# 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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14
15  **Abstract**

16  Used for several decades and recognized today as a reliable method, fishery acoustics is

17  commonly used in scientific studies and monitoring surveys. In Europe, during the last

18  decades, the most frequently used scientific echo-sounder has been the EK60 from the Simrad

19  company (Simrad Kongsberg Maritime AS, Horten, Norway). A new echo-sounder model,

20  the EK80, has been recently developed, and it is therefore necessary to check whether the

21  results obtained by the two generations of echo-sounder (EK60 and EK80) give the same

22  results. This is of main importance in the context of time series. Recent works have already

23  addressed this comparison, focusing on $S_A$ (nautical area backscattering coefficient) but the

24  systems' reliability to accurately measuring target strength (TS, in dB) has only been tested

25  using calibration spheres. Our work aims to test the hypothesis that, at a given frequency, the

26  TS recorded simultaneously *in situ* by an EK60 and an EK80, in CW mode, were not

27  statistically different. Data were recorded in two peri-alpine lakes using the two systems

28  sampling sequentially a similar volume. Using statistical tests, acoustics metrics were

29  compared. For TS, statistically significant differences were found between the two

30  generations of echo-sounder. However, these differences were not large enough to affect the

31  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).

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

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

88  Therefore, our work aimed to test the hypothesis that, at a given frequency, the TS
89  values, recorded simultaneously *in situ* by an EK60 and an EK80 in CW mode, were not
90  statistically different, and finally that one can consider that data from the two generations of
91  echo-sounder are the same. Preliminary, as observed in previous works (De Robertis et al.,
92  2019; MacCaulay et al., 2018), we checked that no significant difference was observed on the
93  $S_A$ means from the two sounders. We acquired data at two lakes using the two systems
94  sampling sequentially a similar volume, at the most used frequency in lakes (Draštík et al.,
95  2017). Data were analyzed using the same software and parameters. In this way, we tested
96  whether the data series could be continued without breakage, despite the change of echo-
97  sounders.

98

99  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

132    of 50 W for the EK80 and 100 W for the EK60 records. These parameters are the ones most

133    used in lakes (Draštík et al., 2017).

134    The surveys, georeferenced by a GPS connected to the echo-sounder, followed a zigzag

135    course at a navigation speed of about 8 $km.h^{-1}$ in calm to moderate wind conditions (CEN,

136    2014; Draštík et al., 2017). The surveys were performed at night, approximately 1 h after

137    sunset, to sample the fish when their distribution is as dispersed as possible within the water

138    column (Girard et al., 2020). Calibrations were performed using the EK80 software for both

139    echo-sounders according to the standard protocol of Foote et al. (1987) (Demer et al., 2015)

140    and the manufacturer's manual. For the EK80, the calibration was performed in a "calibration

141    tank" at Ifremer (Brest, France), and for the EK60, the calibration was performed *in situ*. To

142    overcome the variability inherent in *in situ* calibrations, the echo-sounder was calibrated three

143    times, and the results averaged following recommendations of De Robertis et al. (2019).

144    2.3. Acoustic data process

145    Data were analyzed using Sonar5-Pro software (Balk and Lindem, 2021), a software regularly

146    used in freshwater studies. The TS threshold was set at -60 dB for Single Echo Detection

147    (SED) according to monitoring surveys in lakes (Draštík et al., 2017). This threshold allowed

148    fish detection greater than ~ 0.02 m using Love's equation (Love, 1971), an equation

149    commonly used in freshwater surveys (Emmrich et al. 2012; Morrissey-McCaffrey et al.,

150    2018; Tessier et al., 2020). SED was determined in Sonar5-pro using the following

151    parameters: a pulse length ratio between 0.8 and 1.3; a maximum gain compensation of 3 dB

152    (one way); and a sampling angle standard deviation of 0.3 degrees (Godlewska et al., 2011;

153    Guillard et al., 2014). The threshold of the mean volume backscattering strength, $S_v$ (in dB re

154    1 $m^{-1}$), was set 6 dB lower, at - 66 dB, according to Parker-Stetter et al. (2009). The data from

155    the two echo-sounders were simultaneously processed, using the multi-frequency function of

156    Sonar5-Pro, creating two channels (Balk and Lindem, 2021). The bottom was automatically

157    detected using the software's tool, including a margin of 0.5 m and, in rare cases, was

158    manually rectified on both channels. The Elementary Distance Sampling Unit (EDSU) was set

159    to 250 m (same as applied by Guillard et al. 2014; Mouget et al., 2019) and allowed to extract

160    the mean Target Strength (calculated in the linear domain) by layers, and in the same way, the

161    $S_A$ values (expressed in hectare acoustic scattering strength, in $m^2.ha^{-1}$). The study focusing

162    on fish surveys, to avoid analyzing unwanted non-fish echoes (Emmrich et al., 2014), the

163    Sonar5-Pro cleaning tool was simultaneously used on both echograms to remove ghost echoes,

164  bubbles, debris accumulations, ropes from gillnets/buoys, and fake bottoms. A few EDSU

165  with too many noises and artefacts (e.g., buoys) were excluded from the analysis. Finally, the

166  Sawada index (Sawada et al., 1993) was set to ensure that conditions permitted estimation of

167  TS. Thus, to overcome the presence of multiple echoes that would impact the TS estimation,

168  only EDSU with a Sawada index < to 0.1 were used for the size distribution analyses

169  (Godlewska et al., 2011).

170  2.4. Statistical analysis

171  The mean values of TS were compared using the Mann-Whitney U-test, as the data did not

172  follow a normal distribution. For TS, the test was performed in the linear domain (Simmonds

173  and MacLennan 2005). Furthermore, to compare data from each EDSU, i.e., pairs of TS from

174  EK60 and EK80 for each EDSU, the procedure developed by Warton et al. (2006) was done

175  in addition to linear regression, the slopes of the data set were compared with a 1:1 line. This

176  statistical approach is recommended when the measurement error is unknown, which is the

177  case with the acoustic data set (Mouget et al., 2019). This statistical procedure was performed

178  in previous analysis of comparisons of acoustic data set (Godlewska et al., 2011; Guillard et

179  al., 2014; Mouget et al., 2019). The statistical test evaluated whether the two metrics from the

180  EK60 and EK80 meet the $H_0$ hypothesis that the two sets of data are the same. SED

181  distributions were tested using the Kolmogorov-Smirnov test. The Lake Annecy and Lake

182  Bourget data were merged to perform statistical tests on a larger sample. Finally, fish

183  densities were calculated for each layer and lake using Forbes and Nakken's (1972) equation

184  (Tessier et al., 2020).

185

186  3. Results

187  3.1. Data set

188  In Lake Bourget, 582 EDSU were recorded for the surface layer, 578 for the deep layer; in

189  Lake Annecy, 284 EDSU were recorded for the surface layer and 290 for the deep layer

190  (Table 1). Analyses were performed on a total of 1652 ESDU for TS analysis and 1654 ESDU

191  for $S_A$ comparisons (Table 1) , two EDSU being excluded for TS due to an inappropriate

192  Sawada index. Echograms from the two devices appeared to be similar (Fig. 1). According to

193  previous works (De Robertis et al., 2019; MacCaulay et al., 2018) no significant difference in

194  the $S_A$ means between the two generations of echo-sounders, regardless of the layer, were

195     found (Annex 1).

196     3.2. TS values according to the echo-sounders

197     The number of SED detected by each echo-sounder was very close. The EK60 detected
198     43,631 SED for the two layers compared to 43,726 for the EK80, a difference of 0.2%. This
199     difference was mainly due to a higher number of targets detected by the EK80 in the deep
200     layer: 19,490 SED for the EK80 against 18,779 SED for the EK60, i.e., a difference of 3.6%.
201     In the surface layer, the number of SEDs recorded by the EK80 is slightly lower, with 24,236
202     against 24,852 for the EK60, a difference of 2.5%. For the surface layer, there is a slight shift
203     in the main mode of the TS distribution, - 47.8 dB for EK60 values against -47.3 dB for the
204     EK80 values. There was no offset for the secondary mode (-59.3 dB) (Fig. 2). For the deep
205     layer, the distributions were similar, with the same modes for the two echo-sounders (main
206     mode: -37.6 dB; secondary mode: -52 dB), even if there were significant statistical difference
207     between the SED distributions using the Kolmogorov-Smirnov test ($p < 0.01$).

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

216     3.3. Fish density

217     Regarding fisheries and ecosystem management, it is meaningful to express the acoustic
218     metrics in fish density, i.e., number of fish by surface. Thus, the fish densities per layer
219     obtained with the two generations of echo-sounders were calculated. Results were very close
220     between the two echo-sounders : for the surface layer, 1203 (EK60) and 1183 (EK80) fish.ha-
221     [1] and 583 (EK60) and 529 (EK80) number of fish.ha^{-1} for the deep layer.

222

223     4. Discussion

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

225    MacCaulay et al., 2018) have addressed the comparison of the two generations of echo-
226    sounder and thus made it possible to validate the continuity of the data for time series.
227    However, these previous works focused mainly on $S_A$ (nautical area backscattering
228    coefficient), the TS intercalibration between the two sounders was only done using calibration
229    spheres. So, our work completes the previous ones with *in situ* data. Our comparison being of
230    main importance for lake fishery studies, we choose the most used parameters (frequency,
231    pulse length, power) in lakes (Draštík et al., 2017). Bonar and Hubert (2002) have highlighted
232    that standardized methods ensure robust estimates. To facilitate comparisons between datasets
233    acquired using different equipment, inter-calibration is needed. The main goal of this study
234    was to evaluate the difference on TS recorded *in situ* by two generations of echo-sounder,
235    EK60 and EK80. This approach is necessary to inter-calibrate the echo-sounders due to the
236    discontinuation of the production of the EK60. Many long-term monitoring surveys have been
237    performed with EK60 in freshwater ecosystems (Draštík et al., 2017; Ostrovsky et al., 2014;
238    Pollom et Rose, 2016) and the continuity of the series is of paramount importance (Bonar and
239    Hubert, 2002). The previous comparisons (Demer et al., 2016 ; Macaulay, et al. 2018, De
240    Robertis et al. 2019) showed that there is a deviation between the two echo-sounders, a ratio
241    EK80/EK60 <1, mainly due to a slight over-amplification of low-power signals by the EK60.
242    This difference would be related to the linearity of the echo-sounders, especially for the EK60,
243    which differs for weak targets and targets located at long distances to the echo-sounder. This
244    over-amplification biases abundance estimates because it modifies the assumption inherent in
245    echo-integration (Foote, 1983). However, according to the authors, for depths not exceeding
246    100 m, over-amplification is not present. Furthermore, the authors highlighted that the impact
247    is relatively small for data from strong scatters, i.e., fish with swimbladders. Therefore, our
248    results, focusing on *in situ* TS complement previous works, in a lake context, where the
249    depths are shallower (max Bourget depth: 145 m; Annecy max depth: 82 m), and fish are
250    rarely located below 100 m depth and have a swimbladder (Yule et al., 2013).

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

258    averages, is small and thus not noticeable for fish management or research perspectives.

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

275    For this kind of approach, to minimize potential biases related to the acquisition chain, the
276    EK80 software was used to record the data and perform the calibrations. A strict comparison
277    of the echo-sounders should have been made with the same transducer, as in De Robertis et al.
278    (2019), but it requires a specific electronic installation not accessible during our surveys. In
279    this case, we overcome the differences specific to the use of two independent transducers,
280    which do not have the same characteristics, the equivalent beam angle is not characterized by
281    the standard calibration method, and then can be a major source of uncertainty in echo-
282    integration measurements (De Robertis et al., 2019). In our configuration, the difference can
283    be due to the own characteristics of the transducers and obviously from calibrations, which
284    despite the care taken, imply variability.

285    For a more global approach, other tests using different frequencies, power parameters, pulse
286    lengths, etc. should be done in the future but overall, our work highlights that the two
287    generations of echo-sounder give very close results, using the most used configuration in
288    lakes. The differences between EK60 and EK80are likely to be smaller than errors related to
289    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.

*References*

Andersen, L.N., 2001. The new Simrad EK60 scientific echo sounder system. J. Acoust. Soc. Am. 109, 2336. doi.org/10.1121/1.4744207

Balk, H., Lindem, T., 2021. Sonar4 and Sonar5-Pro post processing systems, Operator manual version 606.23, 489 p. Lindem Data Acquisition, Oslo (Norway).

CEN, 2014. CSN EN 15910 - Water quality - Guidance on the estimation of fish abundance with mobile hydroacoustic methods, Category: 7577 Water quality. Biological. Https://Www.En-Standard.Eu Brussels, p. 41.

319  Baran, R., Blabolil, P., Čech, M., Draštík, V., Frouzová, J., Holubová, M., Jůza, T., Koliada,
320  I., Muška, M., Peterka, J., Prchalová, M., Říha, M., Sajdlová Z., Šmejkal M., Tušer, M.,
321  Vejřík L., Kubečka J., 2021. New way to investigate fish density and distribution in the
322  shallowest layers of the open water. Fish. Res. 238, 105907.
323  doi.org/10.1016/j.fishres.2021.105907.

324  Benoit-Bird, K.J., Waluk C.M., 2020. Exploring the promise of broadband fisheries
325  echosounders for species discrimination with quantitative assessment of data processing
326  effects. J. Acous. Soc., 147, 411. https://doi.org/10.1121/10.0000594

327  Bonar, S. A., Hubert, W. A., 2002. Standard sampling of inland fish: Benefits, challenges, and
328  a call for action. Fisheries 27: 10–16. doi:10.1577/1548-8446(2002)

329
330  Braun, L.-M., Mehner, T., 2021. Size Spectra of Pelagic Fish Populations in a Deep Lake—
331  Methodological Comparison between Hydroacoustics and Midwater Trawling. Water, 13,
332  1559. https://doi.org/10.3390/w13111559
333

334  Blanluet, A., Doray, M., Berger, L., Romagnan, J.B., Le Bouffant, N., Lehuta, S., Petitgas P.,
335  2019. Characterization of sound scattering layers in the Bay of Biscay using broadband
336  acoustics, nets and video. PLOS ONE, https://doi.org/10.1371/journal.pone.0223618

337  Blanluet A., Gastauer S., Cattanéo F., Goulon C., Grimardias D., Guillard J., 2022. Acoustic
338  discrimination between schools and submerged trees in reservoirs: A preliminary approach
339  using narrowband and broadband acoustics. Canadian Journal of Fisheries and Aquatic
340  Sciences, https://doi.org/10.1139/cjfas-2021-0087
341  Blanluet A., Goulon C., Lebourges-DhaUssy A., Eymar-Dauphin P., Guillard J., 2020. Effect
342  of a transducer horizontality default on lake fish stock assessment. Acoustics Australia, 48,
343  473–479. https://doi.org/10.1007/s40857-020-00206-1

344  De Robertis, A., Bassett, C., Andersen, L. N., Wangen, I., Furnish, S., Levine, M, 2019.
345  Amplifier linearity accounts for discrepancies in echo-integration measurements from two
346  widely used echosounders. ICES J. Mar. Sci. 76(6): 1882–1892. doi:10.1093/icesjms/fsz040

347  Demer, D. A., Andersen, L. N., Bassett, C., Berger, L., Chu, D., Condiotty, J., Cutter, G.R.,
348  Hutton, B., Korneliussen, R., Le Bouffant, N., Macaulay, G., Michaels, W.L., Murfin, D.,
349  Pobitzer, A., Renfree, J.S., Sessions, T.S., Stierhoff, K.L., Thompson, C.H., 2017. 2016
350  USA–Norway EK80 Workshop Report: Evaluation of a wideband echosounder for fisheries
351  and marine ecosystem science. ICES Cooperative Research Re-port No. 336. 69 pp.
352  doi.org/10.17895/ices.pub.2318

353 Demer, D.A., Berger, L., Bernasconi,M., Eckhard, B., Boswell, K., Chu, D., Domokos, R.,
354 Dunford, A., Fässler, S., Gauthier, S., Hufnagle, L.T., Jech, J.M., Le Bouffant, N., Lebourges-
355 Dhaussy, A., Lurton, X., Macaulay, G.J., Perrot, Y., Ryan, T.E., Parker-Stetter, S., Stienessen,
356 S.,Weber, T.,Williamson, N., 2015. Calibration of acoustic instruments. Technical report 326,
357 ICES, Denmark

358 Draštík V., Godlewska M., Balk H., Clabburn P., Kubečka, J., Morrissey E., Hateley J.,
359 Winfield I.J., Guillard J., 2017. Hydroacoustic standardization: a new step forward based on
360 comparisons of methods and systems from a large deep lake. Limnology & Oceanographic
361 Method, 15 (10) 836–846. DOI: 10.1002/lom3.10202

362 Emmrich, M., Winfield, I.J., Guillard, J., Rustadbakken, A., Vergès, C., Volta, P., Jeppesen,
363 E., Lauridsen, T., Holmgren, K., Argillier, C., Mehner, T., 2012. Strong correspondence
364 between gillnet catch per unit effort and hydroacoustically derived fish biomass in stratified
365 lakes. Freshw. Biol. 57 (12) : 2436 – 2448. doi:10.1111/fwb.12022

366 Foote, K. G., 1983. Linearity of fisheries acoustics, with addition theorems J. Acoust. Soc.
367 Am. 73: 1932–1940.

368 Foote, K.G., Knudsen, H.P., Vestnes, G., MacLennan, D.N., Simmonds, E.J., 1987.
369 Calibration of acoustic instruments for fish density estimation: a practical guide ICES
370 Cooperative Research Report, 144. 81

371 Forbes, S.T., Nakken, O., 1972. Manuel des méthodes de prospection et d'évaluation

372 des ressources halieutiques. FAO, Rome.

373 Frossard, V., Goulon, C., Guillard, J., Hamelet, V., Jacquet, S., Laine, L. , Rimet, F., V. Tran-
374 Khac, V.,  2020. Suivi de la qualité des eaux du lac d'Annecy. Rapport 2019. SILA (éd) et
375 INRA-Thonon 94 + annexes.

376 Girard, M., Goulon, C., Tessier, A., Vonlanthen, P., Guillard, J., 2020. Comparisons of day-
377 time and night-time hydroacoustic surveys in temperate lakes. Aquat. Living. Resour. 33, 9.
378 doi.org/10.1051/alr/2020011

379 Godlewska, M., Izydorczyk, K., Kaczkowski, Z., Józwik, A., Długoszewski, B., Ye, S., Lian,
380 Y., Guillard, J., 2016. Do fish and blue-green algae blooms coexist in space and time? Fish.

381     Res. 173, 93–100(2016). doi.org/10.1051/alr/2020011 10.1016/j.fishres.2015.06.018

382     Godlewska, M., Colon, M., Józwik, A., Guillard, J., 2011. How pulse lengths impact fish

383     stock estimates during hydroacoustic measurements at 70 kHz. Aquat. Living Resour. 24, 71–

384     78. doi.org/10.1051/alr/2011104

385     Gugele, S. M., Widmer, M., Baer, J., DeWeber, J. T., Balk, H., Brinker, A., 2021.

386     Differentiation of two swim bladdered fish species using next generation wideband

387     hydroacoustics. *Scientific reports, 11(1), 1-10*. https://doi.org/10.1038/s41598-021-89941-7

388     Guillard, J., Lebourges-Dhaussy, A., Balk, H., Colon, M., Jóźwik, A., Godlewska, M., 2014.

389     Comparing hydroacoustic fish stock estimates in the pelagic zone of temperate deep lakes

390     using three sound frequencies (70, 120, 200 kHz). Inl. Waters 4, 435–444. DOI: 10.5268/IW-

391     4.4.733

392     Guillard J., Lebourges-Dhaussy A., Brehmer P., 2004 . Simultaneous Sv and TS

393     measurements on YOY fresh water fish using three frequencies. ICES Journal of Marine

394     Science, 61,267-273. 10.1016/j.icesjms.2003.11.007

395     Guillard, J., Brehmer, P., Colon, M., Guennegan, Y, 2006. Three dimensional characteristics

396     of young–of–year pelagic fish schools in lake. Aquat. Living Resour. 19, 115–122.

397     DOI10.1051/alr:2006011

398     Jacquet, S., Cachera, S., Crépin, L., Espinat, L., Goulon C., Guillard, J., Hamelet, V.,

399     Hustache, J.C., Laine, L., Perney, P., Quétin, P., Raphy J., Rasconi, S., Rautureau, C., Rimet,

400     F., Tran-Khac, V., 2021. Suivi environnemental des eaux du lac du Bourget pour l'année

401     2020. Rapport INRAE-CISALB, 188 pages.

402     Koslow, J. A., 2009. The role of acoustics in ecosystem-based fishery management. ICES

403     Journal of Marine Science, 66(6):966–973. doi.org/10.1093/icesjms/fsp082

404     Love, R.H., 1971. Dorsal ‑ Aspect Target Strength of an Individual Fish. The Journal of the

405     Acoustical Society of America 49: 816–823. doi:10.1121/1.1912422

406     Macaulay, G.J., Scoulding, B., Ona, E., Fässler, S.M.M., 2018. Comparisons of echo-

407     integration performance from two multiplexed echo-sounders. ICES J. Mar. Sci., 75: 2276–

408     2285. doi:10.1093/icesjms/fsy111

409    MacLennan, D.N., Fernandes P.G., Dalen, J., 2002. A consistent approach to definitions and
410    symbols in fisheries acoustics. ICES J. Mar. Sci. 59, 365–369. doi:10.1006/jmsc.2001.1158

411    McKenzie, D.J., Geffroy, B. , Farrell, A.P., 2021. Effects of global warming on fishes and
412    fisheries. J Fish Biol, 98: 1489-1492. https://doi.org/10.1111/jfb.14762

413    Mehner, T. 2012. Diel vertical migration of freshwater fishes proximate triggers, ultimate
414    causes and research perspectives: Diel vertical migration in freshwater fishes. Freshw Biol 57:
415    1342–1359. doi.org/10.1111/j.1365-2427.2012.02811.x

416    Morrissey-McCaffrey, E., Rocks, K., Kelly, F.L., Kelly-Quinn, M., 2018. Effects of differing
417    ground-truth data, transect design and statistical analysis on the repeatability of hydroacoustic
418    assessments of pollan *Coregonus autumnalis p*ollan. Fish. Manag. Ecol. 25(4), 304–318.
419    doi.org/10.1111/fme.12295

420    Mouget, A., Goulon C., Axenrot T., Balk H., Lebourges-Dhaussy A., Godlewska M., Guillard
421    J., 2019. Including 38 kHz in the standardization protocol for hydroacoustic fish surveys in
422    temperate lakes. Rem. Sens. Ecol. Cons., 5 (4) : 332–345 doi.org/10.1002/rse2.112

423    Ostrovsky, I., Goren M., Shapiro, J., Snovsky, Z., Rynskiy, A., 2014. Fish biology and
424    ecology. In:  Lake Kinneret: Ecology and Management. Aquatic Ecology Series, vol 6 (Eds T.
425    Zohary, A. Sukenik, T. Berman, A. Nishri). Springer, Dordrecht. pp 273-292. doi:
426    10.1007/978-94-017-8944-8_16

427    Parker-Stetter, S.L., Rudstam L.G., Sullivan P.J., Warner D.M, 2009. Standard operating
428    procedures for fisheries acoustic surveys in the Great Lakes. Gt. Lakes Fish. Comm. Spec.
429    Publ. 09, 180.

430    Pollom, R.A., Rose, G.A., 2016. A global review of the spatial, taxonomic, and temporal
431    scope of freshwater fisheries hydroacoustics research. Environ. Rev. 24: 333–347.
432    dx.doi.org/10.1139/er-2016-0017

433    Rimet, F., Anneville, O., Barbet, D., Chardon, C., Crépin, L., Domaizon, I., Dorioz, J.M.,
434    Espinat, L., Frossard, V., Guillard, J., Goulon, C., Hamelet, V., Hustache, J.C., Jacquet, S.,
435    Lainé, L., Montuelle, B., Perney, P., Quetin, P., Schellenberger, A., Tran-Khak, V., Monet, G.,
436    2020. The Observatory on Lakes (OLA) database: Sixty years of environmental data
437    accessible to the public. Limnology, 79(2) https://doi.org/10.4081/jlimnol.2020.1944

438   Rudstam L.G., Jech J.M., Parker-Stetter S.L., Horne J.K., Sullivan P.J., Mason D.M., 2012.
439   Fisheries hydroacoustics. *In*: A.V. Zale, D.L. Parrish, T.M. Sutton (eds.), Fisheries
440   Techniques (3rd edn.) Bethesda, Maryland: American Fisheries Society, pp. 40

441   Sawada, K., Furusawa M., Williamson N.J., 1993. Conditions for the precise measurement of
442   fish target strength in situ. J. Mar. Acoust. Soc. Jpn. 20, 73–79.

443   Simmonds J, MacLennan DN. 2005. Fisheries Acoustics: Theory and Practice, 2nd edn.
444   Fisheries Series. Oxford: Blackwell Publishing.

445   Tessier A., Richard A., Masilya P., Mudakikwa E., Muzana A., Guillard J., 2020. Spatial and
446   temporal variations of *Limnothrissa miodon* stocks and their stability in Lake Kivu. Journal of
447   Great Lakes Research 46 (2020) 1650–1660. https://doi.org/10.1016/j.jglr.2020.09.009

448   Trenkel V.M., Ressler P.H., Jech M., Giannoulaki M., Taylor C., 2011. Underwater acoustics
449   for ecosystem-based management: state of the science and proposals for ecosystem indicators.
450   Mar Ecol Prog Ser. 442:285–301. https://doi.org/10.3354/meps09425

451   Warton, D.I., Wright I.J., Falster D.S., Westoby, M., 2006. Bivariate line-fitting methods for
452   allometry. Biol. Rev. 81, 259–291. doi: 10.1017/S1464793106007007

453   Wheeland L.J., Rose, G., 2016. Acoustic measures of lake community size spectra. Can. J.
454   Fish. Aquat. Sci. 73: 557–564. dx.doi.org/10.1139/cjfas-2014-0446

455   Yule, D.L., Evrard, L.M., Cachera, S., Colon M., Guillard, J., 2013. Comparing two fish
456   sampling standards over time: largely congruent results but with caveats. Freshw. Biol. 58,
457   2074–2088. doi:10.1111/fwb.12192

458

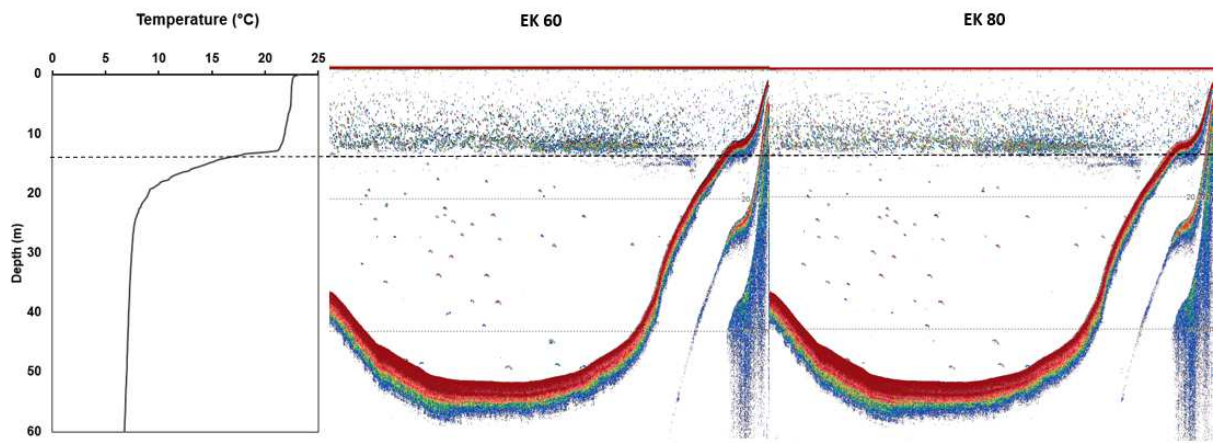459 *Credit author statement*

460 Clément Rautureau : Methodology , Investigation, Data curation, Writing - Reviewing

461 Chloé Goulon : Methodology, Investigation, Validation, Reviewing and Editing

462 Jean Guillard : Conceptualization, Methodology, Investigation, Validation, Writing-

463 Reviewing and Editing, Supervision

464

465

466 Figure 1. Left side -Temperature profile acquired in the Lake Annecy (14 September 2020).

467 Right side – echograms, at left EK60 and at right EK80, using a -66 dB threshold in Amp-

468 echogram recorded in the Lake Annecy ; the dashed line shows the separation between layers.

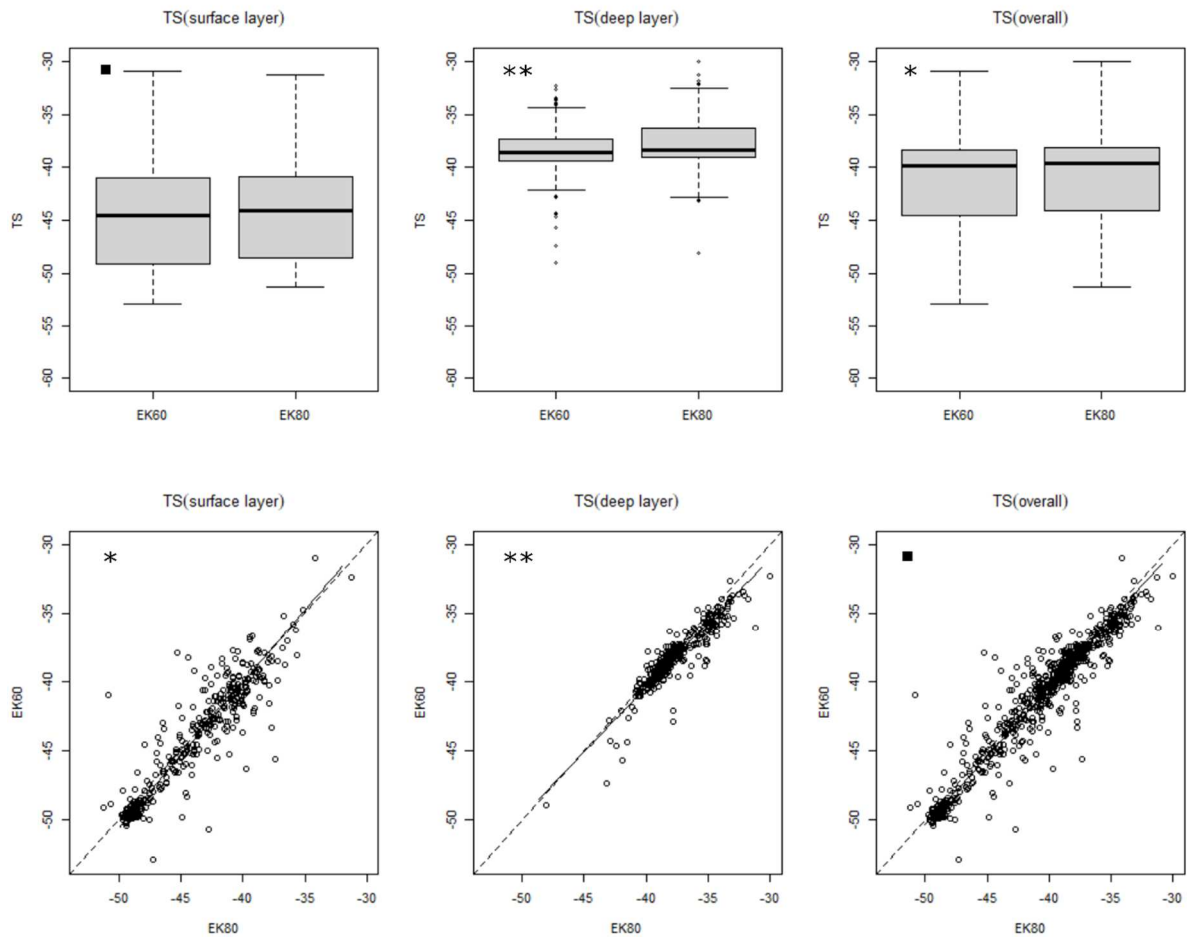469 Data from OLA, Observatory of LAkes (http://www6.inra.fr/soere-ola ©SOERE OLA-IS).

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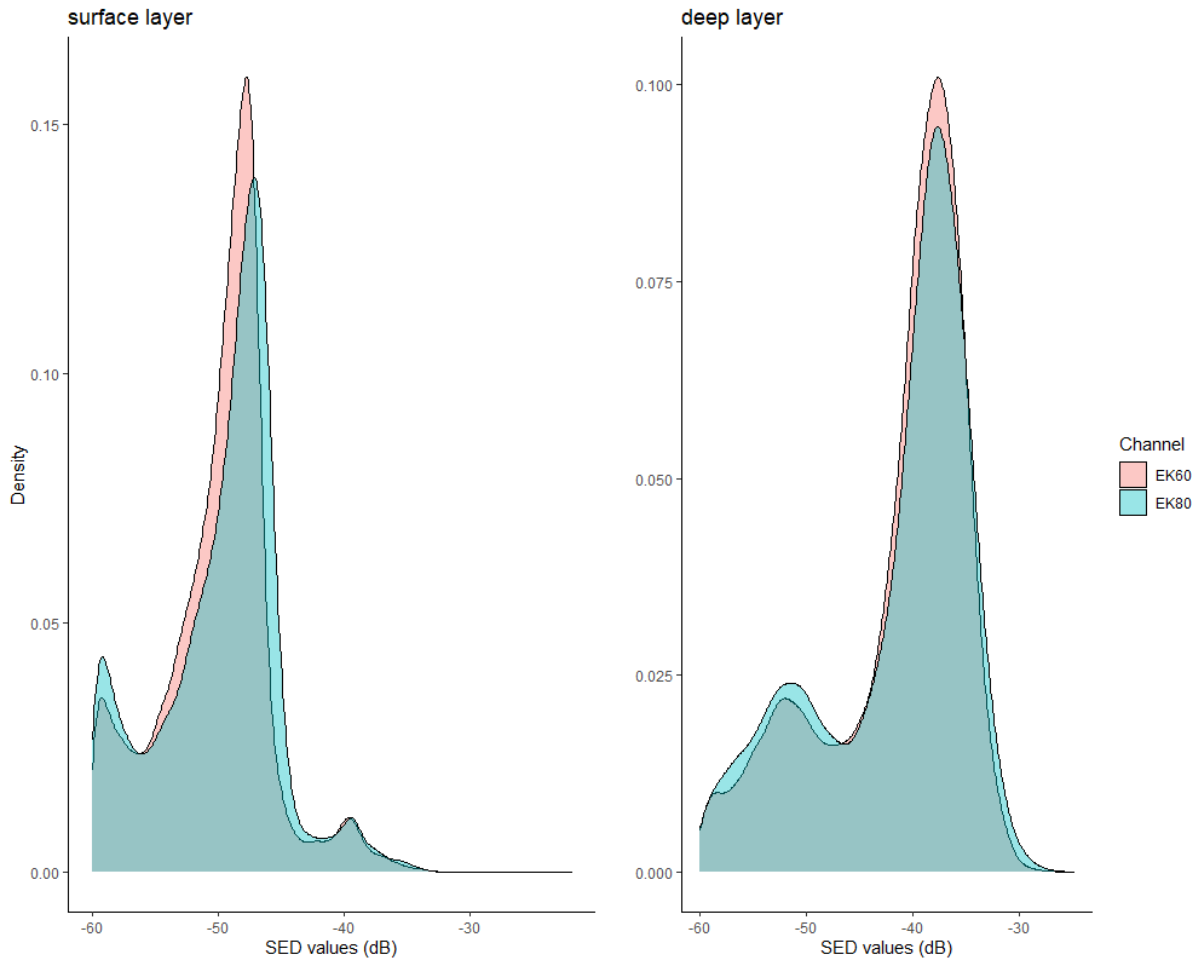
Figure 2. TS distribution of the Single Echo Detection (SED) for the two layers. Pink for the

EK60 values, green for the EK80 values.

475

476

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 = **.

482

483

484 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 |

485

| | Lake Annecy | | Lake Bourget | |
|---|---|---|---|---|
| | Surface layer | Deep layer | | |

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

487

| 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 |

488

489

490     *Annex*

491

492     $S_A$ values according to the echo-sounders

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

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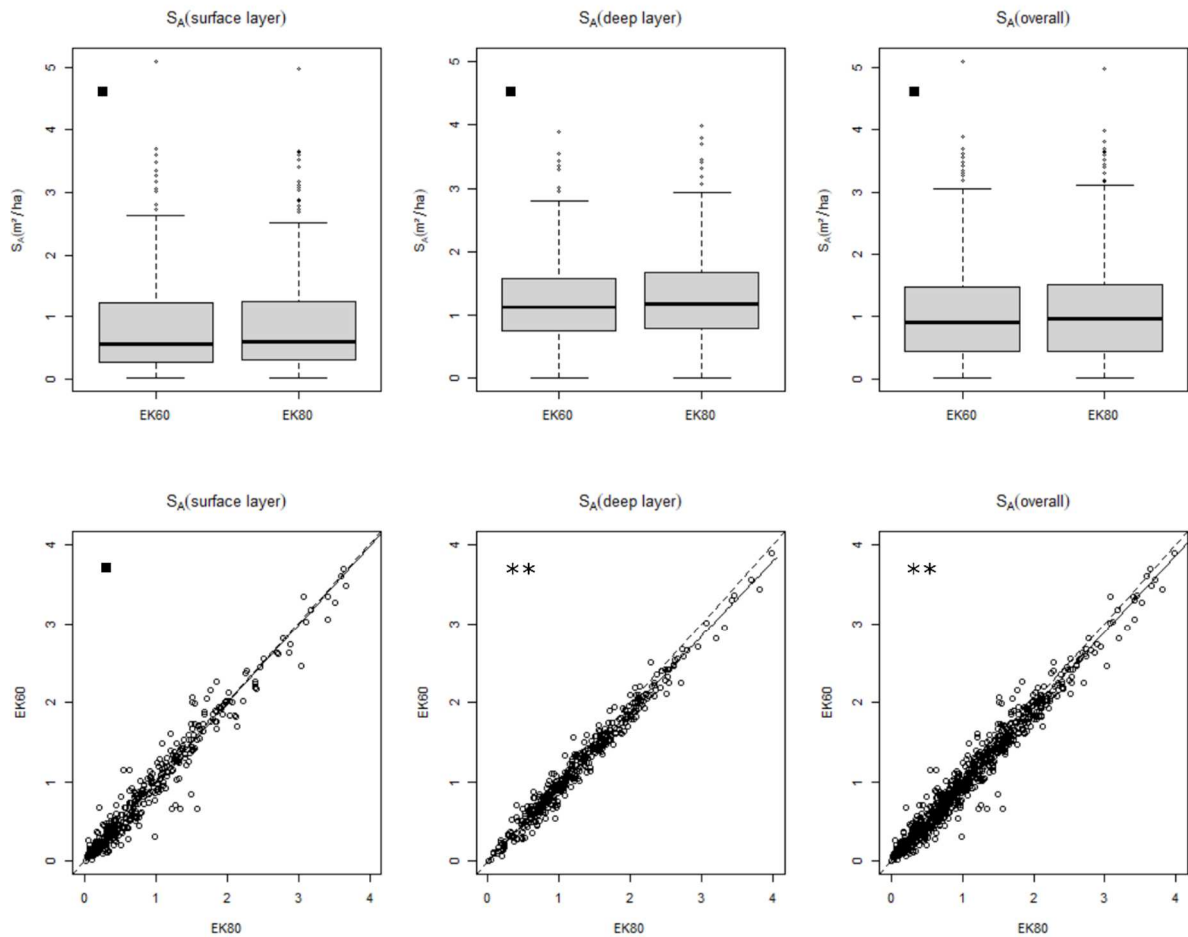
Figure 1- Annex. Mean $S_A$ (m².ha$^{-1}$) and boxplots values for the two layers and the total dataset. Comparison by pairs of $S_A$ from EK60 and EK80 for the two layers and for the total dataset. Statistical tests on the mean values and between the 1:1 line (black) and the linear regression model (dotted line) were : not significantly different = ■; significantly different results p-value < 0.05 = *; highly significant p-value < 0.01 = **.

513

514    Table 1- Annex: Average values of $S_A$ (m²: ha$^{-1}$) according to the layer.

| Mean $S_A$ (m² :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 |

515