FISHERY RESEARCH

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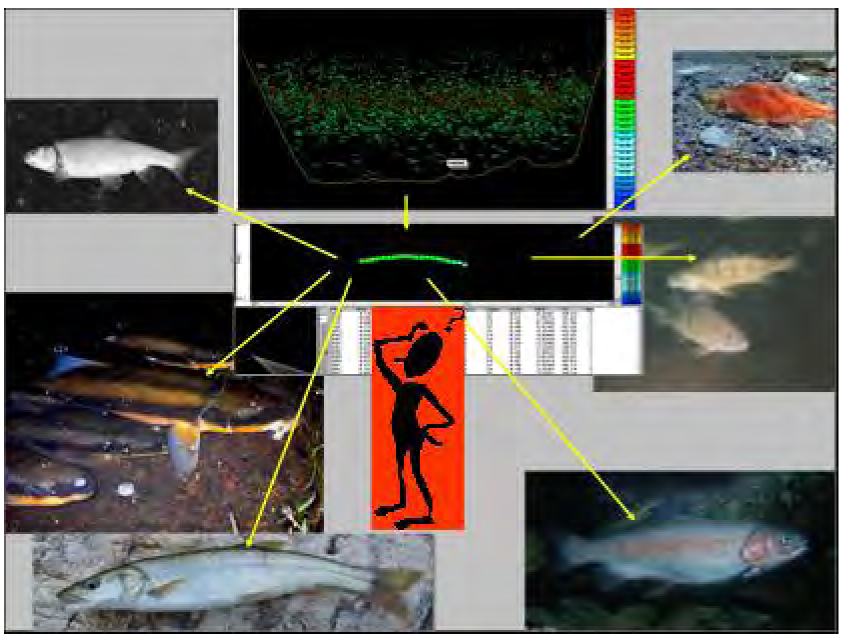

Arthur E. Butts
Senior Fishery Research Biologist

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Project 5—Lake and Reservoir Research

By

Arthur E. Butts

Idaho Department of Fish and Game
600 South Walnut Street
P.O. Box 25
Boise, ID 83707

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ANNUAL PERFORMANCE REPORT

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ABSTRACT

In 2000, Idaho Department of Fish and Game acquired a split-beam digital echosounder with multiplexing capabilities between horizontally- and vertically-aimed transducers. Since then, there has been some question about the utility and validity of hydroacoustics in obtaining a population estimate for an individual species within a water body containing a diverse species assemblage. During the 2003 field season, hydroacoustic surveys were used to estimate fish abundance and size structure in Anderson Ranch, Arrowrock, Cascade, Daniels, Deadwood, Oneida, Palisades, and Sage Hen reservoirs, and Henrys, Payette, and Williams lakes. Many of the water bodies contain multiple species, overlapping in both distribution and size. Hydroacoustic surveys were conducted at night except when the target species were rainbow or cutthroat trout. Experimental net curtains were deployed overnight for multiple nights in eight of the 12 surveys so that hydroacoustic estimates could be partitioned into individual species estimates. Limnological data were collected at sites along the trophic gradient at most water bodies to assist in the explanation of fish distributions. Hydroacoustics provided reasonable population estimates of target species at most reservoirs, but estimates for Yellowstone cutthroat trout at Henrys Lake and Palisades Reservoir were confounded by lake morphology and fish behavior. At Cascade Reservoir, the total estimated cost of the survey was approximately $3,800 to estimate northern pikeminnow abundance with a 90% confidence interval ± 30%. In Idaho, hydroacoustics can provide a reasonable population estimate for an individual species in water bodies with complex species assemblages with a few caveats: 1) the target specie(s) must utilize pelagic habitats and not be limited to the benthic region, 2) biologists should have some understanding of the biology and behavior of the target specie(s), 3) intensive fish collection efforts are crucial to obtaining reliable estimates of species proportions and the number of nets that are deployed should be based on the desired error bound for a proportion, 4) surveys that are repeated during different seasons are extremely helpful in determining the appropriate timing for the optimal population estimate, and finally 5) as with trend netting, every effort should be made to conduct future surveys during the same seasonal or environmental period as previous surveys so that behavioral biases are minimized. The costs in terms of time and labor can be high because of the required fish collection efforts. Therefore, the benefits and value of a survey should be carefully evaluated before deciding to proceed. However, in comparison to other methods such as creel censuses or mark-recapture methods, hydroacoustics is a cost-efficient alternative.

Author:

Arthur E. Butts
Senior Fishery Research Biologist

INTRODUCTION

Hydroacoustic technology has become an increasingly popular tool in fisheries management, and the applications are quite diverse. In lakes and reservoirs, hydroacoustic or sonar techniques have been frequently used to study fish abundance (Thorne 1979; Burczynski and Johnson 1986; MacLennan 1990; Bjerkeng et al. 1991), distribution (Maiolie and Elam 1996; Aku et al. 1997; Beauchamp et al. 1997), behavior (Levy 1991; Luecke and Wurtsbaugh 1993; Maiolie et al. 2001), and survival (Thiesfeld et al. 1999; Butts 2002). Sonar has also been used to estimate entrainment losses through hydroelectric facilities (Ransom and Steig 1994; Maiolie and Elam 1996; Ransom et al. 1996).

In shallow waters, fish abundance estimates obtained from downlooking transducers can be prone to bias, because sample volume is limited near the apex of the cone (Yule 2000). Recent development of horizontal or sidelooking hydroacoustics technology has enabled biologists to monitor fish in shallow water habitats (Kubecka 1996; Yule 2000; Teuscher 2001). Multiplexing between a downlooking and sidelooking transducer allows acoustic monitoring of surface-oriented fish in shallow waters (Yule 2000). However, in limnetic environments, target strength measurements are suspect, because there is no way to determine the horizontal orientation of a fish in relation to the acoustic beam axis (Kubecka and Duncan 1998; Yule 2000).

There are many advantages to incorporating hydroacoustics into traditional sampling methodologies such as trawling or gillnetting (Brandt 1996; Yule 2000). Hydroacoustic surveys are extremely cost effective in that a crew of two individuals can collect large quantities of data. In pelagic zones, hydroacoustics are also nonselective in comparison to trawls, seines, gillnets, or other traditional sampling gears. Additionally, multiple fish parameters can be estimated concurrently, and results are readily available.

Hydroacoustics are not limited to simply providing estimates of densities or spatial distributions. Hydroacoustics can be used to estimate individual fish length using equations that relate target strength (measured in decibels, dB) to fish length when fish are dorsal-ventrally oriented to a vertically aimed or downlooking transducer (Love 1971; Love 1977). Resulting length-frequency distributions may be valuable information for managers (e.g., monitor recruitment, estimating age structure and mortality, etc.).

Like any sampling methodology, hydroacoustics do not come without limitations. Hydroacoustics require a high initial investment in equipment and training personnel to operate the equipment. Secondly, monitoring fish that are very close to boundaries, such as the surface or bottom, is difficult using hydroacoustics. Therefore, it is generally not possible to use hydroacoustic technology to examine fish in littoral, benthic, or near-surface habitats. Finally, direct identification of species is not possible with hydroacoustics. Partitioning species generally requires collecting fish through other sampling methodologies and coupling this information with knowledge on fish size, species-specific distributions, and behavior.

The inability to discern species is the primary limitation of using hydroacoustics to collect information that enhances the management of Idaho’s flatwater fisheries (Butts 2004; Butts and Teuscher 2002). Many important fisheries in Idaho contain mixed species assemblages that overlap spatially and temporally. In these environments, hydroacoustics alone cannot provide enough information to assist in management decisions or activities, and thus, attempts to collect fish for target verification data should be made.

Fish sampling for hydroacoustic target verification can be designed to account for collection gear biases as well as vertical and horizontal environmental gradients in water bodies. More than one type of collection gear should be utilized for capturing fish, and collections should occur at a number of sites along hydroacoustic transects throughout a lake or reservoir.

Acoustic assessments of fish populations can also be enhanced by the collection of environmental data. Temperature and dissolved oxygen (DO) are critical variables that structure lake and reservoir habitats along both vertical and horizontal gradients. This in turn influences fish distribution and movement (Baldwin et al. 2002) and the structure of fish communities within a water body (Engel and Magnuson 1976; Jackson et al. 2001).

MANAGEMENT GOAL

1. Improve sportfishing and fisheries management in Idaho lakes and reservoirs.

OBJECTIVE

1. To determine during the 2003 field season whether hydroacoustic methods can be used to produce useable population estimates in complex fish communities.

TASKS

1. Estimate the number of pelagic fish at Arrowrock Reservoir, Cascade Reservoir, Deadwood Reservoir, Henrys Lake, Oneida Reservoir, Payette Lake, Palisades Reservoir, Sage Hen Reservoir, and Williams Lake.

2. Describe the temporal aspects of susceptibility to sampling by sonar gear.

3. Develop fish sampling techniques to partition hydroacoustic abundance estimates by species, with reasonable error bounds (30-50%).

METHODS

Hydroacoustics

Hydroacoustic estimates of fish densities, lengths, and vertical depth distributions were obtained with a Hydroacoustic Technology, Inc. (HTI) Model 241-2 split-beam digital echosounder. The 200 kHz sounder was equipped with two transducers: a 15° vertically aimed transducer (downlooking) and a 6° horizontally aimed transducer (sidelooking), which was set at a 6° angle below the surface. Transducers were suspended at a 1 m depth using a retractable pole mount mounted on the port side of the boat. Boat speed during data collection ranged from 1 to 1.5 m/s. Sampling transects were determined prior to surveys and were followed using Global Positioning System (GPS) coordinates (Appendices).

Data were collected by fast multiplexing equally between both transducers at a sampling rate of 3.0-12.5 pings/s, which allowed for near-simultaneous data collection at 1.5-6.25 ping/s per transducer. A transmit pulse width of 0.2 ms was used for both transducers.

Yule (2000) determined that the effective detection angle of the 15° transducer approached nominal beam width at 8 m of range and the 6° effective detection angle approached nominal beam width at 10 m of range. However, recent evaluations of this approach suggest that the nominal beam width of the 15° transducer may actually occur at 6 m of range. Therefore, the sidelooking transducer (6°) collected data in 0.5-6 m of the water column at a range of 10-42 m, which was manually adjusted in situ using an oscilloscope as a reference. The downlooking transducer (15°) collected data in the remaining water column. Downlooking ranges (depth), sidelooking ranges, and GPS coordinates were automatically recorded to data files at 10 s intervals during surveys.

Thresholds were generally established so that targets larger than –60 dB and –44 dB along the acoustic axis were accepted for the downlooking and sidelooking transducers, respectively. Thresholds corresponded to a minimum size acceptance of 19 mm fish targets for the downlooking transducer (Love 1977) and 132 mm for the sidelooking transducer (Kubecka and Duncan 1998). The bottom threshold was set at 2.0 V, and echoes within 1.5 to 2.0 m of the bottom were excluded from analysis (bottom window). However, in some instances, the bottom was tracked manually in efforts to detect fish closer to the bottom. In these instances, the bottom was manually traced using the returning echo strength and bottom editing functions within the software during fish tracking analyses.

Target tracking was used to classify returning echoes as fish and thus obtain fish density estimates. This method combines individual echo returns that meet specific criteria and records them as individual fish. Following methods described by Teuscher (2001), fish tracking criteria included: 1) a minimum of three echoes with a minimum acceptable change in range between echoes of 0.2 m, 2) a maximum difference in returning echo strength of 10 dB, 3) maximum swimming velocity of 3 m/sec, and 4) mean target strength for a tracked fish between a size range of –20 and –60 dB. During the survey, data were collected and processed, and fish were tracked and recorded using the HTI software, Digital Echo Processor (DEP). However, because the default tracking parameters may allow gas bubbles, bottom or complex substrate to be counted as fish, we individually examined tracked fish using HTI's EchoScape software. The software allows the user to further examine individual echoes within a fish trace and thereby reduce errors associated with using the automatic tracking procedures, i.e., overestimating fish density.

Estimates of downlooking fish densities (>6 m deep) for each transect were obtained using a range weighting technique as described by Yule (2000). This method standardizes fish density estimates by accounting for expanding sampling volume with increasing range. Tracked fish are weighted back to a 1 m swath at the surface using the following formula:

$$F_w = \frac{1}{(2*R*\tan(7.5°))}$$

where F_w is weighted fish,
R is range, and
7.5° equals half the nominal transducer beam width.

Fish densities (fish/m^2) for each transect were calculated by summing weighted fish and dividing that value by transect length (m). Fish detected by the downlooking transducer that were in the top 6 m of the water column were excluded from analysis to avoid double counting.

Sidelooking fish densities (<6 m deep) for each transect were estimated by dividing the number of fish detected by the volume of water sampled. The volume of water sampled (m^3) was estimated by multiplying transect length (m) by the average range sampled by the sidelooking transducer (m) by the average height of the cone (m). The first 10 m of range (near field) was not included in the sample volume estimate because of the effective detection angle of the sidelooking transducer (Yule 2000).

Because the distribution of fish density estimates from transects was not normal, the geometric mean density was calculated for expansion to population estimates. The geometric mean and 90% confidence interval for density estimates was computed using methods described by Elliott (1983). A log(x+1) transformation was used because density estimates sometimes contained zero values. Total fish abundance was estimated by multiplying the geometric mean sidelooking and downlooking fish density (fish/ha) by the surface area of the reservoir on the survey date and summing them together. The standard error for the total population estimate was calculated using the following equation (Elliot 1983):

$$SE = \sqrt{\frac{s^2{}_x}{n_x} + \frac{s^2{}_y}{n_y}}$$

where $s^2{}_x$ is the variance of x,

$s^2{}_y$ is the variance of y, and

n_x and n_y is the sample size of each estimate.

The Bureau of Reclamation (BOR) provided surface area and volume data for most of the reservoirs sampled during 2003. When data was not available, surface area estimates were obtained using ARCVIEW software. Ninety percent confidence intervals were calculated for population estimates using the methods described in Scheaffer et al. (1996). Regardless of transect length, each transect was considered a sample unit.

Vertical depth distributions of tracked fish were calculated for most 2003 surveys after accounting for transducer depths. Downlooking depth distributions were calculated by simply summing the number of targets at each depth interval. Sidelooking vertical depths for each tracked fish were calculated using the following equation:

$$F_d = \sin(radians(6°) * R) - Y + T_d$$

where F_d is fish depth (m),

6° is the angle at which the horizontal transducer was aimed,

R is range,

Y is total distance (m) traveled vertically by the fish in the beam, and

T_d is the physical depth sidelooking transducer (m).

Fish were then summed across each 1 m depth interval to attain vertical depth distributions detected by the sidelooking transducer.

Target Verification

An array of net curtains were set at various depths in pelagic regions for target verification and species partitioning at Arrowrock Reservoir, Cascade Reservoir, Deadwood Reservoir, Henrys Lake, Oneida Reservoir, Payette Lake, Palisades Reservoir, Sage Hen Reservoir, and Williams Lake during nighttime periods. Nets were not set during daytime periods because of poor catch rates observed the previous field season (Butts 2004). Nets were set at various sites along hydroacoustic transects using GPS; sites were spaced longitudinally from inlet to outlet. During most net nights, 2 49 m x 6 m net curtains were suspended at various intervals between depths covered by sinking and floating gillnets to ensure that the entire water column was sampled. Each net curtain consisted of 3 m long panels of different mesh arrays that were randomly placed. One net curtain was comprised of 19, 25, 32, 38, 51, 76, and 102 mm stretch mesh, while the other net was comprised of 51, 57, 64, 76, 89, 102, 127, and 152 mm stretch mesh. Each net curtain was considered an individual sampling unit during our analyses.

Because of netting restrictions that were in place in waters containing bull trout, the following procedure was implemented to minimize potential mortality at Arrowrock and Deadwood reservoirs: Two net curtains were set at dusk for one hour each at the beginning of each survey. When no bull trout were observed in catches, the full array of nets was set overnight.

Fish were identified, and total lengths (TL; nearest mm) and weights (nearest g) were measured and recorded. For each fish, capture depth (m) was estimated, and net mesh size (mm) was recorded. Total depth at each netting site was also recorded. In cases where fish lengths were converted to hydroacoustic target strengths or vice versa, total lengths were converted to standard lengths using species-specific conversion factors (Carlander 1969).

Species proportions were calculated separately for day and night periods using the cluster sampling formulas described by Scheaffer et al. (1996):

$$\hat{p} = \frac{\sum_{i=1}^{n} a_i}{\sum_{i=1}^{n} m_i}$$

where $\hat{p}$ is an estimator of the population proportion p,

a_i is the total number of elements in cluster i that possess the characteristic of interest, and

m_i is the number of elements in the ith cluster, i = 1, 2, . . . , n.

The variance around the proportion estimates were calculated using the following equations (Scheaffer et al. 1996):

$$\hat{V}(\hat{p}) = \left(\frac{N-n}{Nn\bar{M}^2} \right) s_p^2$$

where N is the number of clusters in the population,
n is the number of clusters selected in a simple random sample,
$\bar{M}$ is the average cluster size for the population, and
s_p^2 is calculated as follows:

$$s_p^2 = \frac{\sum_{i=1}^{n} (a_i - \hat{p} m_i)^2}{n-1}$$

Relative abundance estimates for individual species were estimated by multiplying the species proportions obtained from gillnets by the total fish abundance obtained from hydroacoustics. Because abundance estimates for individual species were the products of two random variables, the error around these estimates was calculated using the following equation for the variance around the product of two independent variables (Goodman 1960):

$$v(\bar{x}\bar{y}) = \bar{x}^2 \frac{s^2(y)}{n(y)} + \bar{y}^2 \frac{s^2(x)}{n(x)} - \frac{s^2(x)s^2(y)}{n(x)n(y)}$$

where $v(\bar{x}\bar{y})$ is the variance of the product $\bar{x}\bar{y}$,
$s^2(y)$ is the variance of $\bar{y}$,
$s^2(x)$ is the variance of $\bar{x}$, and
$n(x)$ and $n(y)$ are the sample sizes for each estimate.

Obtaining an appropriate estimate of error, s_p^2, around the population proportion, $\hat{p}$, allows for the estimation of the required sample size for a desired error bound. The number of clusters that should be sampled to estimate p, within a bound of B units, can be calculated as follows (Scheaffer et al. 1996):

$$n = \frac{N\sigma_p^2}{ND + \sigma_p^2}$$

where $D = B^2\bar{M}^2 / 4$, and
σ_p^2 is estimated by s_p^2.

Because the total possible number of clusters N is unlimited, it was assumed that $N = \infty$ in our estimates. I used the above formula to calculate the appropriate number of clusters that should be sampled for rainbow trout at American Falls Reservoir and rainbow trout and northern pikeminnow at Cascade Reservoir.

In addition to using gillnets and net curtains in the parsing of hydroacoustic targets, I attempted to collect fish using a purse seine in two study waters. Purse seining does not result in the size selectivity and fish activity biases that are often associated with gillnets, because it is an active sampling methodology. A 9.1 m deep purse seine was used at American Falls Reservoir and Cascade Reservoir. The 183 m long net consisted of 19 mm stretch mesh (knotless) with an 8 m long bunt in the center of the seine comprised of 6 mm long stretch mesh. The purse seine encircled 0.27 ha and was set and retrieved in 30 min, using a 9 m long barge and a 5 m long skiff. Scuba divers employed by the Wyoming Game and Fish Department (WGFD) estimated the effective sampling depth of a purse seine of the same dimensions to be 7.6 m (Yule 2000).

Limnology

Limnological data were collected concurrently with most of the hydroacoustic surveys to help explain horizontal and vertical fish distributions. Limnological variables were measured at 1-3 sites along the longitudinal axis of each reservoir, from inlet to outlet. Vertical temperature (°C) and dissolved oxygen (mg/L) profiles were measured at 1 m intervals using a calibrated Hydrolab data logger (model Surveyor 4a) and depth probe (model MiniSonde 4a). Mean Secchi transparency was recorded at each site by two different observers using a 15 cm disc.

To describe gradients in forage availability for pelagic fish, I collected data on size structure and abundance of zooplankton communities in the lower, middle, and upper reaches of four reservoirs. Zooplankton was collected using three 50 cm diameter, Wisconsin-style plankton nets with 153, 500, and 750 μm mesh. Two samples were taken per site using each net so that six zooplankton samples were collected at each station. Vertical hauls were taken from the entire water column and samples were preserved in denatured ethyl alcohol, using a 1:1 (sample volume:alcohol) ratio. Zooplankton was analyzed and indices were calculated using methods described by Teuscher (1998), with the exception that indices were calculated at each sampling site instead of the entire reservoir. This allowed me to measure potential gradients in secondary production along a horizontal axis in addition to assessing the overall availability of zooplankton resources within a water body. The zooplankton ratio index (ZPR) was calculated by dividing the mean zooplankton biomass in the 750 μm net by the mean biomass collected in the 500 μm net (Yule and Whaley 2000). The zooplankton quality index (ZQI), which accounts for abundance, was calculated by multiplying the sum of the zooplankton weight collected in the 500 and 750 μm nets by the ZPR (Teuscher 1998).

Survey Cost Estimate

Survey expenditures were tracked in order to approximate the expense of a survey in relation to the quality of the population estimate, i.e., error bound. Labor costs for netting, hydroacoustics, data entry, and data analysis were recorded during 2003 surveys. Additional survey costs such as groceries, fuel, and travel were approximated for Cascade Reservoir so that the relationship between total survey cost and the population estimate error bound could be examined.

Data Collected

Density, distribution, and abundance estimates were obtained for American Falls Reservoir, Anderson Ranch Reservoir, Arrowrock Reservoir, Cascade Reservoir, Deadwood Reservoir, Lucky Peak Reservoir, and Payette Lake. Limnological measurements were taken at most water bodies and data were coupled with hydroacoustic estimates to enhance the understanding of fish distribution and movement. Fish were collected at American Falls Reservoir, Arrowrock Reservoir, Cascade Reservoir, and Lucky Peak Reservoir. Species-specific abundance estimates were limited to American Falls, Anderson Ranch, Cascade, and Deadwood reservoirs and Payette Lake because fish collections were either not attempted or sample sizes were restricted because of logistical problems.

RESULTS

Anderson Ranch Reservoir

Anderson Ranch Reservoir was surveyed with hydroacoustics on August 27, 2003. Transects began at the upper end of the reservoir, downstream from the inlet, and ended along the dam (Appendix A). All pelagic targets were considered kokanee, and therefore fish collection was not conducted during the survey. Limnological data were not collected because of time constraints. Based on midwater trawling conducted in previous years, estimates were divided into age classes where <100 mm were age-0 fish, 100-200 mm were age-1 fish, and >200 mm were older fish (Butts 2004).

The majority of targets were smaller fish, which was expected since the survey was conducted after most mature fish would have entered the inlet to spawn (Figure 1). The target strength distribution suggested a strong year class of age-0 fish. The modal depth of tracked fish was at approximately 45 m (Figure 2).

Densities of all size classes were variable between transects with targets <100 mm dominating density estimates (Table 1). I estimated 329,671 (215,793 to 503,646) age-0 kokanee, 29,569 (20,862 to 41,910) age-1 kokanee, and 18,590 (13,116 to 26,349) age-2 and older kokanee (Table 1). The total population estimate of kokanee at Anderson Ranch Reservoir was 407,263 (278,265 to 596,061), comparable to the 2002 estimate of 285,421 ± 44,332 kokanee (Butts 2004).

Arrowrock Reservoir

Arrowrock Reservoir was surveyed by hydroacoustics and gillnets from July 2 through July 10, 2003, with the hydroacoustic survey occurring on July 8. Transects began at the upper end of the reservoir and continued downstream to the dam (Appendix B). Gillnet sites were selected randomly along the hydroacoustic transects. Limnology data were collected at three stations.

The majority of tracked targets were less than 230 mm, and most fish were tracked with the downlooking transducer (>6 m; Figure 3). Fish were fairly distributed throughout the water column with the largest proportion (20%) occurring in the top 10 m (Figure 4).

Fish densities were variable between transect with the upper half of the reservoir containing the highest density estimates (transects 1-8; Table 2). I estimated 1,359 (518 to 2,639) fish in the top 6 m and 16,228 (12,836 to 20,446) in the remaining depths, for a total of 18,533 (14,414 to 23,745) fish (Table 2). The 2003 population estimate was lower than the 2002 estimate (85,877 ± 32,015; Butts 2002).

Twelve net curtains were set at various depths during the Arrowrock Reservoir survey. Gillnet catches were primarily comprised of largescale sucker (61%), northern pikeminnow (26%), kokanee (8%), and rainbow trout (3%). Length frequency data for these species are shown in Figure 5. No bull trout were captured at Arrowrock Reservoir in 2003. Using the proportion estimates obtained from netting along with hydroacoustic abundance estimates, I estimated 11,335 ± 976 largescale suckers, 4,858 ± 841 northern pikeminnow, 1,439 ± 363 kokanee, and 540 ± 190 rainbow trout (Table 3). Interestingly, Arrowrock Reservoir has not been stocked with kokanee in the last 30 years, suggesting that the reservoir receives a fair number of fish through entrainment from Anderson Ranch Dam and perhaps natural recruitment in the Middle Fork or South Fork of the Boise River.

Arrowrock Reservoir was thermally stratified at all four sampling sites during the survey, with the thermocline occurring between 5-10 m (Figure 6). Surface temperatures were warmest near the dam (Station 4), and because depths were greatest at this site, it held the coolest available habitats in the reservoir. Dissolved oxygen levels did not fall below 6 mg /L at any depth in the reservoir. Zooplankton resources were lowest near the Middle Fork of Boise River inlet (Station 2), where ZQI was measured at 0.30 but appeared to be more abundant throughout the rest of the reservoir (Table 4). ZQI values suggested that adequate forage resources were available for planktivorous species.

Cascade Reservoir

Cascade Reservoir was surveyed with hydroacoustics on August 20, 2003 while netting was conducted July 16-22, 2003. The hydroacoustic survey was conducted during a later period because equipment had to be repaired. Ten nonadjacent hydroacoustic transects of similar length were surveyed (Appendix C). Gillnet sites were selected randomly along or near the hydroacoustic transects. Limnology data were collected at three stations. Population estimates of total fish abundance and fish >250 mm were calculated so that I could make comparisons between hydroacoustics and a northern pikeminnow and largescale sucker mark-recapture study.

The distribution of target strength showed multiple modes with the majority of tracked fish below 300 mm (Figure 7). Seventy-four percent of the tracked fish were utilizing depths of 3-7 m with a modal depth of 4 m (Figure 8).

Despite attempts to reduce variability by standardizing transect lengths, density estimates fluctuated considerably between transects throughout the reservoir (Table 5). More fish were detected with the sidelooking transducer where an estimated 214,318 (151,072 to 302,506) fish were in the top 6 m, of which 39% or 83,656 (60,928 to 113,740) were >250 mm (Table 5). In depths >6 m, I estimated 173,299 (130,611 to 229,009) fish with only 2% of detected fish >250 mm. A total of 431,226 (350,151 to 530,588) fish were estimated using hydroacoustics in 2003, of which 88,289 (21%; (63,963 to 120,692) were 250 mm or larger.

Twenty-seven net curtains were set during the 2003 Cascade Reservoir survey. Gillnet catches were primarily comprised of northern pikeminnow (40%), rainbow trout (27%), and largescale suckers (23%; Table 6). These estimates are similar to proportion estimates obtained during 2002 where 43% were northern pikeminnow, 24% rainbow trout, and 26% were largescale suckers (Butts 2004). The length frequency of fish captured in gillnets did not agree with hydroacoustic target strength distributions, as most fish captured were larger than 300 mm (Figure 7). Length frequency data for largescale sucker and northern pikeminnow suggest that these populations are comprised of mainly older individuals with limited recruitment (Figure 9). However, target strength distributions collected with hydroacoustics show a large portion of the detected fish to be much smaller than what gillnetting would suggest (Figure 7).

Using the proportion estimates obtained from gillnetting, abundance estimates for individual species were calculated (Table 6). A total of 174,246 ± 7,171 northern pikeminnow were estimated with 35,675 ± 1,500 fish >250 mm. The estimate of fish >250 mm is comparable to results obtained from a Lincoln-Petersen mark-recapture study conducted during the same period where 24,413 ± 7,089 northern pikeminnow were estimated. I also estimated 115,328 ± 5,003 rainbow trout and 97,778 ± 6,168 largescale suckers with hydroacoustics and gillnetting.

Cascade Reservoir was thermally stratified at all collection sites during gillnetting with the thermocline occurring between 4-9 m (Figure 10). Temperature profiles were similar throughout the reservoir. Dissolved oxygen levels were also similar throughout the reservoir with values below 2.0 mg/L at approximately 8 m depth. Zooplankton resources, as measured by the ZQI, were abundant at all sampling stations (Table 4).

Daniels Reservoir

Daniels Reservoir was surveyed during the day with hydroacoustics on June 10, 2003. A zigzag pattern of transects was conducted beginning at the dam and heading upstream (Appendix D). Fish collection and limnology sampling were not conducted. All targets were considered a mixture of rainbow trout, cutthroat trout, or their respective hybrids.

Target strength distributions suggested that larger fish were in deeper waters (Figure 11). The sidelooking and downlooking distributions were much different from what is typical of multiplexing data. Generally fish detected with the sidelooking transducer are larger because of the greater source of error associated with not knowing the aspect of the fish. Compared to results in 2000 (Teuscher 2001), the size frequency distribution also showed a prominent increase of smaller fish between -50 and -40 dB (100 mm to 345 mm SL; Kubecka and Duncan 1998; Figure 12). This is likely a result of stocking, as Daniels Reservoir has received a large number of fingerling and catchable trout between 2001 and 2004.

Fish densities were considerably higher than a previous survey in 2000, although both surveys were conducted during early summer (Teuscher 2001). Densities were variable between transects and ranged from 22.4 to 442.4 fish/ha (Table 7). An estimated 5,554 (2,698 to 10,749) fish were in the top 6 m, while 761 fish (502 to 2,053) inhabited deeper water. The total population estimate of 8,935 (3,233 to 13, 984) was over two times the 2000 population estimate of 4,000 ± 640, but the estimates did not differ significantly because of the large error estimates.

Deadwood Reservoir

Deadwood Reservoir was surveyed with hydroacoustics on August 1, 2003 and with gillnets from July 30 through August 3, 2003. Eleven standardized transects were chosen to ensure coverage throughout the reservoir (Appendix E). Gillnet sites were selected randomly along the hydroacoustic transects. Limnology data were collected at three stations.

The majority of fish were detected below 6 m depth with a predominant peak located between 10-15 m, which likely corresponded to schooling kokanee (Figure 13). The size frequency distribution of tracked fish displayed a prominent group of fish below 100 mm, which would correspond to age-0 kokanee (Figure 13). Age-1 and older cohorts were not discernable from the target strength distribution.

Fish densities were very low in the top 6 m, where I estimated 0.9 fish/ha (0.45 to 1.54), but dramatically increased in deeper waters with 140.9 fish/ha (71.6 to 276.6; Table 8). An estimated 967 (474 to 1,617) fish inhabited 0-6 m depth, while 148,300 (75,325 to 291,000) were >6 m for a total estimate of 176,431 (112,594 to 276,126) fish.

Twenty-one net curtains were set during the 2003 Deadwood Reservoir survey. Gillnetting resulted in catches made up of predominately kokanee (63%), mountain whitefish (20%), westslope cutthroat (5%), and redside shiner (8%) (Table 9). Dace species and rainbow trout were also captured. Multiple cohorts of kokanee were captured, ranging from 90 mm to 498 mm (Figure 14). Kokanee were not separated into age classes. Using the catch proportion estimates, I estimated 111,838 ± 7,089 kokanee, 9,957 ± 1,001 westslope cutthroat, and 35,803 ± 3,606 mountain whitefish (Table 9).

A kokanee population estimate was also made using all targets between 9 and 26 m depth to provide an estimate that was comparable to previous years where netting was not conducted (Table 10). This estimate was separated into cohort estimates using the target strength frequency distribution of returning echoes. Age-0 kokanee were the most predominant cohort, as I estimated 121,115 ± 28,799 fish. Age-1+ fish had an estimated population size of 32,526 ± 10,608, and the total overall estimate of four size groups of kokanee combined was 207,763 ± 41,820 fish.

Deadwood Reservoir was thermally stratified throughout the reservoir during the August 2003 sampling, and both temperature and dissolved oxygen levels were accommodating to coolwater fish species (Figure 15). Temperatures ranged from a high of 24.1°C at the surface to 7.3°C near the bottom. Dissolved oxygen levels ranged from approximately 7 mg/L at the surface, 8.5 mg/L at the thermocline, and a low of 5.5 mg/L at the bottom. Secchi transparencies ranged from a high of 7.1 m at the northwest arm to a low of 6.4 m near the dam, which supports the reservoir's classification as oligotrophic. ZQI values were variable between sampling sites ranging from a low of 0.05 at the dam (station 2) to a high of 0.33 at station 3 near the inlet (Table 4). ZQI values suggest that forage resources for zooplanktivorous fish were limited.

Henrys Lake

Henrys Lake was sampled May 12 through May 16, 2003 and September 3, 2003 in an effort to estimate Yellowstone cutthroat trout abundance. Gillnetting was conducted in concert with the May 13 daytime hydroacoustic survey (Appendix F). Temperature and DO data were collected routinely by Henrys Lake hatchery staff. Both surveys were adversely affected by the presence of macrophytes. An abundance estimate was still possible in May, because macrophyte growth was inhibited by the recent winter months. However, the September survey was impacted to such a large degree that tracking individual fish among the macrophytes was not possible. Therefore, no further analysis was made using the data collected on September 3, 2003.

Accepted fish targets ranged from -55 dB to -32 db (Figure 16), which would correspond to trout lengths of 54 mm to 928 mm, respectively (Kubecka and Duncan 1998). Because the orientation of fish detected with the sidelooking transducer is unknown, fish lengths converted from target strength values are suspect.

Thirteen transects ranging from 1,725 m to 4,702 m were followed during the hydroacoustic survey (Table 11). Because of the limited depth at Henrys Lake, only data from the sidelooking transducer (0-6 m) were used for density and abundance estimates. Density estimates ranged from 2.2 fish/ha to 75.6 fish/ha with a geometric mean of 27.3 (17.5 to 42.8) fish/ha (Table 11). This resulted in an overall population estimate of 71,871 (45,913 to 101,201) fish.

Twelve net curtains were set at Henrys Lake during the 2003 spring survey. Gillnet catches were primarily comprised of cutthroat trout, cutthroat x rainbow trout hybrids, brook trout, and Utah chub. Length frequency data suggested that multiple cohorts were captured for each species except for brook trout, which have not been stocked into Henrys Lake since fingerlings were stocked in 1998 (Figure 17). Otoliths and scales were not collected for age classification. Cutthroat trout made up 46% of the total fish caught, cutthroat x rainbow hybrids were 28%, and Utah chub were 20% of the total catch (Table 12). The gillnet species proportions along with the hydroacoustic data resulted in an estimated 33,199 (±1,999) Yellowstone cutthroat trout, 20,248 ± 1,964 hybrids, and 14,593 ± 2,392 Utah chub (Table 12).

Because of the bathymetry of Henrys Lake, the sonar boat was not able to sample within approximately 100 m of the shoreline. However, during the spring, cutthroat trout and hybrids frequently inhabit the littoral regions of the lake. Therefore, my abundance estimates for these species most certainly underestimated the actual population of cutthroat trout and cutthroat x rainbow hybrids.

Oneida Reservoir

Oneida Reservoir was surveyed between June 4 and June 9, 2003 with the hydroacoustic survey during the night of June 8, 2003. Gillnetting and limnological data were also collected during the survey (Appendix G).

Returning signal strength of targets ranged from -59 dB to -20 dB with multiple modes present in both sidelooking and downlooking data (Figure 18). Both transducers detected a large number of small pelagic targets (<90 mm), which were possibly larval perch or walleye. Depth distribution of tracked fish by size showed that fish inhabiting depths that were >15 m were primarily smaller fish <-50 dB or 68 mm (Love 1977; Figure 18). This may be a result of the bathymetry and hydrology of the reservoir where the upper half of the reservoir is somewhat shallow, and reservoir flows may push the smaller fish to the downstream end of the reservoir where greater depths are available.

Fifteen transects were surveyed beginning at the upper end of the reservoir near the inlet and continuing downstream to the dam. Estimated fish densities were extremely high with both the sidelooking and downlooking transducers (Table 13). Densities in 0-6 m ranged from 37.3 to 2,399.6 fish/ha while densities >6 m ranged from 117.8 to 2,112.4 fish/ha. Fish densities in the upper 6 m declined as greater depths became available (transects 10-15). The mean fish density at 0-6 m was 334.8 (193.4 to 579.1) fish/ha while the density in depths >6 m was 750.6 (579.6 to 972.1) fish/ha for a total mean fish density of 1311.9 (977.6 to 1,760.5) fish/ha. Estimates of total population abundance were 65,049 (37,574 to 112,509) at 0-6 m, 145,848 (112,607 to 188,883) at depths >6 m, and a total of 254,909 (189,945 to 342,070).

During the survey at Oneida Reservoir, 14 net curtains were deployed. Gillnet catches were composed of mainly walleye (38%), yellow perch (35%), and carp (25%), with Utah sucker, rainbow trout, and redside shiners being caught less frequently (Table 14). Walleye lengths ranged from 201 mm to 440 mm with a mean of 281 mm, yellow perch lengths ranged from 80 mm to 284 mm and had a mean of 210 mm, and carp lengths ranged from 300 mm to 637 mm with a mean length of 492 mm (Figure 19). Unfortunately, catches of fish <90 mm were extremely limited, and I was not able to identify the smaller targets detected by hydroacoustics.

Netting proportion estimates were used to partition overall hydroacoustic estimates into estimates of individual species abundance (Table 14). I estimated 96,014 ± 8,340 walleye, 89,252 ± 7,175 yellow perch, and 64,234 ± 10,124 carp. Estimates of other species are displayed in Table 14.

Reservoir temperatures only varied by 2°C from surface to bottom near the inlet where depth did not exceed 8 m, while the reservoir was thermally stratified downstream near the dam (Figure 20). Surface temperatures near the dam ranged from 20.4°C to 9.3°C at the bottom with the thermocline occurring between 11-14 m. Dissolved oxygen levels ranged from 9.7 to 4.8 mg/L near the inlet and 8.9 to 0.2 mg/L near the dam. Dissolved oxygen levels near the dam fell below 2.7 mg/L at 12 m depth and should have been avoided by fish. Presence of fish at depths below 12 m occurred upstream (transects 6-12) from the limnology sampling station, which would correspond to transects 14-15. Zooplankton levels, measured by the ZQI index, suggested that near the inlet Daphnia was present in moderate-to-low levels (ZQI = .29) and were limited in availability near the dam where a ZQI of 0.06 was measured (Table 4).

Palisades Reservoir

Palisades Reservoir was surveyed from May 3 through May 7, 2003 with the hydroacoustic survey occurring from May 6-7, 2003. The hydroacoustic survey consisted of both pelagic and nearshore transects because of concerns about missing Yellowstone cutthroat trout that may inhabit littoral regions (Appendix H). Palisades Reservoir is comprised of numerous areas of steep shorelines that allowed the hydroacoustic vessel to navigate within 3-4 m of the shoreline with the sidelooking transducer aimed toward the open water area. Limnology data were not collected.

In the nearshore transects, target strengths ranged from -56 dB (32 mm; Love 1977) to -20 dB (2,838 mm; Kubecka and Duncan 1998), and the majority of fish were detected by the sidelooking transducer because of the limited depth of the nearshore regions (Table 15). Target strengths were more evenly distributed between the sidelooking (0-6 m) and downlooking

(>6 m) transducers, and tracked fish ranged from -59 dB (22 mm; Love 1977) to -24 dB (1,706 mm; Kubecka and Duncan 1998; Figure 21).

Fish densities in the pelagic habitats ranged from 0.0 to 50.5 fish/ha with a mean of 2.2 fish/ha in the top 6 m, while densities varied from 0.0 to 62.8 fish/ha with a mean of 8.3 fish/ha in depths >6 m (Table 16). The total fish density for the pelagic region was 11.5 (7.6 to 17.4) fish/ha. In nearshore habitats, fish densities were higher in the top 6 m because of limited available depths below 6 m (Figure 22). Estimated fish density in the top 6 m was 7.3 (4.4 to 11.7) fish/ha and 1.7 (0.6 to 3.7) fish/ha in depths > 6 m, for a total density of 10.3 (6.0 to 17.3) fish/ha (Table 15). A total of 85,461 (56,043 to 128,519) fish were estimated in pelagic habitats, whereas 32,990 (19,237 to 55,175) fish were estimated nearshore.

Fifteen net curtains were set overnight at Palisades Reservoir, with six deployed in nearshore habitats and eight set in pelagic habitats. Utah chub occurred most frequently in pelagic (74%) and nearshore (47%) gillnets, followed by Utah suckers and brown trout (Table 17). Yellowstone cutthroat comprised only 1% of pelagic catches and 2% of nearshore catches. Lake trout were only captured in the pelagic region at 1% of the total catch. Yellowstone cutthroat trout ranged from 160 to 420 mm with a mean of 322 mm, brown trout ranged from 150-610 mm with a mean of 430 mm, and lake trout ranged from 450 to 610 mm with a mean of 553 mm (Figure 23). As for the nongame species, Utah chub ranged from 120 to 460 mm with a mean of 309 mm, and Utah sucker ranged from 220 to 540 mm with a mean TL of 409 mm.

Despite concentrating my efforts on providing an estimate of Yellowstone cutthroat trout, estimates of cutthroat trout were much lower than expected. I estimated 950 ± 592 Yellowstone cutthroat trout in the pelagic region and 544 ± 211 in nearshore habitats for a total of 1,494 ± 610 fish (Table 17). Utah chub and Utah suckers were much more abundant with total population estimates of 78,765 ± 5,901 and 23,153 ± 4,039, respectively. Additional population estimates by species and habitat are shown in Table 17.

Payette Lake

Payette Lake was surveyed with hydroacoustics to monitor kokanee abundance June 22, 2003 and August 29, 2003. In addition to hydroacoustics, temperature and DO profiles were also recorded (Appendix I). Fish were not collected for target verification or age information.

Kokanee age classes were not discernible from target strength distributions with the June data but were more apparent during the August survey (Figure 24). Fish with returning signal strengths <-40 dB increased dramatically in numbers between the two surveys. The most pronounced increase involved fish <-49 dB, which would correspond to age-0 fish.

Overall, fish occupied similar depths during both sampling periods but were more concentrated during the August survey (Figure 25). During the June survey, age-0 kokanee were occupying shallower depths, but by August these fish inhabited depths similar to that of larger fish.

The seasonal difference between surveys resulted in an August population estimate that was over twice that of the June estimate, although both surveys were conducted during the new moon lunar phase and were conducted only one month apart (Tables 18 and 19). All size classes showed a remarkable increase in densities between the surveys, which suggests that the increased numbers were not merely a result of out-migration of kokanee fry into the lake. Because the increase was observed in all year classes, the increase is likely related to fish behavior and environmental conditions that make kokanee more susceptible to sampling by sonar gear. In June, the overall mean density of fish was 102.6 fish/ha, which resulted in an overall estimate of 221,608 (169,744 to 289,120) kokanee (Table 18). In August, mean density increased to 224.1 fish/ha, which translated into a total population estimate of 483,990 (374,953 to 624,554) kokanee (Table 19).

The surface water temperature warmed from 7°C in June to 22°C in August, and a much more pronounced thermocline had developed as well (Figure 26). The cooler epilimnion may have allowed kokanee to be more surface-oriented, where they were less likely to be sampled with the hydroacoustics gear. The well-developed thermocline observed in August may have also resulted in the higher concentrations of kokanee observed between 20 and 40 m depth, as kokanee would have been pushed to deeper water by the warm epilimnion that occurred above 15 m.

Sage Hen Reservoir

Sage Hen Reservoir was surveyed from June 18 through June 23, 2003 with the hydroacoustic survey occurring on June 20, 2003. During the survey, both fish and limnological data were collected (Appendix J).

Because of the shallow bathymetry of Sage Hen Reservoir, the majority of fish were detected with the sidelooking transducer, and depths >6 m were not present in the upstream area of the reservoir (transects 4-6; Table 20). Using the target strength frequency distribution, a number of different size groups were detected by the sidelooking transducer, but the downlooking distribution was limited because of the small sample size (Figure 27).

Density estimates were extremely variable between transects and ranged from 6.3 fish/ha to 237.7 fish/ha (Table 20). The highest densities occurred in the shallow regions near the inlet area (transects 5 and 6). In the top 6 m, a mean density of 33.8 fish/ha was measured, while depths below 6 m contained an average of 3.8 fish/ha. The total population estimate for Sage Hen Reservoir was 3,778 (1,744 to 8,087) fish.

Sixteen net curtains were set overnight during the 2003 Sage Hen Reservoir survey. Rainbow trout were the only species captured in gillnets, and attempts were made at visually determining whether fish were of wild or hatchery origin using fins, color, and the presence of parr marks. Hatchery rainbow trout ranged from 175 mm to 439 mm with a mean of 298 mm (Figure 28). Rainbow trout that were classified as wild ranged from 100 mm to 480 mm with a mean of 336 mm. Four age groups of hatchery trout were identified with length frequency analysis, while separate cohorts were more difficult to detect in wild fish >250 mm. I estimated 4,057 ± 3,533 wild rainbow trout and 2,803 ± 2,443 hatchery trout (Table 21). However, individual population estimates should be taken lightly; the potential for error in visually classifying the origin of rainbow trout was high, particularly because of the large size of fish, where visual cues for hatchery origins (eroded fins, scars, dull coloring) likely disappeared with older fish.

Sage Hen Reservoir was thermally stratified during the June 2003 survey (Figure 29). Temperature profiles were similar near the inlet (Site 1) and dam (Site 2) with temperatures ranging from approximately 19.5 C at the surface to approximately 7 C at the bottom. Dissolved oxygen levels remained in acceptable ranges (>4.6 mg/L) for trout throughout the water column. The homogeneity of environmental conditions between the two sites suggested that temperature and dissolved oxygen should not have been a major influence on the extremely high fish densities that were observed in the upstream portion of the reservoir. ZQI was only measured at site 1 and the ZQI value of 0.07 was considered extremely low, which corroborated the observed high fish densities, suggesting that competition for forage resources was occurring.

Williams Lake

Williams Lake was sampled during the day with hydroacoustics on September 16, 2003, and a temperature and DO profile were also measured. Transects began at the lower end of the reservoir and continued upstream toward the inlet until shallow depths prevented further sampling (Appendix K).

Larger fish (>-30 dB) were primarily detected in the upper 20 m while smaller fish (<-40 dB) were observed in deeper waters (Figure 30). The bimodal depth distribution shown in Figure 30 is likely a result of differences in target strength measurement error between the two transducers. Individual target strength measurements ranged from -59 dB to -22 dB with the downlooking transducer and -42 dB to -20 dB with the sidelooking transducer (Figure 31).

Fish density measurements were variable between depth and transects, with the highest densities measured near the middle of the reservoir (transects 9-13; Table 22). Sidelooking densities ranged from 31.8 to 567.6 fish/ha and downlooking densities ranged from 22.0 to 537.2 fish/ha. The mean fish density in the top 6 m was 83.7 (61.3 to 114.2) fish/ha while it was 207.5 (157.1 to 274.1) fish/ha below 6 m. Density estimates were expanded to calculate abundance; 14,942 (11,308 to 19,736) fish were at 0-6 m depth and 6,028 (4,415 to 8,222) fish were in depths >6 m for a total abundance estimate of 22,820 (17,665 to 29,472) fish. These estimates are substantially higher than the August 2000 estimate of 5,500 ± 3,135 fish reported by Teuscher (2001).

Two floating and three sinking nets were set on September 16, 2003 by regional personnel in order to partition hydroacoustic estimates. Gillnet catches were comprised of only rainbow trout and bull trout. Seventy-eight rainbow trout (84%) were captured, ranging from 164 to 480 mm with a mean total length of 280 mm (Figure 32). Bull trout were captured less frequently as a total of 15 fish (16%) were collected that ranged from 180 to 400 mm and a mean total length of 269 mm. By combining hydroacoustic population estimates and gillnetting proportion data, I estimated the population of rainbow trout in Williams Lake to be 19,168 ± 7,388 and the bull trout population to be 3,651 ± 3,419 (Table 23).

The water column at Williams Lake was strongly stratified during the September survey (Figure 33). The surface water temperature was 15.5°C and dropped to 4.2°C at the bottom with the thermocline occurring between 10 and 15 m depth. Dissolved oxygen levels ranged from 8.7 to 2.0 mg/L in the top 13 m but were <1 mg/L at 15 m depth. Extremely low levels of dissolved oxygen explain why the majority of fish were observed in the top 15 m although fish were detected in depths below this. Targets that were detected below 15 m depth in waters that should be described as inhospitable to salmonids varied in size.

Survey Cost Estimate

Figure 34 shows the relationship between total survey cost and the desired error bound of a population estimate for two species of interest at Cascade Reservoir. As the desired error bound drops below 10%, survey costs rise sharply; the estimated required sample size at a 90% error bound is 26 nets or $3,800 for northern pikeminnow and $2,360 for rainbow trout. In the unlikely scenario that a 5% error bound is desired, the required number of nets would be 102, which would increase the total survey cost to $11,758 for northern pikeminnow. However, if a 20% error bound were acceptable, then six net curtains would need to be deployed for a total cost of $1,800 for northern pikeminnow and $1,450 for rainbow trout. The difference between cost estimates for the two species is based on required sample size calculations; northern pikeminnow estimates had a slightly higher variance than rainbow trout estimates, and therefore required more samples to be taken.

DISCUSSION

Twelve hydroacoustic surveys were conducted in 2003, of which eight were accompanied by intensive netting so that population estimates of individual species could be calculated. Because of these surveys, there is a better understanding of the strengths and limitations of hydroacoustics in regards to species assemblage, fish behavior, and lake bathymetry. In addition to these findings, monetary costs can be estimated for a typical survey and for a desired precision level. The latter will help IDFG biologists evaluate whether or not a complete population survey is warranted at any given water.

The validity of the use of hydroacoustics to estimate fish abundance is dependent upon many factors including community assemblage, fish behavior, habitat use, the bathymetry of the water body, and the seasonal influences upon these factors as well. The 2003 Cascade Reservoir survey illustrates how the influence of these factors can be minimized over time through the collection of hydroacoustic data and knowledge about the biology and behavior of the target species. Cascade Reservoir has been sampled at least once annually since 2000 with spring and fall sampling occurring in 2000 and 2001 in order to determine northern pikeminnow abundance and monitor the success of removal efforts. From that information, it was decided that August was the best month in which to conduct hydroacoustic sampling. During this period in 2002 and 2003, the reservoir has proven to be thermally stratified with a layer of anoxic water close to the bottom, which may increase the echosounder's ability to detect fish because fish are inhibited from staying close to the reservoir bottom. To reduce the relatively large error bound around the overall population estimate, hydroacoustic transects were standardized by length beginning in 2002. This reduced the error around the hydroacoustic population estimate from 73% in 2001 to 47% and 40% in 2002 and 2003, respectively. Finally, using species proportion information collected using gillnets during 2002, it was determined that a minimum of 20 nets should be set to reduce the variance around proportion estimates (Butts 2004; Scheaffer et al. 1996). Proportion estimates were very similar between years, suggesting that these estimates can be used as a reliable indicator of relative abundance and will aide in partitioning hydroacoustic estimates into individual species estimates when variance is calculated. Although there is now a better understanding of the importance of seasonality on the timing of hydroacoustic assessments, there remains uncertainty about the seasonal impact upon species proportion estimates.

The 2003 survey at Cascade Reservoir also provided a unique opportunity to compare a hydroacoustic estimate with a Petersen mark-recapture estimate. Between May and July 2003, regional biologists captured and marked 1,427 northern pikeminnow >250 mm TL using Merwin traps. Fish were subsequently recaptured using gillnets in August and September 2003. The resulting estimate of 24,413 ± 7,089 was similar to the estimate of 35,675 ± 1,500 northern pikeminnow that was generated from hydroacoustics and gillnetting. The similarity between the two estimates validates the use of hydroacoustics in complex systems when surveys are accompanied with intensive netting efforts to estimate species proportions.

Estimates of species abundance, however, should be limited to species that occur frequently in nets. In a number of reservoirs, species were captured infrequently because either nets were set in non-preferred habitats or the species are actually rare within a water body. In Arrowrock Reservoir, smallmouth bass comprised 1% of the total catch, which resulted in a population estimate of 445 ± 169. This estimate is unreliable, because smallmouth bass primarily inhabit littoral regions. Because hydroacoustics sampling is limited to pelagic regions, I only deployed nets within these habitats, and thus smallmouth bass were not sampled effectively with either methodology. Similar cases occurred at all other reservoir where multiple species were sampled. Therefore, it should be recognized that a hydroacoustic survey would generally only produce meaningful estimates for the most abundant, pelagically occurring species in a water body.

One of the goals of this study was to develop methods to estimate species abundance with 90% confidence intervals that were within 30-50% of the abundance estimate. I used intensive gillnetting to partition hydroacoustic estimates into 49 individual species abundance estimates during the 2003 field season. Ninety-percent confidence intervals ranged from 4-94% of the abundance estimate with a mean of 30%. Forty-one of the 49 confidence intervals actually met or exceeded the goal of 30-50%. Estimates that did not meet these criteria, such as chiselmouth at Arrowrock Reservoir and Yellowstone cutthroat trout and kokanee at Palisades Reservoir occurred when species comprised ≤1% of the total catch for the respective reservoir. However, the small bounds on abundance estimates are also a result of partitioning the overall error (hydroacoustic and netting error) across a number of species using the Goodman (1960) equation. This is demonstrated by the species estimates obtained at Sage Hen Reservoir and Williams Lake. Except for rainbow trout at Williams Lake, bounds approached or exceed 90% because the overall error from both hydroacoustics and gillnetting were partitioned between only two species at each water body. Therefore, although the methods presented in this report met or exceeded goals for the bounds on error estimates, they should be used judiciously.

Attempts at estimating Yellowstone cutthroat trout abundance at Henrys Lake and Palisades Reservoir brought about interesting examples of the importance of considering fish behavior when determining the validity or timing of a survey. It is well documented that fish behavior can have a profound influence on the outcome of hydroacoustic surveys. Kokanee have long been known to undergo diel vertical migrations where fish move up and disperse in the water column, which generally enhances the detection of individual fish, resulting in better population estimates. This migration is affected by seasonal water temperatures and lunar phases so surveys are often planned accordingly. The Henrys Lake survey occurred just after ice off to avoid detection problems from the abundant macrophytes that cover much of the lake. However, during this period, trout inhabit shoreline areas that are much too shallow to sample with a boat. It was known that our survey would likely underestimate trout abundance because of the use of these shallow littoral regions in the spring, but the extent of the underestimation was unknown. The survey did result in a much lower estimate of trout abundance than was expected, and managers did not consider the survey useful.

Palisades Reservoir presented both physical and fish behavioral sampling problems. Surveying too early in the spring is problematic because of the likelihood of snow and ice. Waiting until fall in hopes of the fish returning may result in difficult boat access and large areas of the reservoir too shallow to navigate with a boat because of extreme drawdown during the summer months.

At Palisades Reservoir, the survey was conducted in early May in hopes of sampling before the bulk of mature Yellowstone cutthroat trout immigrated into the many spawning tributaries that connect to the reservoir. However, while gillnetting the reservoir it became apparent that the window of opportunity for targeting Yellowstone cutthroats had been missed as they only made up 1% of the pelagic catch and 2% of the nearshore catch. This resulted in a total population estimate of 1,494 ± 610 fish, which grossly underestimated the population simply based on population estimates of adfluvial spawners conducted in the tributaries (Meyer and Lamansky, in press). Both Henrys Lake and Palisades Reservoir provide examples of how important it is to understand the behavior of the target species, and some trial and error may occur before a successful sampling plan can be implemented.

Measurements of environmental characteristics have enhanced the interpretation of fish distributions and aided in determining survey timing. For example, seasonal thermal differences between the June and August surveys at Payette Lake resulted in a two-fold increase in estimated fish abundance. In August 2002 and 2003, Cascade Reservoir approached anoxic conditions at depths >8 m, which should actually aid hydroacoustics by keeping fish away from the bottom where they are less detectable. At Williams Lake, the large majority of fish were detected above 15 m depths, despite the lake having available depths of up to 60 m. However, DO fell below 1 mg/L at 15 m depth, which explains why fish were suspended in the upper portion of the water column. As more water bodies are repeatedly surveyed through time, limnological parameters should aid in determining appropriate sampling periods and identifying potential sources of variability in results.

Another important factor in determining whether to use hydroacoustics as a tool to estimate fish population abundance is cost. In general, the relatively low cost of hydroacoustics in comparison to other methods such as mark-recapture estimates is often considered one of the primary advantages to hydroacoustics. However, managers must consider the relatively intensive netting that must accompany hydroacoustics in most Idaho waters. These relationships that were developed based on the survey at Cascade Reservoir provide a good index for estimating the potential cost of conducting a hydroacoustic survey in concert with netting for species proportions at almost any given water body (Figure 34). This also demonstrates the cost effectiveness of hydroacoustics in comparison to more labor intensive methods such as mark-recapture studies.

Of the 12 hydroacoustic surveys conducted in 2003, eight were accompanied by intensive netting efforts so that estimates of individual species could be calculated. This was a vast improvement from 2002, when only two reservoirs were sampled intensively enough to allow species populations to be estimated. When netting was conducted, the goal was to set a minimum of 10 net curtains at each reservoir with 20 sets considered optimum. Because only two net curtains were available each evening, the high sample size required that a crew was stationed at any given reservoir between 5 and 10 days. The purchase of additional net curtains so that 4-5 curtains can be deployed each night will result in surveys that only require 4-5 nights of netting. This will result in more cost effective surveys in terms of personnel and allow more water bodies to be surveyed during the field season.

The use of the geometric mean instead of the arithmetic mean when expanding mean density estimates into population estimates resulted in more conservative numbers. In general, density estimates for individual transects are not normally distributed, as was the case for all of the surveys conducted in 2003. Perhaps this was because data collected from adjacent transects are more similar to one another, and changes in density estimates reflect changes along environmental gradients within the water body (i.e., inlet to outlet). Therefore, although the arithmetic mean has been used in all previous hydroacoustic population estimates conducted by this project, utilizing the geometric mean, when appropriate, should provide population estimates that are less biased by the often large variability between density estimates from individual transects.

Overall, the success of hydroacoustics to obtain fishery population estimates has been good during 2003, despite the drawbacks. A great deal has been learned over the past two years in regards to our ability to partition hydroacoustic estimates into estimates of individual species using gillnets for species verification and reduce the inherent variation. As illustrated by the Cascade Reservoir surveys from 2000 to 2003, hydroacoustics can provide a reasonable and stable population estimate for an individual species in water bodies with complex species assemblages with a few caveats: 1) the target specie(s) must utilize pelagic habitats and not be limited to the benthic region, 2) biologists should have some understanding of the biology and behavior of the target specie(s), 3) intensive fish collection efforts are crucial to obtaining reliable estimates of species proportions and the number of nets that are deployed should be based on the desired error bound for a proportion, 4) surveys that are repeated during different seasons are extremely helpful in determining the appropriate timing for the optimal population estimate, and finally 5) as with trend netting, every effort should be made to conduct future surveys during the same seasonal or environmental period as previous surveys so that behavioral biases are minimized. The costs in terms of time and labor can be high because of the required fish collection efforts. Therefore, the benefits and value of a survey should be carefully evaluated before deciding to proceed. However, in comparison to other methods such as creel censuses or mark-recapture methods, hydroacoustics is a cost efficient alternative. The question as to whether these proposed methods under- or overestimate actual species abundance is likely irrelevant as long as they continue to provide a stable relative population estimate, which offers many of the same advantages as an absolute estimate (Thorne 1983; Yule 2000).

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Table 1. Fish densities (fish/ha) per transect and total fish abundance estimates calculated using both the arithmetic and geometric mean densities at Anderson Ranch Reservoir on August 27, 2003.

		Fish densities (number/ha)			
Transect	**Transect length (m)**	**<100 mm**	**100-200 mm**	**>200 mm**	**Total**
1	984	30.5	15.0	19.1	64.6
2	1148	45.4	17.8	34.1	97.4
3	450	81.0	16.1	10.8	107.9
4	652	75.4	3.1	13.8	92.3
5	551	108.7	4.9	17.3	130.9
6	600	121.8	4.9	14.7	141.3
7	835	96.4	10.2	12.4	119.0
8	1124	50.9	5.4	0.7	57.0
9	1151	77.6	9.3	14.7	101.6
10	1352	236.3	20.6	22.0	278.9
11	967	462.5	52.8	20.9	536.2
12	717	387.3	70.0	30.0	487.3
13	1536	225.4	19.8	4.8	250.0
14	1456	400.3	99.5	67.6	567.4
15	1601	299.4	64.7	61.9	426.0
16	916	533.5	39.8	9.9	583.1
17	656	1211.3	45.4	9.6	1266.2
18	1017	967.1	42.2	13.3	1022.6
19	397	1569.8	72.9	9.4	1652.0
20	948	1173.8	42.8	11.9	1228.5
21	688	1528.5	25.7	15.9	1570.0
22	1223	275.6	16.3	2.2	294.1
23	396	226.2	28.1	23.4	277.7
	Arithmetic Mean (AM)	**442.8**	**31.6**	**19.1**	**493.6**
	90% CI (AM)	**175.1**	**9.3**	**5.9**	**179.3**
	Abundance (AM)	**609,287**	**43,496**	**26,346**	**679,128**
		±240,940	**±12,847**	**±8,091**	**±246,768**
	Geometric Mean (GM)	**239.6**	**21.5**	**13.5**	**296.0**
	90% CI (GM)	**156.8 to 366.0**	**15.2 to 30.5**	**9.5 to 19.1**	**202.2 to 433.2**
	Abundance (GM)	**329,671**	**29,569**	**18,590**	**407,263**
		215,793 to 503,646	**20,862 to 41,910**	**13,116 to 26,349**	**278,265 to 596,061**

Table 2. Fish densities (fish/ha) per transect and total fish abundance estimates calculated using both the arithmetic and geometric mean densities at Arrowrock Reservoir on July 8, 2003.

		Fish densities (number/hectare)		
Transect	**Transect length (m)**	**Sidelooking (0-6 m)**	**Downlooking (>6 m)**	**Total**
1	571	0.0	13.6	13.6
2	835	4.7	23.6	28.3
3	1,065	0.0	26.8	26.8
4	1,631	2.9	13.9	16.9
5	951	0.0	33.5	33.5
6	689	0.0	28.4	28.4
7	779	8.2	16.5	24.7
8	717	0.0	7.2	7.2
9	975	2.9	11.1	14.0
10	2,200	0.5	5.8	6.3
11	798	2.5	22.7	25.2
12	1,177	0.0	6.8	6.8
13	484	13.2	14.3	27.5
14	797	0.0	14.5	14.5
15	777	0.0	8.7	8.7
16	705	6.0	19.8	25.8
	Arithmetic Mean (AM)	**2.6**	**16.7**	**19.3**
	90% CI (AM)	**1.7**	**3.7**	**4.0**
	Abundance (AM)	**2,795**	**18,253**	**21,048**
		±1,830	**±3,996**	**±4,395**
	Geometric Mean (GM)	**1.2**	**14.6**	**17.0**
	90% CI (GM)	**0.5 to 2.4**	**11.8 to 18.7**	**13.2 to 21.7**
	Abundance (GM)	**1,359**	**16,228**	**18,533**
		518 to 2,639	**12,836 to 20,446**	**14,414 to 23,745**

Table 3. Abundance estimates for individual species from data collected during the July 2003 fish assessment survey at Arrowrock Reservoir. Abundance was estimated as the product of a species proportion from gillnetting data and the total abundance estimate from hydroacoustics.

Species	**Proportion ± 90% CI**	**Abundance**	**90% CI**
Chiselmouth	0.01 ± 0.02	180	98
Kokanee	0.08 ± 0.07	1,439	363
Largescale Sucker	0.61 ± 0.19	11,335	976
Northern Pikeminnow	0.26 ± 0.16	4,858	841
Rainbow Trout	0.03 ± 0.04	540	190
Smallmouth Bass	0.01 ± 0.01	180	73

Table 4. Mean biomass (g/m), zooplankton ratio index (ZPR), and zooplankton quality index (ZQI) values for water bodies sampled during the 2003 field season.

Water	Station	Mean biomass (g/m)			ZPR	ZQI
		153 um	500 um	750 um	750 um / 500 um	(500 um ± 750 um)ZPR
Arrowrock 7/3/2003	1		0.306	0.186	0.606	0.298
	2		0.422	0.359	0.851	0.663
	3		0.350	0.248	0.708	0.423
	4		0.420	0.337	0.801	0.606
Cascade 7/24/2003	1	0.347	0.168	0.202	1.199	0.443
	2	0.643	0.309	0.389	1.259	0.879
	3	0.555	0.330	0.318	0.962	0.623
Deadwood 8/1/2003	1	0.134	0.098	0.077	0.781	0.136
	2	0.082	0.048	0.031	0.642	0.050
	3	0.295	0.246	0.189	0.768	0.334
Oneida Narrows 6/9/2003	1	1.328	0.767	0.226	0.294	0.292
	2	0.421	0.078	0.041	0.526	0.063
Sagehen 6/20/2003	1	1.032	0.122	0.050	0.407	0.070

Table 5. Fish densities (fish/ha) per transect and total fish abundance estimates for (A) fish >250 mm and (B) all fish, calculated using both the arithmetic and geometric mean densities at Cascade Reservoir on August 20, 2003.

A. Fish > 250 mm.

		Fish densities (number / ha)		
Transect	**Transect length (m)**	**Sidelooking (0-6 m)**	**Downlooking (>6 m)**	**Total**
1	2,852	9.5	2.2	11.7
2	3,707	8.1	0.0	8.1
3	3,010	12.1	0.0	12.1
4	2,736	16.5	0.0	16.5
5	2,932	8.5	2.1	10.6
6	2,621	8.0	0.0	8.0
7	2,814	3.0	0.0	3.0
8	2,615	2.0	0.0	2.0
9	2,702	24.0	0.0	24.0
10	3,102	16.6	1.9	18.5
	Arithmetic Mean (AM)	**10.8**	**0.6**	**11.4**
	90% CI (AM)	**3.9**	**0.6**	**3.9**
	Abundance (AM)	**100,805**	**5,703**	**106,508**
		±36,506	**±5,338**	**±36,732**
	Geometric Mean (GM)	**9.0**	**0.4**	**9.5**
	90% CI (GM)	**6.6 to 12.2**	**0.11 to 0.76**	**6.9 to 13.0**
	Abundance (GM)	**83,656**	**3,685**	**88,289**
		60,928 to 113,740	**1,016 to 7,045**	**63,963 to 120,692**

B. All fish.

		Fish densities (number / hectare)		
Transect	**Transect length (m)**	**Sidelooking (0-6m)**	**Downlooking (>6m)**	**Total**
1	3,707	16.6	25.7	42.3
2	2,852	15.0	69.0	84.0
3	3,010	36.6	33.0	69.6
4	2,736	26.3	3.7	30.0
5	2,932	17.9	31.3	49.2
6	2,621	15.4	8.5	23.9
7	2,814	9.1	43.0	52.1
8	2,615	5.5	16.9	22.4
9	2,702	56.4	32.7	89.0
10	3,102	24.0	25.1	49.1
	Arithmetic Mean (AM)	**22.3**	**28.9**	**51.2**
	90% CI (AM)	**8.6**	**10.7**	**13.7**
	Abundance (AM)	**207,295**	**268,891**	**476,186**
		±80,222	**±99,464**	**±127,783**
	Geometric Mean (GM)	**18.6**	**23.0**	**46.3**
	90 % CI (GM)	**14.0 to 24.6**	**16.2 to 32.5**	**37.6 to 57.0**
	Abundance (GM)	**214,318**	**173,299**	**431,226**
		151,072 to 302,506	**130,611 to 229,009**	**350,151 to 530,588**

Table 6. Abundance estimates for individual species from data collected during the August 2003 fish assessment survey at Cascade Reservoir for (A) fish 250 mm and (B) all fish. Abundance was estimated as the product of a species proportion from gillnetting data and the total abundance estimate from hydroacoustics.

A **Species**	**Proportion ± 90% CI**	**Abundance**	**90% CI**
Coho	0.05 ± 0.04	4,106	814
Kokanee	0.03 ± 0.02	3,080	351
Largescale sucker	0.23 ± 0.07	20,019	1,274
Northern pikeminnow	0.40 ± 0.08	35,675	1,500
Rainbow trout	0.27 ± 0.01	23,612	1,044
Whitefish	0.003 ± 0.03	257	91
Yellow perch	0.02 ± 0.03	1,540	547

B **Species**	**Proportion + 90% CI**	**Abundance**	**90% CI**
Coho	0.05 ± 0.04	20,057	3,970
Kokanee	0.03 ± 0.02	15,043	1,708
Largescale sucker	0.23 ± 0.07	97,778	6,168
Northern pikeminnow	0.40 ± 0.08	174,246	7,171
Rainbow trout	0.27 ± 0.01	115,328	5,003
Whitefish	0.002 ± 0.03	1,254	446
Yellow perch	0.02 ± 0.03	7,521	2,669

Table 7. Fish densities (fish/ha) per transect and total fish abundance estimates calculated using both the arithmetic and geometric mean densities at Daniels Reservoir on June 10, 2003.

		Fish densities (number/hectare)		
Transect	**Transect length (m)**	**Sidelooking (0-6m)**	**Downlooking (>6m)**	**Total**
1	328	29.6	21.6	51.1
2	237	3.2	19.1	22.4
3	429	166.2	92.9	259.1
4	263	109.2	95.2	204.4
5	224	276.3	0.0	276.3
6	403	306.2	136.2	442.4
7	308	238.2	0.0	238.2
8	445	301.5	0.0	301.5
9	439	42.3	33.5	75.8
	Arithmetic Mean (AM)	163.6	44.3	207.9
	90% CI (AM)	75.6	31.4	107.0
	Abundance (AM)	9,654	2,612	12,266
		± 4,461	± 1,854	± 4,831
	Geometric Mean (GM)	**94.1**	**12.9**	**151.5**
	90% CI (GM)	**48.4 to 182.2**	**4.4 to 34.8**	**96.6 to 237.0**
	Abundance (GM)	**5,554**	**761**	**8,935**
		2,698 to 10,749	**502 to 2,053**	**3,233 to 13,984**

Table 8. Fish densities (fish/ha) per transect and total fish abundance estimates calculated using both the arithmetic and geometric mean densities at Deadwood Reservoir on August 1, 2003.

		Fish densities (number/ha)		
Transect	**Transect length (m)**	**Sidelooking (0-6m)**	**Downlooking (>6m)**	**Total**
1	943	0.0	255.5	255.5
2	856	0.9	249.5	250.3
3	912	0.8	236.0	236.9
4	898	5.5	294.7	300.1
5	953	1.2	285.6	286.8
6	634	0.0	180.2	180.2
7	827	0.0	238.7	238.7
8	879	0.7	236.1	236.8
9	614	5.4	0.0	5.4
10	773	0.0	207.6	207.6
11	839	1.5	169.0	170.5
	Arithmetic Mean (AM)	**1.5**	**213.9**	**215.3**
	90% CI (AM)	**1.1**	**44.1**	**43.7**
	Abundance (AM)	**1,523**	**225,062**	**226,586**
		± 1,171	**± 46,419**	**± 45,982**
	Geometric Mean (GM)	**0.9**	**140.9**	**167.7**
	90% CI (GM)	**0.45 to 1.54**	**71.6 to 276.6**	**107.0 to 262.4**
	Abundance (GM)	**967**	**148,300**	**176,431**
		474 to 1,617	**75,325 to 291,000**	**112,594 to 276,126**

Table 9. Abundance estimates for individual species from data collected during the August 2003 fish assessment survey at Deadwood Reservoir. Abundance was estimated as the product of a species proportion from gillnetting data and the total abundance estimate from hydroacoustics.

Species	**Proportion ± 90% CI**	**Abundance**	**90% CI**
Kokanee	0.63 ± 0.17	111,838	7,089
Westslope Cutthroat	0.05 ± 0.02	9,957	1,001
Mountain Whitefish	0.20 ± 0.09	35,803	3,606
Rainbow Trout	0.01 ± 0.01	1,107	239
Dace (Var. Sp.)	0.02 ± 0.03	4,060	1,243
Redside Shiner	0.08 ± 0.10	14,026	4,124

Table 10. Kokanee densities (fish/ha) and total abundance estimates by transect and size class in Deadwood Reservoir on August 1, 2003.

		Kokanee densities (number/hectare)				
Transect	**Transect length (m)**	**<100 mm**	**100-200 mm**	**200-450 mm**	**>450 mm**	**Grand Total**
1	943	131.1	48.5	45.2	9.5	234.4
2	856	132.1	27.5	52.2	26.0	237.7
3	912	98.3	43.3	62.1	20.8	224.5
4	898	138.3	75.0	43.0	1.6	257.9
5	953	190.7	36.6	25.8	0.0	253.2
6	634	114.6	29.6	29.4	0.0	173.6
7	827	123.6	38.2	62.4	2.3	226.5
8	879	160.3	20.8	22.9	3.7	207.7
9	614	0.0	0.0	0.0	0.0	0.0
10	773	113.4	40.1	36.9	12.3	202.7
11	839	63.7	32.7	45.2	12.2	153.8
	Mean	**115.1**	**35.7**	**38.6**	**8.0**	**197.5**
	90% CI	**27.4**	**10.1**	**10.1**	**4.9**	**39.7**
	Abundance	**121,115**	**32,526**	**40,658**	**8,464**	**207,763**
		±28,799	**±10,608**	**±10,599**	**±5,180**	**±41,820**

Table 11. Fish densities (fish/ha) per transect and total fish abundance estimates calculated using both the arithmetic and geometric mean densities at Henrys Lake on May 13, 2003.

		Volume	**Sidelooking**
Transect	**Distance (m)**	**sampled (m^3)**	**Density (fish/ha)**
1	3,463	89,663	36.8
2	3,423	98,866	32.2
3	3,447	91,344	29.6
4	2,899	65,704	38.4
5	3,307	47,186	14.0
6	4,702	93,672	42.3
7	3,062	80,015	13.5
8	5,084	70,728	33.9
9	2,946	54,604	62.6
10	1,725	34,997	24.0
11	1,777	27,025	2.2
12	1,548	21,415	75.6
13	3,169	41,925	51.5
		Arithmetic Mean (AM)	**35.1**
		90% CI (AM)	**10.0**
		Abundance (AM)	**92,391 ± 26,256**
		Geometric Mean (GM)	**27.3**
		90% CI (GM)	**17.5 to 42.8**
		Abundance (GM)	**71,871**
			45,913 to 101,201

Table 12. Abundance estimates for individual species from data collected during the May 2003 fish assessment survey at Henrys Lake. Abundance was estimated as the product of a species proportion from gillnetting data and the total abundance estimate from hydroacoustics.

Species	Proportion ± 90% CI	Abundance	90% CI
Henrys Lake Cutthroat Trout	0.46 ± 0.09	33,199	1,999
Rainbow X Cutthroat Trout	0.28 ± 0.09	20,248	1,964
Brook Trout	0.04 ± 0.01	2,919	293
Utah Chub	0.20 ± 0.11	14,593	2,392
Redside Shiner	0.01 ± 0.01	912	269

Table 13. Fish densities (fish/ha) per transect and total fish abundance estimates calculated using both the arithmetic and geometric mean densities at Oneida Reservoir on June 8, 2003.

		Fish densities (number/ha)		
Transect	**Transect length (m)**	**Sidelooking (0-6 m)**	**Downlooking (>6 m)**	**Total**
1	191	1574.2	408.1	1982.3
2	203	2399.6	1853.6	4253.2
3	203	1426.7	443.9	1870.6
4	247	1436.4	922.2	2358.6
5	304	1435.3	1456.8	2892.1
6	186	1260.3	2112.4	3372.7
7	318	1457.9	1376.5	2834.4
8	343	556.0	786.7	1342.7
9	397	148.6	307.6	456.2
10	312	71.6	689.0	760.6
11	423	83.8	853.2	937.0
12	276	56.0	1264.9	1320.9
13	367	52.5	843.5	896.0
14	272	37.3	573.0	610.3
15	435	62.3	117.8	180.1
	Arithmetic Mean (AM)	**803.9**	**933.9**	**1737.8**
	90% CI (AM)	**359.9**	**261.1**	**444.6**
	Abundance (AM)	**156,197**	**181,464**	**337,661**
		±69,922	**±50,724**	**±86,383**
	Geometric Mean (GM)	**334.8**	**750.6**	**1311.9**
	90% CI (GM)	**193.4 to 579.1**	**579.6 to 972.1**	**977.6 to 1760.5**
	Abundance (GM)	**65,049**	**145,848**	**254,909**
		37,574 to 112,509	**112,607 to 188,883**	**189,945 to 342,070**

Table 14. Abundance estimates for individual species from data collected during the June 2003 fish assessment survey at Oneida Reservoir. Abundance was estimated as the product of a species proportion from gillnetting data and the total abundance estimate from hydroacoustics.

Species	Proportion ± 90% CI	Abundance	90% CI
Walleye	0.38 ± 0.12	96,014	8,340
Yellow Perch	0.35 ± 0.11	89,252	7,175
Common Carp	0.25 ± 0.15	64,234	10,124
Utah Sucker	0.01 ± 0.02	3,381	1,372
Rainbow Trout	0.003 ± 0.005	676	331
Redside Shiner	0.01 ± 0.01	1,352	543

Table 15. Nearshore fish densities (fish/ha) per transect and total fish abundance estimates calculated using both the arithmetic and geometric mean densities at Palisades Reservoir on May 6-7, 2003.

		Nearshore fish densities (number/hectare)		
Transect	**Transect length (m)**	**Sidelooking (0-6 m)**	**Downlooking (>6 m)**	**Total**
1	3044	391.2	192.7	583.9
2	495	50.5	96.5	147.0
3	399	29.1	0.0	29.1
4	389	19.1	0.0	19.1
5	394	2.7	0.0	2.7
6	415	6.4	0.0	6.4
7	401	5.3	0.0	5.3
8	387	9.6	23.7	33.3
9	410	1.3	0.0	1.3
10	401	5.3	0.0	5.3
11	388	15.6	9.3	24.9
12	107	0.0	0.0	0.0
13	390	4.2	0.0	4.2
14	406	6.7	0.0	6.7
15	400	0.0	0.0	0.0
16	383	4.3	28.0	32.3
17	407	10.7	0.0	10.7
18	403	1.4	18.2	19.5
19	388	49.1	10.6	59.8
20	411	26.5	0.0	26.5
21	393	5.6	0.0	5.6
22	407	12.1	0.0	12.1
23	384	4.2	13.4	17.5
24	403	6.6	0.0	6.6
25	397	4.0	0.0	4.0
26	407	6.5	0.0	6.5
27	302	0.0	0.0	0.0
	Arithmetic Mean (AM)	**25.1**	**14.5**	**39.6**
	90% CI (AM)	**24.4**	**13.3**	**27.8**
	Abundance (AM)	**46,460**	**80,275**	**126,735**
		± 42,586	**± 78,061**	**88,922**
	Geometric Mean (GM)	**7.3**	**1.7**	**10.3**
	90% CI (GM)	**4.4 to 11.7**	**0.6 to 3.7**	**6.0 to 17.3**
	Abundance (GM)	**23,169**	**5,437**	**32,990**
		13,950 to 37,345	**1,822 to 11,654**	**19,237 to 55,175**

Table 16. Pelagic fish densities (fish/ha) per transect and total fish abundance estimates calculated using both the arithmetic and geometric mean densities at Palisades Reservoir on May 6-7, 2003.

		Pelagic fish densities (number/ha)		
Transect	**Transect length (m)**	**Sidelooking (0-6 m)**	**Downlooking (>6 m)**	**Total**
1	783	46.1	62.8	108.9
2	794	50.5	12.9	63.4
3	799	24.2	45.3	69.5
4	784	13.0	14.5	27.6
5	811	7.2	17.6	24.7
6	798	10.7	26.3	37.0
7	797	1.0	35.1	36.1
8	543	9.4	8.3	17.7
9	785	3.8	20.3	24.1
10	791	0.9	15.6	16.5
11	792	0.7	34.8	35.5
12	788	2.7	1.9	4.6
13	782	0.8	1.3	2.0
14	797	0.0	1.4	1.4
15	798	0.0	10.6	10.6
16	581	0.9	10.5	11.4
17	787	0.0	9.9	9.9
18	783	3.2	15.0	18.3
19	804	0.7	11.6	12.3
20	793	3.2	18.0	21.2
21	736	0.8	0.0	0.8
22	789	0.8	6.4	7.2
23	786	0.7	13.1	13.8
24	623	0.0	40.7	40.7
25	783	1.9	0.0	1.9
26	786	0.0	3.8	3.8
27	804	1.1	0.0	1.1
28	786	0.0	0.0	0.0
29	801	0.0	3.4	3.4
	Arithmetic Mean (AM)	**6.4**	**15.2**	**21.6**
	90% CI (AM)	**4.0**	**4.9**	**6.3**
	Abundance (AM)	**47,076**	**112,620**	**159,696**
		±29,854	**±36,258**	**±46,968**
	Geometric Mean (GM)	**2.2**	**8.3**	**11.5**
	90% CI (GM)	**1.2 to 3.6**	**5.3 to 12.7**	**7.6 to 17.4**
	Abundance (GM)	**16,107**	**61,341**	**85,461**
		8,850 to 26,604	**39,186 to 94,032**	**56,043 to 128,519**

Table 17. Pelagic and nearshore abundance estimates for individual species from data collected during the May 2003 fish assessment survey at Palisades Reservoir. Abundance was estimated as the product of a species proportion from gillnetting data and the total abundance estimate from hydroacoustics.

	Species	Proportion ± 90% CI	Abundance	90% CI
Pelagic	Brown Trout	0.10 ± 0.04	8,863	1,118
	Lake Trout	0.01 ± 0.01	950	187
	Utah Chub	0.74 ± 0.15	63,304	4,016
	Utah Sucker	0.13 ± 0.10	11,395	2,712
	Yellowstone Cutthroat Trout	0.01 ± 0.02	950	592
Nearshore	Brown Trout	0.15 ± 0.13	5,008	1,505
	Kokanee	0.01 ± 0.01	218	155
	Utah Chub	0.47 ± 0.40	15,461	4,608
	Utah Sucker	0.36 ± 0.28	11,759	3,186
	Yellowstone Cutthroat Trout	0.02 ± 0.02	544	211
Total	Brown Trout	—	13,871	13,952
	Kokanee	—	836	729
	Lake Trout	—	1,774	704
	Utah Chub	—	78,765	5,901
	Utah Sucker	—	23,153	4,039
	Yellowstone Cutthroat Trout	—	1,494	610

Table 18. Kokanee densities (fish/ha) per transect and total fish abundance estimates calculated using both the arithmetic and geometric mean densities at Payette Lake on June 22, 2003.

		Fish densities (number/ha)			
Transect	**Transect length (m)**	**Age-0**	**Age-1**	**Age-2+**	**Total**
1	1160.3	73.5	0.0	0.8	74.4
2	694.1	33.2	3.7	1.5	38.4
3	402.3	22.1	9.4	2.3	33.9
4	844.4	22.7	14.4	1.2	40.0
5	1636.4	163.2	52.9	8.0	228.7
6	1281.9	177.2	62.3	9.8	249.9
7	2220.8	47.0	7.2	8.8	70.0
8	969.8	168.4	29.5	20.9	220.4
9	1157.8	30.2	11.7	8.4	51.2
10	1064.0	46.0	27.1	14.7	92.5
11	1577.7	39.5	25.9	33.8	100.5
12	1875.7	101.0	39.5	30.7	173.6
13	1646.4	117.3	39.2	44.0	202.9
14	1647.0	119.6	49.5	68.8	241.0
	Arithmetic Mean (AM)	**82.9**	**26.6**	**18.1**	**127.7**
	90% CI (AM)	**27.1**	**9.4**	**9.4**	**39.8**
	Abundance (AM)	**179,142**	**57,452**	**39,165**	**275,759**
		±58,600	**±20,246**	**±20,312**	**±85,981**
	Geometric Mean (GM)	**64.8**	**17.4**	**9.9**	**102.6**
	90% CI (GM)	**49.5 to 84.8**	**11.3 to 26.6**	**6.2 to 15.6**	**78.6 to 133.9**
	Abundance (GM)	**140,042**	**37,592**	**21,489**	**221,608**
		106,946 to 183,178	**24,314 to 57,529**	**13,405 to 33,772**	**169,744 to 289,120**

Table 19. Kokanee densities (fish/ha) per transect and total fish abundance estimates calculated using both the arithmetic and geometric mean densities at Payette Lake on August 29, 2003.

		Fish densities (number/ha)			
Transect	**Transect length (m)**	**Age-0**	**Age-1**	**Age-2+**	**Total**
1	1468.51	141.71	76.12	35.36	253.19
2	1553.31	329.99	67.49	18.65	416.12
3	1460.17	399.56	150.58	83.00	633.14
4	1504.66	96.66	50.50	63.33	210.50
5	1379.88	91.45	19.35	10.52	121.32
6	1588.05	123.57	53.21	42.88	219.66
7	1480.97	34.56	24.56	12.49	71.60
8	1683.14	74.94	22.10	23.68	120.72
9	1692.29	119.73	80.73	53.99	254.45
10	1748.44	195.85	136.81	87.77	420.43
11	1603.17	132.84	43.33	28.40	204.57
	Arithmetic Mean (AM)	**158.3**	**65.9**	**41.8**	**266.0**
	90% CI (AM)	**60.7**	**24.0**	**14.8**	**89.8**
	Abundance (AM)	**341,841**	**142,319**	**90,344**	**574,504**
		±131,005	**±51,745**	**±31,989**	**±194,017**
	Geometric Mean (GM)	**129.2**	**53.8**	**33.9**	**224.1**
	90% CI (GM)	**98.2 to 169.9**	**40.7 to 71.1**	**25.3 to 45.3**	**173.4 to 289.2**
	Abundance (GM)	**279,143**	**116,229**	**73,201**	**483,990**
		212,152 to 367,075	**87,837 to 153,580**	**54,587 to 97,919**	**374,953 to 624,554**

Table 20. Fish densities (fish/ha) per transect and total fish abundance estimates calculated using both the arithmetic and geometric mean densities at Sage Hen Reservoir on June 20, 2003.

		Fish densities (number/ha)		
Transect	**Transect length (m)**	**Sidelooking (0-6 m)**	**Downlooking (>6 m)**	**Total**
1	392.5	22.3	22.8	45.1
2	858.2	19.8	17.6	37.4
3	822.1	8.8	26.9	35.7
4	559.1	6.3	0.0	6.3
5	367.0	237.7	0.0	237.7
6	247.9	212.9	0.0	212.9
	Arithmetic Mean (AM)	84.6	11.2	95.9
	90% CI (AM)	90.0	10.4	90.6
	Abundance (AM)	6,056	804.0	6,860
		±6,442	±745	±6,484
	Geometric Mean (GM)	**33.8**	**3.8**	**52.8**
	90% CI (GM)	**13.4 to 82.7**	**0.8 to 12.1**	**24.4 to 113.0**
	Abundance (GM)	**2,416**	**273**	**3,778**
		962 to 5,915	**55 to 864**	**1,744 to 8,087**

Table 21. Abundance estimates for individual species from data collected during the June 2003 fish assessment survey at Sage Hen Reservoir. Abundance was estimated as the product of a species proportion from gillnetting data and the total abundance estimates from hydroacoustics.

Species	Proportion ± 90% CI	Abundance	90% CI
Wild rainbow / Redband	0.59 ± 0.07	4,057	3,533
Rainbow Trout (Hatchery)	0.41 ± 0.07	2,803	2,443

Table 22. Fish densities (fish/ha) per transect and total fish abundance estimates calculated using both the arithmetic and geometric mean densities at Williams Lake on September 16, 2003.

		Fish densities (number/hectare)		
Transect	**Transect length (m)**	**Sidelooking (0-6 m)**	**Downlooking (>6 m)**	**Total**
1	292	31.8	100.2	132.0
2	335	58.4	169.2	227.6
3	357	20.8	167.5	188.2
4	288	24.3	22.0	46.3
5	644	41.6	218.9	260.5
6	674	52.9	65.5	118.4
7	395	70.8	400.9	471.7
8	475	55.3	537.2	592.5
9	187	276.5	472.0	748.5
10	271	402.0	133.5	535.5
11	150	142.9	233.7	376.6
12	152	567.6	409.5	977.1
13	184	250.8	502.5	753.3
14	419	27.8	300.0	327.8
15	502	56.9	54.6	111.5
16	379	49.8	228.6	278.4
17	300	162.5	505.2	667.8
18	344	158.0	438.2	596.2
	Arithmetic Mean (AM)	**136.2**	**275.5**	**411.7**
	90% CI (AM)	**62.0**	**71.3**	**94.5**
	Abundance (AM)	**19,836**	**9,803**	**29,639**
		±5,134	**±4,463**	**±6,803**
	Geometric Mean (GM)	**83.7**	**207.5**	**316.9**
	90% CI (GM)	**61.3 to 114.2**	**157.1 to 274.1**	**245.3 to 409.3**
	Abundance (GM)	**14,942**	**6,028**	**22,820**
		11,308 to 19,736	**4,415 to 8,222**	**17,665 to 29,472**

Table 23. Abundance estimates for individual species from data collected during the September 2003 fish assessment survey at Williams Lake. Abundance was estimated as the product of a species proportion from gillnetting data and the total abundance estimates from hydroacoustics.

Species	Proportion ± 90% CI	Abundance	90% CI
Rainbow trout	0.84 ± 0.30	19,168	7,388
Bull trout	0.16 ± 0.30	3,651	3,419

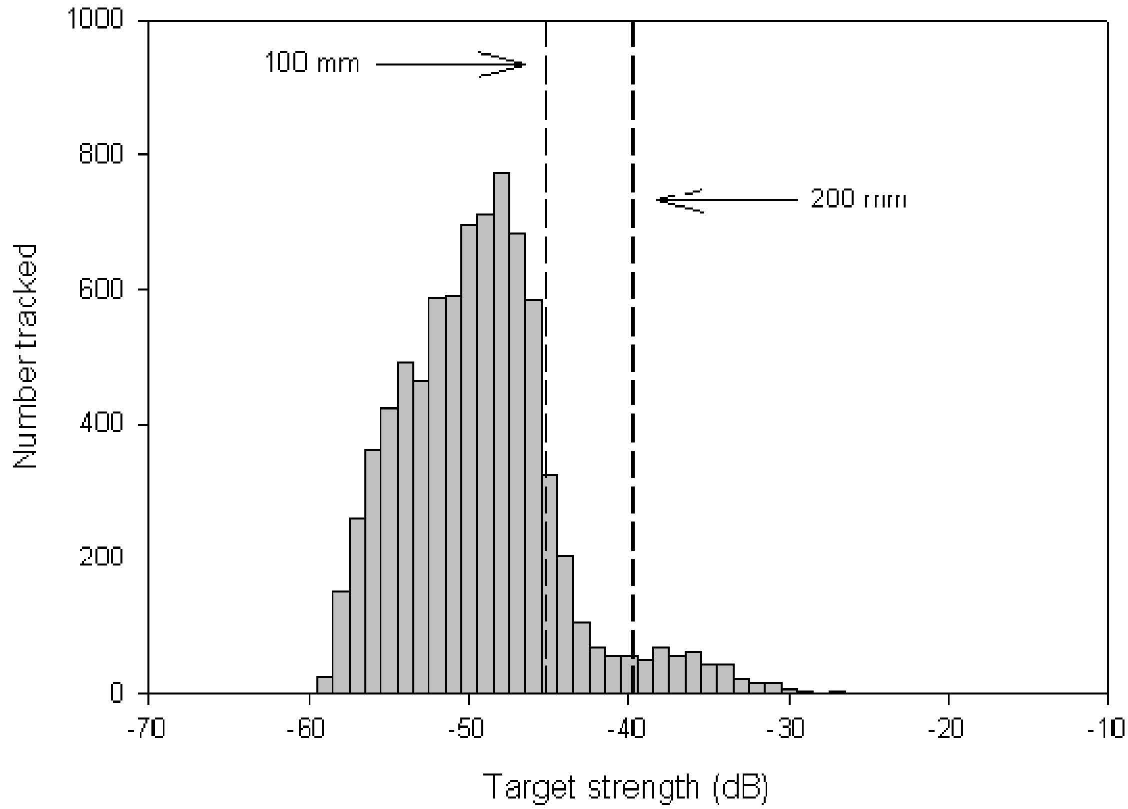


Figure 1. Target strength (dB) distribution of fish tracked during the August 2003 hydroacoustic survey at Anderson Ranch Reservoir.

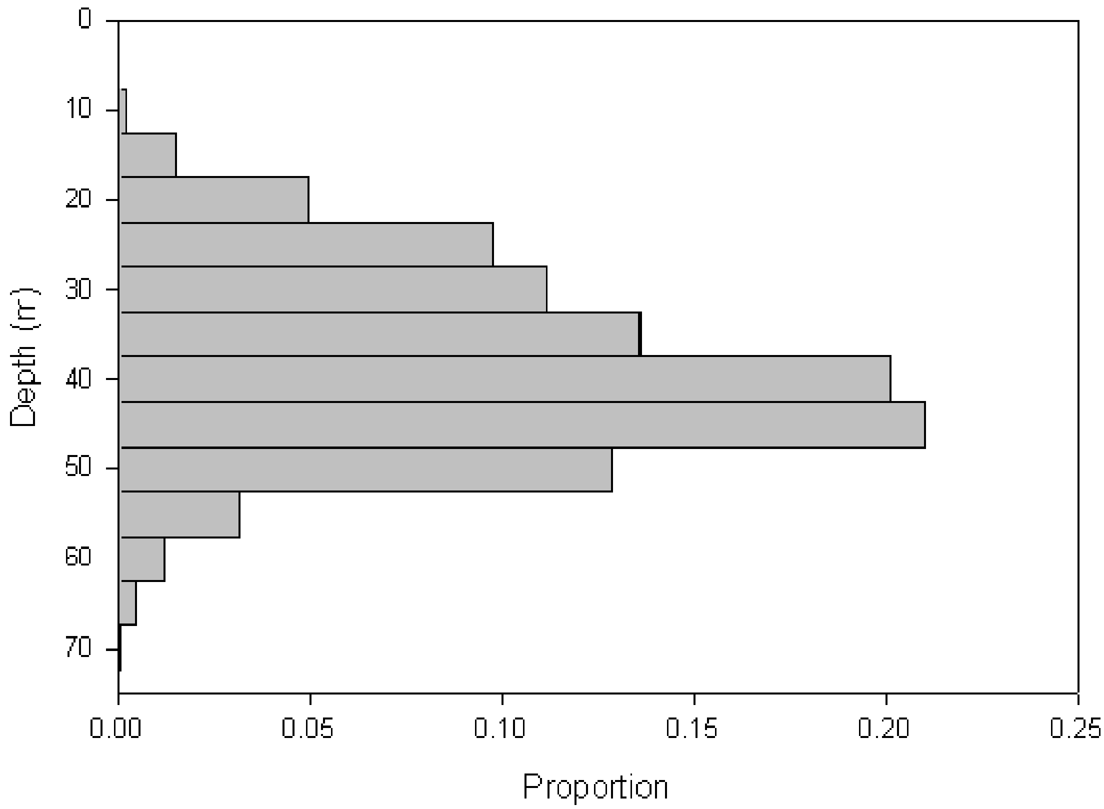


Figure 2. Proportional depth distribution of fish at Anderson Ranch Reservoir during August 2003 survey.

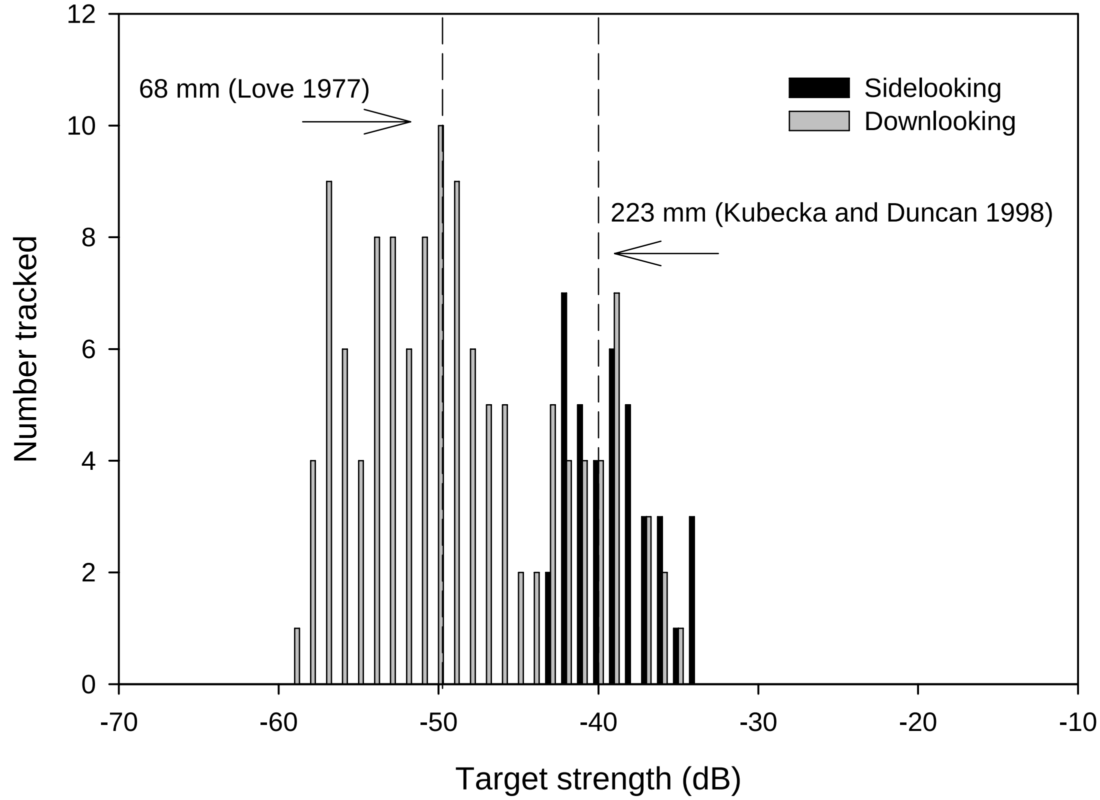


Figure 3. Target strength (dB) distribution of fish tracked during the July 2003 hydroacoustic survey at Arrowrock Reservoir.

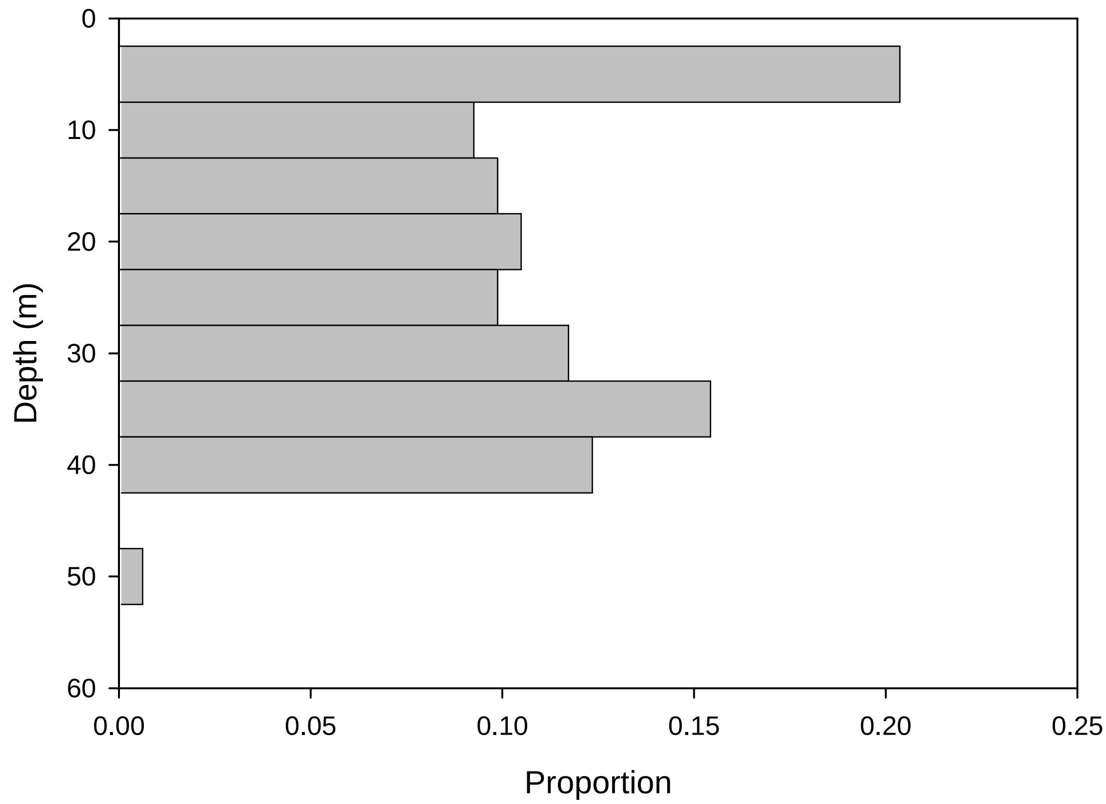


Figure 4. Proportional depth distribution of fish tracked at Arrowrock Reservoir in July 2003.

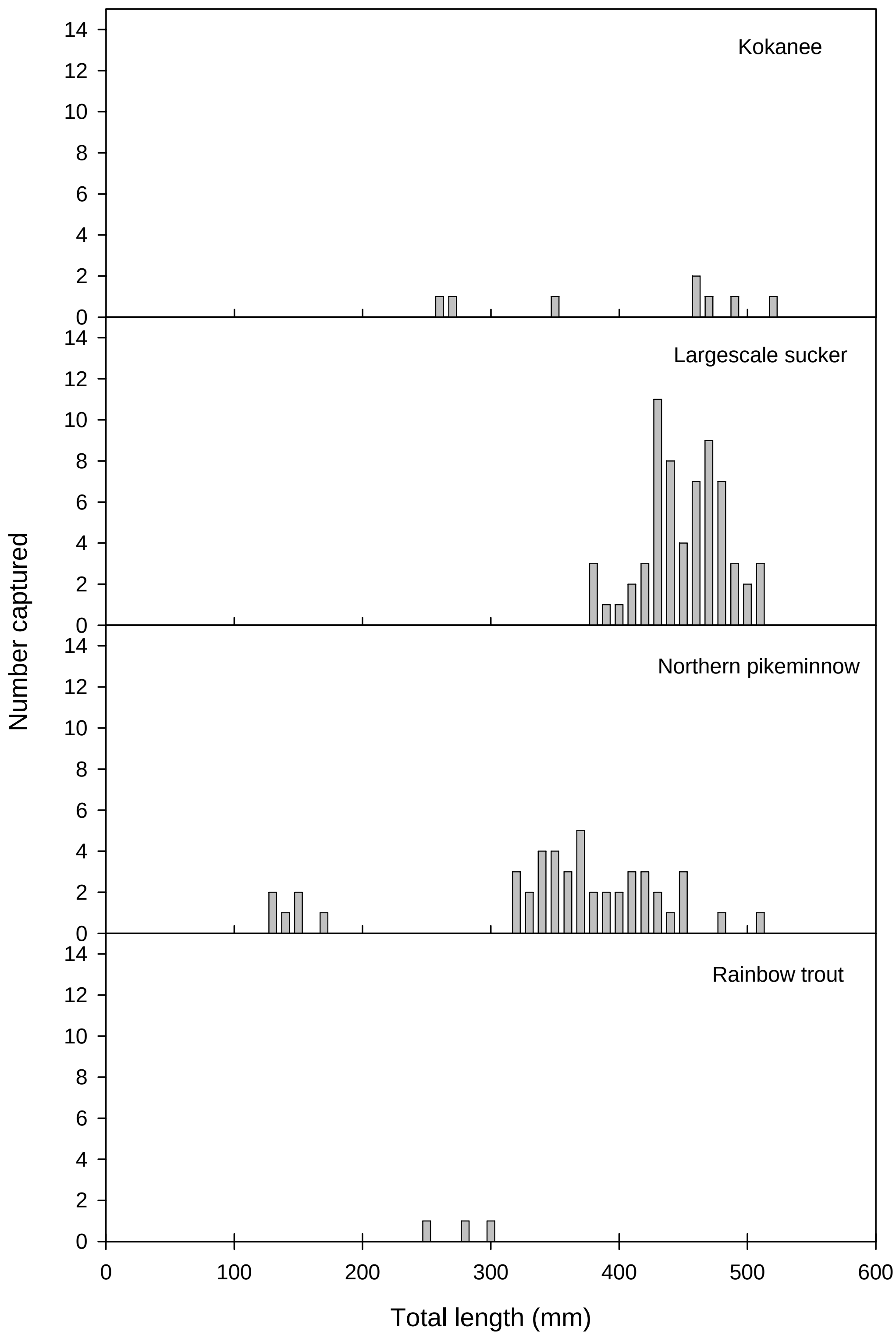


Figure 5. Length distributions of dominant fish species caught in net curtains at Arrowrock Reservoir from July 2-10, 2003.

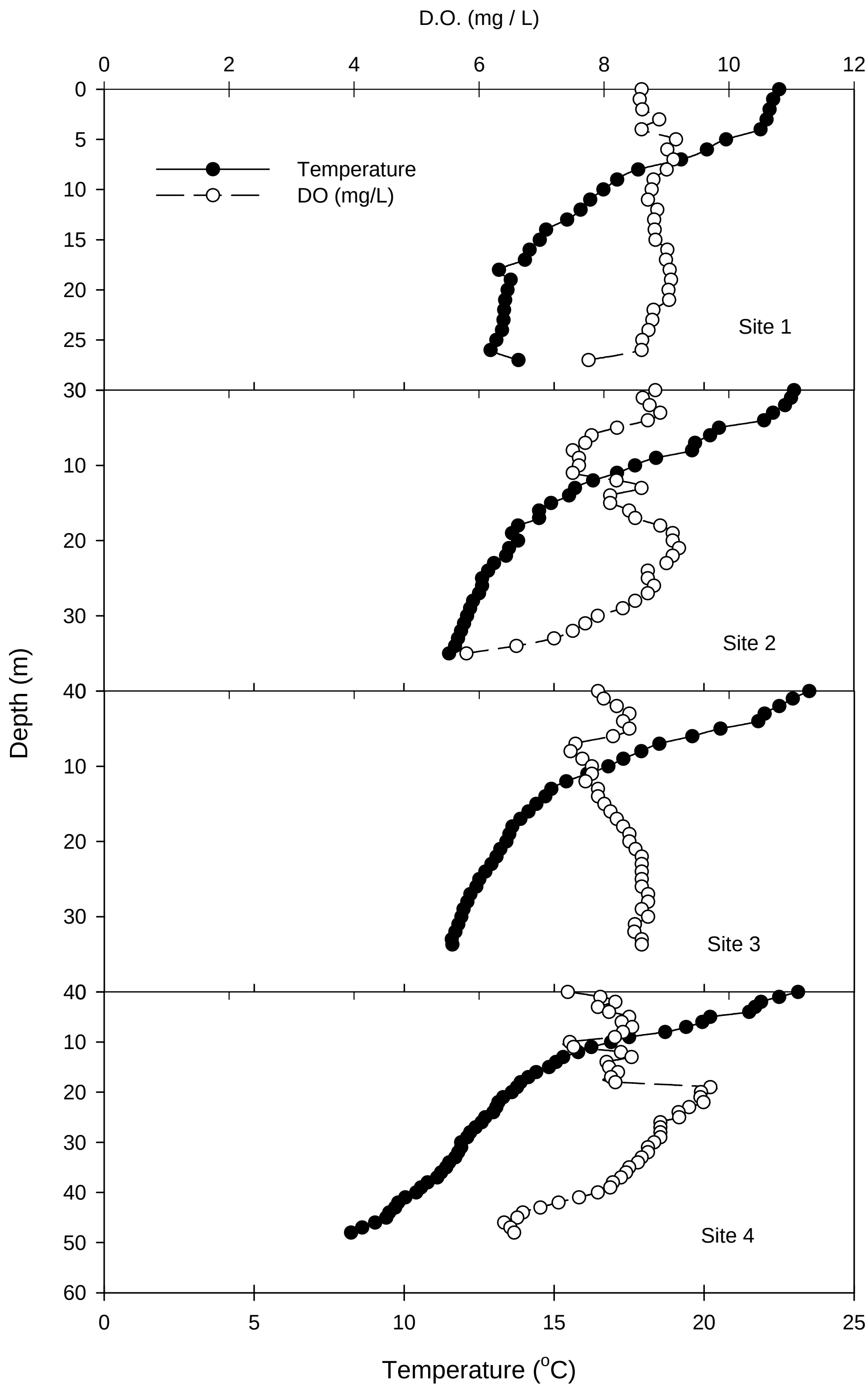


Figure 6. Vertical temperature (°C) and dissolved oxygen (DO; mg/L) profiles at four sites in Arrowrock Reservoir during the fish assessment survey in July 2003.

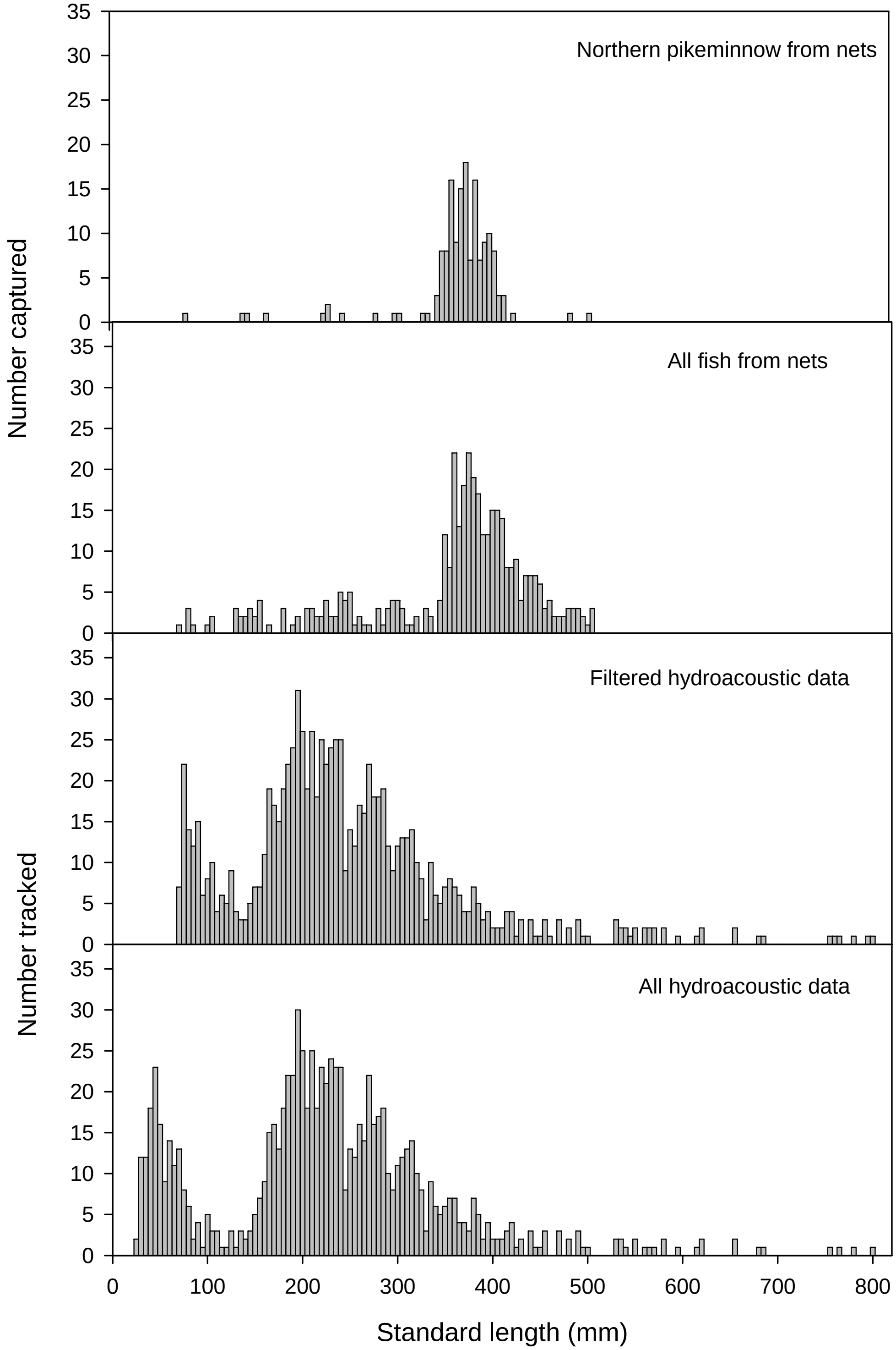


Figure 7. Fish length and converted target strength (dB) distributions of fish sampled by net curtains and hydroacoustics at Cascade Reservoir from July 16-22, 2003.

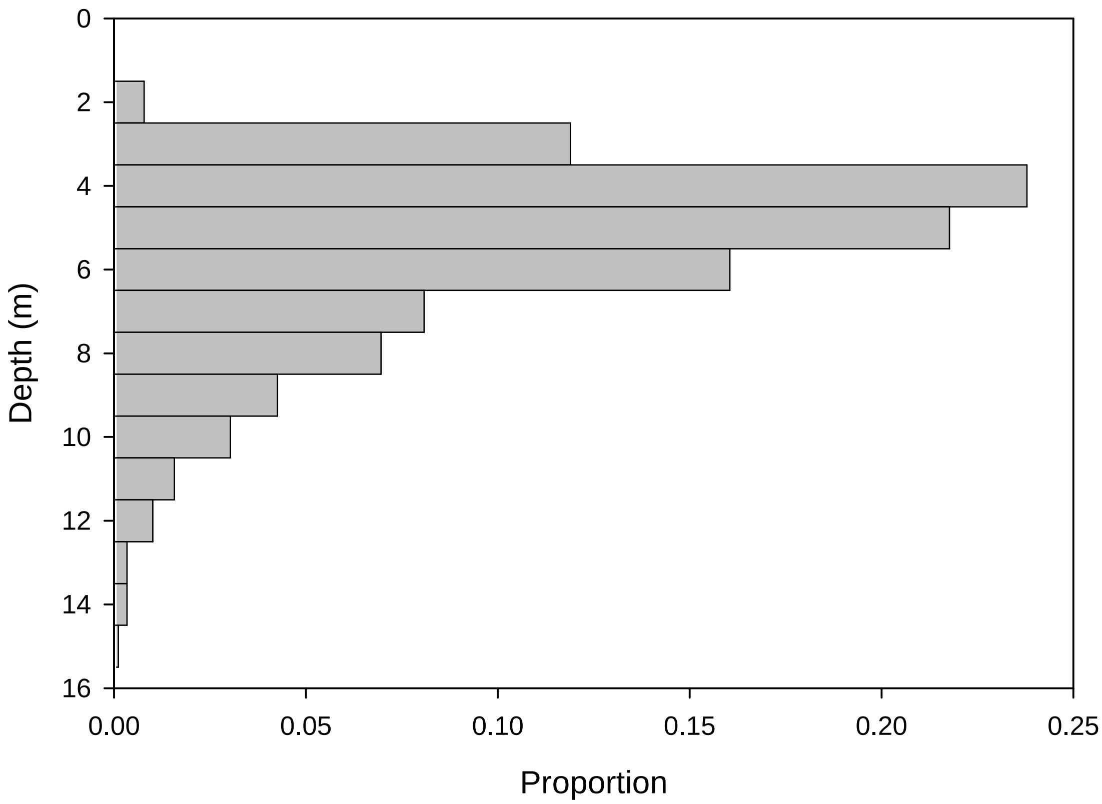


Figure 8. Proportional depth distribution of fish tracked at Cascade Reservoir in July 2003.

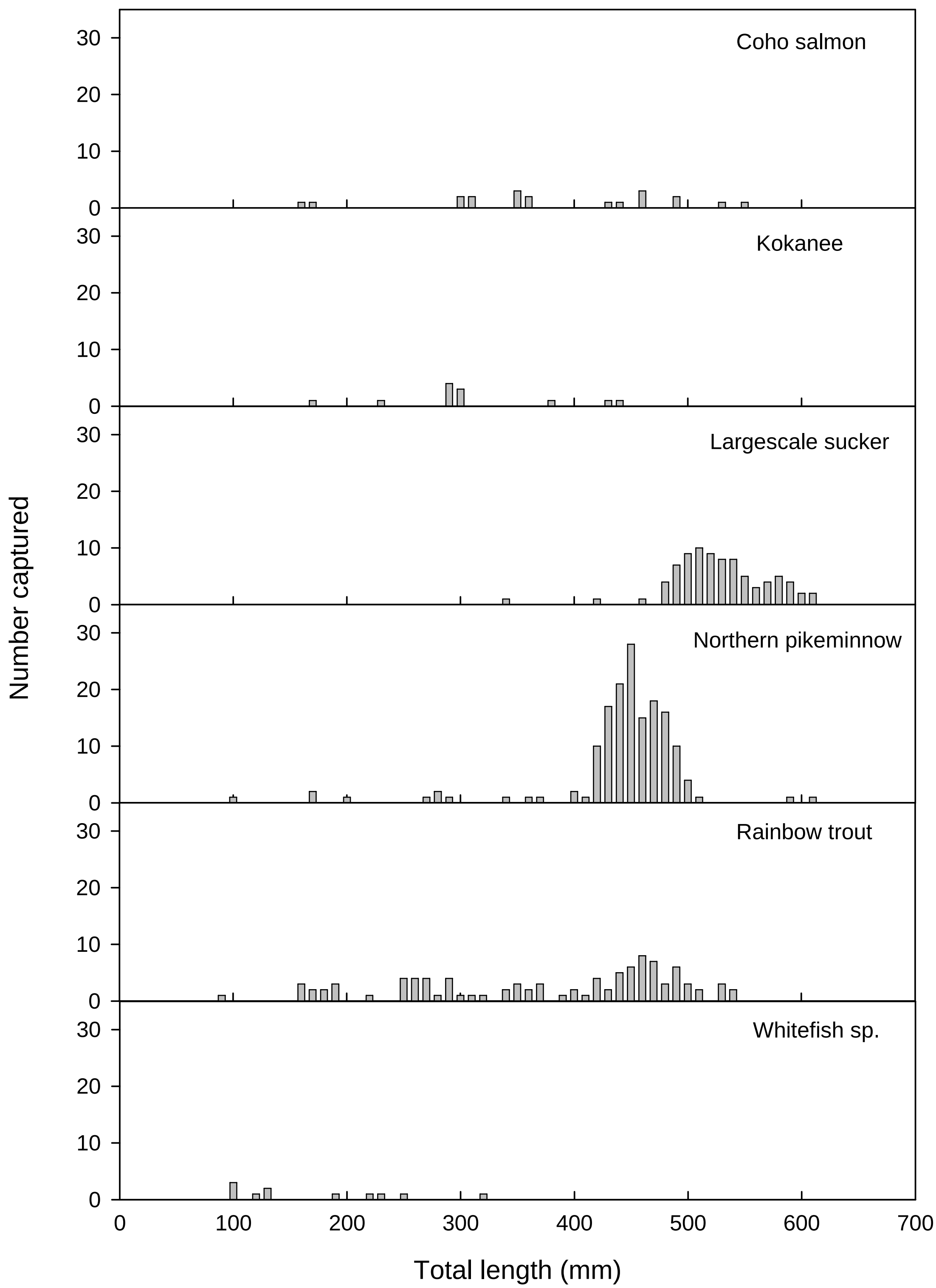


Figure 9. Length distributions of dominant fish species caught in net curtains at Cascade Reservoir from July 16-22, 2003.

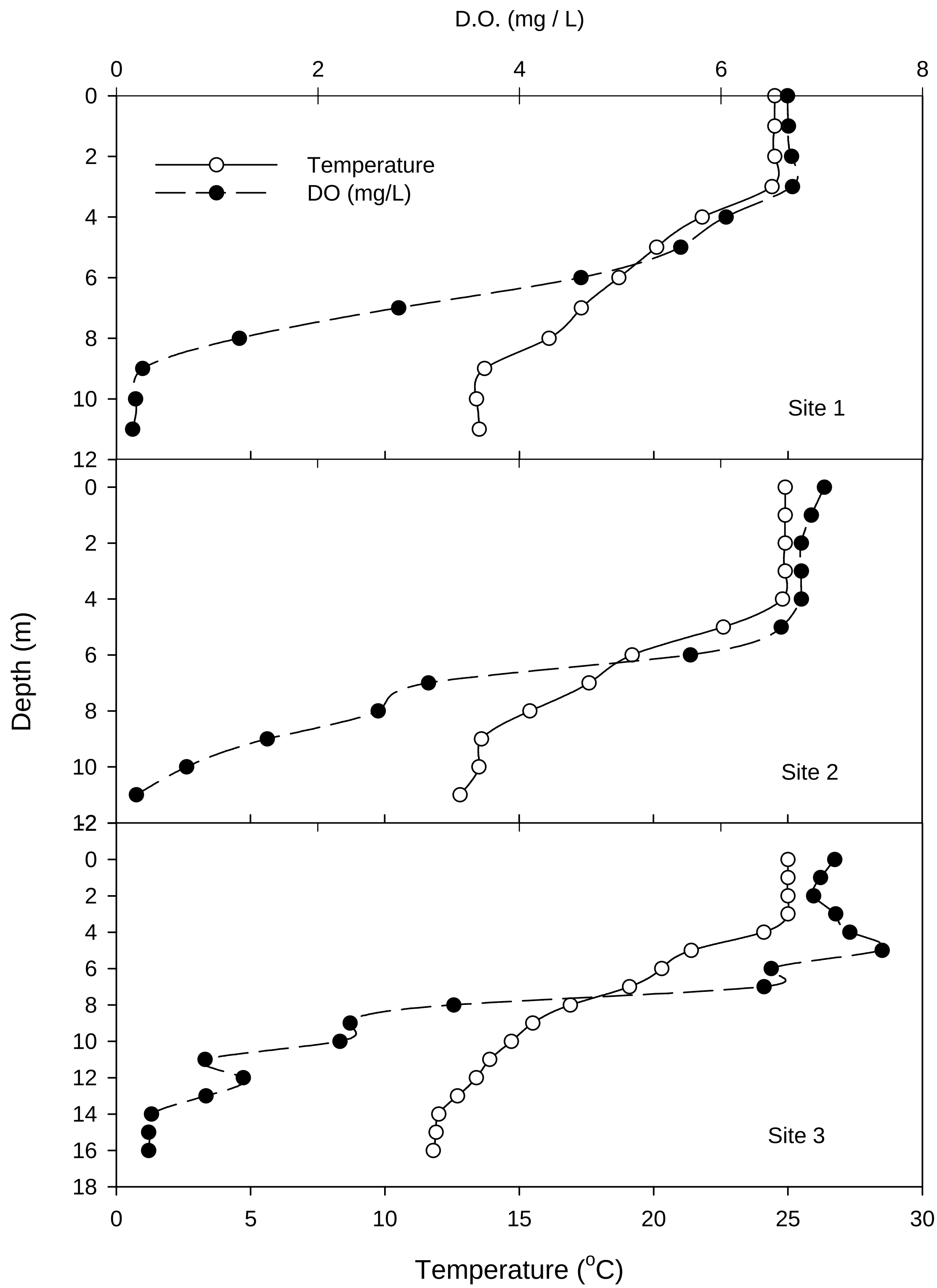


Figure 10. Vertical temperature (°C) and dissolved oxygen (DO; mg/L) profiles at three sites in Cascade Reservoir during the fish assessment survey in July 2003.

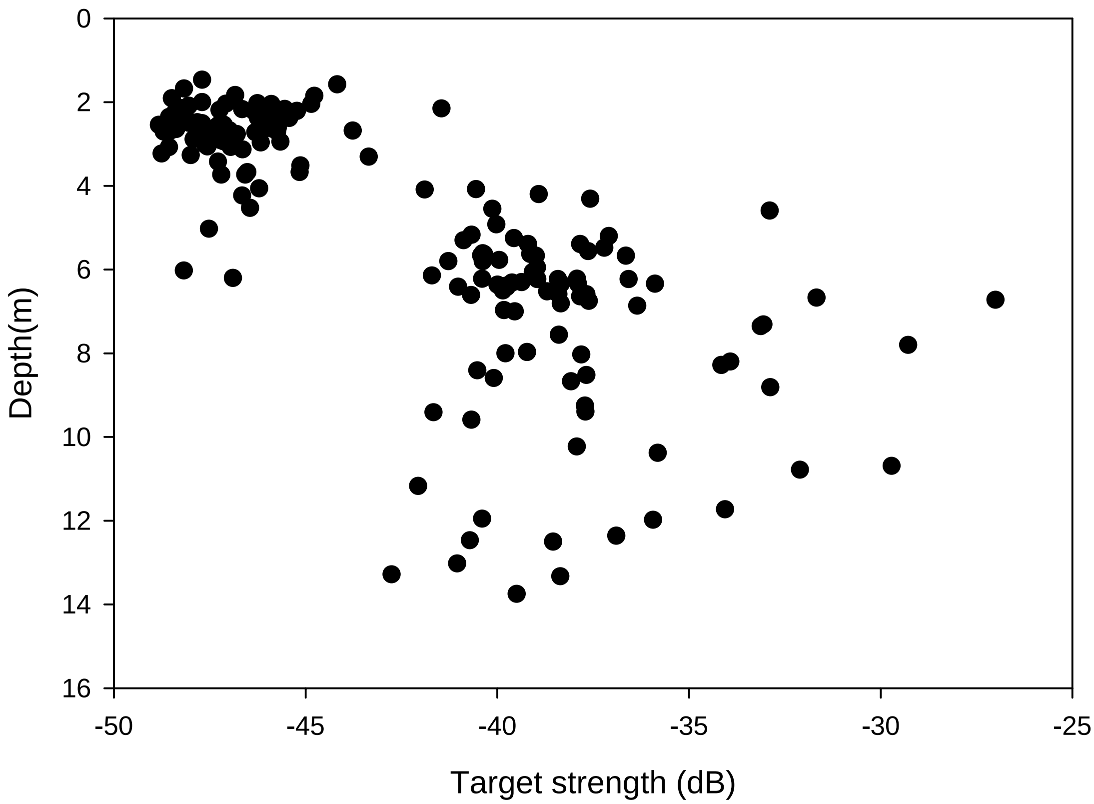


Figure 11. Distribution of targets by size (target strength, dB) and depth at Daniels Reservoir in June 2003.

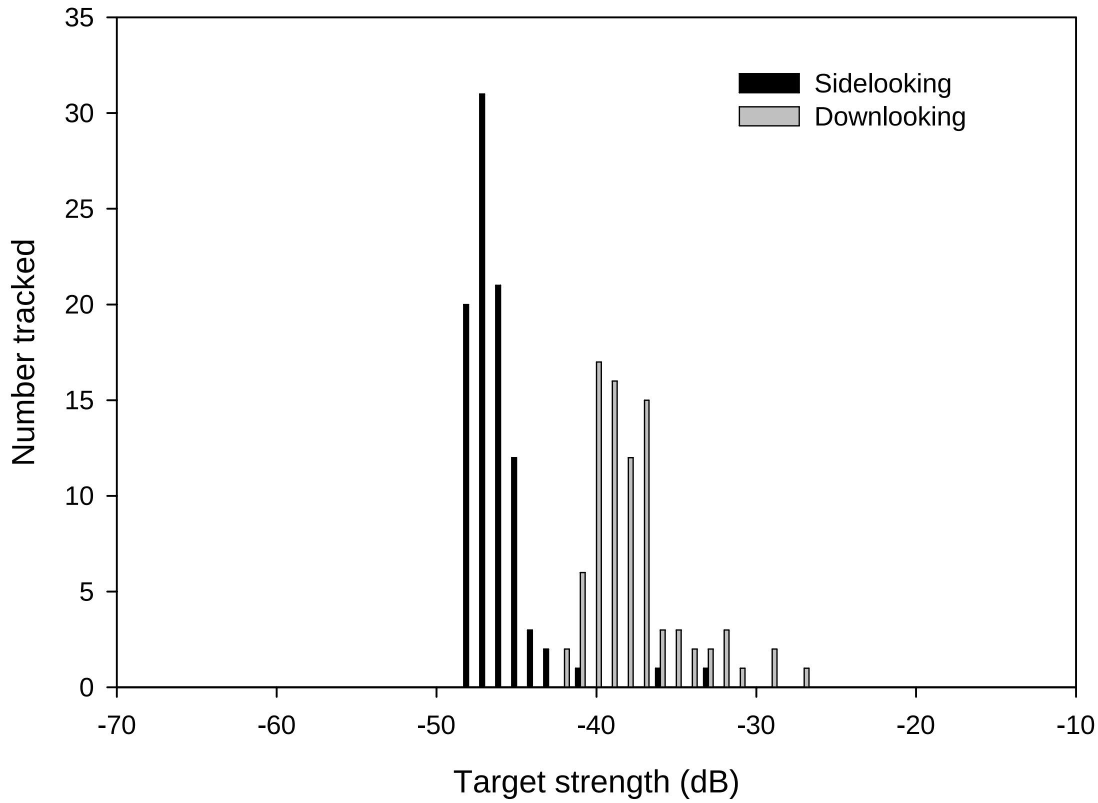


Figure 12. Target strength distribution of tracked fish during the June 2003 survey at Daniels Reservoir.

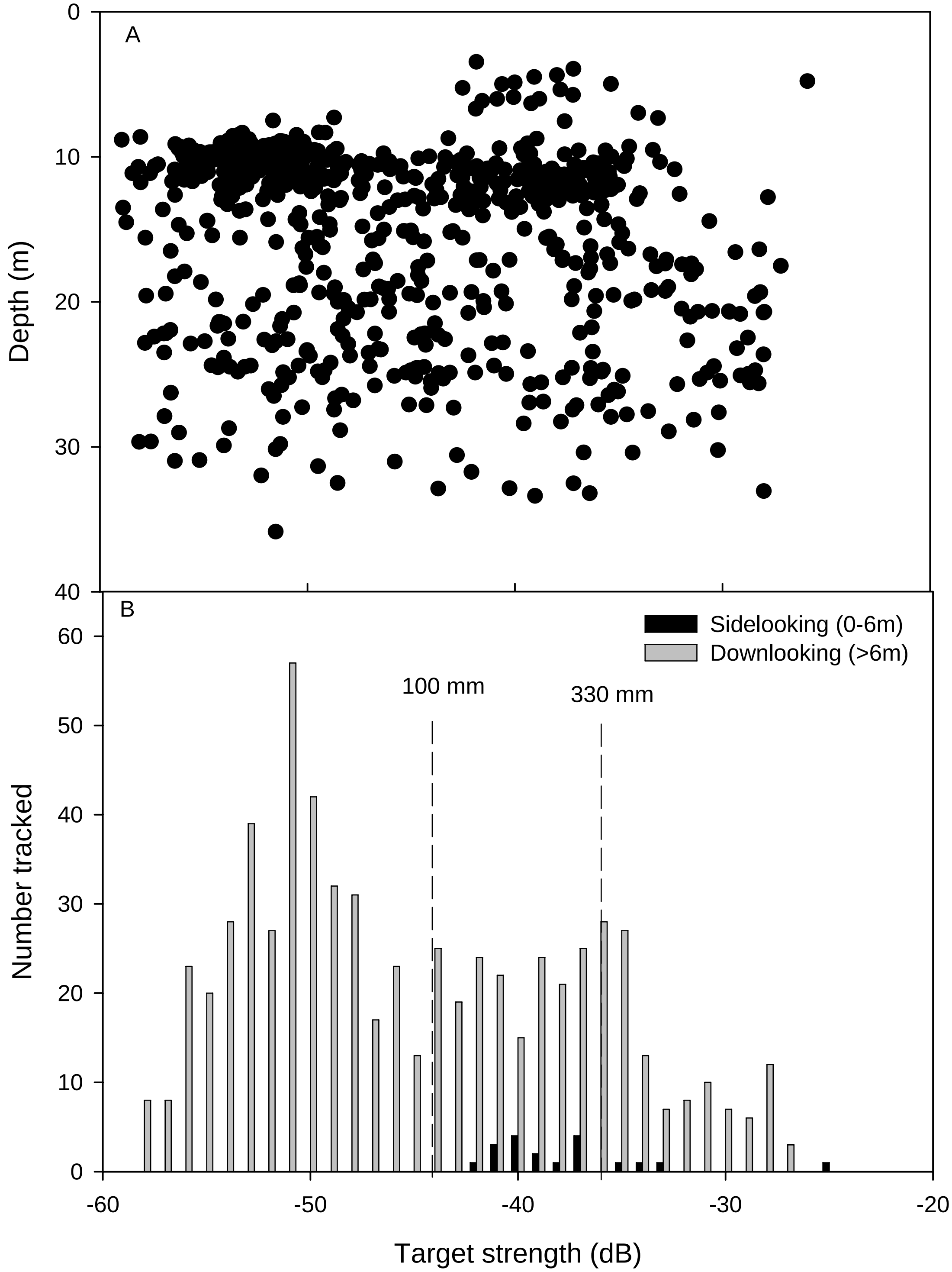


Figure 13. Distribution of tracked fish by size and depth (A) and frequency distribution (B) of approximate fish length (target strength, dB) at Deadwood Reservoir in August 2003.

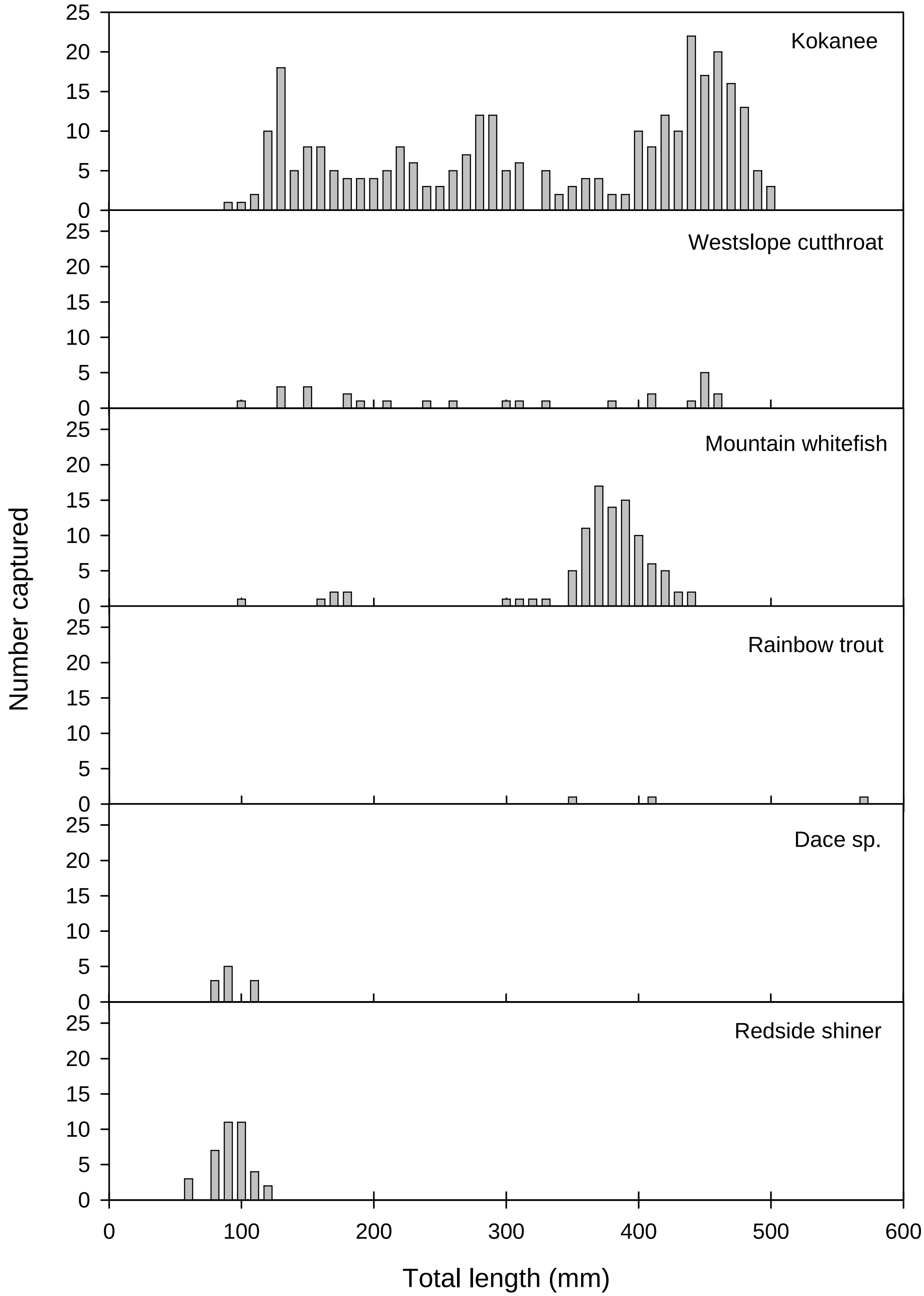


Figure 14. Length distribution of fish caught in gillnets during the 2003 Deadwood Reservoir survey.

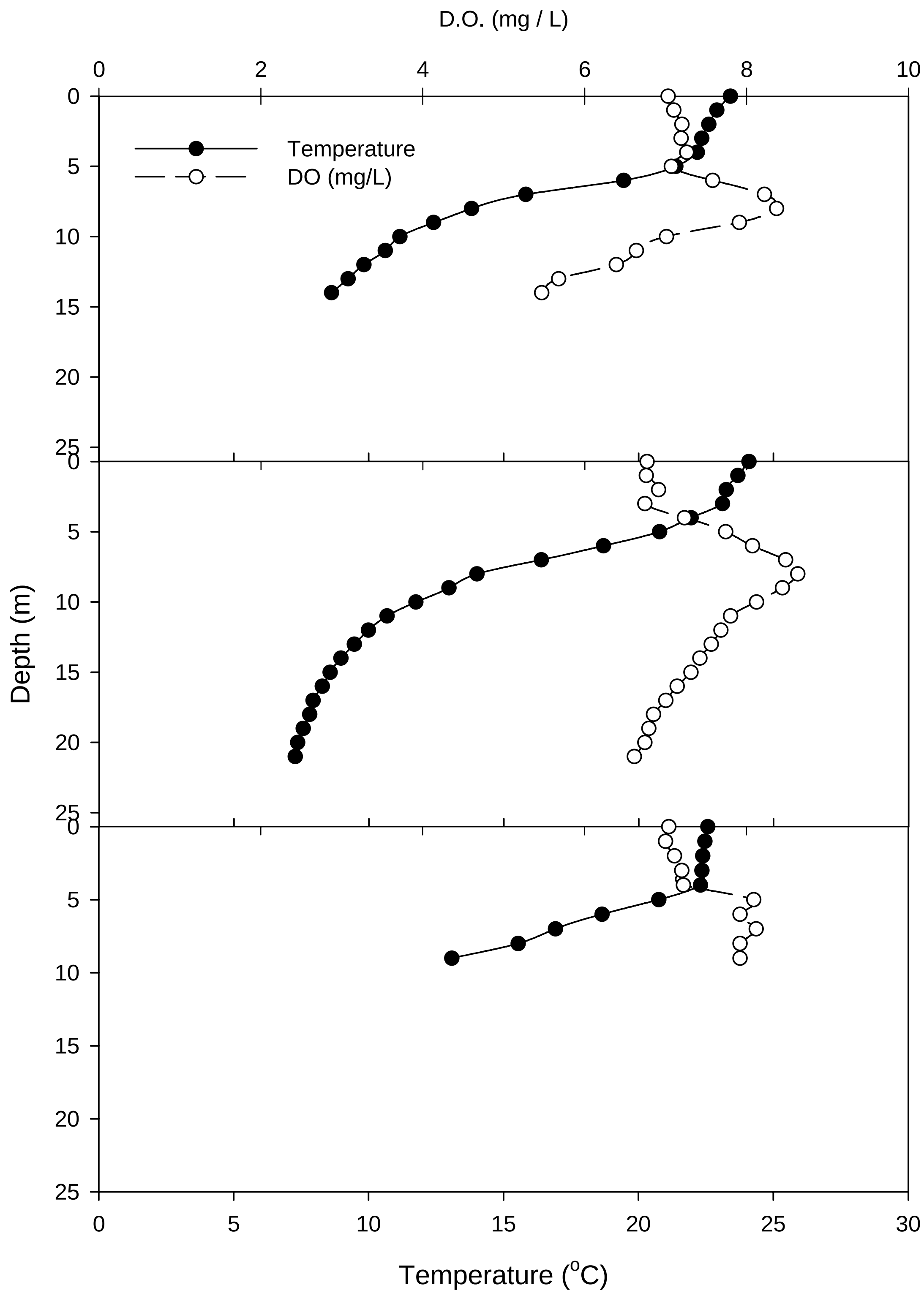


Figure 15. Vertical temperature (°C) and dissolved oxygen (DO; mg/L) profiles at three sites in Deadwood Reservoir during the fish assessment survey in August 2003.

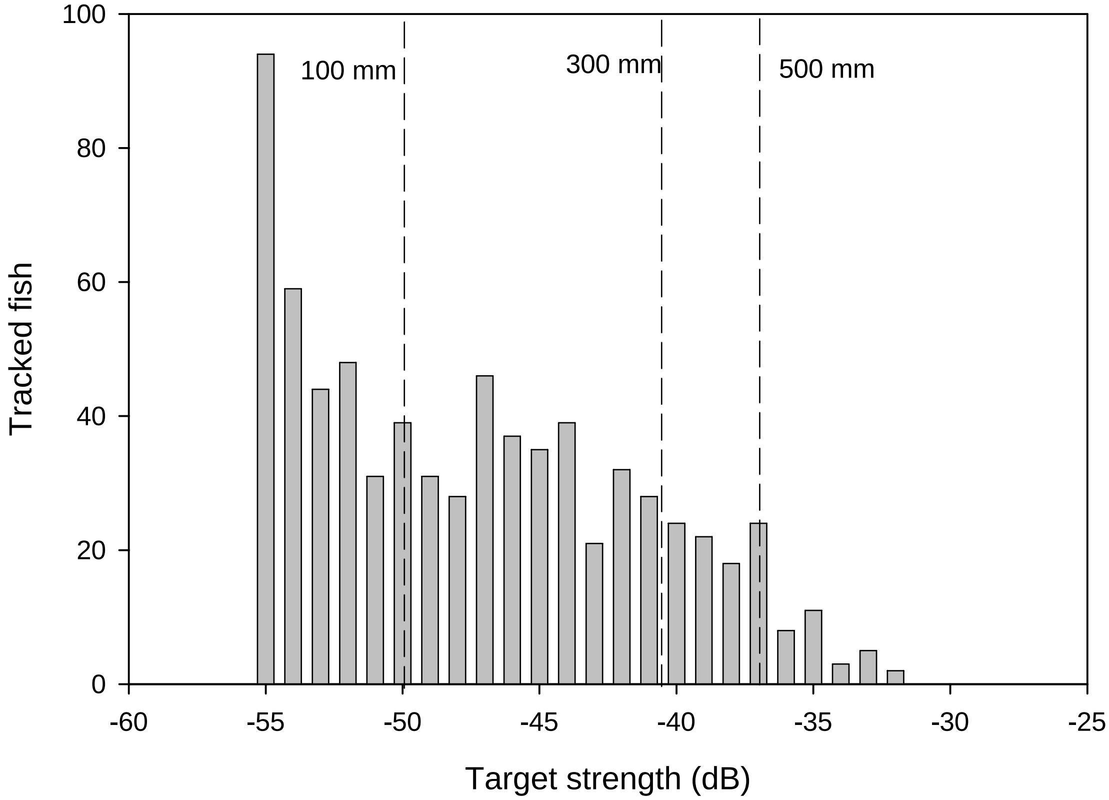


Figure 16. Target strength distribution of tracked fish during the May 2003 Henrys Lake survey.

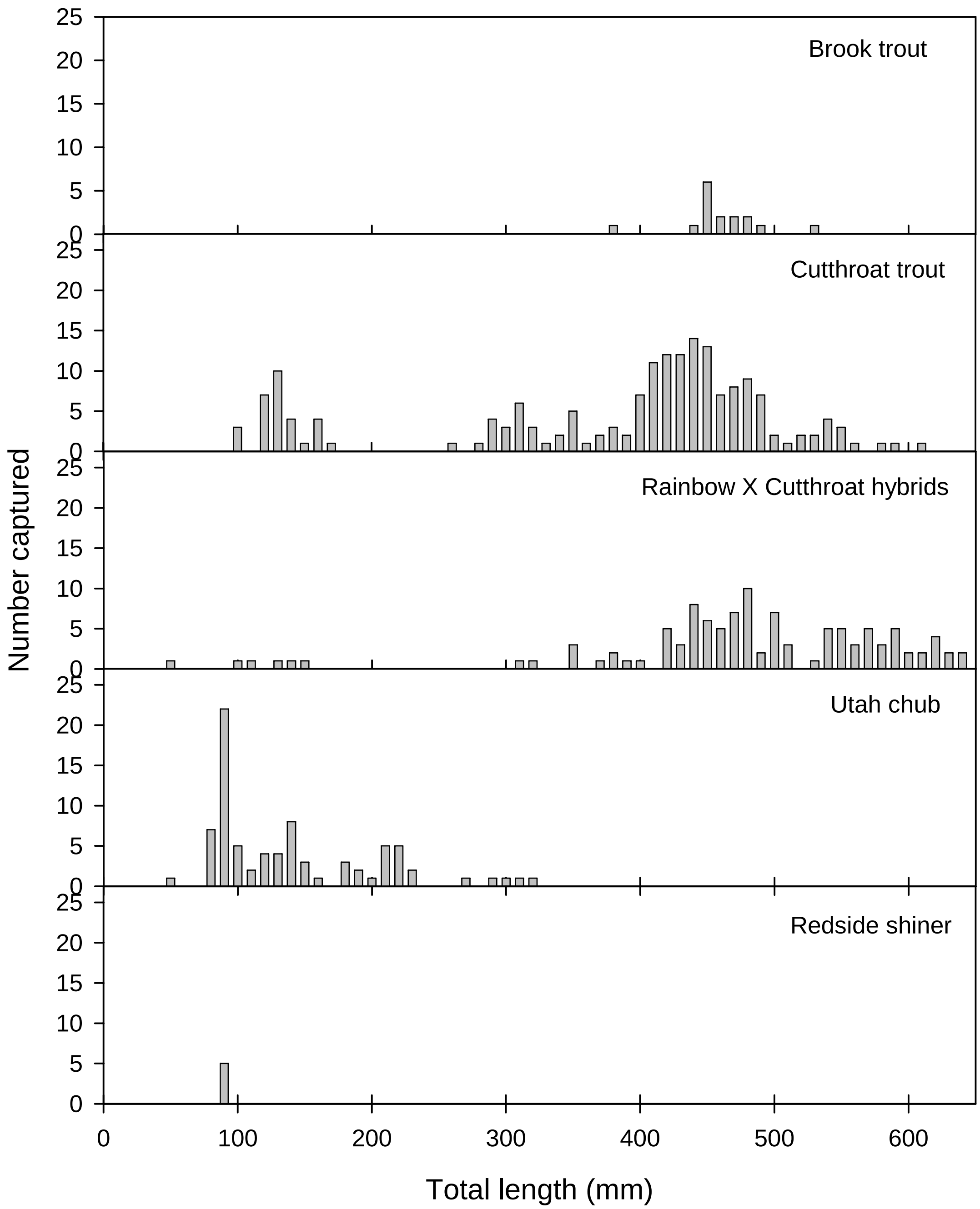


Figure 17. Length distribution of fish captured in gillnets at Henrys Lake in May 2003.

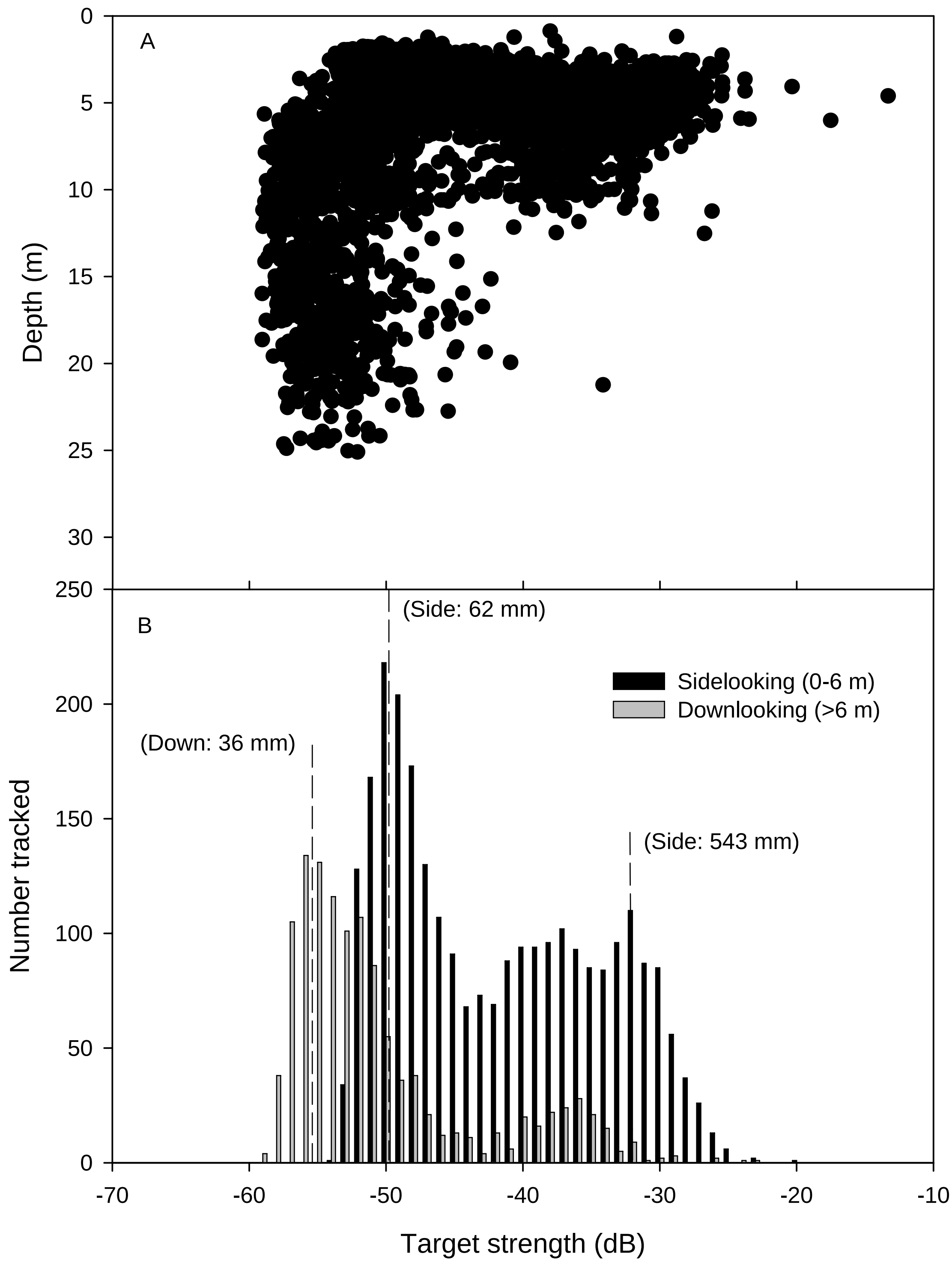


Figure 18. Fish distribution by size (target strength, dB) and depth (A) and length frequency distribution (B) of tracked fish at Oneida Reservoir in June 2003.

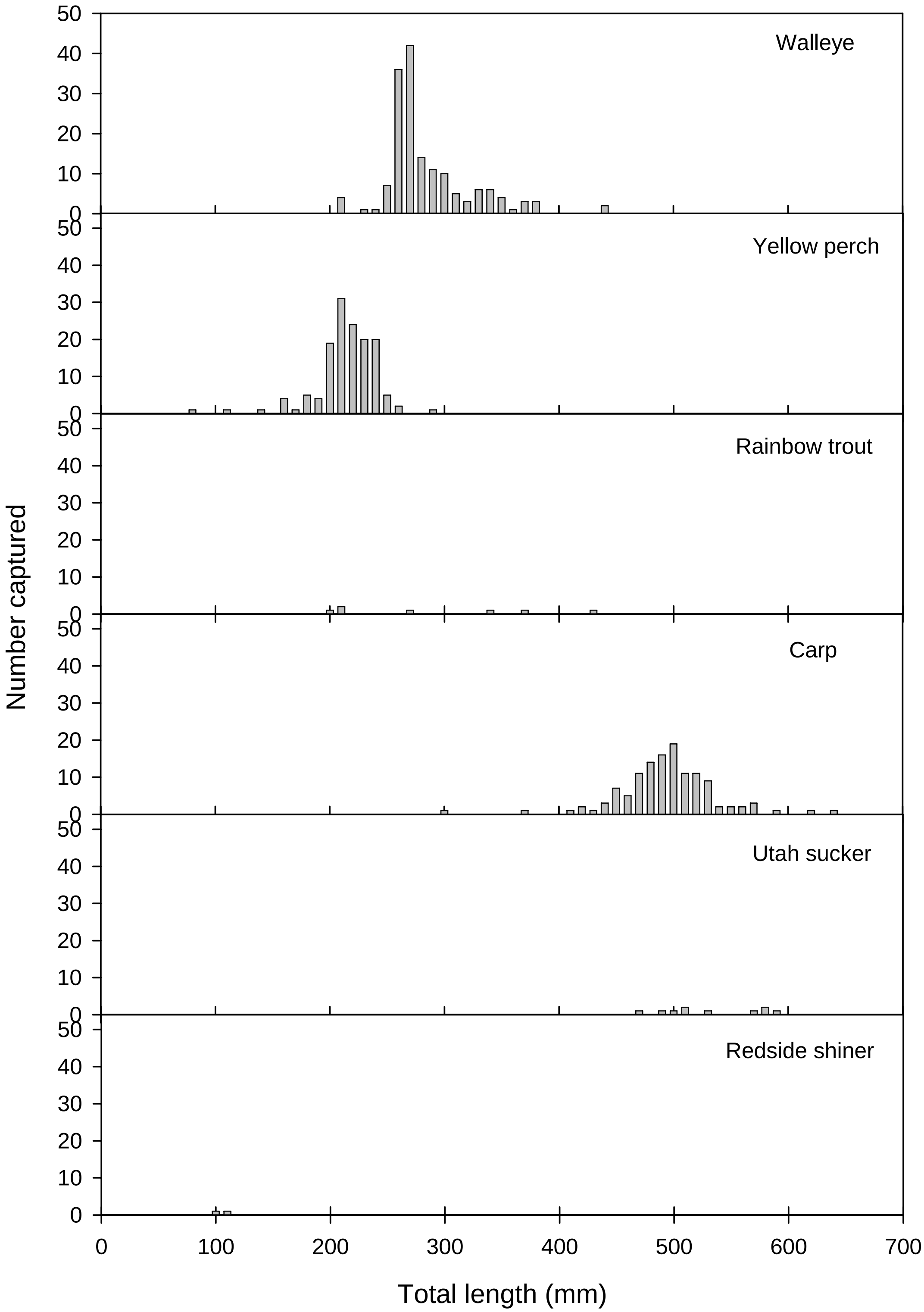


Figure 19. Length frequency of fish captured in gillnets at Oneida Reservoir in June 2003.

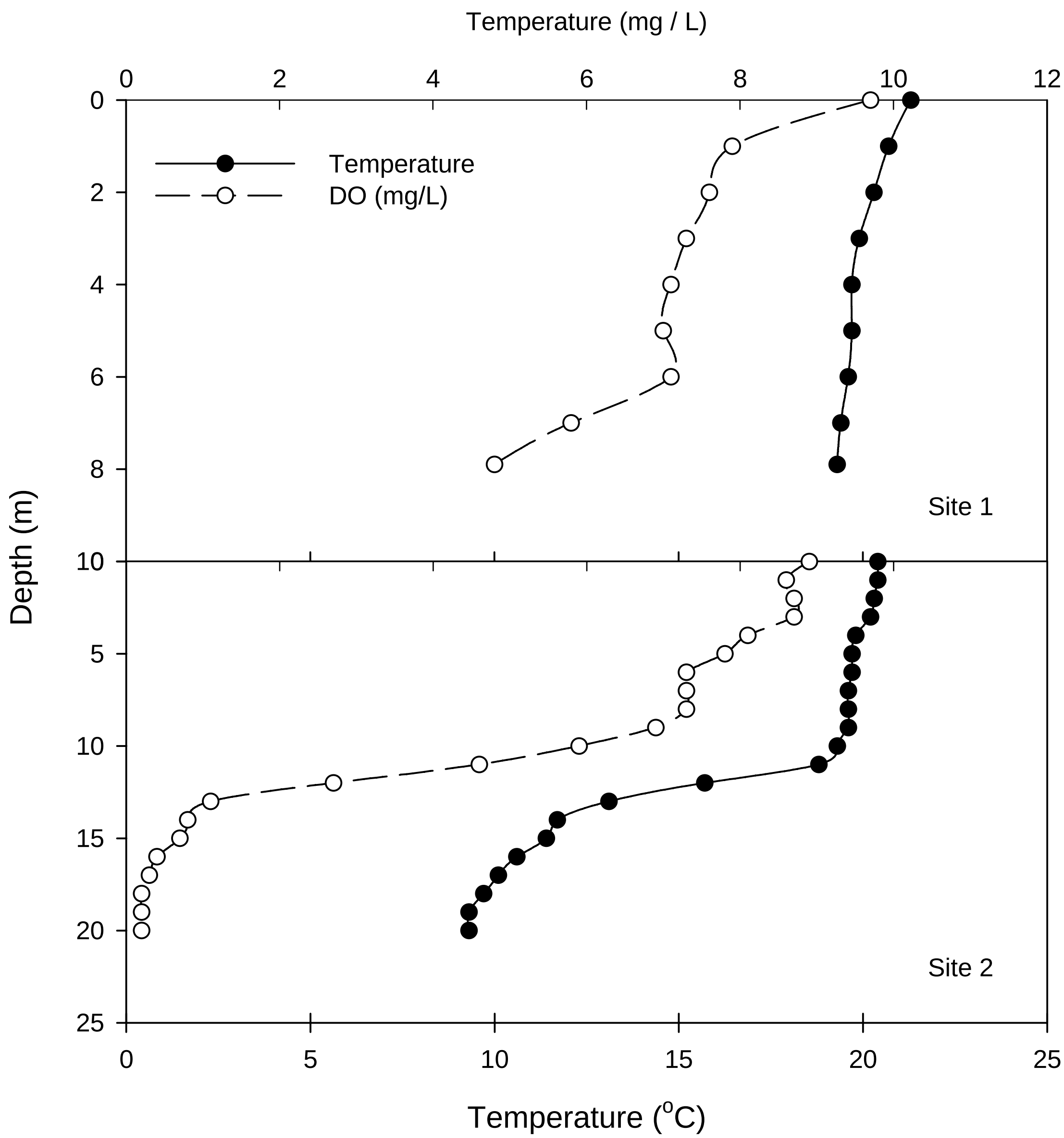


Figure 20. Vertical temperature (°C) and dissolved oxygen (DO; mg/L) profiles at two sites in Oneida Reservoir during the fish assessment survey in June 2003.

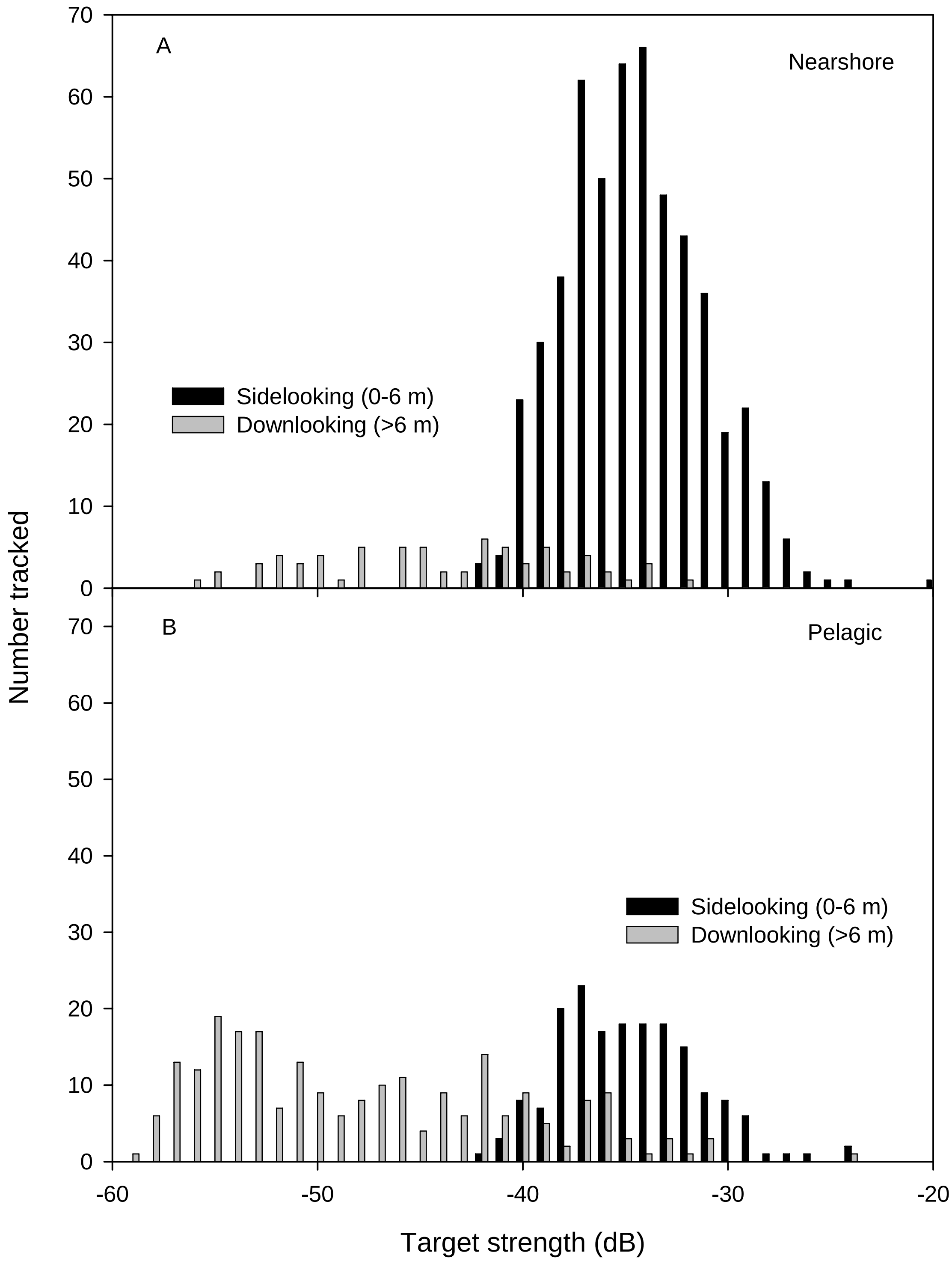


Figure 21. Target strength distribution of tracked fish in nearshore (A) and pelagic (B) habitats in May 2003 at Palisades Reservoir.

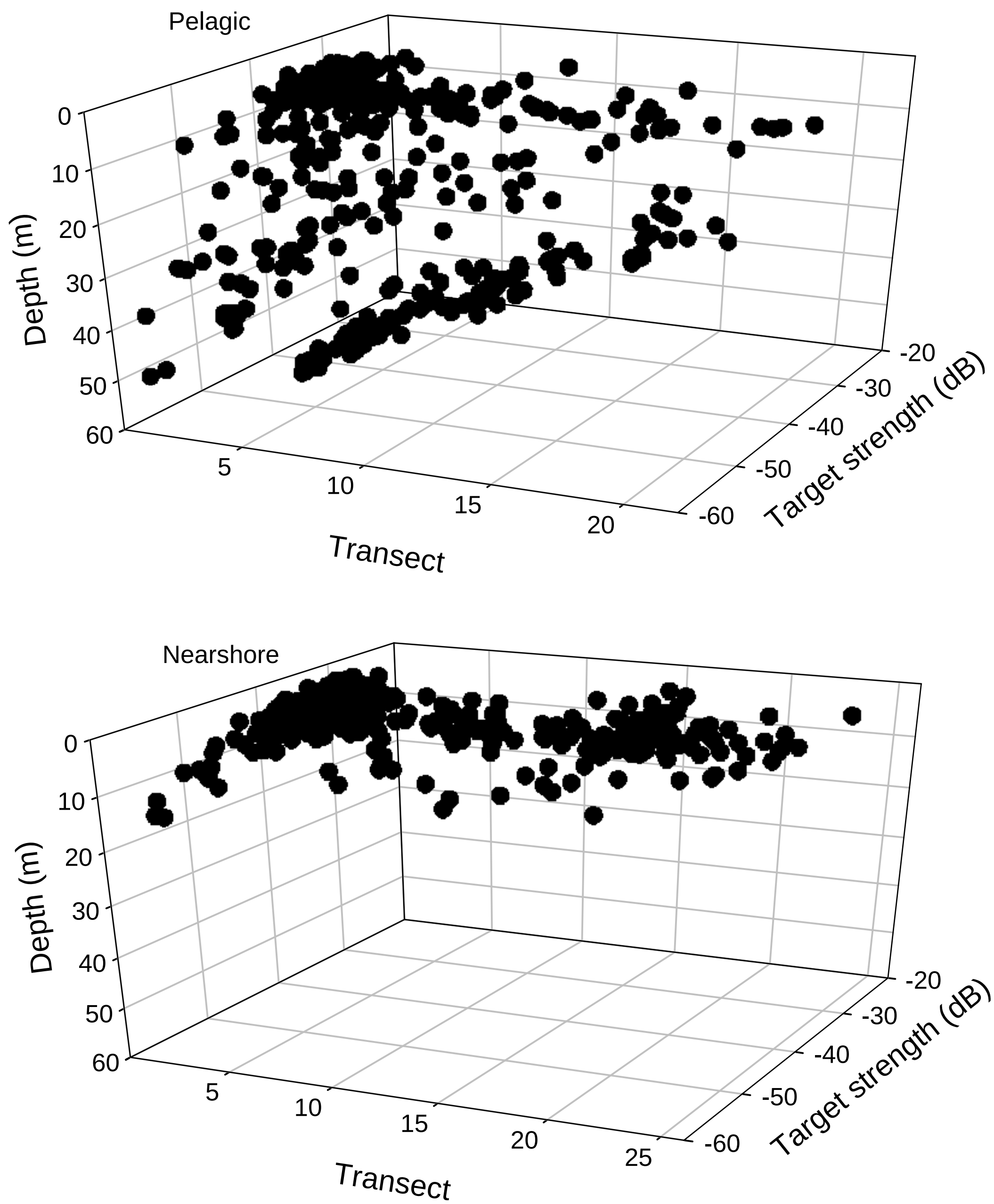


Figure 22. Horizontal and vertical depth distribution of tracked fish by size in both nearshore and pelagic habitats in May 2003 at Palisades Reservoir.

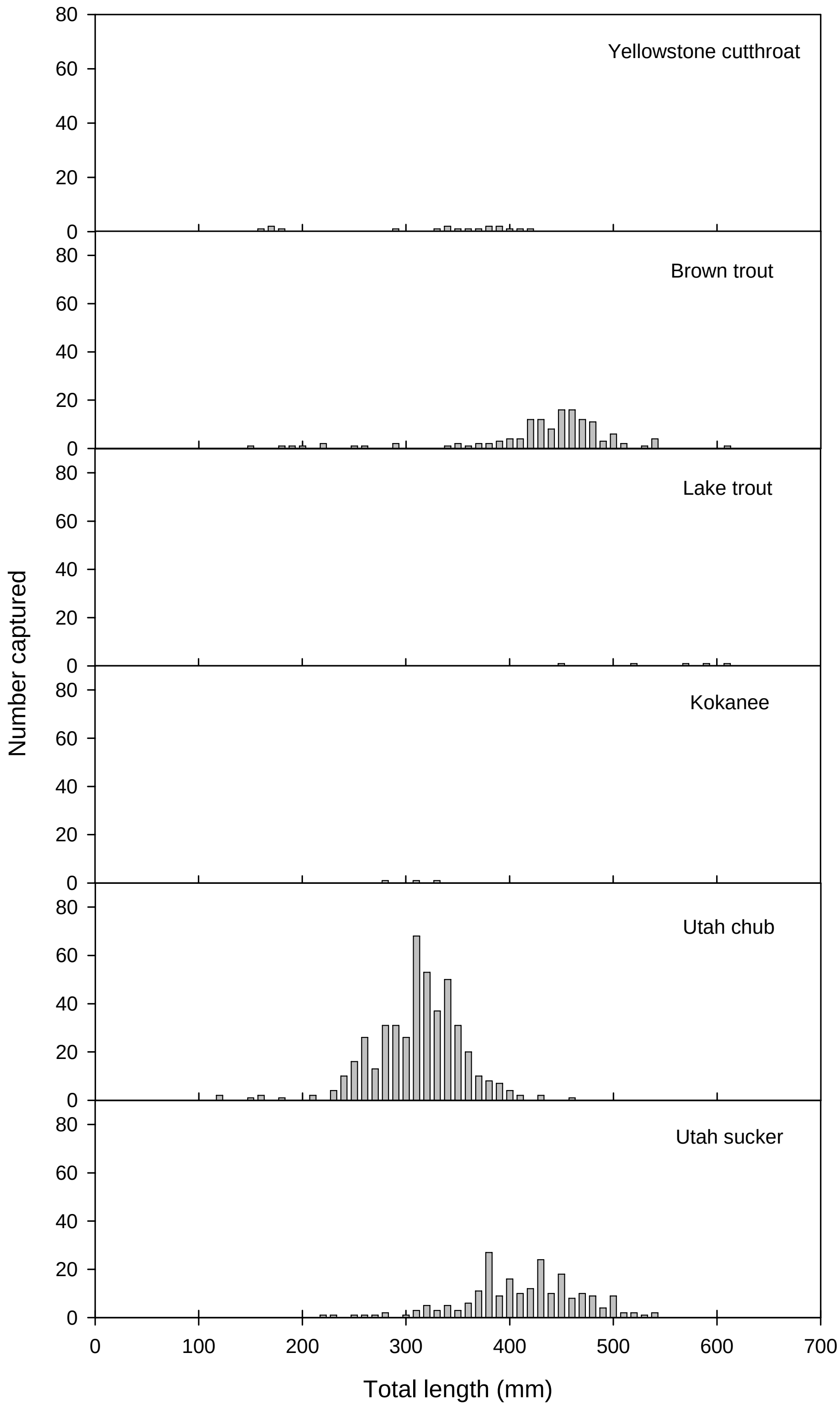


Figure 23. Length distributions of fish captured in gillnets at Palisades Reservoir in May 2003.

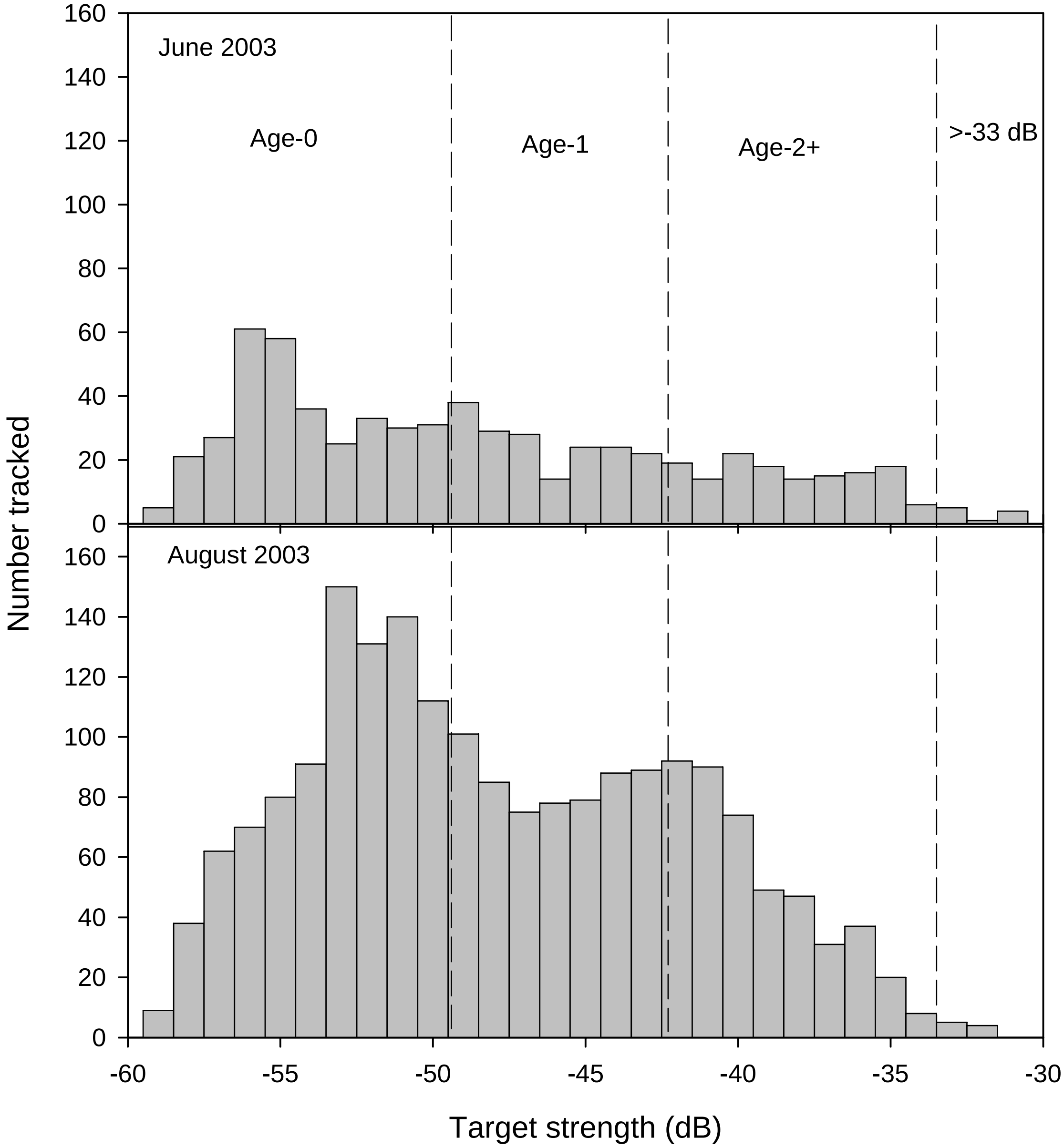
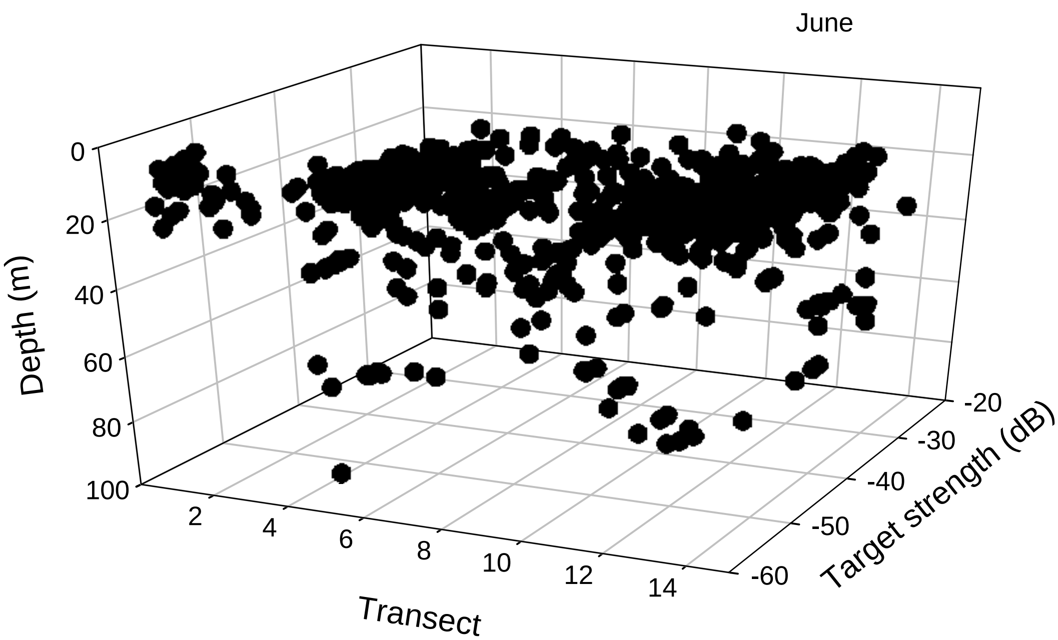


Figure 24. Target strength and age distribution of kokanee (<-33 dB) during June and August 2003 at Payette Lake.



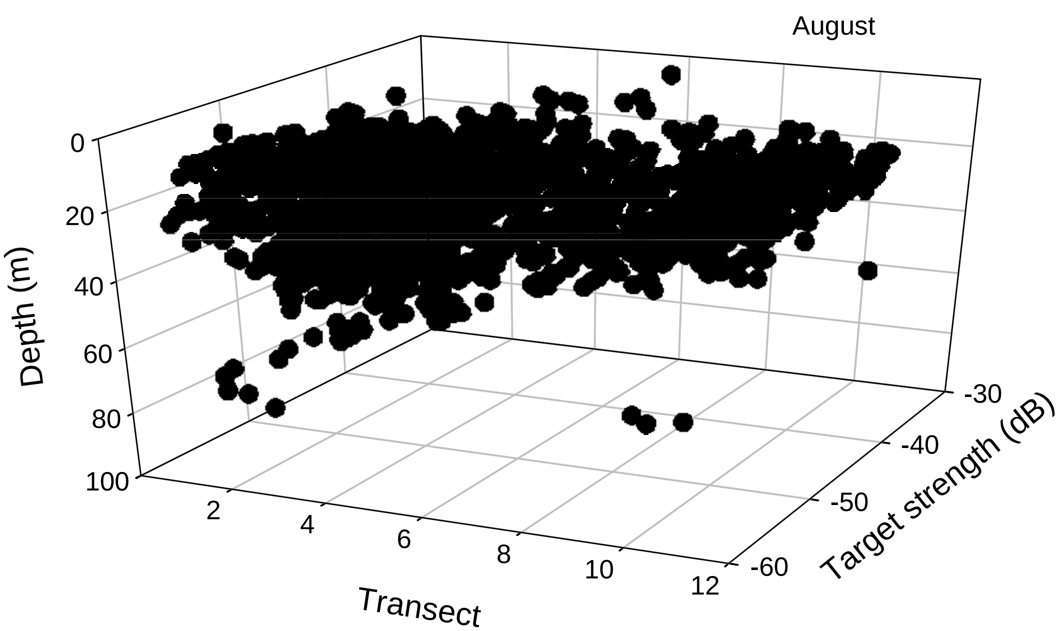


Figure 25. Horizontal and vertical distribution of tracked fish at Payette Lake in June and August 2003.

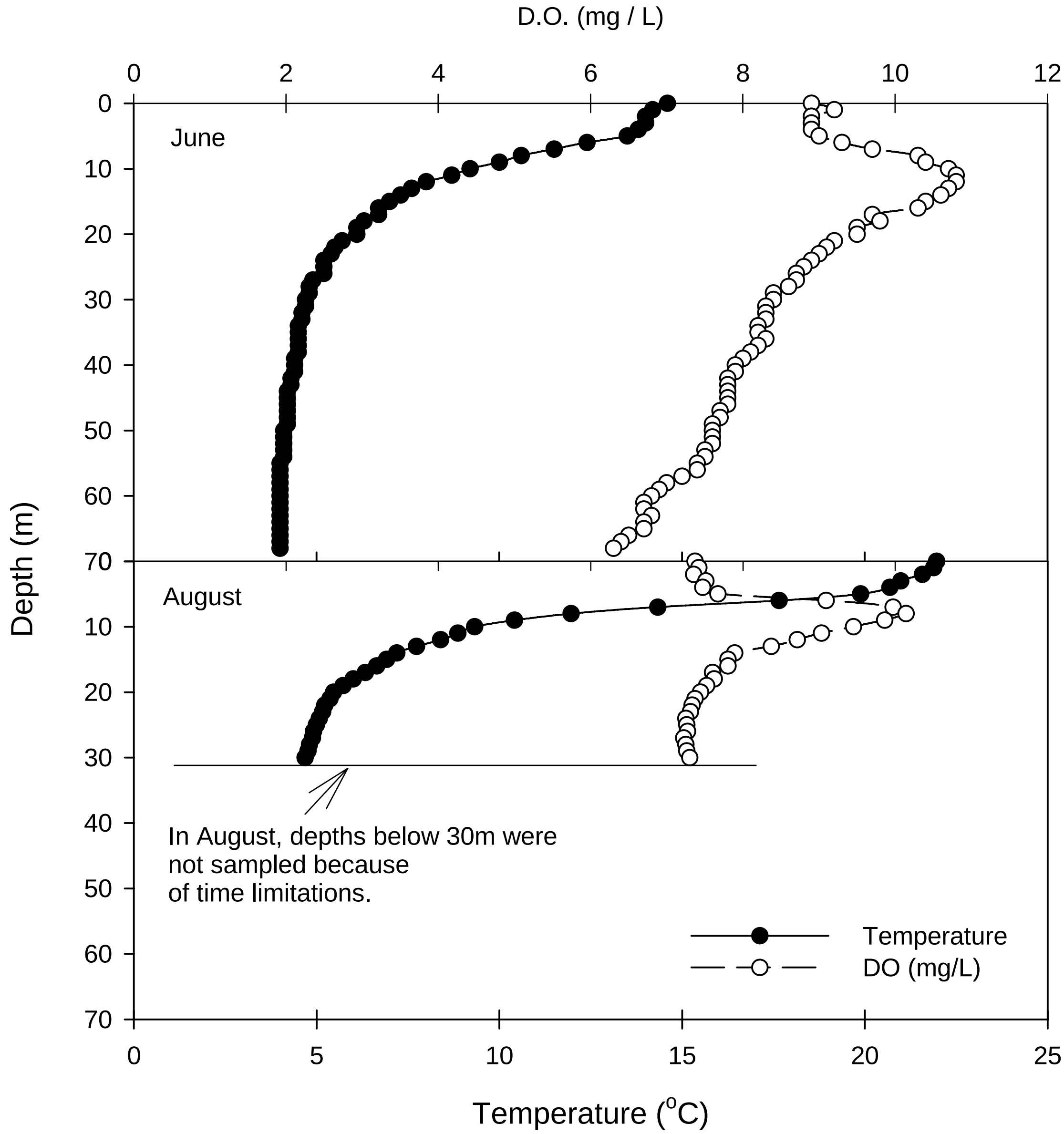


Figure 26. Vertical temperature (°C) and dissolved oxygen (DO; mg/L) profiles at three sites in Payette Lake during the fish assessment survey in June and August 2003.

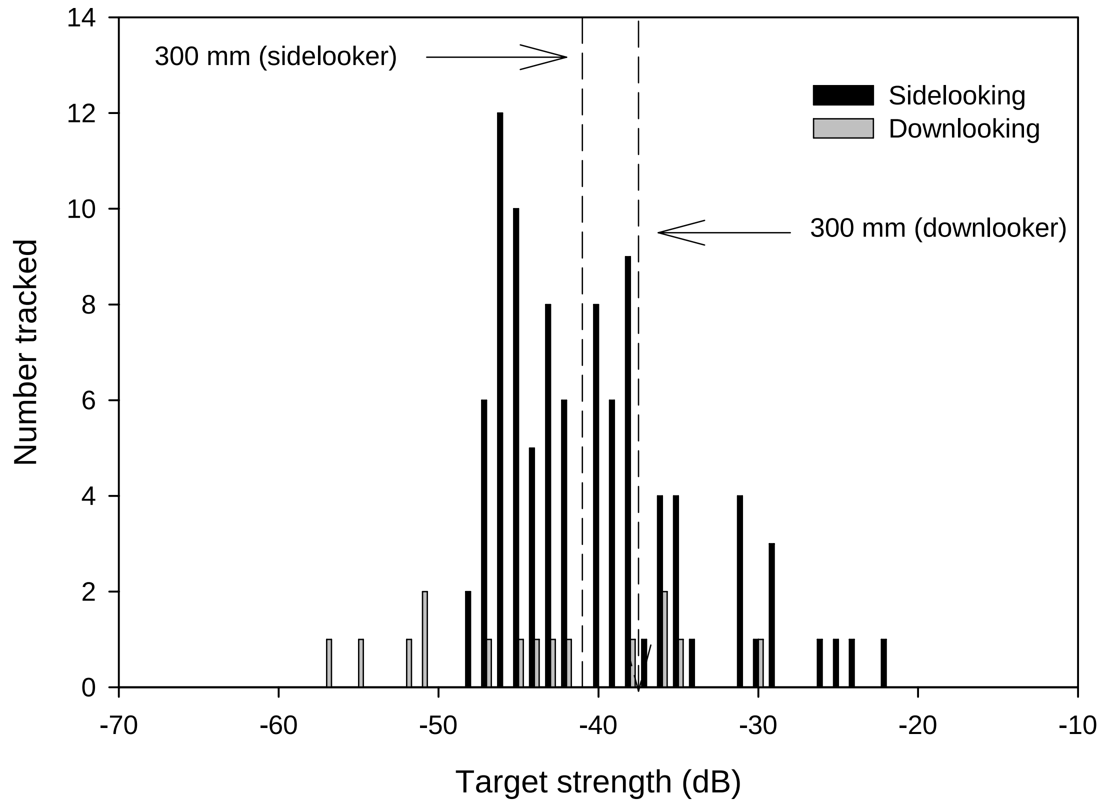


Figure 27. Target strength frequency distribution of fish detected by hydroacoustics at Sage Hen Reservoir during the June 2003 survey.

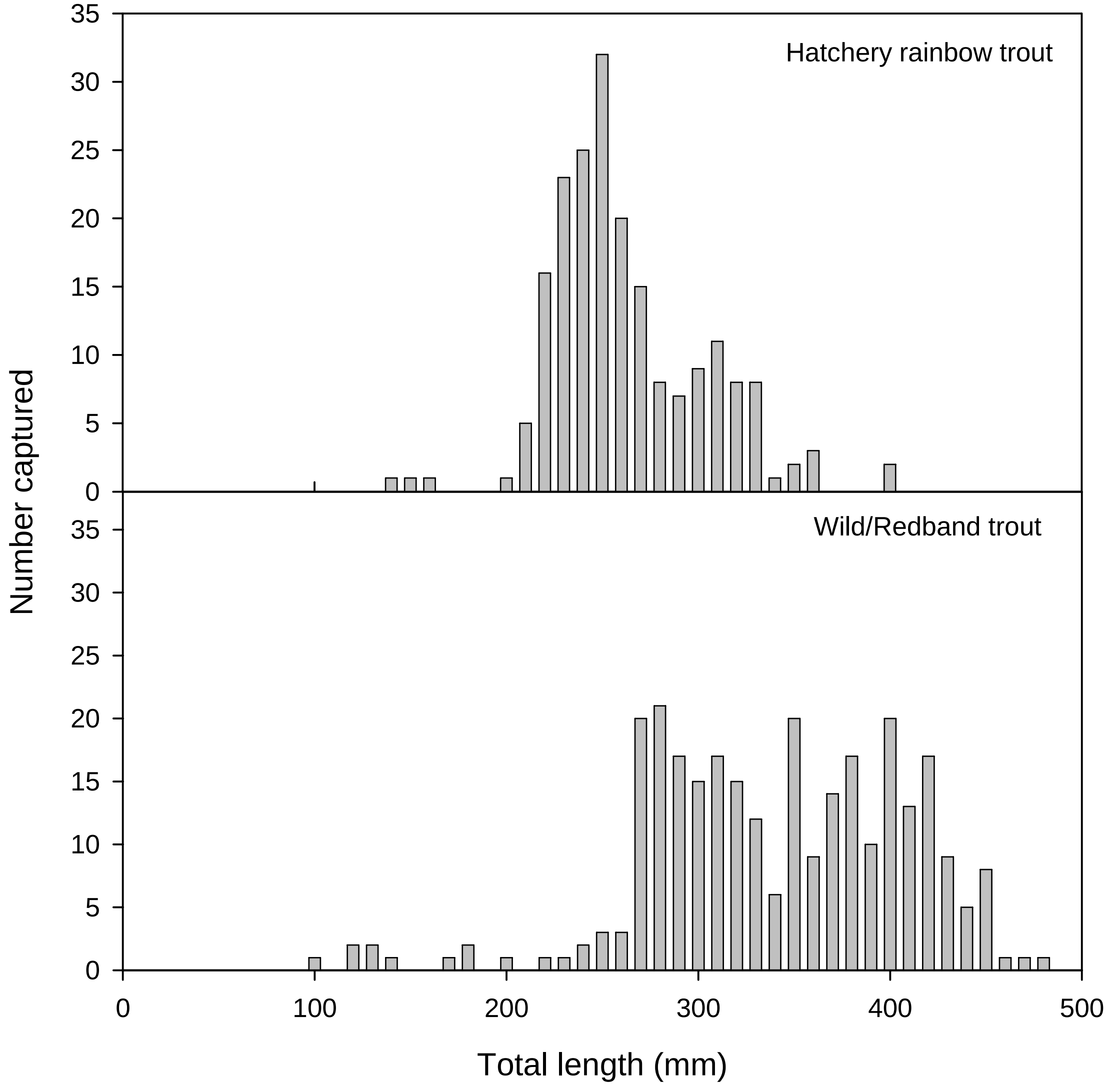


Figure 28. Length distribution of fish captured in gillnets at Sage Hen Reservoir during the June 2003 survey.

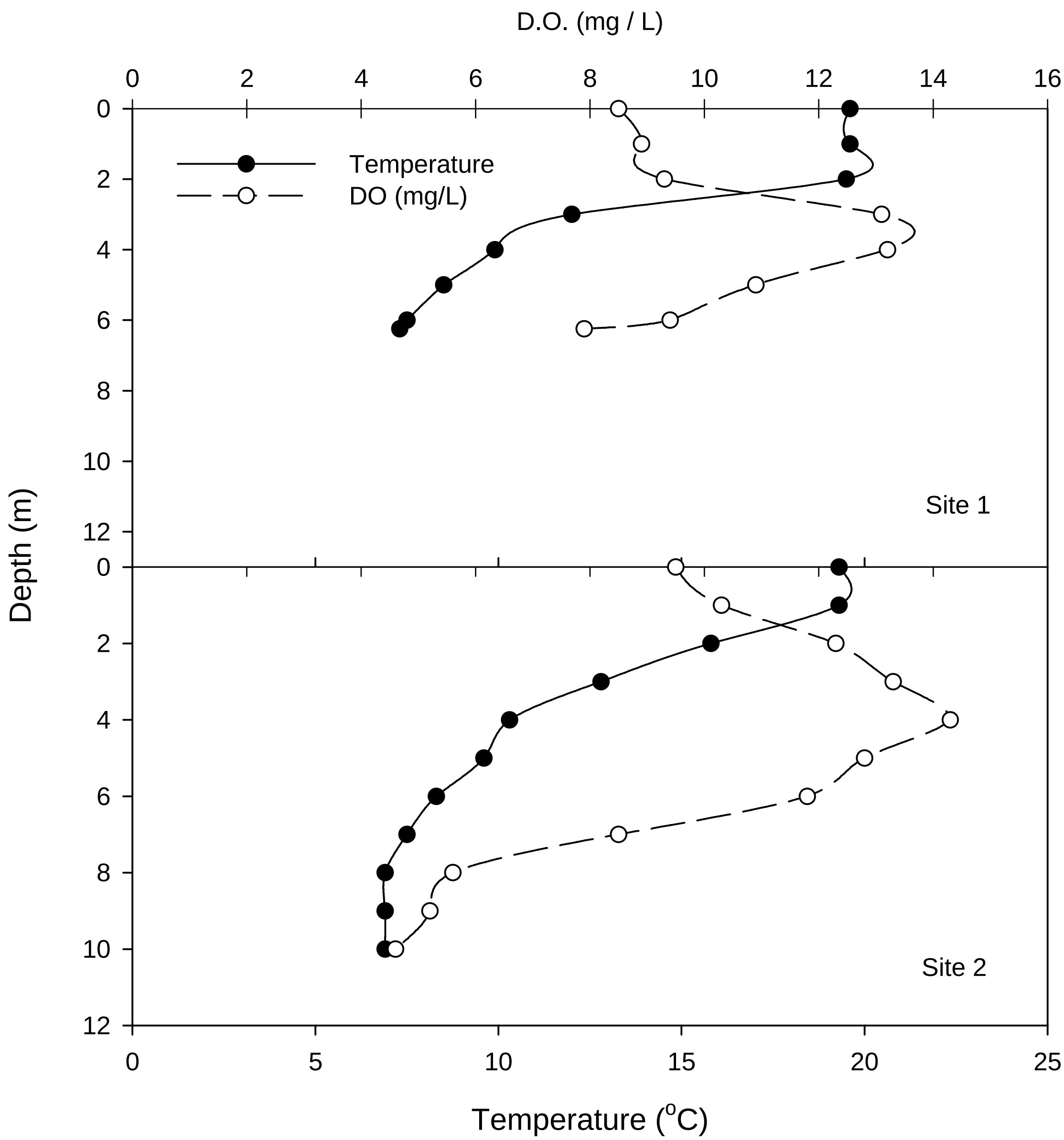


Figure 29. Vertical temperature (°C) and dissolved oxygen (DO; mg/L) profiles at two sites in Sage Hen Reservoir during the fish assessment survey in June 2003.

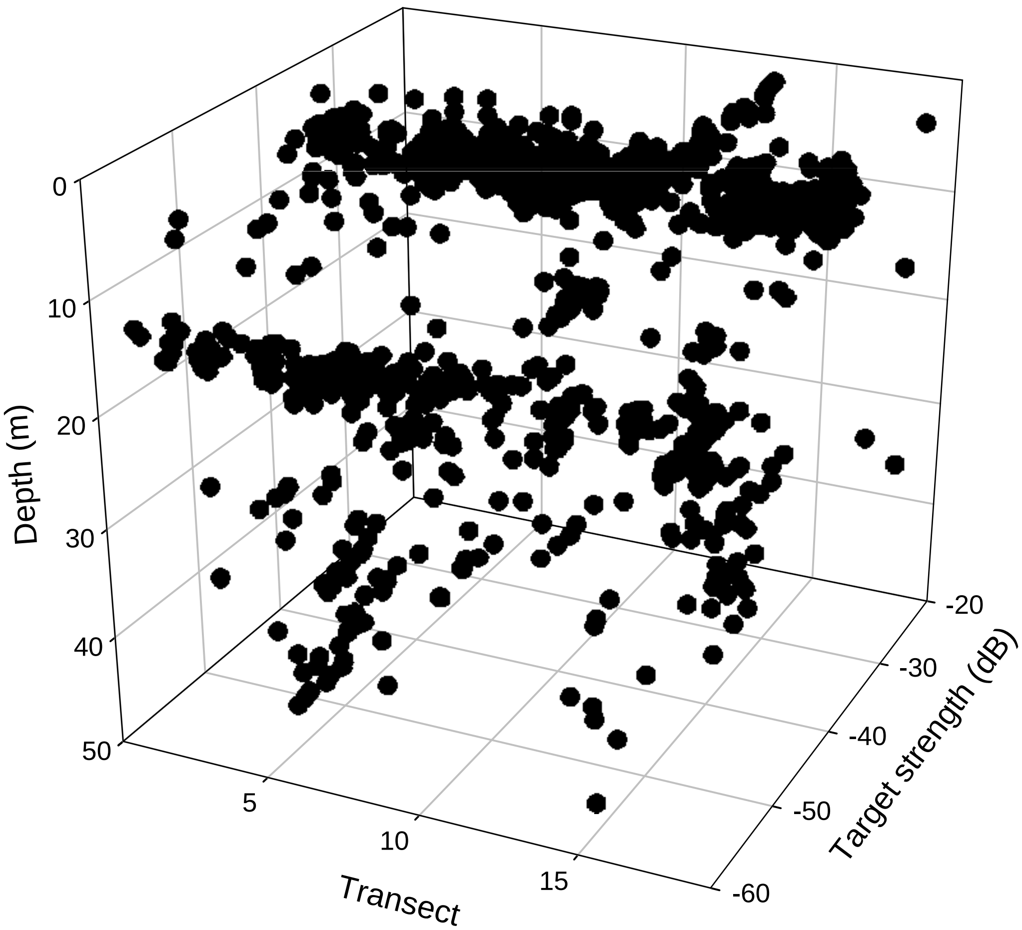


Figure 30. Horizontal and vertical distribution of tracked fish at Williams Lake in September 2003.

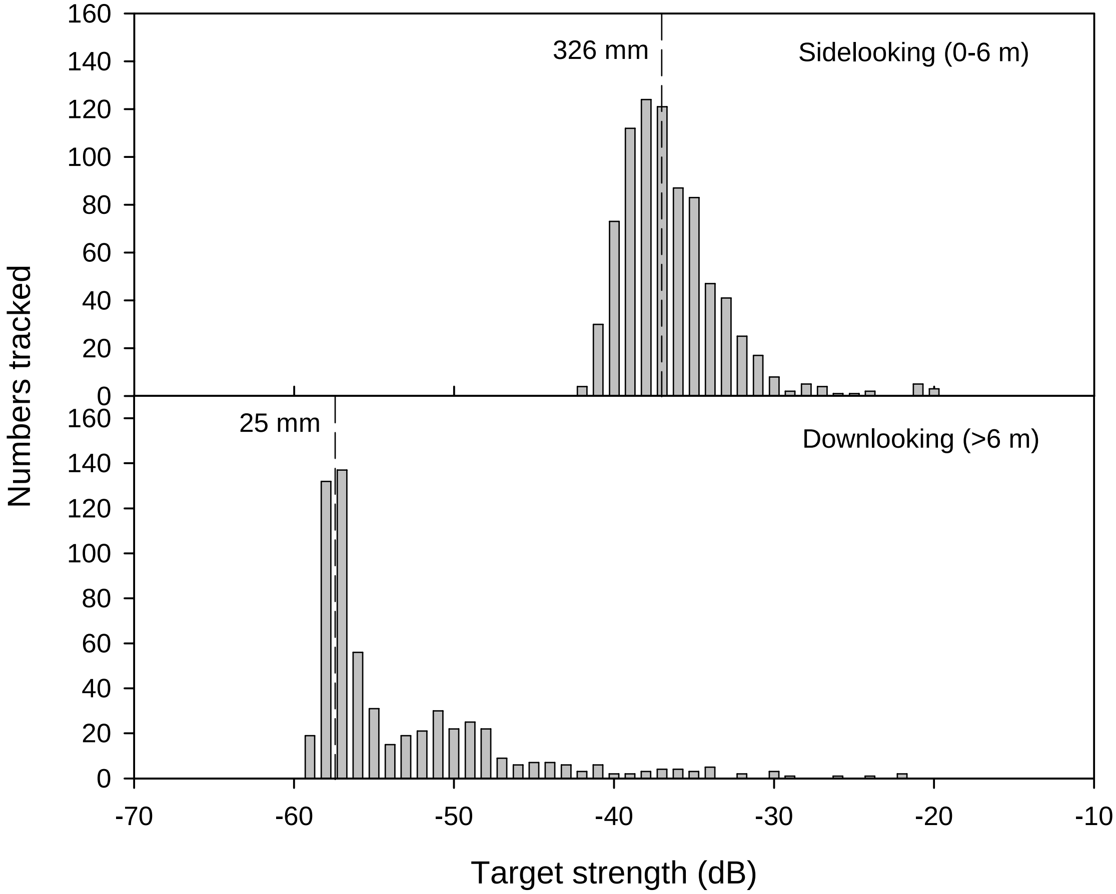


Figure 31. Target strength distribution of targets detected during the September 2003 survey at Williams Lake.

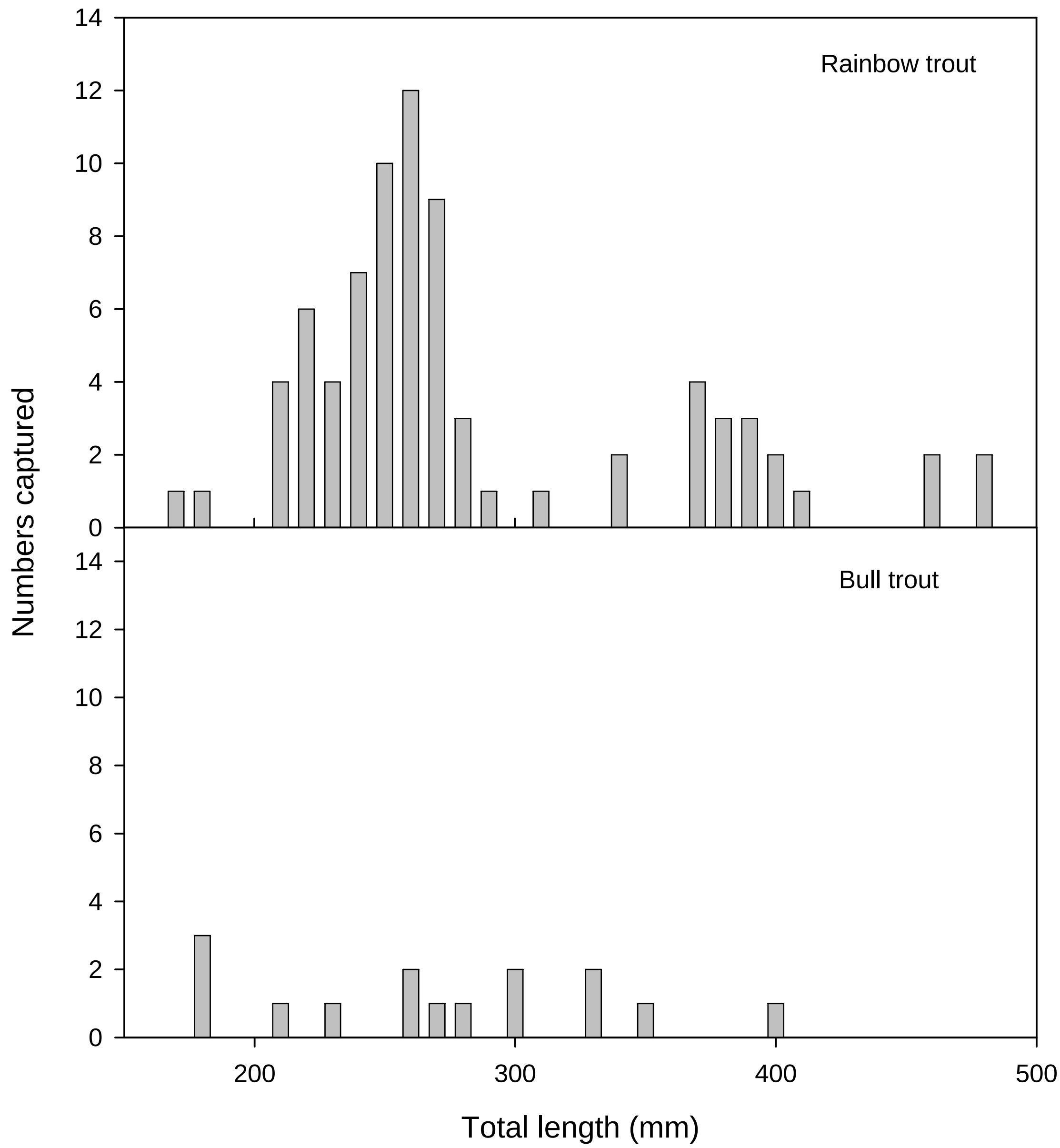


Figure 32. Length frequency of fish captured in gillnets at Williams Lake in September 2003.

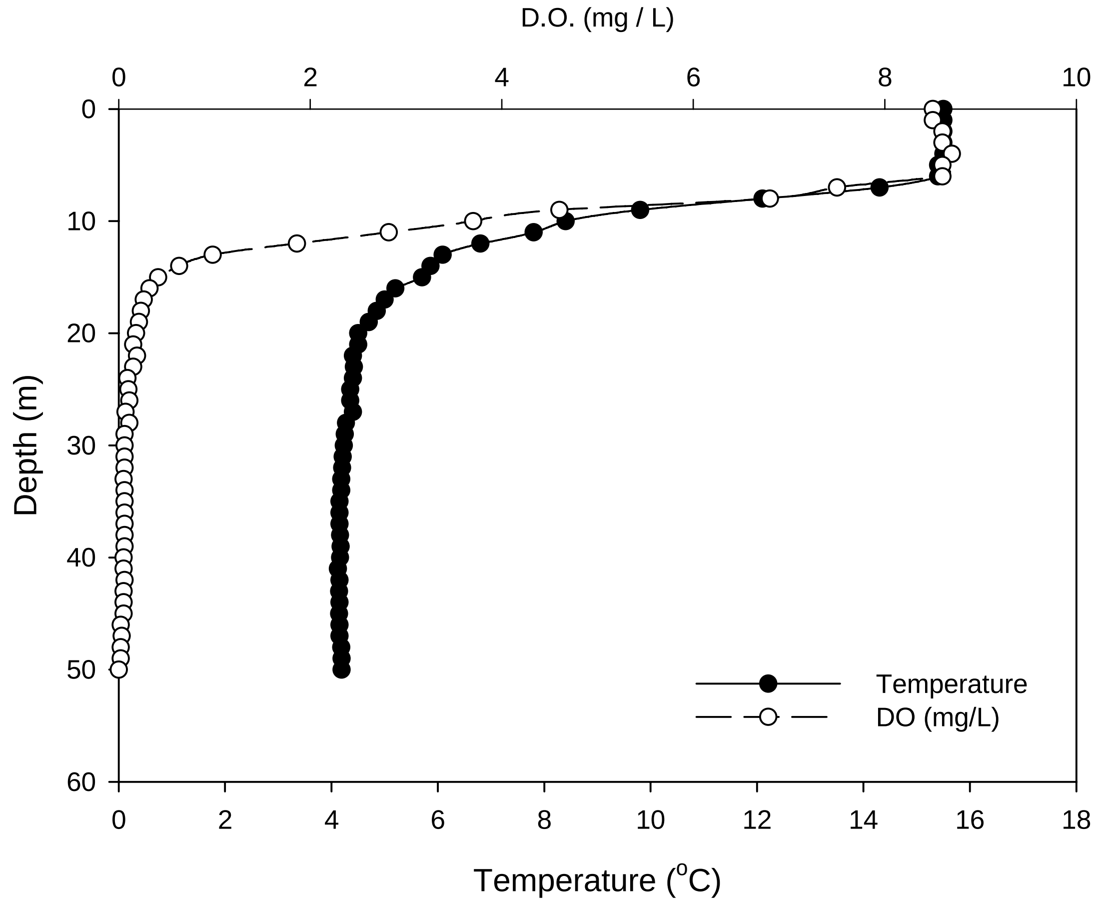


Figure 33. Vertical temperature (°C) and dissolved oxygen (DO; mg/L) profiles at Williams Lake during the fish assessment survey in September 2003.

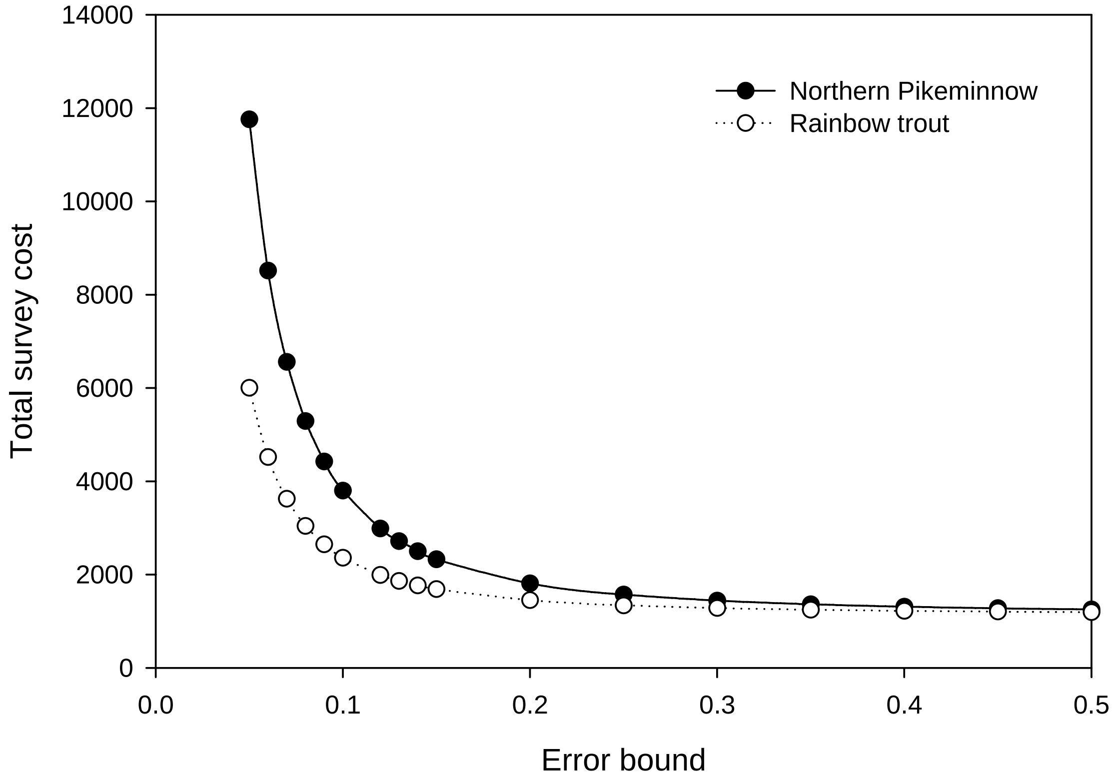


Figure 34. Relationship between the desired error bound around an individual species abundance estimate and total survey cost, including labor, fuel, and meals.

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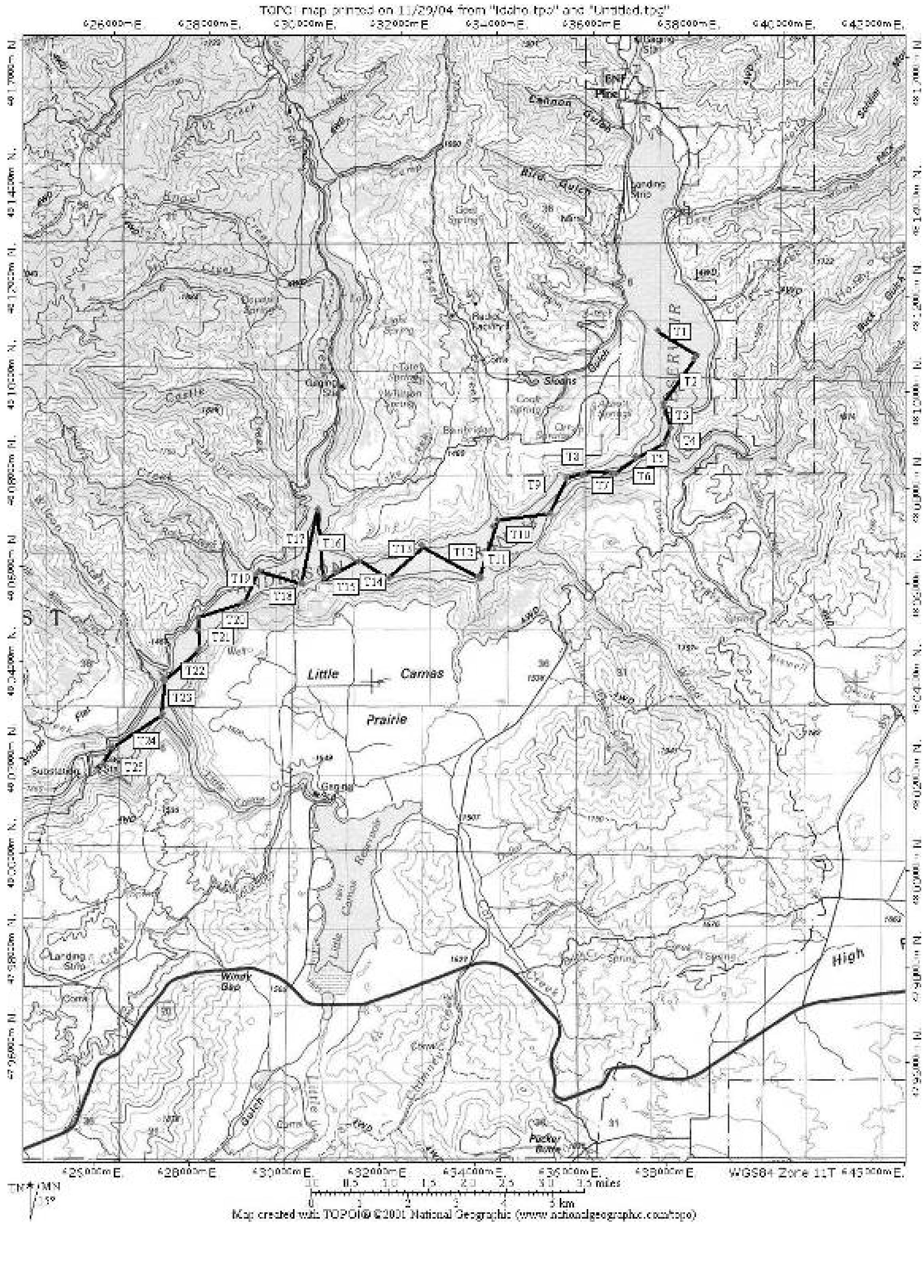
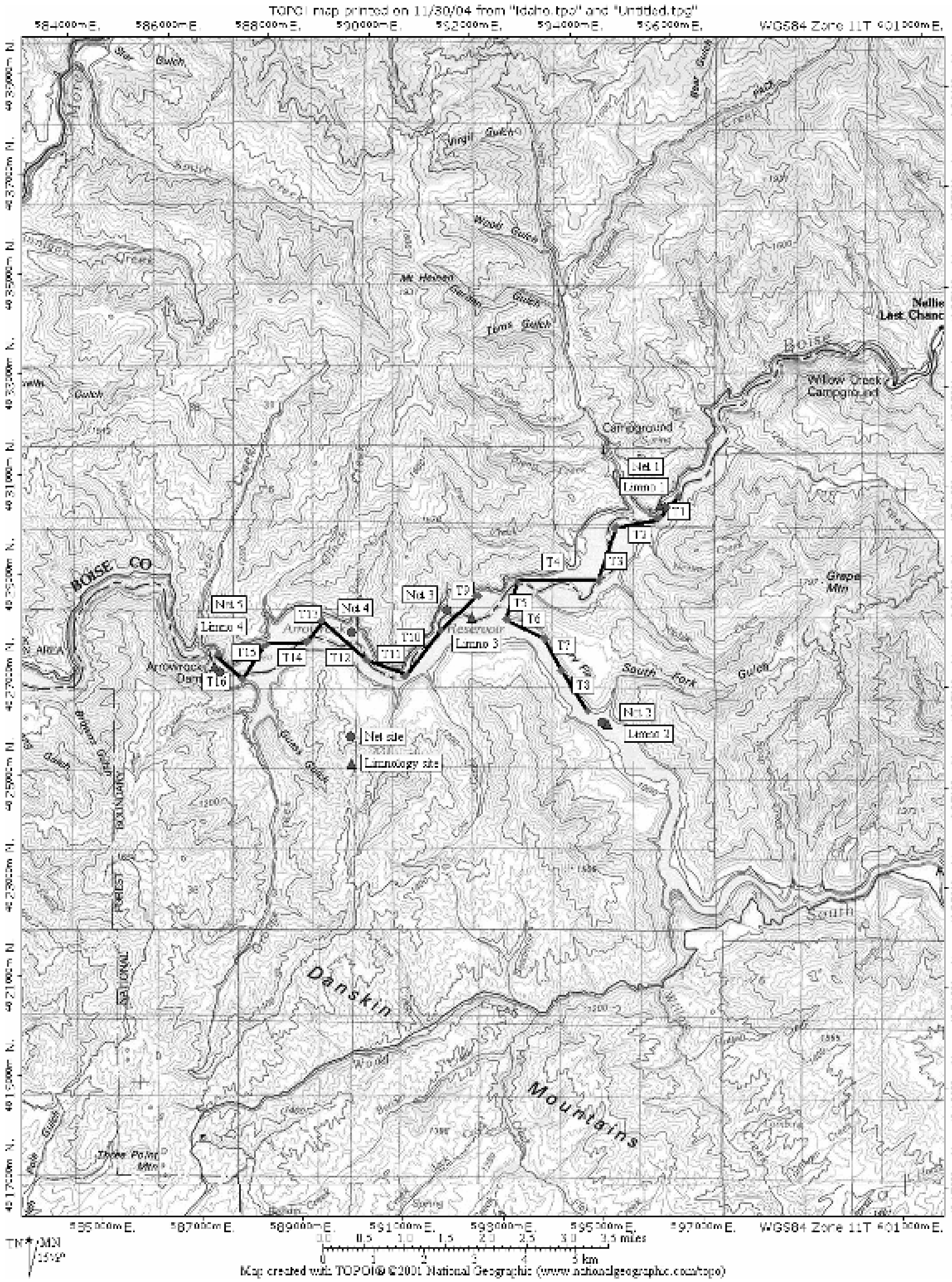
APPENDICES

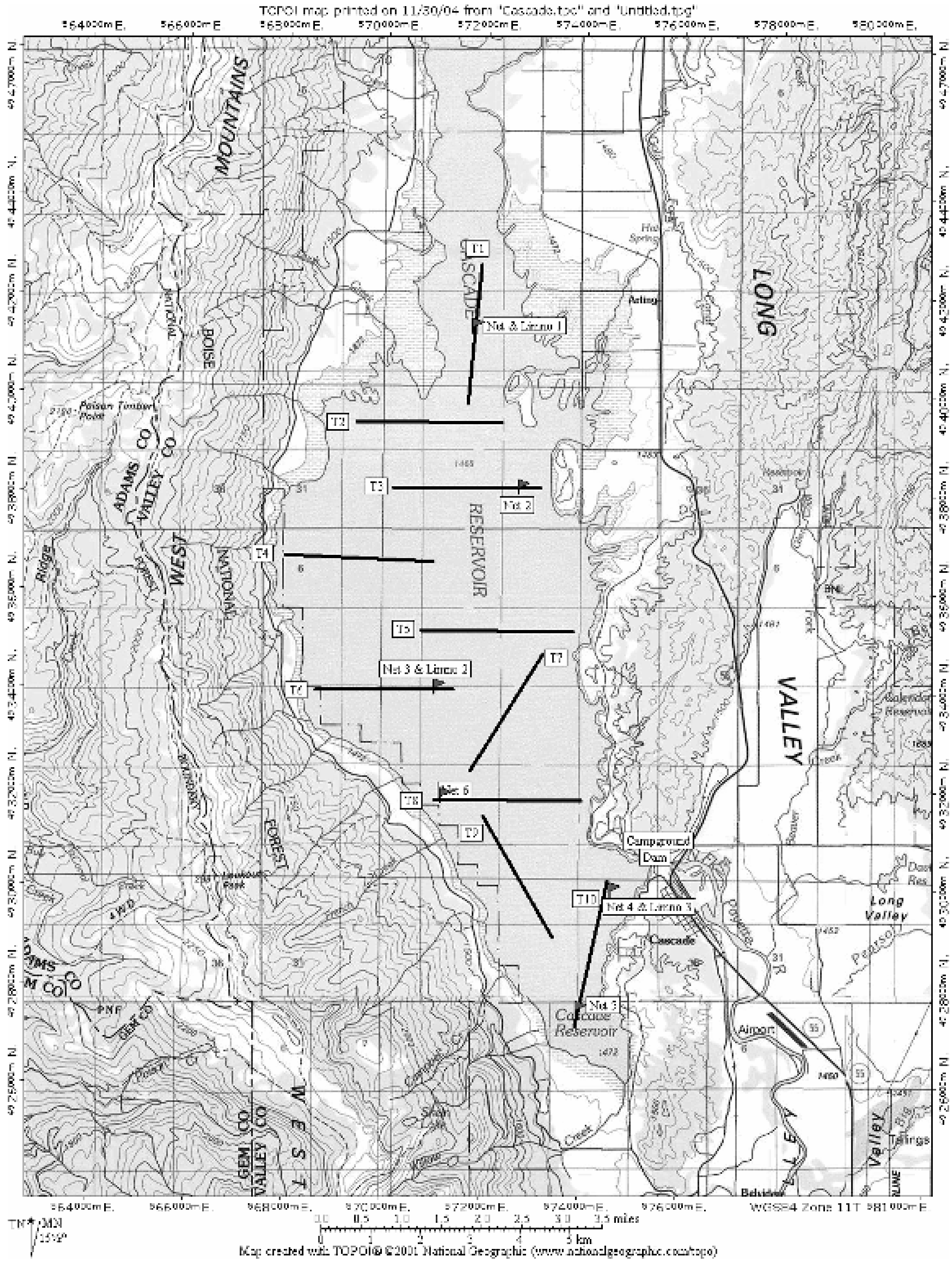
Appendix A. Hydroacoustic transects sampled during August 27, 2003 survey at Anderson Ranch Reservoir.



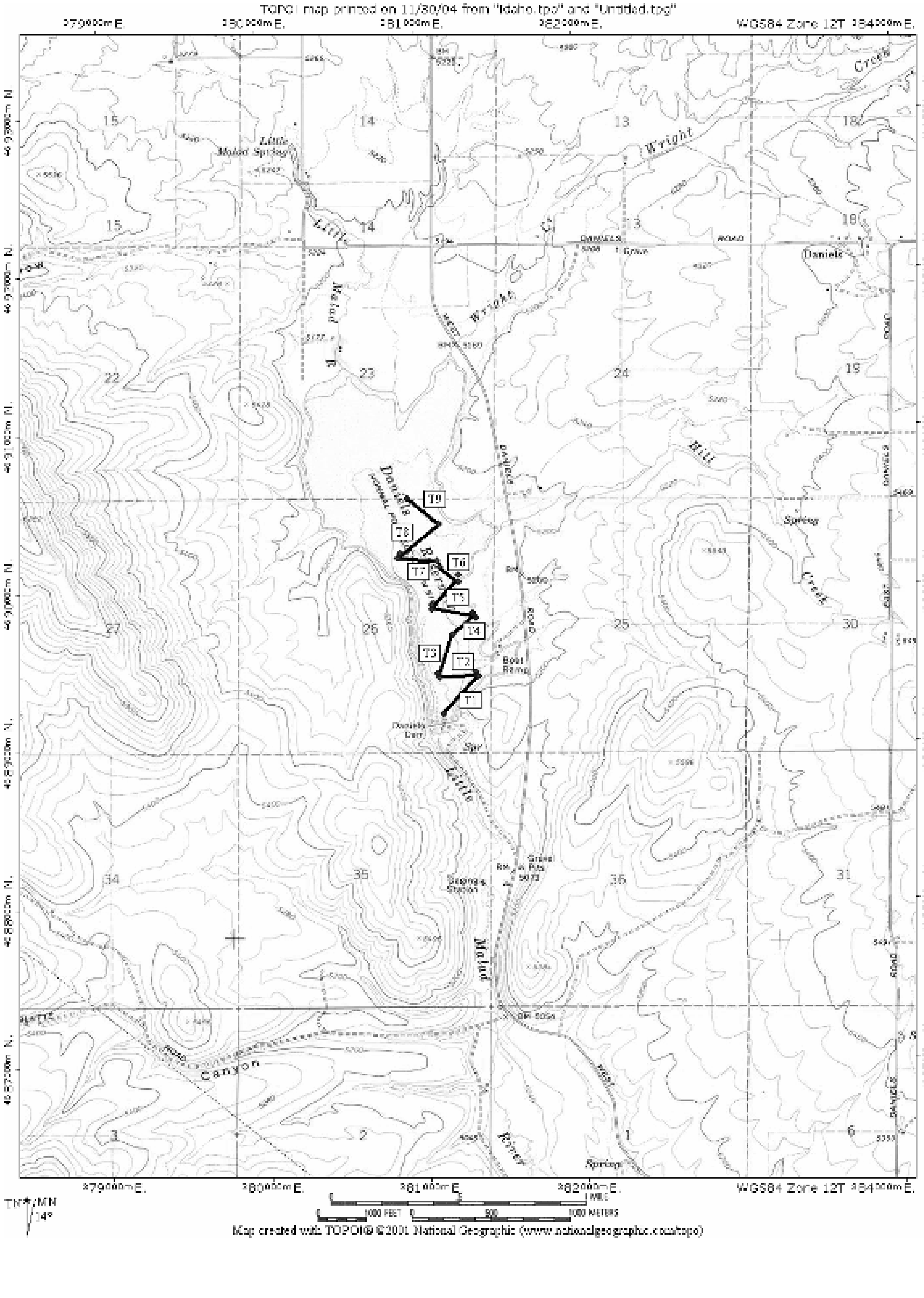
Appendix B. Hydroacoustic transects, netting sites, and limnology stations for the 2003 fish assessment surveys at Arrowrock Reservoir.



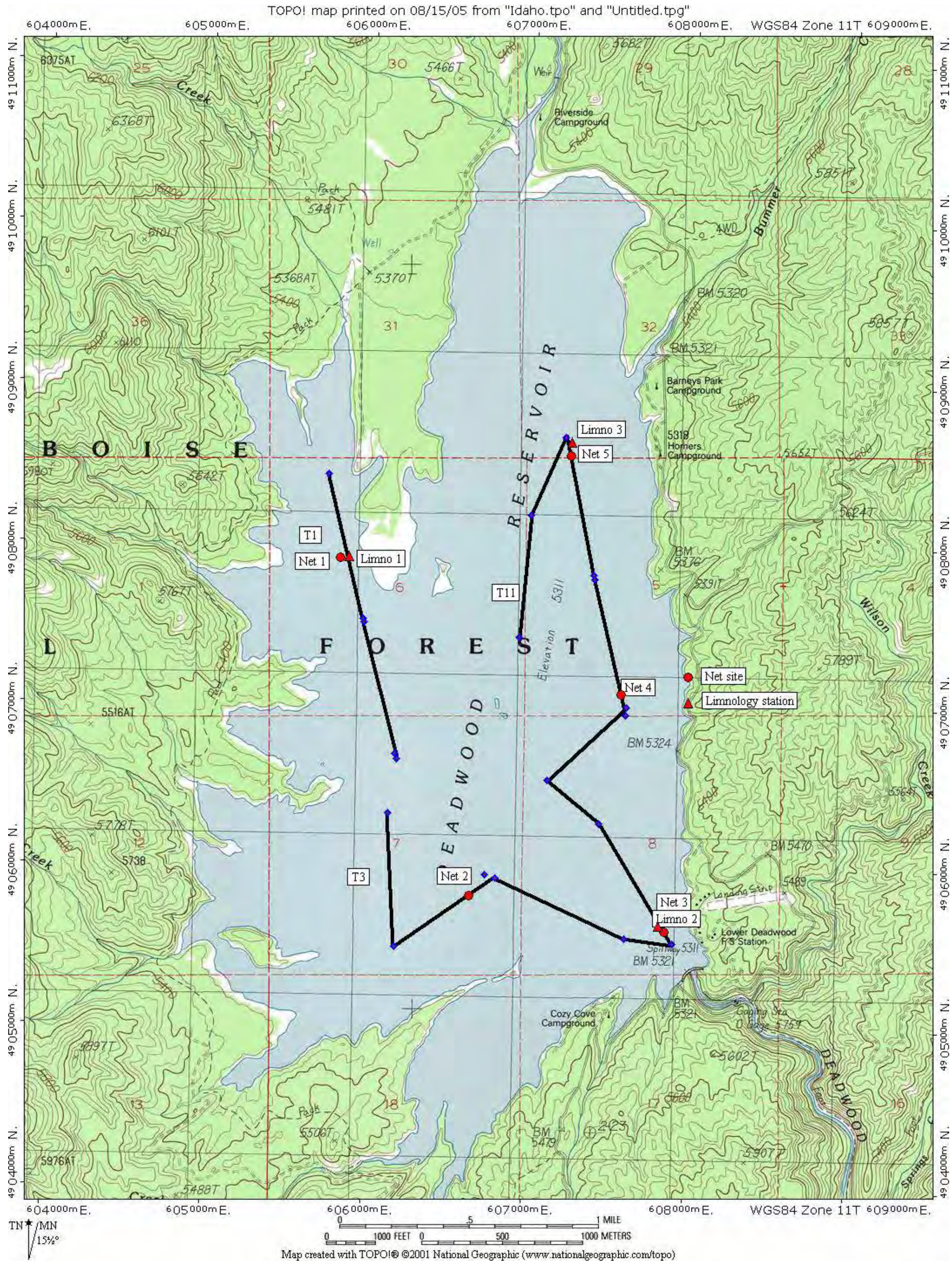
Appendix C. Hydroacoustic transects, netting sites, and limnology stations for the 2003 fish assessment survey at Cascade Reservoir.



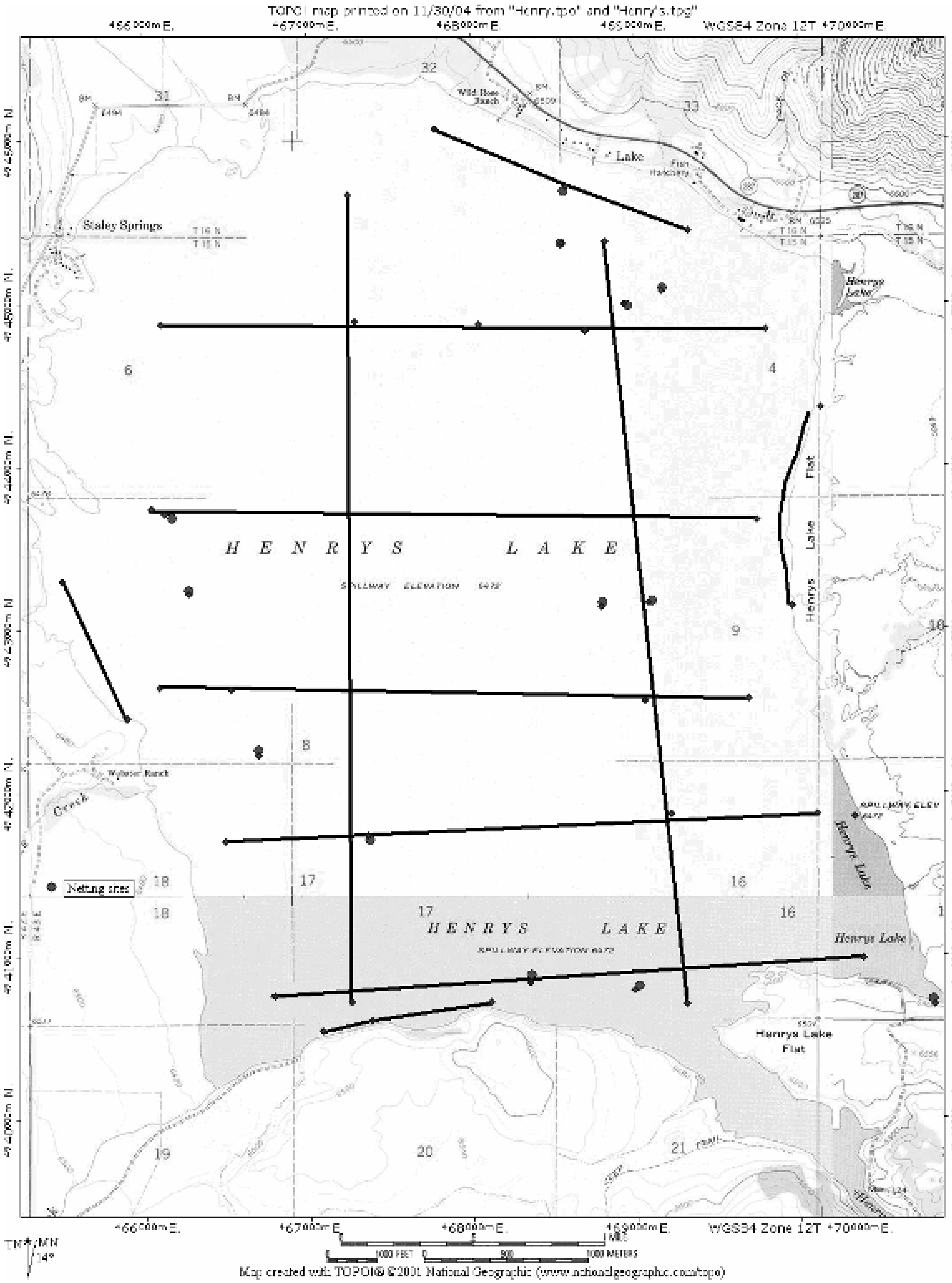
Appendix D. Hydroacoustic transects sampled during the 2003 survey at Daniels Reservoir.



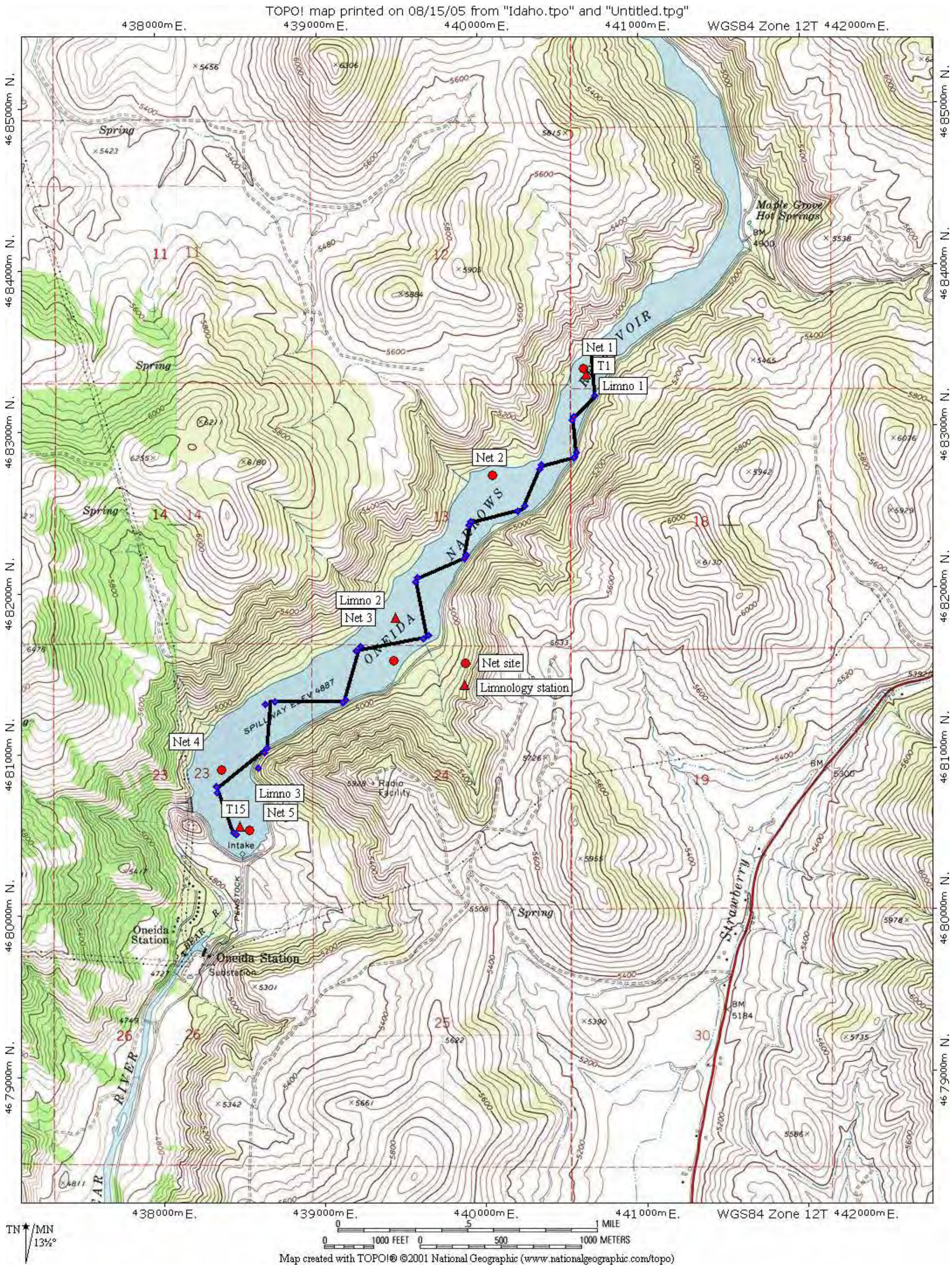
Appendix E. Hydroacoustic transects, netting sites, and limnology stations for the 2003 fish assessment survey at Deadwood Reservoir.



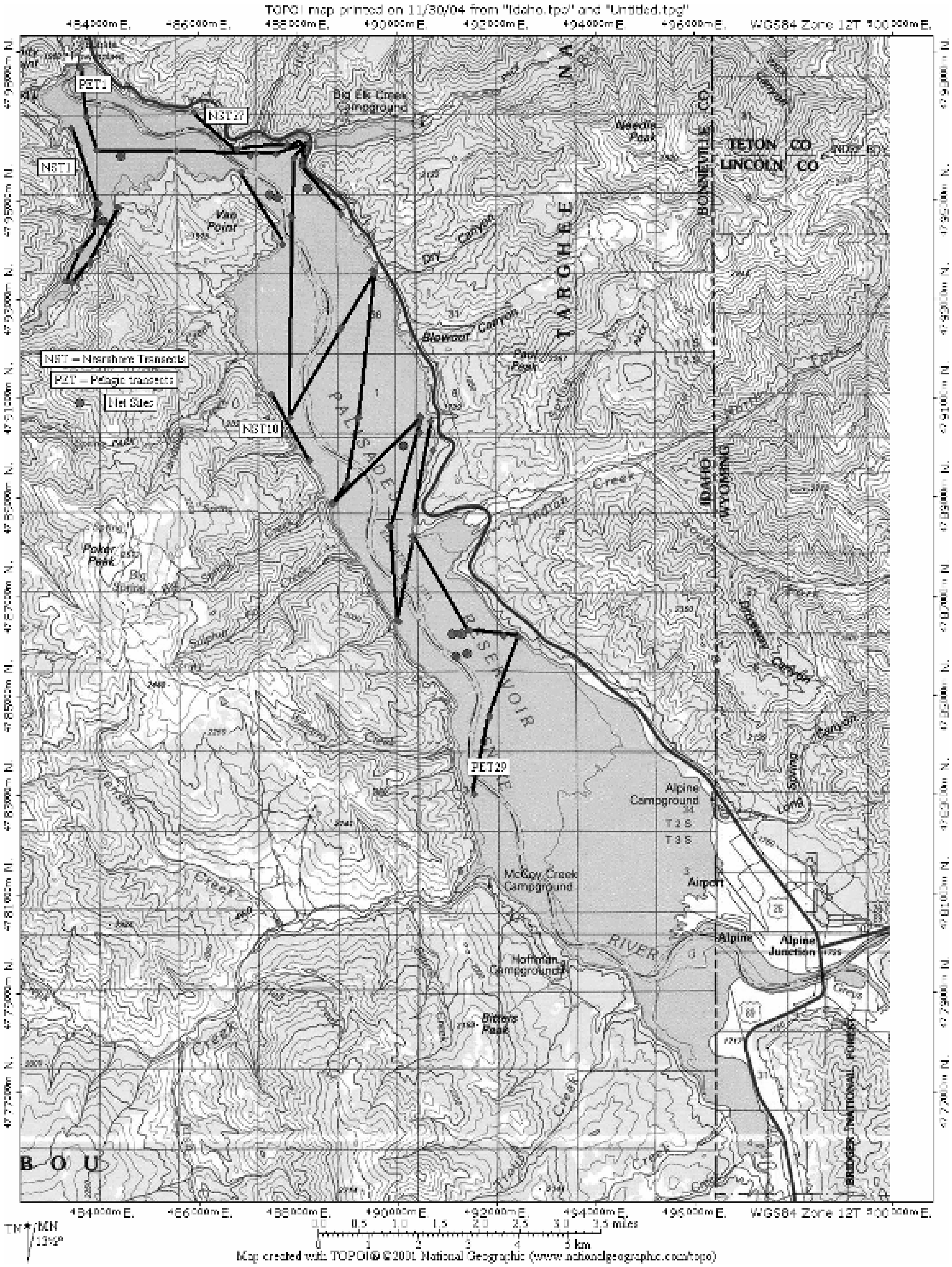
Appendix F. Hydroacoustic transects and netting sites sampled during the May 2003 survey at Henrys Lake.



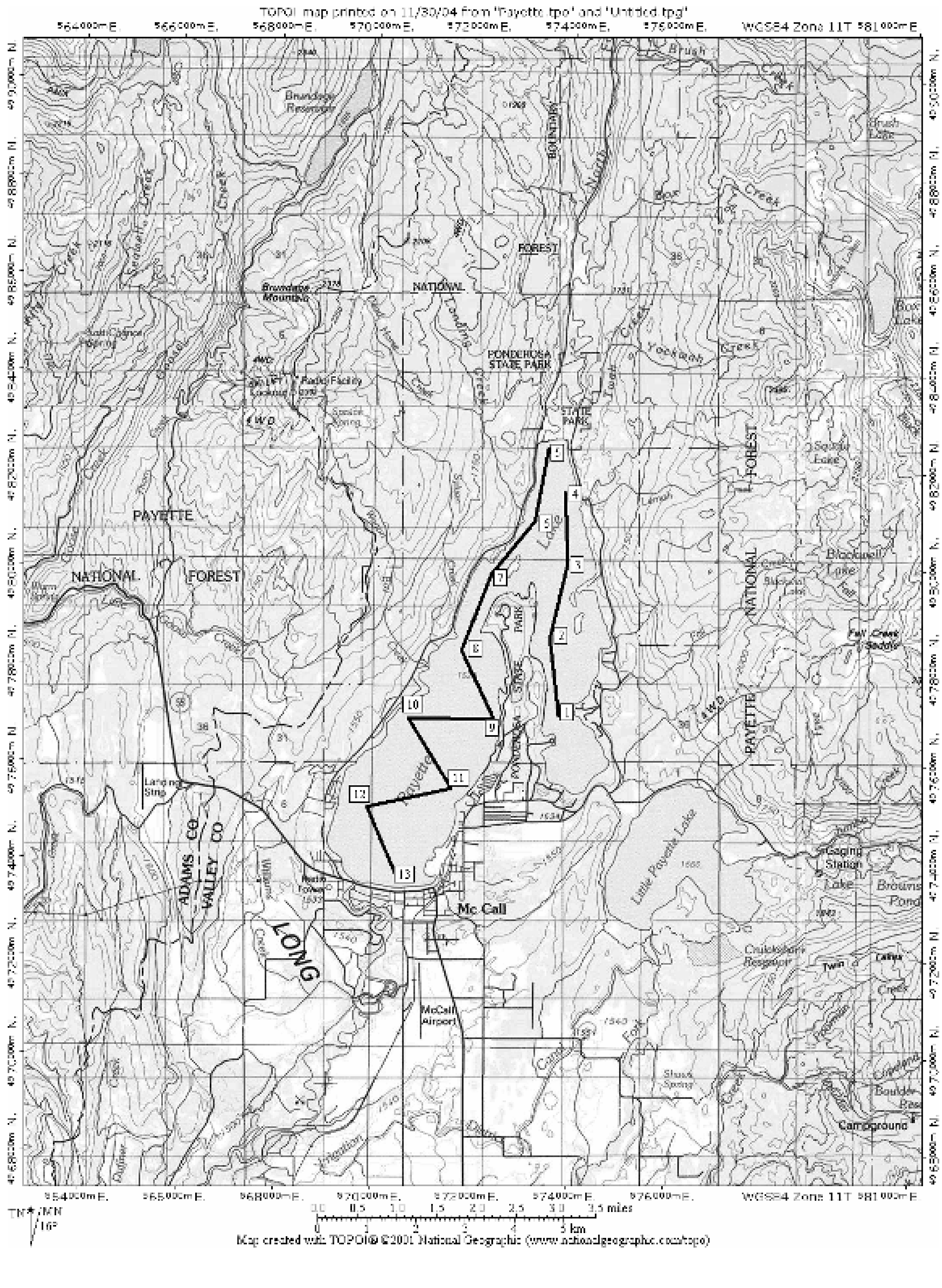
Appendix G. Hydroacoustic transects, netting sites, and limnology sites sampled during the June 2003 survey at Oneida Reservoir. The upper portion of the reservoir was too shallow to sample safely with sonar.



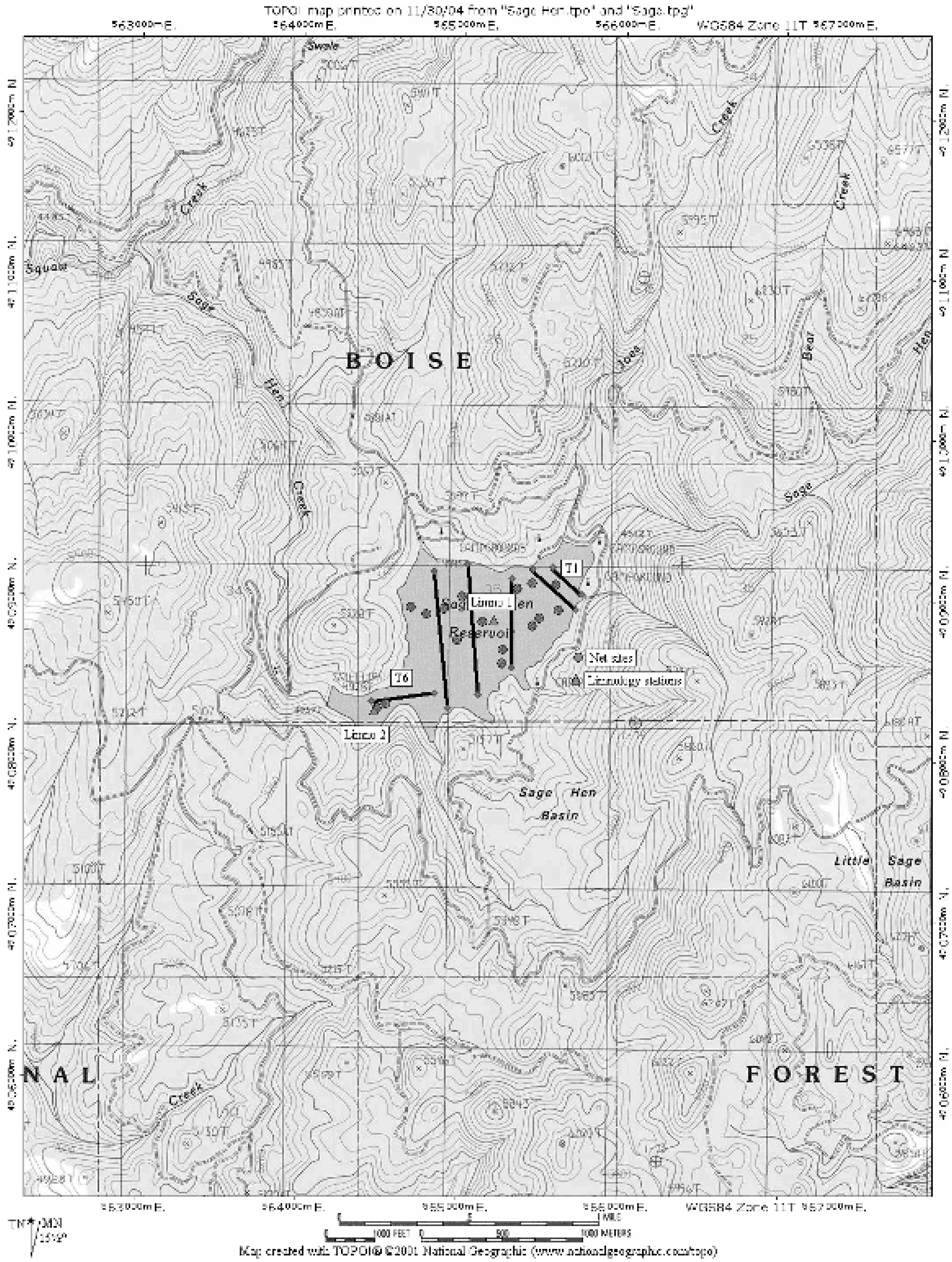
Appendix H. Hydroacoustic transects and netting sites sampled during the 2003 Palisades Reservoir survey. The upstream area of the reservoir was too shallow to sample with hydroacoustics.



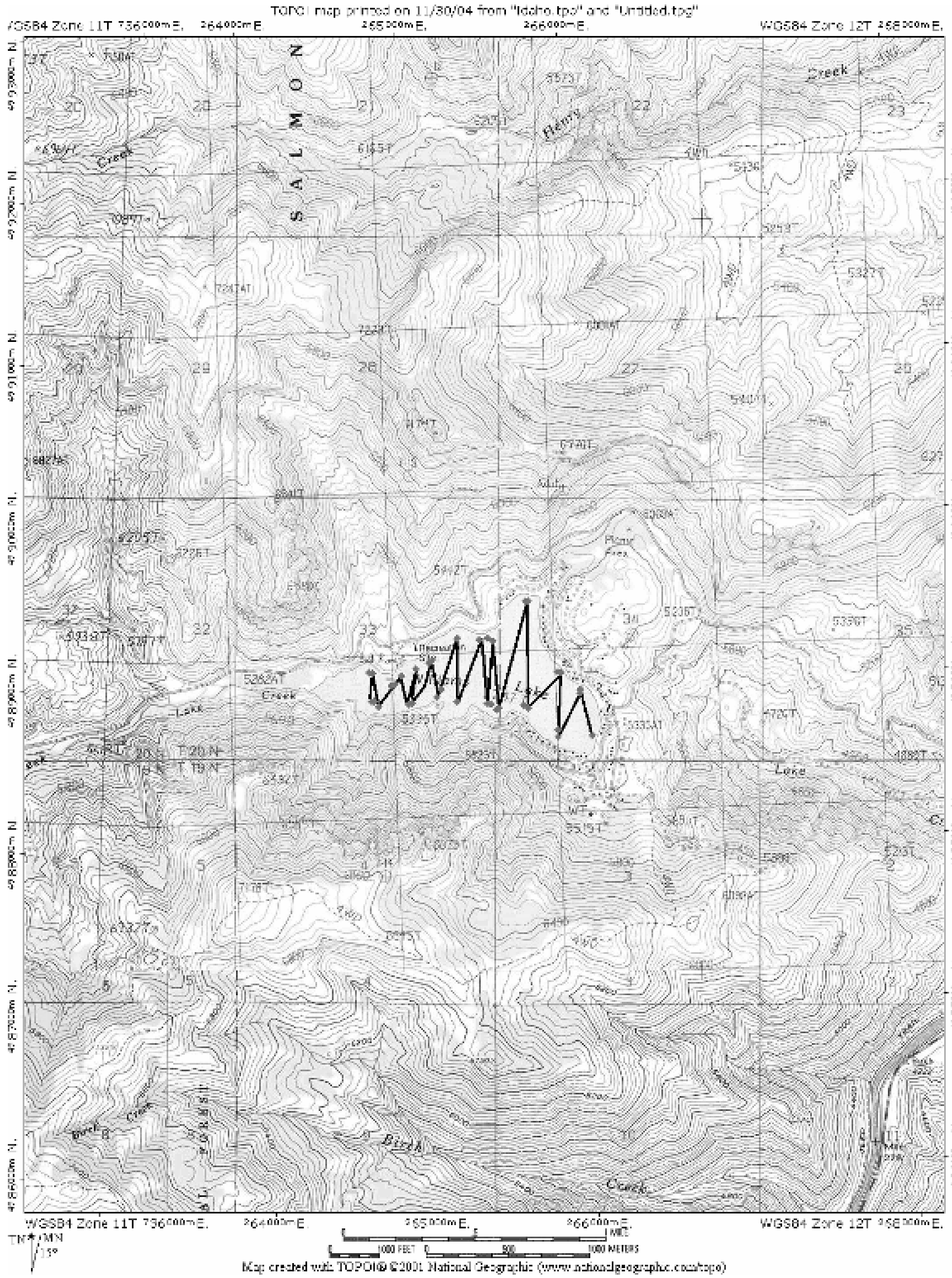
Appendix I. Hydroacoustic transects sampled during the June and August 2003 survey at Payette Lake.



Appendix J. Hydroacoustic transects, netting sites, and limnology stations sampled during the June 2003 Sage Hen Reservoir survey.



Appendix K. Hydroacoustic transects for September 2003 survey at Williams Lake. Coordinates for nets were not recorded.



Prepared by:

Arthur E. Butts
Senior Fishery Research Biologist

Approved by:

IDAHO DEPARTMENT OF FISH AND GAME

Virgil K. Moore, Chief
Bureau of Fisheries

Daniel J. Schill
Fisheries Research Manager