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In situ TS detections using two generations of echo-sounder, EK60 and EK80 : the continuity of fishery acoustic data in lakes

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Abstract

Used for several decades and recognized today as a reliable method, fishery acoustics is commonly used in scientific studies and monitoring surveys. In Europe, during the last decades, the most frequently used scientific echo-sounder has been the EK60 from the Simrad company (Simrad Kongsberg Maritime AS, Horten, Norway). A new echo-sounder model, the EK80, has been recently developed, and it is therefore necessary to check whether the results obtained by the two generations of echo-sounder (EK60 and EK80) give the same results. This is of main importance in the context of time series. Recent works have already addressed this comparison, focusing on S_A (nautical area backscattering coefficient) but the systems' reliability to accurately measuring target strength (TS, in dB) has only been tested using calibration spheres. Our work aims to test the hypothesis that, at a given frequency, the TS recorded simultaneously *in situ* by an EK60 and an EK80, in CW mode, were not statistically different. Data were recorded in two peri-alpine lakes using the two systems sampling sequentially a similar volume. Using statistical tests, acoustics metrics were compared. For TS, statistically significant differences were found between the two generations of echo-sounder. However, these differences were not large enough to affect the fish density used for fishery management or researches on the fish population. The continuity

of the time series acquired with the EK60 is ensured when one switches to the EK80 echo-sounder for lake ecosystem research and monitoring.

Highlights

- Fishery acoustics is commonly used and reliable.
- A new echo-sounder, the EK80, has been recently developed.
- It is necessary to check *in situ* whether the results obtained by the two generations of echo-sounder give same results.
- *In situ* differences on TS values were not large enough to affect the fish density results.
- The continuity of the time series acquired with the EK60 is ensured when one switches to the EK80.

Keyword

Hydro-acoustics, Freshwater, Target Strength, *In situ*, Lake

1. Introduction

Hydro-acoustics is a non-invasive method to assess fish abundance in aquatic ecosystems (Rudstam et al., 2012; Simmonds and MacLennan, 2005) and to describe their relationships with ecosystem features (Koslow, 2009; Trenkel et al., 2011). It has been standardized for lake surveys both on the North American continent for the Great Lakes (Parker-Stetter et al. 2009) and on the European continent related to the Water Framework Directive (CEN, 2014; Draštík et al., 2017). Used for several decades and recognized today as a reliable method (Rudstam et al. 2012), fishery acoustics is commonly used in scientific studies and monitoring surveys in lakes (Baran et al., 2021; Godlewska et al., 2016; Pollom and Rose, 2016; Wheeland and Rose, 2016).

During the last decades, in Europe, the most frequently scientific echo-sounders used for research and monitoring surveys, both in freshwater and marine environments, are from the Simrad company (Simrad Kongsberg Maritime AS, Horten, Norway). The EK60 echo-sounder was marketed about 20 years ago (Andersen, 2001), and a new echo-sounder model, the EK80, has been recently developed. In the medium term, EK80 will replace the EK60; its maintenance will be no longer assured. EK80 has the capacity to emit in CW mode (continuous wave), as the EK60, as well as in broadband mode (Frequency Modulated signal) (Demer et al., 2017). The broadband method is an opportunity to discriminate between different targets using the acoustic spectrum, to develop new broadband school parameters to classify echo-traces, and to improve size detection (Bassett et al., 2018; Benoit-Bird and Waluk; 2020; Blanluet et al., 2019; Blanluet et al., 2022 ; Gugele et al., 2021).

In the medium term, research works and monitoring surveys using the EK60 will have to migrate to the new model EK80. The components and software of the EK80 are obviously different from those of the EK60 (Demer et al., 2017), and therefore it is necessary to check whether the results obtained by the old (EK60) and the new (EK80) systems give similar results. This is of main importance to maintain time series (Pollom and Rose, 2016; Braun and Mehner, 2021).

Recent works (De Robertis et al., 2019; MacCaulay et al., 2018), as well as a ICES (International Council for the Exploration of the Sea) report (Demer et al., 2017), have already addressed this comparison, focusing on S_A (nautical area backscattering coefficient, in $m^2. nmi^{-2}$) (MacLennan et al., 2002), a metric proportional to the fish abundance (Simmonds and MacLennan, 2005). If they have shown some dissimilarities between EK60 and EK80 data, notably at low power (De Robertis et al., 2019), these differences were negligible when working in normal survey conditions (strong backscatters, medium range). These works have been carried out in marine environment, using several frequencies. The systems' reliability to accurately measuring target strength (TS, in dB) (MacLennan et al., 2002) has only been tested using calibration spheres (De Robertis et al., 2019; MacCaulay et al., 2018). This metric, corresponding to a proxy of the individual fish size (Rudstam et al., 2012), allows to describe the size spectra of fish population and then to calculate a biomass per unit area (Simmonds and MacLennan, 2005). TS is widely used in freshwater research and surveys (Draštík et al., 2017; Pollom and Rose, 2016; Wheeland and Rose, 2016).

Therefore, our work aimed to test the hypothesis that, at a given frequency, the TS values, recorded simultaneously *in situ* by an EK60 and an EK80 in CW mode, were not statistically different, and finally that one can consider that data from the two generations of echo-sounder are the same. Preliminary, as observed in previous works (De Robertis et al., 2019; MacCaulay et al., 2018), we checked that no significant difference was observed on the S_A means from the two sounders. We acquired data at two lakes using the two systems sampling sequentially a similar volume, at the most used frequency in lakes (Draštík et al., 2017). Data were analyzed using the same software and parameters. In this way, we tested whether the data series could be continued without breakage, despite the change of echo-sounders.

2. Materials and Methods

2.1. Study site

The surveys were performed in two deep peri-alpines lakes in France, Lake Annecy (45°51'24"N; 06°10'20"E) (14 September 2020) and Lake Bourget (45°43'55"N; 5°52'06"E) (29 and 30 September 2020), as part of annual monitoring surveys of the Observatory of LAkes (OLA) (Rimet et al., 2020). The fish population in the two lakes are similar (Guillard et al., 2014) and well known (Frossard et al., 2021; Jacquet et al., 2021). Furthermore, methodological acoustic surveys were regularly performed in these two lakes (Blanluet et al., 2020; Perrot et al., 2010; Guillard et al., 2014).

At the time of the surveys – end of summer (CEN, 2014) – the two lakes were stratified (Fig. 1) (data from OLA http:// www6.inra.fr/soere-ola ©SOERE OLA-IS, AnaEE-France, INRAE Thonon-les-Bains, CISALB, SILA, Eco-Informatics ORE INRAE Team). This stratification between the upper (warm) and deeper (cold) layers structures the distribution of the fish communities, according to their thermal preferendum (Mehner 2012; Yule et al., 2013). Salmonids are in the deeper layers, while *Percidae* and *Cyprinidae* are dominant in the upper layers (Guillard et al., 2006; Guillard et al., 2014). According to the thermal profiles, the two layers were defined as i) the “surface layer”, set from 3 m (the volume between the surface and 3 m depth was excluded to avoid near field and surface-related noise) to 14 m in Lake Annecy and to 16 m in Lake Bourget ; and ii) the “deep layer”, from respectively 14 and 16 m depth to the bottom. Shallow near-ground areas (bottom less than 5 m) were excluded from the analyses.

2.2. Surveys

Hydroacoustic surveys were performed following the acquisition standard (CEN, 2014), using a EK60 GPT and a EK80 WBT-Mini echo-sounder, respectively link to two ES120-7C transducers with a theoretical open angle of 7° degrees at -3 dB (EK60 transducer Along ship: 6.75° / Athwart ship: 6.76°; EK80 transducer Along ship: 6.55° / Athwart ship: 6.60°) and recording using the EK80 software from a unique laptop. The transducers were set one behind the other, in the direction of sailing, to maximize the overlap of the sampling volume on a vertically oriented frame and set 0.70 m below the surface. This setup has already been used in previous methodological surveys to test the impact of frequencies and pulse length on fish stock assessments (Guillard et al., 2014; Mouget et al., 2019). The two echo-sounders, driven by the same computer and acquisition software, emitted sequentially at 120 kHz, with a pulse length set at 0.256 ms (Godlewska et al., 2011), a ping rate at 5 Hz and a transmission power of 50 W for the EK80 and 100 W for the EK60 records. These parameters are the ones most used in lakes (Draštík et al., 2017).

The surveys, georeferenced by a GPS connected to the echo-sounder, followed a zigzag course at a navigation speed of about 8 km.h^{-1} in calm to moderate wind conditions (CEN, 2014; Draštík et al., 2017). The surveys were performed at night, approximately 1 h after sunset, to sample the fish when their distribution is as dispersed as possible within the water column (Girard et al., 2020). Calibrations were performed using the EK80 software for both echo-sounders according to the standard protocol of Foote et al. (1987) (Demer et al., 2015) and the manufacturer's manual. For the EK80, the calibration was performed in a "calibration tank" at Ifremer (Brest, France), and for the EK60, the calibration was performed *in situ*. To overcome the variability inherent in *in situ* calibrations, the echo-sounder was calibrated three times, and the results averaged following recommendations of De Robertis et al. (2019).

2.3. Acoustic data process

Data were analyzed using Sonar5-Pro software (Balk and Lindem, 2021), a software regularly used in freshwater studies. The TS threshold was set at -60 dB for Single Echo Detection (SED) according to monitoring surveys in lakes (Draštík et al., 2017). This threshold allowed fish detection greater than ~ 0.02 m using Love's equation (Love, 1971), an equation commonly used in freshwater surveys (Emmrich et al. 2012; Morrissey-McCaffrey et al., 2018; Tessier et al., 2020). SED was determined in Sonar5-pro using the following parameters: a pulse length ratio between 0.8 and 1.3; a maximum gain compensation of 3 dB (one way); and a sampling angle standard deviation of 0.3 degrees (Godlewska et al., 2011; Guillard et al., 2014). The threshold of the mean volume backscattering strength, S_v (in dB re 1 m^{-1}), was set 6 dB lower, at - 66 dB, according to Parker-Stetter et al. (2009). The data from the two echo-sounders were simultaneously processed, using the multi-frequency function of Sonar5-Pro, creating two channels (Balk and Lindem, 2021). The bottom was automatically detected using the software's tool, including a margin of 0.5 m and, in rare cases, was manually rectified on both channels. The Elementary Distance Sampling Unit (EDSU) was set to 250 m (same as applied by Guillard et al. 2014; Mouget et al., 2019) and allowed to extract the mean Target Strength (calculated in the linear domain) by layers, and in the same way, the S_A values (expressed in hectare acoustic scattering strength, in m^2.ha^{-1}). The study focusing on fish surveys, to avoid analyzing unwanted non-fish echoes (Emmrich et al., 2014), the Sonar5-Pro cleaning tool was simultaneously used on both echograms to remove ghost echoes, bubbles, debris accumulations, ropes from gillnets/buoys, and fake bottoms. A few EDSU with too many noises and artefacts (e.g., buoys) were excluded from the analysis. Finally, the Sawada index (Sawada et al., 1993) was set to ensure that conditions permitted estimation of TS. Thus, to overcome the presence of multiple echoes that would impact the TS estimation, only EDSU with a Sawada index < to 0.1 were used for the size distribution analyses (Godlewska et al., 2011).

2.4. Statistical analysis

The mean values of TS were compared using the Mann-Whitney U-test, as the data did not follow a normal distribution. For TS, the test was performed in the linear domain (Simmonds and MacLennan 2005). Furthermore, to compare data from each EDSU, i.e., pairs of TS from EK60 and EK80 for each EDSU, the procedure developed by Warton et al. (2006) was done in addition to linear regression, the slopes of the data set were compared with a 1:1 line. This statistical approach is recommended when the measurement error is unknown, which is the case with the acoustic data set (Mouget et al., 2019). This statistical procedure was performed in previous analysis of comparisons of acoustic data set (Godlewska et al., 2011; Guillard et al., 2014; Mouget et al., 2019). The statistical test evaluated whether the two metrics from the EK60 and EK80 meet the H_0 hypothesis that the two sets of data are the same. SED distributions were tested using the Kolmogorov-Smirnov test. The Lake Annecy and Lake Bourget data were merged to perform statistical tests on a larger sample. Finally, fish densities were calculated for each layer and lake using Forbes and Nakken's (1972) equation (Tessier et al., 2020).

3. Results

3.1. Data set

In Lake Bourget, 582 EDSU were recorded for the surface layer, 578 for the deep layer; in Lake Annecy, 284 EDSU were recorded for the surface layer and 290 for the deep layer (Table 1). Analyses were performed on a total of 1652 ESDU for TS analysis and 1654 ESDU for S_A comparisons (Table 1) , two EDSU being excluded for TS due to an inappropriate Sawada index. Echograms from the two devices appeared to be similar (Fig. 1). According to previous works (De Robertis et al., 2019; MacCaulay et al., 2018) no significant difference in the S_A means between the two generations of echo-sounders, regardless of the layer, were found (Annex 1).

3.2. TS values according to the echo-sounders

The number of SED detected by each echo-sounder was very close. The EK60 detected 43,631 SED for the two layers compared to 43,726 for the EK80, a difference of 0.2%. This difference was mainly due to a higher number of targets detected by the EK80 in the deep layer: 19,490 SED for the EK80 against 18,779 SED for the EK60, i.e., a difference of 3.6%. In the surface layer, the number of SEDs recorded by the EK80 is slightly lower, with 24,236 against 24,852 for the EK60, a difference of 2.5%. For the surface layer, there is a slight shift in the main mode of the TS distribution, - 47.8 dB for EK60 values against -47.3 dB for the EK80 values. There was no offset for the secondary mode (-59.3 dB) (Fig. 2). For the deep layer, the distributions were similar, with the same modes for the two echo-sounders (main mode: -37.6 dB; secondary mode: -52 dB), even if there were significant statistical difference between the SED distributions using the Kolmogorov-Smirnov test ($p < 0.01$).

There was no significant difference in mean TS (Table 2) using Wilcoxon's nonparametric test to compare the two types of echo-sounder for the surface layer (p-value > 0.05), but this difference was significant for the deep layer (p-value = 0.0004). When the layers were merged, there was still a slightly significant difference between the means (p-value = 0.02) (Table 2). The box plots of the TS values (Fig. 3) also show the similarities between the datasets acquired by the EK80 and the EK60, regardless of the layer. When the mean TS values were compared by pairs for the same EDSU via the Warton et al. (2006) test, no difference between the EK80 and the EK60 was observed on the whole sample (Fig. 3).

3.3. Fish density

Regarding fisheries and ecosystem management, it is meaningful to express the acoustic metrics in fish density, i.e., number of fish by surface. Thus, the fish densities per layer obtained with the two generations of echo-sounders were calculated. Results were very close between the two echo-sounders : for the surface layer, 1203 (EK60) and 1183 (EK80) fish.ha^{-1} and 583 (EK60) and 529 (EK80) number of fish.ha^{-1} for the deep layer.

4. Discussion

The previous works done in marine environment (Demer et al., 2017 ; De Robertis et al., 2019;

MacCaulay et al., 2018) have addressed the comparison of the two generations of echo-sounder and thus made it possible to validate the continuity of the data for time series. However, these previous works focused mainly on S_A (nautical area backscattering coefficient), the TS intercalibration between the two sounders was only done using calibration spheres. So, our work completes the previous ones with *in situ* data. Our comparison being of main importance for lake fishery studies, we choose the most used parameters (frequency, pulse length, power) in lakes (Draštík et al., 2017). Bonar and Hubert (2002) have highlighted that standardized methods ensure robust estimates. To facilitate comparisons between datasets acquired using different equipment, inter-calibration is needed. The main goal of this study was to evaluate the difference on TS recorded *in situ* by two generations of echo-sounder, EK60 and EK80. This approach is necessary to inter-calibrate the echo-sounders due to the discontinuation of the production of the EK60. Many long-term monitoring surveys have been performed with EK60 in freshwater ecosystems (Draštík et al., 2017; Ostrovsky et al., 2014; Pollom et Rose, 2016) and the continuity of the series is of paramount importance (Bonar and Hubert, 2002). The previous comparisons (Demer et al., 2016 ; Macaulay, et al. 2018, De Robertis et al. 2019) showed that there is a deviation between the two echo-sounders, a ratio EK80/EK60 <1, mainly due to a slight over-amplification of low-power signals by the EK60. This difference would be related to the linearity of the echo-sounders, especially for the EK60, which differs for weak targets and targets located at long distances to the echo-sounder. This over-amplification biases abundance estimates because it modifies the assumption inherent in echo-integration (Foote, 1983). However, according to the authors, for depths not exceeding 100 m, over-amplification is not present. Furthermore, the authors highlighted that the impact is relatively small for data from strong scatters, i.e., fish with swimbladders. Therefore, our results, focusing on *in situ* TS complement previous works, in a lake context, where the depths are shallower (max Bourget depth: 145 m; Annecy max depth: 82 m), and fish are rarely located below 100 m depth and have a swimbladder (Yule et al., 2013).

We confirm that the echo-integration measurements from the EK80 are slightly higher than those of the EK60 on the entire water column for a frequency of 120 kHz, but the ratio EK80/EK60 remains very close to 1. The Warton et al. (2006) test showed that the acoustic response between the EK60 and EK80 echo-sounders was similar for data from the surface layer. Whereas the test showed a significant difference for data from the deep layer, with higher values for the EK80 echo-sounder, but ultimately had a very small impact on the overall dataset results. This difference, which was not highlighted by the Wilcoxon test on averages, is small and thus not noticeable for fish management or research perspectives.

To complement the previous comparison works, we studied the difference in TS obtained from the two generations of echo-sounder. The fish size distribution is important to calculate fish density by unit area (Rudstam et al., 2012; Simmonds and MacLennan, 20) and to monitor fish size spectra (Wheeland and Rose, 2016), a reliable metric of fish population evolution (McKenzie et al., 2021). Working *in situ* on fish populations is a reliable approach to compare systems (Blanluet et al., 2020; Draštík et al., 2019; Guillard et al., 2004;) and will serve as references for lake fishery studies. Statistical differences were observed in the deep layer when comparing the TS values obtained between EK60 and EK80. This was true on the mean test and using Warton et al. (2006) test, which showed a deviation to the line 1:1 when comparing the TS by pairs. The difference in TS between the two generations of echo-sounder was weakly significant in the upper layer and was not observed when the dataset was considered as a whole. If we referred to the mean TS per layer, the difference in dB between the two generations of transducers could be considered as small, < 0.5 dB. The mode of digitization differs between the EK80 and the EK60 could be at the origin of this variability observed between the two generations of echo-sounders. The number of SEDs was not the same (Demer et al. 2016).

For this kind of approach, to minimize potential biases related to the acquisition chain, the EK80 software was used to record the data and perform the calibrations. A strict comparison of the echo-sounders should have been made with the same transducer, as in De Robertis et al. (2019), but it requires a specific electronic installation not accessible during our surveys. In this case, we overcome the differences specific to the use of two independent transducers, which do not have the same characteristics, the equivalent beam angle is not characterized by the standard calibration method, and then can be a major source of uncertainty in echo-integration measurements (De Robertis et al., 2019). In our configuration, the difference can be due to the own characteristics of the transducers and obviously from calibrations, which despite the care taken, imply variability.

For a more global approach, other tests using different frequencies, power parameters, pulse lengths, etc. should be done in the future but overall, our work highlights that the two generations of echo-sounder give very close results, using the most used configuration in lakes. The differences between EK60 and EK80are likely to be smaller than errors related to other factors (Simmonds and MacLennan, 2005) as behaviour, sampling, navigation conditions, uses of different transducers, and calibration procedures. Our findings agree with the hypothesis put forward by De Robertis et al. (2019). Therefore, we can assert that the data acquired in shallow environment (< 100m) using the same frequency (120 kHz) by the two generations of echo-sounder, namely the EK60 and the EK80, are similar and that detection of changes over time in fish abundance and size spectra can be achieved using this method.

In a nutshell, as already shown for the S_A, no significant difference was observed for the means. For the first time at our knowledge, *in situ* TS from EK60 and EK80 were compared and if statistical significant differences were found between the TS from the two echo-sounders, these differences were not large enough to affect the fish density used in fish management studies or researches in lakes. The continuity of the time series acquired with the EK60 is ensured when one switches to the EK80 echo-sounder for lake ecosystem research and monitoring surveys, obviously keeping the need to continue to acquire data using the recommendations developed in the standards (e.g., seasons, night-time, boat speed, weather conditions) and performing regular calibrations. Further works are needed to better understand the observed differences on individual targets.

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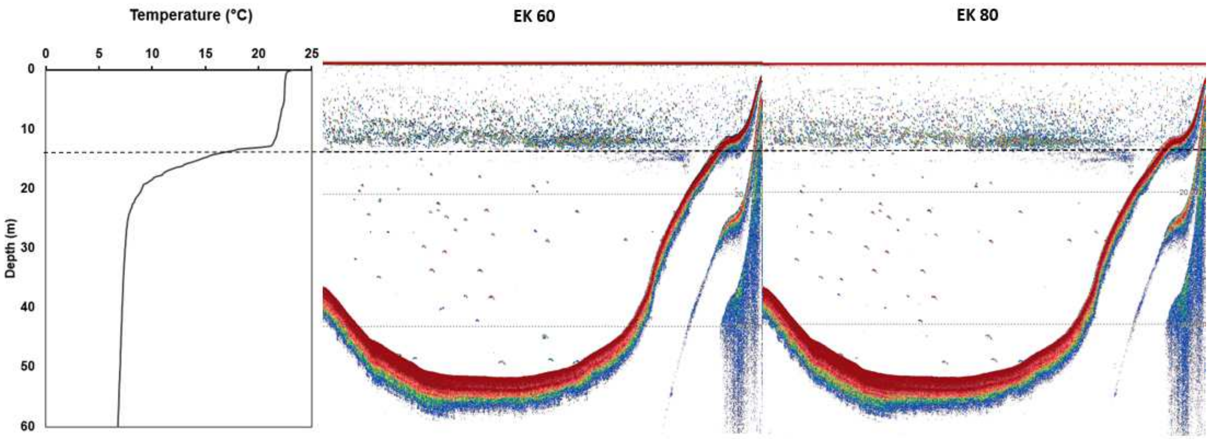

Figure 1. Left side -Temperature profile acquired in the Lake Annecy (14 September 2020). Right side – echograms, at left EK60 and at right EK80, using a -66 dB threshold in Amp-echogram recorded in the Lake Annecy ; the dashed line shows the separation between layers. Data from OLA, Observatory of LAkes (http://www6.inra.fr/soere-ola ©SOERE OLA-IS).

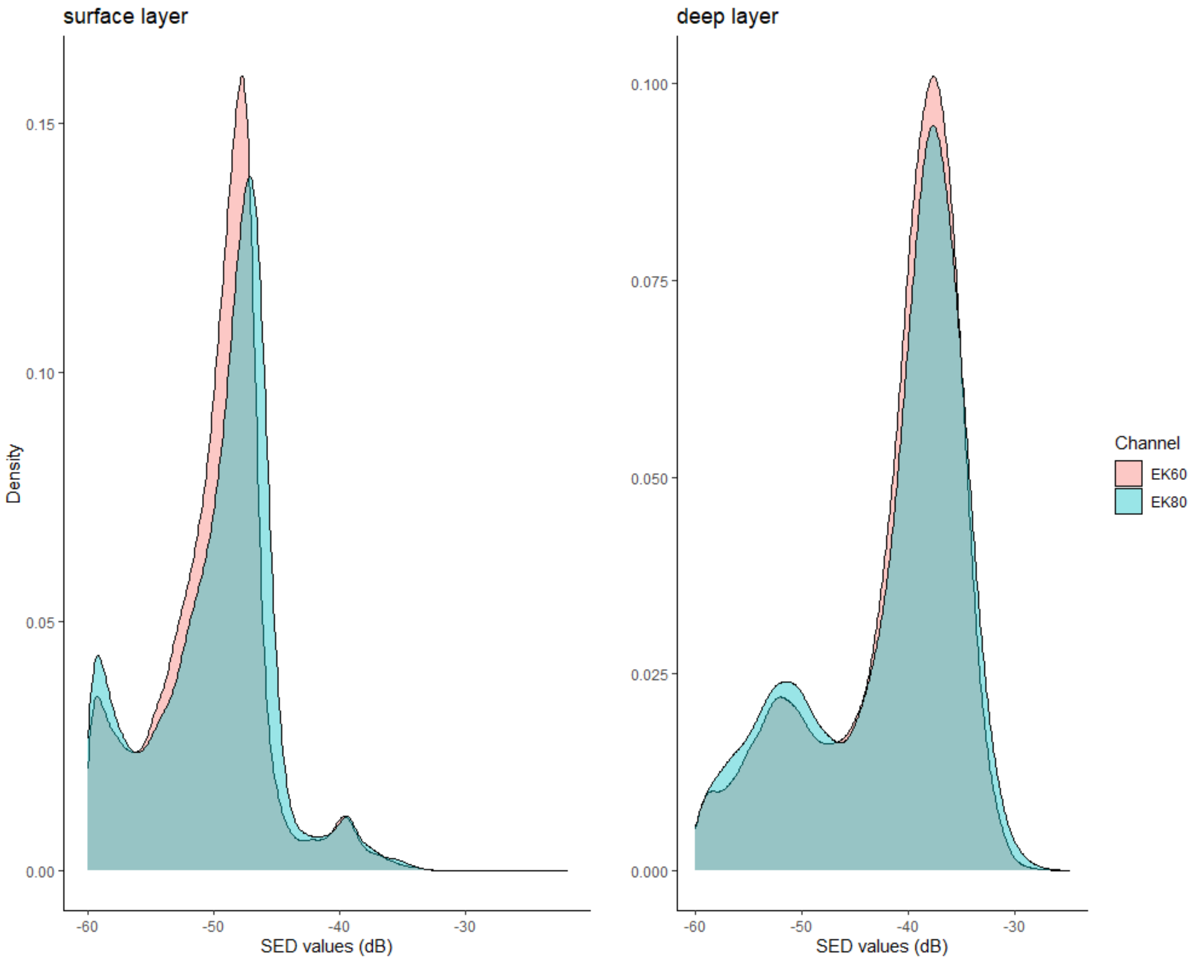

Figure 2. TS distribution of the Single Echo Detection (SED) for the two layers. Pink for the EK60 values, green for the EK80 values.

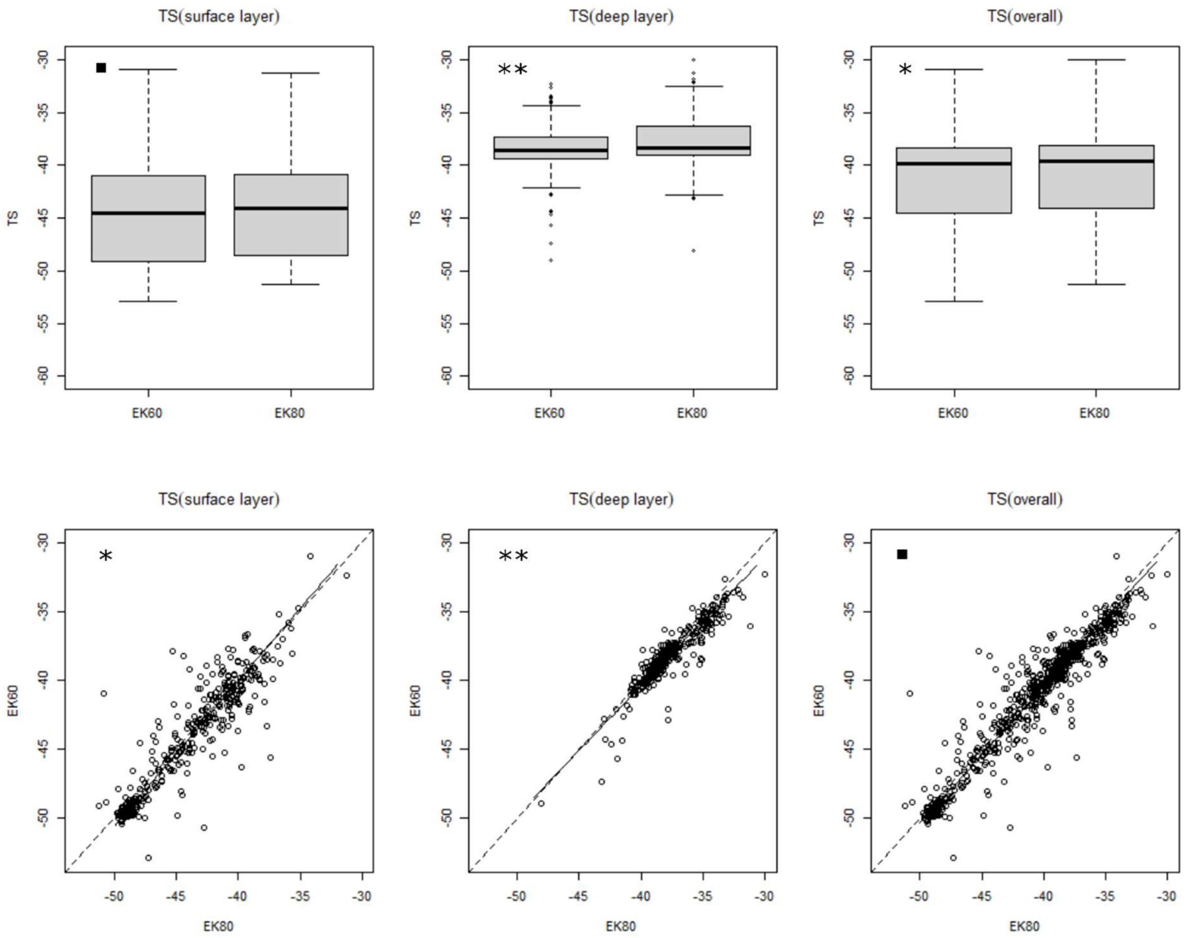

Figure 3. Mean TS (dB) and boxplots values for the two layers and the total dataset. Comparison by pairs of TS from EK60 and EK80 for the two layers and for the total dataset. Statistical tests on the mean values and between the 1:1 line (black) and the linear regression model (dotted line) were : not significantly different = ■; significantly different results p-value < 0.05 = *; highly significant p-value < 0.01 = **.

Table 1. ESDU data set.

	Lake Annecy		Lake Bourget	
	Surface layer	Deep layer	Surface layer	Deep layer
Number of EDSU	284	290	582	578
ESDU with noises or/and artifacts		8	46	26
Sawada Index > 0.01			2	
Total for				
S_A analysis	284	282	536	552
TS analysis	284	282	534	552

Table 2. Mean TS values, calculated in the linear domain, according to the layers

Mean TS (dB)	EK60	EK80	p-value
Global	-39.5	-39.0	0.02
Surface layer	-42.5	-42.4	0.06
Deep layer	-37.8	-37.1	0.0004

Annex

S_A values according to the echo-sounders

No significant difference in the S_A means between the two generations of echo-sounder, regardless of the layer, were found (Table 1 - Annex). The box plots of the S_A values (Fig. 1 - Annex) also showed the similarities between the datasets acquired by the EK80 and the EK60, regardless of the layer. Using the procedure of Warton et al. (2006), the data were compared by EDSU (Fig. 1 - Annex). For the surface layerthere was no difference between the line of the major axis and the 1:1 relationship (p-value = 0.7). For the lower layer, there was a significant difference with the line 1:1 ($p < 0.05$), as for the overall dataset (p-value $p < 0.05$). This resulted in slight deviance between the two echo-sounder for a few high values. Following De Robertis et al. (2019), a ratio (S_A EK80 values / S_A EK60 values) between the two echo-sounders' values was computed : the backscattered energy recorded by the EK80 is slightly higher than the one recorded by the EK60, the ratio being very close to 1 for the whole data set (1.07) or by layer (surface layer 1.08, deep layer 1.06).

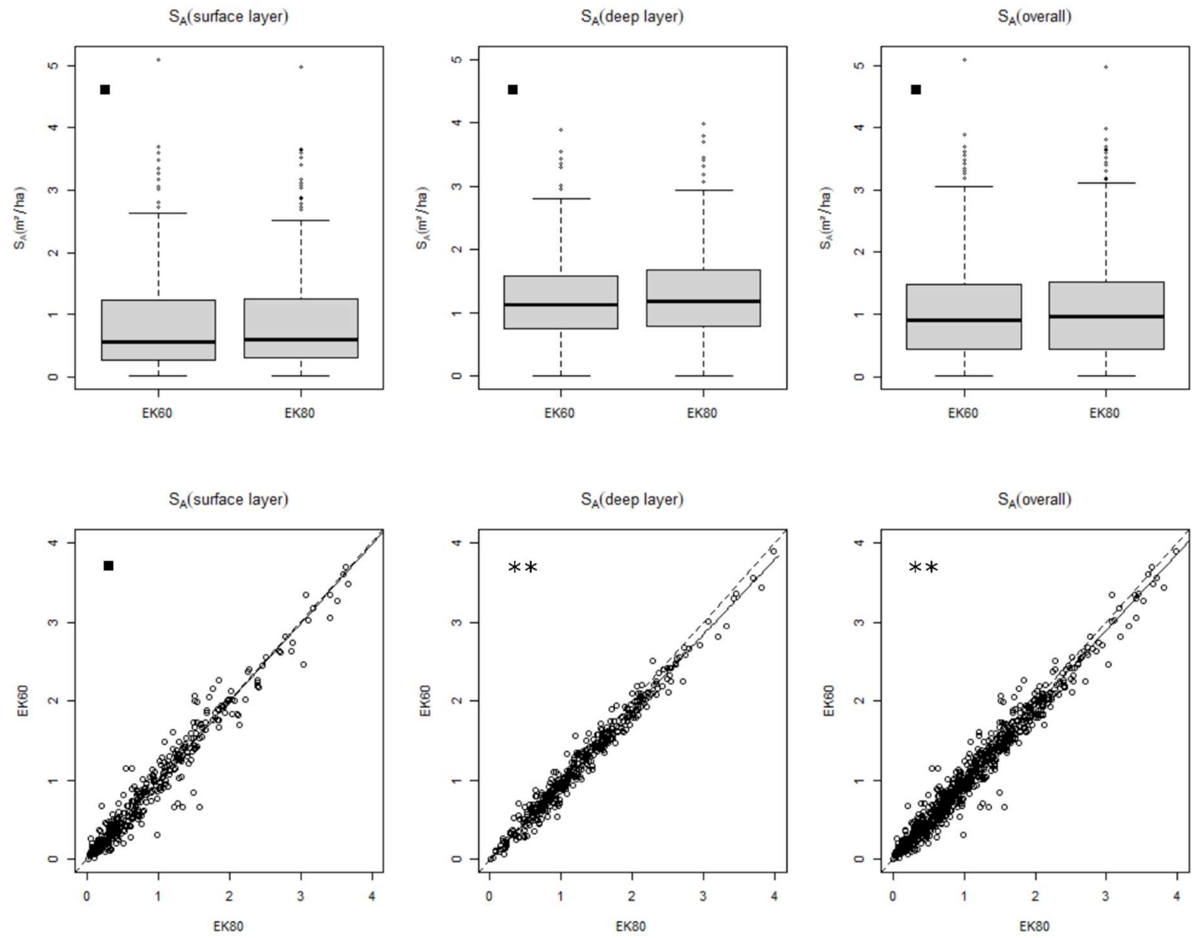

Figure 1- Annex. Mean S_A ($m^2.ha^{-1}$) and boxplots values for the two layers and the total dataset. Comparison by pairs of S_A from EK60 and EK80 for the two layers and for the total dataset. Statistical tests on the mean values and between the 1:1 line (black) and the linear regression model (dotted line) were : not significantly different = ■; significantly different results p-value < 0.05 = *; highly significant p-value < 0.01 = **.

Table 1- Annex: Average values of S_A (m^2: ha^{-1}) according to the layer.

Mean S_A (m^2 :ha^{-1})	EK60	EK80	p-value
Global	1.04	1.08	0.35
Surface layer	0.85	0.85	0.83
Deep layer	1.22	1.29	0.15