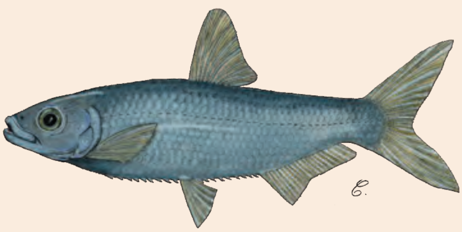
Fisheries



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The continental waters of Africa are generally rich in fishes, and fishing has long been practiced there as a subsistence activity, like hunting and gathering. To face growing demand after the Second World War, the development of aquaculture was seen as a way of satisfying the human need for animal protein. In practice, there was little development of fish farming in Africa, whereas the use of natural fish communities grew at a spectacular rate for reasons both direct (high demographic growth leading to an increased demand for protein; use of new environments and species) and indirect (development of road networks and transport; improvement of trading circuits; use of newer and more resistant materials such as nylon, which reduced the manufacture and repair times for equipment, leading to a significant rise in individual fishing efforts; introduction of more powerful fishing equipment) (Daget, 1988b; Laë, 1994). In addition, there were changes in the food behaviour of certain ethnic groups such as pastoral societies that formerly did not eat fish owing to customs or taboos.

Consequently, African waters are extensively used. For many countries, fresh or frozen marine and freshwater fish constitute a basic food product. As food, fish is more or less identical to meat in terms of protein content (17 to 20%) and nutritional value. Moreover, fish flesh is rich in minerals and oligo-elements, as well as vitamins A and D, which are often deficient in the diet. In these countries, fish is usually cheaper than meat.

The "fisheries system"

For a long time, the study of fisheries was confined to specialists, fisheries biologists who focused their efforts on the dynamics of the resource and its use. This approach turned out to be inadequate, and the current trend is to take a more holistic approach to the problems arising from the use of natural resources by including fishing behaviour along with other natural and man-made constraints encountered by the system. We thus speak of studying socio-eco-systems, an approach that integrates the tools and knowledge of several disciplines such as ecology, geography, anthropology, economics, and so forth.

Fisheries is, indeed, a complex system of interactions between a biological resource with its own dynamics in an environment that is itself evolving, and diverse predation strategies that are carried out differently in time and space on this resource. In such a system, the main elements are thus:

• the resource composed of different compartments: phytoplankton, zooplankton, molluscs, shells, and different fish species of variable trophic levels, with interspecific relationships that determine the dynamic of the whole;

• exploited fish stocks and those that are hardly or not used, where the trophic cascade phenomenon can lead to variations in abundance that are independent of fishing pressure;

• the environment in which the resource is found. Changes that occur in this environment (climate change, impact of human activity) can significantly modify the resource renewal rate, the abundance of stocks used, as well as their specific composition, and thus fisheries production;

• fishing techniques and modes, as well as fish conservation methods. Not all species are fished, even if subsistence fishing in Africa concerns a majority of them. Moreover, species vulnerability varies according to the fishing equipment used;

• fishing communities and their socio-economic strategies that are conducted in the context of regional trade. Demand for fish can fluctuate according to season, availability of the resource and thus its price, and possible trade circuits. Fishers try to adapt to these different constraints by choosing different forms of fish processing and sale (fresh, smoked, dried). We often note the absence of a strategy, which manifests as day-to-day crisis management due primarily to poor catches.

For Beverton (1983), the "fisheries system" is composed to two main parts: on one hand, the resource and its environment; on the other hand the fishers and their activities, techniques, and modes of organization. The interaction between these two sub-systems is found at the level of catching operations, that is, the removal of a biomass that has consequences on the ecosystem as well as the economy.

Indeed, fisheries is now studied as a complex whole where we must distinguish flows (of materials, currency, information), levels and centres of action and decision-making (production, sale, management, administration, research), as well as behavioural rules for each level of decision or action. These elements may change over time (Chaboud & Charles-Dominique, 1991; Quensière, 1994; Bousquet, 1994).

Ecosystemic approach to fisheries and biological indicators

The state of generalized overexploitation of aquatic resources is worrying, and preserving the ecosystem requires the implementation of management methods that ensure responsible fishing (Reykjavik Conference of October 2001; World

Summit on Sustainable Development in Johannesburg on September 2002). Global catches appear to have reached their limit in a context of growing demand: 60 to 70% of marine stocks are fully or overexploited (Garcia *et al.*, 1999), and the average trophic level of catches has been going down for the last fifty years (Pauly *et al.*, 1998). Such fishing pressure is sure to affect the structure of trophic networks, with probable consequences in terms of the diversity and productivity of aquatic ecosystems (Bœhlert, 1996). This major disturbance is compounded by profound changes – stemming from natural or manmade causes – in ecosystems that lead to stressful situations for the species that inhabit them. Some of the species respond to these disturbances using remarkable physiological adaptations, such as resistance to pollution or high salinity. They may also adapt by modifying their reproductive or growth mechanisms, in order to thrive in areas where other, less adaptive species are doomed to disappear. Cases of dwarfism and early sexual maturity have thus been observed. The effects of these disturbances occur at various levels of organization, individuals, populations, and communities. As such, their composition and structure end up being profoundly transformed. Although these adaptive responses are often noted, they remain poorly understood.

We now recognize that exploited populations are an integral part of the ecosystem rather than units that evolve independently of their environment, hence the need to prioritize ecosystem-based fisheries management (Daan *et al.*, 2005) and define indicators that provide an accurate picture of the state of aquatic ecosystems. To do so requires developing new tools that take into account the multiple and interactive ways we use ecosystems. In terms of exploitation, we need to consider not only the target species but also their effects on prey species or competitor species, as well as the habitats shared by these species (Cury & Christensen, 2005). In terms of organization, the measures applied to a species can have significant consequences on the exploitation of other species that may, moreover, be the target of other fisheries.

In this context, the use of biological indicators of the state of communities and populations should allow an assessment of both the state of fish communities and the ecosystem in which they evolve. Indeed, many authors find that the community level and the fish compartment are particularly suited to this type of study (Soto-Galera *et al.,* 1998; Whitfield & Elliot, 2002). They favour an ecosystemic approach and the development of biological indicators for the state of health of ecosystems using fish communities and populations (Lévêque, 1995b; Blaber *et al.,* 2000).

The advantages of the use of multispecific ichthyological data in decision-making systems for rational ecosystem management have been reviewed and discussed by several authors including Whitfield & Elliott (2002):

- fish are present in all aquatic systems,
- the life traits of many species as well as their response to environmental changes are known,
- compared with many invertebrates, fishes are relatively easy to identify and most samples can be processed in the field (sometimes with the possibility of releasing the individuals),

• fish communities usually include a range of species that are found on various levels of the trophic network and that use sources of nutrition from both terrestrial and aquatic environments,

• compared with other aquatic organisms, fishes have a longer lifespan and can thus record the length of environmental stresses,

• they comprise a large variety of life forms and functional guilds that can cover all elements of aquatic ecosystems that are affected by disturbances,

• some species are sedentary while others are mobile, making it possible to assess the effects of disturbances at various spatial and temporal scales,

• they are known to a wide audience and are more representative than invertebrates or aquatic plants, especially in Africa where they are of major economic, social, and cultural importance.

Using fishes as biological indicators nonetheless has certain limitations, such as the selectivity of sampling tools, movement-related bias, high tolerance to certain chemical substances compared with other organisms, the capacity for escape, etc. Nonetheless, most of these drawbacks are largely compensated for by the many advantages cited previously.

Although it is based on already old concepts, the use of biological indicators to evaluate the state of aquatic ecosystems gained much traction over the past ten years (Adams, 2002). Today there is a growing interest in the use of biological communities in order to evaluate aquatic resources (Paller *et al.,* 1996; Simon *et al.,* 2000). Most of the work done has focused on defining and using biological indicators in interior freshwater bodies (lakes, rivers, streams) in the United States (Environmental Protection Agency) and Europe (Water Framework Directive). There is a very large number of potential indicators which can be classified into broad categories:

• environment: temperature, salinity, turbidity, biotic capacity, primary production indicator, habitat indicator;

• fisheries: at population scale, the maximum sustainable yield (MSY), CPUE(catch per unit effort), yield per recruit (Y/R), fishing effort, maximum rate of fishing mortality (FMSY), the rate between exploited/potential area, distance of fishing sites, captures/biomass, rate of fishing mortality on total mortality (F/Z), capturability q. At community scale, total landings, proportion of exploited areas, total captures per zone, distance of fishing sites, effort per km^2, yields per km^2;

• biology: gonado-somatic index, sex ratio, growth variations, early maturity, fecundity, migration index (Sr/Ca);

• species: at the population scale, occurrence, abundance, biomass, extinction risk. At community scale, total biomass, total abundance, species richness, K-dominance curves, ABC curves, Spatial Biodiversity index;

• trophodynamics: at population scale, the trophic level. At community scale, Fishery is Balanced (FIB index), trophic level of catches, trophic level of communities, trophic spectrum

• Fish lengths: at population scale, average length, maximum length, proportion of large lengths, length spectrum, lengths slope. At community scale, average length, maximum length, length spectrum (slope and order at origin, diversity of length structures, proportion of large lengths).

Biological consequences of hypersalinity in West African estuaries
(from Laë *et al.*, 2004; Albaret *et al.*, 2004; Panfili *et al.*, 2004a, b; Vidy *et al.*, 2004)

Estuaries, which are interface zones between continental and oceanic hydrosystems, play an important role for ichthyological communities. An estuary serves as a nursery zone for fish juveniles, as it offers them favourable trophic conditions (abundant phyto- and zooplanktonic resources), and refuge zones from predators (turbid waters and profuse vegetation). Yet these estuaries are also historically sites of human occupation, originally serving as shelters and providing a wealth of halieutic resources. The space is increasingly coveted (exploitation of living and mineral resources, urbanization, harbour use, construction of reservoirs in upstream areas) and its nursery function is threatened. The comparison of two West African estuaries has highlighted significant differences in the composition and structure of fish communities that cannot be attributed to fishing activities.

The Gambia estuary is a preserved estuary system that receives large amounts of fresh water, leading to a seasonal fluctuation of salinity between 0 and 40 psu. Meanwhile, the Sine Saloum in Senegal is a "reverse" estuary that receives no feeders, with rainfall accounting for most of its freshwater supply. Salinity there is generally higher than that of the ocean, and increases from downstream to upstream, where it can reach very high levels of up to 135 psu, or four times the salinity of sea water.

In these conditions, species that have their full biological cycle in brackish water are more numerous in the Gambia estuary than species of marine origin. The latter, which reproduce in sea water and whose juveniles use the estuary as a nursery, are hardly diverse and rather scarce. Meanwhile, the Sine Saloum estuary appears to be more accessible to juveniles of marine species, except in its saltiest parts.

When we consider adult stages, significant differences are also seen in the fish communities of the two estuaries, in terms of composition (specific diversity, ecological category) and trophic structure as well as in the life traits of the individuals comprising them. Such differences are heightened in the hypersaline area in upstream Sine Saloum, above the 60 psu threshold. The diversity of biological cycles and ecological categories of these fish communities could therefore serve as a good indicator of biodiversity to assess the ecological state of West African estuary environments.
In addition, few species are able to survive in the saltiest zones of hypersaline estuaries. In the Sine Saloum estuary, at least two species, *Tilapia*, *Sarotherodon melanotheron,* and *Ethmalosa fimbriata,* can live in these extreme conditions by modifying their life traits, particularly reproduction and growth.
In the most saline zones of Sine Saloum, size at sexual maturity of both male and female fishes is smaller than that of individuals in the Gambia estuary. Moreover, other life traits such as relative fecundity and oocyte size also vary according to the environments. Growth, evaluated through otolith analysis, is found to be limited in hyperhaline systems (salinity above 60 psu). It is nonetheless comparable in both estuaries in the first year of growth, during which the fishes achieve sexual maturity. In the most saline environments, the reduced size at sexual maturity can thus be explained by a phenomenon of early maturation rather than dwarfism. Based on results of research conducted on the bonga shad, there is no genetic differentiation between the "upstream-downstream" sub-populations of Sine Saloum and Gambia. Modifications in biological characteristics are thus a phenotypic response to environmental constraints rather than the result of genetic isolation.

Recent work has discussed the evaluation of the state of ecosystems by characterizing fish communities. In Mali, the comparison of two artificial reservoirs, lakes Sélingué and Manantali, was made using only ecological indicators related to the specific composition (Kantoussan *et al.*, 2007), structure size

(Kantoussan *et al.*, 2009), trophic spectrum, (Kantoussan *et al.*, 2010), and catch-per-unit-effort and yields (Kantoussan *et al.*, 2014). Similar work has already been carried out in marine ecosystems (ICES/SCOR, 2000), but they often lack scientific rigour and are missing reference values obtained using reproducible protocols. These shortcomings preclude all possibility of making comparisons between observed situations and initial states. Such deficiencies have been pointed out by different authors in their assessments of MPAs (marine protected areas) based on a set of ecological, economic, and social indicators (Halpern 2003; Pomeroy *et al.*, 2005; Lester *et al.* 2009). Software tools have nonetheless been developed for estuary and lagoon systems (Habasque *et al.*, 2012) which allow joint analysis of these groups of indicators that thus serve to evaluate the extent of disturbances suffered by communities as well as the repercussions in terms of economics or ecosystem management. Ultimately, fisheries management using multidisciplinary indicator tables should make it possible to establish a diagnosis of the state of fish populations and communities, their production potential, and their renewal capacity, and take into account the multiple-use component of ecosystems.

State of fisheries in Africa

Quantity of fish landings

Between 1.5 and 2 million tonnes of fish are captured in African continental waters. This production is unevenly divided according to country and the size of aquatic systems in its territory (table 25.I). With the exception of Egypt, aquaculture production is negligible in comparison to the fishing exploitation of natural resources.

While overall results (tables 25.I and 25.II) give an indication of the extent of fishing, they must nonetheless be analysed with care because the share of captures that do not enter the trade circuit is often not known. Yet this share represents more than 60% of total captures in some West African countries.

Continental fishing represents nearly 80% of total production in East Africa (table 25.II). Lake fishing developed considerably over the past ten years, primarily due to the significant increase of production in Lake Victoria following the introduction of *Lates niloticus* in the 1960s. However, the increase in productions, as observed through fishing statistics, does not depend solely on the level of exploitation of stocks or on more efficient fishing activity, but may simply reflect better coverage of fishing activities. Thus, the end of interior conflict (as in the case of Eritrea or Mozambique) is often followed by resumed monitoring of fishing activity by the relevant authorities and the inclusion of these data in national statistics, thus giving a misleading impression of an increase in captures.

It is interesting to note the significant differences that exist between East and West Africa (tables 25.I and 25.II). Although the annual total captures are comparable (> 1,000,000 tonnes), fish come from different sources: continental in East Africa, where the great lake ensembles are found; marine in West

TABLE 25.I.
Fish catches and fish aquaculture production in inland waters of Africa (from Van den Bossche & Bernacsek, 1990; 1991).

Country	Fisheries inland capture (tonnes)	Aquaculture inland capture (tonnes)	% inland fish to total fish production
Angola	8 000	0	10
Benin	31 973	14	76
Botswana	1 900	0	100
Burkina Faso	6 964	36	100
Burundi	4 984	25	100
Cameroon	19 863	137	24
Central African Republic	8 800	88	100
Chad	110 000	0	100
Congo	13 385	115	43
Côte d'lvoire	27 353	847	27
Democratic Republic of the Congo	163 300	700	99
Egypt	141 700	60 000	81
Equatorial Guinea	400		10
Ethiopia	3 500	0	87
Gabon	1 897	3	9
Gambia	2 700	0	19
Ghana	53 614	386	14
Guinea	1 999	1	7
Kenya	124 096	210	95
Liberia	3 997	3	21
Madagascar	45 806	194	72
Malawi	88 485	103	100
Mali	55 690	12	100
Mozambique	246	21	0,7
Namibia	150	0	0,03
Niger	2 386	14	100
Nigeria	103 209	5 528	44
Rwanda	1 565	65	100
Senegal	14 966	34	5
Sierra Leone	15 982	18	30
Sudan	22 757	43	95
Tanzania	265 735	35	85
Togo	705	9	5
Uganda	200 000	387	100
Zambia	66 980	1 020	100
Zimbabwe	17 344	156	100
Total	**1 632 431**	**70 204**	

Africa where continental aquatic ecosystems are less developed. We can also note a stabilization of captures in the continental system in this part of the continent, whereas maritime fishing grew significantly in the same period (figure 25.1).

Year	Catches marine water fisheries (tonnes)	Catches inland water fisheries (tonnes)	% lakes	Total (tonnes)
1970	76.7	601.3	50.0	678.0
1971	82.0	605.2	48.1	687.2
1972	84.1	576.3	49.6	660.4
1973	66.0	621.8	48.3	687.8
1974	77.3	593.5	51.4	670.8
1975	94.0	614.0	52.4	708.0
1976	87.9	696.0	49.9	783.9
1977	77.8	750.4	48.5	828.1
1978	75.9	692.2	46.9	769.1
1979	64.0	631.7	52.1	695.7
1980	86.0	667.7	47.8	753.7
1981	83.2	644.9	49.3	728.1
1982	70.3	700.1	50.0	770.4
1983	79.6	734.8	54.8	814.4
1984	80.4	843.7	60.4	924.1
1985	134.4	847.6	66.7	982.0
1986	140.9	917.8	74.3	1 058.7
1987	136.8	954.2	74.0	1 091.0
1988	145.8	1 044.0	74.6	1 189.8
1989	143.7	1 034.3	78.7	1 178.0

TABLE 25.II.
Trends in production of fisheries in inland and marine African waters between 1970 and 1989 (from Greboval et *al.*, 1994).

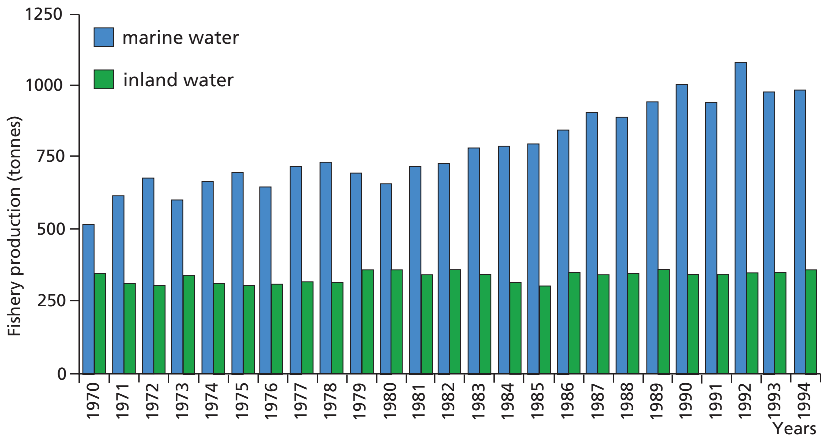

FIGURE 25.1.
Trends in production of fisheries in inland and marine waters of Western Africa between 1970 and 1994 (source: FIDI, 1996).

Major fish species caught

In Africa, continental fishing involves a large number of species. In fluvial environments, there is significant spatio-temporal variability in continental ecosystems that has led to the definition of fisheries based on the existence of a biotope, a season, a species, and a gear (Fay, 1989). In these conditions, fishing pressure can be strong and the variety of gears used makes it possible to capture most of the species found in the system, given that few species are currently subject to a ban.

In the lakes, however, a large portion of commercial catches is composed of a small number of species (table 25.III). These are Cichlidae which are most often demersal fishes, Latidae, and pelagic Clupeidae. In West Africa, pelagic Clupeidae represent just a small portion of captures. In some East African lakes such as Kivu, Kariba, or Victoria, the bulk of total catches is represented by introduced species.

TABLE 25.III.
Major commercial species groups by lake in East and West Africa (from Greboval *et al.*, 1994; Laë, 1995; Van den Bossche & Bernacsek, 1990).

Water body	Species or family	Family	Contribution to present catches (%)	Origin
Lakes				
Albert	*Hydrocynus forskalii*	Alestidae	40	endogenous
	Lates niloticus	Latidae	20	endogenous
	Oreochromis niloticus	Cichlidae	20	endogenous
Rwemu	*Oreochromis niloticus*	Cichlidae	70	*introduced*
	Oreochromis macrochir	Cichlidae	0	endogenous
Edward	*Oreochromis niloticus*	Cichlidae	60	endogenous
Kivu	*Limnothrissa miodon*	Clupeidae	80	*introduced*
Malawi	*Engraulicypris*	Cyprinidae	20	endogenous
	Cichlidae	Cichlidae	40-60	endogenous
Mweru	*Oreochromis macrochir*	Cichlidae	25	endogenous
	Microthrissa moeruensis	Clupeidae	50	endogenous
Tanganyika	*Stolothrissa tanganicae*	Clupeidae	70-80	endogenous
	Limnothrissa miodon	Clupeidae	0	endogenous
	Luciolates stappersii	Latidae	5-15	endogenous
Turkana	*Tilapia* spp.	Cichlidae	15-20	endogenous
	Lates niloticus	Latidae	30	endogenous
Victoria	*Lates niloticus*	Latidae	60	*introduced*
	Oreochromis niloticus	Cichlidae	15-20	*introduced*
	Rastrineobola argentea	Cyprinidae	20-25	endogenous
Reservoirs				
Sélingué	*Labeo senegalensis*	Cyprinidae	16	endogenous
	Chrysischthys nigrodigitatus	Claroteidae	15	endogenous
	Schilbe niloticus	Schilbeidae	9.5	endogenous
	Tilapia spp.	Cichlidae	14	endogenous
Ayamé	*Oreochromis niloticus*	Cichlidae	50	*introduced*
	Heterotis niloticus	Arapaimidae	0	*introduced*
Volta	*Tilapia* spp.	Cichlidae	38	endogenous
	Lates niloticus	Latidae	16	endogenous
	Labeo sp.	Cyprinidae	10.5	endogenous
	Alestes	Alestidae	6	endogenous
Manantali	*Sarotherodon galilaeus*	Cichlidae	37	endogenous
	Tilapia monodi	Cichlidae	12	endogenous
	Lates niloticus	Latidae	9	endogenous
Kainji	Cichlidae	Cichlidae	44	endogenous
	Bagridae	Bagridae	15	endogenous
	Citharinidae	Citharinidae	15	endogenous
	Alestidae	Alestidae	10	endogenous
Kariba	*Limnothrissa miodon*	Clupeidae	85	*introduced*

Table 25.IV provides an overview of the evolution of fish production on both quantitative and qualitative levels between 1970-1972 and 1988-1990 for some natural and artifical East African lakes. Cichlidae (tilapias and haplochromines) as well as pelagic species comprise about a quarter of captures in 1970. Some twenty years later, total production had nearly tripled and catch composition had changed significantly, dominated by *Lates* and small pelagic fishes. If Lake Victoria is not taken into account, we can observe the growing importance of small Clupeidae that represent nearly half of total captures. At the same time, the share of tilapias and haplochromines is decreasing. These changes are mainly the result of the introduction of *Limnothrissa miodon* and *Lates niloticus* in certain East African lakes. In West Africa, chronological data of such length is not available, and it is impossible to track the evolution of captures over time. Nonetheless, species introductions were rare, which explains why Cichlidae still represent between 35 and 50% of total captures depending on the environment in question.

TABLE 25.IV.
Relative importance of major species groups in fish production from some natural or artificial African lakes (1970/72–1988/90) (1,000 tonnes) (from Greboval *et al.*, 1994).

Lakes		**1970-1972**					**1988-1990**				
		small pelagics	*Lates*	*Tilapia*	*Haplochromis*	others	small pelagics	*Lates*	*Tilapia*	*Haplochromis*	others
Albert	natural	1	3.3	1.6		10.6	0.8	4.8	4.8		13.5
Chilwa	natural			1.3		3.9					
Edward	natural			7	*	3.1					
Kariba	reservoir			0.5		3					
Kivu	natural			0.2	0.7	*					
Malawi	natural	3.3		23	29.5	9.9					
Mweru	natural	*		10		2.7					
Tanganyika	natural	62	4	1		10.5					
Turkana	natural		0.7	0.3		3.3					
Victoria	natural	12	*	23	36.3	25					
Total		**78.3**	**8**	**76.6**	**66.5**	**72.4**	**240.8**		**97.3**	**29.9**	**114.9**
Total %		**25.9**	**2.5**	**25.3**	**21.9**	**13.9**	**29.2**	**41.2**	**11.8**	**3.6**	**13.9**
without Lake Victoria											
Total		**66.3**	**8**	**53.6**	**30.2**	**47.4**	**144.9**	**18.7**	**41.8**	**24.6**	**84.3**
Total %		**32.3**	**3.9**	**26.1**	**14.7**	**23.1**	**46.1**	**5.9**	**13.3**	**7.8**	**26.8**

Dynamic of the resource

Biomass (fishery scientists often use the term stocks) is the quantity of fishes present in an environment at a given moment, expressed as a unit of weight per unit of area (such as kg/ha). The production of this biomass is the quantity of biological matter produced during a given time period. Biomass tends to increase with growth and reproduction (arrival of fry and juveniles) of individuals, whereas it tends to decrease as a result of natural mortality or mortality from fishing activity or other causes related to increased anthropization of ecosystems (pollution, transformations, etc.). This biomass has its own dynamics in the absence of fishing, which depends on the biological characteristics of species, and the seasonal and inter-annual dynamics of the aquatic environments in which these species live.

Resource, and more specifically fishing resource, refers to the set of species that may be captured in fishing activities. In effect, the biomass produced by the ecosystem is only a resource inasmuch as it is used.

Relation between biological production and biomass

Biological production is the total quantity of organic matter produced by a given biomass in a given period. The ration between production (P) and biomass (B), or P/B ratio, given per unit of time, expresses the biomass turnover rate of the population under study in the absence of exploitation.

The higher the P/B, the faster the turnover of biomass. There is in effect a relationship between P/B and species longevity. The longer the average lifespan, the lower the P/B and thus the biomass turnover rate (Lévêque *et al.*, 1977). In fact, for exponential mortality, it has been shown that P/B was equivalent to the instantaneous mortality coefficient (z) (Allen, 1971), which is tantamount to saying that biological production per unit of time is a function of biomass and mortality rate. For example, observations show that P/B is around 1 for fishes with a lifespan of 4 to 5 years. This means that biological production is equivalent each year to biomass. For annual species, P/B is between 4 and 6, while for species that live around ten years, P/B is about 0.5-0.6.

In an outlook of long term biomass equilibrium, biological production serves in part to compensate for natural mortality, and possibly for fishing-related mortality. Fluctuations (ΔB) of biomass (B) can be schematically represented by the following equation:

$$\Delta B = B + C + R - M - F$$

where B is biomass, C is biomass growth from weight gain of individuals in the biomass, R is recruitment of fry and juveniles, that is, entry into the biomass of individuals yielded by reproduction, M is natural mortality due to predation, disease, etc., and F is mortality from fishing.

The quantity of fishes that can be captured, or fishery production, is necessarily a fraction of biological production. This capture should remain limited enough to ensure that the productive potential represented by the biomass is not affected, as this would eventually lead to a reduction in the fraction of biological production that can be used for fishing. In extreme cases, overexploitation can lead to the disappearance of a stock. The art of fisheries management lies entirely in the capacity to determine what amount of biomass can be removed without undermining the stock, which must essentially remain identical year-on-year in order to maintain its productive potential.

Stock assessment

The assessment of fish stocks, *i.e.*, their biomass, is a highly difficult exercise for which no simple methods exist.

For African continental environments, some estimations (table 25.V) have been carried out using various methods. For shallow lakes, one can use purse seines, as was the case for Lake George or Lake Nakuru. For a few Great African lakes, the use of acoustic methods made it possible to estimate fish stocks. In Lake Tanganyika, the biomass of pelagic fishes was estimated at various periods, and the values observed were between 1,200 kg ha^{-1}, which seems an exceptionally high value for a lake, and 200 to 300 kg/ha (Coulter, 1991a). The differences can be ascribed to seasonal and inter-annual variations in the abundance of *Stolothrissa*. Acoustic prospecting in Lake Malawi yielded lower figures: 168,000 tonnes of pelagic fishes, or around 70 kg/ha (Menz *et al.*, 1995). In Lake Kainji, the biomass of pelagic fishes is relatively low (18 kg/ha) compared with Cichlidae (105 kg/ha) or Bagridae/Claroteidae (36 kg/ha).

TABLE 25.V.
Assessments of the average fish biomass in various types of African inland aquatic environments.

Water body	System	Biomass (kg/ha)	Source
Shallow lakes	Nakuru	300-400	Vareschi, 1979
	George	290	Gwahaba, 1971
Deep lakes	Malawi, pelagic zone	70	Menz *et al.*, 1995
	Tanganyika, pelagic zone	200-300	Coulter, 1991
	Kainji	240	Pitcher & Hart, 1995
	Kariba	31-650	Pitcher & Hart, 1995
Rivers and floodplains	Kafue Flats		
	- peak flood	338	Kapetsky *et al.*, 1971
	- low-water	435	Kapetsky *et al.*, 1971
	Bandama		
	- peak flood	125-175	Daget *et al.*, 1973
	- low-water	305	Daget *et al.*, 1973
	Nile, Sudd	306-433	Mefit-Batbie, 1983

As for rivers and floodplains, estimates are even more difficult to carry out given the spatial and temporal variability of these physical systems. A few attempts to qualify them were made (table 25.V). These must be taken as estimates and orders of magnitude that should not be used to extrapolate.

Aquatic environment and fisheries

Fish population dynamics are controlled by the dynamics of the environments inhabited by these populations. The available habitat (see chapter *Diversity of fish habitats*) will influence, at all stages of development of a species, the quantity of fishes that the environment can host and which constitutes the stock from which fishes will be captured.

In this context, any change to water regime or volume will have direct repercussions on stocks, and therefore on fishing. Such changes may result from natural phenomena related to climate fluctuations or human activity, to the extent that freshwater is used in a variety of ways such as irrigation, domestic consumption, and the production of hydroelectric energy, which all can be factors. These different forms of water use, often given priority in the context of national economies, lead to disturbances in water regimes which have consequences on fish populations. In this situation, fishing activities are often marginalized owing to the inadequate assessment of their social and economic importance.

Historically speaking, interest in the relationships between fisheries resources and their environment only began for tropical systems in the 1970s. Prior to that, in many countries, the water and forests services were in charge of fisheries management, relatively independently of limnologists who studied the aquatic environment, its components, and its productivity (Rigler, 1982). The convergence between these two areas of activity has proved to be particularly fertile, but the question of sustained cooperation between fisheries management and environmental specialists is still relevant (Magnuson, 1991).

Hydrological variability and variability of fisheries

In many fluvial environments associated with floodplains, flood duration and extent are deciding factors for the abundance of fish stocks (Welcomme, 1979). During floods, plains provide plentiful and varied nutrition to fishes that leave the minor bed of rivers as well as the permanent pools where the fall of water levels forced them to take shelter during the dry season. The larger the water surface, the longer the flood duration, and the more fishes are able to find favourable conditions for their reproduction and growth. Vegetation also allows them to escape the many predators hunting them. A good flood thus signifies low natural mortality, low fishing mortality in floodplains, strong individual growth, and high captures as the flood recedes and water flows out.

There is thus a close relationship between yearly fluctuations in hydrology and captures. Fisheries production for a given year *n* depends on the intensity of floods in years *n*-1, *n*-2, or *n*-3, with decreasing weight. In rivers, most captures involve 1- or 2-year-old fish. By taking into account the hydrological indices (HI) of years *n*-1 and *n*-2, Welcomme computed the following relationships:

- for the Kafue River: $P = 2962 + 70.54\ (0.7\ HI_{n-1} + 0.3\ HI_{n-2})$ (1969-1973 period) (Welcomme, 1979).
- for the Niger: $P = 151.73 \log (0{,}7\ HI_{n-1} + 0.3\ HI_{n-2}) - 4281.26$ (1966-1984 period) (Welcomme, 1986).

In the central Niger delta, Laë (1992b; 1994) showed that there was a good correlation between total fish catches expressed in tonnes and water loss (m^3) from one year to another for the 1966-1989 period (figure 25.2). The estimate of flooded surfaces is indirectly obtained by calculating a flood index expressed as the volume of water that is lost through evaporation or infiltration of the lake basin (difference between inflows and outflows). These water losses are related to flood intensity and are proportional to the extent and duration of the flood. Thus, when the average annual flow of the Niger is cut in half (1972-1973 or 1977-1978), the flooded surfaces are divided by four and represent only 5,000 km^2. The calculated ratio is:

$$P = 780.95\ (\text{losses})_n + 770.71\ (\text{losses})_{n-1} + 32304\ (R^2=0.93)$$

Annual catches and the flood index for the same year are well correlated as the first term alone of this relation accounts for 77% of the variation. This strong correlation is explained by the composition of catches, which concerns some 60 species, primarily at younger stages as it is estimated that about 69% of fish catches are individuals less than a year old (Laë, 1992b; 1994).

In the Cross River, Moses (1987) also showed good correlation between catches and the flood index of the two previous years.

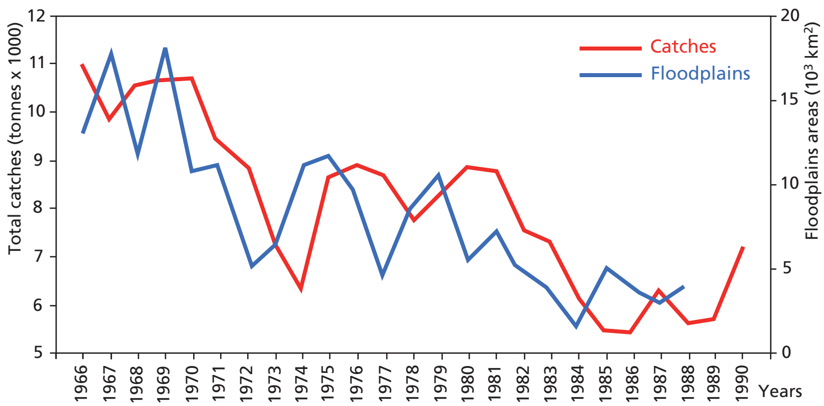

FIGURE 25.2.
Relation between lost water (floodplains areas 10^3 km^2) and total fish catches (tonnes) in the Inner Delta of the Niger River from 1966 to 1990 (from Laë, 1992b).

Types of aquatic ecosystem and fisheries production

From the standpoint of fisheries production, lacustrine systems have been studied the most (table 25.VI). For a majority of them, fisheries production is between 50 and 100 kg/ha, but there may be significant variations locally, with values reaching as high as several hundred kg/ha.

In rivers and floodplains, fisheries production is highly dependent on the seasonal cycle, as well as the extent and duration of the flood. Overall, catch by unit area is lower than in lakes (table 25.VII), but the surface area occupied is much greater. The difficulty of obtaining reliable statistics for this hard-to-access area should not fool us into underestimating their role in African fisheries production.

Effects of dams on the environment and on fisheries

Controlling river flooding is important for watercourse regulation, agriculture, and livestock farming. Production of hydroelectric energy in Africa began much later than in Europe and North America, thus benefiting from technologies that had been tried and tested in developed countries. The 1960s were marked by the construction of large reservoir such as Lake Volta in Ghana, Lake Nasser in

System	Max. area (km²)	Mean depth (m)	Catch (tonnes)	Yield (kg/ha)	Period	Source
Reservoirs						
Kossou	900	18	4 700-9 300	67-147	1972-1978	v.d. Knaap, 1994
Lagdo	700	11	7 700-13 400	175-340	1985-1991	v.d. Knaap, 1994
Maga	360		700-3 600		1984-1992	v.d. Knaap, 1994
Manantali	500	20-25	1 500	30	1995	Laë & Weigel, 1995a
Sélingué	400	5.3	4 000	100	1995	Laë & Weigel, 1995b
Jebel Aulia	1 500	2.3	7 000-8 000	50	1975	v.d. Knaap, 1994
Mtera	600	6	3 250-5 000	80	1986-1991	v.d. Knaap, 1994
Mwadingusha	1 000	2.6	674-8 000	50	1953-1983	v.d. Knaap, 1994
Kafue Flats	4 300	2	2 450-10 850	6-25	1957-1982	v.d. Knaap, 1994
Kainji	1 270	11	4 500-6 000	35-47	1974-1978	Crul & Roest, 1995
Kariba	5 300	29	30 700	30-41	1990	Greboval *et al.* 1994
Nasser	6 200	25	15 600-31 200	6-25	1981 -1991	v.d. Bossche & Bernascek, 1990
Volta	7 400	19	40 000	55	1970-1979	v.d. Bossche & Bernascek, 1990
Lakes						
Turkana	7 560	31	350-22 000	9-16	1962-1988	Greboval *et al.* 1994; Kolding, 1994
Baringo	130	5.6	152-600	10-50	1964-1986	v.d. Bossche & Bernascek, 1990
Naivasha	115-150	11	44-950	5-60	1964-1986	v.d. Bossche & Bernascek, 1990
Albert	5 270	25	23 900	47-65	1989	v.d. Bossche & Bernascek, 1990; Greboval *et al.*, 1994
Chilwa	750	2	13 700	77	1989	v.d. Bossche & Bernascek, 1990
Chiuta	200		1 100	75	1989	v.d. Bossche & Bernascek, 1990; Greboval *et al.*, 1994
Edward	2 300	34	14 400	61 -70	1989	v.d. Bossche & Bernascek, 1990; Greboval *et al.*, 1994
Kivu	2 370	240	4 600	27-42	1991	v.d. Bossche & Bernascek, 1990; Greboval *et al.*, 1994
Malawi	30 800	426	69 400	35-45	1991	v.d. Bossche & Bernascek, 1990; Greboval *et al.*, 1994
Mweru	4 650	7	20 200	60	1990	v.d. Bossche & Bernascek, 1990; Greboval *et al.*, 1994
Tanganyika	32 900	700	133 900	90	1990	v.d. Bossche & Bernascek, 1990; Greboval *et al.*, 1994
Victoria	68 000	40	562 900	29-59	1991	v.d. Bossche & Bernascek, 1990; Greboval *et al.*, 1994

TABLE 25.VI.
Estimation of the fisheries production (total catches in tonnes and average yield in kg/ha) in different lakes and reservoirs of Africa.

River	Area at peak flood (km²)	Catch (tonnes)	Number of fishermen	Catch per unit area (kg/ha)
Niger (Benin)	242	1,200		49.6
Niger (Inner Delta)	20,000	90,000	54,112	45.0
Niger (Nigeria)	4,600	14,340	4,600	31.2
Benue	3,100	9,570	5,140	30.9
Pongolo	104	400		38.5
Shire (1970)	665	9,545	2,445	143.5
Shire (1975)	665	7,890	3,324	118.7
Yaérés (Cameroon)	7,000	17,500		25.0
Logomatia	600	300	70	5.0
Kafue (1970)	4,340	6,747	670	15.6
Kafue (1982)	4,754	7,400		15.6
Ouémé (1957)	1,000	10,400	25,000	104.0
Ouémé (1968)	1,000	6,500	29,800	65.0
Senegal	5,490	30,000	10,400	54.7
Barotse	5,120	3,500	912	6.9
Cross	8,000	8,000	4,000	10.0
Nile (Sudd)	31,800	28,000		8.8

TABLE 25.VII.
Maximum flooded area, total catch and number of fishermen for some African floodplains. (from Welcomme, 1989).

Fish and fisheries in the Senegal River

"When it rains, the bush fills with water that spills into bodies of water called marigots. The flooded marigots rise and join the river. At this point the fishes go up into the marigots."

"When they go up to the bush, the fishes fill the marigot, both where it is narrow and where it is wide. It's like a herd of cattle heading for fresh grass. You see the fishes in the grass like cattle passing by.

At this time, grass grows in the pools.
The grass isn't very high, just up to the knees.
You can see the grass move.
The fishes moving it as they swim.
Fishing in the ponds yields a good catch."

"As soon as the water level begins to rise, fishes also start going to the bush.
What will they look for there?
They will look for *jaaje* [wild fonio] seeds that have fallen into the water because of the flood. They eat this and fatten up.
For them, it's a time of plenty; for us, those are lean times, when we have to venture out in dugouts to find food."

"The fishes spawn in the bush, in the pools. The eggs of some fishes hatch two or three months after they are laid, but for all the eggs to hatch, you need to wait for the end of the rainy season. By then, the fishes will have stopped breeding and all the hatchlings will have been released.

But it would be wrong to say that as long as the water rises then recedes, the fishes can reproduce. Two months aren't enough for fish reproduction. The water has to remain in the bush for three or four months."

"When the river begins to recede, some of the fishes know it. They leave the bush to go back to the river. The fishes then split up in two groups. All of them, young and adult alike, want to join the river.
But in some places, when the water goes down, the water is cut off. Those fishes have no way of joining the river, and they stay where they are, in what we call pools."

"Sometimes, when the water falls, the fishes return to the river like a flock of birds.
It's like when you throw a stone at a tree where birds are perched: they all fly off at the same time. When the fishes go to the bush, they go up one by one.
But when they all leave together,
when they leave at night, at dawn
there won't be a single adult fish in the bush.
All of them will be gone.
If they leave in the daytime, at sunset
no adult fish will be left in the bush.
They will all be gone.
Only the small fishes are left, the ones who aren't smart and didn't leave in time.
Those fishes are the ones people will catch until the water in the pools has dried up."

Excerpts from Poissons et Pêches du fleuve Sénégal. Fédération des paysans organisés of the Département de Bakel. Dakar (Adams-Sow, 1996)

Egypt, or Lake Kariba in Zimbabwe and Zambia, along with many other reservoirs that are more modest in size (Anne *et al.*, 1991). The construction of these artificial reservoirs obviously had major repercussions on the ecosystems found upstream and downstream (Ward & Stanford, 1979; Petts, 1984). The main effects on fisheries were as follows (Welcomme, 1985):

- changes to river water flow. These lead to changes in the fish reproduction process due to inappropriate stimuli or brief artificial floods.

Consequently there are changes to the composition of fish communities, since species with flexible reproduction are more resistant than ones that reproduce seasonally. There is also a decrease in productivity within communities triggered by the shift from an irregular system to a stable dynamic system. The increase in the speed of water flow that follows river channeling encourages the emergence of rheophilic species, whereas the slowing of currents in reservoirs favours lentic species;

• habitat loss. The absence or reduction of floodplains downstream following the construction of a reservoir, or conversely, the flooding of spawning substrates found upstream or the channelling of watercourses lead to a decrease in biodiversity and generally a decrease in the ecosystem's productivity;

• closure of rivers. Unequipped reservoirs (as is usually the case in Africa) interrupt fish migration circuits and lead to the elimination of diadromous species by preventing adults from joining upstream spawning sites and slowing down the downstream movement of juveniles;

• changes in sedimentation processes. The creation of dams leads to more deposits in the reservoir, which in turn brings about a decrease in suspended matter and a deficit in sediments downstream from the dams. This leads once again to decreased habitat and biodiversity, changes in plant density, modifications in available food and the benthos, leading to a reduction in biological diversity and productivity;

• increase in phytoplankton and zooplankton in the reservoirs or downstream from the dams owing to reduced flows and increased transparency. This encourages the development of planktophagous fishes;

• changes in temperature. This can lead to a stratification of reservoirs and hamper the migrations of certain fishes. They may also lead to deaths upstream from the dam owing to the release of anoxic or H_2S-rich water.

Thus, according to Lelek & El Zarka (1973) and Adeniji (1975), changes in the fish fauna of the Niger followed the construction of the Kainji dam. Captures between Jebba and Lokoja went down by 50% in a space of three years from 1967 to 1969 (Otobo, 1978b). This was accompanied by changes in the composition of communities, with a decline in Alestidae, Mormyridae and Clariidae and an increase in predatory species such as *Lates* or certain Bagridae/Claroteidae (Sagua, 1978). Also downstream, the fisheries of the Anambra basin decreased by 60% owing to the exundation of traditionally flooded plans following the dam's construction (Awachie & Walson, 1978).

For some dams, a highly localized increase of predator fishes was noted below the structures. This is the case for the Nile just after the Owen dam, where populations of *Barbus altianalis* and *Lates niloticus* are particularly abundant. The same phenomenon has been observed below the Kainji dam with Mochokidae, Alestidae and Cyprinidae. It can be accounted for by the enrichment of reservoir water which, when it passes through locks, transports zooplankton, insects, and fishes (Whitley, 1974). This enrichment is only felt locally.

Finally, we should note the significance of the contributions of rivers to ecosystems found downstream. The retention of nutritional matter in Lake Nasser led to a decline in pelagic fisheries in the eastern Mediterranean, whereas yields increased sharply for the lake.

Laë (1992c, 1994) described the repercussions of the Markala and Sélingué dams in Mali on fishing activities in the Central Delta of the Niger River found downstream from the dams (figure 25.3). These repercussions can be felt at different levels.

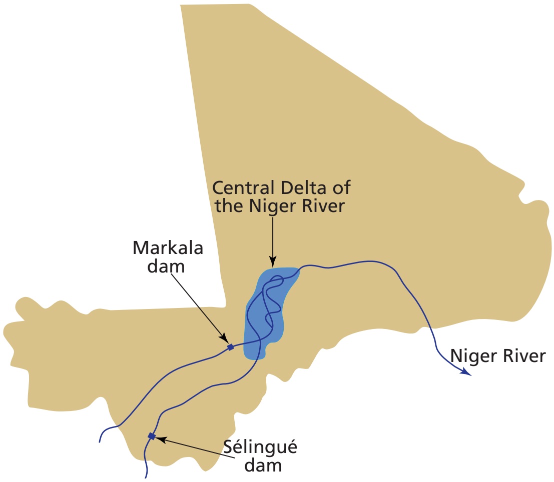

FIGURE 25.3.
Location of the two dams on the upper Niger upstream of the Central Delta of the Niger River.

Perturbation of longitudinal migrations

It is generally thought that dams disturb the spatial distribution of fish fauna and interrupt the breeding migrations of certain species, leading to their disappearance and/or a change in stock composition (Welcomme *et al.*, 1989). This situation does not match the case of the Central Delta, as the Markala dam, build upstream of the floodplains, is not an obstacle to species seeking to join the spawning grounds downstream of the structure (Daget, 1959c).

Longitudinal migrations observed at the approaches of the dam are not related to the fish reproduction process as these are triggered and maintained by external stimuli related to the progressive and regular decrease of available water during the recession period (Daget, 1949). Schools of juveniles from floodplains thus find themselves trapped at the bottom of the dam, and the possibilities of taking the fishway constructed in 1946 are limited, as the pass was designed for the anadromous migrations of a few breeders rather than the much larger migrations, in terms of fish quantities, of juvenile schools. Schools are thus dispersed downstream of the dam, leading primarily to a significant decrease in fishing yields upstream of the dam.

Reduction of the flooded area and the duration of the flood

During the flood, the filling of the two structures leads to a suppression of the flood, which manifests as a decrease in flows entering the lake basin found downstream, and a reduction in the extent and duration of the flood. The action of dams thus reduces the hosting capacity of floodplains, which in turn leads to a decrease in recruitment, slower increase in weight, and ultimately, a poorer fish catch. The loss of captures that is ascribed to the two dams is estimated at 5,000 tonnes per year. Welcomme (1985) also points out that in Nigeria a loss of 6,000 tonnes of fish resulted from the construction of the Kainji dam on the Niger. On the Mekong River, the Pa Mong dam prevents the flood over approximately 700 km downstream, causing a loss of 2,150 tonnes (Petts *et al.*, 1989).

Decrease of activities during low water

The impact of dams is also palpable during periods of low water, and in an even more pronounced manner during droughts in Africa. At times, some spaces no longer receive water while others are flooded for short periods only, although traditionally fishing was deferred for part of the year as the waters were kept undisturbed, and then subjected to collective fishing once the "master of waters" lifted the deferral (Fay, 1989). This results in a considerable reduction of customary fishing activities during low water.

In the same vein, fishing is not allowed in certain parts of the river when waters are low. This measure allows fishes to move past thresholds and become concentrated in the deeper ares of the minor bed, where they are easier to capture once the fishing ban is lifted (Daget, 1956). Currently, large volumes of water are used to run turbines during low water periods to ensure the production of electricity, such that currents in March, April, and May are much faster downstream from the dam (100 to 150 m^3/s higher than their normal rate). Meanwhile, the successive releases of water often hamper fishing considerably, as the artificial floods trigger fish dispersion and makes them less vulnerable to fishing gear.

Indirect protection of the spawning stock

Authors such as Welcomme & Hagborg (1977) and Welcomme (1979) also emphasise the importance of the severity of low water levels in stock renewal. Adult fishes that will be spawning at the next flood need to find refuges that do not dry out during periods of low water.

As average water outflow rates have not changed much over the years, no relationship has been established between fisheries production and water levels during this period. It appears that the reserve of breeders is sufficient at the end of the period to ensure good recruitment levels in the case of the central delta. In other words, low water conditions are not a limiting step. For several years, water releases from the Sélingué dam also reinforce natural water outflow rates. This additional water, which disturbs fishing in pools, thus has an indirect positive effect on fisheries by encouraging the survival of breeders and decreasing their fishing mortality at low water periods.

Fishing gears employed and fishing practices

There is an enormous variety of fishing gears and an exhaustive list cannot be provided (figure 25.4). They come in different forms and show numerous variants that each correspond to precise usages (biotope used, target species, hydrological season). Subsistence fishing has long been practiced using artisanal gear, such as fish traps, harpoons, and so forth. These capture techniques have been grouped according to the main categories established by Nédelec *et al.* (1979) and Moal (1981), following the basic means of construction, size, and use.

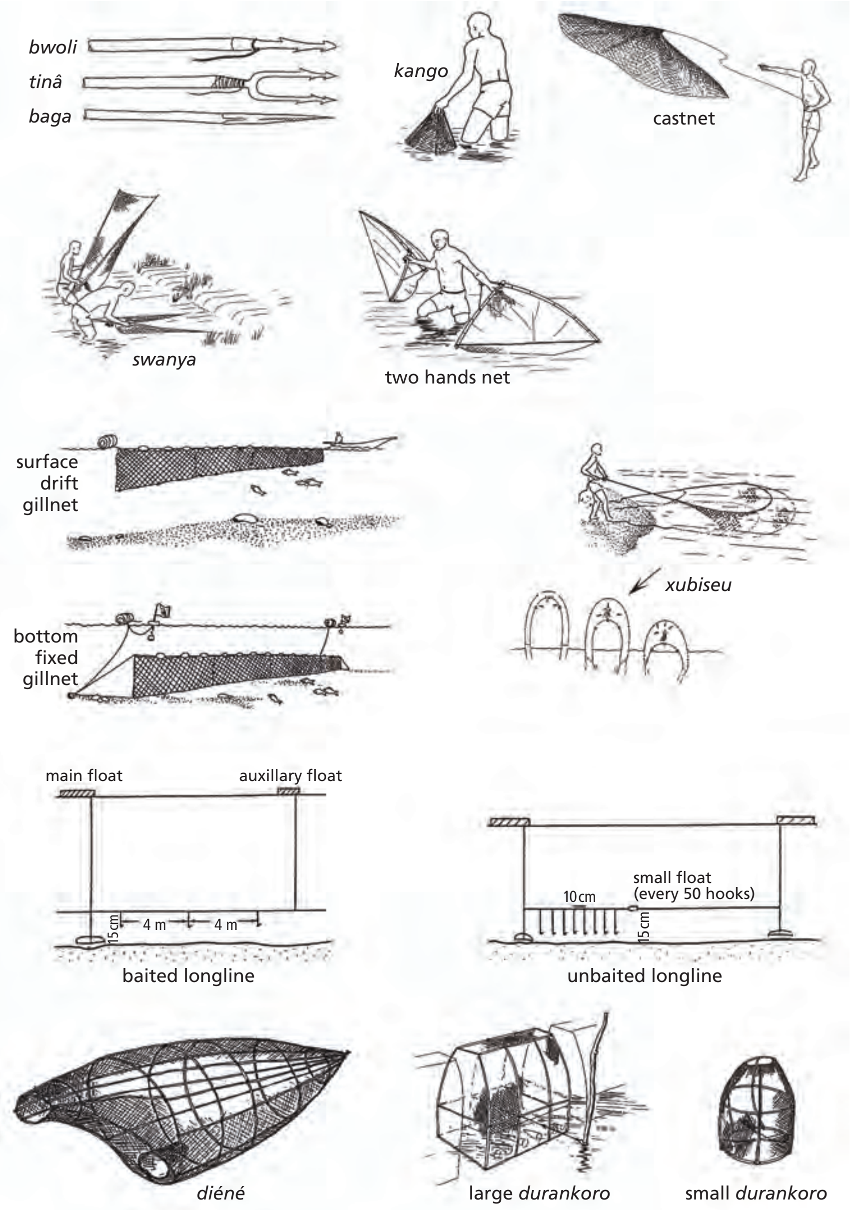

FIGURE 25.4.
Schematic illustration of the main gears used in the Central Delta of the Niger River (from Laë *et al.*, 1994).

Fishing gears

In Africa, the pirogue is often the preferred means of transport. Aside from fishing, it is used to transport people or merchandise. In forested areas, pirogues are carved out of a hardwood trunk. They are monoxylon boats propelled using oars or paddles, or more recently, though this is still rare, motors.

In the Sahelian zone where wood is rarer, fishing pirogues used to be built in two halves made from planks of African mahogany that were nailed together and connected by an enormous transverse seam (Gallais, 1967). Nowadays they are built as a single piece using wood planks from sawmills, making them more watertight and more solid. The use of outboard motors has not become widespread as their price, maintenance, and operation are often too costly compared with the expected benefits. Fishers prefer to set up temporary campsites near fishing areas instead.

Active fishing practices

- Individual fishing

– Wounding gears, such as harpoons, are designed for capturing large fishes, mainly in pools that are drying up, flooded plains, and during collective fishing.

– Cast nets are circular and have lead weights at their perimeter. Once fish are located, nets are casted and capture the fish by falling and closing in on them.

– Different types of push nets include: triangular nets fixed in a "V" and used during dam fishing or collective fishing by a fisher who is waist-deep in water; two-hand nets consisting of two pockets that are held open then closed once the fish has been spotted; and nets used to cover fish on the bottom, which can be clapped over the prey thanks to a large conical frame found on its base.

- Collective fishing

– Beach seines are operated from the shore and used in shallow waters near the shore or on shoals. Some are several hundred metres long (up to 1 km) and require much manpower, of up to twenty people. The use of seines became widespread with the invention of nylon netting. These fine-meshed nets (15 mm) are equipped with large floats and weights. They are set out in a wide arc to surround the fish. Two teams found on the same shore then pull in the ends of the net until the fishes are trapped inside the net. Manipulating the seine is a long and arduous task, and is only carried out once a day.

– Purse seines have a purse line at the bottom of the net which can be drawn in to close the net and retain fish. They are used in deep waters, and the fishing operation mainly consists of surrounding a previously-located fish aggregation. Smaller (300 m) and with a greater drop (50 m) than the previous type, they require the use of a motorised pirogue so that the fish can be encircled rapidly. The operation can be carried out several times a day and targets primarily pelagic species that move in schools.

TABLE 25.VIII.
Evolution of small-scale and semi-industrial fleet size in East African lakes (from Greboval *et al.*, 1994).

Lakes	1969	1979	1989
Albert	20	8	1
Edward	5	1	
Kariba		65	213
Kivu			1
Malawi		17	22
Mweru		14	1
Tanganyika	14	35	52
Victoria		5	22

- Industrial fishing practices

– Semi-industrial fishing techniques have developed significantly in the East African great lakes since the late 1960s (table 25.VIII). The largest fleet by far is the one on Lake Kariba with 213 vessels (rigs/liftnets units). The second-largest fleet is on Lake Tanganyika where 52 seine net boats currently target small pelagic species.

In Burundi and Tanzania these possibilities are limited, and given the efficiency of artisanal fishing, semi-industrial fishing is not highly viable and currently on the decline (Horemans, 1992).

Passive fishing practices

Passive gear are generally fixed, though some mobile types exist (drift gillnets), and take advantage of fish movements to capture them.

- Fixed or drift gillnets

– Fixed gillnets are generally set out in the late afternoon. They are stretched between two poles and remain in place overnight before being retrieved in the morning. As fishes move, they become entangled in the netting. Depending on the type of mesh, the ballasting, and buoyance, the nets may be used near the surface, midwater, or at the bottom, and they have a high degree of selectivity for species. Throughout the year, a net's design may be modified according to the target species and biotope.

– Meanwhile, drift gillnets are not anchored to poles but drift between two pirogues or a pirogue and a float. During an expedition, the fisher drifts with the current for an hour or two, hauls in the net, removes the fish and then goes against the current to return to the starting point. This operation may be repeated several times in a single night. Drift nets have few weights and are used heavily during periods of strong currents.

- Fish traps

– There are numerous variants throughout Africa. In the Ébrié lagoon (Côte d'Ivoire), we can cite the case of fisheries that are located along the shore in locations where waters are barely deeper than 1.50 m. A screen starting from the bank blocks off the lagoon over a distance of about fifty metres. This screen, perpendicular to the shore, leads to a capture chamber in which fish traps are placed. In the lagoons of Benin, barriers are made from screens fashioned from braided Raphia palm or oil palm leaf midribs, gathered together at the bottom and reinforced with stakes. These barriers are arranged in a zigzag manner, forming a broken line with open angles acting as funnels, and each with a fish trap at their end (Pliya, 1980).

– In Mali, in the Central Delta of the Niger, these traps are also placed parallel to the banks or perpendicular to channels or river branches. They are fashioned from branches and fish traps of different shapes depending on water level and surrounding vegetation. The fish traps may be cylindrical (*papolo*) and used when water levels rise in the marigots or flow out of floodplain channels. Other, more recent (1980) traps (*durankoro*) are shaped like truncated cones and installed in low waters (plains, river branch). They may be baited and are used practically throughout the year. Considerably larger in size, *diéné* traps (5 m long and 2 m in diameter), are used in the period when flood waters abate, to create barriers across entire river branches. Traps are made using a bamboo or rônier frame and nylon netting.

– Aside from these fish traps, traps may take other forms, such as 1 m-long hollowed-out bamboo sections placed at the bottom of Ivorian lagoons. These traps target mainly *Chrysichthys* that seek cavities where they can spawn.

Low water fishing in Logone Gana

The Yaérés (flooded plains) of inland middle Logone are trained by the Ba-Illi which empties into the Logone at Logone-Gana. This area is the heart of intensive fishing at periods of water outflow. This "outflow" fishing takes advantage of fish movements out of the floodzone, particularly *Alestes dentex* and *A. baremoze*. To do so, the Kotokos set up at the river opening, on a natural threshold of sorts, a grid barrier, upstream of which they place 400-500 fish traps with their openings facing downstream, to capture *Alestes*. Downstream from the barrier, and attached to it, about a hundred pirogues are ready to meet the *Hydrocynus* and *Alestes* that have managed to traverse the barrier. Fishing lasts about a week, with yields of 36 tonnes in 1955 and 34 tonnes in 1956 (Blache & Miton, 1962).

Upstream from the barrier and for about fifteen kilometres along the river, fisher folk set up camp with unbaited longlines.

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The great traditional fishing event of Logone-Gana (North Cameroon, 1969)

1. Transport of basket traps from the village to the fishing site.
2. Start of barrier construction.
3. Establishment of basket traps behind the wooden fences.
4. Hundreds of basket traps are arranged upstream of the fishing area, their opening facing downstream in front of the wooden fence.
5. View of the basket traps during the fishing period.
6. Establishment of stakes used to build the capture compartments.

5

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7. Construction of the of the capture compartments barrier. Fishermen bring the wooden fences.
8. Capture compartments barriers.
9. Dozens of canoes use drift gillnets, downstream of the basket traps and barriers.
10. Overview showing in the foreground numerous basket traps attached to a wooden fence barrier upstream. These are followed by canoes collecting fish that have jumped over the barrier. Capture compartments barriers are seen next. Finally, in the background, canoes located downstream use drift gillnets to catch fish.
11. Basket traps with fish (*Alestes*).
12. *Alestes baremoze* is the most abundant caught fish during the great traditional fishing event. This species makes long migrations from Lake Chad to breed in the floodplains.

10

12

– There are also crab traps fashioned from a section of netting affixed to a wooden hoop about 30 to 40 cm in diameter. A piece of meat or rotten fish is used as bait.

- Baited or unbaited longlines

The two most common forms are baited longlines placed above the bottom, with spaces of 4-5 metres between hooks, and unbaited longlines consisting of a horizontal main line from which hooked snoods spaced at 5 cm intervals are attached. They are placed just above the bottom and form a barrier for the targeted prey, primarily catfish. Hooks used can vary in size depending on the desired species.

Seasonality of fishing practices

Many fishing gears and their variants are designed to meet specific use norms: hydrological season, target species, type of biotope used. The use of different fishing gears can thus be considered a true adaptive strategy addressing spatiotemporal variations in the systems and in species availability, particularly in rivers and their floodplains.

As such, the activities of fishers in the central Niger delta vary considerably in space and time, as they are dictated by the annual hydrological cycle that is the deciding factor for fish breeding and migration dynamics, and consequently, of fish availability (abundance and vulnerability) (Laë & Morand, 1994). During the flood fishes spawn and spread in nutrient-rich floodplains that are not just areas favourable for their dietary needs, but also safe zones against numerous predators. Transfers from the river to the floodplain occur via channels and marigots that permit the lateral spread of the flood. In low water periods, fishes that stayed for four to five months in the floodplains enjoyed rapid growth (larger size), and return to the river when the current is reversed in the channels and marigots. Other fishes engage in longer longitudinal migrations in schools, going back against the current to the river while being followed by numerous predators. As the current weakens when the water runs out, fishes find themselves concentrated in the minor bed and in the many crevices that follow its course. In some sections, they are once again trapped between sandbars and thresholds owing to the significant drop in water level. The variations of the water level make it impossible to use the same fishing gears throughout the year. This connection between time, space, and fishing activities form the basis for the exploitation of halieutic systems. By combining mobility and diversifying fishing gears, the fisher takes advantage of changes in the system. During the flood and high water periods, halieutic activities are reduced because fishes are dispersed in the water mass and thus less vulnerable, and fishing gears are difficult to use owing to abundant vegetation and low depths. Barrier fishing is practised when water level goes down in river branches and channels, by using different types of fish traps depending on water depth. In the rivers, during water outflow, driftnet fishing is practised, as well as collective fishing using push nets in residual pools during low water levels. Fixed gillnets are used in the period from high to low water levels (October to April).

In the lower Ouémé River, Welcomme (1985) also showed that different gears are used throughout the year depending on the hydrological cycle to capture different species (figure 25.5).

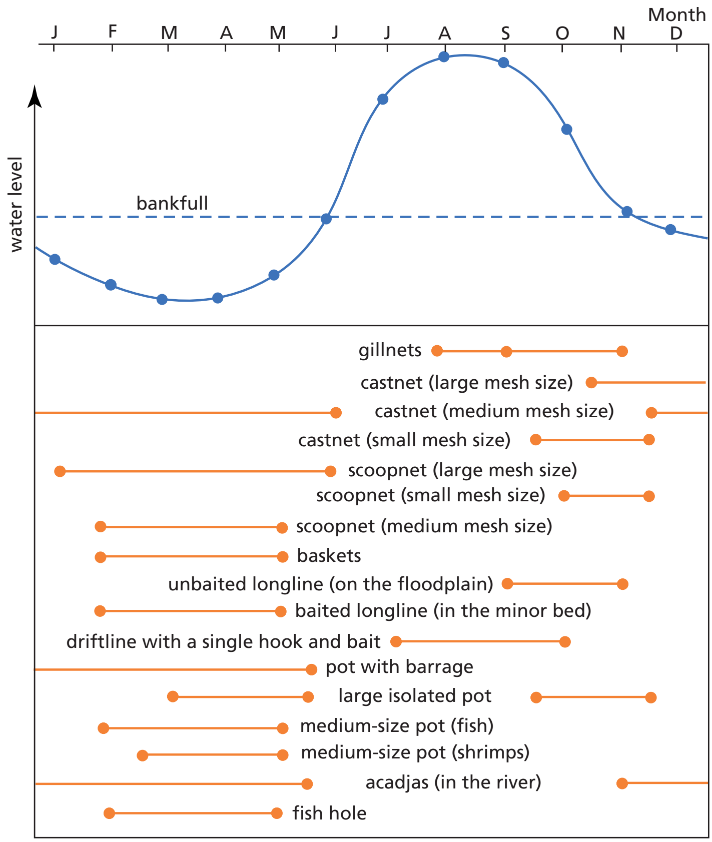


FIGURE 25.5.
Fish gear utilization in the Lower Ouémé River during the course of one year (from Welcomme, 1985).

Evolution of the practices

Subsistence fishing began with locally-manufactured artisanal gear such as fish traps, etc. But significant progress has been made in fishing techniques since the early 20th century. The introduction of gillnets in Lake Victoria in 1905 by Aarup, from Norway (Worthington & Worthington, 1933) was a major technological innovation that spread slowly to other regions of Africa. Nets were initially made locally from cotton or other cheap local materials, but they took a long time to make and the cotton was very fragile. After the Second World War, they were rapidly replaced by nets made from woven nylon, then partially in the 1980s by monofilament nets, more efficient but also more fragile.

The use of synthetic materials makes it possible to keep nets in good condition and use them for several consecutive years. Freed from the arduous work of preparing and maintaining gears, fishers can now devote their time to the activity of fishing itself, while benefiting for a greater number of fishing gears. Because fishers are better equipped nowadays, effective fishing effort continues to grow.

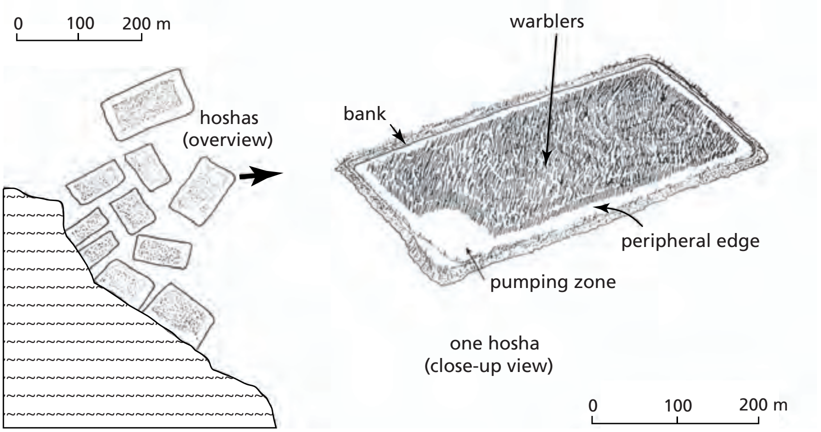
Industrial marine fishing techniques were also introduced in the East African great lakes. Trawling was practiced on an experimental basis in Lake Malawi as early as 1965 and this technique was rapidly adopted by fishers (Jackson & Ssentongo, 1988).

Biomanipulations and improvement of the fishing production

Biomanipulation of natural environments

Capture methods based on the exploitation of natural stocks have been completed by traditional techniques intended to improve production of natural fishing environments. This is the case for the *acadjas* in Benin (Kapetski, 1981) or the "*garse system*" in Cameroon (Stauch, 1966) and the *hoshas* of Egypt (Hem, 1991) (figure 25.6).

FIGURE 25.6.
Overview and close-up view of *hoshas* (from Hem, 1991).



The principle behind these different techniques is to promote the development of natural food in a fisheries environment, thereby reducing the need for providing artificial food supplements and thus significantly reducing the costs of fish production (Hem *et al.*, 1994). For example, the *acadjas* used in Benin are a pile of branches placed in lagoons in shallow areas. These *acadjas* promote the concentration and multiplication of fishes in natural environments through an attractive effect that is caused by the increase in the surface area for microfauna and epiphytes to develop, which provide fishes with food, and by the shelter provided by the structures themselves. The average annual productivity varies from 5 to 10 tonnes/ha (Welcomme, 1972b), a figure that is much higher than commonly observed figures in West African lagoons that barely reach 200 kg/ha at best.

Introductions of species in aquatic ecosystems

Fish communities in tropical waters are generally diverse enough for most ecological niches to be used. In some hydrosystems, however, fauna may be poor for historical reasons. Moreover, large reservoirs create new lacustrine habitats that are not always colonized by riverine fauna. To justify introductions, fisheries managers provide examples that are seen as positive for fisheries development (see chapter *Species introductions*).

One example of species introduction involves pelagic systems. *Limnothrissa miodon* and *Stolothrissa tanganyicae* are small pelagic zooplanktivorous Clupeidae in Lake Tanganyika, where they are major fisheries targets. *L. miodon* was introduced in 1967 and in 1968 in Lake Kariba, a large reservoir lake on the Zambezi, where it flourished (figure 25.7) to the point of supplying a fishery as well (Marshall, 1984a). The species then colonized another dam, Cahora Bassa, downstream from the Kariba. *L. miodon* and *S. tanganyicae* were also introduced in Lake Kivu in 1958-1960. Here, they also occupied the vacant niche of pelagic zooplanktivores, and the introduction is deemed an economic success, with no negative impact identified (Spliethoff *et al.*, 1983).

Oreochromis niloticus was introduced in numerous natural and artificial water bodies in Africa, Asia, and South America, particularly in many small dams that were built in recent decades. Several tilapia species are currently established throughout the intertropical belt. In Africa, *Lates niloticus* and *Oreochromis niloticus* were introduced in Lake Kyoga in the 1950s and rapidly flourished. In 1977, each species represented around 40% of artisanal fishing estimated at 167,000 tonnes, compared with 4,500 tonnes in 1956. In 1985 the situation had changed, with *O. niloticus* representing 78% of captures compared with only 17% for *O. niloticus* (Ogutu-Ohwayo, 1990). These introductions were accompanied by a sometimes significant regression of native species.

In Lake Victoria (see chapters *Fish communities in East African rift lakes* and *Species introductions*), the introduction of *Lates* was also behind a spectacular growth in fisheries production.

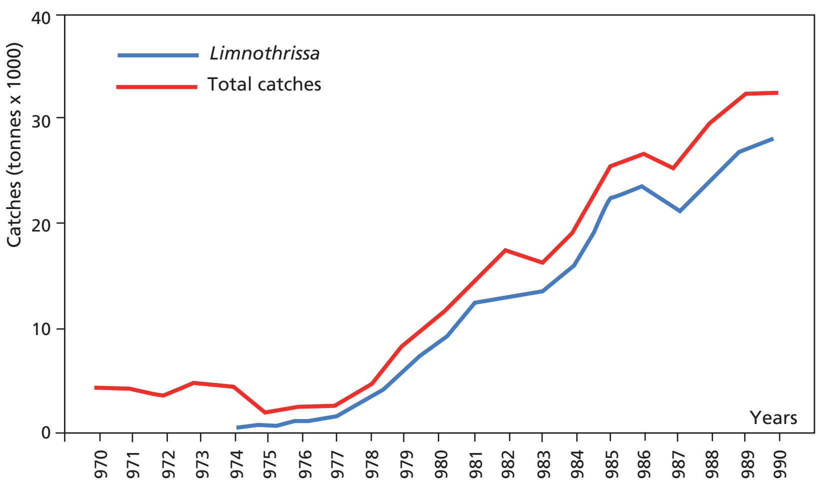


FIGURE 25.7.
Evolution of catches in Lake Kariba after the introduction of *Limnothrissa miodon* (from Marshall, 1984a).

Marketing and processing of fish

Generally speaking, three major fish markets can be identified in relation to fishing locations:

• wholesale markets that centralize production and redistribute it to distant areas;

• semi-wholesale markets found in production and consumer centres;

• retail markets in towns and villages (Breuil & Quensière, 1995). Wholesale markets can be bypassed by sales to local consumers.

Products are brought from fishing sites by the fishers themselves or their representatives, by traders who go from site to site, or by wholesalers. The means of locomotion used are generally large pinnaces, lorries, or vans.

The circuits between fishing sites and wholesale markets are short and require few intermediaries, whereas redistribution to retail markets requires the participation of a large number of intermediaries.

Fish that is not consumed fresh is processed using traditional or modern techniques that are designed to retard the natural process of decomposition and thereby increase shelf life. It is in effect necessary for fish to be processed for storage in one way or another when fishing takes place in areas that are poorly accessible or located far away from major trading and consumer centres.

In some cases, when the road network is sufficiently developed and the country is likely to acquire the needed facilities, it is possible to use cold rooms to preserve fish that are then transported in refrigerated lorries or on ice. Marine fish are in fact most often traded in this form in inland areas.

In Africa, however, a large proportion of fish must be processed for marketing because of inadequate road infrastructure. Moreover, in a continental setting, it is rare for fishing pirogues to be equipped with isothermic crates containing ice. Depending on the length of fishing expeditions, it becomes necessary to process fish as soon as it reaches the site. In these cases, fishers resort to traditional techniques of fish processing.

Drying is one of the most common techniques in Africa. The simplest method is sun-drying. Once fish are gutted and opened, they are placed on mats or grills, or hung on drying racks. This type of traditional processing is efficient in a dry climate, but nonetheless leaves fish vulnerable to insect attacks. For pelagic species of lesser market value, sun-drying is often done directly on the ground, exposing products to all sorts of contaminants carried by dust, insects, and sand. Fish lose three-quarters of their weight.

Drying is often associated with smoking. This consists of partially eliminating the water contained in the fish while imparting a flavour that is obtained when smoke is absorbed by the flesh. However, despite it being the main artisanal processing method in most African countries, smoking is often badly performed: fish are sometimes charred on the surface, badly smoked, and shelf life is short. Many studies have been carried out with moderate success to improve smoking methods and conditions (GRET, 1993). The FAO in particular has improved the *chorkor* oven and encouraged its spread, and it has been accepted by women fish processers. Finished products have a better golden colour and quality than those processed using traditional round ovens. Smoking in the Sahelian area is also responsible for deforestation and in current conditions, it is becoming increasingly difficult to find the wood needed for this type of processing. Women often use dried cow dung. After smoking, fish lose two-thirds of their weight.

The technique of burning can also be used, although it is rarer than the two previous ones. Fish are laid out on a layer of dry grass or rice stalks which is then set on fire.

Salting is a proven effective technique that has not met with much success, probably because of costs but also of dietary habit.

Processed fish are often treated with chemical products (K'Othrine or Gardona) to stave off deterioration by mould or ichtyophagous insects. However, because of the fish storage time (several months depending on distance from trading centres), losses can be as high as 20% of total production (Coulibaly *et al.*, 1992).

The choice of processing method partly depends on the species. In the Sahel area, species that are preferably smoked are the *Clarias* as well as many species of the Bagridae and Claroteidae families (*Chrysichthys*, *Bagrus*, *Auchenoglanis*), *Synodontis,* and *Labeo*. Species that are exclusively dried are the Alestidae except for *Brycinus leuciscus* which is used to produce oil, the *Citharinus,* and the Mormyridae. Those that are preferably dried belong to the Schilbeidae family. Certain species, such as *Lates* or tilapias, are either smoked or dried. In this case, the method selected depends on situational factors such as price or demand.

Empirical models for evaluating the fishing potential

It is difficult to collect fisheries statistics in a continental setting because of the nature of fisheries themselves: use of a large variety of fishing gears, significant annual and inter-annual fishing effort and captures depending especially on hydrology, extensive scattering of fishing points and loading sites, highly variable individual strategies and behaviour of fishers. For these reasons, which are compounded by the lack of training for personnel in charge of fisheries management, we have little reliable data on fishing statistics in African continental waters (and more specifically the large riverine systems). Obtaining more reliable figures will require the definition of clear methodologies, better personnel training, and more organized collection of statistical data and information processing. Such a data-gathering system is, in principle, quite compatible with the means available to fisheries authorities, as long as basic funding is provided for.

Given the aforementioned difficulties, several scientists think that rather than seeking to improve the collection of fishing statistics for a given system, it is a more useful exercise to focus on the research and development of even just rough empirical models that would make it possible to predict the fishing potential of an aquatic system based on simple ecological parameters. According to Rigler (1982), an empirical theory's purpose is to generate forecasts based on a comparative approach of different systems. An empirical model should make it possible to predict complex biological effects from simple ecological parameters. Given a variable that we wish to predict, we try to establish correlations between this variable and other ecological variables or combinations thereof.

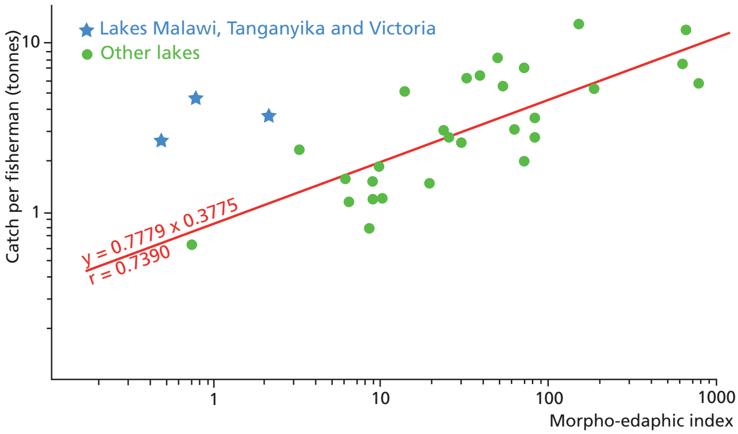
One of the first empirical approaches was to establish a relationship between fish production in a lake and its average depth (Rawson, 1952). This rather simplistic yet interesting approach led to a series of studies afterwards.

Henderson & Welcomme (1974) calculated, for 31 African lakes whose level of exploitation is close to maximum, a relationship of the type:

$$P = 14.3136\ MEI^{0.4681}$$

Where MEI (morpho-edaphic index) is a synthetic index corresponding to the ratio of water conductivity expressed in µS cm^{-1} by average depth expressed in metres (figure 25.8).

FIGURE 25.8.
Relationship between the morpho-edaphic index and catch per fisherman in 31 African lakes (from Henderson & Welcomme, 1974).



This model was later modified by Toews & Griffith (1979) who introduced lake area (A in km^2):

$$P = 1.4071 + 0.3697 \log MEI - 0.00004565\ A$$

Later, Schlessinger & Regier (1982) proposed an estimation model of the maximum sustainable fishing production (P) based on a multiple regression involving annual average air temperature (T in°C), and the morpho-edaphic index (MEI) which is dissolved salt content divided by average depth:

$$\log P = 0.0236 + 0.280 \log MEI + 0.050T$$

For rivers with no large floodplains, and based on a data series, Welcomme (1985) calculated for Africa an empirical model of fish production (P in tonnes) based on the area of the river's drainage basin (A in km^2):

$$P = 0.03\ A\ 0.97\ (r = 0.91)$$

If we replace the basin area by the length of the principal channel (L in km), we obtain:

$$P = 0.0032\ L^{1.98}\ (r = 0.90);\ \text{or approximately: } P\ (\text{in kg}) = L^2 / 300$$

Laë (1997) showed that these empirical models were highly imprecise when used for a predictive purpose (table 25.IX). The use of abiotic data for 65 African lakes shows that adjustments with previous models making use of the morpho-edaphic index and yields (not statistically significant), the total area and total captures ($R^2 = 0.76$), or fishing effort and yields (not statistically significant) are quite inexact and insufficiently reliable for predicting potential captures. The confidence interval of estimates can vary from a relationship of between 1 and 10 whereas on average, African lakes have yields of between 50 and 200 kg/ha/year.

Relationships using yields and lake latitude or altitude do not render statistically significant results. Those that use average depth, surface area, or volume are significant, but only account for a small percentage of variance (respectively 13, 11 and 17%). The morpho-edaphic index remains the least poor parameter ($r^2 = 0.42$) when fishing effort is greater than 2 fishers per km^2. The search for empirical relationships must be conducted from complete and reliable databases. This type of approach has been the target of many attempts in countries of the North (Cyr & Peters, 1996; Havens *et al.*, 1996; Persson *et al.*, 1996; Mavuti *et al.*, 1996; Bachmann *et al.*, 1996). In Africa, the data needed for this type of modelling are not currently available and it is urgent to remedy the situation by establishing permanent fisheries observatories. These should make use of several models, including physico-chemical and hydrological monitoring, as the estimation of primary production is a complement to regular, structured information on the biological, economic, and social components of fishing. This step is necessary for the comprehension of the ecosystems and the fisheries-system under investigation. Under no circumstances can they be replaced by the use of empirical relationships, even if the reliability of the latter were to improve, if the ultimate goal is fisheries management.

Explanatory variable	Value of the explanatory variable	Expected yield	Confidence interval 95%
		(kg/ha)	(kg/ha)
MEI (Henderson & Welcomme) (µS/cm)	6.3	32	7 - 126
	39.8	74	23 - 282
	158.5	144	36 - 1000
		(tonnes)	(tonnes)
Surface (Crull) (km^2)	10	70	18 - 271
	100	585	152 - 2 253
	1 000	4 908	1 264 - 19 055
	10 000	41 523	10 441 - 165 214

TABLE 25.IX.
Confidence intervals of expected yields computed with models of Henderson & Welcomme (1974) and Crul (1992), (from Laë, 1997).

Expected yields and their confidence intervals are provided for different values of the explanatory variables. These intervals are very large: between 36 and 1,000 kg/ha for an expected yield of 144 kg/ha, between 10,441 and 165,214 tonnes for expected total captures of 41,523 tonnes.

Fisheries management

The term "management", now often accompanied by the adjective "sustainable", means that we are no longer content to simply extract a given amount of an exploitable resource, but that we are also concerned about the long-term maintenance of the resource in question. Fish is a renewable resource for fisheries, but it may run out if its exploitation is not controlled by implementing a number of regulations.

Fisheries management at the basin scale

Continental fisheries management must be designed within a larger context of drainage basin water management. Water is put to diverse uses: household use, irrigation, energy in particular which leads to occasionally significant changes in the appearance and function of aquatic systems. Dams create new types of systems while interrupting upstream-downstream connections. Water withdrawals for dams or irrigation modify river currents and the annual flood cycle. Sometimes they can even interrupt the flood cycle entirely, as is the case in the lower Nile valley.

Water management for agricultural use and energy generation has long been given priority over other uses of water. In particular, the many interventions carried out on African continental aquatic systems rarely took into account the biological resource represented by fish. Consequences on fish populations and fisheries are mixed. On one hand, the disappearance of floodzones led to the rarefaction of certain species that use these physical systems to breed. Meanwhile, the creation of reservoir lakes has made it possible to develop populations of other fish species, whose exploitation can underlie new fisheries, without necessarily compensating, qualitatively or quantitatively, for losses suffered downstream.

The future of continental fishers is tightly bound up with the choices made in terms of hydrosystem management. Depending on the preferred goals or the technical choices made, live resources will either obtain or be deprived of the conditions for their maintenance or development.

Fisheries models

Most continental fisheries are either artisanal or subsistence fisheries, which makes their management particularly complex. In the 1950s and 1960s, in a bid to implement rational stock management, there was an attempt to use stock management models developed for maritime fishers to the management of continental fish stocks. At the time, fish biologists believed that the fishing activity-resource interaction was measurable and manageable.

In this context, fisheries is viewed as a biomass extraction industry, which can result in the depletion of this biomass (overexploitation) if the pressure on stocks increases with little consideration. The intervention of a manager is thus necessary to regulate this predator-prey relationship. To do so requires measurable indicators such as fishing effort and total catches, and management tools such as halieutic models postulating that the size of the future population can be determined from information on the biological characteristics of the exploited stock and the extent of exploitation (Schaefer, 1954; Beverton & Holt, 1957; Ricker, 1954). Two types of models were developed: global models which established empirical relationships between the exploitation rate and overall production, and analytical models which analyse the effects induced in the demographic structure of the resource by changes in its mode of exploitation.

These models, and in particular the principles from which they were established, are not suited to continental waters. We now know that they make use of two debatable assumptions:

- the assumption that it would be possible to manage wild animal populations by simply regulating the exploitation rate of the said populations;
- the presumption of an equilibrium state of exploited populations, which assumes that the environment has a negligible influence on the dynamics of the resource.

In fact, the same criticisms emerged for the management of fisheries in marine environments (Rothschild, 1989). Much work then focused on the variability of marine populations (Bakun, 1989), the deciding factors for recruitment (Lasker, 1989), or the variability, instability, and changes in pelagic marine fisheries (Cury & Roy, 1991). These models nonetheless remain difficult to use in a continental context because:

- fisheries is studied as a whole and covers a large number of species (around 50 for example in the Niger) that do not all have the same behaviour, biologically speaking or with regard to fisheries;
- generally, they only take into account the direct impact of resource exploitation on stock, but not the indirect impact resulting for the natural variability of the ecosystem and its consequences in terms of resource fluctuation;
- they are totally inapplicable in many countries, given the difficulties encountered for gathering information: global models require long data series on effort and total captures, and these are rarely available in developing countries. Analytical models, meanwhile, require biological data on the different exploited species (growth, reproduction, natural mortality, etc.) as well as fisheries data (capture by fishing gears and corresponding size structures, fishing mortality, etc.), which are often difficult to gather given the number of species involved;
- these models ignore the motivations and strategies of fisheries stakeholders.

Even aside from these models, the proposed solutions for improving fisheries conditions often depend on reducing fishing effort or modifying it (increasing mesh size, banning certain gears) that would initially lead to a decrease in captures. It is thus very difficult to implement decisions that run counter to the immediate interests of fishers. Although laws have been passed on the nature and size of fishing gears or the start of fishing season, they are not enforced owing to a lack of means (personnel, transport, etc.) to the point that fishers are not always informed of their existence (Thomas *et al.*, 1993).

While the concept of maximum sustainable yield has been largely contested, it *de facto* remains high on the list of preoccupations of managers attempting to make plans in terms of fisheries development. Yet many observations have shown that the influence of environmental factors often carries the greatest weight. Inter-annual variability can be considerable, and is often tied to hydrological variability which itself is difficult to predict from one year to another.

However, the exploitation of natural resources has ramped up considerably over the last two centuries, sometimes exceeding their regenerative capacities and leading to changes in ecosystems. In this context, estuary and lagoon ecosystems have been hit especially hard, as they are at the convergence of demographic, economic, and ecological pressures. Given the deterioration of habitats, the overexploitation of resources, climate change, and an overall increase in natural and anthropogenic constraints, we are experiencing a catastrophic collapse in biodiversity even though it is a key factor in the resiliency of these living systems. One of the options under consideration to combat biodiversity loss in aquatic environments consists of establishing Protected Areas.

Marine Protected Areas (MPA)

In this context, a Marine Protected Area (MPA) is defined as "an area within or adjacent to the marine environment, together with its overlying waters and associated flora, fauna, and historical and cultural features, which has been reserved by legislation or other effective means, including custom, with the effect that its marine and/or coastal biodiversity enjoys a higher level of protection than its surroundings" (Kelleher, 1992). Following initial experiments with establishing MPA, there has been great enthusiasm for this approach whose applications should multiply in coming years.

In the field of biology, research has concentrated on MPA as instruments for halieutic management (Sanchirico, 2000), showing that they may serve as a means for protecting and even increasing the income of fishers when fishing pressure is high.

From this point of view, MPA are a major tool for the protection of habitats essential to breeding and the growth of juvenile ecophases (Gell & Roberts 2003). They can play a dominant role in biodiversity conservation (figure 25.9). Their effectiveness for halieutic purposes is based on the following hypotheses:

- Effects inside the MPA: the suspension of fishing in the MPA and the preservation of habitats lead to a drop in natural mortality and fishing mortality, and an improvement in growth and reproduction. All these phenomena work together to produce a significant increase in biomass (Lester *et al.* 2009).

- Effects outside the MPA: the increase in biomass within the MPA leads to greater competition between the individuals present, pushing part of the community to leave the MPA. In addition, aside from these density problems, the biological cycle of some species which cannot breed in estuary areas is the reason for ontogenic migrations and the departure of pre-adult individuals that join the marine environment (Harmelin-Vivien *et al.* 2008).

- Effects at the ecosystems level: the displacement of eggs, larvae, the departure of juvenile or adult stages depending on the species may have beneficial effects in areas located far from the MPA (Nowlis & Roberts, 1999; Claudet, 2006).

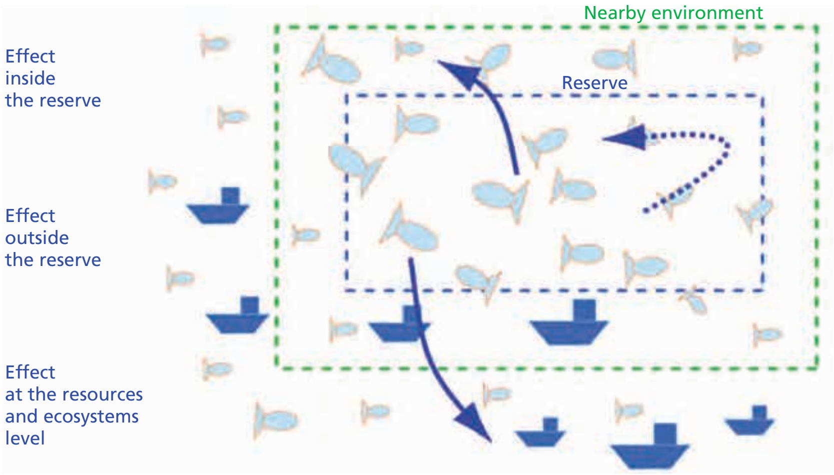


FIGURE 25.9.
Expected effects after the creation of a marine protected area (from Henichart & Gascuel, 2011)

While these different effects appear logical, at this stage many hypotheses still need to be verified, in particular the speed at which such processes are established as well as the time needed for an MPA to mature.

Hence, as part of the AMPHORE project (2008-2011) designed to test MPA as tools for biodiversity conservation and sustainable management of halieutic resources, monitoring was carried out in the Bamboung bolon (channel), located in the estuary of the Sine Saloum in Senegal. There, waters are shallow and the area is highly biodiverse, particularly for birds, fishes, and marine mammals (dolphins and manatees). Fishing has been banned there since 2004 (Breuil 2011) but remains very active in the rest of the estuary and on the maritime front. A number of changes have been observed in the reserve (Écoutin *et al.*, 2013; Écoutin *et al.*, 2014; Laë *et al.* 2015):

- increase in the number of species present,
- increase in the percentage of large and/or emblematic and highly sought after species,
- modification in the community structure characterized by:

– more small fish

– more large fish (new large fish species and/or larger individuals in species already present)

– fewer midsized fishes

- change in trophic structure (greater percentage of predators),

- change in the community in terms of representation of different ecological categories,
- no significant increase in total biomass in the MPA.

While some indicators suggest that the creation of the Bamboung MPA has had a positive effect, this is not an obvious conclusion on the scale of the community as a whole for the 2004-2011 period. At this scale, only four indicators provide positive information on the fishing ban: the average trophic level and three indicators describing the evolution of maximum sizes and the presence of large individuals. These observations appear to be confirmed by trophodynamic modelling (Colleter *et al.*, 2012) which yields relatively constant biomass before and after a fishing ban, but an increase in the number of predators by a factor of 2.5 and a drop in the number of their prey by a factor of 1.7, illustrating the MPA's role as a refuge zone or a "pantry" zone for some predator species. These observations were also made in the OSMOSE model (Brochier *et al.*, 2013) which shows relative stability in biomasses but a sharp change in populations within the MPA leading to an increase in trophic level and an estimated spillover of 30% of interior biomass. These results explain the change in CPUE outside the MPA and matches similar observations showing an increase in the biomass of some target species in the area adjacent to the reserve, leading to a concentration in fishing effort in the bordering zone (Alcala *et al.*, 2005; Russ & Alcala, 1996; Russ *et al.*, 2003 and 2004; Goñi *et al.*, 2008).

Finally, the coastal area is strongly influenced by the presence of essential habitats such as estuaries, rias, lagoons, grass patches, and mangroves, all of which contribute to the conservation and renewal of a resource containing at least one ecophase that is bound to the interfacing physical systems. The spatial distribution of a resource composed of migrating species which cross borders and the mobility of users, particularly fishermen, thus makes it necessary to consider conservation and management measures at the regional level. This was the case in West Africa, with the establishment in 1996 of a coastal planning regional network. A Regional Strategy for the MPA in West Africa was developed on 2002 and based on the creation of a coherent MPA network in West Africa, managed in a participative manner by strong institutions, that put natural and cultural diversity to work in contributing to the region's sustainable development. Hence, in Mauritania, Senegal, Cape Verde, Gambia, Guinea-Bissau and Guinea, a substantial proportion of habitats that are critical for the reproduction of renewable natural resources or act as significant sites for biodiversity currently enjoy protected status. In the wake of these initial measures, the concept of MPA networks is often put forward to improve the protection and management of aquatic ecosystems (Hansen, 2003) with the creation of environmental corridors to ensure the protection of the most sensitive ecophases. The MPA regional network in West Africa (RAMPAO) was created in 2007 to ensure, at the marine ecoregion level for West Africa, the maintenance of a coherent set of critical habitats necessary for the dynamic function of ecological processes that are necessary for the regeneration of natural resources and the conservation of biodiversity in the service of society.

At the international level, by 2020, 10% of marine and coastal zones should either be designated as protected areas or have conservation measures applied to them. The notion of efficiency seems to be a priority of the strategic plan, as the conservation measures should be in place and protected areas managed effectively (Bonnin *et al.*, 2015).

In summary, the goals of MPA are (Claudet & Pelletier, 2004):

• To conserve and protect natural resources in areas that are important for ecological diversity.

• To restore altered or overexploited areas that are considered indispensable for the survival of species or that play a significant role in the life cycle of economically important species.

• To improve the relationships between humans, their environment, and economic activities while maintaining traditional practices and the balanced exploitation of resources, by protecting them from outside activities that are harmful to MPAs and by protecting and managing historical, cultural, and aesthetic sites.

• To improve fish yields by protecting breeding stocks, encouraging the dissemination of recruited and post-recruited stages in adjacent spaces, restoring the age structure of natural populations, and acting as a safeguard against the mismanagement of exploited areas.

• To resolve past and present conflicts between users of coastal areas.

• To improve the state of knowledge of the marine environment by promoting research and awareness-building for stakeholders.

• To assess the value of these ecosystems for local authorities through tourist and economic activities that are profitable for residents.

Social environment and fisheries management

To understand the dynamics of fisheries, it is necessary to take the social dimensions of fishing into account. Fishing strategies developed by fishermen change according to the socio-economic context, and the conditions for access to resources have changed drastically over the past few decades.

Fishing in the African continent is practiced by different groups of individuals with different degrees of investment in both equipment and activity in their fishing practices. Several investigations in the West African lagoons (Laë, 1992a) or in river-floodplain systems (Laë & Morand, 1994) have shown that three modes of behaviour can be distinguished schematically. In practice few groups are exclusively devoted to fishing. Most of these cases involve migrant fishermen that are very well-equipped and specialized, and whose main strategy is to go to where fish are found to capture them. In the majority of cases, fishing and farming are complementary activities and many sedentary fishermen split their time between the two. Some are also traders.

The organization and management of continental fishing has evolved along similar lines over the 20th century in many regions of Africa. The broad lines of such progress can be described schematically.

In the early part of the century, customs and lineage-based rights codified access to fishing areas and resources. Modes of fishing, mostly collective (such as fishing weirs) required significant manpower.

Fishermen typology

Around Lake Togo, three distinct classes emerge in fishermen typology (Laë, 1992a):

- A group practicing fishing regularly throughout the year.
These "professional" fishermen for whom fishing is the primary activity use sophisticated gear (gillnets and longlines) that require solid experience and relatively heavy investments in relation to their revenues.

- A second group appears to limit fishing activity to the wet season and flood season.
There is less pronounced specialization in fishing gear.
These "seasonal" fishermen are also farmers and modulate their fishing activities according to their agricultural activities and fishing yields.

- A third group comprises fishermen whose activities are minimal or sporadic throughout the year, and the most commonly used fishing gear is the cast net.
Fishing is only a supplementary activity for this group which includes farmers, civil servants, students, and so on.

Towards the middle of the century and the technological advances that were made, individual fishing gears began spreading: gillnets, cast nets, longlines, etc. Fishing became a source of profit and speculation. Production increased with the diversification of captured species and a reduction in the size of captures.

As countries achieved independence in the early 1960s, the state replaced traditional rights. Under the influence of western ideas, there was much talk of rational resource management, which implied a regulatory arsenal, good knowledge of stocks, and the means to apply and control regulations. In practice, the state lacked the means to perform this role, which led to many conflicts between fishermen and fierce competition for access to the resource. The system often led to fragile compromises between the fishermen and the new masters of the water embodied by representatives of the public authorities, and such compromises were regularly called into question.

To illustrate these changes in the modes of resource management, let us take two examples that were the object of well-documented studies: the Central Delta of the Niger River in Mali (Quensière, 1994) and the coastal lagoons of Côte d'Ivoire (Durand *et al.*, 1994).

Case study: the Central Delta of the Niger River

The management of waters and fishing among the Bozo (group of Malian fishers) has been the subject of much investigation (Daget, 1949; 1956; Gallais, 1967; Fay, 1994) owing to the multiple technical and social modes of fishing.

The so-called traditional mode of water management is based on the alliance made by the founding ancestor of a community of fisherfolk with divinities or "genies" of the water, an alliance that allowed the group to fish under the aegis of the "water master", the eldest of the founder's descendants. Each year, this water master renewed the initial pact with the genies through a series of appropriate sacrifices, and established the general conditions of fishing (date of large-scale collective fishing, suspension of fishing, bans of fishing in certain areas, etc.). Some fishing was granted to all members of a given group, within the bounds of the authorized fishing periods. Some fisheries, such as weirs, came under a collective lineage-based appropriation. A third of the production was turned over to the owners of the fishery by outsiders who wanted to fish there, a proportion that was referred to as "the water's share" among the Bozo (Daget, 1956; Fay, 1994).

In traditional fishing rights, the resource is not shared, as uncaptured fish belongs to no one (Daget, 1956). Rights are granted for fisheries exploiting, at certain moments of the hydrological cycle, specific aquatic systems with a given set of fishing gears. "Traditional" access to fisheries was thus not generally free, but was based on lineage.

From the time of colonization to independence, the monetarization of the sector would push fishermen to increase yields, even in defiance of traditional regulations, and the appearance of new fishing gears would lead to migrations, the arrival of new stakeholders, and a technological differentiation between groups according to their means of financial investment. Between 1935 and 1950, cotton lines appeared, then nylon, then netting, cast nets, lines with steel hooks, etc. which would lead to a fishing boom. In about twenty years, fishing production tripled and became one of the main sources of revenue. In 1963, the Malian state proclaimed its sovereignty over the waters and declared traditional regulations illegal. Access to waters was officially "open", and determined by the acquisition of a fishing permit as from 1975. In practice, the resource now belonged to the state which was its sole proprietor. It distributed temporary exploitation rights as it deemed fit. These rights authorized the use of one or several fishing gears and/or the access to a portion of fishing territory. Such a management style would require a knowledge of stock status and the application of measures to limit fishing as decided by the managing authorities. However, in the absence of a service tasked with tracking the evolution of resources, and suitable legislation for regulating fishing, the spirit of the law was not respected. It would have also been necessary to create a body of officials in charge of inspecting fishing practices and sanctioning infractions. This type of inspection becomes merely hypothetical and expensive when the fishing in question involves large, poorly accessible areas, as is the case for the Central Delta.

In the early 1970s, the state attempted to establish the rules for rational management, based on a technological approach of the solutions that needed to be implemented, with the help of input from international experts. It reaffirmed its sovereignty over all continental waters, made regulations regarding gears stricter, and created fisheries councils and committees. These were composed of administrative officers and representatives of fishermen, and their role was to manage conflicts. Meanwhile, laws also granted residents use rights, which conferred legitimacy but also led to territorial conflicts and disagreements with migrant fishermen. The arrival of a drought in the early 1970s would lead to the stepping up of administrative inspections.

In 1986 then 1995, new fisheries legislation was put in place, representing an important step forward in opening fisheries management to fishing communities. This was intended to promote decentralized management of halieutic resources. In this framework, the national piscicole domain was divided into three distinct domains placed under the authority of the state (public waters), decentralized territorial communities (hydraulic or piscicultural arrangements made by the community), and individuals (arrangements of their property). The new legislation reflected a desire to protect halieutic resources, including initiatives from professional categories other than fishermen. Its new provisions made it possible to establish sustainable management of fishers by a vision of planning that favoured ecological management as well as by giving a sense of responsibility and agency to the future decentralized territorial communities. Nonetheless, it shows some gaps (Breuil & Quensière, 1995):

- each entity responsible for a halieutic area was tasked with adopting measures to protect the resource, but the law did not provide any general rule for management that would allow local communities to orient the measures that they need to take;
- in terms of the environment, the law stated a few general principles but did not take into account the full scale of the function of productive hydrosystems, whereas the conservation of halieutic species cannot be entirely carried out at the local level.

Aside from the mode of management, it must also be noted that fishing pressure has increased considerably in the Central Delta of the Niger over the past thirty years (increase in population, progress in fishing techniques and gears) and that this trend has been compounded by the shrinkage of water spaces. Confronted with the same problems, traditional authorities would probably have encountered the same difficulties as the Malian state. The survival of the fishing sector depends on controlling fishing pressure, which is extremely difficult to do in traditional societies that replicate themselves. This will no doubt be a major challenge for decentralized management.

History of fisheries management in Côte d'Ivoire lagoons

The history of halieutic exploitation of the lagoon systems in Côte d'Ivoire also illustrates the transformation of relationships between societies and their environments since the start of the 20th century. Forms of access to the field, to different fishing techniques, to certain sites or spaces, and consequently, to the resource itself, vary and combine differently depending on the period (Verdeaux, 1994). Three configurations have succeeded each other chronologically since the early 1900s (table 25.X).

Before 1930

Up to the early 20th century, organization of fishing around the Aby lagoon (Côte d'Ivoire) was handled by lineage-based authority. This authority mandated and imposed rules regulating fishing activities and ensured, partly to its

Fishing gear	before 1910	1910-1914	1935-1950	1960-1967	1970-1975	1979-1982
Fixed fisheries	**rainy season**		**gradual abandonment**		**disappeared**	
beach seine (ali)						
length (m)	60	150	300-600	800-1000	800-1200	800-1200
mesh size (mm)	50	40	40 puis 25	14	14	14
width (m)	1.5	2	4.5	6 à 12	12	12
"syndicat"						
length (m)			100-150	250-300	400-500	400-500
mesh size (mm)			20-25	14	14	14
width (m)			10	15		12
purse seine						
length (m)					400-650	500-650
mesh size (mm)					14	14
width (m)					15-20	15-20
Individual gears	**dry season**		**all seasons**		**'sardine' net**	

TABLE 25.X.
History of the management of fisheries and the fishing gear used in the Aby lagoon, Côte d'Ivoire (from Verdeaux, 1994).

benefit, control of the environment (Perrot, 1989). The effectiveness of the regulation was guaranteed by religious faith; breaking it was tantamount to violating the prohibitions of the lineage's protective genie. Indeed, the area was ruled by a pantheon of "genies" that guarded access and guaranteed productivity, and it was necessary to seek their intercession in order to fish. Each main lineage had special relationships with local genies whose influence generally extended to a shoal on which a fixed fishery was established. The elder of the line was the favoured interlocutor with this genie, and the group of "relatives" for which he served as interpreter respected the precepts and prohibitions of the divinity (Verdeaux, 1994). By domesticating the power of genies, appropriation procedures could be controlled.

During this historical period, we can distinguish, in the course of a year, two major periods in terms of the intensity of fishing activity and the types of social cooperation or techniques that came into play. The main fishing season began with the main rainy season (May), and ended at the end of the minor rainy season (October-November). The panoply of fishing techniques was used, though with a preponderance of fixed traps built collectively by the lineage or the villages. In the 19th and early 20th centuries, fisheries were characterized by the use of fixed gears, such as the *atterre*, a vegetable barrier that formed labyrinths from which fishes could not escape. Some of these could be hundreds of metres long, requiring for their construction and handling considerable manpower and, consequently, forms of cooperation that required the input of entire lineages and even villages. During the main dry season from November to April, halieutic activity was reduced, with a preponderance of individual and selective techniques: traps, hollow woods, longlines and cast nets. The prohibition of access to fixed fisheries from October to May the following year was a means of encouraging the renewal of stock. In case of infractions, sanctions were severe and acted as deterrents.

The shift from one period to another was marked by religious manifestations. In May, priests and chiefs of the lineage solemnly closed the "door of the genies" and in October, they "opened their door", inaugurating the cycle of celebrations and sacrifices related to the beliefs of the lineage (Verdeaux, 1986; 1994). In one of the villages of the Ébrié lagoon, according to popular belief, the "whale" genie nestled against the bottom of the lagoon kept fishes in its belly until the opening ceremony of the fishing season in late April to early May. Thanks to these offerings, the genie would then be attracted to the surface, thus freeing the fishes that it had kept captive during the dry season. Only then could the main fishing season begin.

Aside from the explicit attribution of fixed sites for fisheries, the spatial and seasonal combination of different techniques made it possible to determine, at the lagoon level, the spaces and territories that could be exploited by different groups — villages, clans, lineages. This partly symbolic distribution had the advantage of controlling and limiting the most predatory techniques and codifying access during the main fishing season.

From 1930 to 1960

In the 1930s and up to the 1960s, large fixed fisheries (*atterre*) gradually disappeared, to be replaced by other types of fishing gears. The "*ali*" net introduced shortly before the first World War was small and originally handled by two men. Fishing was done close to the shore or on shoals by surrounding a small area. The dimensions of the "*ali*" net gradually increased and gave way to beach seines that spread in the lagoon in the mid-1930s. This type of gear was preferred over fixed traps as it was more profitable and could be used for several seasons. Morever, fishing gears became more diverse with the adoption of a series of gillnets and lines that could be used throughout the year. This period was thus marked by the shift from the passive mode of controlled access to the fishing area, mainly owing to fixed fisheries, to a direct and active access to the resource with the development of beach seines and new gears. In particular, the proliferation of gillnets occurred with the importation of cotton lines at the instigation of the authorities.

Simultaneously, we witnessed a transformation in trade circuits. Fishing became a lucrative activity that allowed urban centres to be supplied. In addition, authorities introduced territorial organization, and the lagoon became a strategic point with the definition of village territorial waters.

From 1960 to 1982

Starting in the 1960s, an increase in the size of beach seines can be seen, with some reaching over a kilometre in length and supplanting the traditional "*ali*" net. Another type of fishing mode appeared: the "syndicate net", a purse seine used in open water rather than near the shore, hunting mainly pelagic species such as bonga shad. It is operated by associations of fishermen (hence the name) that form each year during bonga shad season, then break apart afterwards.

Broadly speaking, the evolution of fishing techniques during this period is marked by the transition of fishing for demersals (bottom fish) to pelagic fish (especially

Fisheries in Benin (based on Pliya, 1980)

In Benin, prior to the colonial period, access to water and fishing was controlled by religious authorities, and lakes were the joint property of villagers. There were many prohibitions, religious beliefs, and local customs that forbade access to certain areas or banned the use of some types of fishing gears. These protected areas, often sacred sites, were important locally for fish reproduction. Societies had thus developed a number of mechanisms that led to a balanced use of the shared resource.

During the colonial period up to the Second World War, changes in social structures contributed to weakening traditional authority in favour of the central administration. But the Water and Forests service did not put new legislation in place, and traditional rules were gradually transgressed. This led to the chaotic development of fishing that rapidly resulted in overexploitation and conflicts.

Between the Second World War and the country's independence, there were various attempts to improve the role of the Fisheries service, which added to the weakening of traditional authorities and control of access to shared resources. By the late 1970s there was no control at all. With the accumulation of conflicts, fishermen proposed a reinstatement of traditional management methods, but the government paid no heed to these proposals.

bonga shad) as dominant target species (Verdeaux, 1990). In the 1960s, seine mesh diminished in stages, making it possible to catch other species and new size classes. As seines were no longer selective and their number increased, this ended up in a competition with the captures of individual gears.

This led to a first crisis in 1969, known as the "war of nets", with several coastal villages in the lagoon refusing to grant fishing rights to seines. After the intervention of authorities, seines were limited to the territorial waters of villages willing to accept them. Nonetheless, by the end of the 1970s, seines accounted for three-quarters of captures. Seines did not always follow regulations, and the unfavourable bioclimatic conditions of the early 1980s contributed to a collapse of halieutic resources. Numerous incidents took place between seine fishers and individual fishers who felt dispossessed as a result of the disappearance of their basic resource, building up to a major crisis in 1982. Several villages demanded a ban on seines, and after several – sometimes violent – incidents, this measure was approved by the administration in 1985. This decision was a departure from a type of relationship with the system that had ended up being reduced to a dynamic of competing for stocks. Free access to the system that was initially obtained by individual fishermen morphed little by little into the cornering of the sector by economic groups who were able to fund seines.

The crisis in the 1980s shone a light on the state's inability to serve justice in the public realm. Introduction of a domanial system was accompanied by free access to the environment, initially well-received by individual fishers. But such free access rapidly turned into differential access to the resource (Verdeaux, 1994). This thus led in 1985 to a situation that was similar, but not comparable, to the one prevailing in the early part of the century: regulation of access to the resource by controlling access to the environment.

Conclusions

For a long time, fishing in Africa was simply an activity that consisted of removing a portion of a natural resource that was controlled as best as could be by traditional practices or the adoption of the western method of centralized management. Demographic pressure as well as the consequences of anthropogenic activity gradually changed the original situation. Unfortunate practices, such as the pouring of large quantities of insecticides into a river to capture fish, developed in many countries.

It seems likely that the exploitation of natural fish stocks has reached its peak in Africa. The increase of catches, in fishing statistics, is often the result of better data on captures rather than the discovery or exploitation of new resources. In these conditions we can predict that, in the absence of proactive measures that are always difficult to apply in countries where fishing is an important component of local economies, captures will stagnate or even fall in the coming years. One of the major issues at stake is without a doubt finding the right balance between the participation of local societies and that of the state in the sustainable management of water resources and live resources.

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