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# Comparing Fish Density and Echo Strength Distribution Recorded by Two Generations of Single Beam Echo Sounders

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**Abstract:** Hydroacoustic acquisition was performed by means of two different single beam systems, the Simradmodel EK15 from 2015 and the Simrad model EY-M from the 1980s to explore potential differences of fish density and target strength (TS) distribution between EK15 and EY-M-based estimates. The oligotrophic Lake Storsjøen (48 km$^2$) with steep shores, was chosen for the survey. The pelagic fish stock is dominated by whitefish (*Coregonus lavaretus* L.), and, recently, illegally stocked smelt (*Osmerus eperlanus* L.), and a low proportion of Arctic charr (*Salvelinus alpinus* L.). The total density was estimated at two depth layers (18–32 and 32–48 m), and was quite similar for TS ≥ −56 dB: 755 and 498 fish ha$^{-1}$, respectively for the EK15-based estimates and similarly 766 and 490 fish ha$^{-1}$ for the EY-M estimate. Target strength distributions were similar for TS > −48 dB. The proportion of single fish detected with EK15 was negatively affected by the long pulse duration. Six acquisitions from 1986 to 2016 showed a dramatic increase of density of TS = −46 to −44 dB echoes (>10 cm) between 2013 and 2016. This was due to the growth of the introduced smelt population.

**Keywords:** echo sounding; single beam; comparison; smelt; whitefish; monitoring

## 1. Introduction

For the management of water resources, monitoring ecologically important fish species is crucial. Pelagic salmonids and cyprinids predate zooplankton in temperate lakes, and affect the species composition and size structure of the zooplankton community, which in turn affects the abundance of planktonic algae [1,2], and further, influencing water quality and its suitability for public use [3–5]. The hydroacoustic assessment is an efficient method to estimate the density and size distribution of pelagic fish, and has been used in lakes for more than three decades, and in marine environments for much longer [6,7]. The available equipment has been developing, and single beam transducers from the early stage are replaced by split beam echosounders. Nevertheless, a transceiver, first presented in 2012 [8], Simrad EK15, has kept the single beam character.

Historical hydroacoustic data, recorded by means of older equipment are important for comparison with current and future surveys in a climate change perspective, and there is a need for calibration of old to new equipment. A few comparative studies are published, like a comparison of the single beam Simrad EY-M with the split beam Simrad EY200 [9] and with the Simrad EY500 with both single and split beam transducers [10]. The Simrad EY-M could serve as a common reference.

This study was conducted in Lake Storsjøen in southeast Norway, and the aim was to compare density estimates and target strength distribution of echoes of the pelagic fish community based on two different single beam Simrad echosounders, an EY-M from 1982 and an EK15 from 2015. The effects of different ping repetition frequency and pulse duration on EK15-based density estimates were explored, and density estimates from five former years are also presented as a contribution to monitoring fish density.

## 2. Materials and Methods

### *2.1. Study Area*

This survey was conducted in Lake Storsjøen (outlet 61°23.1′ N, 11°21.9′ E) in southeast Norway. The lake is oligotrophic with concentration of total phosphorus < 10 μgL$^{-1}$ and chlorophyll a <2.5 μgL$^{-1}$ [11]. The surface area is 48 km$^2$, the maximum depth is 309 m, and the pelagic fish stock is dominated by whitefish (*Coregonus lavaretus*) and smelt (*Osmerus eperlanus*) (the latter is recently illegally stocked), with a low proportion of Arctic charr (*Salvelinus alpinus* L) [12].

### *2.2. Methods*

To compare the fish density and target strength distribution attained by two echo sounders Simrad EK15 and Simrad EY-M, records were made along ten 1500–2300 m long transects, obliquely crossing the lake at daytime (11:00–16:00) in late May 2016 (Figure 1) in a speed of 1.6 to 1.9 m s$^{-1}$. Both transceivers were powered by 12 V batteries.

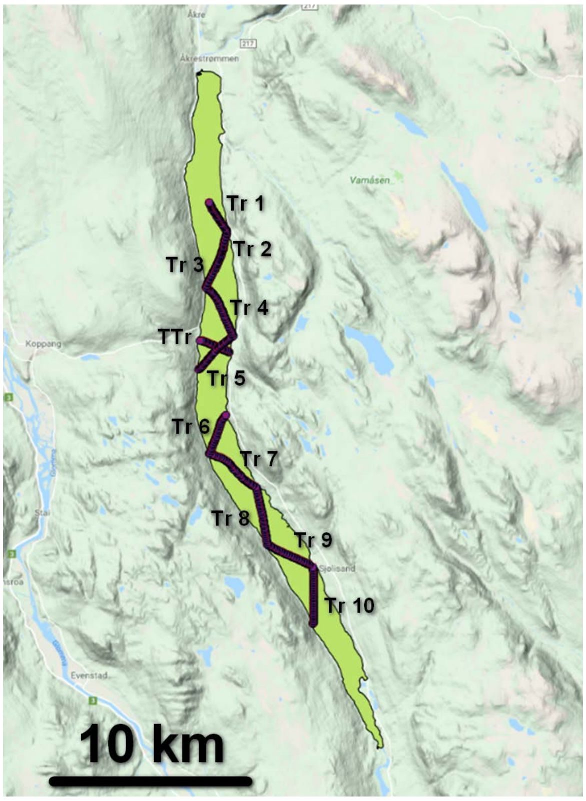


**Figure 1.** Map of Lake Storsjøen with transects Tr 1–10 recorded in May 2016, and the test transect TTr where six transects were performed to test the effects of the ping repetition frequency (PRF) and pulse duration (PD) on density estimates, in September 2017.

Daytime was chosen because the fish are distributed on greater depth than at night [12,13], so a higher number of fish will be detected (in the approximately coned sound beam) at daytime, giving a more representative TS distribution. Jurvelius et al. [10] recommended recording in darkness when recording echoes of TS < −44 dB, (i.e., fish length < 15 cm), at high densities (> 1000 fish per ha), due to schooling behavior during daylight. In Lake Storsjøen, density was lower (< 1000 fish per ha), and the fish larger (30–40% of the echoes had TS ≥ −44 dB).

The EK15 and EY-M echo sounders transmit sound at different frequencies, 200 kHz and 70 kHz, respectively, and this made it possible to run both systems simultaneously. Another difference is that the transducer of EK15 has a beam angle of 9° whereas EY-M has an angle of 11.2°, so the latter covers a slightly larger water volume. The fish density was analyzed in two relatively narrow depth layers of high concentration of fish (Figure 2), thereby making it possible to explore potential effects of different systems on different depths. The equipment was calibrated from the boat when anchored up above 15 m depth with the sphere at 8 m depth. For the EY-M calibration, a 32.1 mm copper sphere (corresponding to TS = −39.4 dB at temperature 5 °C), and for EK15 a 38.1 mm wolfram carbide (WC) sphere (corresponding to TS = −39.2 dB, at water temperature 5 °C) was used.

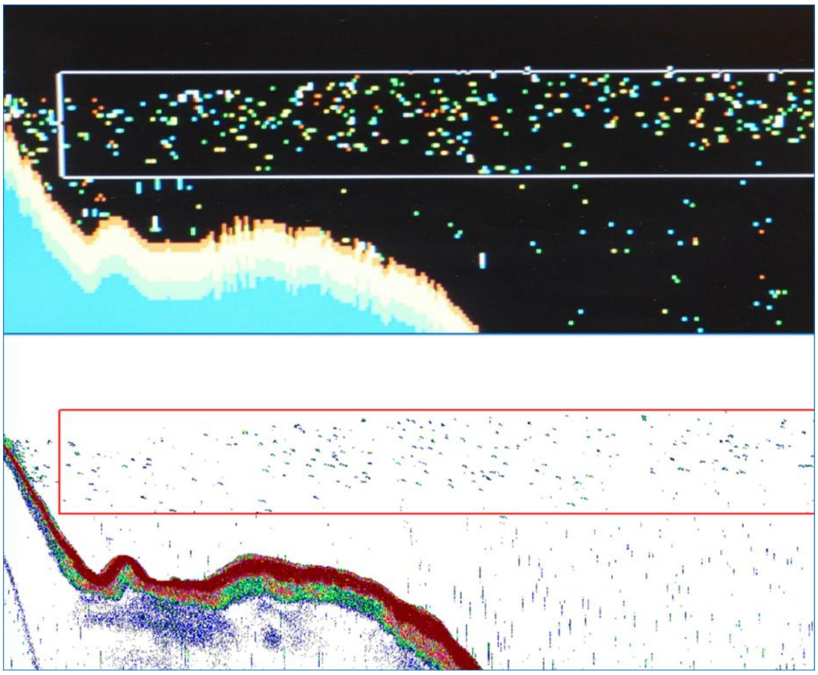

**Figure 2.** Echograms from Transect 2, 27.05.2016, produced by Simrad EY-M/HADAS (**above**) and by Simrad EK15/Sonar5-Pro (**below**). Horizontal lines show 20–47 m depth and cover an approximately 1000 m stretch (vertical spots at depths > 50 m the in the lower chart are due to noise, not fish).

Simrad EY-M operates with a fixed pulse duration (PD) of 0.60 ms, and a ping repetition frequency (PRF) of 1.5 or 3.0 pings $s^{-1}$, whereas the Simrad EK15 has several options; PD of 0.08, 0.16, 0.32, 0.640 and 1.280 ms, and PRF up to 40 pings $s^{-1}$. PD was set to 0.32 ms, assumed to give higher resolution of schools than the higher PD alternative of 0.64 ms. The water temperature in May was 4–5 °C (salinity < 2 ppm), giving a sound speed in water of 1422–1427 m $s^{-1}$. PRF was chosen 1.5 $s^{-1}$ for EY-M and 1.33 $s^{-1}$ for EK15, and the slightly lower PRF was chosen for EK15 because parts of some transects were difficult to analyze with PRF = 1.5, as the (second) bottom echo met the next signal and produced noise on both systems. A 500 m long stretch in the second crossing of the lake was therefore omitted in the analysis of both echo sounders. This divided a crossing in two, forming transect 2 and 3. With 1.33 pings per second, the echo met the next signal at >50 m depth where the detections were sparse.

### 2.3. Gill Netting

Gillnetting was conducted with benthic and pelagic nets on the 24th to the 26th of August in 2015, primarily to explore the abundance of the introduced smelt, and the length distribution from the sampling is used to explain the echo distribution. There were 10 different mesh sizes from 10 to 52 mm of both nets types.

### 2.4. Testing Effects of Ping Repetition Frequency ( PRF) and Pulse Duration ( PD) on Single Fish Detection (SED)

In September 2017, one approximately 1.5 km long crossing over Lake Storsjøen (Figure 1) was repeated six times as an experiment with varying PD (0.16, 0.32 and 0.64 ms) and PRF (1.33 and 1.5 per second) on the EK15. The EY-M was run simultaneously with PD = 0.60 ms and PRF = 1.5. Calibration was conducted only with PD = 0.32 ms, at the start of the experiment. The transect was analyzed in a five to seven meter thick layer with the highest concentration of fish, starting at 18 to 25 m (at 15:48 local time) and raising gradually to 12 to 17 m at the end (at 18:17 local time) as the fish moved higher in the water towards the evening. Each crossing was divided in three approximately 450 m long subdivisions, i.e., elementary sampling units (ESU), resulting in totally 36 ESU, including six replicates of each treatment, (i.e., varying PD and PRF).

### 2.5. Time Trend Monitoring

This study is a part of a long term monitoring of the pelagic fish stock in Lake Storsjøen that started in 1985 [14], aiming to reveal stock changes, whether this is caused by variation in exploitation or environmental changes. The illegal introduction of smelt sometimes between 2000 and 2003 added a new momentum to the research. Density and TS distribution from four previous surveys are presented to demonstrate the fish stock change and emphasize the usefulness of such monitoring of lakes. The surveys were recorded with Simrad EY-M in May 1986, 1988 and 2013, and with Simrad EK15 in September 2015 (first time the EK15 was available).

### 2.6. Data Treatment and Statistical Analysis

Simrad EK15 uses an ordinary pc running Simrad ER15 software for the control and sorting of data. The EK15/ER15 system was set up to store raw data, and these data were later analyzed with the Sonar5-Pro software [15]. The Sawada index $N_v$ [16] warning limit was set to $N_v < 0.1$ (default, Sonar5-Pro [15]), and no warnings were received. Simrad EY-M stores the data on magnetic tape, and the tapes were digitalized and analyzed by means of the HADAS software [17]. The analysis were performed for the same stretches of transects for both transceiver systems, starting from lake depth > 50 m, analyzing $x$ pings of the EK15 and 1.50/1.33 $x$ pings of the EY-M recordings, and never including the bottom line.

Single fish detection was set up in this way for EK15; echo length 0.7–1.3 relative to PD, medium strength of multiple peak criteria (no dip greater than 1.5 dB within the echo) and maximum Gain compensation of 3 dB one way, and a 40LogR threshold model was applied. For EY-M, echoes with duration < 2 relative to PD and ≤ 12 hits (fixed) on the target were considered single fish [17]. Time variable gain (TVG) was set to 40LogR (single fish detection) and Gain was set to 8 on the EY-M.

The measured distribution of the peak voltage response from single fish echoes data were deconvolved by means of a modified Craig and Forbes algorithm to remove the beam pattern effect, due to the single beam character.

The statistical distribution of variables was tested for normality by means of the Shapiro test, and variations of total density $N_{Tot}$ ha$^{-1}$ of the single fish density ($N_{SED}$ ha$^{-1}$) and the proportion of single fish ($PROP_{SED}$, %) were analyzed by means of linear models. PRF and PD were added as categorical predictors, and the total density estimate of EY-M ($N_{EY}$ ha$^{-1}$) was added as a continuous predictor, by means of the r – software [18] ($e$ is the error assumed to be normally distributed):

$N_{Tot}\ ha^{-1} = a \times PRF + b \times PD + N_{EY} + e$

$N_{SED}\ ha^{-1} = a \times PRF + b \times PD + N_{EY}\ ha^{-1} + e$

$PROP_{SED}\ ha^{-1} = a \times PRF + b \times PD + N_{EY}\ ha^{-1} + e$

Differences between estimates based on EK15 and EY-M were tested by means of one-way ANOVA when normally distributed, and in other cases with the non-parametric Wilcoxon test. The effect of PD on mean TS across ESU was tested with PD as the categorical predictor and ESU as the random factor. This was done to reveal effects of PD on TS, as the calibration was only conducted with PD = 0.32.

Assuming negatively distributed N (as based on counting data), confidence intervals of estimates were calculated from ln transformed variables y = ln x, and 95% confidence interval of transformed values: $C.I._y = \bar{y} \pm t_{0.025} \times S.E.$ For untransformed x: Lower $C.L._x$ = mean × ($e^{(\text{Lower C.L.y})}/e^{\bar{y}}$) and Upper $C.L._x$ = mean x ($e^{(\text{Upper C.L.y})}/e^{\bar{y}}$), according to Elliot [19].

## 3. Results

### 3.1. Comparing EK15 with EY-M

The mean TS for EK15 was −48.9 and −49.2 dB, respectively at depth 18–32 and 32–48 m, whereas it was −48.9 dB at both depths for EY-M. The mean proportion of single fish (Table 1) was significantly lower (one-way ANOVA, $F_{1,18} = 19.48$, $p < 0.001$) in the EK15-based data.

**Table 1.** Single fish density (TS ≥ 56 dB), total density and proportion of single fish recorded with Simrad EY-M and Simrad EK15 at two depths along 10 transects on 27 May 2016 in Lake Storsjøen.

| Depth | Transect No. | Single Fish n | | Total N ha$^{-1}$ | | % Single Fish | |
|---|---|---|---|---|---|---|---|
| Interval | | EK 15 | EY-M | EK 15 | EY-M | EK 15 | EY-M |
| 18-32 m | 1 | 710 | 1458 | 263 | 315 | 71 | 80 |
| | 2 | 440 | 1083 | 244 | 392 | 74 | 80 |
| | 3 | 906 | 1791 | 773 | 825 | 65 | 77 |
| | 4 | 2331 | 4069 | 983 | 1075 | 70 | 76 |
| | 5 | 183 | 378 | 292 | 235 | 56 | 78 |
| | 6 | 2088 | 2051 | 780 | 866 | 69 | 71 |
| | 7 | 3634 | 4588 | 934 | 967 | 69 | 73 |
| | 8 | 1206 | 1338 | 587 | 470 | 62 | 69 |
| | 9 | 6406 | 7709 | 1745 | 1616 | 68 | 76 |
| | 10 | 1313 | 1767 | 946 | 903 | 65 | 69 |
| Mean | | 1922 | 2623 | 755 | 766 | 67 | 75 |
| 95% C.I. | | 1722-2122 | 2413-2833correct | 700-810 | 714-818 | 63-71 | 74-76 |
| 32–48 m | 1 | 895 | 1703 | 125 | 131 | 82 | 95 |
| | 2 | 481 | 978 | 106 | 131 | 78 | 96 |
| | 3 | 422 | 699 | 129 | 110 | 88 | 99 |
| | 4 | 2953 | 4443 | 457 | 398 | 80 | 82 |
| | 5 | 731 | 1363 | 286 | 281 | 82 | 93 |
| | 6 | 4055 | 2760 | 579 | 576 | 80 | 80 |
| | 7 | 8931 | 10695 | 927 | 781 | 76 | 85 |
| | 8 | 2724 | 3598 | 532 | 457 | 80 | 96 |
| | 9 | 8532 | 9191 | 919 | 886 | 73 | 72 |
| | 10 | 3422 | 4291 | 922 | 1146 | 68 | 57 |
| Mean | | 3315 | 3972 | 498 | 490 | 79 | 86 |
| 95% C.I. | | 2963-3667 | 3646-4298 | 446-551 | 439-540 | 26-50 | 83-88 |

The mean integrated densities (TS ≥ −58 dB) estimated by means of EK 15 and EY M in late May 2016 were quite similar, with 755 and 766 fish ha$^{-1}$, respectively at 18–32 m depth, and similarly, 498 and 490 fish ha$^{-1}$ at 32–48 m depth (Table 1). The EY M based estimate was slightly higher at 18–32 m depth, whereas it was opposite at 32–48 m, though not significantly (pairwise Wilcoxon test, $p > 0.05$). Comparison of the TS distribution showed quite comparable patterns for echoes with TS > −48 dB, but there was some discrepancy between the two echo sounders regarding echoes of TS = −50 and TS < −0.54 dB (Figure 3).

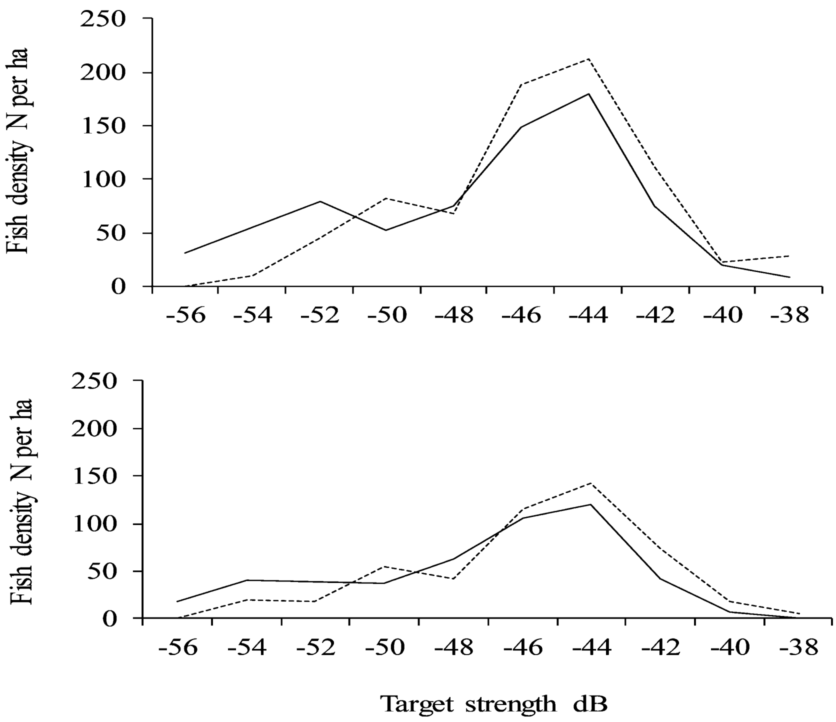


**Figure 3.** (**above**): Estimated means of total fish density of 10 transects based on Simrad EK15 (solid line) and Simrad EY-M (dotted line) at depth interval 18–32 m and (**below**): interval 32–48 m run simultaneously in May 2016.

### *3.2. Gill Netting*

Most of the smelt were caught in benthic nets, and the length groups between 12 and 24 cm dominated, whereas whitefish were mostly caught in pelagic nets, with peaks around 17 cm, 20 to 26 cm and between 34 to 40 cm (Figure 4).

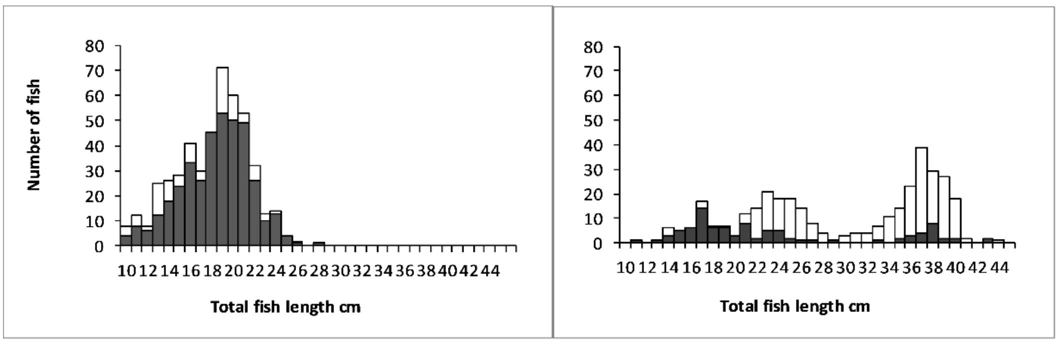


**Figure 4.** (**left**): Total length frequency distribution of smelt and (**right**): whitefish caught in benthic nets (filled columns) and pelagic nets (open columns)

### *3.3. Effects of Ping Repetition Frequency (PRF) And Pulse Duration (PD) On EK15-Based Estimates*

During the test crossing along the test transect (TTr)transect (Figure 1) in September 2017, the fish were concentrated in two layers. The density was highest at 18–25 m depth during the 12 first ESUs (starting at 14:48, local time). The fish gradually positioned higher in the water, and ended concentrated at 12–17 m during the last three ESUs (ending at 18:17, local time).

This dense layer was analyzed to test the effect of varying PRF (1.33 and 1.5 pings per sec) and PD (0.16, 0.32 and 0.64 ms). The EK15-based total density $N_{EK}$ ha$^{-1}$ ranged from 264 to 885 fish ha$^{-1}$, with a mean 521 (95% C.I: 481-572), across the 36 ESUs, regardless of PRF and PD, that means the

95% C.I. was ±8.7% of mean. The EY-based total density $N_{EM}$ $ha^{-1}$ ranged from 106 to 556 fish $ha^{-1}$, with a mean 503 (95% C.I.: 462-573), and 95% ±C.I. comprising ±8.4% of mean. The EK-based estimate was higher, but not significantly as both estimates were within the 95% C.I. of the others. Single fish detection comprised 83.6–94.4% of the EK15 estimate and 80.7–100% of the EY-M estimate, with exception of one ESU where single fish comprised only 66.0% of $N_{EM}$.

The effect of PRF was non-significant in all models, though close to significantly positive for $N_{EK}$ and $N_{SED}$ $ha^{-1}$ ($p$ = 0.052–0.064), and was excluded from the models. Then, there was a negative effect of the longest PD in all models, and also a negative effect of PRF = 0.32 on the proportion of single fish ($PROP_{SED}$) (Table 2, Figure 5). $N_{EK}$ and $N_{SED}$ were both positively related to $N_{EY}$. The mean TS (S.E.) across ESUs with PD = 0.16, 0.32 and 0.64 ms, was −49.2 (0.33), −47.3 (0.46) and −48.5 (0.72) dB, respectively, and was significantly higher at PD = 0.32 ms than at PD = 0.16 ms (t = 4.2, d.f. = 28, $p$ < 0.01) and PD = 0.64 ms (t = 2.6, d.f. = 22, $p$ < 0.05), suggesting the importance of PD specific calibration to achieve the correct TS.

**Table 2.** Results of linear modelling of EK15 based total density ($N_{EK}$ $ha^{-1}$), density of single fish detection ($N_{SED}$ $ha^{-1}$) and the proportion of single fish density ($PROP_{SED}$) explained by the estimated total density by means of Simrad EY-M ($N_{EY}$ $ha^{-1}$) and ping duration (PD); S.E.: standard error, T: t-test value, p: probability of null-hypothesis to be true.

| Variables | Estimate | S.E. | T | p |
|---|---|---|---|---|
| $N_{EK}$ $ha^{-1}$ | | | | |
| Intercept | 267.5 | 89.9 | 2.98 | **<0.01** |
| $N_{EY}$ $ha^{-1}$ | 0.55 | 0.15 | 4.135 | **<0.0001** |
| PD = 0.32 | 3.90 | 42.6 | 0.09 | n.s. |
| PD = 0.64 | −119.3 | 56.6 | 2.11 | **<0.05** |
| $N_{SED}$ $ha^{-1}$ | | | | |
| Intercept | 265.4 | 79.6 | 3.34 | **<0.01** |
| $N_{EY}$ $ha^{-1}$ | 0.47 | 0.14 | 3.47 | **<0.01** |
| PD = 0.32 | −18.8 | 37.74 | 0.50 | n.s. |
| PD = 0.64 | −140.5 | 50.1 | −2.80 | **<0.01** |
| $PROP_{SED}$ | | | | |
| Intercept | 94.6 | 1.69 | 56.1 | **<0.0001** |
| $N_{EY}$ $ha^{-1}$ | −0.002 | 0.003 | 0.85 | n.s. |
| PD = 0.32 | −3.94 | 0.80 | 4.94 | **<0.0001** |
| PD = 0.64 | −6.52 | 1.06 | −6.15 | **<0.0001** |

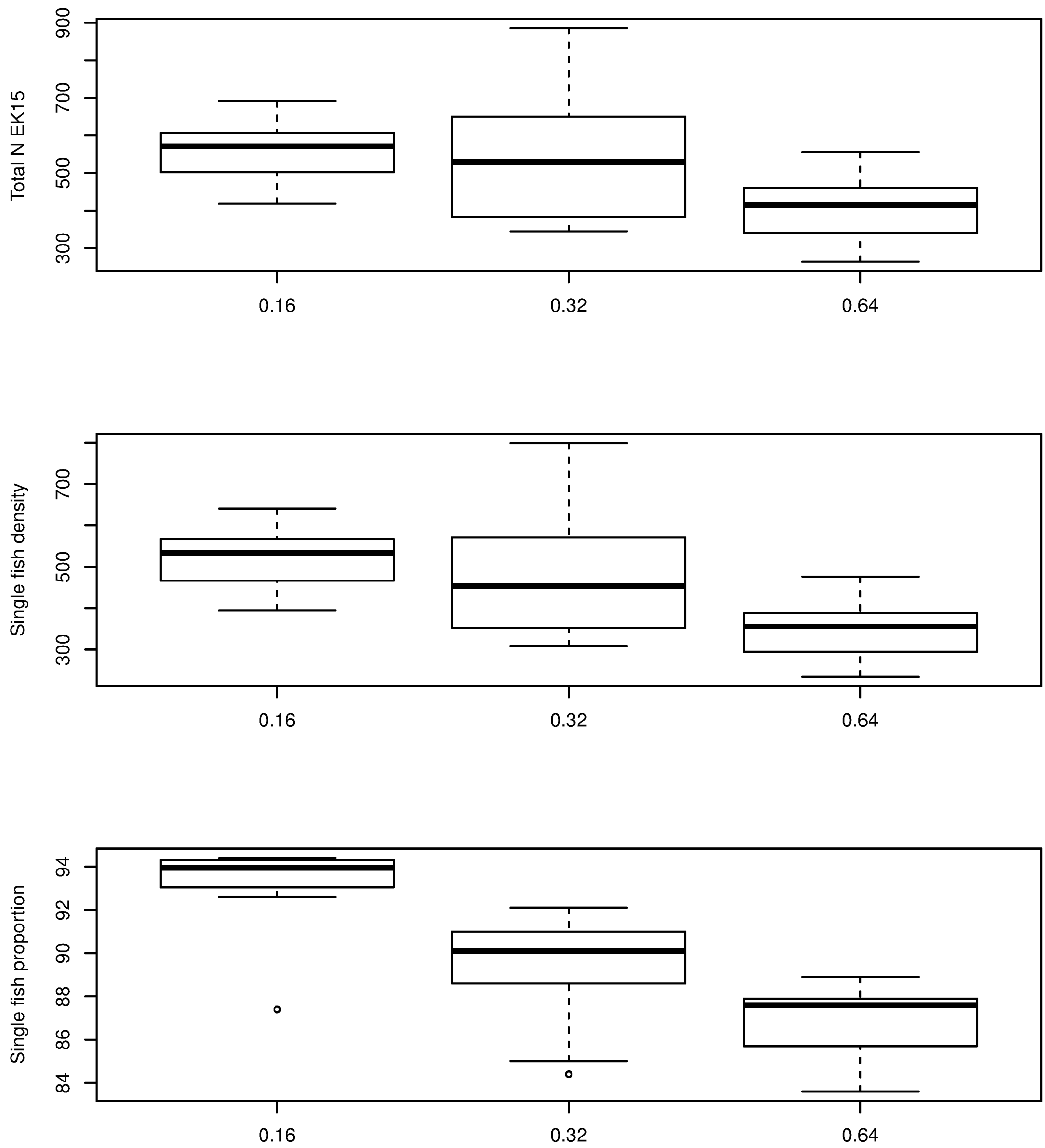


**Figure 5.** Bloxplots (bold horizontal line = median, box showing 25 and 75 percentiles, whiskers show min - max) showing EK15-based estimates of the total density (**above**), single fish density (**middle**) and proportion of single fish plotted against tree different pulse durations (**below**).

### *3.4. Time Trend*

The pelagic fish density (analyzed in one layer, 2–50 m depth) in Lake Storsjøen increased more than seven fold from 1986 to 2016. The increase was most pronounced from September 2015 to May 2016, i.e., during a period with no recruitment, but recorded at different seasons. There was an increased proportion of echoes with TS < −48 dB from 2013, and high density of echoes with TS = −48 to −46 dB in 2016 (Figure 6).

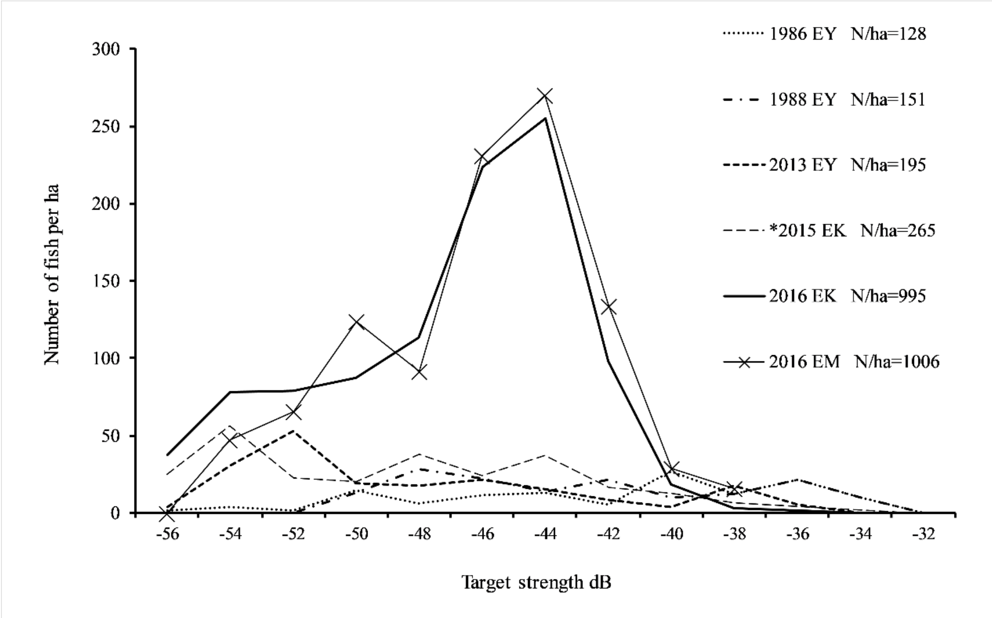


**Figure 6.** Estimated total density at 2–50 m depth from six surveys in Lake Storsjøen during 1986 to 2016. All surveys except *2015 were done during daytime in May (* = night in September).

## 4. Discussion

Density estimates based on two echo sounders, Simrad EK15 and Simrad EM Y, were quite comparable for echoes of TS ≥ −54 dB, i.e., for fish lengths > 5 cm, according to the TS – FL regression of Lindem and Sandlund [20]. The TS distribution was comparable for TS ≥ −48 dB, i.e., for fish lengths approximately 10 cm and larger, according to the regression. This means that density estimates of the pelagic fish in lakes with Simrad EK15 should be comparable with earlier estimates with Simrad EY-M. The estimates from nighttime in September 2015 compared with the records at daytime in May 2016, showed that the spatial distribution of fish might lead to underestimation of density. The gillnetting in August 2015 showed that smelt were more abundant in benthic than in pelagic habitat as compared with whitefish. Although there were no gillnet catches from May 2016, the echo sounding suggested a high abundance of echoes with TS = −46 to −44 dB, which according to the above mentioned regression, were fish between 12 and 20 cm of length, and corresponded to the peak of smelt caught in both types of gillnet in 2015. Length groups larger than 30 cm, corresponding to TS > −40 dB, dominated in the whitefish catches, and the proportion of those were lower in the density estimate of 2016 than in the earlier years.

The test recordings in September 2017 showed that the fish moved higher in the water column in the afternoon, probably to feed on plankton at night. The recordings at daytime in May, may be assumed comparable across years, and the estimates of 1986, 1988 and 2013 were rather similar, with the exception of the appearance of TS < −50 dB in 2013, probably due to the occurrence of smelt, as one-year old whitefish are about 10 cm of length [12], giving slightly stronger echoes (≈−48 dB). The bimodal length distribution in the fish samples from 2015, with smelt contributing most to a peak between 12–20 cm length, and with a peak between 32–40 cm of whitefish suggested that the dramatic density increase was due to smelt.

A tendency of higher proportion of single fish in the EY-M estimates in the survey in 2016, might be due to different settings for single fish detection in the two systems. Echo duration < 1.3 × PD (default) was the threshold for single fish detection in EK15, and < 2 × PD for EY, so the latter could include more SED. The fact that EY-M transmits sound at a lower frequency, 70 kHz compared with 200 kHz of the EK15, may also have affected the results [21]. The lower PRF chosen for EK15, 1.33 compared with 1.50 pings $s^{-1}$ on EY-M, may have contributed to the lower single fish detection, as there was a close to significantly positive effect of PRF on the single fish density. This was in part compensated for with the shorter PD on the EK15, 0.32 ms compared with 0.64 ms, as the single fish proportion was negatively related to PD in the experimental test. The total density estimate was negatively affected by PD = 0.64, but was also close to the significantly positively affected by PRF. The effects of lower PD and lower PRF on EK15, is difficult to judge as they counteract each other. Nevertheless, the estimates of the total density were quite comparable.

Annual recording in a lake with the same equipment may show considerable variation, not necessarily reflecting population fluctuations, but rather demonstrating different spatial distribution of fish between years [13]. Though, when more pronounced differences are recorded, such as when the density is doubled, or more, from previous estimates [22,23], the changes are significant and must be expected to affect the lake ecology. In Lake Storsjøen, the introduction of smelt, first time recorded in 2008, appeared in large amounts in test fisheries in 2015 and 2016 [12]. The smelt are larger than what is common in Lake Mjøsa, the suspected source of the smelt in Lake Storsjøen [24], and where the smelt are less than 14 cm with few exceptions. The length distribution of smelt may change in the years to come, and will be interesting to follow. Zooplankton sampling should be included to monitor effects from zooplankton feeding fish.

**Author Contributions:** Conceptualization, A.N.L. and K.L.; methodology, A.N.L.; software, A.N.L.; validation, A.N.L., K.L. and K.Ø.; formal analysis, A.N.L.; investigation, A.N.L.; resources, F.N.; data curation, A.N.L.; writing—original draft preparation, A.N.L.; writing—review and editing, F.N.; visualization, A.N.L.; supervision, A.N.L.; project administration, A.N.L.; funding acquisition, A.N.L.

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## References

1. Onandia, G.; Dias, J.D.; Miracle, M.R. Zooplankton grazing on natural algae and bacteria under hypertrophic conditions. *Linetica* **2015**, *34*, 541–560.
2. Jürgens, K. Impact of Daphnia on planktonic microbial food webs—A review. *Mar. Microb. Food Webs* **1994**, *8*, 295–324.
3. Jeppesen, E.; Jensen, J.P.; Sondergaard, M.; Lauridsen, T.L. Response of fish and plankton to nutrient loading reduction in eight shallow Danish lakes with special emphasis on seasonal dynamics. *Freshw. Biol.* **2005**, *50*, 1616–1627. [CrossRef]
4. Jeppesen, E.; Jensen, J.P.; Søndergaard, M. Response of phytoplankton, zooplankton, and fish to re-oligotrophication: An 11 year study of 23 Danish lakes. *Aquat. Ecosyst. Health Manag.* **2002**, *5*, 31–43. [CrossRef]
5. Jeppesen, E.; Lauridsen, T.; Mitchell, S.F.; Burns, C.W. Do planktivorous fish structure the zooplankton communities in New Zealand lakes? *New Zealand J. Mar. Freshw. Res.* **1997**, *31*, 163–173. [CrossRef]
6. Rudstam, L.; Jech, J.; Parker-Stetter, S.; Horne, J.; Sullivan, P.; Mason, D. Fisheries Acoustics. In *Fisheries Techniques*, 3 ed.; Zale, A., Parrish, D., Sutton, T., Eds.; American Fisheries Society: Bethesda, MD, USA, 2012; p. 40.
7. Pollom, R.A.; Rose, G.A. A global review of the spatial, taxonomic, and temporal scope of freshwater fisheries hydroacoustics research. *Environ. Rev.* **2016**, *24*, 333–347. [CrossRef]
8. Kongsberg Maritime, A.S. *SIMRAD EK15. Reference Manual*; Kongsberg Maritime AS: Kongsberg, Norway, 2014; p. 309.
9. Rudstam, L.G.; Hansson, S.; Lindem, T.; Einhouse, D.W. Comparison of target strength distributions and fish densities obtained with split and single beam echo sounders. *Fish. Res.* **1999**, *42*, 207–214. [CrossRef]

10. Jurvelius, J.; Marjomäki, T.J.; Peltonen, H.; Degtev, A.; Bergstrand, E.; Enderlein, O.; Auvinen, H. Fish density and target strength distribution of single fish echoes in varying light conditions with single and split beam echosounding and trawling. *Hydrobiologia* **2016**, *780*, 113–124. [CrossRef]
11. Løvik, J.E. *Miljøtilstanden i Innsjøer og Vassdrag i Hedmark ved Årtusenskiftet.*; Norsk Institutt for Vannforskning: Oslo, Norway, 2001.
12. Museth, J.; Johnsen, S.I.; Eloranta, A.; Sandlund, O.T.; Linløkken, A.N.; Bærum, K.M.; Dokk, J.G. *Fiskesamfunnet i Storsjøen i 2016—Effekter av Reguleringsinngrep, Fiske og Introdusert krøkle*; NINA rapport nr. 1374; Norwegian Institute for Nature Research: Trondheim, Norway, 2017; p. 43.
13. Linløkken, A. Monitoring pelagic whitefish (*Coregonus lavaretus*) and vendace (*Coregonus albula*) in a hydroelectric reservoir using hydroacoustics. *Regul. Rivers-Res. Manag.* **1995**, *10*, 315–328.
14. Linløkken, A. *Ekkoloddregistreringer i Storsjøen i Rendalen, Osensjøen og Engeren, Sommeren og Høsten 1985*; Fylkesmannen i Hedmark; Miljøvernavdelingen Hedmark Energi AS: Hamar, Norway, 1986; p. 17.
15. Balk, H.; Lindem, T. *Sonar4 and Sonar5 Post Processing Systems*, Operator Manual version 601; Lindem Data Acquisition Humleveien: Oslo, Norway, 2011; p. 464.
16. Sawada, K.; Takahashi, H.; Abe, K.; Ichii, T.; Watanabe, K.; Takao, Y. Target-strength, length, and tilt-angle measurements of Pacific saury (Cololabis saira) and Japanese anchovy (Engraulis japonicus) using an acoustic-optical system. *ICES J. Mar. Sci.* **2009**, *66*, 1212–1218. [CrossRef]
17. Lindem, T. *Hydro Acoustic Data Acquisition System Instruction Manual ver. 3.9*; Lindem Data Acquisition: Oslo, Norway, 1990; p. 25.
18. R. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing: Vienns, Austria, 2013.
19. Elliot, J.M. *Some Methods for the Statistical Analysis of Samples of Benthic Invertabrates*, 2nd ed.; Titus Wilson & Son LTD: Kendal, UK, 1979.
20. Lindem, T.; Sandlund, O.T. Ekkoloddregistreringer av pelagiske fiskebestander i innsjøer. *Fauna* **1984**, *37*, 105–111.
21. Guillard, J.; Lebourges-Daussy, A.; Balk, H.; Colon, M.; Jóźwik, A.; Godlewska, M. Comparing hydroacoustic fish stock estimates in the pelagic zone of temperate deep lakes using three sound frequencies (70, 120, 200 kHz). *Inland Waters* **2014**, *4*, 435–444. [CrossRef]
22. Linløkken, A.N.; Sandlund, O.T. Recruitment of sympatric vendace (Coregonus albula) and whitefish (C. lavaretus) is affected by different environmental factors. *Ecol. Freshw. Fish* **2015**, *25*, 652–663.
23. Linløkken, A.N. Climate Change and Monitoring of Temperate Lakes. In Recent Developments in Fish Biology Researches. Bozkurt, Y., Ed.; IntechOpen: London, UK, 2019; in press.
24. Hagenlund, M.; Østbye, K.; Langdal, K.; Hassve, M.; Pettersen, R.A.; Anderson, E.; Gregersen, F.; Præbel, K. Fauna crime: Elucidating the potential source and introduction history of European smelt (*Osmerus eperlanus* L.) into Lake Storsjøen, Norway. *Conserv. Genet.* **2015**, *16*, 1085–1098. [CrossRef]