ANALYSIS OF SIDE-LOOKING DEPLOYMENT OF HYDROACOUSTIC TRANSDUCERS IN FISHERIES SCIENCE

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ABSTRACT

Side-looking (SL) deployment of hydroacoustic transducers is an effective approach to manage the issue of the near-field effect that limits abundance estimation of fish near the surface (<2 m) when using down-looking (DL) deployment in acoustic surveys. However, determining appropriate target strength (TS) thresholds for SL is more difficult due to the greater variability of orientation of fish and thus greater variability in the TS compared to DL. In this paper, I derive appropriate TS thresholds for SL acoustics in two alewife (*Alosa pseudoharengus*) dominated lakes, one in New York and the other in Pennsylvania. I use *ex situ* TS distribution of alewife from a net cage experiment as well as *in situ* TS distribution of alewife from the lakes to determine the appropriate TS thresholds. With the thresholds applied, I explore the feasibility of using SL deployment as a fisheries assessment technique by comparing fish density estimates of SL with DL and multimesh vertical gill nets. DL and SL acoustic surveys were conducted at Cayuta Lake in October 13, 2008 and October 29, 2007, and at Silver Lake in October 14, 2008. In addition, vertical gill nets were set in the lakes for length (mm), weight (g), and distribution in the top 6 m. *Ex situ* net cage experiments were conducted in 2006 at Oneida Lake using 5 alewives. Results from the net cage experiment shows a TS distribution that is both wide and skewed to the right with more targets observed that are greater than −55 dB compared to *in situ* TS distribution at Cayuta Lake and Silver Lake. SL deployment at Cayuta Lake and Silver Lake observed more targets per km than DL deployment. The catches of alewife in the gill nets at Cayuta Lake in 2008 and 2007 were unevenly distributed with a greater proportion of alewife, both young-of-the-year (YOY) and adults, caught in the top 2 m. Catches of alewife in Silver Lake were more evenly distributed with an equal proportion of YOY alewife caught between 0-6 m, whereas the adults were only

caught between 0-4 m. Hydroacoustic and vertical gill net abundance comparisons shows a positive correlation between gill net catch/hr with SL acoustics. However, the correlation between gill net and DL acoustics is negative. I conclude that this study demonstrates the importance of using SL and DL deployment of transducers in abundance estimation. Traditional gear like vertical gill nets should also be used in order to obtain accurate assessment of species and size structure. Further study of the TS distribution of alewife in net cages using SL deployment is needed to improve the determination of the appropriate TS thresholds for data analysis.

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LIST OF ABBREVIATIONS AND SYMBOLS

σ_{bs} : Backscattering cross-section (dB m^2)

DL: Down-looking

SL: Side-looking

TS: Target strength (dB)

S_v: Volume backscattering strength (dB)

s_v: Volume backscattering coefficient (dB re: 1/m)

YOY: Young-of-the-year

1. INTRODUCTION

Hydroacoustics is a valuable technique in fisheries science for assessing fish abundance and biomass (Brandt et al., 1991; Fabrizio et al., 1997; Kubecka and Wittingerova, 1998; Yule, 2000; Knudsen and Sægrov, 2002; Boswell et al., 2007; Winfield et al., 2009), studying fish behavior (Brandt, 1980; Arrhenius et al., 2000; Romare, 2000; Torgersen and Kaartvedt, 2001), and detecting and identifying fish species (Soule et al., 1996; Soule et al., 1997; Burwen and Fleischman, 1998). Although there are many advantages in using hydroacoustics compared to other sampling gear, like multimesh gill nets, mid-water trawls, and seining, the application of hydroacoustics in "shallow" waters (<10 m) or for analyzing fish near the surface (<2 m) is limited due to the near-field effect at the face of the transducer. Simmonds and Maclennan (2005) describe the near-field as a phenomenon associated with the propagation of sound by the transducer elements. In essence, the sound within the near-field has not fully developed into a coherent beam and therefore any data obtained within the near-field is unreliable and should be excluded during data analysis. Echo returns from targets within the near-field may be higher or lower than predicted by standard sound propagation equations used in the far-field (Simmonds and MacLennan, 2005). This will result in a bias of the abundance, particularly when the transducer is deployed vertically, or down-looking (DL), as in typical surveys. As a result, for shallow water acoustics or for near-surface fish analysis, the transducer is deployed horizontally, or side-looking (SL). However, SL deployment does have its limitations.

One pertinent issue is determining the appropriate target strength (TS) threshold during data analysis. Thresholds are an important aspect of hydroacoustic data analysis as a means to remove unwanted “noise” that would affect abundance estimation. However, the application of thresholds will invariably result in the loss of data. A threshold is a compromise that needs to be accepted if realistic abundance estimates are to be obtained. But a difficulty with determining the appropriate TS threshold is the differences of the TS distribution with SL and DL deployment. With SL, the range of the TS distribution of a species of fish will be larger due to the greater variability of the orientation of the fish in relation to the transducer (Kubecka and Duncan, 1998; Frouzova et al., 2005; Henderson et al., 2008). The amount of sound reflected back to the transducer from a fish is highly dependent on the tilt angle (Simmonds and MacLennan, 2005). In other words, the sound can be reflected from the posterior or anterior ends, or from either lateral sides. Conversely, with DL deployment the sound is predominately reflected from the upper dorsal side. As a result, different TS thresholds must be applied to SL and DL data during analysis.

The benefits of SL compared to DL have been studied (Kubecka and Wittingerova, 1998; Knudsen and Sægrov, 2002), but many questions remain. SL alone does not provide an accurate assessment of fish density. Several researchers have conducted comparative studies of DL with other traditional sampling gear like vertical gill nets or trawling (Everson et al., 1996; Ransom et al., 1996; Fabrizio et al., 1997; Peltonen et al., 1999; Yule, 2000; Mehner and Schulz, 2002; Stockwell et al., 2006; Winfield et al., 2009). Yet few have included SL in their comparative studies. How feasible is SL as a fisheries assessment technique? What are some issues with determining appropriate TS thresholds for SL deployment? This paper is aimed to address these questions.

In this paper, I derive appropriate TS thresholds for SL and DL deployment of hydroacoustic transducers in two alewife (*Alosa pseudoharengus*) dominated lakes, one in New York and the other in Pennsylvania. I use *ex situ* TS distribution of alewife from a net cage experiment as well as *in situ* TS distribution of alewife from the lakes to determine the appropriate TS thresholds. With the thresholds applied, I explore the feasibility of using the SL deployment as a fisheries assessment technique for the two alewife dominated lakes by comparing fish density estimates of SL with DL and multimesh vertical gill nets.

MATERIAL AND METHODS

2.1 Study sites

Cayuta Lake (42° 22.050’ N, 76° 43.990’ W) is a relatively small system (152 ha), located southwest of Cayutaville along route 228, with a maximum depth of 7 m. Alewife was first detected in 1977 and since then has established an abundant population in the lake (Arrhenius et al., 2000). Fingerling walleye (*Sander vitreus*) have been stocked from 1992-1996 as part of a larger, statewide study to determine factors affecting the success or failure of walleye fingerling stocking in various alewife dominant New York lakes (Brooking et al., 2002).

Silver Lake (41° 55.955’ N, 75° 57.202’ W) is a small system (90 ha) in Pennsylvania, south of Binghamton along route 167, with a maximum depth of 30 m (Jirka 2009, personal communication). Alewife was believed to have been introduced to Silver Lake sometime after 1992, which has led to subsequent declines in water clarity due to overgrazing of large zooplankton (Jirka et al. 2009).

2.2 Hydroacoustics

2.2.1 Data collection

Hydroacoustic data were collected in the evening at Cayuta Lake in October 13, 2008 and October 29, 2007, and at Silver Lake in October 14, 2008. A 123 kHz split-beam BioSonics DT-X transducer was used with a transmitted pulse length of 0.4 ms and pulse rate of 5 pings per second. The 3 dB beam angle in 2007 was 7.80° and in 2008 was 7.50°. This was due to slight modifications when the transducer was sent in for inspection at the BioSonics facility during the summer of 2008. A square threshold of

−130 dB was set during data collection for each survey for both DL and SL deployment.

For DL deployment, the transducer was mounted on a rigid pole and set between 0.4 m and 0.5 m below the surface. For SL deployment, the transducer was directed horizontally and set between 0.8 m and 1.0 m below the surface. The near-field distance of the transducer is approximately 0.8 m, but the acoustic analysis is generally restricted to twice the near-field distance as a safe measure. Thus a depth of 2 m from the surface is excluded from the data analysis.

DL and SL surveys were conducted separately with DL deployment conducted first followed by SL deployment. The survey track consisted of five parallel transects at Cayuta Lake in 2008 and four parallel transects at Cayuta Lake in 2007 and at Silver Lake in 2008. The acoustic data were recorded directly onto a laptop computer in the field.

2.2.2 Data analysis

The data was analyzed with version 4.50 of the Echoview software (Myriax, 2008). All data were visually inspected for consistent bottom detection and corrected when needed. Any area with excess interference from bubbles, vegetation, or other noise was removed from the analysis. For the DL analysis, a lower TS threshold of −60 dB was applied in the TS domain based on results from *ex situ* TS measurements of alewife from a net cage experiment (Brooking and Rudstam, in press). Given that the acoustic return of any target will be 6 dB smaller at half-power beam angle of the sound beam (−3 dB one-way gain reduction, −6 dB two-way reduction), the TS threshold for the DL data was set to −66 dB in the volume backscattering strength (S_v)

domain (Table 1) (Wang et al., submitted). For the SL data, a lower TS threshold of −66 dB was set in the TS domain based on TS frequency distributions from *ex situ*, SL TS measurements of alewife in a net cage experiment conducted in 2006, and *in situ* TS measurements of alewife from acoustic data collected during the surveys (Figure 1). The TS frequency distributions were set with a minimum and maximum value of −80 to −30 dB, and set with the number of bins at 30. A −66 dB threshold translates to a lower threshold of −72 dB in the S_v domain. The same single target detection settings were applied for both down-looking and side-looking data (Table 1).

The data was used to calculate total fish density for each parallel transect. Each transect was considered a sampling unit for variance calculations. Data collected during transit between transects were not included in these estimates. Fish density (ρ_v, fish/m^3) for DL and SL was calculated from:

$$\rho_v = \frac{s_v}{\sigma_{bs}}$$

where s_v is the volume backscattering coefficient for each transect (dB re: 1/m) calculated from $s_v = 10^{(S_v/10)}$ where S_v is the mean volume backscattering strength. σ_{bs} is the backscattering cross section obtained from *in situ* single targets along each transect (m^2) where $\sigma_{bs} = 10^{(TS/10)}$. Mean fish densities were weighted using the length of each transect as the weighting factor. The length of each transect was determined using the tape measure tool in the EchoView software. The along-track distance measurement was used as the weighting factor.

Table 1. Parameters and settings applied in the EchoView software for the down-looking and side-looking thresholds, and for the single target detection.

Parameter	Setting
Down-looking deployment	
S_v minimum TS threshold (dB)	−66
Single target detection minimum threshold (dB)	−60
Side-looking deployment	
S_v minimum TS threshold (dB)	−72
Single target detection minimum threshold (dB)	−66
Single target detection	
TS threshold (dB)	−80
Pulse length determination level (dB)	6
Minimum normalized pulse length	0.6
Maximum normalized pulse length	1.5
Beam compensation model	BioSonics
Maximum beam compensation (dB)	12
Maximum standard deviation of minor-axis angles (degrees)	1
Maximum standard deviation of major-axis angles (degrees)	1

DL densities were limited from 2 m to 6 m for each transect. SL densities were limited to the top 2 m for each transect. The range at which the beam will span the top 2 m was determined by using the depth of the transducer and the 3 dB beam angle of the transducer:

$$range = 2\frac{depth}{\tan\left(\frac{angle}{2}\right)}$$

The range at which the transmitted pulse will span the top 2 m is between 11.21 m and 13.21 m at Cayuta Lake and Silver Lake in 2008, and 13.67 m and 15.67 m at Cayuta Lake in 2007.

2.2.3 Net cage

Ex situ SL acoustic data of alewife was conducted during the summer of 2006 (Sanders-DeMott, 2006). A 36 m^3 mesh net cage (3 m · 3 m · 4 m) was constructed and deployed in the outlet of Chittenango Creek into Oneida Lake. Five alewives with a mean length of 137.2 mm (128, 132, 135, 139, and 142 mm) were used. Acoustic data was recorded over a period of 24 hours using the same 123 kHz split-beam BioSonics DT-X transducer as used in the Cayuta Lake and Silver Lake surveys. The transducer was mounted to a wooden structure 4 m from the net cage and lowered 0.45 m below the surface. A square threshold of −100 dB was set. Acoustic data with fish at 0.2 ms and 0.4 ms transmitted pulse lengths, and acoustic data without fish at 0.4 ms transmitted pulse length were recorded. Only the data with and without fish recorded at 0.4 ms transmitted pulse length were used for the data analysis.

The data was analyzed using the fish tracking tool in the Echoview software. The data, however, suffered noise problems caused by the movements of the cage itself. These movements could be seen as long tracks in the echogram. These tracks made it difficult for the fish tracking tool to differentiate the cage tracks from the actual fish tracks, as the noise would mask regions that were clearly fish. The actual fish tracks could be seen as oscillating tracks in regular and consistent intervals that were not similar to the tracks produced by the cage movements. However, the TS of these fish tracks were not consistent, and only fish tracks with higher TS were easily marked by the fish tracking tool. Fish tracks with similar TS values as produced by the cage were excluded from the data analysis.

2.3 Vertical gill nets

Three vertical gill nets were set during each survey at both lakes. The 6 m deep and 21 m long nets consisted of seven panels, each with a different mesh size: 6.25, 8, 10, 12.5, 15, 18.75, and 25 mm bar mesh. These mesh sizes were selected to catch alewife from 50 to 300 mm in length (Warner et al., 2002). The duration the nets were set varied from an average of 3 hours to 5 hours. The nets were collected and divided into three layers (0-2 m, 2-4 m, and 4-6 m), with the proportion of alewife caught in each of the layers. A sub-sample was collected and measured for total length (mm) and weights (g). Adults and young-of-the-year (YOY) were counted and sorted separately. In Silver Lake, YOY were fish with a total length of <85 mm and adults were fish >85 mm. In Cayuta Lake, the size distribution was used to differentiate YOY and adults. In 2008, fish <105 mm were YOY and fish >105 mm were adults. In 2007, fish <125 mm were YOY and fish >125 mm were adults.

2. RESULTS

3.1 Hydroacoustics

S_v and TS noise levels at Cayuta Lake and Silver Lake at 1 m and at the deepest point in the down-looking transects (Table 2) are safely below the thresholds applied in the down-looking and side-looking acoustic data (Table 1).

3.1.1 Net cage

The net cage results shows an *ex situ* TS distribution of alewife that is both wide and skewed to the right compared to the *in situ* side-looking TS distributions at Cayuta Lake and Silver Lake (Figure 1a, b, c, d). In addition, there are multiple TS peaks between −55 dB and −35 dB in the net cage results.

3.1.2 Cayuta Lake

At Cayuta Lake, the SL TS distribution is unimodal with the proportion of targets observed increasing to a peak TS of approximately −60 dB, after which the proportion declines as TS increases (Figure 1b and 1c). Conversely, the DL TS distribution shows a steep decline in the proportion of targets observed between −80 dB and −55 dB, after which the proportion declines marginally with increasing TS. SL deployment in 2008 and 2007 observed a greater proportion of targets between −65 dB and −35 dB (Figure 1b and 1c) and a greater number of targets per km compared to DL deployment (Table 3). Mean TS of DL and SL in 2008 and 2007 are fairly similar (Table 3). However, DL deployment shows more variability in the TS than SL deployment.

Figure 1. Target strength (TS) frequency distribution of: (a) the net cage data with fish (F), without fish (NF), and the sum *in situ* side-looking (SL) TS at Cayuta Lake and Silver Lake in 2007 and 2008; (b) the *in situ* down-looking (DL) and SL deployment at Cayuta Lake in 2008; (c) the *in situ* DL and SL deployment at Cayuta Lake in 2007; and (d) the *in situ* DL and SL deployment at Silver Lake in 2008.

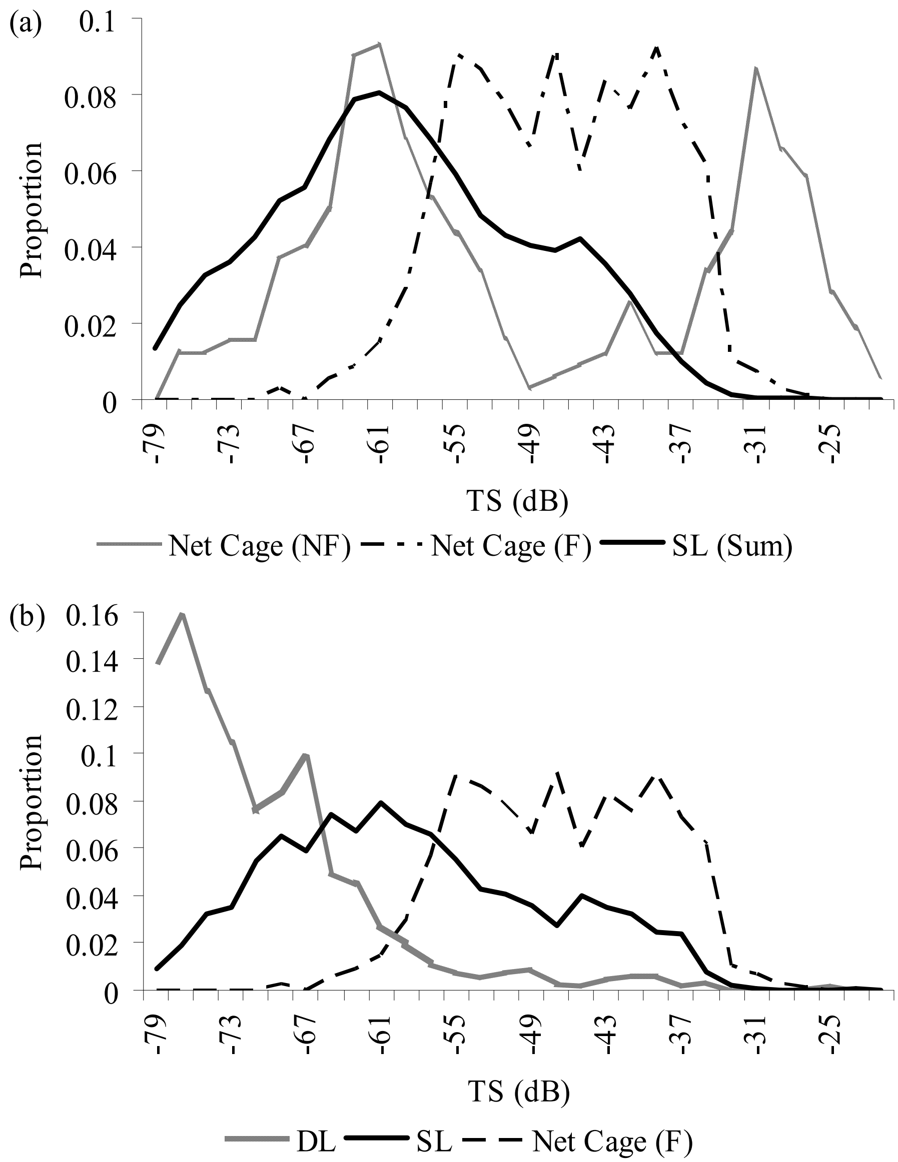
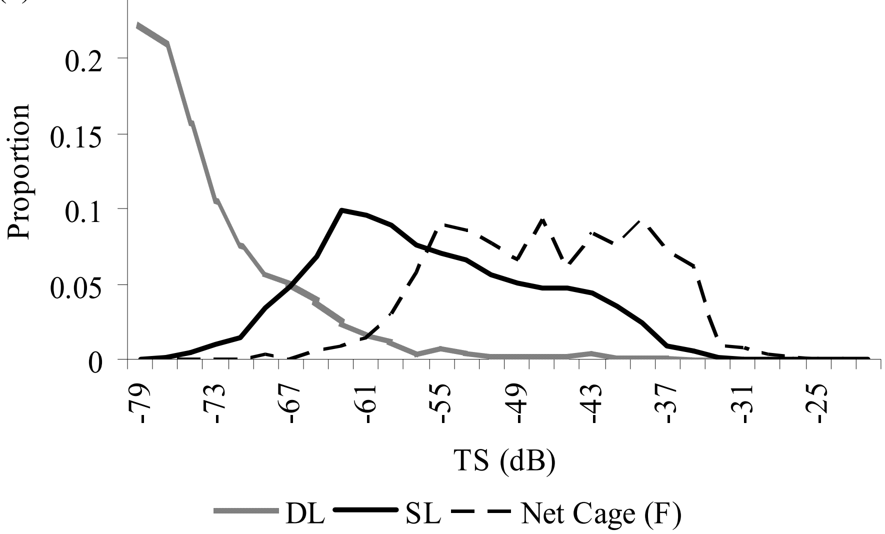


Figure 1 (Continued)

(c)



(d)

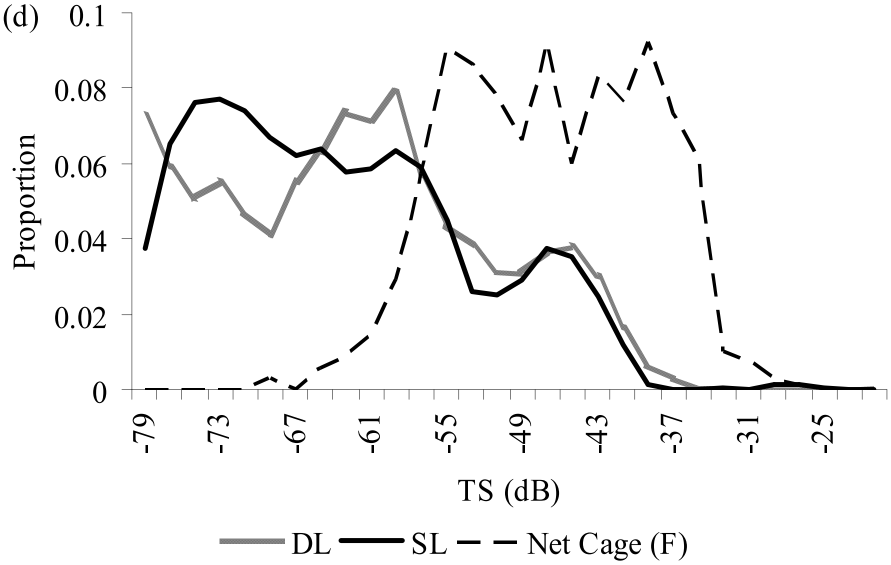


Table 2. Volume backscattering strength (S_v) and target strength (TS) noise levels (dB) in Cayuta Lake and Silver Lake at 1 m, and at the deepest point of the down-looking (DL) transects.

Site	**S_v noise at 1 m**	**TS noise at 1 m**	**S_v noise at deepest point of DL transects**	**TS noise at deepest point of DL transects**
Cayuta 08	−105.19	−130.64	−90.47	−99.15
Cayuta 07	−127.69	−153.53	−106.30	−115.49
Silver 08	−108.80	−134.25	−79.34	−75.33

Table 3. Down-looking (DL) and side-looking (SL) mean weighted acoustic estimates of alewife (fish/m^3) in Cayuta Lake and Silver Lake in 2008 and 2007.

Site	**Total transect length, m (*N*)**	**Mean TS, dB (range)**	**Mean weighted density, fish/m^3 (range)**	**Number of fish targets observed/km**
Cayuta 08 (DL)	2881 (5)	−42.88 (−52.53-−30.77)	0.025 (0.010-0.054)	33
Cayuta 08 (SL)	2878 (5)	−45.54 (−47.44-−42.46)	0.039 (0.020-0.060)	363
Cayuta 07 (DL)	2337 (4)	−48.11 (−51.08-−45.24)	0.024 (0.011-0.060)	33
Cayuta 07 (SL)	2809 (4)	−47.62 (−48.62-−46.87)	0.050 (0.039-0.068)	359
Silver 08 (DL)	1615 (4)	−47.78 (−50.02-−46.72)	0.051 (0.035-0.078)	169
Silver 08 (SL)	1468 (4)	−47.47 (−50.19-−42.40)	0.020 (0.010-0.028)	443

3.1.3 Silver Lake

The SL TS distribution at Silver Lake does not follow the same trend as with Cayuta Lake. Instead, the greatest proportion of targets observed at Silver Lake with SL is at −73 dB, and then the proportion gradually declines with increasing TS. In fact, this trend follows quite closely with the DL TS distribution (Figure 1d). The DL TS distribution at Silver Lake is different from the DL distribution at Cayuta Lake. The TS distribution at Silver Lake is more variable with multiple peaks between −80 and −30 dB. In addition, DL observed more targets per km compared to Cayuta Lake (Table 3). However, DL at Silver Lake observed fewer targets per km compared to SL at Silver Lake. The mean TS for SL and DL at Silver Lake in 2008 are very similar. However, the mean TS for SL is more variable than DL.

3.2 Vertical gill nets

At Cayuta Lake, the number of alewife caught was unevenly distributed across the top 6 m of the nets in 2008 and 2007 (Table 4). The proportion of alewife, which includes YOY and adult, caught between 0-2 m and 2-6 m is 0.57 and 0.43 in 2008, and 0.80 and 0.20 in 2007. When comparing the proportion of YOY and adult catches separately, catches of YOY are very high at top 2 m and then decline from 2 to 6 m. Conversely, the proportion of adult catches between 0-2 m is lower than the proportion of YOY catches but surpasses the YOY catches in deeper depths.

Table 4. Mean proportions of alewife caught in the multimesh vertical gill nets at Cayuta Lake in 2007 and 2008, and at Silver Lake in 2008. The proportions are further differentiated into young-of-the-year (YOY) and adults.

Mean	**Cayuta 08**	**Cayuta 07**	**Silver 08**
Soak time (h)	5.14	3.17	4.34
Proportion 0-2 m (YOY/adult)	0.57 (0.69/0.44)	0.80 (0.82/0.62)	0.31 (0.30/0.27)
Proportion 2-4 m (YOY/adult)	0.31 (0.28/0.37)	0.16 (0.15/0.26)	0.40 (0.39/0.40)
Proportion 4-6 m (YOY/adult)	0.12 (0.03/0.19)	0.04 (0.03/0.12)	0.29 (0.31/0.00)
Number of alewife caught (YOY/adult)	522 (279/241)	223 (192/31)	26 (24/2)
Catch per hour	101.7	70.5	6.1
Length, mm (range)	134.6 (71-175)	126.0 (83-184)	72.1 (57-106)

At Silver Lake, a greater proportion of alewife was caught between 2-6 m compared to 0-2 m. Interestingly, when examining the catches of YOY and adult separately the proportion of catches of YOY is evenly distributed between 0-6 m. The adults, on the other hand, were only caught between 0-4 m with a greater proportion of catches between 2-4 m than 0-2 m. No adult alewife was caught between 4-6 m.

The length-frequency graph shows that the alewife population at Cayuta Lake is composed of at least two size classes in 2007 and at least three size classes in 2008 (Figure 2). Total catches of alewife increased from 2007 ($N = 223$) to 2008 ($N = 522$; Table 4). The mean length of alewife in 2007 is 126.0 mm and in 2008 is 134.6 mm. At Silver Lake, the length-frequency graph indicates a population consisting of at least two size classes, with the greatest proportion of fish caught ranging in size from 40 to 90 mm in length. However, total catches are low ($N = 26$) with 92% of the catches being YOY alewife.

3.3 Hydroacoustic and vertical gill net comparison

Alewife densities based on multimesh vertical gill nets catch per unit effort (catch/hr) with SL acoustics shows a positive correlation (Figure 3). On the other hand, alewife densities based on vertical gill nets and DL acoustics shows a negative correlation. The DL acoustic estimate observed in Silver Lake is higher than the acoustic estimates observed in Cayuta Lake in 2007 and 2008.

Figure 2. Length-frequency distribution of alewife, including young-of-the-year (YOY) and adults, caught between 0-6 m in the multimesh vertical gill nets set in Cayuta Lake in 2008 and 2007, and in Silver Lake in 2008. In Silver Lake, YOY are fish with a total length <85 mm and adults are fish >85 mm. In Cayuta Lake in 2008, YOY were fish <105 mm and adults were fish >105 mm. In Cayuta Lake in 2007, fish <125 mm were YOY and fish >125 mm were adults.

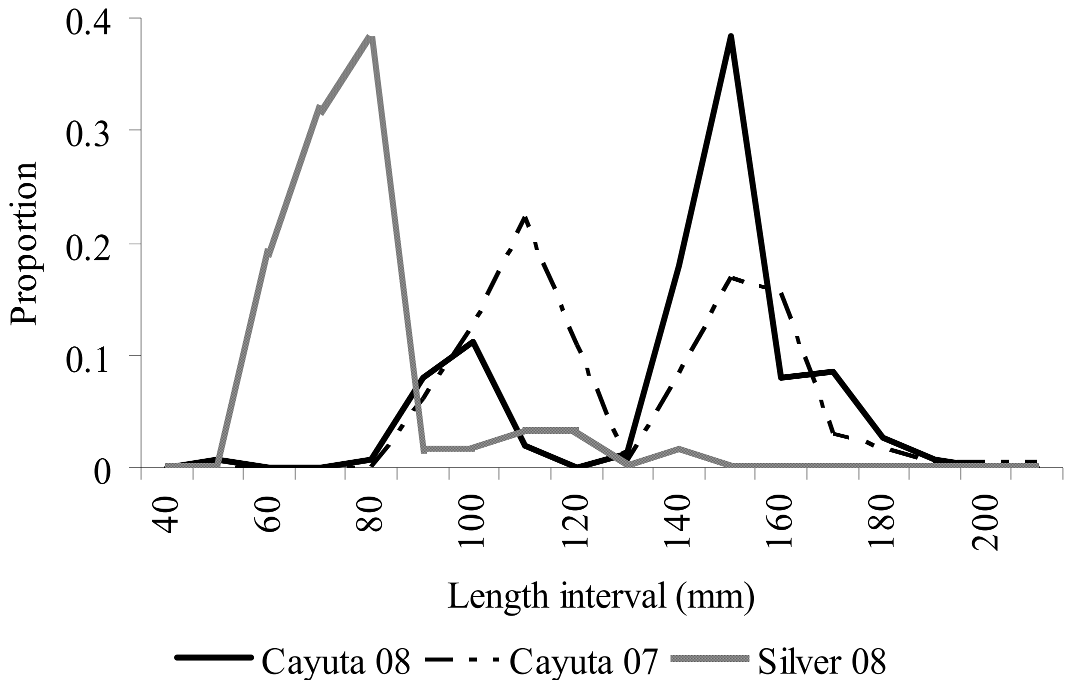
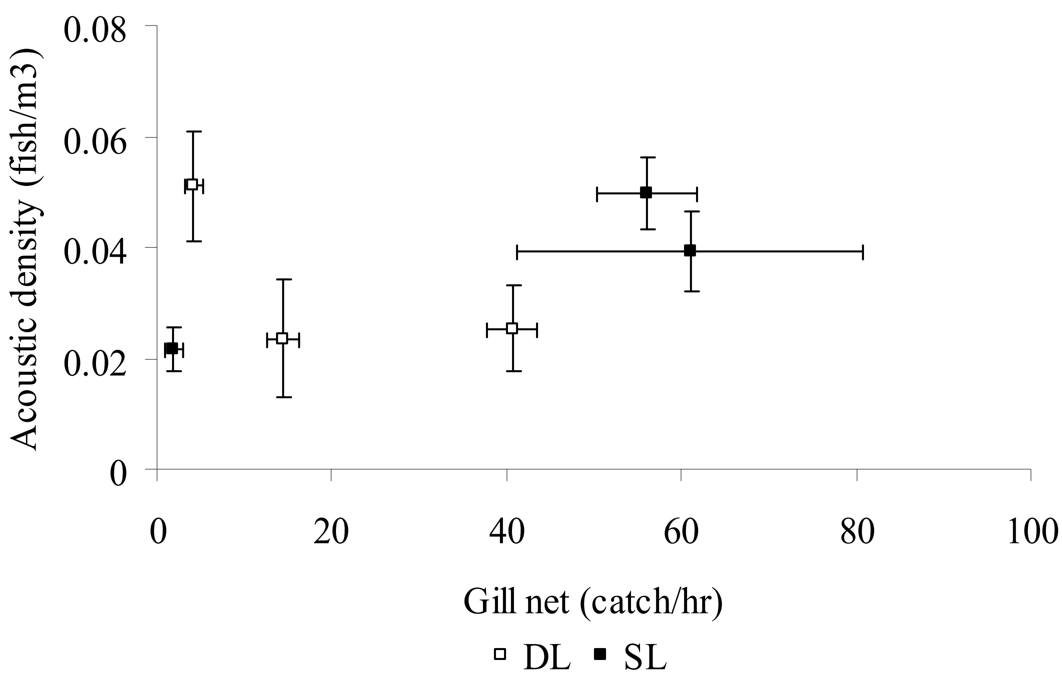


Figure 3. Vertical gill net catch per unit effort (catch/hr) comparison with side-looking (SL) (black squares) and down-looking (DL) (white squares) acoustic estimates (fish/m^3) in Cayuta Lake in 2008 and 2007 and in Silver Lake in 2008. SL and gill net comparisons are limited to 0-2 m. SL and vertical gill net comparisons are limited to 2-6 m. Bars indicate 1 standard error.



3. DISCUSSION

This study demonstrates the importance of using both SL and DL deployment of hydroacoustic transducers for fisheries assessment in two different freshwater lakes. In Cayuta Lake, between 57% and 80% of the fish caught were in the top 2 m of water that is inaccessible to traditional DL deployment. SL deployment can observe more targets per km than DL deployment, which is generally limited by the near-field effect. Also, for relatively deeper lakes like Silver Lake, SL will be an important benefit to the DL assessment because some fish may migrate to the surface at night (Knudsen and Sægrov, 2002).

In addition, this study stresses the importance of using traditional gear, like multimesh vertical gill nets, with hydroacoustics in order to obtain an accurate assessment of the fish size structure and the distribution of fish in the water. This is because hydroacoustics is limited by the difficulty of accurately determining the species and the size of fish. Although species determination and fish size have been studied with DL, fewer studies have explored these issues for SL (Kubecka and Duncan, 1998; Frouzova et al., 2005). In particular, this study explores the problems of determining appropriate TS thresholds during data analysis. *Ex situ* net cage experiments offer the ability to determine the TS thresholds.

However, the net cage experiments conducted during the summer of 2006 shows a TS distribution that is not only wide but skewed to the right (Figure 1a, b, c, d). This is likely due to the inability of the fish tracking tool in the Echoview software to include all the fish tracks in the data. The net cage data was limited due to noise caused by the cage itself, which creates long, fish-like tracks that the fish tracking tool mistakenly included. The TS distribution of the net cage data without the alewife (NF) (Figure 1a) clearly shows the effect of underwater noise and the cage. Noise is a serious issue for both SL and DL acoustics (Mitson and Knudsen, 2003). These noise issues masked the true fish tracks. Therefore, most of the fish tracks that were marked were over −55 dB.

The TS threshold for SL deployment was determined using the *in situ* and *ex situ* TS distribution of alewife. The TS thresholds for DL deployment in alewife dominated lakes have already been studied and determined (Brooking and Rudstam, in press). In Cayuta Lake in 2008 and 2007, more targets between −65 dB and −55 dB were observed with SL compared to DL (Figure 1b and 1c). If the SL threshold was set at −60 dB as used for the DL deployment, this threshold would coincide with the peak proportion of targets observed with SL resulting in the loss of potential targets. However, the TS distribution of fish is generally more variable with SL than with DL, thus it is difficult to say whether the increased proportion of targets observed with SL in Cayuta Lake that are smaller than −60 dB are either YOY or adults that are oriented towards or away from the transducer. This will invariably lower the TS mean and thus increase fish abundance estimates compared to DL.

But at Silver Lake, far more targets are observed between −80 dB and −60 dB with SL than in Cayuta Lake in both 2008 and 2007 (Figure 1d). Most of these targets are likely to be YOY alewife given the proportion of alewife caught in the vertical gill nets and the size structure from the length-frequency distribution (Table 4, Figure 2). YOY are not large targets and thus will not reflect as much sound back to the transducer as adults. As a result, this is a more compelling reason for setting a lower TS threshold for SL deployment.

In this study, vertical gill nets are used in conjunction with hydroacoustics as a means to obtain an understanding of the fish size structure and the distribution in the water. Gill nets in general have become increasingly popular over the past ten years as a cost-effective, easy-to-operate gear compared to other options like trawling and seining (Vašek et al., 2009). However, gill nets are a passive and selective gear and thus suffer from limitations (Olin et al., 2004; Vašek et al., 2009). Clearly, only active fish that swim into the nets are caught. However, the catchability drastically reduces over time as more fish are caught and thus the amount of available mesh decreases (Olin et al., 2004). In addition, gill nets do suffer problems of size selectivity. Prchalová et al. (2009) found that for three European species – roach (*Rutilus rutilus*), perch (*Perca fluviatilis*), and rudd (*Scardinius erythrophthalmus*) – the multimesh gill nets were unable to capture fish smaller than 40 mm in standard length. Yet despite these problems, gill nets provide invaluable information on fish size and distribution that will be difficult to obtain with hydroacoustics alone.

At Cayuta Lake in 2008 and 2007, a majority of both YOY and adult alewife were caught in the top 2 m (Table 4). However, the top 2 m had to be excluded in the DL data due to the effect of the near-field. Given that Cayuta Lake is a relatively shallow lake, the exclusion of the top 2 m in the DL data resulted in a significant loss of data. SL deployment was able to capture these fish.

At Silver Lake, on the other hand, the issue of the near-field effect is not as problematic. Most of the fish were evenly distributed along the water column, which is likely due to the fact that Silver Lake is much deeper than Cayuta Lake (Table 4). Far fewer fish were caught in the vertical gill nets at the top 2 m at Silver Lake compared to Cayuta Lake, though SL still observed more targets per km at Silver Lake than in

Cayuta Lake (Table 3). DL deployment alone may suffice for an accurate assessment of the fish density in deep waters like Silver Lake but SL should still be considered particularly for fish that migrate to the surface at night.

But there is a need for both SL and DL acoustics in relatively shallow waters. Kubecka and Wittingerova (1998) conducted hydroacoustic surveys at four Czech reservoirs during the summer of 1992 and spring and summer of 1995 and 1996. The authors found that the fish were usually confined to depths of 0–4 m due to attraction to warm surface waters in spring and, later, due to avoidance of de-oxygenated hypolimnions. This resulted in an abundance estimation that was 50 times lower with DL than with SL. The authors conclude that DL hydroacoustic surveys must be supplemented by SL deployment.

Further study and understanding of determining appropriate TS thresholds for alewife must be conducted. *Ex situ* TS of fish using SL have been conducted but primarily on species in rivers and streams where SL deployment is predominately used. Yet studies on *ex situ* TS of alewife are rare. Net cage experiments offer the best opportunity to determine the appropriate acoustic software settings for data analysis as well as settings of the transducer during data collection, such as pulse rate and pulse length. The problems of noise caused by the cage itself that mask the fish tracks can be resolved with a better cage design.

APPENDIX

Appendix 1. Summary of alewife, both young-of-the-year (YOY) and adults, caught in the multimesh vertical gill nets at Cayuta Lake and Silver Lake in 2008 and 2007.

Cayuta Lake (October 13, 2008)				
	Net 3	**Net 5**	**Net 7**	**Mean**
Latitude (N)	42° 22.050’	42° 21.726’	42° 21.974’	
Longitude (W)	76° 43.990’	76° 44.281’	76° 44.214’	
Soak time (h)	5.15	5.03	5.25	5.14
# alewife caught (YOY/adult)	381 (125/256)	677 (451/226)	507 (262/245)	522 (279/241)
Catch per hour	74.0	135.0	96.6	101.7
Mean length, mm (range)	137.9 (49-172)	129.8 (79-173)	136.1 (85-181)	134.6 (71-175)
Proportion 0-2 m (YOY/adult)	0.44 (0.58/0.38)	0.74 (0.82/0.57)	0.53 (0.67/0.38)	0.57 (0.69/0.44)
Proportion 2-4 m (YOY/adult)	0.36 (0.40/0.34)	0.21 (0.16/0.31)	0.37 (0.29/0.45)	0.31 (0.28/0.37)
Proportion 4-6 m (YOY/adult)	0.20 (0.02/0.29)	0.06 (0.02/0.12)	0.10 (0.05/0.16)	0.12 (0.03/0.19)

Cayuta Lake (October 29, 2007)				
	Net 1	**Net 2**	**Net 3**	**Mean**
Latitude (N)	42° 22.144’	42° 22.015’	42° 22.015’	
Longitude (W)	76° 44.061’	76° 44.095’	76° 44.180’	
Soak time (h)	3.25	3.17	3.08	3.17
# alewife caught (YOY/adult)	196 (174/22)	213 (185/28)	259 (216/43)	223 (192/31)
Catch per hour	60.3	67.2	84.1	70.5

Mean length, mm (range)	122.0 (81-164)	129.8 (82-210)	126.0 (85-177)	126.0 (83-184)
Proportion 0-2 m (YOY/adult)	0.77 (0.77/0.73)	0.83 (0.88/0.50)	0.79 (0.82/0.63)	0.80 (0.82/0.62)
Proportion 2-4 m (YOY/adult)	0.19 (0.19/0.23)	0.13 (0.11/0.29)	0.16 (0.14/0.28)	0.16 (0.15/0.26)
Proportion 4-6 m (YOY/adult)	0.04 (0.04/0.05)	0.04 (0.01/0.21)	0.05 (0.04/0.09)	0.04 (0.03/0.12)

Silver Lake (October 14, 2008)

	Net 1	**Net 3**	**Net 5**	**Mean**
Latitude (N)	41° 55.955’	41° 56.048’	41° 56.077’	
Longitude (W)	75° 57.202’	75° 57.211’	75° 57.055’	
Soak time (h)	4.15	4.75	4.12	4.34
# alewife caught (YOY/adult)	25 (25/0)	29 (24/5)	25 (23/2)	26 (24/2)
Catch per hour	6.0	6.1	6.1	6.1
Mean length, mm (range)	70.6 (65-76)	72.8 (53-135)	72.8 (52-108)	72.1 (57-106)
Proportion 0-2 m (YOY/adult)	0.20 (0.20/0.00)	0.66 (0.63/0.8)	0.08 (0.09/0.00)	0.31 (0.30/0.27)
Proportion 2-4 m (YOY/adult)	0.52 (0.52/0.00)	0.21 (0.21/0.20)	0.48 (0.43/1.00)	0.40 (0.39/0.40
Proportion 4-6 m (YOY/adult)	0.28 (0.28/0.00)	0.14 (0.17/0.00)	0.44 (0.48/0.00)	0.29 (0.31/0.00)

Appendix 2. Summary of down-looking and side-looking deployment abundance estimates (fish/m^3) at Cayuta Lake and Silver Lake in 2008 and 2007.

Transect	Transect length, m	Number of targets	Mean TS, dB	Mean S_v, dB	s_v, dB re: 1/m	σ_{bs}, dB m^2	Density, fish/m^3
Cayuta Lake (October 13, 2008) Down-looking (2-6 m)							
1	498	1	−52.53	−68.74	$1.34{\cdot}10^{-7}$	$5.58{\cdot}10^{-6}$	0.024
2	575	29	−38.81	−56.65	$2.16{\cdot}10^{-6}$	$1.32{\cdot}10^{-4}$	0.164
3	622	33	−48.62	−61.27	$7.46{\cdot}10^{-7}$	$1.37{\cdot}10^{-5}$	0.054
4	657	24	−43.65	−60.79	$8.34{\cdot}10^{-7}$	$4.32{\cdot}10^{-5}$	0.019
5	529	9	−30.77	−50.75	$8.42{\cdot}10^{-6}$	$8.37{\cdot}10^{-4}$	0.010
Cayuta Lake (October 13, 2008) Side-looking (0-2 m)							
1	425	139	−45.71	−61.14	$7.69{\cdot}10^{-7}$	$2.68{\cdot}10^{-5}$	0.029
2	529	246	−42.46	−57.26	$1.88{\cdot}10^{-6}$	$5.68{\cdot}10^{-5}$	0.033
3	642	312	−45.77	−58.73	$1.34{\cdot}10^{-6}$	$2.65{\cdot}10^{-5}$	0.051
4	639	220	−46.32	−58.56	$1.39{\cdot}10^{-6}$	$2.33{\cdot}10^{-5}$	0.060
5	643	127	−47.44	−65.39	$3.64{\cdot}10^{-7}$	$1.80{\cdot}10^{-5}$	0.020
Cayuta Lake (October 29, 2007) Down-looking (2-6 m)							
1	299	20	−45.24	−57.46	$1.79{\cdot}10^{-6}$	$2.99{\cdot}10^{-5}$	0.060
2	550	12	−51.08	−67.64	$1.72{\cdot}10^{-7}$	$7.80{\cdot}10^{-6}$	0.022
3	656	24	−46.74	−62.98	$5.04{\cdot}10^{-7}$	$2.12{\cdot}10^{-5}$	0.024
4	832	20	−49.38	−68.91	$1.29{\cdot}10^{-7}$	$1.15{\cdot}10^{-5}$	0.011

Appendix 2 (Continued)

Transect	Transect length, m	Number of targets	Mean TS, dB	Mean S_v, dB	s_v, dB re: 1/m	σ_{bs}, dB m^2	Density, fish/m^3
Cayuta Lake (October 29, 2007) Side-looking (0-2 m)							
1	717	375	−46.87	−60.93	$8.08 \cdot 10^{-7}$	$2.05 \cdot 10^{-5}$	0.039
2	911	510	−48.62	−61.84	$6.55 \cdot 10^{-7}$	$1.37 \cdot 10^{-5}$	0.048
3	476	216	−47.07	−60.76	$8.39 \cdot 10^{-7}$	$1.96 \cdot 10^{-5}$	0.043
4	705	412	−47.92	−59.62	$1.09 \cdot 10^{-6}$	$1.62 \cdot 10^{-5}$	0.068
Silver Lake (October 14, 2008) Down-looking (2-6 m)							
1	385	38	−46.72	−60.76	$8.39 \cdot 10^{-7}$	$2.13 \cdot 10^{-5}$	0.039
2	357	91	−47.22	−58.28	$1.49 \cdot 10^{-6}$	$1.90 \cdot 10^{-5}$	0.078
3	354	48	−47.15	−59.41	$1.15 \cdot 10^{-6}$	$1.93 \cdot 10^{-5}$	0.059
4	519	94	−50.02	−64.53	$3.52 \cdot 10^{-7}$	$9.95 \cdot 10^{-6}$	0.035
Silver Lake (October 14, 2008) Side-looking (0-2 m)							
1	388	171	−50.19	−65.71	$2.68 \cdot 10^{-7}$	$9.58 \cdot 10^{-6}$	0.028
2	357	195	−42.40	−58.68	$1.35 \cdot 10^{-6}$	$5.76 \cdot 10^{-5}$	0.024
3	345	171	−49.17	−66.15	$2.43 \cdot 10^{-7}$	$1.21 \cdot 10^{-5}$	0.020
4	378	113	−48.15	−68.29	$1.48 \cdot 10^{-7}$	$1.53 \cdot 10^{-5}$	0.001

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