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The use of biological indicators for monitoring fisheries exploitation: Application to man-made reservoirs in Mali

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Abstract – A comparative study, using biological indicators, was conducted in Mali where two man-made reservoirs (Selengue and Manantali) are particularly suited for investigating the impact of fishing effort on the fish assemblage: these two ecosystems have relatively similar morphological, edaphic and environmental properties but are subjected to radically different levels of fishing exploitation (low at Manantali, high at Selengue). The comparison is based on a three-month survey of commercial fisheries, focusing on fishing activities and catches on the two reservoirs.

The results show that some indicators are useful for evaluating fishing impacts. Among these indicators are: fishing effort which is much higher at Selengue (22 800 fishing trips per month) than at Manantali (3000), catches per unit effort (lower at Selengue than at Manantali following a ratio ranging from 1.5 to 4 according to the gears used), annual yields per ha higher at Selengue (100 kg ha^{-1}) than at Manantali (27 kg ha^{-1}), the average fish lengths in the catches (16.2 cm at Selengue compared to 23.6 cm at Manantali) and the maximum lengths of the targeted species generally smaller at Selengue (10 to 30 cm) than at Manantali (30 to 50 cm). By contrast, a second class of indicators exhibit values that are contrary to expectations: the species richness (52 compared to 36), the species diversity (I_{sh} = 4.02 compared to 3.24) and evenness (0.76 compared to 0.69) were higher at Selengue where 4 species accounted for 50% of the landings compared to only 2 species at Manantali (9 species compared to 7 for 80% of the landings). The trophic structure of the landings is higher (37% primary consumers compared to 49% at Manantali) as well as the mean trophic level (2.74 compared to 2.54 at Manantali).

Even if a good understanding of the two fisheries can explain the unexpected trends of the second class of indicators which increase with fishing effort, it clearly appears from this study that only the first class of indicators is robust and can be used for comparative studies across ecosystems.

Key words: Fish populations / Fishing effort / Diversity / Yield / Mean length / Trophic level / West Africa

Résumé – Évaluation de l'exploitation halieutique au moyen d'indicateurs biologiques : application aux réservoirs artificiels du Mali. Une étude comparative basée sur l'utilisation d'indicateurs biologiques a été réalisée au Mali où deux retenues artificielles (Selengue et Manantali) se prêtent particulièrement bien à l'étude de la pression de pêche sur l'organisation des peuplements de poissons. Ces deux écosystèmes ont des caractéristiques morphologiques, édaphiques et environnementales relativement proches, mais subissent des niveaux d'exploitation halieutique radicalement différents (faible à Manantali et fort à Selengue). L'étude comparative repose sur un suivi des pêches commerciales de trois mois en fin d'étiage et les observations réalisées portent principalement sur la description et l'évaluation des activités de pêche et des captures correspondantes sur chacune des deux retenues.

Les résultats de cette étude montrent que certains indicateurs sont utiles pour évaluer l'impact des pressions de pêche. Parmi ceux-ci, on trouve : l'effort de pêche bien plus élevé à Selengue (22 800 sorties de pêche par mois) qu'à Manantali (3000), les prises par unité d'effort (inférieures à Selengue d'un rapport compris entre 1,5 et 4 suivant les engins utilisés), les rendements annuels par hectare bien supérieurs à Selengue (100 kg ha^{-1}) qu'à Manantali (27 kg ha^{-1}), la taille moyenne des poissons dans les captures (16,2 cm à Selengue contre 23,6 cm à Manantali) et les tailles maximales des espèces cibles généralement inférieures à Selengue (10 à 30 cm) qu'à Manantali (30 à 50 cm). A l'inverse, une seconde classe d'indicateurs donne des résultats opposés à ceux qui étaient escomptés ; la richesse spécifique (52 contre 36), la diversité spécifique (I_{sh} = 4,02 contre 3,24) et l'équitabilité (0,76 contre 0,69) sont supérieures à Selengue. Les 4 premières espèces débarquées à Selengue représentent 50 % des débarquements contre seulement 2 à Manantali. La structure trophique des débarquements est également supérieure à Selengue (37 % de consommateurs primaires contre 49 % à Manantali) de même que le niveau trophique moyen (2,74 contre 2,54).

Même si une bonne compréhension des pêcheries permet d'expliquer les résultats de cette seconde classe d'indicateurs qui, contre toute attente, augmentent lorsque la pression de pêche s'intensifie, il ressort de cette étude que seule la première classe d'indicateurs est robuste et peut être utilisée à des fins comparatives.

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1 Introduction

Fisheries management is based on the principle of the sustainable use of a renewable living resource. Despite the development of increasingly sophisticated tools (global, analytical, stock-recruitment models), the majority of fisheries throughout the world have now passed their peak, many stocks are overfished and some of them have experienced a crash in catches (Garcia and Newton 1997; Buckworth 1998). As a consequence, the weakness of fisheries models has increased the interest for an ecosystem approach and for the development of biological indicators (Simpson 1982; Levêque 1995; Hall 1999; Blaber et al. 2000; ICES 2000). Numerous authors think that fish stratum is a good tool for determining the state of ecosystem health (Paller et al. 1996; Whitfield 1996; Soto-Galera et al. 1998; Whitfield and Elliot 2002). As a general rule, heavy fishing pressure is reflected by a decline in the mean size of fish caught and by a reorganization of the populations in favour of small-sized, fast-growing species (Regier and Loftus 1972; Rapport et al. 1985; Gulland and Garcia 1984; Murawski et al. 1991; Pauly et al. 1998; Faure 2000). Using such knowledge, the aim for scientists is to define representative bio-indicators of fishing pressure and this process can be realized at various levels of biological organisation (Adams 2002): biochemical, physiological, histopathology, individual, population, community (Table 1). Currently most indicators used refer to a standard fish assemblage living in a non-stressed ecosystem (Deegan et al. 1997; Harisson et al. 2000). Then one objective was to find a correlation between detrimental environmental parameters and ecosystem degradation assessed through a biological index based on the fish assemblage (Oberdoff and Hughes 1992; Soto-Galera et al. 1998).

For studies dealing with exploited fish stocks, authors using biological indicators have mainly focused on time series of experimental fishing and/or direct observations on fish biology (Rochet 2000; Rochet and Trenkel 2003; Trenkel and Rochet 2003). But, in many countries and especially in developing countries experimental fishing and/or times series are rare. The data usually available are standard observations on commercial fisheries and monitoring periods are generally short, sometimes shorter than one annual cycle.

This is the reason why it appeared interesting to test the bio-indicators approach using statistical data of artisanal commercial fisheries. The deal was to identify indicators of fishing levels from data (CPUE, fish length…) collected at the landing places. Because of the lack of information about a non–exploited state, a comparative approach was developed in Mali between two man-made reservoirs that have highly contrasted levels of fishing effort. The aim was to define some indicators and test their values with our current knowledge of the real fishing status of the reservoirs.

2 Materials and methods

2.1 The study sites

This study is based on the surveys of two man-made reservoirs in Mali (West Africa): Selengue lake and Manantali lake (Fig. 1). Results on these two reservoirs have been previously reported (Laë and Weigel 1995a,b). The impact of fishing pressure on these two reservoirs is considered to be a major stress, even though many authors have reported the difficulty of isolating the effect of any particular variable on fish populations and communities in both coastal and estuarine environments (Blaber et al. 2000). In the present case, the reservoirs are very similar to each other (Fig. 1): they are both relatively recent since Selengue lake was completed in 1980 and Manantali lake in 1987 and they have similar lengths (80 km), widths (between 3−6 km and 6−8 km) and areas (400 km^2). The inter annual variability is limited since the two lakes are artificially managed with filling of the reservoirs during the flood season up to the same maximum level in each year and a controlled drawdown after the rains and during the dry season. In these conditions, the hydrological cycles of the two lakes are directly comparable: they start in August with a rise in the water level and a filling that takes place quickly, the maximum level being reached by November. Then the level begins to fall slowly in December and faster from April to June, when the electricity demand is at its peak. One difference is in the trophic status of the two reservoirs: Selengue lake is considered as mesotrophic (Arfi 2003) while Manantali lake is oligotrophic (Alhousseini 1999). Nevertheless, the main difference lies in the fact that fishing effort in these two lakes is very different: Manantali reservoir is located in an isolated region in the west part of Mali and access to markets is poor leading to a low fish exploitation. On the contrary, Selengue reservoir is close to the major markets of the capital, Bamako, and as fish demand is high, fishing effort is intensive.

2.2 The sampling design

The surveys of the two lakes were planned on a three months period. The choice of a short monitoring of the fisheries was imposed by the necessity to quickly get an assessment of fishing effort and their impact on fish assemblage. The fact that observation periods were different (August to October 1994 at Selengue, June to August 1995 at Manantali) and covered the end of the fishing high season and the start of the fishing low season, was not deliberate but with hindsight has the advantage of selecting very robust and non seasonally dependent biological indicators.

The sampling design (Laë and Weigel 1995a,b) used was based on 1) a geographical stratification of the two lakes into homogeneous sectors, 2) the choice of sampled fishing villages based on a non random procedure by selection of representative villages where all fishing techniques (gillnets, seine nets, longlines, etc.) were represented within each sector, 3) the sampling of a large number of settlements (14 at Selengue and 12 at Manantali) allowing local fishing specialisations and the seasonal variability to be taken into account.

These settlements that were regularly distributed on the two lakes accounted for 75% of the fishing population working on the Selengue reservoir and 60% on Manantali. Each fishing settlement was monitored for 10 days per month. The information concerning the fishing units (motorized or non motorized canoes with a well identified crew of one or more fishermen

Table 1. Representative indicators measured at various levels of biological organisation (adapted from Adams and Greeley 2000).

Biochemical	Physiological	Histopathology	Individual	Population	Community
MFO enzymes*	Creatinine	Necrosis	Growth	Abundance	Richness
Bite metabolites	Transaminase enzymes	Macrophage aggregates	Total body lipid	Size and age distribution	Index of biotic integrity
DNA integrity	Triglycerides	Parasitic lesions	Organo-indices	Sex ratio	Sensitive species
Stress proteins	Steroid hormones	Functional parenchyma	Condition factor	Bioenergetic parameters	Feeding types
Antioxidant enzymes		Carcinomas	Gross anomalies	Reproductive integrity	Diversity indices

* mixed-function oxidase (MFO) enzyme activities.

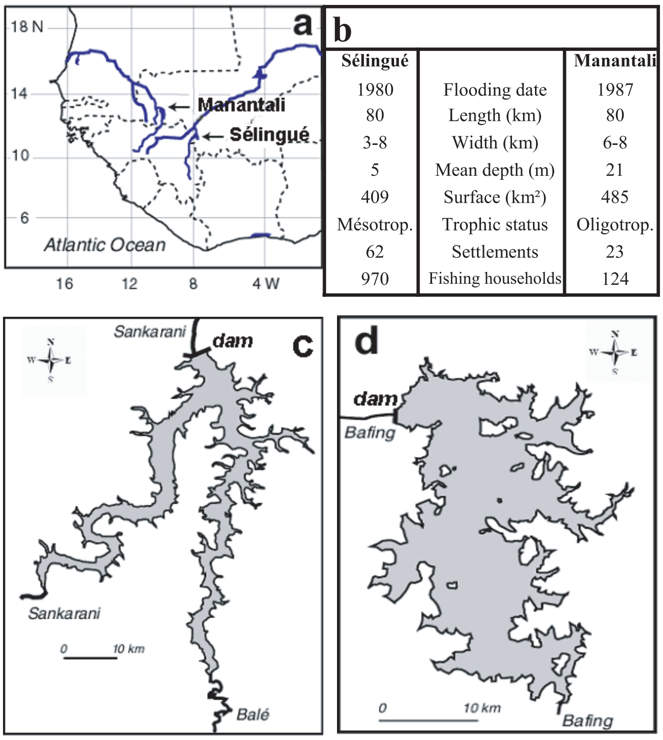

Fig. 1. The Manantali and Selengue man-made reservoirs in Mali. a: geographical localisation in West Africa, b: Main characteristics of the reservoirs, c: map of Selengue, d: map of Manantali.

and associated fishing gear) were collected on the fishing activities and the catches, depending on three main operations:

- A general census of fishing units in all the fishing villages at the start of the survey followed by monthly censuses of the units present in the investigated villages. These surveys were used to extrapolate the results obtained from the sampling to the entire ecosystem.
- An estimation of the fishing effort and monitoring of its spatio-temporal variations. For each village included in the study, the daily activities of 10 randomly selected fishing units were monitored. The following information on the activities of each fishing unit were collected: number of people, fishing location, type of environment exploited, type and number of gear used, other activities (agriculture, mending nets, motor and boat repair, etc.).
- An estimate of the fish landings per species and their corresponding size distributions. The most suitable procedure for small-scale fishing on inland waters is to take an independent random sample within each spatio-temporal stratum. The surveys were conducted on the population of boats unloading. For each boat, the following information was collected: 1) General information on the fishing unit and direct observations related to fishing conditions (temperature, weather conditions, wind, phase of the moon). 2) Information on fishing trips, collected by interviewing fishermen (fishing site, distance, fishing time, gear used, number of nets set, number of people involved in fishing). 3) Information on catches. The total catch and catch of each species were weighed and a sample of 10 individuals for each species was measured.

The data collected were then processed using PECHART software (Laë and Bousquet 1996). The three-month surveys resulted in the collection of data on 899 landings at Selengue and 1196 at Manantali and the monitoring of the daily activities of 131 units at Selengue and 93 at Manantali for 10 days per month.

2.3 The choice of indicators

As we were focusing on the impact of fishing effort on the fish assemblage, we only selected indicators at population and community levels without consideration of individual level. All species landed were included in the analysis, as no discarded fish were noted in this kind of artisanal fisheries. The interest of the following indicators obtained from statistical surveys, relies on the fact that they are calculated from standard information collected when monitoring fisheries and if they prove to be efficient and robust, they can be widely used. Indicators of species diversity (index of species diversity or Shannon index), occurrences of species per fishing trip, catch per fishing trip, size structure and trophic level of the total catch, were expected to decrease when fishing effort was increased.

Fishing effort: for each type of gear, fishing effort included both size (length of nets, number of hooks used, number of individual gear, etc.) and time devoted to fishing. The calculation of fishing effort is given by:

$$F = \Sigma_Z^1 \Sigma_g^1 \left(UP \cdot J(s \cdot e/p \cdot j)\right)$$

UP: number of fishing unit in the sector, *J*: number of days of the month, *s*: number of trips during the sampling period, *e*: average number of gear used during one trip, *p*: number of fishermen sampled, *j*: number of days sampled, *z*: number of zones, *g*: number of types of gear.

Diversity indices: the overall diversity can be estimated by calculating the Shannon diversity index (I_{sh}) which takes into account not only the species richness but also the species abundance. It seems to us, however, unjustified to attribute the same importance to fish of different sizes so the number of fish recorded was replaced directly by their weight in the Shannon formula (Daget 1979):

$$I_{sh} = -\Sigma \left[(p_i/P) \log_2 (p_i/P)\right]$$

p_i: weight per species (kg) in the total catches, *P*: total catches (kg).

In addition, the evenness, which is defined as the ratio of the real diversity to the maximum diversity, was used to directly compare the two communities that do not have the same number of species. The evenness is obtained by dividing the Shannon index by the $\log_2$ of the species richness (Daget 1979).

Fish diets and average trophic levels of the two lakes: the diets are based on the classification proposed by Lauzanne (1983) for Lake Chad. The dominant primary consumers include phytoplankton-feeders, consumers of macrophytes, grazers and detritivores. The dominant secondary consumers include zooplankton-feeders, benthos-feeders and surface-feeders, while the top consumers include strict piscivores and partial piscivores that also consume shrimps and other invertebrates. The main diets of each species were taken from Paugy and Levêque (1999).

Estimates of the trophic level of the species which represent a significant proportion of the landings in the two lakes were obtained from the Fishbase database (Froese and Pauly 2002). The average trophic level of the catches takes into account the trophic index of the level of each species and the relative importance of the species biomass in the total landings.

3 Results

3.1 Fishing effort

On both reservoirs, fishermen originated from Inland Delta of the River Niger. This explains why the major difference between Selengue and Manantali lies in the fishing intensity rather than in fishing practices. Much larger human populations migrated to Selengue than to Manantali where there was less profit to be made because of marketing difficulties. This led to a lower number of fishing villages at Manantali (23) than at Selengue (62) and a much lower number of fishing households: 124 compared to 970. In terms of fishing activity, this was reflected in a major difference with 22 800 fishing trips per month recorded at Selengue compared to only 3000 at Manantali (Fig. 2).

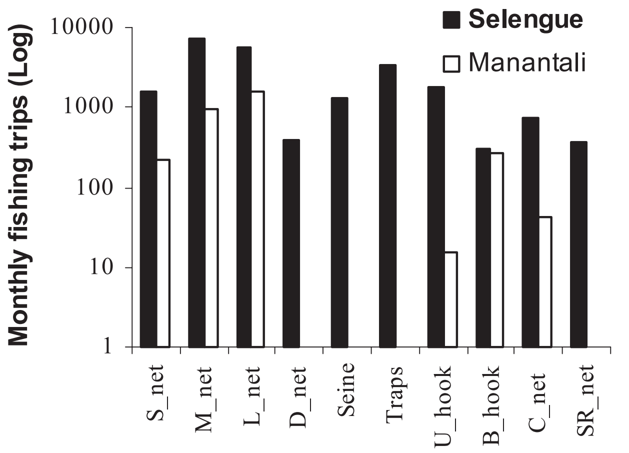

Fig. 2. Monthly fishing trips on the Manantali and Selengue reservoirs. (S_net: Small mesh gillnets, M_net: Medium mesh gillnets, L_net: Large mesh gillnets, D_net: Drift nets, U_hook: Unbaited longlines, B_hook: Baited longlines, C_net: Cast nets, SR_net: Surrounding nets).

Table 2. Average fishing effort per fishing trip at Selengue and Manantali lakes (gillnet in yards, lines in number of hooks).

	Fishing effort per fishing trip	
	Selengue	Manantali
Small mesh gillnets	139	102
Medium mesh gillnets	313	140
Large mesh gillnets	467	216
Unbaited longlines	3470	800
Baited longlines	483	192

The most frequently encountered fishing gears on both lakes were gillnets (with large, medium or small meshes depending on the lake), traps used as keep nets and multiple hooks, baited or unbaited longlines. Cast nets and seine nets were little used because of the many dead trees that hindered their use. At Manantali, the fishing gears that were used (large and medium-sized mesh gillnets and baited longlines) mainly targeted high-valued, usually large-sized species. At Selengue, the use of purse seine nets and small beach seines, unbaited longlines, small-mesh gillnets, and traps operated from the shore already reflected a change in fishing effort directed toward smaller species of lower market value.

On average, the fishing effort per fishing trip (number of gears used or length of lines or nets) was much higher at Selengue than at Manantali (Table 2).

Table 3. Numbers of families, genera and species present in the catches from the Selengue (1994) and Manantali (1995) reservoirs. Distribution of species number per family is also provided.

	Selengue	Manantali
Families	15	13
Genera	32	23
Species	52	37
Alestiidae	6	4
Bagridae	6	2
Centropomidae	1	1
Cichlidae	5	5
Citharinidae	2	2
Clariidae	3	2
Cyprinidae	4	3
Gymnarchidae	1	
Malapteruridae	1	1
Mockokidae	7	6
Mormyridae	8	7
Osteoglossidae	1	
Polypteridae	2	1
Schilbeidae	4	2
Tetraodontidae	1	1

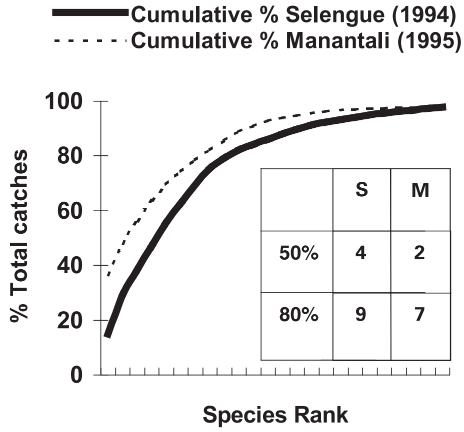

Fig. 3. Cumulative percentage of species occurring in the total landings from the Selengue (1994) and Manantali reservoirs (1995).

3.2 Species diversity of catches

The composition of the catches was rather similar in both lakes in terms of family occurrences: 13 families were recorded at Manantali out of the 15 recorded at Selengue, where Gymnarchidae and Osteoglossidae also occurred (Table 3). By contrast, the number of genera was significantly higher at Selengue (32 compared to 23 at Manantali) as well as the number of species (52 compared to 37), among which 30 occurred in both lakes.

The Shannon diversity index calculated for each reservoir also provides information on the structure of the fish landings and on the way the individuals were distributed between the various species (Daget 1979). This index was higher at Selengue (4.02) than at Manantali (3.24). Similarly, the values of the evenness index were also higher at Selengue (0.76) than at Manantali (0.69).

3.3 Occurrences per fishing trip

The analysis of species occurrences per fishing trip is another way of describing the exploitation system of each lake (Table 4). At Manantali, the most frequently encountered species in the landings was *Lates niloticus* which occurred in 3/4 of the landings. This species was followed by two cichlid species (*Sarotherodon galilaeus* and *Oreochromis aureus*) occurring in 2/3 of the landings. Although *L. niloticus* was the most frequent species in the landings, it only figures in third position in the diagram of total catches, after *S. galilaeus* and *O. aureus*. Together these three species accounted for slightly less than 2/3 of estimated total catches.

At Selengue, the most frequently occurring species in the landings was *Chrysichthys nigrodigitatus*, that was present in only one landing out of 3; after which came *Auchenoglanis occidentalis* and *S. galilaeus* with similar occurrences (1/3).

At Manantali, the exploitation system reflected by the occurrences in the landings (Table 4) could be described as an exploitation targeting few species (*L. niloticus*, *S. galilaeus* and *O. aureus*) whereas at Selengue, the fisheries exploited the whole fish community, using more varied fishing methods to exploit the various biotopes of the lake.

3.4 Catches per fishing trip

The catches per fishing trip recorded at Selengue were much lower than those at Manantali, whatever the gear used. The catches per trip were a function of the type of fishing gear (Table 5). These catches were 150 to 400% higher on the Manantali reservoir.

3.5 Yields and total catches

The use of fishermen surveys and monitoring of fishing activities and landings provided estimates of the catches over a three-month period (322 tonnes at Manantali: 25% in June, 26% in July, 49% in August and 1016 tonnes at Selengue: 28% in August, 41% in September, 31% in October). The yields of the two reservoirs, Selengue and Manantali, after extrapolating the catches to the entire year, were therefore 100 and 27 kg ha^{-1}, respectively.

In terms of the composition of commercial catches, the examination of the total landings (Fig. 3) showed that 50% consisted of only 2 species (*S. galilaeus* and *O. aureus*) at Manantali, compared to 4 at Selengue (*Labeo senegalensis*, *C. nigrodigitatus*, *Schilbe niloticus* and *Synodontis membranaceus*). A similar pattern was observed when the percentage was extended to 80% of total catches, the number of species was then 7 at Manantali (the first two plus *L. niloticus*, *Labeo coubie*, *Synodontis schall*, *Synodontis*

Table 4. Occurrence of the fifteen most abundant fish species in the landings (number of fishing trips surveyed at Manantali: 1196, at Selengue: 899).

Species	Manantali			Selengue		
	Presence	%	Rank	Presence	%	Rank
Lates niloticus	892	74.6	1			
Sarotherodon galilaeus	786	65.7	2	288	32.0	3
Oreochromis aureus	732	61.2	3	235	26.1	6
Synodontis schall	516	43.1	4	105	11.7	9
Synodontis ocellifer	488	40.8	5			
Labeo coubie	400	33.4	6			
Synodontis courteti	393	32.9	7			
Momyrus rume	331	27.7	8	79	8.8	15
Chrysichthys auratus	306	25.6	9	84	9.3	13
Hydrocynus forskalii	297	24.8	10			
Malapterurus electricus	190	15.9	11			
Hyperopisus bebe	149	12.5	12			
Bagrus docmak	148	12.4	13			
Synodontis nigrita	144	12.0	14			
Momyrops deliciosus	132	11.0	15			
Hemichromis fasciatus				83	9.2	14
Citharinus citharus				85	9.5	12
Tilapia zillii				92	10.2	11
Oreochromis niloticus				104	11.6	10
Bagrus bayad				181	20.1	8
Schilbe niloticus				201	22.4	7
Synodontis membranaceus				237	26.4	5
Labeo senegalensis				264	29.4	4
Auchenoglanis occidentalis				307	34.1	2
Chrysichthys nigrodigitatus				311	34.6	1

courteti and *Synodontis ocellifer*) and 9 at Selengue (the first four plus *S. galilaeus*, *Citharinus citharus*, *A. occidentalis*, *Heterobranchus bidorsalis* and *Brycinus leuciscus*). Paradoxically, the more heavily exploited environment had a greater catch diversity.

3.6 Size structure of the catches

The analysis of the size distribution of the catches showed that both the mean and the maximum lengths of the species caught were usually greater at Manantali than at Selengue (Fig. 4). Moreover, for all species combined, the mean size of catches was lower at Selengue (16.2 cm compared to 23.6 at Manantali). The exploitation at Manantali was mostly concentrated on species whose maximum length ranged between 30 and 50 cm whereas at Selengue it was mainly on species with a maximum observed length of 10 to 30 cm (Fig. 5). The size structures of the landings reflected the intensity of fishing pressure applied to the two reservoirs.

3.7 Trophic composition and trophic levels

According to fish diet, approximately 20% of the total number of species collected in the two lakes were classified as primary consumers, 57.8% as secondary consumers and 22.2% as top consumers. The primary consumers included some of the most abundant species in the fish landings of both Selengue and Manantali lakes, including *L. senegalensis*, *S. galilaeus, O. aureus.* Most species showed a relatively low dietary specialization and a great trophic adaptability. The artisanal fishery catches showed that the cumulative weight of fish belonging to the primary consumers group in Selengue lake represented 37% of the total weight of catches and 49% at Manantali (Fig. 6). The secondary consumers group accounted for 56% of fish catches at Selengue and 35% at Manantali. Last, the top consumers group accounted for 7% of fish catches in Selengue and 16% in Manantali.

This result was confirmed by calculating the trophic levels of the landings, taking into account the information derived from Fishbase (Table 6). Lake Selengue had a mean level of 2.74 compared to 2.58 for Manantali. The average trophic

Table 5. Catches per unit effort (100 yards for nets, 100 hooks for baited longlines and 1000 hooks for unbaited longlines) of the main fishing gears of the Malian reservoirs (code given in Fig. 2). P(U): result of average catch comparison using a Mann-Whitney test; Nb: number of unit efforts; Avg: average catch (kg); SD: standard deviation.

Gear	Selengue (S)			Manantali (M)			Ratio (M/S)	P(U)
	Nb	Avg	SD	Nb	Avg	SD		
C_nets	26	12.84	7.57	44	20.27	20.16	1.58	0.26
L_net	101	3.42	3.52	234	13.56	13.43	3.96	0.0
M_net	108	4.40	4.68	132	8.87	7.26	2.02	0.0
S_net	25	8.19	8.29	17	8.81	6.05	1.08	0.11
Hook	133	2.18	3.70	65	3.92	4.41	1.80	0.0
SR_net	13	19.97	11.89	337	31.65	30.33	1.58	0.23

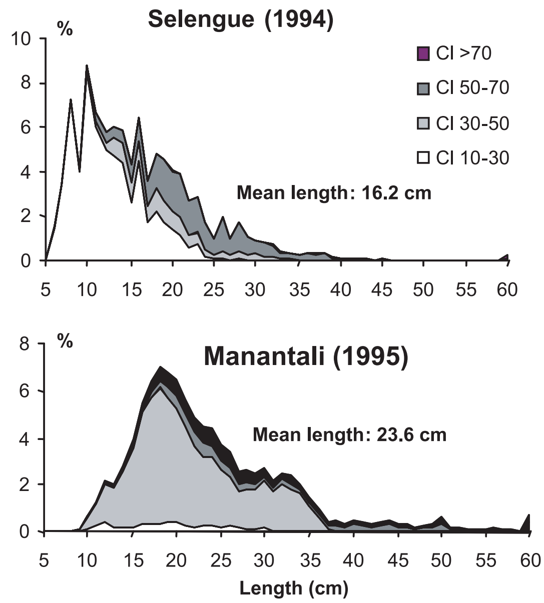

Fig. 4. Overall length frequency distribution of catches in Selengue and Manantali reservoirs. Data are distributed into 4 classes of maximum observed length per species.

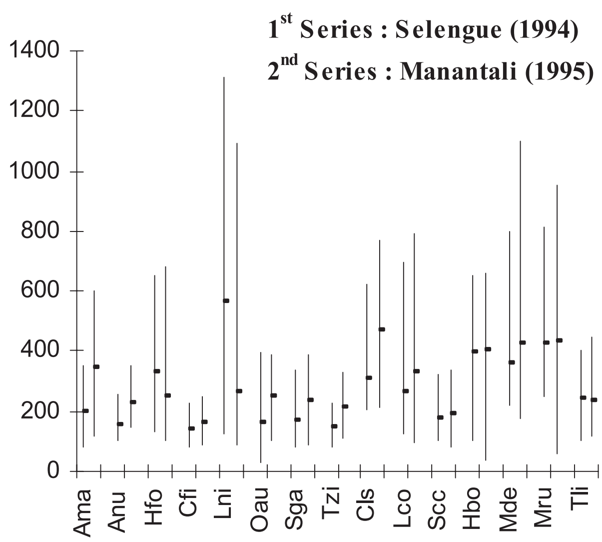

Fig. 5. Minimum, mean and maximum lengths (mm) of the main species occurring in the catches from the Selengue (1994) and Manantali reservoirs (1995): Ama: *Brycinus macrolepidotus*, Anu: *Brycinus nurse*, Hfo: *Hydrocynus forskalii*, Cfi: *Chrysichthys auratus*, Lni: *Lates niloticus*, Oau: *Oreochromis aureus*, Sga: *Sarotherodon galilaeus*, Tzi: *Tilapia zillii*, Cls: *Clarias anguillaris*, Lco: *Labeo coubie*, Scc: *Synodontis schall*, Hbo: *Hyperopisus bebe*, Mde: *Mormyrops deliciosus*, Mru: *Mormyrus rume*, Tli: *Tetraodon lineatus*.

level at Manantali was lower than that of Selengue where the exploitation was much more intensive.

4 Discussion

4.1 Comparison between the two lakes

The interest of this study relies on the fact that a comparison between the two reservoirs is possible, first from an environmental basis. Concerning this point, Selengue dam was built in 1980 and Manantali in 1987 and although both lakes are quite recent, a five-year period seems to be sufficient for stabilizing the main processes inside the two lakes. As a consequence, the maturation of Manantali and Selengue reservoirs was largely underway by 1995 and although the lakes were still not at equilibrium, they were not so far away. The main objection comes from the trophic status of the two reservoirs. As stated by Alhousseini and Kassibo (2000), Manantali is classified as an oligomictic oligotrophic reservoir: mixing of water occurs once a year in January and the chlorophyll concentration is lower than 1 mg l^{-1}. These water characteristics come from the nutrient-poor nature of soil, and from the low human impact in the lake catchment (no urban centers, no use of nitrate or phosphate fertilizers). On the other hand, Selengue is classified as a monomictic reservoir, stratification lasting a few weeks from March to May. Environmental factors change during the annual hydrological cycle; the lake can be regarded as oligotrophic during the high water period, but as meso-eutrophic during the low water period (Arfi 2003).

These differences in trophic status (Selengue reservoir is richer than Manantali) could be a limitation to our analysis but only if biological indicators have safer values in Selengue than in Manantali. If not, this trophic difference only reinforces our observations.

Table 6. Trophic levels of the main species in Selengue and Manantali lakes (Froese and Pauly 2002) and percentage of species landings in total catches.

Species	Trophic level	Manantali % Catches	Selengue % Catches
Malapterurus electricus	4.5	0.8	
Hydrocynus forskalii	4	1.9	0.1
Mormyrops deliciosus	4	0.3	0.5
Lates niloticus	3.8	8.6	2.0
Chrysichthys auratus	3.7	0.7	0.5
Gymnarchus niloticus	3.7		0.2
Heterobranchus bidorsalis	3.7		6.2
Hyperopisus bebe	3.6	1.1	0.9
Tetraodon lineatus	3.6	0.2	
Hydrocynus brevis	3.5	3.3	
Hemichromis fasciatus	3.5		0.7
Physailia pellucida	3.5		0.2
Clarias anguillaris	3.4	1.0	1.4
Bagrus docmac	3.3	0.4	
Bagrus bayad	3.3		1.8
Schilbe niloticus	3.3		9.0
Schilbe mystus	3.3		0.8
Synodontis membranaceus	3.2		8.8
Synodontis ocellifer	3.1	4.0	
Marcusenius senegalensis	3.1		0.2
Alestes baremoze	3.1		1.2
Barbus macrops	3	3.9	
Tilapia zillii	3	0.3	0.8
Heterotis niloticus	3		1.9
Synodontis schall	2.9	5.9	0.5
Auchenoglanis occidentalis	2.9		6.6
Synodontis courteti	2.8	5.0	
Synodontis nigrita	2.8	2.1	
Siluranodon auritus	2.8		0.2
Chrysichthys nigrodigitatus	2.6		14.4
Mormyrus rume	2.5	3.4	0.4
Hippopotamirus harringtoni	2.5		0.2
Brycinus nurse	2.4		0.2
Brycinus leuciscus	2.4		3.6
Brycinus macrolepidotus	2.3		0.2
Labeo senegalensis	2.3		15.0
Sarotherodon galilaeus	2.1	37.3	8.5
Oreochromis aureus	2	11.8	3.1
Labeo coubie	2	7.7	
Citharinus citharus	2		7.1
Distichodus rostratus	2		0.6
Oreochromis niloticus	2		2.0
Total Trophic Levels		2.58	2.74

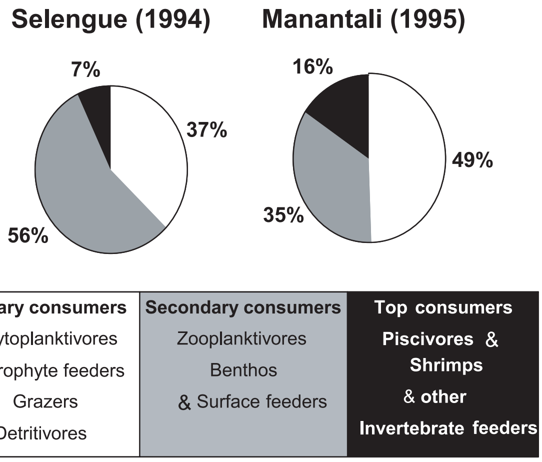

Fig. 6. Comparison of the trophic structure in Selengue and Manantali reservoirs from the small scale fisheries catches (% of total catches).

A second possible limitation is the year of monitoring. Selengue was sampled in 1994 and Manantali in 1995. This point is not crucial as the inter-annual variability of the two lakes is limited by an artificial management and by the annual filling of the reservoirs up to the same maximum level. Each annual flood therefore initialises similar ecological conditions in the water body. In addition, the impact of a short monitoring period is not damageable because the three months sampled covered the end of the dry season, i.e. the period before breeding. In this particular case, the dry period is the best time for assessing the impact of fishing because the main changes in fish assemblages come from the fish catches that occurred during the nine past months.

4.2 Evaluation of biological indicators using fishing indicators

The different fishing efforts recorded at Selengue (22 800 fishing trips per month) and Manantali (3000) result from unequal fishermen density on the two lakes: 4.27 fishermen km^{-2} at Selengue and 0.6 fishermen km^{-2} at Manantali. The comparison of these results with those of other major African lakes (Laë 1997a; 1999) showed that Selengue reservoir was among the most exploited lakes, ranking at the 10^{th} place among the 65 reservoirs listed (Fig. 7). On the contrary, Manantali was among the less exploited lakes. As it has been demonstrated for small-scale inland water fisheries, tropical ecosystems are already fully exploited when there are 2 or more fishermen km^{-2} (Laë 1997b). Based on fishing activity observed in 1994-95, Selengue was intensively fished whereas Manantali was obviously under-exploited. These results are supported by the fishing yield of the two lakes. Selengue reservoir was among the most productive lakes, ranking at the 9^{th} place with an annual yield equivalent to 100 kg ha^{-1} whereas lake Manantali appeared to be less productive (27 kg ha^{-1}) and was positioned at the 44^{th} rank (Fig. 7). Similarly, the catch per unit effort was lower at Selengue (41% of the Manantali value), as expected when fishing effort is much greater. The size distribution of the landings also reflected the difference in the fishing intensity with a lower mean length at Selengue (16.2 cm

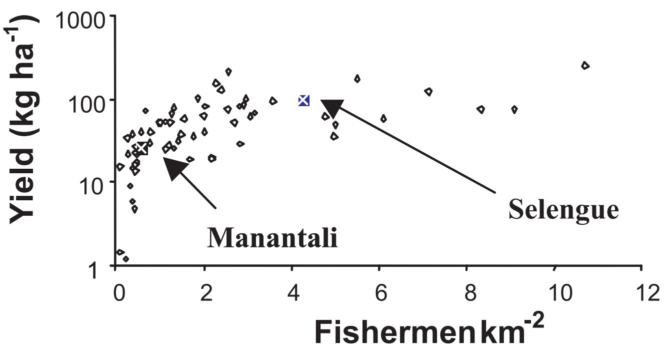

Fig. 7. Position of Selengue and Manantali lakes in relation to the main African lakes (Laë 1997a; Laë et al. 1999).

compared to 23.6 cm) and the target species tended to have a lower maximum length (10 to 30 cm) than the species at Manantali (30 to 50 cm). According to these indicators, the fish assemblage in Selengue was more impacted by fishing effort than in Manantali.

In terms of the composition of commercial catches, species richness, diversity and evenness were higher at Selengue than at Manantali. This result is contrary to our expectations because all studies conducted up till now have reported a lowered species diversity when the exploitation is intensive (e.g. Nelson and Soulé 1987; Jennings and Kaiser 1998; Gislason et al. 2000). Of course, the use of diversity indices can always be criticised because their estimation from commercial fisheries (especially species richness) can be biased due to various technical difficulties (Hurlbert 1971; Washington 1984; Cousins 1991). These contradictory results could have been caused by incomplete sampling and incorrect identification of rare species in the landings (Bianchi et al. 2000). In Mali, such problems cannot be entirely discounted because the people conducting the surveys in the two lakes were different, although the number of landing canoes sampled was higher at Manantali than at Selengue. However, for the most abundant and readily identified species, accounting for 50% or 80% of total catches, where such a bias is very unlikely, the number species involved was much lower at Manantali (2 and 7) than at Selengue (4 and 9). As a consequence, contrary to all expectations, species diversity in fish catches was really higher in Selengue than in Manantali.

Finally, the partitioning of the fish landings according to trophic classes (primary, secondary and top consumers) was realized using published data. In the same way, the mean trophic levels of the two lakes were calculated using values from Fishbase database. These average values are not always representative of our lakes as the diet may change from one ecosystem to another, and also from one ecophase to another. In addition, the mean trophic level has been strongly criticised in the literature for two main reasons: the first is that it can be biased by economic factors (Caddy et al. 1998; Caddy and Garibaldi 2000) and the second is that the way it is calculated is not based on reliable methods (Bowman 1986; Post et al. 2000). Irrespective of these criticisms, these two independently calculated indices showed a similar trend: the distribution among the three trophic categories of the species landed shows that the percentage of primary consumers was much higher at Manantali than at Selengue (49% compared to 37%) and that the mean trophic level at Manantali was lower (2.54) than at Selengue (2.74). This result can be largely explained by the high proportion of *S. galilaeus* in the landings at Manantali. Whatever the reason may be, the mean trophic level, identified as a key indicator of the decline of fisheries (Pauly et al. 1998), proves to be inappropriate in the present case to detect the real effects of fishing.

The fact that some indicators (species richness, trophic level) did not show the expected trends, can to a large extent be explained by the fishing strategies adopted in Manantali. Exploitation started by targeting top consumers and especially *Lates niloticus*, as attested by the occurrences per fishing trip. But fishermen were unable to fish with suitable gear in deep water (50 m maximum depth) or in undeforested areas. As a consequence, the largest fish were partly inaccessible and fishing effort reoriented partly on medium-sized top consumers (the mean size of large carnivorous species was lower in Manantali than in Selengue: 261 mm versus 560 mm for *L. niloticus* and 245 mm versus 331 mm for *Hydrocynus brevis*) and mainly on other profitable lower trophic level species: *Sarotherodon galilaeus* and *Oreochromis aureus*, with large average lengths (232 and 248 mm respectively).

From this example it can therefore be seen that the specialisation of fishing activities led, at Manantali, to the targeting of a small number of species some of which have a low trophic level.

5 Conclusion

Data from fish landings are considered as imperfect because the total catches are often underestimated due to poor reporting or rejected fish so that the commercial catches are not representative of the total assemblage. Furthermore, they are dominated by species of high commercial value and changes in catches can be caused by changes in fishing practices rather than in the assemblage being exploited (Caddy and Garibaldi 2000). These observations are justified, and therefore seriously limit the use of some biological indicators. But for our part, we think that some indicators are very robust and useful for measuring the impact of fishing. Among the latter are the catches per unit effort, the annual yields per unit area, the average fish lengths in the catches and the maximum lengths of the targeted species. All these indicators (except yield) decrease when fishing effort is increased. By contrast, a second class of indicators (species richness, species diversity, evenness, trophic structure of the landings and mean trophic level of catch), contrary to all expectations, increased when fishing effort increased, demonstrating that they are very sensitive to fishing strategies. In this case, the biases mainly affect fisheries at the start of exploitation, when the structure of the catches is very different from that of the fish assemblage. One major conclusion of our study is that only the first class of indicator can be used for comparative studies.

Finally, we only used indicators at the community or population levels but recent works have shown that the action of fishing changes the characteristics of the populations both directly (by decreasing the abundance and biomass of target species and changing their demographic properties) and indirectly (by competition and species replacement, predator-prey relationships), leading to a restructuring of the populations. In such a context, there is much still to be learnt about the capacities of fish populations to adapt to stress (the selection of adaptive strategies concerning especially growth and reproductive traits) and these factors must also be included in biological indicators.

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