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HYDROACOUSTIC METHODS TO ESTIMATE STREAM TROUT ABUNDANCE IN MINNESOTA LAKES[1]

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Abstract—. Hydroacoustics may be a useful technique for surveying stream trout lakes if precision of the population estimates can be improved and accuracy of the technique proven. Coefficients of variation of hydroacoustic abundance estimates from deep stream trout lakes where fish appeared randomly distributed ranged from 9%-44%. Coefficients of variation from shallow lakes ranged from 36%-125%. Two deep, mine pit lakes with patchy fish distributions had coefficients of variation of 93% and 125%. Evidence of acoustic survey accuracy varied. Repeated acoustic surveys over three time intervals and days in Echo Lake, a relatively deep lake, suggested no systematic inaccuracy. Acoustic and capture-recapture population estimates of fish larger than 20 cm TL in Kimball Lake compared favorably. An acoustic survey conducted only one day after 3,000 yearling rainbow trout were stocked in Esther Lake was lower than from a pre-stocking acoustic population estimate. Additionally, an acoustic survey from Pine Mountain Lake yielded a population estimate of 68 carryover brook trout compared to a capture-recapture estimate of 241 carryover brook trout. Esther and Pine Mountain Lakes are relatively shallow lakes, and most of the fish were tracked in a side-looking beam. Many fish may have been acoustically unobservable or difficult to resolve due to interference. Length frequency distributions derived from target strength data were disparate from those derived by netting, making species apportionment problematic. Side-scanning vertically tethered salmonids shows promise as a method to collect dorsal-aspect target strength data needed to validate body length vs. target strength models.

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Management of stream trout populations in Minnesota lakes is often limited by the lack of current information on population abundance, length distributions, fish locations, and exploitation rates. Stream trout are very vulnerable to angling, which quickly reduces populations. Assessment of stream trout relative abundance is usually attempted by trap netting or netting with bottom-set gill nets. Species managed in stream trout lakes include rainbow trout *Oncorhynchus mykiss*, brook trout *Salvelinus fontinalis*, brown trout *Salmo trutta*, and splake *S. namaycush X S. fontinalis* hybrid. Generally, trap nets are used only in lakes that are readily accessible, but stream trout are only vulnerable to trap nets in spring and fall when the littoral zone is cool. Relative abundance of stream trout may be underestimated by gill net sampling because stream trout may avoid gill nets in clear water. Also, rainbow trout may feed pelagically at times and may be better sampled with gill nets suspended at the proper depth. Standard assessment techniques can be costly in terms of time and effort, and some techniques, particularly overnight gill netting, usually result in fish mortality. Furthermore, standard techniques do not estimate absolute abundance. Creel surveys, used to assess angler exploitation, are also expensive. A rapid, non-lethal means of assessing stream trout populations in lakes would be a desirable fish management and research tool. This report evaluates hydroacoustics as a method to assess populations of stream trout that are stocked in lakes. Results of additional experiments to assess hydroacoustic surveys of lake trout *Salvelinus namaycush* populations are presented in Yule and Siesennop (in preparation).

Hydroacoustics has successfully been used to estimate abundance of many pelagic freshwater and saltwater species (Argyle 1992; Tarbox and Thorne 1996; Yule 2000). Scientific-grade hydroacoustic gear samples fish by emitting sound waves, and receiving and processing echoes from the fish. Hydroacoustics has the obvious advantage of being non-lethal. A disadvantage is that fish occupying areas over sloping or rough bottoms may not be acoustically observable because the highest relief (i.e., the top surface of a rock or the shallowest depth in the acoustic cone) defines the maximum usable range (Kubecka 1996; Ona and Mitson 1996; Lawson and Rose 1999; Figure 1). We shall refer to these unobservable volumes as the "acoustic dead zone." Furthermore, fish must be above the bottom by more than 15 cm + the fish's dorso-ventral height above the bottom (Ona and Mitson 1996) to be differentiated from the bottom echo using our equipment. Both abundance and size of acoustically observable fish can be determined, but species identification is problematic. Separating predator species from forage species may be possible using mixture models (C. Anderson, Minnesota Department of Natural Resources, personal communication). Since identification of species is difficult, satisfactory abundance estimates are most likely in lakes with few species. Those stream trout lakes that have few other fish species may be more promising candidates for use of this technique.

Acoustic estimation of stream trout abundance may be more cost effective in the long term than trap net and gill net assessment methods, although the initial investment in scientific-grade echo-sounding equipment and training is relatively high. Analysis of acoustic data can be more time consuming than summarizing netting results, but acoustic fish surveys can usually be completed in a single day for many of Minnesota's stream trout lakes. Traditional netting methods may require several days to acquire similar data. If reliable procedures for estimating stream trout abundance can be developed, evaluation and response to fish management problems could be more rapid and effective.

The objectives of the study were to 1) evaluate the limitations of our hydroacoustic gear for surveying stream trout lakes, 2) evaluate the precision and accuracy of hydroacoustic estimates of stream trout abundance, 3) evaluate the utility of acoustically derived (from target strengths) length frequency distributions for apportioning the abundance and biomass estimates to species in a multi-species community, 4) develop a technique to derive target strength (TS) versus total length (TL) functions, and 5) develop guidelines and procedures for making acoustic estimates of stream trout in accessible and remote lakes.

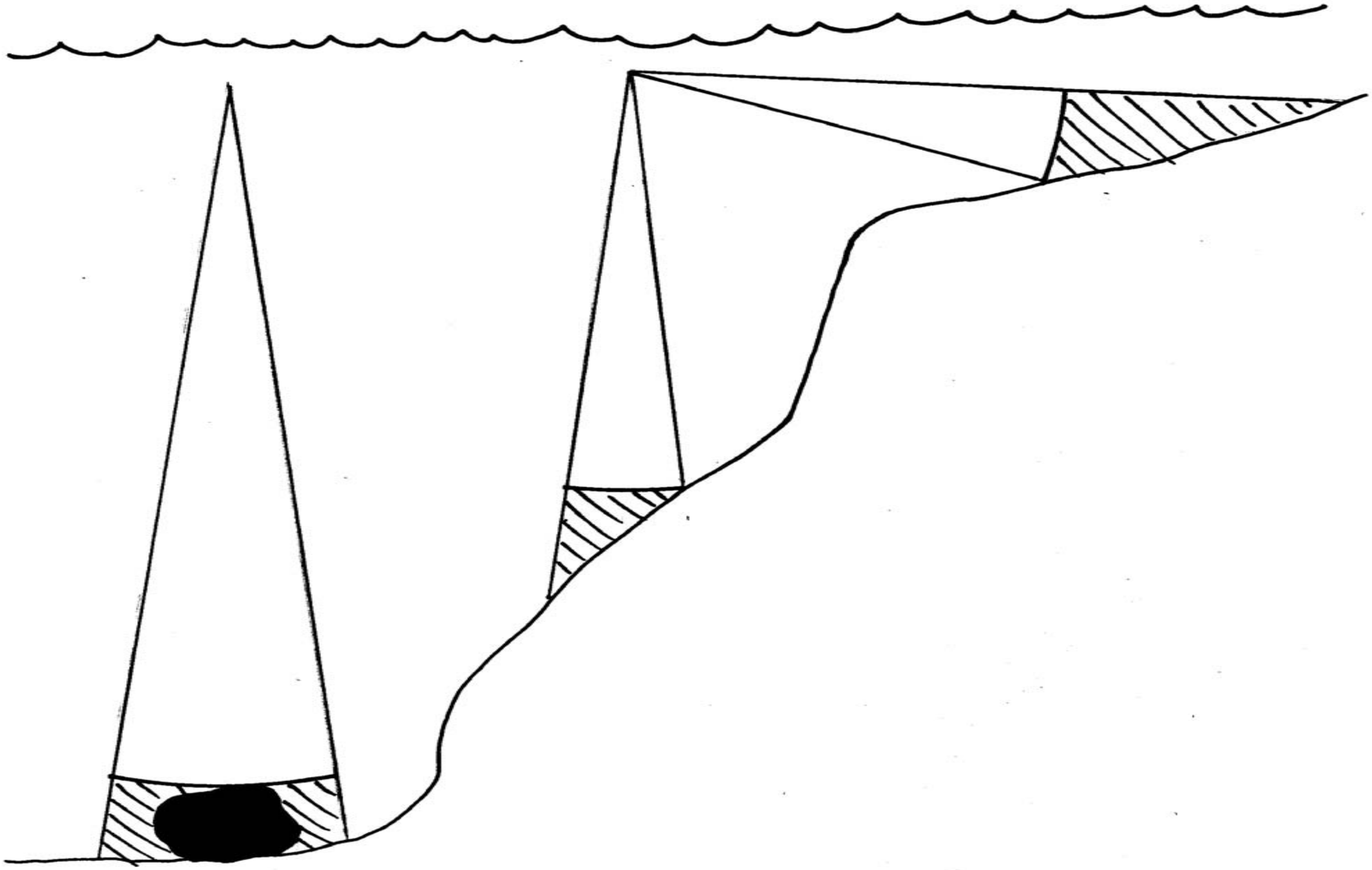

Figure 1. The acoustic dead zone (cross hatched) below the top surface of a large rock and over gradual and steep bottom slopes using down and side looking beams.

Methods

Acoustic work was accomplished with a Hydroacoustic Technology Inc. (HTI) Model 241 echo sounder operating at a frequency of 200 kHz, equipped with two split-beam transducers (6° side-look and 15° down-look). When sampling the deeper stream trout lakes like Echo, South Long, and Tofte, we followed the acoustic techniques described by Yule (2000), and a slow multiplexing rate was used (i.e., 10-14 pings$\cdot$s^{-1} (PPS), or 5-7 per channel). To determine the best technique for sampling fish in shallow stream trout lakes, we evaluated equipment limitations by suspending ping-pong balls (TS = -39.5 dB) and insonifying them at various boat speeds, aiming angles, transducer deployment depths, and ping rates, using both transducers. Ping-pong balls were suspended from wooden floats at depths of 1, 2, 2.5 and 3 m using monofilament line weighted with lead clips attached approximately 1 m beneath each ball. Monofilament fishing line is used to tether targets because it is nearly acoustically transparent, (P. Nealson, HTI Inc., personal communication). Five floats were deployed in a cluster measuring roughly 10 m^2 in area. The side-looking transducer was lowered to a depth of 1.3 m, aimed horizontally, and the targets were insonified at a ping rate of 10 pings$\cdot$s^{-1} as the cluster was circled. Limitations of the down-looking transducer were evaluated similarly by deploying a weighted line on the lake bottom with ping-pong balls attached at various depths.

Ping-pong balls were acoustically visible at depths from 1-3 m when insonified by the side-looking 6° transducer deployed at 1.3 m depth. Small echoes caused by surface reverberation were easily removed by applying a –47.5 dB filter available in the Echoscape software. Early down-looking detection experiments with the ping-pong balls indicated that the surveys in shallow waters should be conducted at 20-30 PPS with the transducer deployed 0.5 m below the surface. With the bottom window (an Echoscape feature used to automatically detect and track the bottom) set at 0.4 m, targets were discernible within 0.2 m of a flat bottom. As we gained more experience with the equipment, we found that we could deploy both transducers at depths ranging from 0.5-0.8 m and satisfactorily detect targets within 0.2 m of a flat bottom. We also found that ping rates as low as 20 PPS (10 PPS per transducer) were satisfactory, and turning off the bottom window aided detection of targets near sloping bottoms.

Estimates of fish abundance were initially obtained by deploying the transducers on a towed-fin lowered to a depth of 0.8 m off the port side of a boat. A side-looking transducer, with axis of insonification aimed approximately 4.5° below horizontal, was used to estimate fish densities in the 1-6 m strata. The down-looking transducer was used to estimate fish densities in strata deeper than 6 m. Later in the study, the towed-fin was replaced by a pole-mount attached to the port side of the boat, offering more precise control of depth and aiming angle. Data were collected by fast multiplexing between the two transducers. For example, at a ping rate of 20 PPS, the sound was transmitted alternately between the two transducers, effectively transmitting 10 PPS from each.

Fish were sampled on line transects established on geo-rectified contour maps using ArcView GIS software. Both zigzag and parallel transects were used. Transect endpoints were established as a point shape theme in an ArcView project file and uploaded to a Garmin 12 XL global positioning system (GPS) as numbered waypoints. Transects were navigated at boat speeds ranging from 1 – 1.5 m$\cdot$s^{-1}. The latitude (LAT) and longitude (LONG) along each transect were stored on the computer hard drive at intervals of from 3 to 10 s.

Our equipment and software can estimate fish densities either by tracking (counting individual fish) or by echo-integration, which is used when individual fish in schools cannot be resolved, or fish are so numerous that tracking is impractical. Fish densities were low and we were assessing fish species that generally do not school, therefore, we used the tracking method. Transducer sensitivity was periodically calibrated in the field by lowering a standard tungsten carbide sphere or a ping-pong ball, both with known target strengths of –39.5 decibels (dB), into the insonified field. When target strength differed from the standard, the target strengths of tracked fish were corrected during post-processing. Using HTI Echoscape software, echoes were manually classified as fish when the fish trace contained a minimum of four echoes that were closely associated in three-dimensional space.

Fish density calculations were automated using Microsoft ACCESS queries. Sample volume of the down-looking transducer increases with depth, so detected fish were normalized to a transect 1-m-wide at the water's surface using the following formula: Fw = 1/[2 * tan(7.5°)] where Fw equals weighted fish, R equals the range, and 7.5° equals the half-angle of the 15° nominal cone. For example, at a range of 3.8 m the 15° nominal cone has a diameter of 1 m, therefore a fish tracked at a range of 3.8 m equals 1 weighted fish at the surface. A fish tracked at a range of 20 m equals 0.19 weighted fish at the surface. Estimates of fish densities (fish · m^{-2}) were derived by summing the number of weighted fish by transect and dividing by the transect length (Yule 2000). In many cases, we attempted to increase the number of sampling units and thus improve the precision of the final density estimates by dividing each transect into sub-units called bins. Estimates using adjacent bins may be spatially autocorrelated, yielding variance estimates that are biased low (Williamson 1982). We determined if our acoustic density data exhibited spatial autocorrelation using Global Moran's I (GMI) spatial statistic (Cliff and Ord 1973, 1981). GMI scores were calculated using a web-based program called Point Pattern Analysis (Chen and Getis 1998). Significance was tested using a standard Z-statistic with two tails because GMI statistics can be both negative and positive. Abundance estimates were calculated using the bin size that minimized variance without significant autocorrelation.

Side-looking sample volumes were calculated in 8 vertical, 1-m-thick depth strata in each bin by multiplying the cone cross-sectional areas by the distance between the LAT LONG coordinates demarcating each bin. The cross-sectional areas at each depth stratum were calculated using ACCESS queries that took into account the maximum side-looking range, the cone angle, the aiming angle, and the transducer depth. Trigonometric functions were used to calculate the depth of each fish target given the range of the fish, and the angle of the fish passage above or below the cone axis. Fish density estimates for each bin were calculated by dividing the number of detected fish in each bin by the bin volume. Bins were used as the sample units in the calculations of mean density and its variability. Estimates of fish in each 1-m-stratum from 1 to 6 m were calculated by multiplying the mean density (fish · m^{-3}) by the water volume in the stratum.

Accuracy and precision of acoustic estimates of abundance was evaluated by repeating surveys across different times of day and across consecutive days (Table 1). Accuracy of the estimates also was evaluated in one experiment by acoustically surveying a lake immediately before and after a known number of yearling rainbow trout were stocked. In other experiments, accuracy was evaluated by comparing acoustic estimates of stream trout abundance to capture-recapture population estimates conducted by Grand Marais Area Fisheries personnel immediately before or after the acoustic surveys.

The utility of using acoustically derived target strength distributions to apportion abundance estimates to species in lakes with multiple species was evaluated by comparing the acoustic size distributions to length frequency distributions derived by gill and trap netting using standard MNDNR lake survey gear. Fish lengths were estimated from TS using formulas relating TS and body length. Lengths of individual fish can only be estimated from the dorsal aspect (down-looking) because in side aspect the orientation of the fish is unknown and target strengths can vary tremendously (up to 30 dB) depending on orientation (see Figure 2 in Buerkle 1987). Individual fish lengths from down-looking surveys were estimated using Love's equation for fish in dorsal aspect at a frequency of 200 kHz (Love 1977). Equations to estimate mean standard length (SL) of riverine species from side-looking data were developed by Kubecka and Duncan (1998). When we could reasonably assume that we were insonifying rainbow trout, the Kubecka and Duncan (1998) equation for rainbow trout was used, otherwise, their generalized equation for all species was used. Standard length of rainbow trout was converted to total length (TL) using the equation TL = 1.145 * SL found in Carlander (1969).

We attempted to obtain target strength data from known length fish in three ways. First we placed live fish in a 2-m-diameter cylindrical cage similar to the cage described by Burczynski (1979). The cage was made of 6.3 mm bar measure nylon mesh hung between two steel hoops, and measured 1.8 m in height. The cage was suspended below the 15° transducer at a depth of 5 m and vertically insonified. In a second attempt, freshly killed adult rainbow trout captured in the French River fish trap were tethered with monofilament fishing line between the corners of a 1.22 m square frame made from 1.6 cm diameter galvanized steel pipe. The frame was suspended 3 m below the 15° transducer and vertically insonified. In our third attempt, a freshly killed rainbow trout was suspended vertically from the end of a boom using monofilament line strung through the floor of its mouth and snout and a weight attached to the tail with a 1 m length of monofilament line. The fish was suspended at a range of 3 m in the beam of a horizontally directed 15° transducer.

Statistical Analyses

Accuracy and precision of successive acoustic surveys were evaluated from surveys made at various times of day on consecutive days. A two-way analysis of variance (ANOVA) tested time and day effects on abundance estimates. Equality of variances was tested using the F_{MAX}-test (Sokal and Rolf 1987). When the variances of the mean densities across surveys were significantly heterogeneous, a square root transformation was applied after adding 0.5 to all the variates to avoid calculating the square root of zero. Inspection of the residuals plot verified correct application of the transformation. All statistical tests used $\alpha = 0.05$. When the population estimate was low, the lower bound of the 95% confidence interval (95% CI) was often negative or lower than the number of fish tracked. In that case, the lower bound of the 95% CI was replaced by the number of tracked fish.

Results

Precision and accuracy of acoustic estimates

2001: Two surveys, one during the day and one at night, were conducted on 27 September, on Echo Lake, Lake County (Table 1). The resulting population estimates were dramatically different with population estimates of 701 during daylight (95% CI = 174-1,228; coefficient of variation (CV) = 38%) and 158 (95% CI = 18-298, CV = 44%) fish after dark, although the 95% confidence intervals did overlap. The lower night estimate was not surprising because rainbow trout migrate toward the surface at night and are less acoustically visible (Yule 2000). Survey accuracy is unknown.

2002: In late August, three consecutive surveys, morning, early afternoon, and late afternoon, were conducted on three consecutive days on Echo Lake (Table 1). Results of those surveys ranged from a low population estimate of 302 fish (95% CI = 126-478, CV = 27%) in the morning to a high of 576 (95% CI = 219-933, CV = 31%) in the late afternoon. Density estimates did not differ significantly across time of day (F = 0.601, P = 0.55, df = 2) or across consecutive days (F= 1.59, P = 0.899, df =2). The interaction term was also not significant (F = 0.266, P = 0.899, df = 4). Significant time, day or interaction effects would have been evidence of systematic inaccuracy, but no inaccuracy was shown. The mean population estimate was 408 with a CV of 22%. Two consecutive surveys (morning and late afternoon) were conducted on Tofte Lake, Lake County, on 17 and 18 September (Table 1). Population estimates ranged from a low of 2,540 (95% CI = 1,770-3,310; CV = 15%) in the late afternoon to a high of 3,090 (95% CI = 1,930-4,250; CV = 19%) in the morning. A two-way ANOVA indicated that densities did not differ between morning and late afternoon (F = 0.136, P = 0.713, df = 1) or between days (F = 0.963, P = 0.329, df = 1). The interaction term was also not significant (F = 0.004, P = 0.947, df = 1), suggesting no systematic inaccuracy. The mean population

Table 1. Hydroacoustic surveys of stream trout lakes, 2001-2003. CV = coefficient of variation.

Year	Lake	Date	Time	Estimated Density (number $\cdot ha^{-1}$)	Population Estimate	95% Confidence Interval (CV)
2001	Echo	9/27	1553-1646	37.9	701	174-1,228 (38%)
		9/27	1948-2103	8.6	158	18-298 (44%)
2002	Echo	8/27	1020-1150	20.1	373	136-610 (32%)
		8/27	1300-1430	17.1	319	70-568 (39%)
		8/27	1530-1715	25.5	475	198-752 (29%)
		8/28	1020-1150	16.2	302	126-478 (27%)
		8/28	1300-1430	20.2	376	100-652 (37%)
		8/28	1530-1715	18.2	338	120-556 (32%)
		8/29	1020-1150	22.4	416	191-641 (27%)
		8/29	1300-1430	26.6	494	175-813 (32%)
		8/29	1530-1715	31.0	576	219-933 (31%)
	Tofte	9/17	0850-1215	49.2	3,090	1,930-4,250 (19%)
		9/17	1530-1815	46.4	2,910	2,230-3,590 (12%)
		9/18	0850-1215	42.4	2,660	1,950-3,370 (13%)
		9/18	1530-1815	40.4	2,540	1,770-3,310 (15%)
	Kimball	9/9	1119-1438	86.6	2,770	790-4,750 (36%)
		10/7	1120-1301	20.6	660	120-1,200 (41%)
	Pine Mountain	10/23	1330-1626	33.2	1,380	160-2,600 (44%)
2003	Esther	5/20	1308-1338	30.1	960	121-3,360 (125%)[c]
		5/22[a]	1226-1412	18.3	576	137-1,824 (100%)[c]
		9/8	1612-1703	26.9	864	141-2,560 (98%)[c]
	South Long	6/17	1239-1330	147.0	8,367	6,784-9,945 (9%)
		6/17[b]	1438-1500	178.8	10,178	62-23,365 (65%)[c]
	Mahnomen Mine Pit	8/4	1149-1458	16.3	1,628	62-5,700 (125%)[c]
	Pennington Mine Pit	8/4	1715-1846	34.8	805	34-2,310 (93%)[c]
	Portsmouth Mine Pit	8/5	0909-1011	56.0	3,127	1,236-5,017 (31%)

[a] 3000 yearling rainbow trout stocked immediately before this survey

[b] One transect only, following the long axis of the lake and generally traversing the deepest portions of the lake

[c] The lower bound of the 95% confidence interval was negative and was replaced by the number of tracked fish.

estimate was 2,800 with a CV of 9%. A 9 September acoustic survey of Kimball Lake, Cook County, yielded a population estimate of 2,770 fish (95% CI = 790-4,750; CV = 36%, 92 fish >20 cm TL). The capture-recapture population estimate of fish >20 cm TL was 65 fish, 35 brown trout (95% CI = 14-64), 18 splake (95% CI = 12-25), and 12 rainbow trout (no recaptures) suggesting reasonable accuracy of the acoustic estimate. It should be noted, however, that the acoustic estimate of fish > 20 cm TL was generated by only one tracked fish. A second survey on 7 October yielded a population estimate of 660 fish (95% CI = 120-1,200; CV = 41%). A 23 October acoustic survey of Pine Mountain Lake, Cook County, yielded an estimate of 1,380 fish (95%CI = 160-2,600; CV = 44%). Sixty-eight (95% CI = 9-130) fish were of a size consistent with carryover brook trout. The capture-recapture estimate of carryover brook trout was 241 (95% CI = 132-505).

2003: A 20 May acoustic survey of Esther Lake, Cook County yielded a population estimate of 960 fish (95% CI = 121-3,360; CV = 125%, Table 1). On 22 May, a second acoustic survey estimated a population of 576 fish (95% CI = 137-1,824; CV = 100%), one day after 3,000 yearling rainbow trout were stocked in the lake. These stocked fish probably were not well-distributed or acclimated to their new surroundings; however, the time required for fish to distribute themselves throughout the lake is unknown. The upper end of the 95% confidence interval (1,824) was considerably less than the 3,000 rainbow trout known to be in the lake. A third survey conducted on 8 September yielded a population estimate of 864 salmonids (95% CI = 141-2,560; CV = 98%). A survey done in South Long Lake, Clearwater County, on 17 June resulted in a population estimate of 8,367 fish with good precision (95% CI = 6,784-9,945; CV = 9%). A 5 August survey of Portsmouth Mine Pit estimated a population of 3,127 fish, also with good precision (95% CI = 1,236-5,017; CV = 31%). Surveys conducted in Mahnomen and Pennington mine pits in Crow Wing County had wide 95% confidence intervals. The accuracy of all the surveys conducted in 2003 is unknown.

Utility of acoustically derived length frequency distributions

Acoustically derived length frequency distributions developed during this study appeared to be of no utility to apportion the population estimates to species in the multispecies populations. Acoustics appeared to sample smaller fish than gill and trap nets (Figure 2). The fish sizes captured during netting efforts were consistently larger than the acoustic estimates predicted by Love's (1977) equation.

Measurements of target strength

Early experiments attempting to measure target strengths of live and tethered fish were unsuccessful, but preliminary results from the vertically tethered fish were promising. Fish placed in the cylindrical cage tended to swim near the perimeter of the cage, outside of the acoustic beam. We were unable to obtain echoes from fish tethered in the pipe frame, and we suspect that echoes generated from the side lobes of the nominal beam masked those from the target fish. Fish tethered vertically in the horizontal beam returned satisfactory echoes (Figure 3). We were unable to complete additional tests due to the lack of target fish and the approach of winter weather.

Discussion

We had good precision of hydroacoustic surveys on deep stream trout lakes when fish were randomly distributed. Most of the CV's were less than 30% in Echo, Tofte, and South Long Lakes, and in Portsmouth Mine Pit (Table 1), water bodies that were relatively deep. In comparison, the shallower Kimball, Pine Mountain, and Esther Lakes had greater littoral areas (Table 2) and CV's greater than 30% (Table 1). Fish were distributed more or less randomly (no significant spatial autocorrelation) in all the lakes except for the Mahnomen and Pennington Mine Pits where fish were found in patches, and CV's were 125% and 93%, respectively. The repeated surveys in Echo and Tofte lakes in 2002 showed that good precision was achievable with no evidence of inaccuracy, at least under the conditions present

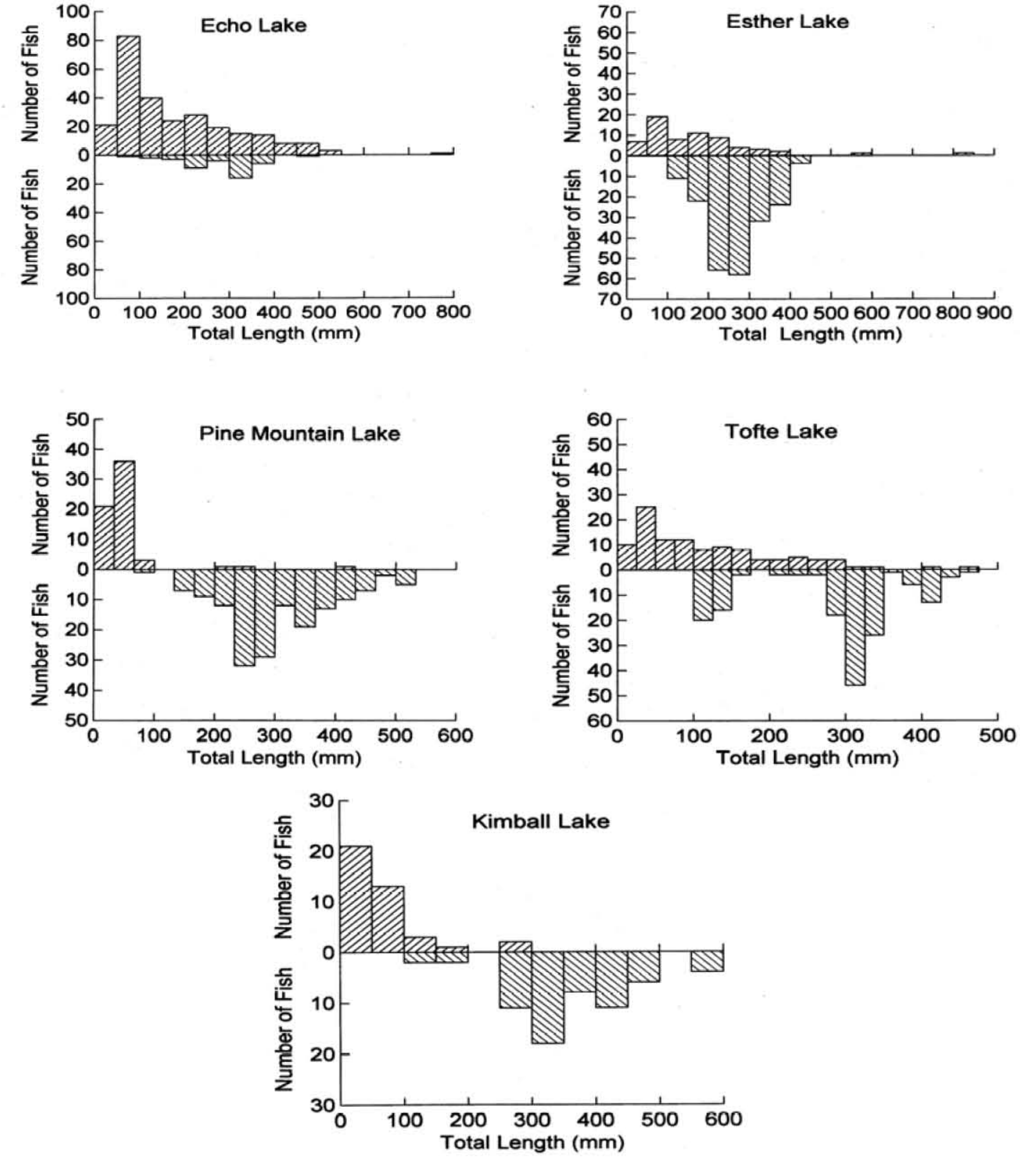

Figure 2. Length frequency distributions of fish populations in five stream trout lakes derived from target strengths collected during down-looking acoustic surveys (upper) and by netting (lower).

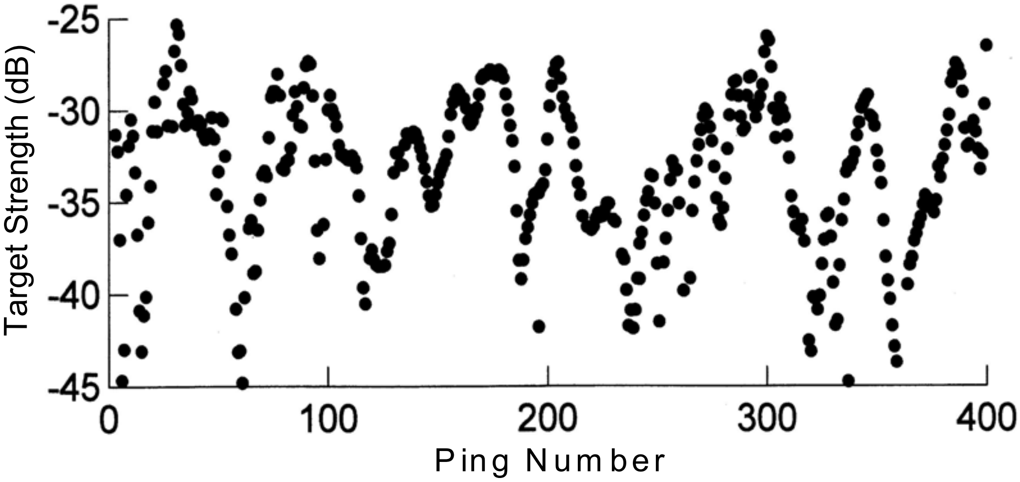

Figure 3. Target strength (decibels) data collected from a side-scanned, vertically suspended rainbow trout measuring 520 mm total length (TL) as it randomly rotated on its head-to-tail axis. The ping rate was 30 PPS. Using Love's (1977) equation to estimate TL, estimates ranged from 1,110 mm (-25 dB) to 100 mm (-45 dB). The mean TS of 1,245 pings was –33.7 dB, which would give an estimated TL of 753 mm.

Table 2. Hydrography of surveyed stream trout lakes.

Lake Name	Lake Area (ha)	Littoral Area (%)	Maximum Depth (m)
Echo	19	26	18.6
Tofte	63	27	22.3
Kimball	32	95	4.9
Pine Mountain	42	66	9.1
Esther	35	40	10.7
South Long	59	17	24.4
Mahnomen Mine Pit	108	14	160.0
Pennington Mine Pit	23	13	78.9
Portsmouth Mine Pit	49	0	107.3

at the time. The population estimates were not significantly different across days and times of day. Confidence in the accuracy would increase if survey estimates made periodically over long periods of time (e.g., an entire open-water season) were close to what was expected after accounting for mortalities, a possible objective for future work.

Changes in survey design and error estimation may improve the precision of future acoustic surveys of lakes with patchy fish distributions. Large variances result from patchy fish distributions (Kimura and Lemberg 1981) and one is usually not aware that the fish were distributed this way until the data is analyzed. Subdividing transects into smaller subunits (bins) can exacerbate the situation by generating more zero estimates from empty bins and large estimates from densely occupied bins. We suggest that survey precision may be improved by transecting the lake as often as is practical with no binning (Kimura and Lemberg 1981). If the fish distribution is found to be patchy (e.g., the fish are concentrated in sub-basins), the data can be stratified to reduce the variation. If there is real-time evidence of a patchy distribution, one could concentrate sampling effort where the fish are concentrated and stratify the data during the analysis to reduce variation. Increasing the sampling effort will result in transects that are more proximate, increasing the probability of spatial autocorrelation for which testing should be done. If significant spatial autocorrelation is found, we recommend using model-based geospatial analysis to estimate the variance of the population estimates (Petitgas 1993). Increased sampling effort may also improve the precision of surveys in shallow stream trout lakes.

Accuracy of the acoustic estimates was contra-indicated by the acoustic survey in Esther Lake on 22 May 2003, and the disparate acoustic and capture-recapture population estimates in Kimball and Pine Mountain Lakes in 2002. Esther, Kimball, and Pine Mountain lakes are shallow with gradually sloping bottoms, and most of the acoustic data was collected with a side-looking beam. Side-looking acoustic beams have a large dead zone when aimed over gradually sloping bottoms (Figure 1), thus most of the fish were probably not acoustically observable. Few, if any, of the 3,000 yearling rainbow trout stocked into Esther Lake shortly before the 22 May acoustic survey were tracked, probably because they remained in shallow water near the stocking site. In addition, side-looking beams often receive echoes from surface reverberation and aquatic plants, making echogram interpretation difficult. We may be able to improve the accuracy of acoustic surveys in shallow lakes by using only a down-looking transducer because the down-looking beam has a smaller dead zone over a gradually sloping bottom than a side-looking beam. In shallow water, the down-looking beam insonifies a smaller volume so more transects will be required to collect sufficient data. We should also experiment with alternative side-looking techniques such as shallow-to-deep insonification while following a shallow contour with the boat or perhaps a fixed transducer scheme. It may be possible to develop winter acoustic survey techniques that reduce the dead zone volume. Using the stable ice as a working platform, the transducer angle can be adjusted to be more nearly perpendicular to sloping lake bottoms and fish near the substrate may be insonified and detected. Alternatively, acoustics may simply be of limited value for sampling fish in shallow lakes.

There are two possible reasons for the disparate acoustic and netting length frequency distributions. Love's (1977) equation may not accurately predict body lengths of the species found in the lakes that were surveyed. Future work should include measurements of dorsal aspect target strengths of known-length fish, and development of TS/TL functions for each species typically found in Minnesota's stream trout lakes. Alternatively, gill and trap nets may have selectively captured only the larger fish. If one focuses only on fish that are large enough to be of interest to anglers and the data sets contain sufficient observations of these fish, one could estimate the abundance and biomass of the larger fish of each species in the mixed population. For example, if we discovered from a creel survey or assumed that in Esther Lake, anglers are only interested in fish larger than 25 cm TL (10 inches), then 11 fish, 15% of the pooled acoustic data set collected in 2003, met this criterion. Two-thirds of the fish from the netting data set meeting this criterion were white suckers *Catostomus commersoni.* Assuming that the netting data accurately represented the species ratios of the larger fish and assuming that Love's equation accurately estimates fish length, one could conclude that of the 960 fish estimated in the 20 May 2003 acoustic survey, 144 were large enough to be of interest to anglers and of those, 48 were salmonids. If we apply the 25 cm length-of-interest criterion to the five lakes where netting was done, then few of the acoustically tracked fish met the criterion (Figure 2), making estimates of species abundance in all the lakes unreliable. Collection of additional acoustic data could result in more observations of large fish and less questionable abundance estimates of fish sufficiently large to be of interest to anglers. In lakes where abundance of salmonids is low, it may be impractical to collect additional acoustic data. In that case, capture-recapture population estimates are recommended.

The TS data displayed in Figure 3 suggest that reliable species-specific TS – fish length relationship can be developed experimentally, at least for dorsal aspect TS data. The fish that was insonified, rotated randomly about its head-to-tail axis during the tests, thus the varying TS. We should be able to obtain more reliable dorsal aspect TS data if we minimize rotation by firmly anchoring the boat, collecting TS data in calm weather, and attaching a third monofilament tether line through the dorsal musculature to stabilize the fish in the dorsal aspect (Figure 4). The variation in peak TS value suggests Love's equation be used with caution when working with rainbow trout.

Management Implications

Hydroacoustic techniques as tested in this study are not yet reliable enough for general use and their accuracy is still unproven. With proof of accuracy and refinement of open-water techniques, reliability may be improved and guidelines for acoustic surveys can be developed. Development and testing of winter acoustic methods is recommended.

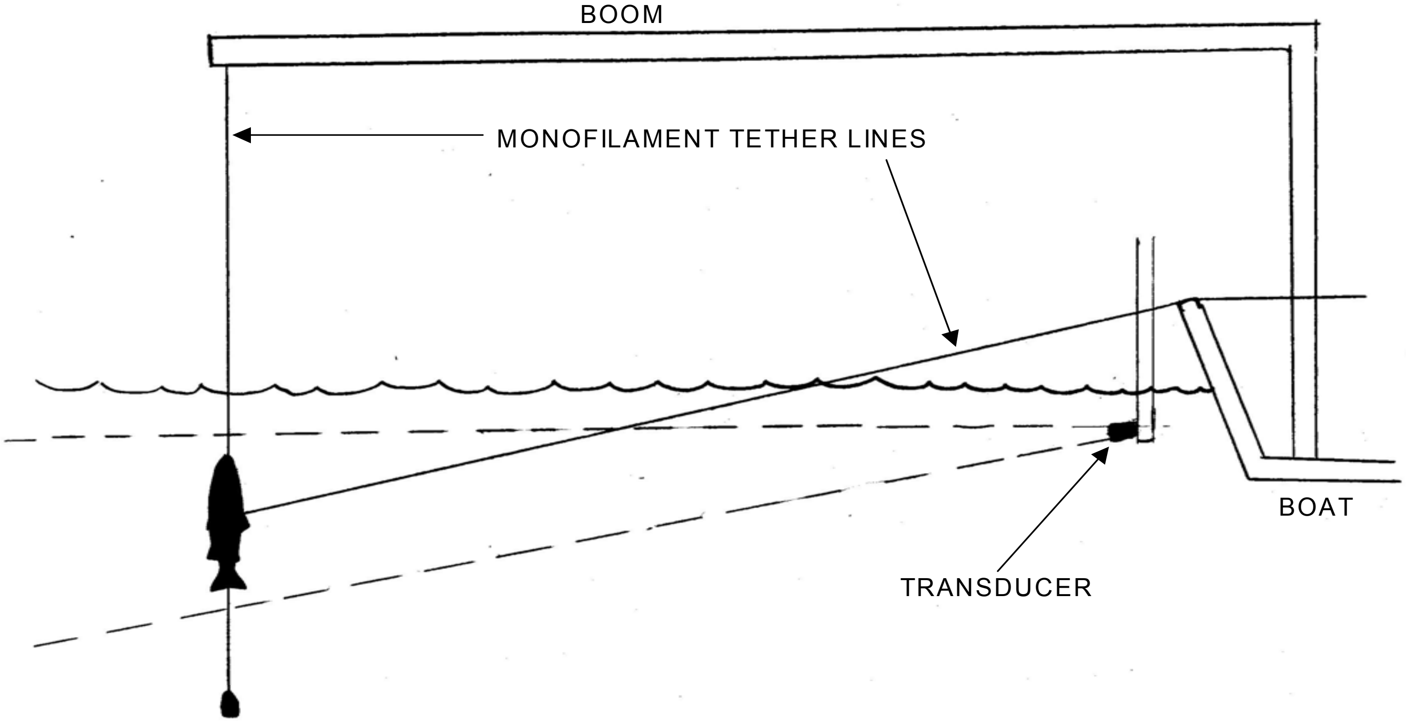

Figure 4. Technique for measuring dorsal aspect target strength of tethered fish by side scanning.

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