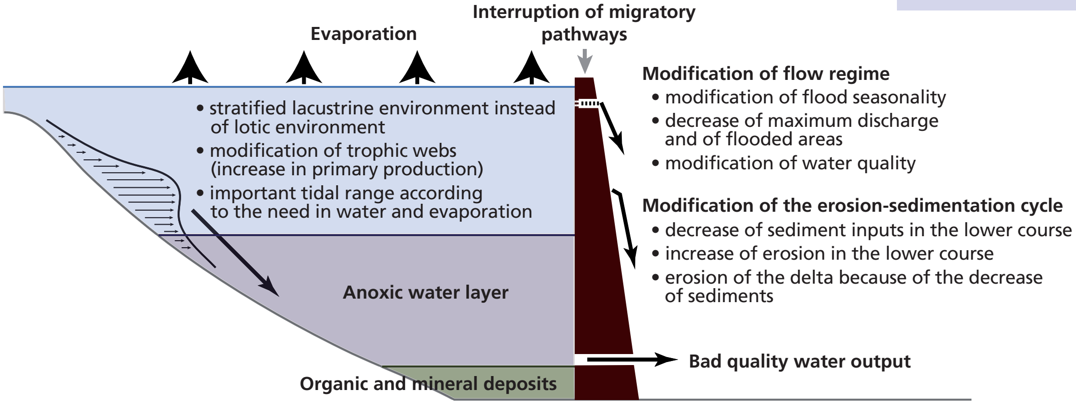


FIGURE 24.4.
Diagram showing the major impacts of the building of a dam on the aquatic environment.

stratification, the benthic zone is generally deoxygenated and unsuited to fish life. Only the littoral and pelagic zones are likely to be colonized by species adapted to lentic conditions. But in the tropical environment, these biotopes are generally brutally exundated, which leads to high mortality in clutches found there. Finally, reservoir lakes are often the site of the uncontrolled development of floating macrophytes (mainly *Pistia stratiotes* and *Eichhornia crassipes* but also *Azolla nilotica* and *Salvinia molesta*) which can favour the establishment, if not the proliferation, of certain fish species, but are also hinder fish capture and movement within the reservoir.

- The modification of the flood regime downstream, and flow regulation in particular, disturbs the biology of species that habitually reproduce in the high waters of flooded areas. This most often results in a simplification of communities, with the disappearance of some species. Moreover, stirring up deep waters that are generally anoxic and methane-rich leads to a more or less pronounced deterioration of water quality downstream. In some extreme cases, this deterioration may reach such an extent that downstream fish production is severely affected. This occurred in Egypt, where the retention of the Nile's organic matter in the Lake Nasser reservoir triggered a decline in the pelagic fisheries of the coastal Mediterranean area.
- In tropical regions, dams are rarely equipped with fish passes. This prevents migrating species from going upstream during floods to spawn in more favourable environments. Likewise, during these migration periods, dams trigger an over-concentration of breeders at the bottom of the dike. This phenomenon is known to local fishermen who manage to make exceptional catches, which could in turn imperil available stocks if they are too intensive.

One of the most well-documented examples for the evolution of fish communities following the damming of an African river is that of Lake Kainji on the Niger (Ita, 1984) where an inventory of fish fauna was carried out before damming (table 24.I). After damming, the most significant changes were as follows:

- A high decrease of Mormyridae, which includes many species that need riverine conditions to reproduce. According to some hypotheses, the disappearance of Mormyridae could come from the submersion of their customary

Fish families	Niger River before damming			Kainji Lake		
	number of species	% of individuals	% weight	number of species	% of individuals	% weight
Mormyridae	19	20.7	19.5	12	1.4	1.4
Alestidae	8	36.3	12.1	8	18.6	10.3
Citharinidae + Distichodontidae	5	6.1	19.8	4	4.7	15
Cyprinidae	5+	3.3	4.3	7	8.6	5.5
Bagridae + Claroteidae	7	7.2	18.2	8	18.5	15
Schilbeidae	3	8	3.6	3	0.1	*
Mochokidae	18	18	18.7	11	2.3	2.5
Clariidae	2	*	*	2	*	2.2
Malapteruridae	1	*	*	1	0.1	2.5
Latidae	1	*	*	1	1.7	1.2
Cichlidae		*	*	7	36.1	43.6

TABLE 24.I.
Relative abundance of fish families caught before and after the closure of the Kainji dam (from Ita, 1984). (*: very low %)

habitats that are now at much greater depths and insufficiently oxygenated. It appears that the rarefaction of species from this family after the damming of Lake Kainji is not a generalized phenomenon, and depends on the species present. Thus the Mormyridae persisted after the damming of Lake Kariba, with the development of both *Mormyrus longirostris* and *Marcusenius macrolepidotus* in particular. These two species also became abundant in the McIlwaine reservoir (Marshall, 1982).

- Extraordinary development in the pelagic zone of small species such as Clupeidae (*Sierrathrissa leonensis*) and Schilbeidae (*Physailia pellucida*, *Schilbe mystus*) during the first year. These species colonized the newly-created pelagic zone, as has also been observed for two clupeids in Lake Volta (*Pellonula leonensis* and *Odaxothrissa mento*). In Lake Kariba, the indigenous pelagic species *Brycinus lateralis* was supplanted by the clupeid *Limnothrissa miodon* introduced from Lake Tanganyika.
- An increase in the stock of fish predators (*Lates*, *Hydrocynus*) consuming the stock of pelagic species. This is also the case in Lake Kariba where *Hydrocynus vittatus* developed particularly well after the introduction of *Limnothrissa*.
- The spectacular increase of *Citharinus citharus* in catches.
- An increase in the proportion of Cichlidae.

Changes continued to take place in the lake in subsequent years, in particular with a decline in *Citharinus* population and a sharp increase in the proportion of Cichlidae in catches. Downstream from the dam, a general decrease in catches was observed in the Niger River.

We were able to monitor the evolution of fish communities in Lake Kariba with the aid of both artisanal fishing and experimental fishing carried out by the Lake Kariba Fisheries Research Institute (Machena *et al.*, 1993; Karenge & Kolding, 1995) (table 24.II).

Taxa / years	1960	1961	1962	1963	1964	1967	1969	1970	1971	1972
Mormyridae										
Hippopotamyrus discorhynchus					13	20	225	318	556	1,090
Mormyrus,longirostris						90	602	294	800	371
Mormyrus anguilloides					4			24	16	68
Marcusenius macrolepidotus					32			6		
Alestidae										
Hydrocynus vittatus	2,900	2,000	2,773	3,258	2,058	1,370	2,876	2,718	5,936	6,042
Brycinus imberi	3,150	2,200	968	1,233	180	110		6	36	50
Distichodontidae	400	650	1,884	109	114	50	5	6		6
Cyprinidae										
Labeo spp	11,650	4,600	2,096	1,384	656		4			6
Siluriformes										
Schilbe depressirostris			46	146	18	80	664	900	1,260	694
Clarias gariepinus	600	1,450	828	667	45	90	209	42	48	172
Heterobranchus longifilis								6		3
Synodontis zambezensis					26		63	18	36	50
Cichlidae										
Oreochromis spp	1,900	50	1,050	408	139	480	915	192	356	1,039
Serranochromis condringtoni		1	50	21	6	140	401	162	312	1,635
Coptodon rendalli		150	23	46	9	40	83	18	80	141

Taxa / years	1973	1974	1975	1976	1977	1978	1979	1980	1982
Mormyridae									
Hippopotamyrus discorhynchus	1,028	532	159	378	389	500	286	565	270
Mormyrus longirostris	324	266	68	96	165	275	112	184	33
Mormyrops anguilloides	141	277	413	460	443	159	91	122	284
Marcusenius macrolepidotus		20	6	11	7	9	8	18	26
Alestidae									
Hydrocynus vittatus	4,466	7,020	4,219	2,906	1,979	1,808	1,332	1,646	2,095
Brycinus imberi	30	206	994	1,093	1,379	827	1,649	1,364	878
Distichodontidae	6	12	2	4	1	4	1		1
Cyprinidae									
Labeo spp	6	4	22	9	45	29	90	87	18
Siluriformes									
Schilbe depressirostris	295	604	212	160	601	299	324	735	162
Clarias gariepinus	104	458	345	231	168	294	73	78	204
Heterobranchus longifilis	4	6	12	12	16	2	1	2	4
Synodontis zambezensis	99	167	88	103	125	80	57	103	84
Cichlidae									
Oreochromis spp	757	2,684	2,046	1,632	1,493	1,178	150	171	332
Serranochromis condringtoni	1,145	1,967	2,439	1,860	1,118	723	571	534	1,567
Coptodon rendalli	64	193	304	314	144	132	248	80	117

TABLE 24.II.

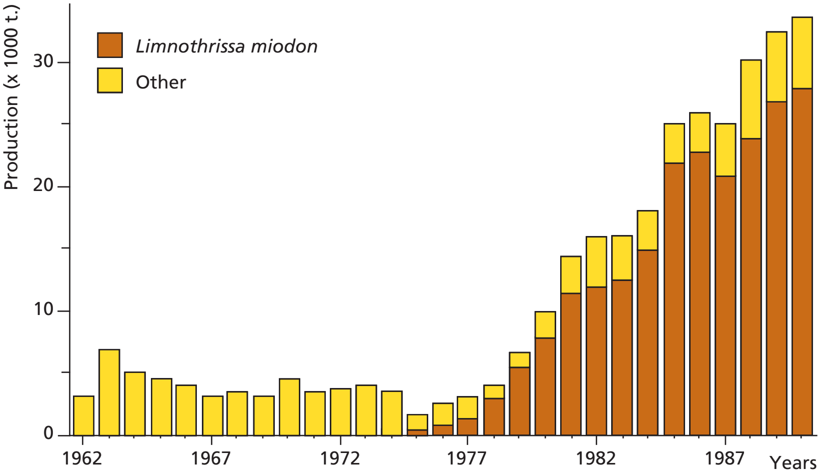
Lake Kariba: change in the abundance of major fish species (tonnes), lakeside station (from Karenge & Kolding, 1995).

The species composition of catches after damming (early 1960s) was essentially the same as prior to it, and included mostly *Labeo* spp., *Distichodus* spp., *Hydrocynus vittatus, Mormyrops anguilloides* and *Clarias gariepinus*. Afterwards, the community evolved and the most striking features were as follows:

- The maintenance of Mormyridae after damming, contrary to what was observed in Kainji, with the development of *Mormyrus longirostris* in particular.
- After the rarefaction of *Labeo congoro* and *Labeo altivelis* in the early 1960s, the latter reappeared in relatively high quantities during the 1980s.

- The pronounced development of Mochokidae, especially *Synodontis zambezensis* during the 1980s, to the extent that the species does not appear to be exploited much (Machena *et al.*, 1993).
- The clupeid *Limnothrissa miodon*, a species introduced from Lake Tanganyika, has acclimatized well and has been heavily exploited by fishers since the early 1980s (figure 24.5).
- *Hydrocynus vittatus* flourished during the lake's filling phase, particularly after the introduction of *L. miodon* (Machena, 1995). During the 1980s it became less plentiful, but the species continues to be well-represented in catches and there appears to be no sign of overexploitation from fishing (Machena *et al.*, 1993).
- A growing importance of Cichlidae in the early 1970s, but whose stocks seem to decrease as a result of fishery overexploitation (Machena *et al.*, 1993).

FIGURE 24.5.
Lake Kariba: trend in fish production from 1960 to 1990 (from Greboval *et al.*, 1994).



River management

In Europe and North America, many rivers were developed with the construction of dikes, the diversion of watercourses, the construction of navigation locks, and so on. Such engineering works are still limited in Africa, but there are nonetheless a few examples of projects that modified natural systems fairly extensively.

In the Senegal valley, for instance, several engineering projects were conducted in order to manage river water resources more effectively and use them for agriculture. The construction of a downstream dam at the level of the estuary (Diama dam) was intended to prevent sea water from moving to the river's lower course during the dry season, whereas the Manantali dam found upstream allows storage of large quantities of water during the flood and release them as required, in particular to supply vast stretches of irrigated farmland. All of the water resources of the Senegal valley is thus now partially under control, but water management is complicated by sometimes contradictory needs in terms

DEVELOPMENT OF THE LOWER VALLEY OF THE SENEGAL RIVER
(FROM ALBARET & DIOUF, 1994)

The estuary, and more generally the area known as the lower valley of the Senegal River, was particularly affected by a series of construction projects. To address the significant imbalance between food resources and local needs, a development programme that included the construction of two dams (Diama and Manantali) was put in place.

The Diama dam, commissioned in 1986, is located about fifty kilometres from the river mouth. Its main functions are to prevent the entry of saltwater, to create a water reserve for irrigation, and to improve the filling of surrounding depressions.

The Manantali dam, in operation since 1988, was built on the Bafing, one of the major tributaries of the Senegal River. It is located in Mali about 1,250 km from the river mouth and serves to regulate the river flood and manage water releases at relevant moments, either to irrigate farmland areas or to produce hydroelectricity.

These dams, along with numerous dikes built along the main riverbed, have had important effects on the ichthyofauna among other things. In the lower valley of the river, the Diama dam is a physical barrier to fish migration and has also considerably reduced the estuarine zone of the Senegal river. From a length of around 200 kilometres before the Diama was built, it now only stretches over some 50 kilometres, leading to a significant loss of habitat for many species, particularly those of estuarine or marine origin (see chapter *Fish communities in estuaries and lagoons*). A comparison of faunistic inventories taken in the areas downstream of the Diama, made before and after the construction of the reservoir, shows that species composition is generally similar in this part of the river (Diouf *et al.*, 1991). This is most certainly because, in the absence of disturbances owing to off-season freshwater releases, recorded surface salinities are essentially the same as in the past (Cecchi, 1992). Upstream, on the other hand, because of the dam, estuarine and marine species have practically disappeared, although some of them used to be found up to more than 200 kilometres from the river mouth. Moreover, the main breeding area of euryhaline fishes prior to damming was found in sectors where salinity was between 5 and 15‰. With the Diama dam, this area is no longer accessible to euryhaline fishes, leading in turn to a loss of recruitment for lower estuarine fish stocks and some marine stocks.

Flood regulation from the Manantali dam leads to a reduction in fish biomass, as the latter depends strongly on the type of flood. Because of evaporation from the Manantali reservoir, the water volume rendered downstream is less than the natural volume, which also reduces halieutic potential (Reizer, 1984). Moreover, the structure makes the flood subside faster. This only has a slight effect on the reproduction of fish that, in theory, have the time to spawn in such conditions. However, growth is significantly reduced, as it depends mainly on the availability of exogenous nutrients or fertilizing nutrients found in the flooded major bed. The longer the flood is, the better the growth of adults and juveniles in particular.

The massive use of fertilizers that came with the rapid development of agriculture in the Senegal River basin is a potential source of water eutrophication. The spread of floating aquatic vegetation in some areas, especially the southern part of Lake Guiers and the Djoudj Park, may be a telling sign. That said, the proliferation of certain floating macrophytes, particularly *Eichhornia crassipes*, in the downstream part of the basin also depends on the absence of saltwater incursions since the damming at Diama. Moreover, the Côte d'Ivoire authorities attempted to resolve the uncontrolled proliferation of *Salvinia molesta* and *Eichhornia crassipes* by keeping a channel open in the dune belt separating the Ébrié lagoon from the ocean, thus encouraging the circulation of saltwater.

of usage. While this has not been clearly demonstrated by quantitative data, it appears that the fish communities of the Senegal river were significantly disturbed by the simultaneous interruption of connections with the estuary, the elimination of seasonal floods, and the use of vast stretches of floodplains for irrigated farming.

In the Nile basin, the monumental Jonglei canal project was supposed to channel the Nile's course as it crossed the Sudd wetlands in South Sudan, to prevent too much water from evaporating in this huge wetland (Howell *et al.*, 1988). The project began in 1978 but had to be interrupted in 1983 owing to political instability in the region. If such a project had been successfully completed, it would probably have led to shrinkage of the permanent wetlands of the Sudd, with an ensuing significant loss of diversity in available habitats as well as a decline in many species depending on the floodplain.

Reduction of floodplains and wetlands

Wetlands are often considered fertile areas suited for farming. Throughout the world, development projects and dam constructions in particular have had a significant impact on hydrosystems by reducing, sometimes considerably, the surface area of floodplains which serve as sites that promote the development of juveniles of many fish species. Even if traditional floodplains are replaced by profitable irrigated areas for rice crops, for example, they cannot replace the usual biotopes needed by certain organisms such as fish to complete their life cycle normally.

Changes in land-use and their consequences for watershed

The quantity and quality of runoff water inputs to aquatic ecosystems depend on the nature of the watershed and its vegetation. But the elimination of forests, for example, whether for conversion to farmland or for the exploitation of wood for domestic use or trade, immediately increases soil erosion and water turbidity, as well as a modification of the hydrological regime, with shorter but more brutal floods resulting from more runoff.

The problem of deforestation affects Africa as a whole, and available information indicates that its extent is worrying. In Madagascar, the deforestation rate has stood at 110,000 ha annually for the past 35 years, and erosion rates of 250 tonnes per hectare have been reported (Helfert & Wood, 1986). Deforestation is also massive in the Lake Tanganyika basin. Significant erosion on the slopes manifests as considerable sediment inputs to the lake and changes in fauna in some particularly exposed coastal regions (Cohen *et al.*, 1993a). Increasingly, sedimentation from watershed deforestation, road building and other anthropogenic activities is impacting lacustrine habitats, particularly those of rock-dwelling fish communities of East African lakes. In West Africa, the reduction in forest cover is also worrying, especially in Côte d'Ivoire and Nigeria (Barnes, 1990), but also in Guinea and Sierra Leone in recent years (table 24.III). If the current trend persists, future figures are of great concern as it is estimated at that this rate, 70% of West African forests, 95% of East African forests, and 30% of the Congolese forest cover will disappear by 2040.

The increased amount of suspended matter in water, and silt deposits in lakes and rivers, has many consequences for aquatic life (Bruton, 1985). It reduces the transparency of water, with all the implications of that turbidity for planktonic or benthic photosynthesis. Suspended matter can also accumulate in the gill systems of fish or cause irritations, and silt deposits significantly alter the quality of substrates in breeding areas.

Countries	Original forest area (km^2)	mean % deforested (%)	human population density (per km^2) 1980	mean area deforested per million people (km^2)
West Africa				
Côte d'Ivoire	44,580	6.95	25.6	375
Nigeria	59,500	4.79	91.7	34
Liberia	20	2.05	16.8	219
Guinea	20,500	1.76	22.1	66
Ghana	17,180	1.57	48.3	23
Sierra Leone	7,400	0.78	48.8	17
Togo	3,040	0.66	45.4	8
Central Africa				
Cameroon	179,200	0.45	17.8	95
DRC	1,056,500	0.16	12.3	57
Congo	213,400	0.10	4.7	137
Gabon	205,000	0.07	2.5	227
EastAfrica				
Kenya	6,900	1.59	28.6	7
Uganda	7,500	1.33	53.4	8
Tanzania	14,400	0.69	19.7	5

TABLE 24.III.
Annual deforestation rates in 1980 for different African countries (from Barnes, 1980).

Water pollution

While water pollution has long seemed a secondary phenomenon in Africa, it has become increasingly obvious in recent years (Dejoux, 1988). In general, however, we do not have enough data and lack detailed information on the extent of pollution in African waters.

Eutrophication

Nutrients (phosphates, nitrates) are generally present at low concentrations in aquatic systems, and may act as limiting factors for biological production. Any additional input of these nutrients is rapidly assimilated and stimulates primary production. Eutrophication occurs when nutrients (mainly nitrogen and phosphorus) are released in excess into freshwaters. Many examples of eutrophication across inland sub-Saharan Africa are reviewed by Nyenje *et al.* (2010). Most of the nutrients causing eutrophication originate from agricultural and urban wastes.

The effects of eutrophication include increases in macrophytes and/or phytoplankton, replacement of diatoms by cyanobacteria, large scale blooms of algae, and ultimately the eradication of fish species due to the deoxygenation of the water column. The decomposition of this large amount of organic matter uses up much oxygen and often leads to massive mortalities in animal species due to asphyxiation. Eutrophication also leads to wide variations in dissolved oxygen concentrations and pH throughout the day.

Blooms of cyanobacteria can disrupt virtually all of the interactions between organisms within the aquatic community and may produce harmful secondary metabolites which are toxic to humans and animals.

A well-known example is the eutrophication of Lake Victoria. The increase in nutrient inputs to the lake is the result of increased human activity in the lake's watershed: growing urbanization, use of fertilizers and pesticides for crops, use of pesticides to control tsetse flies, etc. The increase in algal biomass here is essentially due to nitrogen inputs (Hecky & Bugenyi, 1992). Symptoms indicative of eutrophication have also been observed in Lake Naivasha (Harper *et al.*, 1993), Lake McIlwaine (Thorton, 1982), and Lake Kivu, but many African lakes are probably threatened by eutrophication sooner or later.

Pesticides

One of the most important sources of contamination in African lakes and rivers is the increasing use of pesticides in public and animal health to curb endemic diseases, or for agricultural purposes (Dejoux, 1988; Lévêque, 1989c). There is an enormous range of products in use, and while some have low toxicity for aquatic organisms, many of them are xenobiotics, that is, substances with toxic properties even when they are present in very low concentrations in the environment. This is the case in particular for pyrethroids (permethrin, deltamethrin) but especially for organochlorides (DDT, dieldrin, endrin, endosulfan, malathion, lindane), which, in addition to their toxicity, also have long persistence times, which accentuates their accumulation and thus their concentration in food chains.

Case study: the Onchocerciasis Control Programme (OCP)

A widespread disease in intertropical Africa, onchocerciasis is both a social and economic bane that can lead to irreversible blindness. Prior to the start of vector control measures, the number of onchocerciasis sufferers in West Africa was estimated at nearly three million. The disease is transmitted by a small blackfly, *Simulium damnosum*, which has aquatic larval and nymph stages. The Onchocerciasis Control Programme (OCP) in West Africa targeted the sites where the larval hosts of the vector are found, in river reaches with strong currents. As with all insecticide-based control programmes, OCP represented a major threat to the environment especially as it was planned for a twenty-year period. The programme thus included an aquatic ecosystem monitoring network, covering the entire zone exposed to insecticide spraying (11 countries, or a surface area of over 1,300,000 km^2, in which 50,000 km of rivers were targets for treatment). In total, nearly ten teams of ichthyologists and entomologists of different nationalities carried out, for twenty years, regular monitoring of aquatic fauna that could be affected by the larvicide treatments. This was the first time ever that such an undertaking was conducted at such a large spatial and temporal scale.

The insecticides (organophosphates, carbamates, pyrethroids, and biological insecticides) used were screened rigorously based on their immediate (table 24.IV) and longer-term toxic effects on aquatic fauna, and criteria were defined in view of their use as larvicide treatments. For instance, all insecticides

Species	Larvicides	Mean lethal concentrations (LC50) (µg l^{-1}) 24 hours	48 hours	72 hours
Pollimyrus isidori	Permethrin 20% ca	40 (30-63)	26 (19-31)	-
Chrysichthys maurus	Cyphenothrin 10% ca	630 (501-800)	220 121-270)	-
Barbus macrops	Cyphenothrin 10% ca	15 (14-17)	12 (11-13)	10 (7-11)
Pollimyrus isidori	Pyraclofos TIA-230, 50% ca	170 (149-184)	70 (41-87)	40 (3-66)
Chrysichthys nigrodigitatus	Pyraclofos TIA-230, 50% ca	150 (113-632)	78 (59-95)	68 (48-82)
Pollimyrus isidori	Carbosulfan 25% ca	82 (71-81)	-	71 (61-82)
Schilbe mystus	Carbosulfan 25% ca	180 (124-269)	140 (105-162)	136 (108-152)

TABLE 24.IV.

Mean lethal concentrations (brackets confidence limits) of some insecticides used on West African fish species (from Yaméogo *et al.*, 1991).

that could have toxic effects on fishes at operational doses were eliminated after the lethal concentrations were determined (Yaméogo *et al.*, 1991) (table 24.V).

Given the weekly application of insecticides and the size of the treated area, the aquatic environment monitoring programme placed special emphasis on identifying the short- and medium-term effects on invertebrate populations and the long-term impacts on fish.

	Permethrin	Cyphenothrin	Carbosulfan	Pyraclofos
Operational dose (µg l^{-1})	15.0	15.0	50.0	100.0
24 hrs - LC 50 (µg l^{-1})	40.0	15.0	82.0	150.0

TABLE 24.V.

Comparison between the mean lethal concentrations observed on *Pollimyrus isidori* and operational doses used in the OCP programme (from Yaméogo *et al.*, 1991).

It was found that when insecticides are sprayed, exposed fishes flee the toxic wave by swimming upstream past it, thus avoiding long exposure (Abban & Samman, 1980; 1982). It was also observed at, in the short term, fishes voluntarily exposed to organophosphates suffered from a decrease in cerebral acetylcholinesterase activity, the duration of which depended on the insecticide, the duration of exposure, and the concentration used (Gras *et al.*, 1982; Antwi 1983). However, after studying the brains of fishes caught in the river immediately or at different times after the operational spraying of organophosphates, no decrease in cerebral enzyme activity was found (Antwi, 1985). This appears to prove that fishes avoid the larvicides one way or another.

Nearly 20 years after the start of larvicide treaments, aquatic monitoring showed that they had noticeable, but not irreversible, effects on invertebrate populations (Crosa, 1996). That said, even if a number of intra- or inter-annual variations have been observed, no clear direct effect of the use of insecticides has been shown on either experimental catches (richness and structure) (figures 24.6 and 24.7) or the biology of fishes in rivers of the treated area (Lévêque, 1990; Fermon & Paugy, 1996) (figures 24.8 and 24.9).

FIGURE 24.6.
Trends in mean catches per 100 m^2 gillnets per night (CPUE: catch per unit effort) at different monitoring sites of the aquatic monitoring programme of the OCP programme in West Africa (from Fermon & Paugy, 1996).

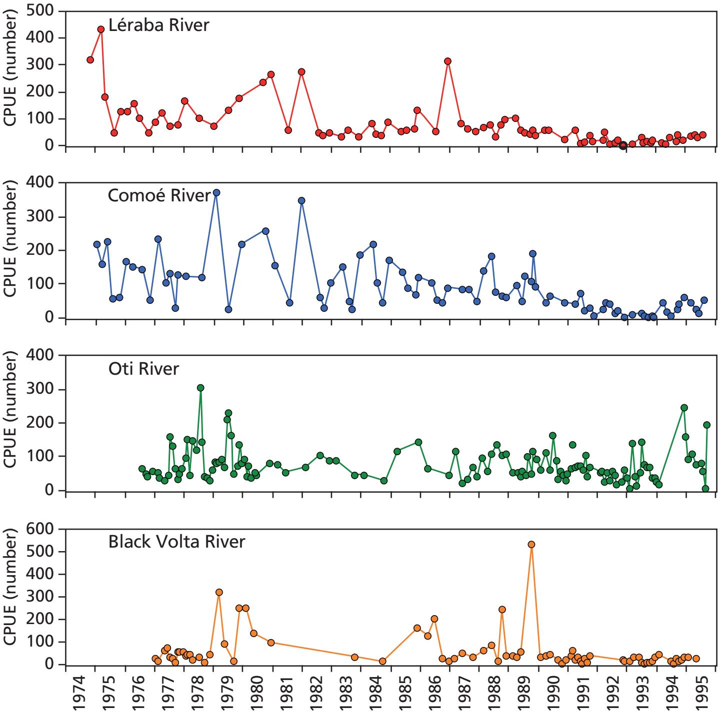
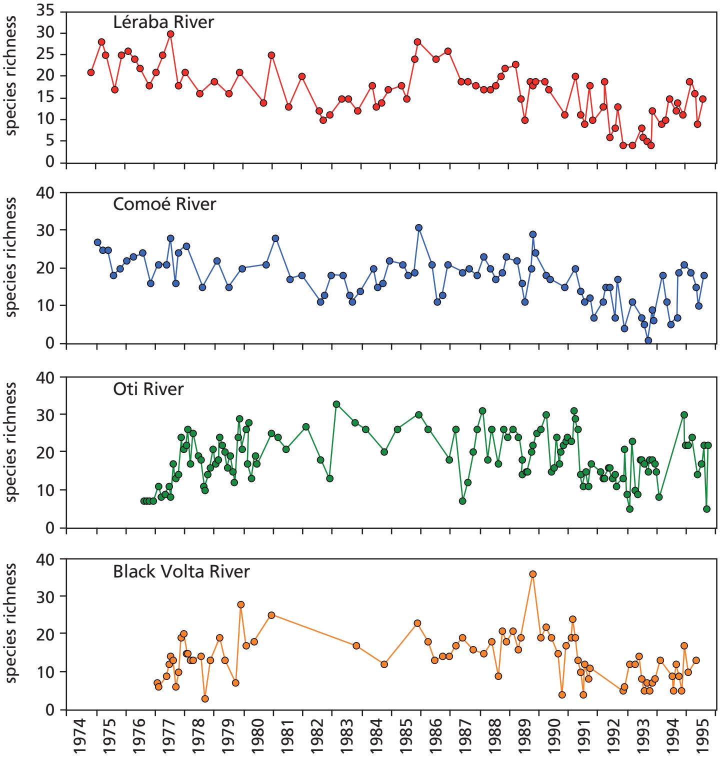


FIGURE 24.7.
Trends in fish species richness at some sampling sites of the aquatic monitoring programme of the OCP programme in West Africa (from Fermon & Paugy, 1996).



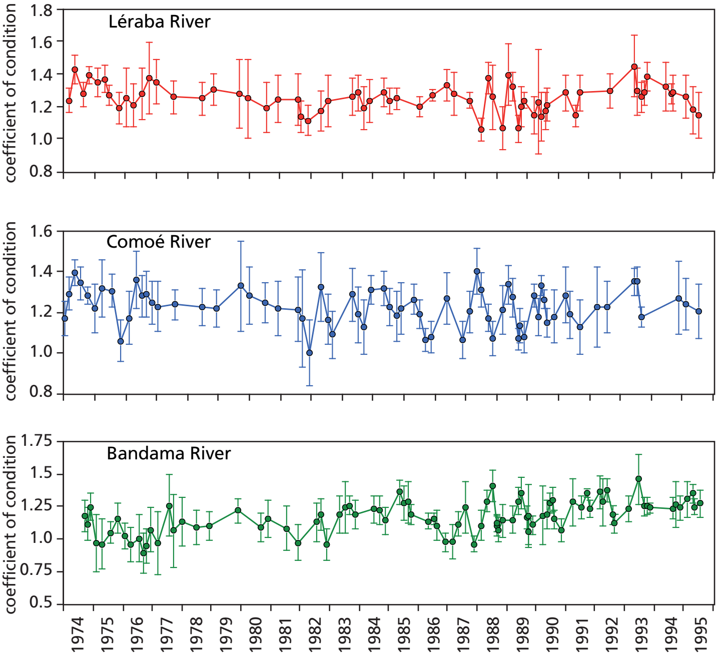


FIGURE 24.8.
Variations of the mean coefficient of condition of *Alestes baremoze* in three rivers from Côte d'Ivoire during twenty years of aquatic monitoring in the framework of the OCP programme in West Africa (from Fermon & Paugy, 1996).

Although insecticide treatments affected the populations of certain invertebrate groups locally, there was no such finding for fish communities. This is a crucial result given that several million children are no longer affected by the endemic disease that is onchocerciasis, and that the resource represented by fishes has been preserved.

Heavy metals

The term "heavy metals" generally includes several groups of substances:

- heavy metals in the strict sense, with a high atomic mass and strong toxicity, and whose presence in small quantities is not needed for life: cadmium, mercury, lead, etc.
- metals with a lower atomic mass, necessary for life (oligo-elements) but which rapidly become toxic when their concentration increases: copper, zinc, molybdenum, manganese, cobalt, etc.

Heavy metals are taken up by both flora and fauna and a few, such as mercury, have been shown to undergo bioaccumulation through the food web. Mercury discharge in freshwater systems is generally linked to gold exploitation, a particular problem in the Congo River system. Nevertheless, in Africa, the occurrence of heavy metal traces is quite low compared with some other parts of the world, like South America for example (Biney *et al.*, 1994; Campbell *et al.*, 2003).

Heavy metals end up in agricultural soils and hydrosystems via the deliberate addition of oligo-elements or pesticides, wastes from refineries or factories treating non-ferrous metals (nickel, copper, zinc, lead, chrome, cadmium, etc.),

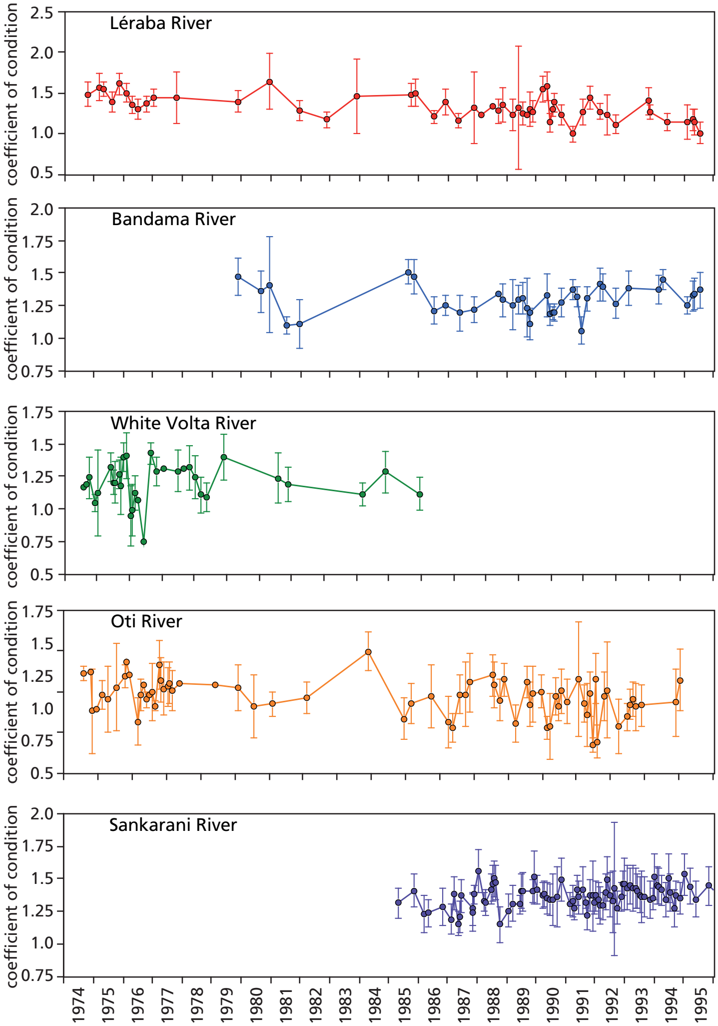


FIGURE 24.9.
Variations of the mean coefficient of condition of *Schilbe mystus* in three rivers from Côte d'Ivoire during twenty years of aquatic monitoring in the framework of the OCP programme in West Africa (from Fermon & Paugy, 1996).

wastes from tanneries (cadmium, chrome) or paper pulp factories (mercury). To these must be added atmospheric deposition of pollutants from human activity (mainly industrial) and household or urban effluents (zinc, copper, lead). Mercury pollution may come from industrial use (paper industry), the exploitation of gold deposits, or the use of organomercury fungicides.

The problems associated with heavy metal contamination result from their accumulation in organisms, sometimes to the point of reaching toxic levels. In general, concentrations of heavy metals in African aquatic ecosystems are low compared with other parts of the world. Nonetheless, some data exist and have been summarized (Dejoux, 1988; Biney *et al.*, 1994). They show that on the whole, concentrations found in the muscles of inland water African fish are below the norms established by the WHO (table 24.VI). Likewise, aside from a few problem areas such as Lake Mariut (Egypt), the Lagos lagoon (Nigeria)

	Mercury	Cadmium	Lead	Arsenic	Copper	Zinc	Manganese	Iron
Lake Mariut, Egypt		0.150			3.70	7.6	0.90	11.2
Lake Idku, Egypt	0.010	0.004	0.67	0.031	1.77	7.4		
Wiwi River, Ghana	0.370	0.190	0.47		0.18	3.0		
Niger Delta, Nigeria	0.034	0.030	0.48		0.70	4.8	1.10	5.4
Lake Nakuru, Kenya	0.044	0.050	0.17	0.360	2.00	22.0	1.80	
Lake Victoria, Kenya		0.04-0.12	0.4-1.1		0.15-0.53	2.21-7.02	0.22-0.74	0.53-4.65
Lake MacIlwaine, Zimbabwe		0.020	0.17	0.280	1.08	9.6	5.40	
Hartbeesport Dam, South Africa		0.020	<0.02	0.400	0.30	6.6	0.24	
WHO limits	0.050	2.0	2.0		30	1000		

TABLE 24.VI.
Mean metal concentration in inland water African fish ($\mu g\ g^{-1}$ fresh weight) (from Biney *et al.*, 1994)

and the Ébrié lagoon (Côte d'Ivoire), the concentrations measured in sediments and some aquatic organisms do not yet pose serious environmental problems (Biney *et al.*, 1994).

Bioaccumulation

A worrying phenomenon with certain contaminants – whether heavy metals or pesticides – is that of bioaccumulation, which leads to the accumulation of a toxic substance in an organism at concentrations that are sometimes much higher than those observed in the natural environment. This phenomenon occurs for various contaminants.

Organisms that have high concentrations of pollutants can in turn enter the food chain, and if the product has not been degraded or eliminated, it will become more and more concentrated at each level of the food chain, for instance from seaweeds to piscivorous fishes. This phenomenon, known as bioamplification, shows that the pollution of a system by substances that are found only in tiny quantities in water can have unexpected consequences at the higher levels of the food chain.

Impact of fishing

Depending on the fishing gears used, the impact of fishing on fish communities manifests mainly as selective pressure on adults or on juveniles of certain species. It is widely believed that fishing activity alone, when practised with traditional fishing gears, cannot be responsible for the extinction of fish species. Indeed, it is hard to imagine that a population can be totally eliminated by catches done blindly, unlike what can occur in hunting. That said, strong pressure associated with changes in habitat can rapidly lead to the rarefaction of certain species.

The effects of fishing are especially clear on large species with low reproductive capacity. One example is the near-disappearance of *Arius gigas* in the Niger basin (Daget *et al.*, 1988). In this species, the male is a mouth brooder of a few large eggs. While captures of 2-metre long specimens were mentioned in the early part of the 20th century, the species seems to have become very rare since the 1950s.

Many observations also seem to show that species of the genus *Labeo* (Cyprinidae) are particularly vulnerable. This is the case in Lake Chad where *L. coubie* has practically disappeared from the fishery of the northern basin in the few years that followed the establishment of a fishery (Durand, 1980). The rarefaction of *Labeo mesops* in Lake Malawi (Turner, 1994) and of *Labeo altivelis* in the Luapula River (Jackson, 1961) is also attributed to overfishing.

Generally speaking, the establishment of a fishery in systems that were hardly exploited up to that moment leads to a considerable modification of the composition of fish communities. We have seen for instance that large predators (*Lates, Hydrocynus*, *Gymnarchus*, etc.) were particularly vulnerable to gillnets even though this fishing gear almost never caught individuals of other species (*Synodontis*, *Alestes*, Mormyridae, etc.) (Bénech & Quensière, 1989).

The introduction of a benthic trawling fishery in Lake Malawi 1968 could be responsible for population reductions, if not the outright disappearance of certain endemic cichlid species (Turner, 1994), and the same phenomenon has been observed in Lake Victoria (Witte *et al.*, 1992a). A rapid decline in the populations of large cichlids (individuals of more than 190 mm) in Lake Malawi was observed after trawling began in 1968, and about 20% of species from this family disappeared from catches after a few years. In the early 1990s, the benthic species *Lethrinops macracanthus* seemed to have completely disappeared, while *Lethrinops microdon*, which accounted for 16% of catches by weight in 1970, now represents less than 2%. In the south of Lake Malawi where intensive fishing occurs, three large haplochromine species have been eliminated while eight others have seen a steep decline.

According to Coulter *et al.* (1986), the experience acquired in the East African great lakes shows that the existence of a mechanized fishery is incompatible with the maintenance of highly diverse Cichlidae populations, mainly owing to the mode of reproduction of the majority of species, characterized by low fecundity and territorial behaviour. Tweddle (1992) holds a different opinion, saying that benthic species rapidly reintegrate the area after the passage of a trawler and that commercial fishing is currently managed well in Lake Malawi.

One of the most marked effects of fishing can be seen demographically, with a reduction in the average size of species and the disappearance of large individuals. Indeed, while fishing generally begins with the use of large-meshed gears, they become smaller as large individuals become rarer. In some cases the mesh is so small that gears capture immature individuals and the populations of species that can no longer reproduce drop drastically. In Lake Malombe for example, *Oreochromis* (*O. karongae, O. squamipinnis*) fishing was done using gillnets. In the 1980s, an increase in the use of small mesh size seines and a concomitant collapse of *Oreochromis* catches was observed. This mode of exploitation is also thought responsible for the disappearance of nine endemic large cichlid species (Turner, 1994).

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