Effect of a Transducer Horizontality Default on Lake Fish Stock Assessment

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Abstract :

reshwater hydroacoustic surveys are frequently performed with small research boats. Thus, the transducer, usually fixed on a pole on the side of the boat, could be misaligned with the horizontal axis (i.e., the lake surface). Given that fish acoustic responses are strongly directional, the transducer angle could induce attenuation of their backscattering strengths. To test the influence of a small shift of the transducer orientation, we compared hydroacoustics estimates from two sampling nights on the Lake Annecy: the first one being a transducer angle of 1.5∘ with the horizontal and the second one being strictly horizontal. We showed that the effect of such an angle is negligible over the sampling variability on the TS distribution of the fish population and the biomass assessment. We conclude that a small shift in the transducer horizontality (≤1.5∘) will not degrade the quality of the acoustic data.

Keywords : Fisheries acoustics, Freshwater, Transducer miss-alignment

1 Introduction

Hydro-acoustics has become a requisite method to assess fish populations in lakes and is on the way of standardization [1, 2, 3]. It is a routine method in many European lakes [4, 5, 6].

Surveys are most of the time performed using small research boats (< 8 m), with non-permanent acoustic equipment; the transducer being generally fixed to a pole at the boat side. These temporary installations can lead to some issues such as noises due to vibration or turbulence near the engine, but also a faulty installation of the transducer (incorrect setting/mounting) or variation of the boat angle due to movements of people on the boat and inadequate weight distribution. In vertical beaming, the transducer face must be oriented parallel to the lake surface. However, these issues could hinder this prerequisite to be filled.

Fish backscattering is highly dependent on fish orientation, over all other factors, such as sizes or species [7, 8]. In horizontal beaming, the fish orientations could have a dramatic impact on fish size estimations, and then on biomass assessments [9]. In vertical beaming, a transducer misalignment with the surface should have an impact on the incident angle of the fish, and then lowering the resulting backscattering [8]. To our knowledge, no publication has directly studied the effect of a transducer misalignment *in situ*.

In this study, we investigate the effect of transducer misalignment by a few degrees with the horizontal on fish stock assessment using two sampling nights performed at a one-day interval on the Lake Annecy (France). The first night of sampling was characterized by a small transducer misalignment.

We analyzed the impact of this misalignment on fish Target Strength (TS, dB,[10]), the corresponding modelled fish size using Love' equations [11] and on the fish biomass estimate at the whole lake scale. This issue is very common in lake fish stock assessment,

and the conclusions of this study will be of great help to the freshwater fisheries acoustic community.

2   Materials and Methods

2.1   Sampling

This study is based on opportunistic data acquired during the annual monitoring fish-stock assessment (OLA, Observatory of LAkes, [12]) and a frequency comparison study [3] on the Lake Annecy. Due to inappropriate installation, the transducer presented a misalignment during the first sampling night, corrected for the second sampling night.

The first night of acquisition (night 1, 13/09/2016) was performed through parallel transects, when the second night (night 2, 14/09/2016) was performed through "Zig-zag" transects (Figure 1). These two types of sampling strategy give similar fish size distributions and biomass estimates [13]. The two nights presented similar weather conditions.

Detailed sampling protocols have been described previously in [3]. In the present publication, we focus on the 70 kHz frequency, our referenced frequency in fish studies [14, 15, 16]. The echo-sounder was a Simrad EK60 with a split-beam transducer of 7 degree opening at -3 dB. The sounder ping interval varied from 0.15 to 0.3 s.The pulse duration was set to 0.256 ms [17] with a transmitting power of 100 W. The echo sounder was previously calibrated in the Ifremer tank at Brest (France), and again *in situ* prior to the survey, following the standard protocol [18, 19], and the manufacturer's manual. The transducer was mounted on a pole fixed on the side of the boat, at 0.7 m deep. The boat was sailing at approximately 8 $km.h^{-1}$.
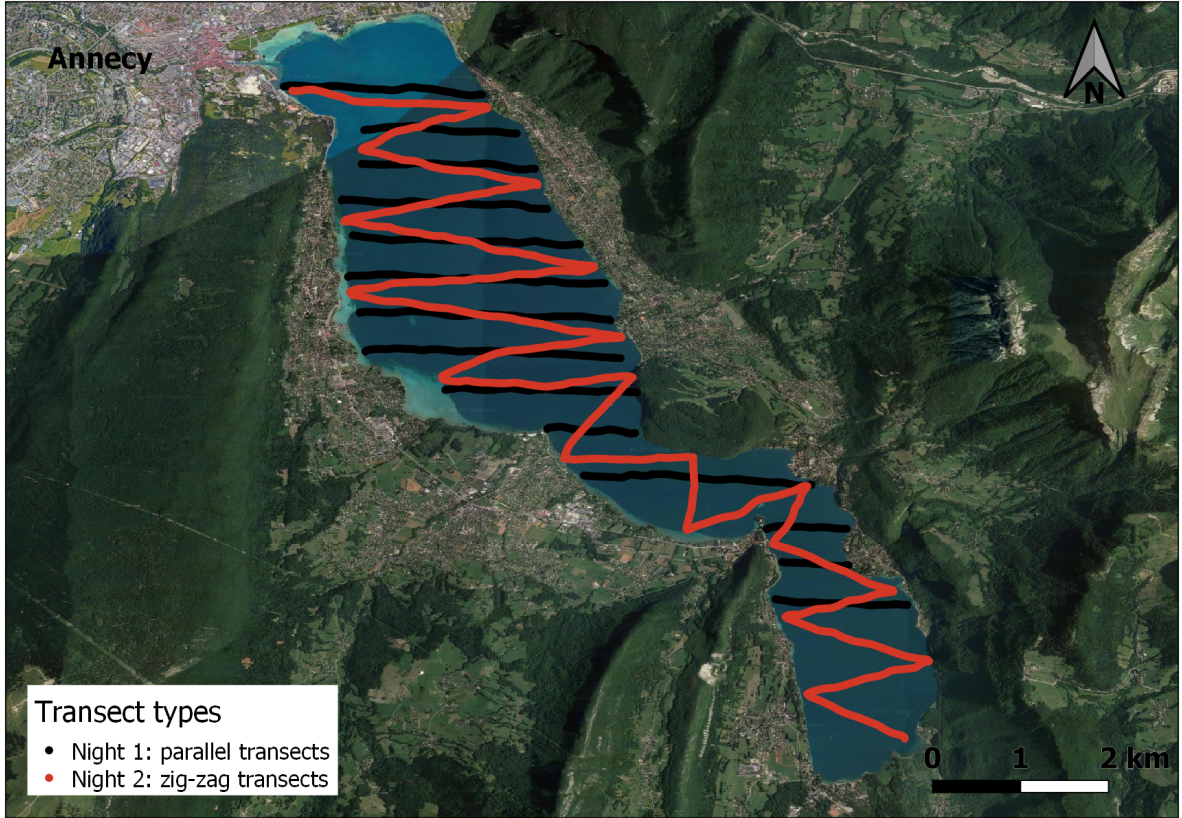
Figure 1: Survey tracks on the Lake Annecy (France) for night 1 (13/09/2019) and night 2 (14/09/2019)

2.2   Data processing

Data were processed with SONAR 5 [20]. The TS threshold was set to -60 dB and the Volume backscattering Strength (S_v, dB re $1m^{-1}$, [10]) threshold to -66 dB according to [21]. The SONAR 5 Single Echo Detection (SED) algorithm was set with an echo 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 [3]. The Elementary Sampling Distance Unit (ESDU) was set to 250 m for the Area backscattering Strength (S_A, $m^2.ha^{-1}$, [10, 20]) computation. The minimal number of pings for tracking was set to 2 above 13 m depth and 3 below this depth.

The methodology to assess fish populations in French alpine lakes is based on European standard [1, 2] and is described in detail elsewhere [3].

After echograms cleaning (noise, bubbles, plankton layers) using SONAR 5 tools, the echograms were split into three layers processed separately according to previous studies [22]. This splitting was based on the thermocline depth (13 m, Figure 2), and on the knowledge from experimental fishing [22] of a shift in the fish composition at around 35 m deep. The layer above the thermocline (2 to 13 m) is mainly composed of Young-of-the-Year perch (*Perca fluviatilis*) and roach (*Rutilus rutilus*) [15]. The layers below the thermocline are mainly composed of Salmonidae [23, 24]: whitefish (*Coregonus lavaretus*) for the second layer (13 to 35 m) and a mix of European whitefish and Arctic charr (*Salvelinus alpinus*, approximately 90% whitefish and 10% Arctic charr, [22]) for the third layer (35 m to the lake bed, around 70 m).
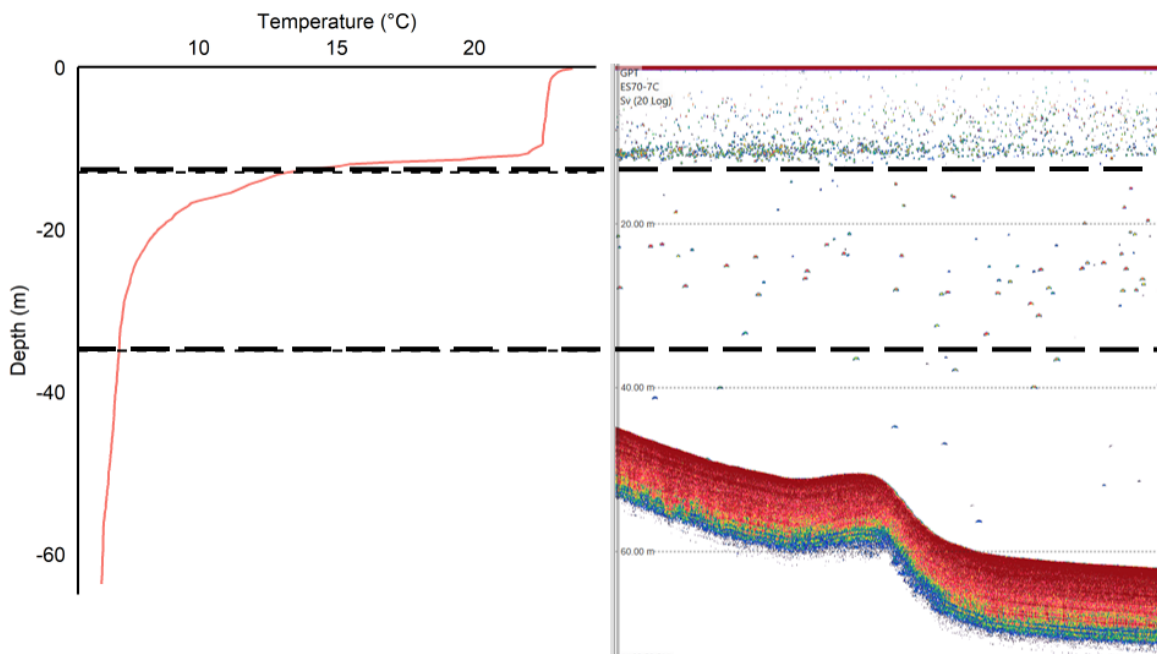

Figure 2: Left side - temperature profile acquired on 13/09/2019 in the Lake Annecy. Right side - echogram acquired on 14/09/2019, the dashed lines show the separation between the layers. Data from OLA, Observatory of LAkes (http://www6.inra.fr/soere-ola ©SOERE OLA-IS.

For each layer, we extracted a mean TS (calculated in the linear domain) and a mean S_A by ESDU all over the lake. The fish mean size, weight, density and then biomass were calculated using the formulae presented in detail in [3] and based on [25, 11] equations.

2.3   Angle determination

As no direct measurement of the transducer angle has been performed during the first sampling night, so we had to estimate the transducer angle offset between the two nights through the fish orientation in the TS tracking after data processing.

The fish orientation has two angles components, the "tilt" angle, and the "swim" angle [26]. The tilt angle is defined by "the angle between the long axis of the fish and the incident wave front" [27], the swimming angle being defined by the fish swim direction on the vertical axis. These two angles are not necessarily equivalent. During echo-tracking, the SONAR 5 calculates the swimming angle, or more specifically, the mean "aspect angle" (or "pitch angle" [28]). The aspect angle is defined by the fish angle between the tracked ping i and $i+1$ on the vertical axis [20].

$$Aspect\ angle_i = \arctan\left(\frac{dz_i}{\sqrt{dx_i^2 + dy_i^2}}\right) \tag{1}$$

With dz_i, dx_i and dy_i the target displacement between the ping i and the ping $i+1$, in each dimension [20, 28].

In practice, for a vertically oriented echo-sounder, the aspect angle, the tilt angle and the swimming angle are similar for a given fish [26].

When the transducer is not perfectly horizontal to the surface, the tilt angle will be a combination of the natural fish swim angle and the transducer angle. This angle divergence can be easily notable on echograms on deep fish (> 20 m, figure 3 (a) and (b)). To calculate the effect of the transducer angle on fish tilt angle, we measured the mean offset of aspect angle between night 1 and night 2 on each layer.

The shift in the distribution of the aspect angle between night 1 and night 2 can be observed in Figure 4. The transducer angle with the horizontal during night 1 have been estimated as 1.5°[±0.13] (with 91.60°[±0.06] and 90.13°[±0.12], as the night 1 and night
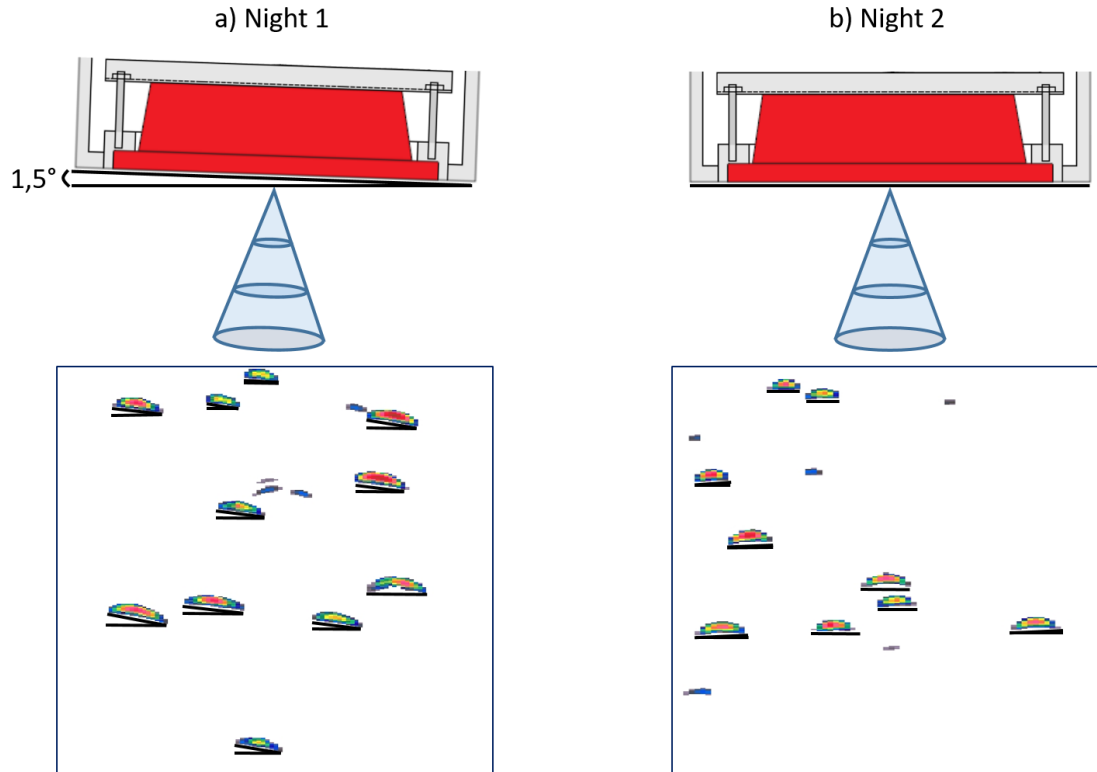
Figure 3: Transducer orientation mismatch between night 1 and night 2 and influence on fish echoes.

2 mean aspect angles for all layers, respectively). This value was relatively stable across layers, but with a higher value and variability for the 2-13 m layer $1.6°[\pm0.33]$ than for the two deeper $(1.3°[\pm0.024]$ for the 13-35 m and $1.3°[\pm0.030]$ for the 35-70 m layer). The aspect angles of fish of the shallower layer were less accurate compared to the deeper layers, as there are fewer pings per track for each fish. If there was some variability on the fish tilt angle (Figures 3 and 4), it was very low and values for each sampling night were tightened around the principal mode.

2.4 Influence on biomass assessments

Because the backscattering of fish highly depends on its orientation [7] and the maximum backscattering is generally obtained for a normal incident angle with the swimbladder axis [29], we hypothesized that the mean TS should be slightly lower for the first night.
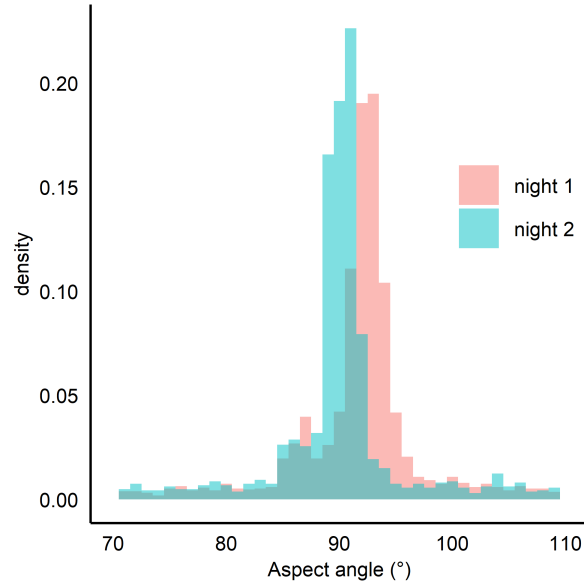
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Figure 4: Aspect angle histograms of night 1 and night 2 for the three layers.

Thus, to investigate the possible transducer angle effect on stock assessment, we compared the two sampling nights TS distributions by layers using Kolmogorov-Smirnov tests (package "stat", R, [30]), and we investigated their influence on biomass evaluation. We estimated a confidence interval by bootstrapping (package "boot", R, [30]) around the mean TS, size, S_A and estimated biomass.

3 Results

During night 1, 1571 tracked fish echoes were recorded for 31.4 km of acquisition. During night 2, 1260 tracked fish echoes were recorded for 28.7 km of acquisition. The fish echoes number ratio between the two sampling nights is relatively stable through the layers (1036/832 for layer 1, 255/198 for layer 2 and 280/230 for layer 3).

The TS distributions are shown in Figure 5 for each layer and sampling nights. The mean TS, calculated lengths, S_A and biomass are shown Table 1. The calculated mean length values are consistent with the net samplings [31].
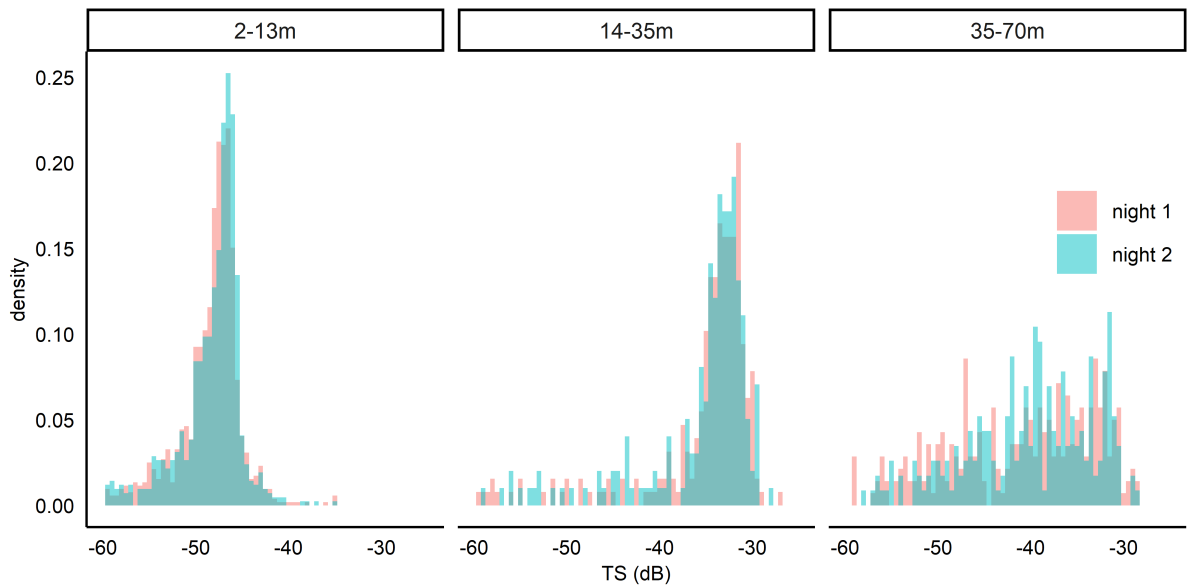

Figure 5: TS (dB) histograms of the three layers ((a) 2-13 m, (b) 13-35 m, (c) 35-70 m) for night 1 and night 2

Estimates for the surface layer (2-13 m): The TS distributions of the surface layer presented similar shapes for night 1 and night 2 (Figure 5 (a)), with a 0.8 dB shift for the mode (Figure 5 (a)), -47.6 dB for night 1 and -46.8 dB for night 2. The two mean TS values were similar (less than 0.1 dB difference between the two values, Table 1). Nevertheless, the two distributions were considered different by a Kolmogorov-Smirnov test (p-value = 0.00088).

Despite this statistical difference for the TS distributions, the two nights bootstrapped confidence limits for mean TS, estimated mean length, S_A and biomass largely overlapped,

Table 1: Mean TS (dB), calculated length (cm), S_A ($m^2.ha^{-1}$), and biomass ($kg.ha^{-1}$) for the three layers (2-13 m, 13-35 m, 35-70 m) for the two sampling nights. 95% confidence interval are presented between brackets.

Depth layer	Night	Mean TS (dB)	mean length (cm)	mean S_A ($m^2.ha^{-1}$)	biomass ($kg.ha^{-1}$)
2-13m	1	-47.2 [-47.4,-46.8]	7.3 [7.1,7.6]	1.11 [0.93,1.33]	17.8 [14.5,22.1]
2-13m	2	-47.1 [-47.3,-46.8]	7.4 [7.2,7.7]	1.10 [0.96,1.27]	18.0 [15.1,20.8]
13-35m	1	-33.3 [-33.6,-33.0]	38.9 [37.4,40.5]	1.08 [0.96,1.23]	107.5 [89.0,125.1]
13-35m	2	-33.4 [-33.6,-33.0]	38.2 [36.5, 40.0]	0.96 [0.85, 1.07]	93.7 [75.7, 111.7]
35-70m	1	-36.1 [-36.7,-35.5]	27.7 [25.7,29.8]	0.11 [0.09,0.13]	7.4 [5.2,9.6]
35-70m	2	-36.4 [-37.0,-35.7]	26.9 [24.8, 29.2]	0.08 [0.07, 0.11]	5.5 [3.8, 7.2]

and these values could be considered similar.

Estimates for the mid layer (13-35 m): The TS distribution for the mid-layer also presented similar shapes for night 1 and night 2 (Figure 5 (b)), with a 2 dB shift for the mode (-31.6 dB for night 1 and -33.6 dB for night 2). However there was no such shift noticed for the mean TS values (Table 1), and the two distributions were not considered significantly different by the Kolmogorov-Smirnov test (p-value = 0.7216).

The mean TS and mean estimated length value were between the two sampling nights (Table 1) as their bootstrapped confidence intervals largely overlapped. However, there was a notable difference between night 1 and night 2 in the mean S_A, their bootstrapped confidence interval did not overlap on an important part of the distribution. This implies a difference in the estimated biomass : +15% between night 1 and night 2.

Estimates for the deep layer ($>$ 35 m): In the deeper layer, TS distributions did not present any mode (Figure 5 (c)); the two mean TS values were close, with a difference of 0.3 dB (Table 1), and the Kolmogorov-Smirnov test did not find a significant difference between the two distributions (p-value = 0.1364).

As for the mid layer, there was a notable shift in bootstrapped confidence intervals for the mean S_A. This implies a significant difference in the estimated biomass: +35% between night 1 and night 2.

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4 Discussions

The transducer angle difference was easily seen when comparing the tracked TS fish tilt angle distributions between night 1 (with a transducer misalignment) and night 2 (without). However, this angle had no impact on the TS mean values for the three layers. On the TS distributions, the surface layer (2-13 m) showed a significant 0.8 dB shift in the TS mode between night 1 and night 2 that could be attributed to the transducer angle effect. No significant differences in TS distribution have been shown between the two nights for the two deeper layers. This difference between layers could be explained by the high number of fish sampled in the upper layer compare to the two deeper layers. A small variation of the TS distribution would be perceptible in a large sample, when it is hidden by the high variability of smaller samples. However, this difference could also be potentially attributed to the natural orientation of the swimbladder in the fish body, which is not generally completely parallel to the fish axis [32], and is highly dependent on the fish species [32, 33]. Thus, perch presents a swimbladder tilt angle of $8 - 10°$ [34] when salmonids like whitefish or salmon (*Salmo salar*) present a lesser tilt angle of $2 - 3°$ [35]. We can hypothesize that the 1.5° transducer angle could have been partly compensated by the whitefish swimbladder tilt angle, while the higher perch swimbladder tilt angle has not compensated the transducer angle effect.

The angle shift between nights 1 and 2 was detectable in the fish aspect angles only because lake fish present a low activity at night [14, 23]. For much marine fish, like herring [26], this 1.5° angle shift and its TS impact will be negligible over their tilt angle variability, even at night [26].

The estimated mean TS were not impacted by the angular misalignment between the two nights. This observation identifies the mean TS as a robust indicator of fish size, as it is not highly sensitive to a small transducer angle mismatch through its average of a set of variable orientations.

However, there was a biomass mismatch between the two surveys for the two deeper layers due to the mean S_A differences. These differences could be attributable to sampling variability between the two nights. Despite previous observations showing a weak impact of the sampling strategy [13], heterogeneity in the spatial fish distribution between the two nights could have occurred. However, from a fisheries management point of view, these differences could be acceptable.

Thus, the angle influence on the calculation of fish biomass is negligible compared to the sampling variability, at least at an error of less than 1.5°.

This study was conducted at 70 kHz, but the fish orientation has a growing influence with frequency [33, 8]. It is expected that the impact of the transducer angle on the TS will be higher for higher frequencies (120 or 200 kHz) and lesser for lower the frequency (38 kHz) [36, 27], as well used for fish stock assessments in lakes.

A default in the transducer horizontality can be empirically assessed on the echograms by scrutinizing the shift between the first and the last ping of deep fish echoes (> 20 m). However, when in the field it is not always easy to obtain a perfect horizontality by moving the transducer. Our study concludes that a small shift in the horizontally ($\leq$ 1.5°) of the transducer has a negligible impact on lake fish stock assessment results. More *in situ* surveys with different angle defaults and different frequencies should still be done to better assess the impact of transducer angle misalignment on fish stock estimations.

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