Seasonal inter-calibration between acoustic and multi-mesh gillnets sampling for fish biomass assessment in reservoirs.

Houcine LAOUAR

Institut National Agronomique de Tunisie, 43, Avenue Charles Nicolle 1082, Mahrajène, Tunis
Tunisie (e-mail : houcine.laouar@gmail.com).

Imed DJEMALI (Corresponding author)

Institut National des Sciences et Technologies de la Mer, 28 rue du 2 Mars 1934, Salammbô, 2025,
Tunis, Tunisie (e-mail : Imed.Djemali@instm.rnrt.tn).

Summary

This paper presents the results of an inter-calibration between acoustic and gillnets sampling in two North African reservoirs according to seasons. Gillnets with multi-mesh were designed for sampling fish in lakes while acoustic surveys were performed with a split beam Simrad EK60 echosounder. Sampling events were carried out during summer (September 2015), autumn (December 2015), winter (March 2016) and spring (June 2016) in two Tunisian reservoirs (Kasseb and Siliana) with different depths and shapes. Gillnet catches showed a high proportion of barbell whatever the seasons in Kasseb Reservoir, while at Siliana Reservoir, significant seasonal changes in relative abundances have been evidenced. The highest fish biomass of the entire water column was observed in winter daytime (103 kg ha^{-1}) in Kasseb Reservoir and in summer daytime (283 kg ha^{-1}) in Siliana Reservoir. Average biomass observed in autumn (December) for the two reservoirs were lower than the other seasons. During spring, density daytime values in Kasseb were higher than during nighttime while it was the opposite in summer and autumn. Fish density detected in Kasseb Reservoir in vertical beaming was higher than those detected in horizontal beaming ($P < 0.05$). The longitudinal distribution of fish in the reservoirs showed that there is no clear trend in fish densities according to strata. High numbers of fish were detected in deep strata and big fish were located in the surface water near the dam of Kasseb Reservoir. A significant linear correlation was showed between acoustic density/NPUE and acoustic biomass/BPUE but the perfect correlation with the 1:1 fit was showed only between acoustic biomass/BPUE.

1 Introduction

In order to respond to an increasing demand for drinking water and irrigation, strategies have been drawn up by the Tunisian authority through the construction of reservoirs and hilly lakes. These man-made lakes, with a total area of 20.000 ha, are exploited secondarily for fishing as in other North African countries. Several introductions of various fish species from European and Moroccan freshwater have been carried out for their commercial value such as *Sander lucioperca*, *Silurus glanis* and *Micropterus salmoides* or to serve as forage fish such as *Rutilus rubilio* and *Scardinius erythrophthalmus*. More than 30 reservoirs are used for aquaculture and the numbers of operating boats exceed 250 with 500 fishers. Freshwater fish production is estimated to 1,200 t per year (DGPA, 2016). The sustainable management of this resource requires knowledge of its size structure and biomass.

Recently, hydro-acoustic has emerged as a reliable method. It is a non-destructive method that has no consequences on fish behavior and it is characterized by its fast investigation and fine description over large spatial scales. It also avoids biases related to accessibility, availability and catchability. Nevertheless, hydro-acoustic cannot distinguish between fish species hence the use of gillnet catches for validation and interpretation of acoustic data (Mehner & Schulz, 2002; Tátrai *et al.*, 2008; Emmrich *et al.*, 2012) is requested. Despite sampling of lake fish assemblages is a challenging task in fish science, gillnet sampling method was used to obtain relative abundance and length distribution of fish populations all over the world whether in natural (Encina & Rodriguez-Ruiz, 2003; Tátrai *et al.*, 2008; Emmrich *et al.*, 2012) or in man-made lakes (Vasek *et al.*, 2004; Loures & Pompeu, 2015; Mili *et al.*, 2016).

In this study, gillnet sampling and acoustic surveys were carried out in two Tunisians reservoirs with different depths and morphologies in order to (1) determinate the higher acoustic fish

biomass detectability according to season and photoperiod and (2) to inter calibrate the two methods of fish sampling.

2 MATERIEL AND METHODS

2.1 Study area

Kasseb Reservoir (36° 45' 32" N, 9° 0' 20" E) was filled in 1968. It belongs to the northern hydrological watershed of Medjerda (Beja, Tunisia) (Figure 1). The volume of this canyon-shaped reservoir fluctuated during this study between 55.46 and 62.23 Mm³ and the mean depth between 15.78 and 17.53 m (Table 1). The reservoir is mainly used as drinking water supply for the capital Tunis with 40 Mm³/year (Soudoud, 2006). The total phosphorus concentrations fluctuated from 0.003 to 0.2 mg L⁻¹ (mean ± s.d., 0.06±0.04 mg L⁻¹) and chlorophyll a concentrations ranged from 0.07 to 5.7 mg L⁻¹ (mean ± s.d., 1.0±1.1 mg L⁻¹) (Sellami *et al.*, 2009). Fishing statistics show the presence of pikeperch, mullet and barbell with an annual yield of 14.5 t (DGPA, 2016).

Siliana Reservoir (36° 09' 26" N, 9° 20' 55" E) was filled in 1978 on the southern hydrological watershed of Medjerda (Siliana, Tunisia) (Figure 1). During acoustic surveys, the reservoir covered an area between 269.2 and 305.3 ha and a volume between 7.05 and 9.63 Mm³ (Table 1). It provides irrigation waters for farmland in the Siliana area. Fishing statistics show the presence of pikeperch, mullet, barbell, carps and rudd with an annual yield of 56.5 t (DGPA, 2016).

2.2 Data acquisition and analysis

2.2.1 Gillnetting

A fish sampling method using multi-mesh gillnets inspired from the European standard CEN prEN 14757 (CEN, 2005) was adopted for qualitative study of fish populations. This technique is based on the use of benthic and pelagic gillnets which are made with non-colored monofilament and contain 8 different mesh-sizes ranging from 18 mm to 80 mm (Table 2). The mesh-sizes follow a geometric series, with a ratio of 1.25. Each net has a length of 20 m and the height of the benthic and pelagic nets was 1.5 and 6 m respectively (Mili *et al.*, 2016).

A stratified random sampling was used to take into account the irregular spatial distribution of fish in reservoirs. Samples were taken seasonally and gillnets were set overnight for approximately 12 hours. The benthic nets were implemented into different depth layers (0 – 2.9 m, 3 – 5.9 m, 6 – 11.9 m, 12 – 20 m and 20 – 34.9 m). A sampling effort of 24 and 56 gillnets per season, in Siliana and Kasseb Reservoirs respectively, was needed in order to detect 50% change in the relative abundance (CEN, 2005). Pelagic nets were put by pairs in the deepest area at multiple depths of 6 (surface, 6 m, 12 m...) but they were not used in the Siliana Reservoir due to its shallow depth. Gillnet catches were used to estimate the number of fish per unit effort (NPUE in fish/1000 m²) and the biomass per unit effort (BPUE in g/1000 m²).

During each season, water temperature and dissolved oxygen concentration were collected in the deepest point of each reservoir using a Wissenschaftlich Technische Werkstätten depth probe (Model oxi 197i; Nova Analytics, Weilheim, Germany).

2.2.2 Hydroacoustics

Acoustic sampling with "zigzag" design was performed on the two reservoirs. Surveys were carried out during summer (September 2015), autumn (December 2015), winter (March 2016) and spring (June 2016). Each reservoir was divided into three strata with same areas and different depths (Figure 1) in order to take into account fish density gradients (Djemali *et al.*, 2016).

We used a SIMRAD EK60 split beam echosounder operating at a frequency of 120 kHz. It was equipped with an elliptical transducer ($4^{\circ} \times 10^{\circ}$ angle at -3 dB level) in horizontal beaming which covered the water column from the surface to 3 m (surface layer), and a circular transducer (7° angle at -3 dB level) in vertical beaming which sampled depths from 3 m below the surface to the bottom (deep layer). The pulse duration was 0.256 ms, the transmitting power 500 W and the ping rate 10 pings s^{-1} with transducers beaming alternately (i.e. fast multiplexing at 5 pings per second per channel). Only horizontal beaming was analyzed in Siliana due to the shallow water of this reservoir. Echosounder was calibrated before each sampling using a copper calibration sphere following the protocol of Foote *et al.* (1987).

Data was processed by the Sonar pro-5 software (Balk & Lindem, 2006) to within 0.5 m of the bottom when down-looking and to a maximum range of 36 m when side-looking (Djemali *et al.*, 2016). Fish density was estimated using the echo-counting method. Single echo detections (SED) criteria were defined by 0.6–1.8 relative pulse width, one-way beam compensation of 3 dB, and maximum phase deviation of 8.3. Each target must be detected at least twice, couldn't contain more than two lost and the vertical distance between two successive positions of the target should not exceed 30 cm.

The echo target strength (TS in decibel, dB) from horizontal beaming was converted into fish total length (TL in cm) using pooled fish species mean equation of Frouzová *et al.*, (2005). The TS

thresholds were set at -70 dB. Smaller targets were considered as noise. Fish lengths were estimated from TS using Love's (1971) equation for vertical beaming (TS threshold = -70 dB). The length weight relationship to convert length fish into biomass came from gillnets catches (Table 3). Each zig transect was used as the elementary sampling distance unit (ESDU) (Jolly & Hampton, 1990). The average density and biomass obtained for each strata of the reservoir corresponded to the weighted average of the ESDU estimates (Sokal & Rohlf, 1981; Djemali *et al.*, 2010).

$$\bar{x}_p = \frac{\sum_{i=1}^{i=n} (B_i * A_{s_i})}{\sum_{i=1}^{i=n} A_{s_i}}$$

Where $\bar{x}_p$ is weighted average biomass (or density), n is the number of ESDUs per zone, B_i is the biomass (or density) along ESDU i and A_{s_i} is the sampled area of transect i .

Fish biomass and density of the entire water column were the sum of surface and deep layers along each ESDU (Kubecka & Wittingerova, 1998).

2.3 Statistical analysis

The acoustical fish length frequency distributions were compared on a diel basis for each season with the Kolmogorov-Smirnov (KS) non-parametric test (Sprent, 1992). This statistical test was also used in order to compare acoustical and gillnet catches fish length frequency distributions of the entire water column.

A multi-way ANOVA was used to test the differences in mean acoustic density and biomass between seasons, photoperiod, layer and strata. Tukey's HSD post hoc tests were used to test the differences in means of significant effects. Data were subjected to the Box Cox transformation for normality of distribution and homogeneity of variance (Cox, 1972).

In order to test for correlation between acoustical and fishing data, we used major axis regression (MAR) instead of ordinary least-square regressions because both variables are subject to sampling and measurement error. Both data were $\log_{10}$ transformed before running the analysis for an approximation to normal distribution and homoscedasticity. If a linear relationship was observed, we test for common slopes and intercepts against the 1:1 fit (slope = 1, intercept = 0) which would indicate a perfect correspondence between hydroacoustic and gillnetting data (ANCOVA of ordinary least-square regressions). The acoustic size class lower than 4 cm was excluded from comparative analysis because gillnets did not include small mesh sizes panels.

Statistical tests were performed with the R statistical software package version 3.4.3 (R Development Core Team, 2017). All statistical tests were considered significant at $\alpha = 0.05$.

3 RESULTS

3.1 Temperature and oxygen profiles

The vertical temperature and oxygen profiles in the two reservoirs were homogeneous. Water temperatures fluctuated between 11.5 (winter) and 26.0 °C (summer) in Kasseb and between 12.1 (winter) and 23.8 °C (summer) in Siliana Reservoir. Lowest dissolved oxygen concentrations were measured in summer with 6.2 and 7.2 mg L⁻¹ in Kasseb and Siliana Reservoirs respectively.

3.2 Fish gillnet sampling

Fish catches evidenced five fish species in Siliana Reservoir: mullet (*Liza ramada*), sander (*Sander lucioperca*), rudd (*Scardinius erythrophthalmus*), barbell (*Barbus callensis*) and carp (*Cyprinus carpio*) but only three species in Kasseb Reservoir (mullet, sander and barbell) (Table 4).

The NPUE in Kasseb Reservoir varied between 10 and 38 fish/1000 m² of gillnet panel. The BPUE varied between 2436 and 11648 g/1000 m². Barbell, a native species, displayed the highest numerical and weight yields (32 fish/1000 m² and 9827 g/1000 m²). Both NPUE and BPUE of pikeperch were very low with a maximum recorded during the summer season (2 fish /1000 m² and 3909 g/1000 m²). For mullet, the maximum catch was recorded during winter with 6 fish /1000m² and 1821 g/1000 m² (Table 4).

The BPUE of fish in Siliana varied between 61705 g/1000 m² and 31511 g/1000 m² and were dominated by pikeperch (53.54%), rudd (52.57%) and mullet (73.89 and 74.37%) during summer, autumn, winter and spring seasons respectively (Table 4). Numerical catches (NPUE) were dominated by rudd, mullet then pikeperch.

3.3 Fish size frequencies

The size of the fish caught ranged from 19 to 87 cm and from 8 to 54 cm in Kasseb and Siliana Reservoirs, respectively. Most of the fish caught by gillnets were in size classes 26 – 30 cm in Kasseb and 18 – 30 cm in Siliana Reservoir (Figures 2 and 3). Gillnetting and acoustic provided different fish size distribution (KS test, $p < 0.05$): The fish length distributions from acoustic sampling had a higher proportion of small fish than those collected by gillnet.

In Kasseb Reservoir, a high proportion of small targets (< 3 cm) were detected at both day and night during winter and spring (Figure 2). The KS non parametric statistical test showed no differences between day and night fish distributions of the entire water column during autumn and spring ($p>0.05$) in contrast to summer and winter ($p<0.05$).

In Siliana Reservoir, the fish distribution was multimodal at both day and night (Figure 3). No significant differences were observed when comparing fish distributions according to photoperiod during autumn, winter and spring ($p>0.05$) in contrast to summer ($p<0.05$).

3.4 Acoustic density and biomass

The density of fish estimated by echo counting in Kasseb Reservoir differed significantly between seasons and layers (Table 5). Tukey's HSD post hoc tests showed that density was significantly different between autumn/winter, autumn/spring and autumn/summer ($P < 0.05$). Average density was lower in the surface than in the deep layer ($P < 0.05$). There was also a significant layer/stratum, layer/season and season/photoperiod interaction (Table 5). The longitudinal distribution of fish density in the reservoir showed that there are no clear trends according to strata whatever the photoperiod and the seasons. On a diel basis, nighttime density values were higher than those of daytime whatever the stratum and the layer only in summer. The highest average density of the entire water column was observed during daytime in spring (9710 ± 4253 fish ha^{-1}). The lowest average fish density of the entire water column was estimated during autumn daytime (929 ± 1019 fish ha^{-1}) (Figure 4).

Biomass was significantly different between season and layer (Table 5). Tukey's HSD post hoc tests showed that biomass was significantly different only between autumn/winter, autumn/spring, autumn/summer and winter/summer ($P < 0.05$). More biomass was detected during nighttime in summer than daytime. The highest average fish biomass of the entire water column was observed in winter daytime with 103 kg ha^{-1} which corresponded to a biomass of 35.8 t (Figure 4). The lowest average fish biomass of the entire water column was observed in autumn daytime.

Fish density in Siliana Reservoir differed significantly between seasons (Table 5). Tukey's HSD post hoc tests showed that density was similar in autumn and spring ($p > 0.05$). Biomass differed significantly between seasons and strata (Table 5). Tukey's HSD post hoc tests showed that biomass was similar in winter and spring (Figure 5) while the highest average biomass of the entire water column in Siliana Reservoir was observed in summer daytime with 283 kg ha^{-1} corresponded to a biomass of 86.5 t . The lowest average fish biomass was observed in autumn daytime (Figure 5).

3.5 Comparison between hydroacoustic and gillnetting

Acoustic fish biomass and gillnets BPUE across seasonal and diel surveys for Kasseb and Siliana Reservoirs were significantly linearly correlated ($R^2 = 0.72$, $P < 0.001$) (Figure 6). The slope (0.96; 95% confidence interval: $0.66 - 1.38$) and intercept (0.78; 95% confidence interval: $-0.64 - 2.22$) of the MAR line did not differ significantly from the 1:1 fit (slope: $r = -0.05$, $P = 0.83$; intercept: $t = 1.17$, $P = 0.25$).

Gillnet NPUE and areal fish density derived from acoustics were significantly linearly correlated ($R^2 = 0.29$, $P = 0.028$) (Figure 6) but the slope (0.22; 95% confidence interval: 0.29–0.44) and the intercept (2.49; 95% confidence interval: 2.10 – 2.89) of the MAR line differ significantly from the 1:1 fit (slope: $r = -0.80$, $P < 0.001$; intercept: $t = 13.55$, $P < 0.001$) (Figure 6).

4. Discussion

Gillnets sampling showed a high proportion of the endemic barbell in catches whatever the seasons which influenced fish assemblage in Kasseb Reservoir. For Siliana Reservoir, fish assemblage differs between seasons; pikeperch was caught essentially in summer, rudd in summer and autumn and mullet in winter and spring. The behavior of these species within seasons can be related to food supply, water temperature increased and spawning migration. Highest activity level of pikeperch occurred during the summer at water temperatures of 20–23° C (Jepsen *et al.*, 1999) and mullet migrates during spawning period from freshwater to seawater. Spawning can take place only at sea; abiotic conditions such as salinity, oxygen and currents inhibit female's maturation in freshwater ecosystems (Brusle, 1981).

The high fish density observed in Kasseb Reservoir during late spring (June) is associated with the recruitment of juvenile fish (total length : 1 – 3 cm) after spawning which occurred in March and early April for pikeperch (M'Hetli *et al.* 2011) and between April and June for barbell (Ould Rouis *et al.*, 2012). Lower biomass observed in autumn (December) for the two reservoirs, can be attributed to the decrease in zooplankton and phytoplankton densities probably caused by high turbidity (Sellami *et al.*, 2009).

Changes in fish behavior between day and night have been demonstrated by several studies (Burczynski *et al.* 1987, Appenzeller and Legett 1992, Fréon *et al.*, 1993, Drastik *et al.*, 2009). Difference between TS distributions and disparity of density and biomass across photoperiods are the direct result of this change. In Kasseb Reservoir, densities detected in nighttime and daytime differed across seasons. Hydro-acoustic surveys reveal a consistent diel biomass in Siliana Reservoir while Djemali *et al.*, 2009 found a higher biomass in nighttime than in daytime. Recent distribution may be influenced by fish habitat loss of after two years of drought. The volume of this reservoir decreased from its normal value of 70 Mm³ (Djemali *et al.*, 2009) to 7 Mm³ (present study), fish are confined and survived in relatively small volume of water. It seems that in reduced volume the diurnal migrations are not worth it.

The use of horizontal and vertical beams in mobile surveys has developed rapidly during the last decades (Kubecka, 1996; Yule, 2000). This arrangement makes possible beaming the entire water column in order to have reliable fish stock estimates (Knudsen & Sægrov, 2002). Nevertheless, horizontal beaming should be avoided with smooth surface water, which can cause errors in the target strength (TS) and split-beam angular position estimates (Balk *et al.*, 2017).

In order to study the longitudinal distribution of fish density and biomass by the acoustic method, each water body was subdivided into three strata with equal surface areas and different bathymetries. This type of subdivision (depending on depth) is used by some authors such as Djemali *et al.*, 2016 to estimate fish biomass in a shallow reservoir, Coll *et al.*, 2007 for assessing fish size spectra and fish abundance in two tropical man-made lakes and Kubecka and Wittingerova (1998) to estimate the fish density of five Czech reservoirs. The longitudinal distribution of fish in the studied reservoirs showed that there was no clear difference in the densities between strata while biomass was uniform, consistent with big fish located at the

278 downstream surface water. This distribution can be related to food requirements. Greatest density
279 and diversity of zooplankton have been observed near the dam by Sellami *et al.* (2011), due to the
280 relative stability of the wide reservoir body.

281 Significant correlation between fish density estimates derived from hydro-acoustic and gillnets has
282 been shown by numerous studies in deep and shallow freshwater ecosystem like Mehner & Shulz,
283 2002 in Lake Stechlin, Tatrai *et al.*, 2008 in the open water of Lake Balaton and Emmrich *et al.*,
284 2012 in stratified European Lakes. Because it is difficult to sample with gillnets the smallest and
285 the largest fish, the correlation would have more significant in excluding these sizes. Furthermore,
286 bias induced by accumulation of fish during gillnet sampling must be taken into account to avoid
287 reduction in its catchability (Marjomäki *et al.*, 2015).

288 The surveys conducted in two Tunisian reservoirs with different depths and morphologies showed
289 spatial and temporal high variations in fish abundance and biomass across season. This study
290 demonstrated that the appropriate time to assess fish biomass in reservoir with acoustic method
291 (i.e. higher detectability) was in winter day in Kasseb Reservoir and in summer day in Siliana and
292 was associated with fish composition and behavior. On the other hand, a significant linear
293 correlation was showed between acoustic biomass/BPUE and acoustic density/NPUE but the
294 perfect correlation with the 1:1 fit was showed only between acoustic biomass and BPUE.

295 Next acoustic surveys must integrate other biotic and abiotic components, for a better explanation
296 of the spatial and temporal distribution of fish fauna in Tunisian reservoirs.

299

300 **Acknowledgements**

301 This study was financed by the Tunisian Ministry for Higher Education and Scientific Research
302 and was carried out as a part of the research project ‘MIHEC’. We express our gratitude to the
303 people of CTA, DGPA and ISPAB for their assistance for fishing.

304

305

306

307

308

309

310

311

312

313

314

315

316

317

318

319

320

321

Tables

Table 1: Some physical and limnological data of Kasseb and Siliana Reservoirs during this study

	Mean depth		Max. depth		Volume		Surface area		Surface/bottom water temperature		Surface/bottom water oxygen concentration	
	(m)		(m)		(Mm ³)		(ha)		(°C)		(mg L ⁻¹)	
Season	Kasseb	Siliana	Kasseb	Siliana	Kasseb	Siliana	Kasseb	Siliana	Kasseb	Siliana	Kasseb	Siliana
Summer	15.53	3.15	30.5	4.5	60.838	9.635	347.05	305.3	26.0/20.6	23.8/22.3	7.1/6.2	7.4/7.2
Autumn	16.09	2.75	29.9	5.1	55.463	7.799	344.7	283.6	13.5/13.2	13.4/12.9	8.6/8.4	8.6/8.2
Winter	17.77	2.35	32.2	4.9	62.236	7.051	371.11	300	12.4/11.5	12.2/12.1	8.8/7.3	9.4/9.2
Spring	16.78	2.93	32.0	4.9	58.349	7.888	369.76	269.2	22.9/18.7	21.1/20.9	9.6/8.1	7.3/7.3

Table 2: Mesh-sizes (mm) distribution and thread diameter (mm) in the multi-mesh gillnets

Mesh no	Mesh size	Thread diameter
1	40	0,28
2	18	0,23
3	55	0,28
4	24	0,23
5	35	0,23
6	70	0,28
7	28	0,23
8	80	0,28

Table 3: Parameters of multispecific length-weight relationship (a, b) of the fish caught in Kasseb and Siliana Reservoirs obtained during gillnetting

Reservoirs	N	a	b	r ²
Kasseb	165	0.0085	3.0334	0.95
Siliana	922	0.0094	3	0.99

Table 4: Catch per unit effort (CPUE) values by number (NPUE, fish/1000 m²) and biomass (BPUE, g/1000m²) in gillnet samples of Kasseb and Siliana reservoirs.

Season	Species	CPUE (Kasseb) (Mean ± SE)		CPUE (Siliana) (Mean ± SE)	
		NPUE (fish/1000 m ²)	BPUE (g/1000 m ²)	NPUE (fish/1000m ²)	BPUE (g/1000m ²)
Summer	<i>Liza ramada</i>			97±20	12080±2031
	<i>Barbus callensis</i>	14±6	3421±1505	7±6	426±366
	<i>Cyprinus carpio</i>			1±0	1803±0
	<i>Scardinius erythrophthalmus</i>			200±23	14359±1613
	<i>Sander lucioperca</i>	2±0	3903±3730	153±16	33036±3500
	Total	16±6	7324±3770	459±56	61704±8638
Autumn	<i>Liza ramada</i>	0±0	48±0	51±14	8311±2276
	<i>Barbus callensis</i>	9±3	2340±1046		
	<i>Scardinius erythrophthalmus</i>			194±72	16565±6195
	<i>Sander lucioperca</i>	0.5±0	48±0	11±5	6635±3785
	Total	10±4	2436±1073	256±82	31511±7709
Winter	<i>Liza ramada</i>	6±2	1821±584	198±40	33792±7091
	<i>Barbus callensis</i>	32±6	9827±1998		
	<i>Scardinius erythrophthalmus</i>			105±9	10483±1018
	<i>Sander lucioperca</i>			3±1	1458±1042
	Total	38±6	11648±2159	307±57	45733±9861
Spring	<i>Liza ramada</i>	1±0	221±0	142±21	33608±5471
	<i>Barbus callensis</i>	24±8	6529±2375	3±2	167±111
	<i>Scardinius erythrophthalmus</i>			75±26	7958±2773
	<i>Sander lucioperca</i>			20±8	3458±2271
	Total	25±8	6750±2413	240±48	45191±10522

Table 5: Multi-way analysis of variance (ANOVA) of fish density (fish ha⁻¹) and biomass (kg ha⁻¹) after Box-Cox transformation in Kasseb ($\lambda_{\text{density}} = 0.26$, $\lambda_{\text{biomass}} = 0.21$) and Siliana ($\lambda_{\text{density}} = 0.72$, $\lambda_{\text{biomass}} = 0.44$) Reservoirs in 2015-2016. Independent variables include season, photoperiod, layer (only for Kasseb Reservoir) and strata.

Source	Kasseb Reservoir				Siliana Reservoir			
	Density		Biomass		Density		Biomass	
	F	P	F	P	F	P	F	P
Season	5.59	0.001	3.63	0.015	7.73	<0.001	4.04	0.013
Photoperiod	1.98	0.162	0.8	0.374	0.04	0.835	0.55	0.461
Layer	41.53	<0.001	14.33	<0.001				
Stratum	0.78	0.461	0.52	0.598	0.88	0.424	3.40	0.043
Season* Photoperiod	3.22	0.025	5.12	0.002	0.25	0.863	0.46	0.713
Season*layer	8.09	<0.001	1.14	0.335				
Season*stratum	0.31	0.931	1.35	0.242	0.7	0.652	1.08	0.389
Photoperiod *layer	0.00	0.954	1.19	0.277				
Photoperiod *stratum	1.02	0.364	0.92	0.401	1.35	0.27	0.55	0.579
Layer*stratum	4.25	0.016	7.16	0.001				

Significative p values are in bold.

Figures

Figure 1: Maps of Kasseb and Siliana Reservoirs showing the three geographic strata (U, upstream; M, middle; D, downstream) and their maximum depths (Z_{max}).

Figure 2: Frequency distributions of fish of the entire water column tracked by acoustic and caught by gillnets in Kasseb Reservoir. White, black and grey areas represent day, night and gillnet data, respectively. (N_d , N_n and N_g represent the number of tracked fish detected during day and night surveys and the number of fish caught with gillnet respectively).

Figure 3: Frequency distributions of fish of the entire water column tracked by acoustic and collected by gillnets in Siliana Reservoir. White, black and grey areas represent day, night and gillnet data, respectively. (N_d , N_n and N_g represent the number of tracked fish detected during day and night surveys and the number of fish caught with gillnets respectively).

Figure 4: Seasonal and diel (white bars: daytime, black bars: nighttime) fish density and biomass (mean $\pm$ S.D.) measured for each layer (1: >3 m, 2: 0 - 3m) and strata (D: downstream, M: Middle, U: Upstream) of Kasseb Reservoir

Figure 5: Seasonal and diel (white bars: daytime, black bars: nighttime) fish density and biomass (mean $\pm$ S.D.) measured for each stratum (D: downstream, M: Middle, U: Upstream) of the Siliana Reservoir

Figure 6: Scatter plots of $\log_{10}$ transformed areal fish acoustic biomass/density and multi-mesh gillnet catches (BPUE/NPUE) from Kasseb and Siliana Reservoirs. (a) represent the regression between acoustic biomass/BPUE and (b) represent the regression between acoustic density/NPUE. Each plot includes the major axis regression line (straight line) and 1:1 fit (dashed line).

References

- Appenzeller, A.R., & Leggett, W.C. (1992). Bias in hydroacoustic estimates of fish abundance due to acoustic shadowing - evidence from day night surveys of vertically migrating fish. *Canadian Journal of Fisheries and Aquatic Sciences*, 49, 2179–2189.
- Balk, H., & Lindem, T. (2006). *Sonar4, Sonar5, Sonar6 post processing systems, operator manual version (5.9.6)*. University of Oslo, Norway.
- Balk, H., Sovegarto, B. S., Tuser, M., Frouzova, J., Muska, M., Drastik, V., Baran, R., & Kubecka, J. (2017). Surface-induced errors in target strength and position estimates during horizontal acoustic surveys. *Fisheries Research*, 188, 149 – 156.
- Brusle, J. (1981). Sexuality and biology of reproduction in grey mullets. In. O.H. Oren (ed.) *Aquaculture of grey mullet* (pp. 99- 154). Cambridge University Press.
- Burczynski, J.J., Michaletz, P.H., & Marrone, G.M. (1987). Hydroacoustic assessment of the abundance and distribution of rainbow smelt in Lake Oahe. *North American Journal of Fisheries Management*, 7, 106-116.
- CEN (2005). Water quality-sampling of fish with multi-mesh gillnets. EN 14757.
- Coll, C., Tito de Moraes, T., Lae, R., Lebourges-Dhaussy, A., Simier, M., Guillard, J., Josse, E., Ecoutin, J. M., Albaret, J. J., & Kantoussan, J. (2007). Use and limit of three methods for assessing fish size spectra and fish density in two tropical man-made lakes. *Fisheries Research*, 83, 306–318.
- Cox, D.R. (1972). Regression models and life-tables. *Journal of the Royal Statistical Society. Series B (Methodological)* 34 (2), 187–220.

452 **DGPA** (Direction Générale de la Pêche et de l'Aquaculture) (2016). *Statistiques de pêche de la*
 453 *Direction Générale de la Pêche et de l'Aquaculture*. Direction Générale de la Pêche et de
 454 l'Aquaculture, Agriculture Ministry, Tunisia.

455 Djemali, I., Toujani, R., & Guillard, J. (2009). Hydroacoustic fish biomass assessment in
 456 man-made lakes in Tunisia. horizontal beaming importance and diel effect. *Aquatic Ecology*,
 457 *43*, 1121–1131.

458 Djemali, I., Laouar, H., & Toujani, R. (2010). Distribution patterns of fish biomass by acoustic
 459 survey in three Tunisian man-made lakes. *Journal of Applied Ichthyology*, *26*, 390-396.

460 Djemali, I., Guillard, J., & Yule, D. L. (2016). Seasonal and diel effects on acoustic fish biomass
 461 estimates: application to a shallow reservoir with untargeted common carp (*Cyprinus carpio*).
 462 *Marine and Freshwater Research*, *68* (3), 528-537

463 Drastík, V., Kubecka, J., Cech, M., Frouzova, J., Riha, M., Juza, T., Tuser, M., Jarolím, O.,
 464 Prchalova, M., Peterka, J., Vasek, M., Kratochvíl, M., Matena, J., & Mrkvicka, T., (2009).
 465 Hydroacoustic estimates of fish stocks in temperate reservoirs. day or night surveys? *Aquatic*
 466 *Living Resources*, *22*, 69-77.

467 Emmrich, M., Winfield, I.J., Guillard, J., Rustadbakken, A., Vergès, C., Volta, P., Jeppesen, E.,
 468 Lauridsen, T.L., Brucet, S., Holmgren, K., Argillier, C., & Mehner, T. (2012). Strong
 469 correspondence between gillnet catch per unit effort and hydroacoustically derived fish biomass
 470 in stratified lakes. *Freshwater Biology*. *57*(12), 2436–2448.

471 Encina, L., & Ridriguez-Ruiz, A., (2003). Abundance and distribution of a brown trout (*Salmo*
 472 *trutta*) population in a remote high mountain lake. *Hydrobiologia*, *493*, 35–42.

473 Foote, K.G., Knudsen, H.P., Vestnes, G., MacLennan, D.N., & Simmonds, E.J. (1987).
 474 *Calibration of acoustic instruments for fish density estimation. a practical guide.* ICES
 475 Cooperative Research Report No. 144.

476 Fréon, P., Soria, M., Mullon, C., & Gerlotto, F. (1993). Diurnal variation in fish density estimate
 477 during acoustic surveys in relation to spatial distribution and avoidance reaction. *Aquatic Living*
 478 *Resources*, 6, 221–234.

479 Frouzova, J., Kubečka, J., Balk, H., & Frouz, J. (2005). Target strength of some European fish
 480 species and its dependence on fish body parameters. *Fisheries Research*, 75, 86–96.

481 Jepsen, N., Koed A., & Okland, F. (1999). The movements of pikeperch in a shallow reservoir.
 482 *Journal of Fish Biology* 54: 1083–1093.

483 Jolly, G., & Hampton, I. (1990). A stratified random transect design for acoustic surveys of fish
 484 stock. *Canadian Journal of Fisheries and Aquatic Sciences*, 47, 1282–1291.

485 Knudsen, F.R., & Sægrov, H. (2002). Benefits from horizontal beaming during acoustic survey.
 486 application to three Norwegian lakes. *Fisheries Research*, 56, 205–211.

487 Kubecka, J. (1994). Simple model on the relationship between fish acoustical target strength and
 488 aspect for high-frequency sonar in shallow waters. *Journal of Applied Ichthyology*, 10, 75–81.

489 Kubecka, J. (1996). Use of horizontal dual-beam sonar for fish surveys in shallow waters. Pages
 490 165–178 in I. G. Cowx, editor. *Stock assessment in inland fisheries.* Fishing News Books,
 491 Oxford, UK.

492 Kubecka, J., & Wittingerova, M. (1998). Horizontal beaming as a crucial component of acoustic
 493 fish stock assessment in freshwater lakes. *Fisheries Research*, 35, 99–106.

494 Loures, R.C. , & Pompeu, P.S. (2015). Seasonal and diel changes in fish distribution in a tropical
 495 hydropower plant tailrace. evidence from hydroacoustic and gillnet sampling. *Fisheries*
 496 *Management and Ecology*, 22, 185–196.

497 Love, R. H. (1971). Dorsal-aspect target strength of an individual fish. *Journal of the Acoustical*
 498 *Society of America*, 49, 816–823.

499 M'Hetli, M., Ben Khemis, I., Hamza, N., Turki, B., & Turki, O. (2011). Allometric growth and
 500 reproductive biology traits of pikeperch *Sander lucioperca* at the southern edge of its range.
 501 *Journal of Fish Biology*, 78, 567-579.

502 Marjomäki, T. J., Paloniemi, M., T., Kuha, J., & Karjalainen J. (2015). Empirical
 503 Estimation of Accumulation-Induced Change in Gill Net Catchability: Mind the Observation
 504 Errors. *The Open Fish Science Journal*, 8, 13-22.

505 Mehner, T., & Schulz, M. (2002). Monthly variability of hydroacoustic fish stock estimates in a
 506 deep lake and its correlation to gillnet catches. *Journal of Fish Biology*, 61, 1109–1121.

507 Mili, S., Ennouri, R., Dhib, A., Laouar, H., Missaoui, H. , & Aleya, L. (2016). Characterization of
 508 fish assemblages and population structure of freshwater fish in two Tunisian reservoirs.
 509 implications for fishery management. *Environmental Monitoring and Assessment*, 188:364.

510 Ould-Rouis, S., Ould-Rouis A., Micha J.C., & Arab A. (2012). Biologie de la reproduction du
 511 Cyprinidae, *Barbus callensis* dans le lac de barrage Hamiz (Algérie). *Tropicultura*, 30 (2),
 512 88–93.

513 R Development Core Team (2017). A Language and Environment for Statistical Computing. R
 514 Foundation for Statistical Computing, Wien. Available from <http://www.R-project.org>.

515 Sellami, I., Ayadi, H., Bouain, A., Aleya, L., & Alaoui Mhamdi, M. (2009). Distribution of
 516 zooplankton related to environmental factors in three interconnected reservoirs. Kasseb,
 517 Mornaguia and Ghdir El Goulla (North of Tunisia). *International Journal of Limnology*, 45, 107
 518 – 117.

519 Sellami, I., Elloumi, J., Hamza, A., Alaoui Mhamdi, M., & Ayadi, H. (2011). Local and regional
 520 factors influencing zooplankton. *Water SA*, vol.37 n.2., 201-212.

521 Sokal, R. R., & Rohlf, F. J. (1981). *Biometry* (2nd ed.). WH Freeman. San Francisco, CA.

522 Soudoud (2006). *Base de données spécifique des grands barrages en Tunisie. Ministère de*
 523 *l'agriculture et des ressources hydrauliques*, Direction générale des barrages et des grands
 524 travaux hydrauliques.

525 Sprent, P. (1992). *Pratique des statistiques non paramétriques*. INRA (ed.), Paris.

526 Tatrai, I., Specziar, A., Gyorgy, A.L., & Biro, P. (2008). Comparison of fish size distribution and
 527 fish abundance estimates obtained with hydroacoustics and gill netting in the open water of a
 528 large shallow lake. *International Journal of Limnology*, 44, 231–240.

529 Vasek, M., Kubecka, J., Peterka, J., Cech, M., Draščík, V., Hladík, M., Prchalová, M., & Frouzová,
 530 J. (2004). Longitudinal and vertical spatial gradients in the distribution of fish within a
 531 canyon-shaped reservoir. *International Review of Hydrobiology*, 89, 352–362.

532 Yule, D. L. (2000). Comparison of horizontal acoustic and purse-seine estimates of salmonid
 533 densities and sizes in eleven Wyoming waters. *North American Journal of Fisheries*
 534 *Management*, 20, 759–775.