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Use and limits of three methods for assessing fish size spectra and fish abundance in two tropical man-made lakes

Céline Coll [a], Luis Tito de Morais [b], Raymond Laë [a], Anne Lebourges-Dhaussy [a,*], Monique Simier [b], Jean Guillard [d], Erwan Josse [a], Jean-Marc Ecoutin [c], Jean-Jacques Albaret [c], Jean Raffray [a], Justin Kantoussan [a]

[a] *IRD, Centre de Bretagne, BP 70, 29280 Plouzané, France*
[b] *IRD, Centre de Recherche Halieutique Méditerranéenne et Tropicale, BP 171, 34203 Sète, France*
[c] *IRD, Centre de Bel Air, BP 1386, Dakar, Sénégal*
[d] *INRA, Station Hydrobiologie Lacustre, UMR CARRTEL, BP 511, 74203 Thonon les Bains, France*

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Abstract

A comparative study, combining three different assessment methods (fish gillnet sampling, artisanal fisheries surveys and hydroacoustics) was conducted in Mali where two man-made reservoirs (Sélingué and Manantali) are particularly suited for investigating the impact of fishing effort on the fish assemblage. These two ecosystems have relatively similar areas, edaphic and environmental properties but are subjected to different levels of fishing exploitation (low at Manantali, high at Sélingué). The comparison is based on two indicator parameters: the abundance indices and the size spectra distributions, obtained by the three methods at two contrasting hydrological seasons (April and October). The results were compared first between the two seasons, and then between the two lakes. The present work is based on two main hypotheses: (1) that there is a higher fish abundance in October associated with smaller overall sizes, after spawning; (2) a lower abundance and smaller sizes in the Sélingué reservoir than in Manantali, because of the much higher fishing pressure in Sélingué. The relevance of each method to the selected indicators is discussed. On the one hand, the three methodologies on the whole gave similar conclusions and they also complement each other. On the other hand, some results do not match the hypotheses because of biases due to difficulties and technical limitations of each method in such ecosystems (shallow water with vegetation and stumps of former forests).

Keywords: Fish sampling; Artisanal fisheries; Hydroacoustic; Abundance estimate; Size distribution; Shallow waters; West Africa

1. Introduction

Fisheries management is based on the principle of the sustainable use of a renewable living resource and fisheries scientists are progressively switching their attention from single species to fish assemblages and ecosystems (Anonymous, 1999; ICES, 2000), increasing the need for biological indicators of fish assemblage health (Caddy and Mahon, 1995; Garcia and Staples, 2000). As a result, many indicators targeting various components of ecosystems have been developed, and used. In multi-specific fisheries, we generally note a reduction in numerical abundance and weighted biomass of targeted species in catches (Duplisea et al., 1997) and a shift towards smaller species and steeper slope of the size–abundance relationship (Gislason and Rice, 1998).

For assessing these parameters, authors have mainly focused on time series of experimental fishing and/or direct observations on fish biology (Rochet, 2000; Rochet and Trenkel, 2003). But in many countries and especially in developing countries experimental fishing and/or time series are rare. The data usually available are standard observations on commercial fisheries and monitoring periods are generally short, sometimes shorter than an annual cycle (Laë et al., 2004). In this case of poorly documented ecosystems, a multi-technique approach is required. In the present study, a comparative approach was developed in Mali between two man-made reservoirs (Sélingué and Manantali) that have highly contrasting levels of fishing effort, combining three different assessment methods:

* Corresponding author.
E-mail address: Anne.Lebourges.Dhaussy@ird.fr (A. Lebourges-Dhaussy).

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- *Fish gillnet sampling*: Gillnets were used in this work since they are widely used in many fish studies and despite several pros and cons discussed below, they have proved to be efficient tools for accessing the fish communities of lakes (Appelberg, 2000; Bonar et al., 2000). Here, the sampling gear consists of a gang of gillnets which are treated as a single gear in the statistical analysis.
- *Statistical data of artisanal commercial fisheries*: When fishing pressure is high (number of fishermen/km^2 >2), some authors have demonstrated that due to the use of a broader range of fishing gears, fishing selectivity (both species and size) was lower and fish catches reflected the composition of the fish assemblage (Laë, 1997a,b; Halls et al., 2006).
- *Hydroacoustic*: Although acoustic methods have been used for studying fish populations for several decades in the sea (Simmonds and MacLennan, 2005) and in lakes (Argyle, 1992; Brandt, 1996; Milne et al., 2005; Wanzenböck et al., 2003), these methods have been used more recently, particularly in tropical waters (Prchalová et al., 2003; Getabu et al., 2003; Krumme and St-Paul, 2003) and for environments such as estuaries, large rivers, shallow lakes and streams (Thorne, 1998; Mulligan, 2000). The miniaturization and the general improvement of the hardware in the echosounder systems and the improvement of the signal-to-noise ratio, related to the development of electronics, have made it possible to use them in shallow waters.

The present work is based on two main working hypotheses:

(1) Most of spawning takes place at the lowest water level season (May) and is followed by the new generation, this is expected to result in higher fish abundance (number of individuals) in October associated with smaller overall sizes (Benech and Dansoko, 1994; Paugy and Levêque, 1999).
(2) Because of the much higher fishing activity in Sélingué than in Manantali, lower abundance and overall smaller sizes are expected in the Sélingué reservoir than in Manantali.

In order to check the consistency between these hypotheses and the results obtained by each method, two seasons will first be compared, then the two lakes.

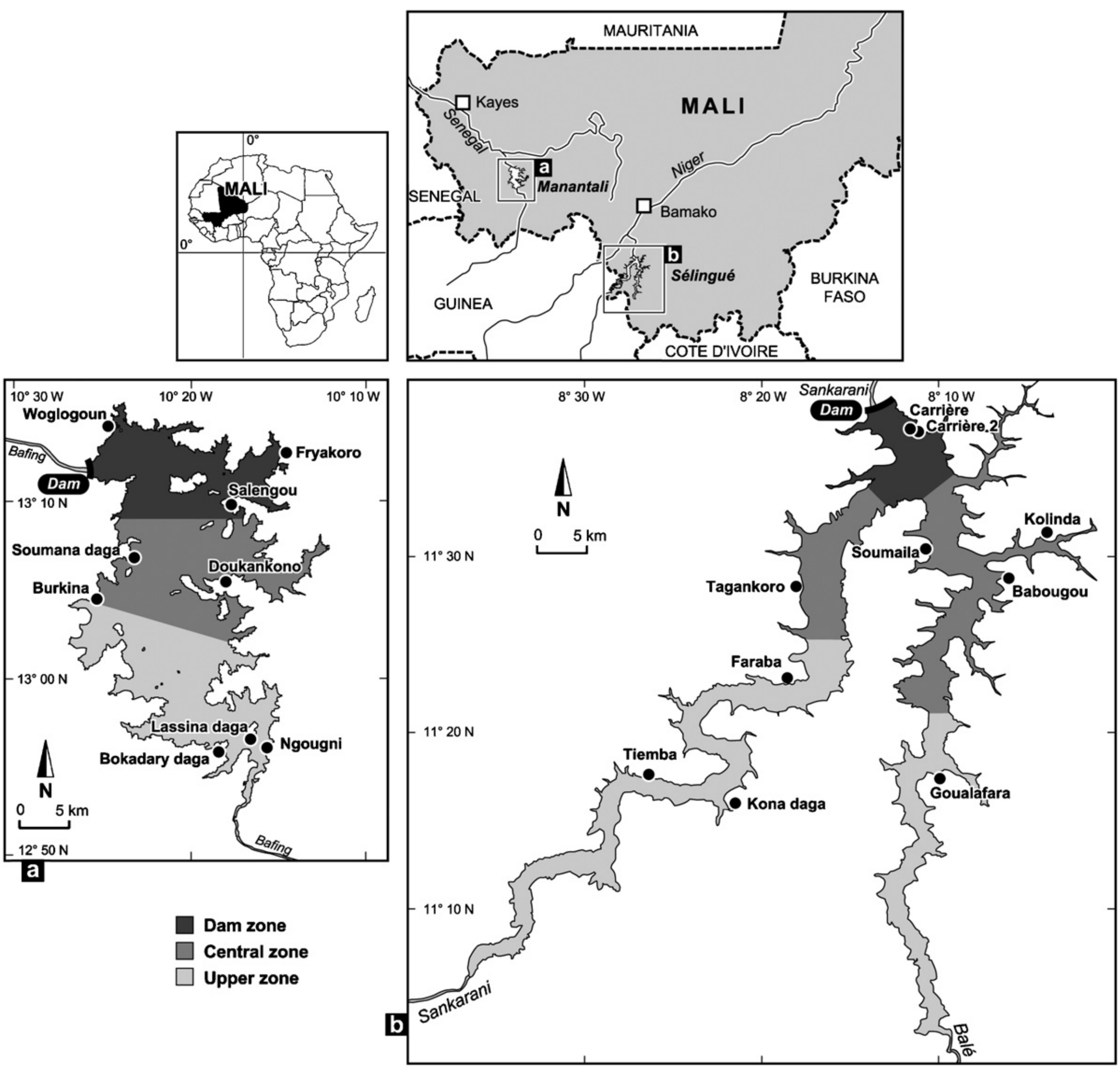

Fig. 1. Location of the two study sites: Manantali (a) and Sélingué (b) Lakes and general maps of the two lakes.

Our aim is to expose the difficulties and technical limitations of each method in such ecosystems, to study their complementarities and their relevance to the selected indicators. The final goal of these experiments is to improve fish stock assessment and management in artificial reservoirs environment, by a three-method approach leading to a better knowledge of fish stock characteristics.

2. Study sites

This study is based on the surveys of two man-made reservoirs in Mali (West Africa): Sélingué Lake and Manantali Lake. Preliminary results on artisanal fisheries in these two reservoirs have already been reported (Laë and Weigel, 1995a,b).

The two reservoirs have similar characteristics (Fig. 1): they are both relatively recent (Sélingué Lake was completed in 1980 and Manantali Lake in 1987) and they have similar lengths (80 km), and areas (approximately 400 km^2). 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 (Fig. 2). The explanation for the two hydrological cycles being in phase, although the two lakes are fed by two different watersheds (Niger and Senegal), comes from the fact that the two rivers have their source at the same place in the "water tower" of West Africa: the Fouta Djalon area.

Because of partial deforestation, many stumps, rocks and plants hinder fishing, particularly at Sélingué. The fish species present in the two lakes are overall the same ones as those listed in the inland Delta of the mid-Niger River. In the Sélingué Lake, this is because when the reservoir was completed, the Niger River species colonized the reservoir. In the case of the Manantali Lake, which belongs to the Senegal River watershed, this is explained by the fact that the fish assemblages in the upper Senegal and mid-Niger rivers greatly overlap (Levêque et al., 1992).

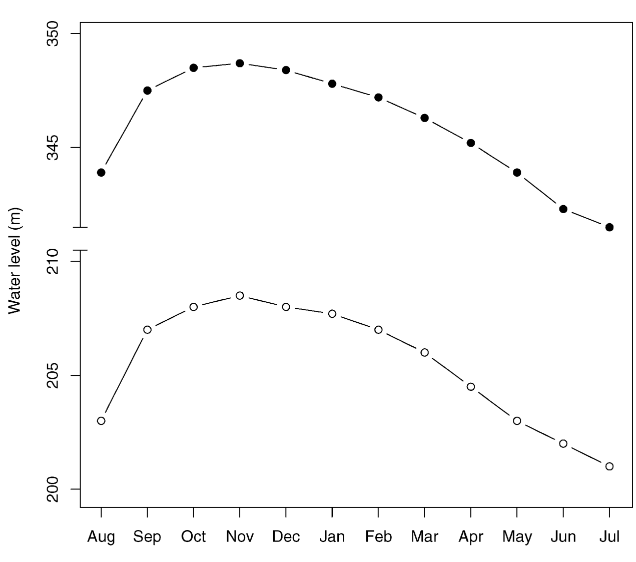

Fig. 2. Monthly water level variation in the two lakes (meter above sea water level). The *Y*-axis has been truncated to allow the presentation of both curves on the same graph. Sélingué: solid circles (upper curve), Manantali: open circles (lower curve).

However, the width and mean depths of the two lakes are different: 3–8 km and 5 m for Sélingué and 6–8 km and 21 m for Manantali, respectively, at the end of the dry season. The maximum depths are 20 m in Sélingué and 60 m in Manantali. The trophic status of the two reservoirs is also different: Sélingué Lake is considered to be mesotrophic (Arfi, 2003) while Manantali Lake is oligotrophic (Alhousseini, 1999). Another difference lies in the fishing effort in these two lakes: Manantali reservoir is located in an isolated region in the west part of Mali and access to markets is difficult, leading to low fish exploitation. On the contrary, Sélingué reservoir is close to the major markets of the capital, Bamako, and as fish demand is high, fishing effort is intensive.

3. Material and methods

3.1. Experimental procedure

In order to describe the space-time variability of fish populations, two acoustic and scientific fishing surveys were carried out in 2003 during the two contrasting hydrological seasons: April, which is in the low water level season and October, which is in the end of the rainy season. Meanwhile an annual survey of artisanal fisheries was set up between 2002 and 2003. At both periods, the acoustical equipment and sampling strategy were the same. Data were collected in most parts of the lakes (Table 1), yet the sampling coverage was more complete near to the dams, which were better deforested than the other zones; the dam zones are of about the same area of 100 km^2.

3.1.1. Fish gillnet sampling

Sampling was carried out using monofilament gillnet panels of five different mesh sizes joined together to form a gang treated hereafter as a single fishing gear. The mesh sizes used follow a geometric series of about 1.5 to cope with the increase in variance in selectivity with increasing mesh size (Holst et al., 1996): 10, 15, 22.5, 45 and 80 mm from knot to knot. Each single mesh panel was 25 m in long and 3 m in height. Each gang therefore had a fishing area of 375 m^2. As stated by Holst et al. (1996), "Interaction between nets can occur in the same gang since the efficiency of one mesh size may be affected by adjacent mesh sizes. For instance, leading effects can occur for larger fish which can be guided along small mesh sizes until they are captured by a larger one. These problems can be minimized by disposing the different mesh sizes at random within each gang, and leaving gaps between them instead of tying them end-to-end". Gangs where thus mounted leaving gaps between each of the five panels and six gangs with pseudo-random different sequences of panels were used simultaneously. At each sampling site the six gangs were set overnight (approximately 12 h), three gangs being placed near the bottom and three near the surface. Each zone of the lakes was divided into 12 sites with approximately equal area and four sampling sites in which sampling

Table 1
Sampling effort for each assessment method and each zone (see Fig. 1 for the location of zones)

Method	Manantali						Sélingué									
	Dam zone		Central zone		Upper zone		Dam zone		Sankarani central zone		Sankarani upper zone		Balé central zone		Balé upper zone	
	April	October	April	October	April	October	April	October	April	October	April	October	April	October	April	October
Fish sampling (number of 75 m^2 gillnets panels period^{-1} sector^{-1})	120	120	120	120			120	120	120	120						
Artisanal fisheries (number of fishing units sampled at the landing places)	425	300	508	469	586	406	346	66	501	196	281	300	433	271	99	73
Acoustical surveys (total transect length, km)	142	58	126	66		73	103	36	74	34	4	12	26	38		6

was actually performed were randomly chosen. The sampling unit per zone thus corresponds to $375 \times 6 \times 4 = 9000\ \mathrm{m}^2$ of fishing nets. Due to limitations in accessibility, time and costs, only two areas in each reservoir were actually sampled: the dam and central zones in Manantali, and the dam and central zones on the Sankarani side in Sélingué. Individuals were identified to species level and individual lengths (±1 mm) were recorded.

3.1.2. Artisanal fisheries surveys

Information on fish resources and fishing effort was collected from studies of fishermen's activities. Data were obtained by sampling small-scale fisheries during a complete annual cycle from May 2002 to May 2003. The study period spanned one hydrological cycle of the lakes, which also corresponded to one biological cycle for the fish and fishery.

The sampling design used on the two lakes involved not entirely random survey procedures. In addition to a first level of geographical stratification with three zones identified at Sélingué (the dam, Sankarani and Balé zones) and Manantali (the dam, central and upper zones), the choice of fishing villages sampled was based on a reasoned procedure (by quota), to ensure that all the fishing techniques (gillnets, seine nets, long lines, etc.) were represented within each stratum while taking into account purely practical constraints such as reducing access costs. Nine settlements were selected at Sélingué, including two in the dam zone (Carrière, Carrière2) and nine at Manantali including three in the dam zone (Woglogoun, Fryakoro, Salengou). These settlements that were regularly distributed on the two lakes accounted for 72% of the fishing population working on the Sélingué reservoir and 77% of those on Manantali. The fishing unit used was the active fishing canoe making a real contribution to fishing effort.

Each fishing settlement was monitored for 10 days per month. The information collected on the fishing activities and the catches was obtained from three main operations:

- A general survey of fishing units in all the fishing villages at the start of the survey followed by monthly censuses of the units present in the study villages.
- An estimation of the fishing effort and monitoring of its space-time variations. For each study village, the daily activities of 10 randomly selected fishing units were monitored by an enquiry each evening on the activities conducted during the day.
- 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 space-time stratum. The surveys were conducted on the population of boats unloading.

For this study, we just used the data for two extended periods corresponding to the fishing sampling and the acoustical surveys: (1) September to November 2002 for October; (2) March to May 2003 for April. The 3 months per season provided a significant number of questionnaires: the period survey resulted in the collection of data on 412 landings at Sélingué and 745 at Manantali and 600 daily activity questionnaires at Sélingué and 900 at Manantali.

3.1.3. Acoustical surveys

The acoustic prospecting was conducted in the day-time, for security reasons, with SIMRAD portable equipment at 70 kHz: an EK60 echosounder with a split-beam transducer opening at 7° (angle at −3 dB) and transmitting vertically. The installation of the transducer and of the equipment was designed to be easy to move and transport by car. A pole was installed vertically on the side of the boat with the transducer fixed to the lowest end. Because of the shallow level of water in Sélingué Lake, the pulse duration was set to 0.256 ms leading to a minimum distance between reflectors of 19.2 cms to be separated. The transmitted power was set to 500 W and the ping rate to "maximum". This choice for the ping rate has been dictated by the need to get as much information as possible on the shapes of the reflecting objects that can be trees or branches as well as fish schools, and by target tracking needs at rather short distances. A PC controlled the echosounder, which was connected to a GPS, data were stored on the hard disk and regularly saved onto CD-ROM; the whole system being powered by a 12 V battery. On and off-axis calibrations were carried out before the surveys in an experimental tank (IFREMER, Brest, France) using a copper calibration sphere and following the standard SIMRAD EK60 protocol. They have been controlled on-axis during each series of acoustic surveys. We got a good stability over the whole experimentation period.

According to the shapes of the lakes, the aim was to conduct acoustic prospecting along parallel transects in Manantali and along zigzag transects in Sélingué, in order to cover a maximum area while crossing the various types of environments related to bathymetric variations (banks and bed). The trajectories were however adapted to the topography and to the presence of trees and branches on the way. The distance prospected was 140 km at Sélingué and 200 km at Manantali for the dam zones.

Two fixed stations of 24 and 18 h durations, have been performed in the Sélingué Lake during the dry season survey, one in the river bed at the Carrière point (12 m deep), the other one near the dam outside the river bed (6 m deep) in order to observe the fish vertical behaviour. It has not been possible to do the same in the Manantali Lake, because of the meteorological conditions during the surveys; only a piece of transect has been realized by night.

3.2. Post processing and data analysis

3.2.1. Post processing of fish sampling data

Unlike the other methods, fish sampling data were not subjected to any particular post processing. No correction for gear selectivity was used. Following field sampling, raw data were stored in a database, from where they could be retrieved for further analysis.

3.2.2. Post processing of artisanal fisheries data

Fishing effort data and fish landing data collected by the survey network were extrapolated to the Sélingué and Manantali dam zones using descriptors of the fishery, such as the number of fishing units classified as full-time and part-time fishermen, which had been estimated during a preliminary survey of the whole lakes. The extrapolation was given by:

$$C = \sum_{Z}^{1}\sum_{G}^{1}\sum_{M}^{1}\left(\mathrm{UP}\, J\left(\frac{s}{p}\, j\right)\mathrm{CPUE}\right)$$

where C is the total catches, UP the number of fishing units in the zone, J the number of days of the month, s the number of trips during the sampling period, p the number of fishermen sampled, j the number of days sampled, CPUE the catch per unit effort for one fishing gear in one area for 1 month, Z the number of zones, G the number of types of gear and M is the number of months.

The extrapolation was made in order to assess the total fish catches in the two lakes and consequently in the dam zones. It could be done in this way even with migration of fishermen, because the monitoring of the fishery produced monthly information on the number of fishermen, fishing activities, CPUE and catch per species for each fishing gear in the three zones of each lake.

3.2.3. Post processing of acoustic data

The EK60 raw data have been stored through this SIMRAD software. The EK60 software has been also used for the isolated targets selection and individual target strengths (TS) estimation using the EK60 classical functionalities. Compensated target strengths are thresholded at −50 dB. Echo integration processing (threshold at −60 dB) and target tracking were performed by means of the Movies+ software (Berger et al., 2003). The thresholds were chosen during readings in order to avoid non-fish echoes. In Movies+, the tracking criteria were set to a maximum number of consecutive missing pings equal to zero and a minimum number of consecutive pings to consider them as a track equal to three pings. The elementary sampling unit (ESU), that is the distance over which the echo integral is cumulated to give one sample, was variable according to the transect length. Indeed, transects were divided into bank–bed–bank with a whole number of ESUs in each section. The very shallow mean depth of the Sélingué Lake may have been a drastic limitation in the TS measurements use. But in the dam zone, in April, when the water is the lowest, 94% of the fish tracks are issued from individual detections made in the river bed which is 15 m deep. In October, 24% of the tracks come from the river bed, but at this season the mean depth in the dam zone is 10 m.

A classification of the detections was necessary prior to an estimation of biomass, in order to separate the vegetation (trees and branches) from the animal (fishes) constituents of the field. This classification was made visually, as no automatic tool can, for the moment, give a satisfying separation of the detections, that the human eye is capable of.

The acoustic estimate of the fish density is expressed through the area scattering coefficient sA in $m^2\,km^{-2}$ instead of the NASC in $m^2\,nmi^{-2}$ (MacLennan et al., 2002). It quantifies the amount of a unit area (1 km^2 here) which is occupied by fish, taking into account the whole water column.

For subsequent comparison needs with the fishing operations results, it was necessary to make a conversion from fish tracked TS values in dB to fish lengths in centemeters. The main difficulty in this exercise lies in the wide diversity of fish species in the lakes (between 30 and 40 species) and in their large size extent. In such a context, there is no way of using a specific TS–length relationship. The more general formula, in terms of number of species and frequencies tested, has been thus chosen, that is the Love's 71 model. It provides the following conversion equation:

$$L = 10^{[(\mathrm{TS}+0.9\ \log 10(F)+62.0)/19.1]}$$

where L is the fish length (cm) and F is the frequency (kHz) (here $F = 70$)

3.2.4. Analysis of the whole data set

Following Persat and Chessel (1989), a factorial correspondence analysis (hereafter COA) was performed on length frequency distributions to achieve an overall description of the size spectra of fish in the whole lake at the study periods. This method allows to highlight groupings or contrasts between samples according to their size spectra. Here a "sample" was defined by a given method (acoustical survey, fish sampling or artisanal fisheries survey) used at a given period (April or October) in a given zone in a lake (Manantali or Sélingué). The input table had 34 rows (the number of distinct quadruplets of lake/zone/method/period actually available according to the results obtained) and 23 columns (size classes with 20 mm intervals from 50 mm up to 480 mm, larger individuals above 480 mm being grouped into a single class). Each cell contains the number of individuals of a given size class caught in a given sample.

Subsequent analyses were only performed on the data from the dam zone as this was the most completely sampled by all three methods.

Histograms of size frequencies were plotted and superimposed to assess the differences between size spectra built by the different methods. In the artisanal fishery statistics for Sélingué, less than 0.5% of the fish are larger than 48 cm and still ten times less exceed 1 m long. Even if the proportions are biased, this indicates a weak quantity of very large fish, those ones for which the TS measurements are critical at short distances.

Abundance indices of all pooled species were calculated as CPUE and expressed in kg period^{-1} for fish samplings and in kg trip^{-1} for artisanal fisheries. Acoustic abundance indices were expressed in m^2 km^{-2}.

4. Results

Beforehand to acoustics/fishing comparisons, which raise the difficulty to compare day-time acoustical data to night-time fish-

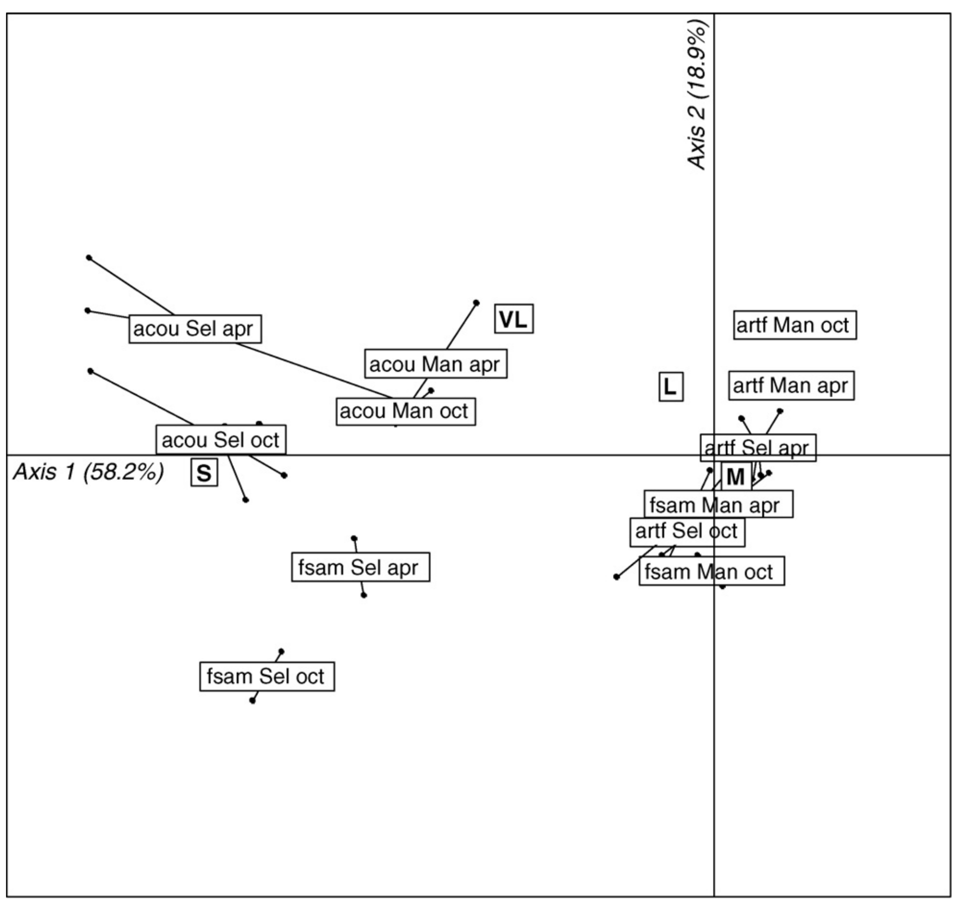

Fig. 3. Correspondence analysis of size spectrum histograms. Bi-plot of the ordination on factorial Axes 1 and 2 of both rows (method/lake/zone/period quadruplets) and columns (size classes). Size classes are represented by the centre of gravity of pooled classes. *S*: small (50–89 mm), *M*: medium-sized (90–249 mm), *L*: large (250–489 mm) and VL: very large (≥490 mm) individuals. Dots representing row quadruplet values at different sampling locations within lakes are grouped and labelled by method (fsam: fish sampling, artf: artisanal fisheries, acou: acoustical surveys), lake (Sel: Sélingué, Man: Manantali) and period (apr: April, oct: October).

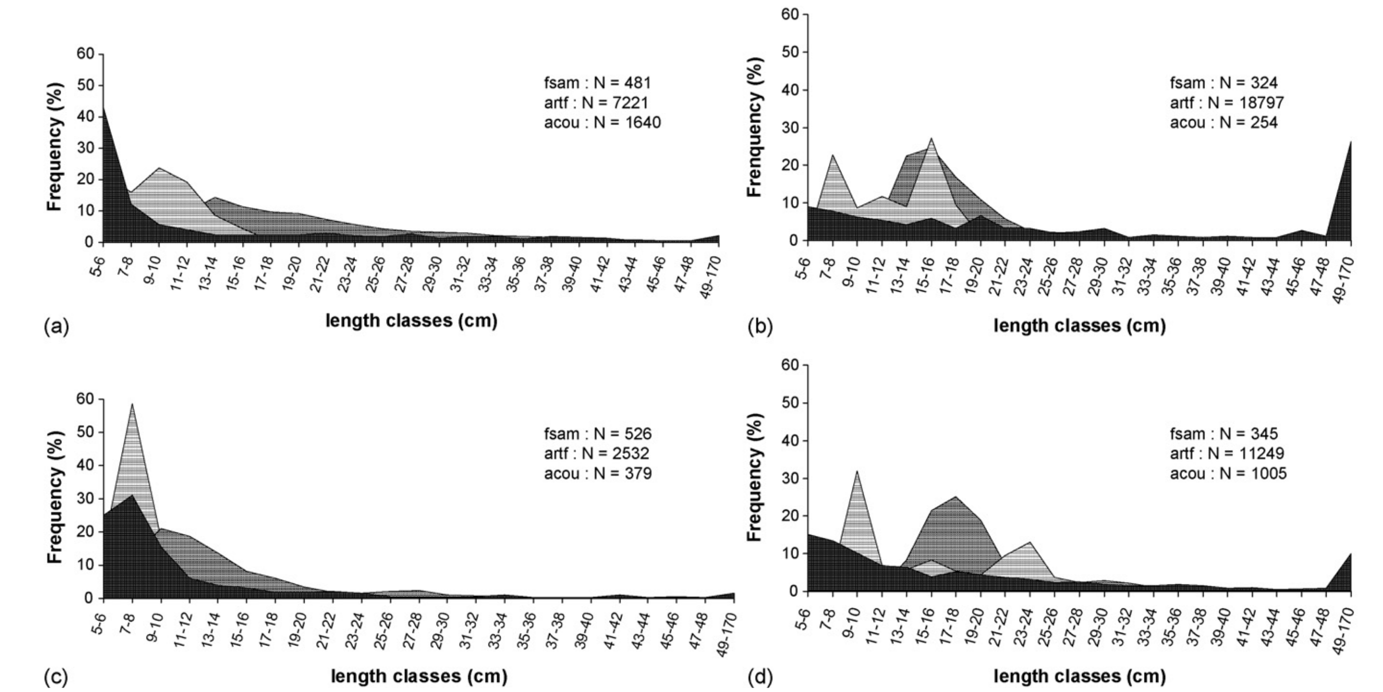

Fig. 4. Dam zones. Size spectra histograms in percentage of the number of sampled fish. (a) Sélingué in April, (b) Manantali in April, (c) Sélingué in October, (d) Manantali in October. Light grey: biological samplings (fsam), medium grey: artisanal fisheries data (artf), dark grey: acoustical surveys (acou).

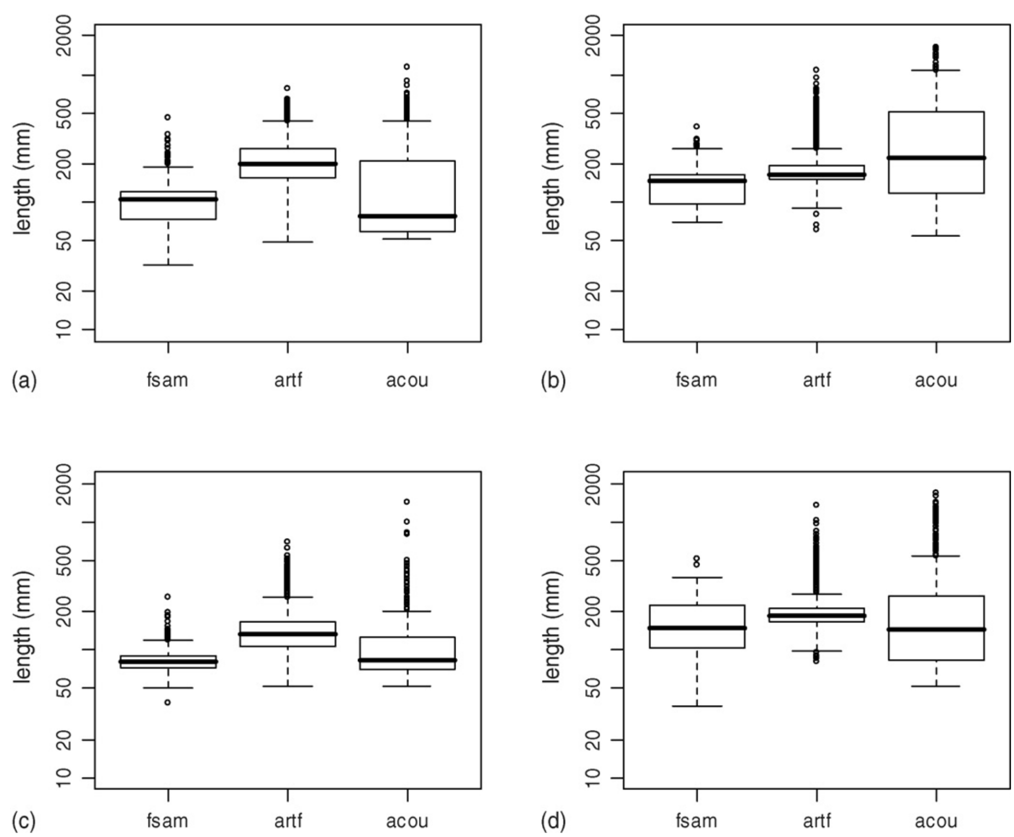

Fig. 5. Dam zone. Box-plots of individual lengths (mm; logarithmic scale) by lake, period and methods: fish sampling (fsam), artisanal fisheries data (artf), acoustical surveys (acou). On these box-and-whisker plots the central box covers the middle 50% of the data values, the "whiskers" extend to those points that are within the 1.5 time the interquartile range and other points are outliers; the central line is at the median). (a) Sélingué-April; (b) Manantali-April; (c) Sélingué-October; (d) Manantali-October.

Table 2
Dam zones: summary of the comparison of size spectrum histograms from Fig. 4 and median length values from Fig. 5 (dam zones)

Method	Between seasons comparison "sizes in April are larger than in October"		Between lakes comparison "sizes in Sélingué are smaller than in Manantali"	
	Manantali	Sélingué	April	October
Fish sampling	No/yes	Yes/yes	Yes/yes	Yes/yes
Artisanal fisheries	No/no	Yes/yes	Yes/no	Yes/yes
Acoustical surveys	Yes/yes	Yes/no	Yes/yes	Yes/yes

Yes/no indicate whether the pattern of the size spectra and the median length values respectively match or not the working hypothesis (in quotation marks).

ing data, fish behaviour from day to night has been observed during the two fixed stations performed in Sélingué. In both cases, the concentrations (more or less dense layers or schools with fish around) that are visible during the day in the deeper half of the water column disperse clearly at the beginning of the night, occupying rather the whole water column, and then concentrate back at sunrise towards the same patterns as the day before. These observations indicate that the same fish are encountered by day and by night, but in various organizing structures. In Manantali a piece of transect that has been covered by night, showed a fish distribution by night equivalent to what it is by day (J. Guillard, unpublished data).

4.1. *Size distributions*

4.1.1. *General overview in the two lakes*

Fig. 3 is the bi-plot of the ordination on factorial Axes 1 and 2 of both rows (method/lake/zone/period quadruplets) and columns (size classes) of the COA. To increase legibility, size classes are represented by the centre of gravity of pooled classes representing small (50–89 mm), medium-sized (90–249 mm), large (250–489 mm) and very large (≥490 mm) individuals. Dots representing row quadruplet values at different sampling locations within lakes are grouped by method, lake and period, joined by lines and labelled.

Axis 1 (58.2% of total inertia) discriminates between medium-sized and large fish (close to the origin), very large fish on the left-hand side and small fish in the left-most position. Axis 2 discriminates between small and medium-sized fish and large and very large fish (in the upper part of the graph). Fish sampling in Manantali and artisanal fisheries in both lakes are characterized by large and medium-sized individuals while fish sampling in Sélingué are characterized by small fish and acoustical surveys by both small and very large fish.

4.1.2. *Size spectra in the dam zones*

The size spectra histograms given in Fig. 4 show the specific size ranges sampled by each method and how they overlap. This allows visual comparison of size spectra between seasons within each lake and between lakes at distinct seasons. Fig. 5 shows the box-and-whisker plots of fish lengths per lake and period for each assessment method. Table 2 summarizes the conclusions inferred from Figs. 4 and 5, according to the histogram pattern and median values.

4.1.2.1. Between seasons comparison. In Sélingué (Fig. 4a–c), the size spectra obtained by the three assessment methods match the working hypothesis that the size spectrum in April is shifted towards larger sizes than in October. The median value is actually larger in April than in October in both fish samplings and artisanal fisheries data but not in acoustical surveys (Fig. 5 and Table 2).

Conversely, in Manantali (Fig. 4b–d), the artisanal fisheries never match the working hypothesis, while acoustical surveys do. Size spectra from fish samplings do not match the working hypothesis, while median values do (Fig. 5 and Table 2).

4.1.2.2. Between lakes comparison. In April (Fig. 4a and b), the size spectra obtained by both fish sampling and acoustical surveys were narrower and shifted towards the small sizes in Sélingué. They were wider and shifted towards the large sizes in Manantali. Size spectra patterns from artisanal fisheries were apparently also shifted towards larger sizes in Manantali than in Sélingué but their median fish size was lower in Manantali than in Sélingué (Fig. 5 and Table 2).

Conversely, in October (Fig. 4c and d), the three methods gave consistent results that matched the second working hypothesis that the size spectrum in Sélingué is shifted towards smaller sizes

Table 3
Dam zones: percentage abundance of small (*S*: 50–89 mm), medium-sized (*M*: 90–249 mm), large (*L*: 250–489 mm) and very large (VL ≥ 490 mm) fish per lake and period for each assessment method (dam zones)

Method	Manantali								Sélingué							
	April				October				April				October			
	S	*M*	*L*	VL	*S*	*M*	*L*	VL	*S*	*M*	*L*	VL	*S*	*M*	*L*	VL
Fish sampling	13.9	82.1	4.0	0.0	0.9	84.6	14.2	0.3	29.1	69.0	1.9	0.0	49.8	50.0	0.2	0.0
Artisanal fisheries	0.0	90.3	9.2	0.5	0.0	84.9	14.5	0.6	0.4	72.9	25.5	1.2	10.3	80.7	8.8	0.2
Acoustical surveys	15.0	39.0	19.3	26.8	21.9	49.4	18.5	10.2	51.8	27.5	18.3	2.4	43.3	48.3	6.9	1.6

100% is the total abundance of fish obtained by each method, all sizes included.

Table 4
Dam zones: abundance indices in specific units for each assessment method (dam zones)

Method	Manantali		Sélingué	
	April	October	April	October
Fish sampling (kg $period^{-1}$)	15.0	28.1	13.5	5.6
Artisanal fisheries (kg $trip^{-1}$)	18.9	13.2	7.5	4.4
Acoustical surveys ($m^2\,km^{-2}$)	11.0	66.1	134.9	56.1

than in Manantali both in size spectra patterns and median fish size values (Fig. 5 and Table 2).

4.2. Abundance indices in the dam zones

The percentage abundance of small (*S*: 50–89 mm), medium-sized (*M*: 90–249 mm), large (*L*: 250–489 mm) and very large (VL ≥ 490 mm) fish per lake and period for each assessment method are shown in Table 3. For artisanal fisheries, the highest percentage abundance always corresponded to medium-sized fish. The medium-sized group remained dominant in the results from the other assessment methods. However, other size groups were also well represented, particularly small-sized fish in Sélingué. As a rule, acoustical surveys gave a broader picture of the size groups distribution than artisanal fisheries surveys and fish sampling.

Table 4 gives the abundance indices (all sizes pooled) calculated by the three assessment methods for each lake and at each season.

4.2.1.1. Comparison between lakes at each season

In April, the indices calculated from fish samplings and from artisanal fisheries surveys match the working hypothesis that abundance was lower in Sélingué than in Manantali. Acoustical surveys gave very different results that do not match the working hypothesis.

In October, all three assessment methods matched the working hypothesis. However, acoustical surveys only indicated a slightly but lower abundance in Sélingué than in Manantali.

4.2.1.2. Comparison between seasons within each lake

In Sélingué, all assessment methods gave similar results, but did not comply with the working hypothesis that abundance was lower in April than in October.

In Manantali, the methods differ. Fish samplings and acoustical surveys matched the working hypothesis while artisanal fisheries surveys did not.

5. Discussion

5.1. Size distributions

It appears clearly from the analysis of size spectra that each method gives a different representation of the fish population. Nevertheless, the overall analysis (Fig. 3), as well as the more comprehensive results obtained in the dam zone in both lakes (Figs. 4 and 5; Tables 2 and 3), are on the whole consistent regardless of the method used. Fish sampling and artisanal fisheries landings focus mainly on a given size interval (medium-sized to large fish), whereas for the scientific fish sampling this interval was wider than that of the artisanal fisheries. This close relationship between artisanal fisheries landings and the large and medium-sized classes is related to the fact that fishermen always tend to capture fish in this size range, disregarding small fish and seldom capturing large fish due to their scarcity. Scientific fish samplings also capture many small individuals (particularly in shallow water conditions as in Sélingué), but do not give a complete representation of the size spectra, either. The very large individuals are only detected by acoustical surveys which are able to sample the whole pattern of the existing sizes. Yet, as a rule, in both acoustic and scientific fishing samples, the Sélingué reservoir is characterized by smaller sizes than Manantali. This reflects the removal of medium-sized and large individuals by artisanal fisheries in Sélingué, as stated in our working hypothesis.

Furthermore, the size distribution obtained from acoustical data matches the first hypothesis that the size spectrum in April is shifted towards larger sizes than in October for both lakes, while the hypothesis is confirmed by the two fishing techniques in the Sélingué Lake but not in the Manantali Lake. The fishing tools used by the artisanal fishery are not suitable for catching fish in deep water. The larger fish being more often deeper than the smaller ones, the accessibility of the large sizes is reduced in Manantali. As for fish sampling, the second peak observed at Manantali corresponding to a higher mode in October, is probably made up of individuals from the previous year that have not been captured and that have grown since.

5.2. Abundance indices

It must be specified first that the acoustical measurements are more related to an area density per unit space occupied by fish than to their abundance in terms of number of individuals, and transforming from one type of variable to the other in such a multi-specific environment is only a rough indication of numerical abundance. On the other hand, the hypotheses are expressed in terms of number of individuals.

From the acoustic and fish sampling data, the seasonal changes in indices in Manantali behave as expected under the hypothesis that abundance is lower in April than in October. Conversely, the artisanal fisheries surveys indicate a more uniform pattern of abundance with a slightly higher abundance in April. In the Sélingué Lake an image opposite to the hypothesis is given by all three methods. This is to be related to both the specific limitations of each given method and alterations in fishing activity in relation to water level changes. During the low water level period (April) the morphological changes are greater in the Sélingué Lake, due to a lower average depth, than they are in Manantali. The margins of the Sélingué Lake become very shallow over large areas and fish concentrate over a much smaller area, mostly associated with the former river bed. The indices measured here reflect density rather than abundance. Fishermen take advantage of this situation and exploit the higher catchability of fish at this period. Besides, marginal areas are more difficult to access by the acoustical surveys and scientific fish sampling, due to the shallow water and the presence of dead trees. In the Manantali Lake, the variation in water level between seasons is lower and the margins are much more abrupt than in Sélingué and remain accessible to acoustic and experimental fishing at all periods. The phenomenon of concentration along the former river bed is less marked than in Sélingué. The artisanal fisheries, even though more efficient in April than in October, give rather similar abundance indices at both periods.

Moreover, the second hypothesis that abundance is lower in Sélingué than in Manantali is confirmed by the three methods, except in April with the acoustical data. At this period, a large part of the Sélingué Lake area was not accessible for prospecting and the strong densities observed show a high fish concentration in the former river bed of Sélingué.

The three methodologies are on the whole similar and they also complement each other. Nevertheless, due to the observed differences between seasons, comparisons between lakes are more reliable than are within-lake comparisons at distinct seasons. In the latter case, as stated above, some of the results do not match the hypothesis.

5.3. Biases inherent to the assessment methods

5.3.1. Fish gillnet sampling

Fish sizes lacking in the gillnet samples, are actually present in the population and were obtained by other assessment techniques. Yet, despite the inherent biases of experimental fish samplings, the use of suitable net gangs composed of a consistent panel of associated mesh sizes (not too many different mesh sizes), associated with a random sample design, contribute to reducing some of the main selectivity biases (Hamley, 1980). Experimental fish samplings are not sensitive for instance to other biases such as biases introduced in fisheries survey data by fishermen choices and the level of exploitation in different areas. Hydrological conditions and lake depth and morphology differences are another source of biases which are hard to reduce.

5.3.2. Artisanal fisheries surveys

Data from fish landings are generally considered as imperfect because of bad reporting of catches, discards and changes in fishing practices (Caddy and Garibaldi, 2000). These observations are justified and could seriously limit the use of fish landings for the assessment of fish assemblages. Nevertheless, artisanal fisheries in developing countries are generally characterized by: (i) the scarcity of discards especially in continental fisheries, (ii) the intensity of fishing activities and the rapid suitability of gears to the variations in abundance. Under these particular conditions fishing provides a good image of the available phase of the populations, on condition that fishing effort is significant. In fact 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. In the future for the processes of evaluation it will be necessary to take into account the intensity of fishing pressure knowing that for low values, the criteria of fishermen selection direct captures towards noble species, of large size and with a high commercial value.

5.3.3. Acoustical surveys

Even though in shallow water environment, horizontal beaming is usually recommended (Kubečka and Wittingerova, 1998; Knudsen and Sægrov, 2002), TS distributions are awkward to compute without knowledge of fish orientations in the acoustic beams, swimming motions, etc. Concurrently, vertical beaming provides quantitative data more easily usable (Guillard et al., 2004).

In the present surveys there was neither background noise problem nor multiple bottom echoes. The theoretical near field for the ES70-7C transducer is 73 cm so the far field is reached between 2.19 and 2.92 m (Lurton, 2002). With a short pulse length of 0.256 ms and a rather narrow beam aperture, the blind zone near the bottom equals about 20 cm.

However, acoustic estimations can be biased by phenomena related to fish behaviour. Particularly in very shallow water, escape reaction of the fish to the approach of the boat (Fréon et al., 1993) can affect the total amount of fish present in the water column, as most avoidance behaviour has been observed with fish smaller than 22 cm (−40 dB) at distances of less than 10 m (Draštík and Kubečka, 2005). Avoidance is expected to underestimate the fish biomass, but that affects particularly the schools (Guillard and Lebourges, 1998).

Escape reaction infers also a change in the fish inclination and so modifies the target strength measurements (Simmonds and MacLennan, 2005).

The fish organization has also an impact on the ability to resolve individual targets. Contrasted behaviours were observed: in the Manantali Lake fish are mainly scattered so isolated targets are available, while in the Sélingué Lake they are more often in small schools with some dispersed fish around the schools.

With both patterns of organization, a great mixing of species is expected. The validity of the conversion from “acoustic sizes” to fish lengths is thus a critical issue and the results must be seen as global information on the size range scanned by acoustics.

5.4. How the methodologies complement each other

For a given season, the combination of the three approaches used, net and fish landing samplings and the vertical echo sounding protocol, gave an image of the fish population in accordance with the working hypothesis, in terms of biomass as well as of size distributions.

We emphasize the obvious interest of the acoustical method, with its reduced cost, except for the initial outlay of the equipment, whereas the use of traditional techniques is often expensive in time and manpower (Schramm et al., 2002). Its additional quality is the quick data acquisition and its ability to provide an exhaustive view of the ecosystem by non-destructive means. The methodological limitations in this type of ecosystem are less now thanks to technological improvements, nevertheless there still remain some particular difficulties: the need for simultaneously collecting biological data for species identification purpose, the impossibility of sampling zones too shallow or too overgrown, fish avoidance, small sampling volume, target strength estimates at short distance, classification between animals and vegetation. The general difficulty of sampling close to

Table 5
Fish species sampled by the artisanal fishery and by the experimental gillnets, in both lakes

Family	Species	Manantali Lake fish samplings	Manantali Lake artisanal fisheries	Sélingué Lake artisanal fisheries	Sélingué Lake fish samplings
Alestiidae	*Alestes baremoze*			+	+
	Alestes dentex			+	
	Brycinus leuciscus			+	+
	Brycinus macrolepidotus	+	+	+	+
	Brycinus nurse	+	+	+	+
	Hydrocynus brevis		+	+	+
	Hydrocynus forskalii	+	+	+	+
Anabantidae	*Ctenopoma kingsleyae*		+	+	
Bagridae	*Auchenoglanis biscutatus*			+	
	Auchenoglanis occidentalis			+	+
	Bagrus bajad		+	+	+
	Bagrus docmak	+	+	+	
	Chrysichthys auratus	+	+	+	+
	Chrysichthys nigrodigitatus		+	+	+
	Clarotes laticeps			+	
Bleniidae	*Paroblennius goreensis*				+
Centropomidae	*Lates niloticus*	+	+	+	+
Cichlidae	*Chromidotilapia guentheri*			+	+
	Hemichromis bimaculatus	+	+	+	+
	Hemichromis fasciatus	+	+	+	+
	Oreochromis aureus			+	
	Oreochromis niloticus		+	+	
	Sarotherodon galilaeus	+	+	+	+
	Tilapia zillii	+	+	+	+
Citharinidae	*Citharinus citharus*		+	+	+
	Citharinus latus			+	
	Distichodus brevipinnis		+	+	+
	Distichodus engycephalus			+	
	Distichodus rostratus		+	+	+
Clariidae	*Clarias anguillaris*	+	+	+	+
	Heterobranchus bidorsalis			+	
	Heterobranchus longifilis		+	+	
Clupeidae	*Pellonula leonensis*				+
Cyprinidae	*Barbus bynni occidentalis*		+	+	
	Barbus macrops				+
	Labeo coubie		+	+	+
	Labeo senegalensis		+	+	+
	Labeo parvus				+
	Raiamas senegalensis		+	+	+
Gymnarchidae	*Gymnarchus niloticus*		+	+	
Hepsetidae	*Hepsetus odoe*		+		
Malapteruridae	*Malapterurus electricus*		+	+	
Mochokidae	*Synodontis batensoda*		+	+	
	Synodontis filamentosus			+	+
	Synodontis membranaceus				+
	Synodontis nigrita	+	+	+	+
	Synodontis ocellifer	+	+	+	+
	Synodontis schall	+	+	+	+
	Synodontis sorex	+			
Mormyridae	*Campylomormyrus tamandua*			+	+
	Hippopotamyrus harringtoni			+	
	Hippopotamyrus pictus				+
	Hyperopisus bebe	+	+	+	+
	Marcusenius senegalensis	+	+	+	+
	Mormyrops anguilloides	+			+
	Mormyrops deliciosus		+	+	
	Mormyrus macrophthalmus				+

Table 5 (*Continued*)

Family	Species	Manantali Lake fish samplings	Manantali Lake artisanal fisheries	Sélingué Lake artisanal fisheries	Sélingué Lake fish samplings
	Mormyrus rume	+	+	+	+
	Petrocephalus ansorgii				+
	Petrocephalus bovei	+	+	+	+
	Petrocephalus soudanensis				+
	Petrocephalus tenuicauda			+	
Ostteoglossidae	*Heterotis niloticus*			+	
Polypteridae	*Polypterus endlicheri*			+	
	Polypterus senegalus				+
Protopteridae	*Protopterus annectens*			+	
Schilbeidae	*Parailia pellucida*			+	+
	Schilbe intermedius		+	+	+
	Schilbe mystus	+	+	+	+
	Siluranodon auritus				+
Tetraodontidae	*Tetraodon lineatus*	+	+	+	
Total number of species recorded		22	39	57	47

the limits (bottom, banks, very shallow areas) leads to a need to use additional techniques and to have some knowledge of the population distribution, to reach a whole description of the environment (Guillard, 1996). Acoustical methods also require some knowledge for processing. It is inextricably tied with the knowledge of the local fish species composition and diversity, to allow proper interpretation of data. It is thus seldom autonomous and requires the use of complementary methods (Guillard and Marchal, 2001). Optical equipment could be envisaged in such shallow environments, nevertheless in the case of the Sélingué reservoir, the water turbidity precludes the use of such a solution. The combined approach of vertical and horizontal sounding may be a good way of improving the image obtained.

Data from fish landings have, nevertheless, provided an important knowledge on the wide fish species diversity in both lakes (Table 5) and also the possibility of reaching large size classes which were not caught during the scientific fish sampling.

Among all indices listed above, the size spectrum and dominance structure are indeed valuable tools for assessing the ecosystem effects of fishing (Rice, 2000; Yemane et al., 2004). Fisheries-induced changes in the structure of fish communities have been documented for several fisheries. Nevertheless, the sampling biases introduced by changes in methodology during long-term surveys and site-specific or method-specific biases are generally not addressed or poorly documented in published papers. Our work shows that the interpretation of observed patterns or trends requires proper interpretation of the biases associated with the sampling or survey method. Our work may provide a framework to help address such issues in man-made reservoirs. The next step forward in our work should be to perform more in-depth studies of size-related indicators of fishing pressure in reservoirs in the light of the present study.

5.5. *Conclusion*

Associating the three methodologies (acoustic, experimental and artisanal fisheries surveys) provides patterns that cannot be inferred from only one of these methodologies and is therefore a good way to obtain indicators on the fishing pressure impact. The response of fish communities to fishing pressure relies on a good comprehension of the answers at various scales of the biological organization: individuals, populations and communities. In this context, the use of biological indicators must make it possible to establish a diagnosis of the state of the fish populations, communities and ecosystems in which they live.

Each method (scientific sampling, acoustic survey and artisanal fisheries survey) has its own limitations in such a difficult environment but they all contribute to the identification and calibration of biological indicators. In the future, for a better description and knowledge of this environment, a synergy between various approaches is really necessary, in particular because these environments are important areas for both fisheries and the conservation of biodiversity from human impacts.

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