Hydroacoustic assessment of resident species in the Ugashik Lakes, Alaska

Garrett James Staines

A Thesis
Submitted to
The Davis College of Agriculture, Forestry, and Consumer Sciences
West Virginia University
in partial fulfillment of the requirements
for the degree of

Master of Science
in
Wildlife and Fisheries Resources

Kyle J. Hartman Ph.D., chair
Patricia M. Mazik, Ph.D
Michael P. Strager, Ph.D
F. Joseph Margraf, Ph.D
James P. Larson, M.S.

Department of Wildlife and Fisheries

Morgantown, West Virginia 2008

Keywords: hydroacoustics, distribution, target strength, management, abundance

Abstract

Hydroacoustic assessment of resident species in the Ugashik Lakes, Alaska

Garrett James Staines

The Ugashik Lakes in southwest Alaska are a large, remote, thereimictic system that does not thermally stratify during the ice-free season. Little research has been done on the resident species of this system and others similar to it. However, with such little baseline information management agencies are still responsible for management of these lakes. In order to provide baseline data on the Ugashik Lakes resident species, hydroacoustic (2001-06) and gillnet (2004-06) surveys were performed.

Chapter 2 uses specific data gathered from the hydroacoustic unit to produce a target strength (TS) and length relationship for salmonids found in the Ugashik Lakes. The equation produced from this experiment is of the standard format using a slope of 20: $TS = 20 \cdot \log_{10}(L_{cm}) - 78.53$ ($R^2 = 0.49$). This relationship differs markedly from the commonly used equations of Love and Foote.

In Chapter 3 using the hydroacoustic and gillnet datasets I determined fish density and abundance estimates for each resident species in the Ugashik Lakes. These estimates showed large annual variances. I discuss the possible causes of these large variance values from the perspective of sampling and systematic error. The large variances prevent meaningful statistical comparisons. However, these estimates may still prove useful in monitoring fish populations through time series analysis.

Along with fish density data, hydroacoustics collects large amounts of data on the spatial distribution of fish and bathymetry of the lakes being sampled. Chapter 4 addresses the use of GIS software to create detailed maps showing the bathymetry and distribution of fish density in The Ugashik Lakes. Natural neighbor interpolation was used to fill in data gaps between hydroacoustic survey transects. This will aid in the visual presentation of fisheries data.

From the hydroacoustic and gillnet surveys I was able to develop an annual sampling strategy as an appendix that a fisheries management agency can implement. I present both echo integration and echo counting procedures used for hydroacoustics data. Within each of these procedures I present various statistical analyses and their strengths and weaknesses that can be used to determine density and abundance estimates. Apportioning species by density estimates was determined using gillnet catch percentages. In addition, I discuss the most efficient means of collecting both hydroacoustic and gillnet data to suit the Ugashik Lakes and other similar lake systems.

Acknowledgements

First and foremost I would like to thank Dr. Kyle Hartman for accepting me as his Master's student with little educational background in fisheries science. I appreciate his patience in my learning the "black art" of hydroacoustics and the difficult statistical analysis that accompanies this fisheries tool. Next, I would like to thank all of those on my committee: Dr. Pat Mazik, Dr. Mike Strager, Dr. Joe Margraf, and Jim Larson for the time they put into my learning fisheries science so that I may apply it vigorously in the future.

A graduate student will gain nothing without the help of good field technicians. My thanks goes out to Lora Tennant, Seafha Blount, and Aleya Nelson for their help in my 2005 field season and to Brett Moore and Jennifer Moore for their help in 2006. In addition to these field technicians I must also thank the USFWS office in King Salmon. Thank you Jim Larson, Jeff Anderson, Mike Edwards, Cheryl Dion, Marion Burgraff, and Kara Cornum. Without you, life in field camp would have been unbearable.

Thank you to Mia Strauss, Jay Valliere, Matt Burdick, Miranda Plumb, Dan Spencer, Paula Smith, and Adam Peterson for introducing me to Alaska and the Ugashik Lakes.

Much thanks goes to Dr. George Seidel and Dr. Pat Sullivan for their help in statistical analysis.

I must also thank Bob and Carol Dreeszen for all of their hospitality. Without them our field season would have been a little less comfortable. Their local knowledge proved indispensable at times. Another local I must thank is Ludwig Bröd for making my time at The Narrows so colorful.

Funding for this project came from the United States Fish and Wildlife Service.

Lastly, thanks to Ryan, Chris, Ken, Jason, Jon, Andy, Jered, Holly, Sarah, Walt, Lora, Aaron, Janine, Kit, John, Donna, Autumn, Bill, Brett, and Emily for making my time in West Virginia so much fun.

I dedicate this thesis to my parents, Reggie and Judy Staines.

Table of Contents

Chapter 1: Literature Review

The Ugashik Lakes are located in the Alaska Peninsula National Wildlife Refuge 120 km southwest of the town of King Salmon. The upper lake flows into the lower lake via the Ugashik Narrows. The Narrows is a short river-like area approximately 0.5 km long (Figure 1). The Narrows is where the majority of the recreational fishing pressure occurs. The lower lake then flows out into the Ugashik River and empties into the Ugashik Bay, which is in Bristol Bay. Most inflow of the two lakes comes from the east in the form of tributaries. Access to the lakes is limited to boat or floatplane. The nearest village is Ugashik, Alaska, located 40 km down the Ugashik River.

The Ugashik Lakes are a good representation of large, deep, remote lakes that are found on the Alaska Peninsula. The surrounding area is a source of sport fishing and subsistence fishing. Recently, recreational fishing pressure has increased and will likely continue in the future. Dunaway and Jaenicke (2000), report that angler-days have increased in this area from 25,000 in 1970 to 140,000 in 2000. Local subsistence residents have raised concern about the Arctic char (*Salvelinus alpinus*) and round whitefish (*Prosopium cylindraceum*) populations, citing decreased quantity and size of catches (USFWS 2003).

Like most remote lakes in Alaska, there is little known about the Ugashik Lake system and the dynamics of its fish populations. This is because, at present, there is no commercial fishery or significant in-lake sport fishery from which to obtain catch-data. Despite this limitation management agencies must find a way to manage these lakes and monitor fish populations. One way of monitoring this system is to gather initial baseline data and then continue to monitor populations over time to determine any changes in the fish population. The majority of past research in the area has been done in The Narrows between the upper and lower lakes as well as the outlet into the Ugashik River, mostly on Arctic grayling (*Thymallus arcticus*) (Meyer 1990; Villegas 1993). The Narrows is a well-known trophy grayling fishery. There have also been a number of studies on the sockeye (*Oncorhynchus nerka*) and coho salmon (*Oncorhynchus kisutch*) runs in this drainage, usually in the form of counting escapements into the drainage (Sands et al. 2002; Edwards and Larson 2004). However, in-depth studies on the resident populations of the Ugashik Lakes are lacking. The USFWS is currently trying to develop a methodology to assess density and abundance of the fish populations in the Ugashik Lakes and other nearby large lakes. The resident species presently found in the two lakes include: round whitefish, pygmy whitefish (*Prosopium coulterii*), lake trout (*Salvelinus namaycush*), Arctic char, Arctic grayling, and Dolly Varden (*Salvelinus malma*) (Plumb 2006). There are also significant runs of sockeye salmon and coho salmon, with small runs of pink (*Oncorhynchus gorbuscha*) and chum salmon (*Oncoryhnchus keta*) (Morrow 1980).

One significant feature of the Ugashik Lakes is their lack of vertical stratification, likely due to the frequent winds brought about by meteorological events from the Pacific and Arctic Oceans. In other lake systems it is known that resident lake salmonids congregate in relation to thermoclines and thermal fronts (Baldwin et al. 2002; Bosch et al. 1995). However, without the thermal structure of the Ugashik Lakes, the resident fish have little temperature stratification with which to orient, so they may accumulate around other features such as slope, structure, depth, bottom substrate, current, and of course food sources (Beauchamp et al. 1997; Sellers et al. 1998).

Management of these lakes is difficult and using typical monitoring techniques to estimate density and abundance would be extremely costly on large remote lakes like Ugashik. A mark/recapture or gillnet design would work, but would be very labor intensive. Another drawback is that catch-per-unit-effort estimates produce only relative abundance indices (Thorne 1983; Brandt 1996). Active capture like trawling is not feasible based on the extreme variation in lake bathymetry. The main drawback of all other monitoring techniques is time. Each of the above methods is time intensive and time is at a premium in the short sampling seasons of the sub-Arctic. Added is the fact that the study site is remote, expensive to maintain, and accessible only by plane or small boat; thus, a survey technique like hydroacoustics seems ideal.

Hydroacoustic surveys allow a large amount of the lake volume to be sampled in a relatively short time. This reduces the need for costly long-term field camps and study designs. Hydroacoustics also helps to minimize the temporal and spatial variation of fish movement between samples. Also, there is minimal physical fish sampling required so actual environmental interference is reduced. In addition, hydroacoustics are independent from fishery catch statistics, have a relatively low operational cost, low variance estimates, and have the capability for absolute abundance estimates (Thorne 1983). This ultimately leads to a more accurate assessment of the fish populations and their dynamics and allows surveying to be done with a minimum of effort and resources (MacLennan and Simmonds 2005).

The use of hydroacoustics to assess fish stocks has been extensively researched. The first hydroacoustic units were simple single beam transducers that did little more than determine if fish were present or absent. Abundance estimates began to take shape but with considerable amounts of error. With the advent of split-beam transducers, the target strength of individual fish could be measured directly, allowing more precise estimates, especially in dispersed populations of fish such as those in lakes and rivers (MacLennan and Simmonds 2005). For each transmission using a split-beam transducer, echoes are observed simultaneously on each of the four transducer quadrants and echoes are combined in pair-wise fashion. Differences in port and starboard half beams and fore and aft half beams allow target direction to be determined which allows for pattern loss to be determined out of the total signal. Compensation of the signal then allows direct determination of target strength (Foote 1987).

The accuracy and precision of hydroacoustic technology has been tested in various scenarios, showing its validity for use in fish stock assessments. Wanzenböck et al. (2003) reported on the quality assurance of hydroacoustic surveys. The team conducted identical hydroacoustic surveys with differing equipment. The surveys were run using independent manufacturers' transducers, differing frequencies, beam width, shape, pulse length, ping rate, acquisition software, and post-processing software. One survey included two research vessels steaming in line 300 meters apart. The second survey included one survey vessel with two differing transducers. Both surveys found highly correlated abundance estimates for biomass. This gives evidence that hydroacoustic sampling is an accurate method to estimate density and abundance of fish populations. Hartman et al. (2000) also attempted to validate hydroacoustic samples. They sampled lock chambers on the Ohio River to maintain a static population. The locks prevented fish movement into and out of the sampled population. The surveys were performed with a 120 kHz split-beam hydroacoustic gear and one-day rotenone surveys, and they compared the abundance estimates and length distributions of each method. There was a strong positive correlation (r = 0.938) between each abundance estimate. However, the length distributions showed significant differences between methods, especially for the smaller sizes. This difference was attributed to shadowing of fish due to schooling affects, which occur with smaller fish. The larger individuals showed more of a correlation between the two survey types because they do not tend to school up and therefore do not over-shadow other individuals. These results add to the evidence that hydroacoustic surveys are more accurate for dispersed individuals rather than tightly schooled or shoaled fish (Johnson 1985).

The use of hydroacoustics for abundance estimation is not without problems. There are a suite of problems that must be overcome to obtain accurate estimates. These problems usually occur as a result of fish behavior. There are problems with fish "shadowing" other fish when being surveyed. Shadowing can lead to problems of target strengths being biased towards larger or solitary fish, ultimately leading to biased density estimates (Brandt 1996). Another problem is the fish blending in to the lake bottom and being interpreted as the bottom (Ona and Mitson 1996). Fish tend to avoid surveying vessels in shallow water and this may also affect estimates (Olsen 1990).

Another major problem is from inconsistent target strength values that result from how acoustic signals react to a fish's swim bladder under differing conditions (MacLennan et al. 1990). Swim bladders change based on recent depth history, and even age (Blaxter and Batty 1990). Experimental evidence shows that approximately 90 percent of the reflected sound of a fish is due to the swim bladder (Foote 1980). Target strength is very important to making meaningful conclusions about hydroacoustic data.

Values for target strength are in decibels which are a logarithmic measure of the ratio between the amount of sound reflected from the fish and the intensity of the transmitted sound (MacLennan and Simmonds 2005). The larger the target strength value, the larger the target; thus, large fish are presumed to have higher target strength values than small fish. For our application it is important to have a relationship between target strength and actual length to allow us to exclude migratory species (immature salmon), immature resident species, and non-harvested resident species [pygmy whitefish (*Prosopium coulteri*)] from the resident species in abundance estimates. To understand target strength, it is important to view it as a stochastic parameter having a distribution around a mean. This includes the target strength of an individual fish as well as the sampled population (MacLennan and Simmonds 2005).

The only literature available on hydroacoustic surveys for the Ugashik Lakes is from Lemberg and Mathisen (1975). In their study both Becharof and Ugashik Lakes were surveyed for fish stock assessment and to examine the lakes for use as nursery areas for juvenile sockeye salmon. Their survey used 105-kHz single-beam Ross 200A echo-sounder with an eight degree beam angle, interface amplifier, and a Sony 560D magnetic tape recorder. There was no partitioning of species or size in this survey. Echo-integration was used to determine an abundance estimate of all fish in the lakes. For Upper Ugashik Lake it was 11,114,000 and the Lower Ugashik Lake was 5,692,000. These estimates include all immature salmon in addition to resident species.

The previous estimate did not apportion species or separate migratory versus resident species. My project's goal was to produce an estimate of abundance for separate species and eliminate migratory species. My survey is important because it provides a baseline during an increasing trend in fishing pressure in this geographic region of Alaska, subsistence fishing complaints, and the existence of private land holdings around the lakes that could be used for vacation lodges. Having baseline data and preliminary fish stock estimates are important for future management decisions of these lakes.

My hydroacoustic survey design consisted of simple parallel transects that covered the entirety of both lakes (MacLennan and Simmonds 2005). This design insured the sampling of all available habitats as well as creating the largest amount of bathymetry data. Fish densities were found to be low so an echo counting model was used instead of echo integration (Mulligan and Chen 1998). In addition, I performed a tethered fish experiment to determine a target strength to length relationship for the resident salmonids (Nakken and Olsen 1977; Hartman and Nagy 2000). *In situ* relationships based on relationships of sampled shoals of fish (Fleischer et al. 1997; MacLennan and Menz 1996) were not feasible as the fish densities in the Ugashik Lakes are low making a good size distribution difficult. In addition, it would be difficult to capture the same fish in gillnets that were previously insonified by the hydroacoustic gear. The gillnet survey design was simple stratified random placement of nets separated into near-shore and off-shore locations. Gillnet catches were used to speciate hydroacoustic targets based on the proportions of each species caught within certain depth strata.

The goal of my study was to develop a survey methodology that will assess the density, abundance and distribution of the resident fish populations in the Ugashik Lakes using hydroacoustic and gillnet gears. The specific objectives were:

1. Determine a means of assigning a species identification of acoustic targets.

2. Determine target strength to length relationships for common Ugashik resident species.

3. Determine density and abundance estimates of each resident species in each lake.

4. Determine the effort and survey design requirements needed to detect different levels of change in fish populations through annual surveys.

5. Recommend a survey design for annual assessment of the Ugashik Lakes fish populations by fisheries management agencies.

6. Develop an accurate bathymetric map of the lakes.

References

Baldwin, C.,M., D.A. Beauchamp, and C.P Gubala. 2002. Seasonal and diel distribution and movement of Cutthroat trout from ultrasonic telemetry. Transactions of the American Fisheries Society 131: 143-158.

Beauchamp, D., A., P. E. Phaedra, R. Dillinger, H. G. Gross, C. P. Gubala, S. Spaulding, and W. A. Wurtsbaugh. 1997. Hydroacoustic assessment of abundance and diel distribution of Sockeye salmon and Kokanee in the Sawtooth Valley Lakes, Idaho. North American Journal of Fisheries Management 17: 253-267.

Blaxter, J. H. S. and R. S. Batty. 1990. Swim bladder "behavior" and target strength. Pages 233-244 in Karp, W. A., editor. Developments in fisheries acoustics: a symposium held at Seattle. International Council for the Exploration of the Sea, France.

Bosch, D., L. Coggins, and R. E. Minard. 1995. Evaluation of the thermal habitat volume for lake trout in selected lakes of Southwest Alaska, 1994. Alaska Department of Fish and Game, Fishery Data Series No. 95-26, Anchorage, AK.

Brandt, S. B. 1996. Acoustic assessment of fish abundance and distribution. Pages 385-419. in Murphy, B. R., and D. W. Willis, editors. Fisheries Techniques. American Fisheries Society, Bethesda, Maryland.

Dunaway, D. O. and M. J. Jaenicke. 2000. Area management report for the recreational fisheries of the Southwest Alaska Sport Fish Management Area, 1998. Alaska Department of Fish and Game, Fishery Management Report 00-3, Anchorage.

Edwards, M. R., and J. P. Larson. 2004. Estimation of coho salmon escapement in the Ugashik lakes, Alaska Peninsula National Wildlife Refuge, Alaska, 2001-2003. U.S. Fish and Wildlife Service, King Salmon Fish and Wildlife Field Office, Alaska Fisheries Technical Report Number 69, King Salmon, Alaska.

Fleischer, G.W., R.L. Argyle, and G.L. Curtis. 1997. *In situ* relations of target strength to fish size for great lakes pelagic planktivores. Transactions of the American Fisheries Society 126: 786-794.

Foote, K. G. 1980. Importance of the swimbladder in acoustic scattering by fish: a comparison of gadoid and mackerel target strengths. Journal of the Acoustical Society of America 67: 2084-2089.

Foote, K., G. 1987. Fish target strengths for use in echo integrator surveys. Acoustical Society of America 82: 981-987.

Hartman, K. J., B. Nagy, and R. C. Tipton. 2000. Verification of hydroacoustic estimates of fish abundance in Ohio River lock chambers. North American Journal of Fisheries Management 20: 1049-1056.

Hartman, K. J. and Nagy, B. 2000. A target strength and length relationship for striped bass and white perch. Transactions of the American Fisheries Society 134: 375-380.

Johnson, R. L. 1985. Application of dual-beam acoustic procedures to estimate limnetic juvenile sockeye salmon. International Pacific Salmon Fisheries Commission. Progress Report No.41. New Westminister, B.C.

Lemberg, N. A. and O. A. Mathisen. 1975. Hydro-acoustic fish stock assessment survey in Becharof and Ugashik lakes, 1975. Report 1735 of Alaska Department of Fish and Game, Anchorage, Alaska.

MacLennan D. N., A. E. Magurran, T. J. Pitcher, and C. E. Hollingworth. 1990. Behavioral determinants of fish target strength. Pages 245-253 in Karp, W. A., editor. Developments in fisheries acoustics: a symposium held at Seattle. International Council for the Exploration of the Sea, France.

MacLennan, D. N. and A. Menz. 1996. Interpretation of *in situ* target strength data. ICES Journal of Marine Science 53: 233-236.

MacLennan, D. E. and E. J. Simmonds. 2005. Fisheries Acoustics. Chapman and Hall. London.

Meyer, S. C. 1990. Stock assessment of Arctic Grayling at Ugashik Lakes, Alaska. Master of Science Thesis, University of Alaska, Fairbanks. 176 pp.

Morrow, J. E. 1980. The Freshwater Fishes of Alaska. Alaska Northwest Publishing Company. Anchorage, Alaska.

Mulligan, T. J. and D. G. Chen. 1998. A split-beam echo counting model: development of statistical procedures. ICES Journal of Marine Science 55: 905-917.

Nakken, O. and Olsen, K. 1977. Target strength measurements of fish. Rapports et Proces-Verbaux des Reunions, Conseil International pour 1' Exploration de lamer 170: 52-69.

Olsen, K. 1990. Fish behavior and acoustic sampling. Pages 147-158 in Karp, W. A., editor. .Developments in fisheries acoustics: a symposium held at Seattle. International Council for the Exploration of the Sea, France.

Ona, E. and R.B. Mitson. 1996. Acoustic sampling and signal processing near the seabed: the dead zone revisited. ICES Journal of Marine Science 53: 677-690.

Plumb, M. P. 2006. Ecological factors influencing fish distribution in a large sub-arctic lake system. Master's Thesis. University of Alaska Fairbanks.

Sands, T., S. Morstad, K. A. Weiland, J. B. Browning, and C. J. Anderson. 2002. Annual Management Report, 2000 Bristol Bay Area. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 2A02-18, Anchorage, Alaska.

Sellers, T., J., B. R. Parker, D. W. Schindler, and W. M. Tonn. 1998. Pelagic distribution of lake trout (*Salvelinus namaycush*) in small Canadian shield lakes with respect to temperature, dissolved oxygen, and light. Canadian Journal of Aquatic Science 55: 170-179.

Thorne, R. E. 1983. Assessment of Population Abundance by Hydroacoustics. Biological Oceanography 2: 253-262.

USFWS. 2003. Quantification of Resident Fish Populations in the Ugashik Lakes Using Hydroacoustics. Research Proposal. Prepared by KSFO. ID number 04-R7-XX.

Villegas, S. V. 1993. Arctic grayling in the Ugashik Drainage. Master of Science Thesis, University of Arizona. 115 pp.

Wanzenböck, J., T. Mehner, M. Schulz, H. Gassner, and Winfield, I. J. 2003. Quality assurance of hydro-acoustic surveys: the repeatability of fish-abundance and biomass estimates in lakes within and between hydro-acoustic systems. ICES Journal of Marine Science 60: 486-492.

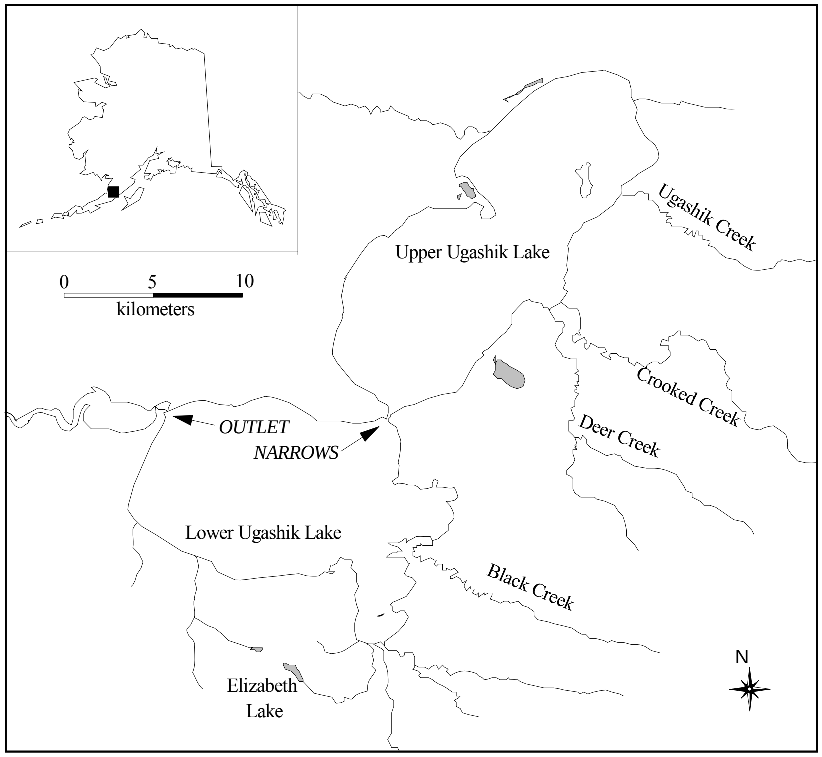


Figure 1. A map of the study area for hydroacoustic survey of the Ugashik Lakes, Alaska Peninsula.

Chapter 2: Target strength to length relationship for salmonids

Abstract: Target strength (TS) and fish length relationships are an important yet often overlooked aspect of fisheries acoustic assessments. This study measured the mean dorsal aspect target strength of several species of salmonids. Fish were tethered using a hook and weight apparatus and insonified at ~15-m depth to determine TS values with a 70 kHz split beam transducer. Fish TS were found to differ markedly from the predictions of Love's and Foote's equations, so I developed my own. The TS to length relationship is of the standard format using a slope of 20: $TS = 20 \cdot \log_{10}(L_{cm}) - 78.53$ ($R^2 = 0.49$). This equation will have broad application in Alaska lakes as well as the Great Lakes and other systems containing salmonid fishes.

Introduction

Acoustic surveys require accurate target strength (TS) characteristics for the fish being insonified (Foote 1987; MacLennan and Simmonds 2005). The TS is required to allow volume backscattering strength to be converted to fish biomass, or in the case of echo-counting, to include or exclude certain size classes of fish. Several studies have researched TS to length relationships *in situ* (MacLennan and Menz 1996) and *ex situ* (Nakken and Olsen 1975; Gauthier and Rose 2002). *In situ* methods use natural conditions, but require capture of the recently insonified fish in sufficient quantities to produce a good size distribution, often making this approach impractical (Gauthier and Rose 2002). *In situ* methods may also suffer from gear selectivity problems. *Ex situ* methods allow direct measurement on a fish of known size and allow control on species and depth adaptation (Ermolchev and Zaferman 2003) and are appealing in surveys where fish populations are not in shoals or are at such low densities that *in situ* methods are impractical.

Despite the importance for accurate TS to length relationships, equations are lacking for many species of surveyed fish. Typically, researchers borrow the oft used Love's (1971) or Foote's (1987) equations or develop their own. Foote's equations are based on clupeids and gadoids while Love used a multitude of fishes and various frequencies ranging from 15 to 1,000 kHz (Foote 1987; Love 1971). These two equations do not address a number of ecologically and economically important species.

Salmonids make up an important sport fishery and subsistence fishery for the state of Alaska (USFWS 2003) and they are also important in the Great Lakes where hydroacoustic surveys are commonly used in stock assessment (Knuth 2002). Therefore, salmonids represent an important family for surveying with hydroacoustics. My study created a TS to length relationship for Alaska lake-dwelling salmonids using a modified tethering method. I hope this will reduce any error due to borrowing of TS to length equations in future acoustic salmonid surveys. In addition, I show the potential error that could occur when borrowing a TS to length relationship on a test data set from an Alaska lake.

Methods

The Ugashik Lakes are located in the Alaska Peninsula National Wildlife Refuge 120 km southwest of the town of King Salmon. The lakes can be classified as warm thereimictic (Cole 1994). The upper lake flows into the lower lake via the Ugashik Narrows. Combined; both lakes are 342 km^2, have a max depth of 180 m and rarely thermally stratify due to consistent high winds. The resident species are, Dolly Varden

(*Salvelinus malma*) (Walbaum), Arctic char (*Salvelinus alpinus*) (Linnaeus), lake trout (*Salvelinus namaycush*) (Walbaum), round whitefish (*Prosopium cylindraceum*) (Pallus), and Arctic grayling (*Thymallus arcticus*) (Pallus).

In situ methods were not used because the fish density in the Ugashik lakes is low and salmonids are typically non-schooling. In addition, complex cage and tethering apparatus were not used because of the remote location of the experiment.

Instead, I used an apparatus with locally collected fish to develop a salmonid TS equation. Fish were collected from the Ugashik Lakes by gillnet and hook and line. Fish were held in ventilated tanks and anchored to the lake bottom in one meter of water until used in the TS experiment (< 6 days). Fish were lowered to depth using a fishing rod spooled with 0.52 mm diameter monofilament line to which a one kilogram weight was attached to the end. One meter above the weight a size 8 hook connected the fish to the apparatus. For smaller fish a size 18 hook was used (Figure 1). Fish tethered in this manner were visually observed before being lowered to depth to insure minimal fish movement was taking place to allow the majority of acoustic pings to be of dorsal aspect. After lowering the fish to 15 m the fish were allowed to equilibrate to the change of depth for ~20 minutes. The monofilament line and small hook were verified to have no significant echo return.

Target strength data were collected using a Simrad® EK60 echo sounder with a 70 kHz split beam transducer with a 7.1-degree beam width. Calibration followed the methods described in the operators manual (Simrad 2003) using a 32.1-mm copper reference sphere (TS = -39.1 dB).

The transducer was mounted on a 3-meter long rod held over the side of the boat in a down looking manner. After the fish had been at depth for 20 minutes, data collection commenced. Fish were pinged from 5-15 minutes allowing between 150-1500 measures of TS per fish, which allowed for a good distribution of TS values. An attempt was made to have the majority of the pings directly in the center of the split-beam transducer. The fish was able to move while hooked to the monofilament allowing a range of tilt angles to be represented in the TS distribution.

Collected acoustical data were processed with Sonardata Echoview 4.0 (Sonardata®, Pty Ltd Hobart, Australia). The TS means were calculated by converting to backscatter cross-section ($\sigma = 4\pi \cdot 10^{(TS/10)}$) then converted to TS ($= 10 \log(\sigma/4\pi)$). These means were used in the TS-length relationships in regression analysis. Large outliers outside of the fish's normal TS distribution were eliminated to exclude those pings where the fish may have been in a vertical orientation.

The regression analysis included a total of 14 fish, two arctic char, three immature coho salmon (*Oncorhynchus kisutch*) (Walbaum), four Dolly Varden, four lake trout, and one round whitefish. Data from this variety of species was combined as they all belong to the same family, and they all overlap in this lake system making a mixed model more practical. Total lengths ranged from 3.5 to 57.8 cm. Linear-regression was used because the least squares method gave the best fit.

The equation produced from linear-regression had a smaller slope than would be expected from a TS to length relationship for salmonids. This small slope is likely a result of having a small sample size (n = 14) and a small range of sizes (MacLennan and Simmonds 2005). This especially pertains to those fish representing the lower end of the range of sizes. There were only three individuals that represented the lower range of sizes, all of which were immature coho salmon. Small sizes and sample sizes, plus the fact that coho salmon are not resident species could have an effect on the "anchoring" of the low end of the regression line. From this I thought it necessary to force the regression line through a slope of 20 as is commonly done (Foote 1987; McClatchie et al. 2003). The vast majority of *ex situ* and *in situ* TS-length relationships have a slope value of 20 or a value very close to that (Foote 1987; Gauthier and Rose 2001; Gauthier and Rose 2002; MacLennan and Simmonds 2005). It is typical to use a standard slope of 20 for TS-length relationships in situations where the sample size and range of sizes are small. I still present the original regression line as well. Using the original slope of 12.9 would decrease our TS threshold used in chapter 3 and 4 from -52.56 to -50.55 for a 20 cm long fish, leading to a lower estimate of the resident species density in these lakes.

To compare the relationship I produced with those of Foote (1987) and Love (1971), I compared the observed mean TS of the salmonids measured in the tethered fish with the predicted TS values from each model. Using a simplified version of Love's (1971) equation, $TS = 19.1 \cdot \log_{10}(L_{cm}) - 63.66$ which accounts for the transducer frequency term and using centimeters instead of meters in the length term and Foote's (1987) equation, $TS = 20 \cdot \log_{10}(L_{cm}) -71.9$ and the observed fish length, I calculated the expected TS for each fish using each equation. These values were compared by performing a paired t-test for each equation. In addition, these values were subtracted from the actual TS of the fish from tethering and plotted as the residuals.

Results and Discussion

The tethering method used here provided good estimates of mean TS values (Table 1). Distributions for TS values approximate normality and time series for all fish and gave stable outcomes (Figure 2). The range of TS values were greater than what would be expected in an anesthetized fish in a tethered frame (Hartman and Nagy 2000). This is due to the fish having free range of motion which enabled a wider range of tilt angles to be pinged. A summary of each fish insonified can be found in the Table I.

A moderately strong linear relationship ($R^2 = 0.49$, df = 12, $p < 0.0001$) was found between TS and the logarithm of total length for the salmonids in this study (Figure 3). A slope of 20 (standard format) (Foote 1987) was used in the regression line instead of the smaller slope of 12.9, found in the original calculation. This was due in part to the fact that there are a small number of individuals insonified, the range of sizes is similarly small, which led us to believe the original slope may be inaccurate, and larger TS values have more realistic length predictions (MacLennan and Simmonds 2005). The original calculated equation was, $TS = 12.9 \cdot \log_{10}(L_{cm}) - 67.33$.

Comparing our TS values with those predicted from both Foote (1987) and Love's (1971) equations show significant differences and the negative effects of borrowing a TS relationship. The paired t-test for comparing TS values from our equation with those of Foote's and Love's equation showed significant differences respectively ($t = -5.56$, df = 13, $p < 0.0001$) ($t = -12.57$, df = 13, $p < 0.0001$). Both published equations overestimated fish TS values compared to our predictions (Figure 4). Foote's equation was more accurate only overestimating a mean of 6 dB while Love's equation overestimated by a mean of 13 dB. Foote's equation was expected to be closer because it is based on herring (*Clupea harengus*) and sprat (*Sprattus sprattus*) which are physostomes like salmonids. However, the morphology of swim bladders between clupeids and salmonids is very different. Clupeids have a shorter, larger diameter swim bladder, while salmonids have a long, thin swim bladder running the length of the kidney. The difference in TS values from our model and Foote's is likely due to this difference. Lastly, it should be noted that Love's equation was produced using the maximum target strength value of each fish whereas Foote's equation used the mean TS like our equation. This could have an impact on overestimating fish density for Love's equation. Had Love used the mean TS value or if I used the maximum TS value then it might lead to less disparity between the TS values.

Bias from using improper TS relationships can lead to significant amounts of error in fish density assessments. If a survey has a mean Sv value of -65 dB and a mean fish size of 40 cm from physical fish sampling, using our model for echo integration would predict fish densities of 141 fish/10,000 m^3. Foote's equation would erroneously predict fish densities of 31 fish/10,000 m^3, while Love's equation would drastically underestimate density with 7 fish/10,000m^3. In addition, if using an echo counting model the size threshold would be inaccurate when trying to exclude, include, or partition size classes. This is evidence that if the survey's goal is absolute fish abundance or fish size, then researchers should test available TS relationships from the literature to determine their appropriateness and ultimately they may need to develop their own relationships for the species of interest.

This study provides a combined relationship between TS and length for several salmonids. However, I think more work is warranted for this relationship given the fact that the sample size was small as was the range of sizes of the fish. This led us to change the original equation produced from regression to what is considered as the standard format utilizing a slope of 20. I do think additional TS work with salmonids at this time and other frequencies is warranted. To facilitate this, summary data for the 14 fish used in this study are provided in Table 1.

References

Cole, G.A. 1994. Textbook of Limnology. 4th edition. Waveland Press, Inc. Prospect Heights, Illinois.

Ermolchev, V. A. & Zaferman, M. L. 2003. Results of experiments on the video-acoustic estimation of fish target strength *in situ*. ICES Journal of Marine Science 60:544-547.

Foote, K. G. 1987. Fish target strengths for use in echo integrator surveys. Journal of the Acoustical Society of America 82: 981-987.

Gauthier, S. & Rose, G. A. 2002. *In situ* target strength studies on Atlantic redfish (*Sebastes* spp.). ICES Journal of Marine Science 59: 805-815.

Gauthier, S. & Rose, G. A. 2001. Target strength of encaged Atlantic redfish (Sebastes spp.). ICES Journal of Marine Science 58: 562-568.

Hartman, K. J. & Nagy, B. W. 2005. A target strength and length relationship for striped bass and white perch. Transactions of the American Fisheries Society 134: 375-380.

Knuth, B. A. 2002. The Many Faces of Salmon: Implications of Stakeholder Diversity in the Great Lakes. Sustaining North American Salmon: Perspectives Across Regions and Disciplines. pp. 181-194.

Love, R. H. 1971. Measurements of fish target strength: a review. U.S. National Marine Fisheries Service Fishery Bulletin 69: 703-715.

McClatchie, S., McCauley, G. J., and Coombs, R. F. 2003. A requiem for the use of 20 log10 Length for acoustic target strength with special reference to deep-sea fishes. ICES Journal of Marine Science, 60: 419–428.

MacLennan, D. N. & Simmonds, E. J. 2005. Fisheries Acoustics. Chapman and Hall, New York.

MacLennan, D. N. & Menz, A. 1996. Interpretation of *in situ* target strength data. ICES Journal of Marine Science 53: 233-236.

Nakken, O. & Olsen, K. 1977. Target strength measurements of fish. Rapports et Procés-Verbaux des Réunions, Conseil International pour l'Exploration de la Mer 184: 25-33.

Simrad. 2003. Calibration of the ER60/BI60. Simrad Norge AS, Horten.

USFWS. 2003. Quantification of Resident Fish Populations in the Ugashik Lakes Using Hydroacoustics. Research Proposal. Prepared by KSFO. ID number 04-R7-XX.

Table 1. Summary statistics of size (L_{cm}) and target strength of individual fish used in developing the regression model. The mean is the average of individual values. The standard deviation of the mean target strength, minimum and maximum target strengths are also provided. Acoustic baskscatter cross sections were used to calculate means and standard deviations then converted to target strengths.

		Target Strength			
Fish	L_{cm}	**Mean**	**SD**	**Min**	**Max**
Arctic char	50.8	-42.12	0.19	-59.84	-31.00
Arctic char	53.3	-41.52	0.19	-59.93	-22.21
coho salmon	3.5	-59.15	0.02	-59.99	-57.45
coho salmon	9.3	-56.80	0.04	-59.83	-42.31
coho salmon	9.6	-54.56	0.07	-59.93	-43.35
Dolly Varden	39.7	-47.08	0.21	-60.00	-34.14
Dolly Varden	44.1	-45.28	0.19	-59.97	-31.02
Dolly Varden	44.6	-46.65	0.20	-59.94	-37.21
Dolly Varden	45.4	-51.41	0.14	-59.99	-37.90
lake trout	48.0	-39.17	0.13	-59.99	-37.44
lake trout	36.0	-47.23	0.14	-59.98	-23.08
lake trout	54.3	-47.24	0.11	-59.98	-33.47
lake trout	57.8	-48.33	0.08	-60.00	-31.94
round whitefish	45.4	-46.89	0.13	-59.95	-37.05

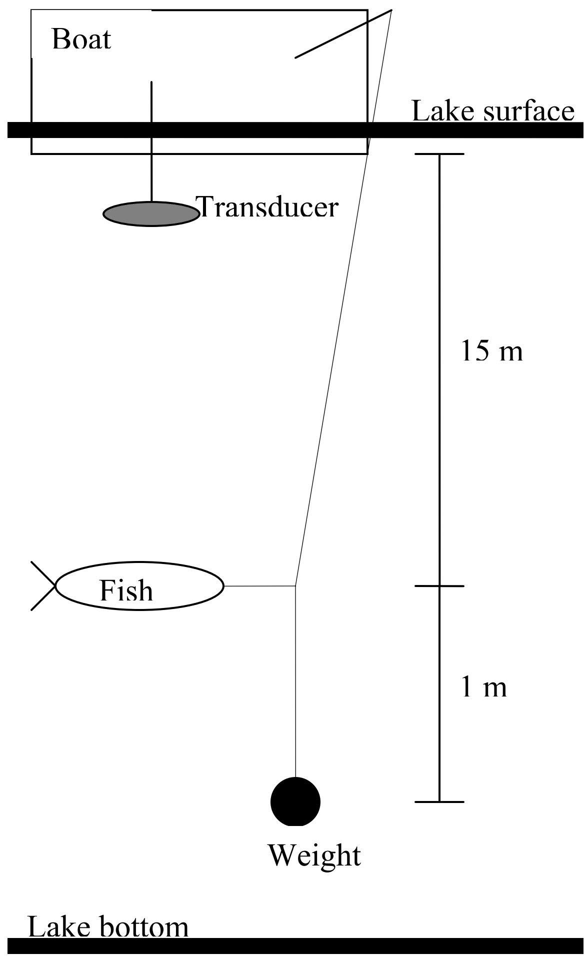
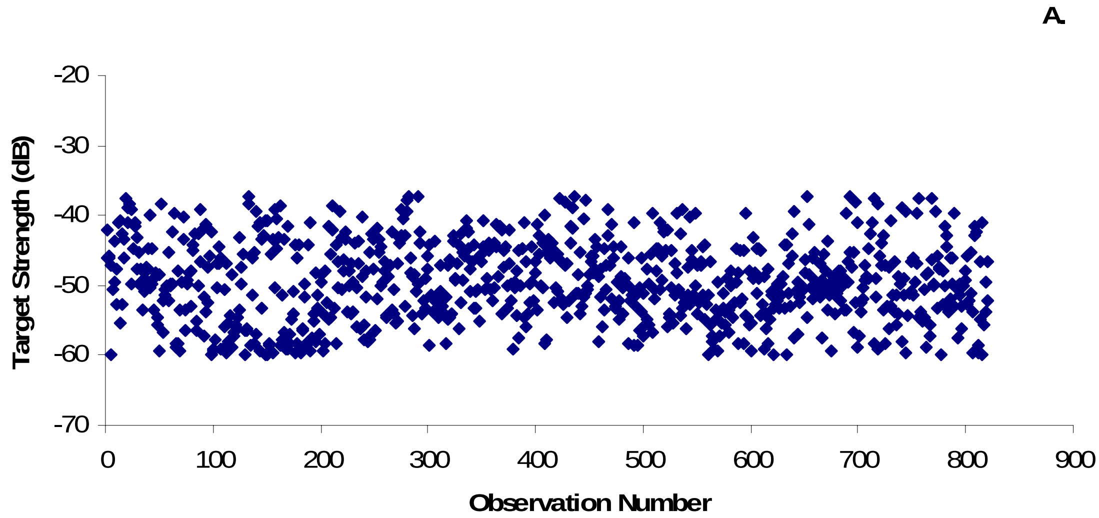


Figure 1. Diagram of the transducer and fish tethering setup used to collect TS information on individual fish. The transducer was attached to a short metal rod to allow slight adjustments to keep the fish in the main lobe of the beam.



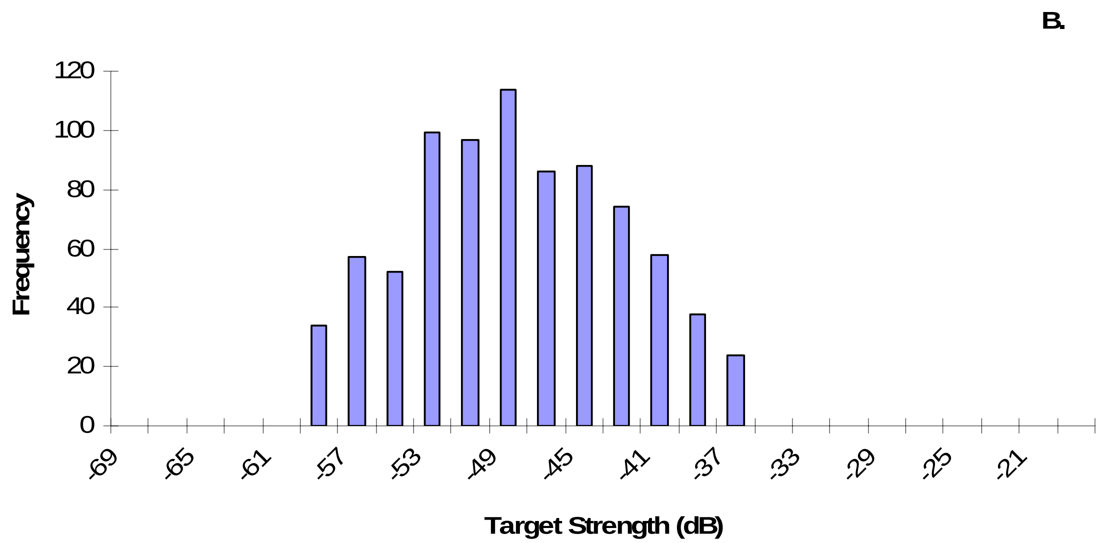


Figure 2. (A) Time series and (B) frequency histogram of individual target strength (TS) measures of a typical fish (here, a 44.6 cm Dolly Varden, see Appendix) used in making the TS-length relationship.

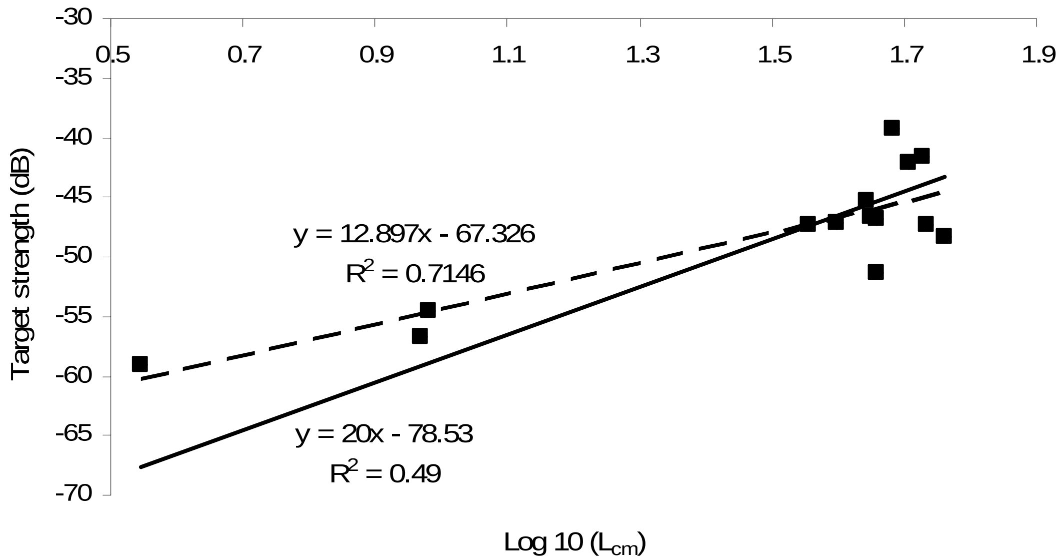


Figure 3. Mean TS plotted against $\log_{10}$ total length (cm) for salmonids. Dashed line represents original equation. Solid line represents equation after slope is changed to standard format of 20.

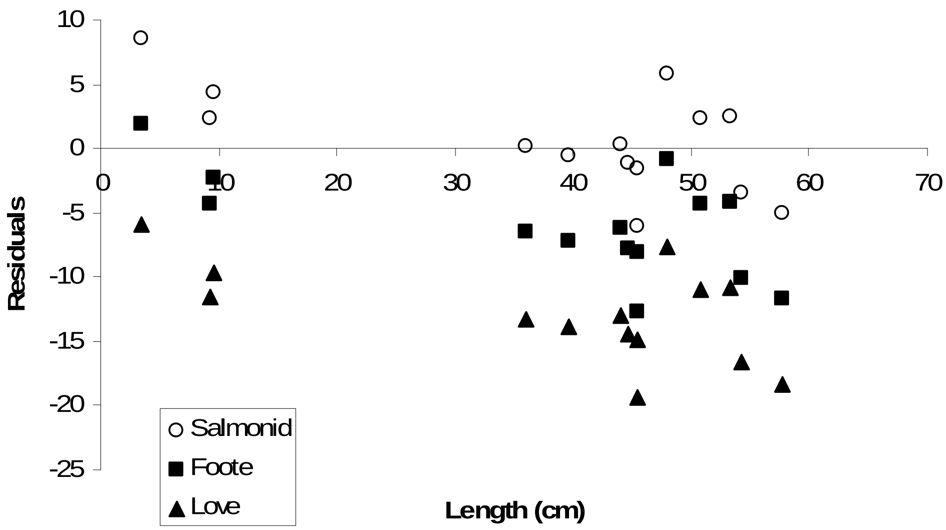


Figure 4. Predicted dorsal aspect target strength versus actual length for salmonids. Predictions are from Love's (1971) equation, Foote's equation (1987), and our equation derived from salmonids.

Chapter 3: Annual density and spatial size variation of resident salmonid populations in the sub-arctic Ugashik lakes using hydroacoustics and gillnets

Abstract: The Ugashik Lakes in southwest Alaska are a unique system that lack thermal stratification during the summer. Fish density and abundance were determined acoustically in both lakes annually from 2001-06. Species composition, acoustic apportionment, and depth stratification were determined using gillnet surveys from 2003-06. This paper examined differences in density and size composition within depth strata among years, and within depth strata with years combined. In addition, the 2005 dataset was used to test for significant distribution differences within the lakes. Density estimates between years within depth strata were variable and had large confidence intervals making determination of significant statistical differences difficult. Such large variances were evidence of extremely contagious, patchy fish distribution. Species apportionment found Arctic char (*Salvelinus alpinus*), Arctic grayling (*Arcticus thymallus*), Dolly Varden (*Salvelinus malma*), lake trout (*Salvelinus namaycush*), and round whitefish (*Prosopium cylindraceum*) in water 0-20 m deep, Arctic char and lake trout in water 20-80 m deep, and only lake trout in >80 m of water. Density varied in space and in time within space. There were significant differences in size composition between the three depth strata with years combined. Both hydroacoustics and gillnet size distributions show larger fish in 0-20 m water compared to >20 m depths throughout the summer. Overall, despite collecting up to 85 hours of hydroacoustic data per year, survey variation exceeded year-to-year variation in abundance estimates of resident species. This variation prevents meaningful comparisons from being made about changes

in abundance estimates from annual stock assessment surveys, but may still have utility in monitoring fish populations through time series analysis.

Introduction

The Ugashik Lakes in southwest Alaska represent a remote, sub-arctic lake system in that it is cold, resource limited, and has little to no fishing pressure (United States Fish and Wildlife Service 2003). These lakes lack thermal stratification during the ice free season. The remoteness of these lakes makes them difficult candidates for monitoring and management for fisheries management agencies. Future fishing pressure increases are a real possibility (Dunaway and Jaenicke 2000) with some private land holdings still existing around the lake shore which could lead to possible fishing lodges. Also, recent communications with local Native organizations have discussed decreases in their round whitefish (*Prosopium cylindraceum*) (Pallus) and Arctic char (*Salvelinus alpinus*) (Linnaeus) subsistence catches (USFWS 2003). Such annual variation in catches could be attributed to annual differences in the hatching of fish, recruitment of fish into older age classes, emigration/immigration, low and patchy fish distribution, and natural mortality. Annual variation could also represent declines in stocks due to undocumented over-fishing. Knowledge of the trends in density estimates of resident fish species is necessary to take management actions. However, the remote nature of these lakes, their size, and depth present challenges for monitoring and managing fish populations.

Fish stock abundance estimates are difficult to determine. Passive gears, such as gillnets and trapnets depend on fish activity and give only relative abundance estimates

(Rudstam et al. 1984). Also, many passive gears are simply avoided by fish in clear water, such as the Ugashik Lakes, leading to decreased catches and underestimation of stock abundance. Active gears, such as seining and trawling require a large spatial coverage if absolute abundance is the goal, which leads to high labor costs (Heales et al. 2007). Mark-recapture is another possibility for absolute abundance, but labor costs are still an issue, and gaining a large enough sample size can often be problematic, especially in a system where fish densities are low like the Ugashik Lakes.

Hydroacoustics is a well established technique for quantifying fish density, abundance, and size distribution (Hartman et al. 2000; Wanzenböck et al. 2003; MacLennan and Simmonds 2005). Hydroacoustics allows large areas of the lake to be sampled, and has the advantages of short duration, low impact on the fish studied, is independent of catch statistics and population history, and allows for absolute abundance estimates (Thorne 1983). New developments in software, ease of use, speed, and mainly smaller size of sonar equipment make it easy to use even in a remote setting. These characteristics of hydroacoustic surveys make it a good candidate for surveying such difficult, remote systems such as the Ugashik Lakes.

Previous studies of these lakes have been in the form of gillnet surveys (Plumb 2006) and relative abundance estimates without separating resident from migratory species (Lemberg and Mathison 1975). This is the first study to investigate a detailed approach to density and population estimation of resident species estimation by looking at a 6-year dataset. The objectives of this paper are to determine annual fish density estimates and investigate annual variation in fish densities and fish size based on depth stratification. Then using hydroacoustic surveys (2001-06) and gillnet surveys I developed annual population estimates for non-resident species to provide a baseline for future population monitoring in this system.

Methods

General Methods

I conducted summer surveys at various times from May to September from 2001-06 to identify distribution and density of resident species in the Ugashik Lakes. Surveys were restricted to this time period because the summer is the only time that these lakes are reliably ice free. Surveys consisted of mobile down-looking hydroacoustics and traditional fishery gears to identify species composition.

The Ugashik Lakes are located in the Alaska Peninsula National Wildlife Refuge 120 km southwest of the town of King Salmon. The lakes are classified as warm thereimictic (Cole 1994). The upper lake flows into the lower lake via the Ugashik Narrows. Combined, both lakes are 342 km^2, have a max depth of 180 m and rarely thermally stratify during ice-free periods due to consistent high winds (Edmundson and Todd 2000).

Gillnet Methods

Multi-mesh gillnets were deployed to capture physical samples of fish to determine species composition and allow speciating acoustic targets. Gillnet surveys were performed only in years 2003-2006. In 2003-04, four types of floating and sinking multifilament nylon experimental gillnets were used. Two gill nets were 120-m long made up of six 20-m panels. Two gill nets were 60-m long made up of six 10 m panels. The panels of one net were composed of 10-, 12.5-, 16-, 19-, 22-, and 25-mm bar mesh sizes. The panels of the other 60-m net was composed of 10-, 19-, 33-, 45-, 55-, and 60-

mm bar mesh sizes. All gill nets were 1.8-m deep. In 2005, large diameter (0.20-0.57-mm) monofilament nets of bar mesh sizes 51-, 64-, 76-, 89-, 102-, 114-, 127-mm were used. In 2006, I used the large diameter monofilament nets from 2005, but added a new set of monofilament nets of smaller diameter (0.10-0.25-mm) monofilament with mesh sizes from the 2003-04 multi-filament nets. The combination of these nets allowed us to capture the large numbers of the majority of fish sizes from 200-450 mm and the rare large individuals over 650 mm.

Effort is displayed in Table 1 in number of net sets per year. Sets were approximately 4-hours long and were placed randomly around the lake in three depth strata: 0-20 m, 20-80 m, and >80 m. The 0-20 m stratum includes all nets set from the edge of the lake perpendicular to shore. This 0-20 m stratum was further split into 0-4 m and 4-20 m for the littoral areas of the lakes. In addition catch per unit effort (CPUE) was calculated for both 0-4 m and 4-20 m littoral depth strata. Exclusion of 0-4 m water would underestimate the population estimates of all species of fish. Gillnet CPUE from water 4-20 m deep littoral water was compared to CPUE of water 0-4 m deep littoral water. The ratio of CPUE of 4-20 m littoral water to 0-4 m littoral water was applied to 4-20 m littoral hydroacoustic density data to determine density estimates of 0-4 m littoral water. For instance, if the CPUE ratio of 4-20 m littoral to 0-4 m littoral is 2 to 1, then for every two sonar targets in 4-20 m littoral water it is assumed there is one in the 0-4 m littoral water. This is done by water volume. Only acoustic samples from 4-20 m that have benthic habitat were used for this calibration. The majority of 4-20 m acoustic samples are over deeper pelagic water. In addition, the 4-20 m density estimates are comprised of both 4-20 m littoral and 4-20 m pelagic samples. This was necessary as there are large numbers of fish in 0-4 m littoral water and acoustic sampling in this depth is impossible due to small sample volume related to acoustic dead zones just in front of the transducer (near-field boundary) and near the bottom (Ona and Mitson 1996). Adult migrating salmon use this littoral area for their spawning runs (personal observation) so I wanted to make sure not to sample them in this water. Speciation of acoustic targets from 2001-02, used 2003 gillnet data while 2003-06 used gillnet data collected in each respective year.

Gillnets were used to apportion species percentages to all acoustic density estimates. For example, if 20% of all gillnet catches in the 20-80 m depth stratum are Arctic char, then I assumed that 20% of all acoustic targets in 20-80 m of water are also Arctic char. The 0-20 m water has the chance for the most bias because it contains all five resident species of interest. So catching more fish here is important to improve the accuracy and precision of apportionment estimates for the acoustic section of this study.

The target sample size of gillnet captured fish for speciation of acoustic targets was determined using a multinomial probability model from Bromaghin (1993). This paper models pre-determined sample size on the number of categories of capture. In this instance the categories are the different species of fish in the Ugashik Lakes. From this a target number of fish caught instead of a target number of nets set for each depth strata can be determined. The more categories and greater confidence desired, the larger the target sample sizes. From this information the target number of fish to be caught will be larger for the 0-20 m because it has all five species of interest where 20-80 m has two and >80 m has only one species (lake trout). Based on Bromaghin (1993), our target number of fish caught was 130 for 0-20 m stratum with a 90% confidence interval and 10% error.

Our target number of fish caught was 64 for 20-80 m stratum with a 90% confidence interval and 10% error. The >80 m stratum has only one category (species) so this computation was unnecessary. Species were determined for netted fish and total length was measured to the nearest millimeter.

Hydroacoustic Methods

Acoustic surveys were performed annually from 2001-2006 at various times from May - September. Upper lake surveys in 2001 were not attempted due to inclement weather. The majority of survey time was during daylight hours as low light conditions in Southwest Alaska are limited during ice-free periods. Table 1 lists lakes, years, and effort of acoustic and gillnet surveys.

Acoustic data were collected with a Simrad EK60 echo-sounder, with a 70 kHz split-beam transducer (2005-2006) and Simrad EY500 echo-sounder, with a 120 kHz split-beam transducer (2001-2004); both operating at a 7.1° beam angle. The units were calibrated with appropriate 32.1 mm copper sphere (target strength (TS) = -39.1 dB) and 23.0 mm copper sphere (TS = -40.4 dB), respectively in accordance with standard calibration procedures (Foote 1990). Calibrations were performed once before each survey. Table 2 displays acoustic settings by year. Data were collected to a notebook computer at pulse duration 0.300 ms for 2001-2004, 0.512 ms for 2005, and 0.128 ms for 2006. A threshold of -53.67 dB for the 70 kHz data, and -53.88 dB for the 120 kHz data was set to eliminate all targets less than 175 mm based on the *ex situ* salmonid TS equation developed in Chapter 2. This threshold eliminates the large number of non-resident immature salmon in the lakes (Thedinga 1994).

The two approaches to determining fish density are echo counting and echo integration. Echo integration uses total back scatter of the insonified fish. The echo integration is the total accumulation of acoustic backscattering cross-sectional areas within a sampling volume. If TS is known, then absolute abundance can be calculated. Echo integration is typically used in situations where fish are in schools or shoals. Echo counting counts single targets within a sampling volume. The fish must be sufficiently dispersed to avoid overlapping echoes that could be interpreted as a single fish. To avoid this, fish must be separated by a range of at least half the pulse length of the sound wave. The largest pulse length used was in the 2005 survey (0.512 ms). This equals a length of 11 cm and half of this is 5.5 cm. So the actual pulse window traveling through the water column is 11 cm. Therefore, at a maximum a fish must be 5.5 cm or more from other fish for them to be counted as two separate echoes instead of one. An echo-counting model as opposed to echo-integration was used in this study as these lakes have low fish densities. Echo-counting is simpler and preferred in low density situations (Brandt 1996; Jurvelius et al. 1987).

Overall mean fish density with 95% confidence intervals was computed for each depth strata of each lake for each year using cluster sampling analysis (Scheaffer et al. 1996, Williamson 1982). Cluster sampling is a preferred statistical analysis for transect-based acoustic data as the collection is continuous and likely serially correlated. Cluster sampling also eliminates the need of complicated geo-statistical analysis such as variograms which are difficult to interpret and fit a model to, with low densities of fish. Also, cluster sampling takes into account the length of transects so a weighting is performed and as a result short transects affect variance estimates less than larger transects. This leads to lower overall variance estimates.

Total abundance estimates were also computed for each species by year and by lake. Total abundance estimates are computed by multiplying the fish density by the volume of water in the lake the species is found. The equation below describes the means of determining abundance for a given species *i*.

$$Abundance_i = P_{i\,0\text{-}20} * [Volume_{0\text{-}20} * Density_{0\text{-}20}] + P_{i\,20\text{-}80} * [Volume_{20\text{-}80} * Density_{20\text{-}80}] + P_{i\,>80} * [Volume_{>80} * Density_{>80}]$$

Where:

P_i = proportion of catch in strata comprised of species *i*.

Volume = water volume (m^3) of that particular depth strata (0-20, 20-80, >80 m).

Density = fish density (fish/m^3) value for that particular depth strata.

Volumes for each depth strata of the lakes were determined using interpolated bathymetry maps in GIS (Chapter 5). It is important to note that if a new lake volume is determined in the future it must be applied to previous abundance estimates so as not to introduce bias from differing lake volumes.

Fish density was split into the four depth strata mentioned in the gillnet survey: 0-4 m littoral, 4-20 m, 20-80 m, and >80 m. Density estimates for 0-4 m littoral water are determined by using the ratio of gillnet CPUE between 0-4 m and 4-20 m littoral water. The pelagic water that is 0-4 m deep across the lakes was excluded from estimates. This part of the water column is where salmon generally make their migrations (G. Staines, personal observation) and it has large amounts of noise and reverberation from the lake surface caused by the boat wake and wind.

Six general linear models (proc glm SAS®) were completed, comparing: (1) total density estimates within depth strata among years *(e.g. did density change in 4-20 depth strata from 2001 to 2002 to 2003 etc.),* (2) species specific density estimates within depth strata among years *(e.g. did species density change in 4-20 from 2001 to 2002 to 2003, etc)*, (3) total density estimates between depth strata with years combined *(e.g. are there differences in density between 0-4, 4-20, 20-80, and >80 m depth strata),* (4) species density estimates between depth strata with years combined *(e.g. was there a density difference between 0-4, 4-20, 20-80, and 80+ with all years combined)*, (5) total density estimates between north/south transects of the 2005 survey in order to determine horizontal distribution of fish *(e.g. what areas of the lakes have higher densities than the rest)* , and (6) mean TS measurements between depth strata with years combined *(e.g. was there a difference in TS distribution between 4-20, 20-80, and 80+ with all years combined).* The year 2005 is used for spatial distribution testing because it had the most acoustic effort covering the whole of both lakes. Figure 1 shows how the acoustic survey was performed in north/south and east/west transects. A post-hoc Tukey's HSD comparison test was performed on each GLM to determine which of the years or depth strata differed specifically. All analysis used an alpha value of 0.05.

I also tested for differences in TS distributions of the 120 kHz (2001-04) and the 70 kHz (2005-06) transducers using a t-test, ANOVA, KS test, and Chi-square. For this I used a data set created from surveying a portion of the upper lake simultaneously using both the 120 kHz and the 70 kHz systems in 2005. No significant differences were found in TS distributions between the 70 and 120 kHz samples. From this I assumed comparing data across years that used the two different transducers would not bias analysis.

Distributions of gillnet fish length and acoustic fish lengths were compared. However, no statistical tests were performed as the two gears are usually without question significantly different in their distributions (Hansson and Rudstam 1995; Mehner and Schulz 2002). A simple comparison of means and modes is useful in this instance to have a general idea of fish sizes in the various depth strata and to see if the two gears show the same sizes.

Results

Gillnets

A total of 1,709 fish, in 161 net sets were caught from 2003-06. Gillnet surveys did not occur from 2001-02. Target number of captured fish was achieved in all depth strata from 2003-04. Target number of captured fish was not achieved in 2005 for any depth strata. Target number of captured fish was achieved from 0-20 m depth strata but not 20-80 and >80 m for 2006. So confidence for species apportionment was less than 90% for all depth strata in 2005 and 20-80 and >80 m depth strata for 2006. Species composition varied with depth strata in the Ugashik Lakes (Figure 2). Species composition by year and by depth strata is found in Table 3. All species of interest were found in water 0-20 m in depth. Lake trout and Arctic char were the only species found in 20-80 m deep water. In water deeper than 80 m I found only lake trout. Average CPUE was higher for the upper lake than the lower lake. The ratios used for calibrating density estimates of 0-4 m water from gillnet CPUE for acoustic data are found in Table 4.

The largest individuals were caught in gillnets from 0-20 m of water. Only lake trout and Arctic char can be compared to other depth strata as other species were only found in less than 20 m of water. In the lower lake, gillnets captured the largest lake trout and Arctic char in 0-20 m of water with mean total lengths of 434 and 411 mm, respectively. The 20-80 m depth stratum of the lower lake had smaller individuals for both species with mean total lengths of 338 and 373-mm total length for lake trout and Arctic char respectively. Lastly, water 80 m and deeper found only lake trout and they were the smallest of all three depth strata with a mean of 279-mm total length. The upper lake results differed. Arctic char captured in gillnets were larger in 20-80 m of water with a mean of 441 mm compared to 0-20 m of water with a mean of 419 mm. Lake trout from 20-80 m of water were smaller (mean of 394 mm) than those in 0-20 m and >80 m of water which had mean values of 472 mm and 432 mm, respectively.

Comparison of means between gillnets and acoustics, with exclusion of the large acoustic targets (>775 mm) not caught in gillnets, were very similar. For 0-20 m, the mean for acoustics is 429 mm and 401 mm for gillnets (Figure 3). For 20-80 m, the mean for acoustics is 364 mm, and 378 mm for gillnets (Figure 4). And for >80 m, the mean for acoustics is 326 mm, and 334 mm for gillnets (Figure 5).

Hydroacoustics

Fish densities varied by lake, year, and depth strata (Tables 5 and 6). Mean fish densities ranged from 0.13 fish/100,000 m^3 to 17.60 fish/100,000 m^3 across depth strata and years in the lower lake (Table 5). Densities were generally higher in the upper lake, ranging from 0.21 to 31.65 fish/100,000 m^3 across strata and years. The years 2005 and 2006 show the highest density values. These years also coincided with the most sampling effort. The large confidence intervals, however, were found in all years, expressing the trend of large sampling variation within surveys no matter what the sampling effort. Fish densities by species by depth strata by year are found in Tables 7-16. Fish densities by depth strata with years combined are found in Tables 17 and 18.

Abundance estimates varied greatly by year. Lake trout were the most numerous species (Table 19, 20, and 21). Arctic char abundance ranged from 2,051 to 61,790 in the lower lake and 4,208 to 48,924 in the upper lake. Arctic grayling abundance ranged from 0 to 20,040 in the lower lake and 1,136 to 150,236 in the upper lake. Dolly Varden abundance ranged from 0 to 16,734 in the lower lake and 0 to 18,602 in the upper lake. Lake trout abundance ranged from 4,030 to 252,553 in the lower lake and 19,395 to 600,204 in the upper lake. Round whitefish ranged from 2,706 to 106,914 in the lower lake and 1,846 to 131,634 in the upper lake. There was considerably more variation in 2001-2004 acoustic estimates. This was likely a result of poor sample coverage due to time and inclimate weather restraints. Water volume for depth strata of the lower lake is 1002 km^3 for 0-20 m, 2468 km^3 for 20-80 m, and 49 km^3 for >80 m depth strata. Water volume for depth strata for the upper lake is 1420 km^3 for 0-20 m, 2600 km^3 for 20-80 m, and 118 km^3 for >80 m depth strata.

General Linear Models

GLM (1); comparing total density estimates within depth strata among years

For the lower lake, density in 2005 was significantly higher than all other years in the >80 m depth strata ($F=30.87$, $df=5$, $p<0.0001$) (Table 5). For the upper lake, density in 2005 was significantly higher than 2003 in the 20-80 m depth strata ($F=5.30$, $df=4$, p=0.0003) and density in 2005 significantly higher than all other years in the >80 m depth strata (F=17.17, df=4, p<0.0001) (Table 6).

GLM (2); comparing species density estimates within depth strata among years

For the lower lake, there were significant fish density differences for Arctic char in 20-80 m depth strata (F=5.45, df=5, p<0.0001) (Table 7), Arctic grayling in 0-4 m (F=25.64, df=5 p<0.0001) and 4-20 m depth strata (F=7.29, df=5, p<0.0001) (Table 8), Dolly Varden in 4-20 m depth strata (F=22.64, df=5, p<0.0001) (Table 9), and lake trout in 4-20 m (F=5.29, df=5, p<0.0001) and >80 m depth stratum (F=30.87, df=5, p<0.0001) (Table 10). For the upper lake there were significant differences for Dolly Varden in 0-4 m (F=7.20, df=4, p<0.0001) and 4-20 m depth strata (F=24.60, df=4, p<0.0001) (Table 14), and lake trout in 20-80 m (F=5.61, df=4, p=0.0002) and >80 m depth strata (F=17.17, df=4, p<0.0001) (Table 15).

GLM (3); comparing total density estimates between strata with years combined

For the lower lake, no significant differences in density were found (Table 17). For the upper lake there were significant differences between 4-20 and >80 m depth strata (F=12.56, df=3, p<0.0001) (Table 18).

GLM (4); comparing species density estimates between depth strata with years combined

For the lower lake, significant differences in density were found for Arctic char between 4-20 and 20-80 m depth strata (F=6.82, df=2, p<0.0001), Dolly Varden between 0-4 and 4-20 m depth strata (F=49.51, df=1, p<0.0001), and lake trout between all depth strata except 0-4 and 4-20 m (F=75.46, df=3, p<0.0001) (Table 23). For the upper lake differences were found for: Arctic char between depth strata, 0-4, 4-20, and 20-80 m (F=60.36, df=2, p<0.0001), Arctic grayling between 0-4 and 4-20 m depth strata

(F=84.88, df=1, p<0.0001), Dolly Varden between 0-4 and 4-20 m depth strata (F=13.97, df=1, p=0.0002), and lake trout between 0-4, 4-20, 20-80, and >80 m depth strata (F=66.65, df=3, p<0.0001) (Table 22).

GLM (5); comparing north/south transects to determine horizontal fish distribution

For the lower lake, no significant differences in density were found. For the upper lake, transect 14 density was significantly higher than transects 4, 5, 6, and 7 (F=1.67, df=16, p<0.049). This coincides with the northern half of the upper lake having higher fish densities than the southern half. In addition, the mean densities for all sections of transects in the northern basin of the upper lake are higher than those found in the southern basin but without significant differences.

GLM (6); comparing TS measurements between depth strata with years combined

The lower lake had significant differences among all three depth strata (F=188.23, df=2, p<0.0001). The upper lake had significant TS differences between all three depth strata (F = 936.68, df = 2, p <0.0001). The mean TS for 0-20 m stratum was significantly higher than 20-80 m and >80 m strata, and 20-80 m was significantly higher than the >80 m stratum. Both the lower and upper lake had the highest TS values in the 0-20 m stratum, than the 20-80 m stratum, and the smallest were in >80 m stratum. The lower lake has larger mean TS values for all three depth strata than the upper lake. For the lower lake, 0-20 m stratum is 0.85 dB larger, the 20-80 m stratum is 1.33 dB larger, and the >80 m stratum is 1.34 dB larger than the upper lake.

Discussion

Fish Density

Based upon the large acoustic variance values, fish densities in the Ugashik Lakes are low and patchily distributed. For each species, annual density variability is high within depth strata with each often having several extreme values. This variability can be attributed to sampling error, systematic error, and fish behavior.

Sampling error is the loss of precision caused by measurements being stochastic samples of the true density. Variances arise from taking a sub-sample from a non-uniform distribution (Cochran 1977). Survey design can have implications on the degree of variance found within a density estimate. Our data set covers 6 years and several survey designs were used throughout. Having little prior knowledge of the fish population in the Ugashik Lakes made survey design difficult. In addition, years 2001-04 allowed only short working times to perform the acoustic surveys due to bad weather and the need to allow time for other activities such as gillnet surveys and calibration of the transducer. Due to temporal restrictions in 2001-04 maximizing survey time took precedent over survey design. Degree of coverage also became an issue with time restraints.

Degree of coverage is an approach looking at the relationship between sampling error and the fraction of the population that has actually been observed. Intuitively, the greater the sampling intensity, the better the precision should be. Aglen (1983; 1989) investigated this idea in differing circumstances from Norwegian fjords to open ocean. He defined degree of coverage as the total length of cruise track divided by size of the surveyed area. He found that as degree of coverage increases, precision does indeed increase. Thus taking more samples will likely lead to a more precise estimate of fish density.

Systematic error is the second form of bias to affect density estimates. Unlike sampling error, systematic error affects all observations similarly. Sampling error can be reduced by taking more samples, systematic error cannot. There are several sources of systematic error.

The first form of systematic error is target strength. Target strength is a stochastic measure that relates the amount of sound reflected from a fish to the original amount of sound transmitted (MacLennan and Simmonds 2005). There is no accepted model for target strength so experiments must be performed (Middtun 1984; Foote 1980a; 1980b) and thus estimations are necessary. Many aspects of fish behavior affect target strength. The angle the fish is swimming (Gauthier and Rose 2002; Foote 1980a; 1980b), swim bladder physiology, recent water depth history, and an empty or full stomach (Ona 1990) can all have effects on target strength measurement. Salmonids are physostomes and lack the *rete mirabile* that physoclists have allowing them to diffuse gases into and out of their swim bladder (Jobling 1995). So depth change makes air bladder volume compensation difficult. Physostomes do have the ability to release air from the air bladder to their gut and then “burp” it out when they increase their depth (Jobling 1995). This physiology can affect TS values and thus bias density estimates (Horne et al. 2006, Mehner 2006). This is an unavoidable form of bias as there is no control nor any way to determine an individual fish’s depth history. Any error in this relationship will bias all observed densities.

Other forms of systematic error that can bias density estimates are equipment sensitivity, transducer motion, hydrographic conditions, and noise and reverberation. Equipment sensitivity represents the process of calibrating the transducer. Calibration is performed by measuring the signal from a standard target. Any change in calibration settings between the time of calibration and the survey will bias the density estimate (Foote 1990). Transducer motion bias is caused by the transducer moving any unwanted direction. In this case, it is any direction except forward through a horizontal plane. This especially pertains to surveys in bad weather. Any other movement degrades the amplitude of the received signal (Masahiko and Kazuo 2006; Takao and Furusawa 1996). This changes the target direction as seen from the transducer and can thus affect target strength in a split-beam transducer (Stanton 1982). This form of systematic error could pertain to our surveys because bad weather often occurred during a survey period causing unwanted motion to the vessel which then gets transferred to the transducer. Hydrographic conditions can also bias density estimates through inaccurate sound speed and absorption coefficient values. These are determined by water salinity, turbidity, and temperature. This especially pertains to echo counting procedures for density estimation in that it affects the time varied gain (TVG) function. TVG compensates for depth in the strength of the transmitted sound pulse. It is unlikely that hydrographic conditions affected any of our acoustic surveys. The water temperature is similar throughout the water column due to the high winds experienced here preventing thermal stratification (Edmundson and Todd 2000). Lastly, noise and reverberation can bias density estimates. Noise refers to any unwanted signal produced by the echo sounder, whether it is true electrical noise, reverberation, or merged echoes from a biological source. Examples of this are the bubble layer produced on the lake surface from wind and boat wake (Vagle and Burch 2005; Ostrovsky et al. 2003), electrical noise from the boat engine or power source (Parks 1998), and even dense schools of immature sockeye salmon. Electrical noise was an issue in many segments of the surveys performed from 2001-04 due to weak power supplies (batteries) and interference from the boat engine which forced us to not use portions of acoustic surveys in those years. Fish behavior also pertains to systematic error but will be discussed separately here.

Different behavior factors for each species may be responsible for the high variability in the acoustic density estimates. One factor that may influence density estimates for Dolly Varden and Arctic char is emigration and immigration. It is known that Dolly Varden move large distances between bodies of fresh water (Bernard et al. 1995; Johnson 1980) and the populations in the Ugashik Lakes are no exception. Early summer of all years saw increases in Dolly Varden numbers in The Narrows between the upper and lower lakes (USFWS, unpublished data). Some populations of Arctic char are known to do this also (Nordeng 1983), but knowledge of the Ugashik population movements, if any, is unknown. Numeration and whether or not levels of these migrations are variable in these migratory “resident” species is unknown and therefore their affect on annual abundance estimates is presently undetermined. The other species present in the Ugashik Lakes are not known for migratory movements. With lake trout, round whitefish, and Arctic grayling it is assumed the lakes represent a closed system and that there are no significant movements into or out of the lakes. However, certain species may follow migrating salmon into tributaries of the lakes for foraging on eggs, and later, flesh of spawned out salmon (Meka et al. 2003). No testing has been done in the Ugashik

Lakes to determine if this type of movement had any affect on resident species density estimates.

The lack of migration does not exclude the other fish species from other forms of movement that can bias density estimates. Low densities and patchy distribution are typical of fish populations in a resource limited environment (Jurvelius et al. 1984; Encina and Rodriguez-Ruiz 2003). The Ugashik Lakes represent an extreme environment with low productivity, low ionic concentrations, long ice cover period, low temperature, and a short growing season (Edmundson and Todd 2000). It is important here to define patchiness in this instance. In most literature it refers to part of a transect with few or no fish and then running into a school or shoal of fish (patch). The patchiness in the Ugashik Lakes refers similarly to the part of a transect with no fish, but here there were no schools or shoals of fish that are encountered. The "patches" were often single fish or in some instances up to 20 individuals within a 100 m transect distance. During our surveys there were almost no concentrations of resident fish above the TS threshold of -53.67 dB for 70 kHz and -53.88 dB for 120 kHz (175 mm). Any shoals or schools encountered were made up of small individuals and were most likely non-resident immature salmon which were not included in the abundance estimates.

This patchiness is likely a result of the general lack of thermal stratification as fish often concentrate in thermocline areas (Baldwin et al. 2002; Sellers et al. 1998). Without a thermocline fish are possibly distributed in a random pattern. A previous study on the Ugashik Lakes using telemetry to track lake trout could not statistically derive patterns to movements (J. Valliere, unpublished data). Because the lakes are thermally mixed (6-13° C), lake trout are not influenced by temperature (Edmundson and Todd 2000).

According to Valliere's data, hook and line capture of fish for radio tag implementation was only performed in littoral areas. This capture became very difficult later in the summer giving an indication that lake trout may be moving away from shallow littoral habitat to deeper offshore habitat. A total of 26 fish were tagged. Some moved as much as 36 km in 98 days, while others moved less than one km in 98 days. During an individual's movement they were found along the lake bottom close to shore, typically in less than 15 m of water. The patchiness of these lakes is also suggested by Valliere's finding of no tagged fish being located near others. The literature also suggests that lake trout and Arctic char are solitary fish, only coming together for spawning. (Martin and Olver 1980; Johnson 1980).

Movements in the absence of thermal barriers could also be a result of foraging behavior. Fish follow and can be found near their forage base (Wellenreuther and Connel 2002). According to Plumb (2006) the most prevalent food items in salmonid stomachs in the Ugashik Lakes were isopods and amphipods. Many aquatic invertebrates are known to have patchy distributions (Krieger 1992). Ugashik Lake's fish predominantly ate invertebrates (Plumb 2006) and they have patchy distributions which may also lead to the fish also having similar distributions. If the majority of the fish population is found as patches, then during an acoustic survey it is paramount that these patches are insonified by the acoustic beam to have an accurate and precise density estimate. However, survey effort variability along with the patchy distribution of fish could be another culprit leading to annual variation. Those years where little of the lake was surveyed could lead to deflated density estimates simply because the majority of patches were missed or it could lead to inflated density estimates if the few transects performed happen to coincide with patches. Also, these patches are not likely stationary. It is likely they result from a forage source. Forage sources such as invertebrates are controlled by such natural forces as weather patterns (Williams et al. 2007) and thus will change location based on prevailing winds and temperature. To continue foraging, fish will follow these food patches. Thus, patches could be missed altogether if acoustic surveys are split up into multiple days or weeks as they may move to locations not being surveyed at the time. However, the time restraints on hydroacoustics are minimal compared to other gears such as gillnets. So, bias from surveys being performed on multiple days will still be less for hydroacoustics. The littoral area was often the most ignored strata in our acoustic surveys leading to low estimates and even a zero estimate for 2003.

The GLMs performed on the acoustic density data show very few significant differences within strata, between years and between strata within years. The large annual variance values of these findings must be taken into account. Such variances make it difficult to determine meaningful relationships with the acoustic density data and make tracking of any changes in fish abundance over time difficult. Changes large enough to affect population dynamics or recruitment are likely to be too small to be determined statistically. Density data from 2005 where the lake was extensively surveyed with transects one kilometer apart (east/west and north/south) still have large confidence intervals showing that survey effort has little to do with the large variation in density values. This is evidence of the patchy distribution of the fish in Ugashik Lakes.

Fish Size

All three non-littoral depth strata were significantly different from each other based on fish size. The 4-20 m stratum had the largest fish, followed by 20-80 m, and then by >80 m. Most of these fish were found along the littoral zone of the lake or a mid-lake reef that provided benthic habitat to which fish could relate. This is typical of nutrient poor lakes as the majority of forage are going to be along the littoral zone such as invertebrates, larval and juvenile fish, and even small vertebrates (Yuma et al. 2006). The Ugashik Lakes are characterized by having a sandy or fine silt bottom off-shore while the littoral near-shore area is dominated by cobble and boulder (Plumb 2006). This alone provides more forage as the interstitial spaces created by the cobble and boulders allow for macro-invertebrates and small fish, especially slimy sculpin (*Cottus cognatus*) (Richardson), to live. Offshore substrates provide amphipods, isopods, and small mollusks as prey, which yield lower caloric intake than near-shore areas (Plumb 2006). However, as summer progresses in many lakes the shallow littoral area becomes too warm and fish must move offshore to deeper water (Biro 1998). The Ugashik Lakes stay cold enough year-round in the shallow littoral area for constant foraging throughout the ice-free part of the year. The bigger fish found here compared to the rest of the lake is likely due to the decreased predatory threats that a larger fish encounters in shallow water near the edge of the lake (Jeppeson et al. 2006; Sass et al. 2006). The larger the individual the less threatened it will be from predation (Trzcinski et al. 2006). In addition, the larger fish have a competitive advantage over resources such as forage in shallow water (Werner and Hall 1977). In shallow water, fish will be in closer proximity which will increase competitive interactions. This then could lead to the observed near-shore target strength distributions that indicate the presence of larger fish. However, the lower lake means for Arctic char in 0-20 and 20-80 m strata were very close with the 0-20 m stratum actually being slightly larger. Arctic char may lack the aggressiveness to maintain their positions in shallow littoral habitat (Langeland et al. 1991). The 20-80 m depth stratum and >80 depth stratum length distributions are bi-modal and have the same modes in their distribution -53 (19 cm) and -42 (67 cm) dB, but 20-80 m depth strata finds a larger percentage of its fish between these modes than in the >80 m depth stratum.

Smaller fish found in deeper water makes sense in the context of predator/prey interactions. Smaller fish in the >80 m depth stratum are at less risk of being predated. In addition, fish foraging in the presence of a predator will often reduce intake because foraging behavior is not conducive to avoidance (Dill 1983; Huntingford et al. 1988; Harvey and Brown 2004). The larger fish will dominate the shallow more productive littoral water while the less productive offshore depths are left to smaller less competitive individuals. In deeper areas, food resources are more spread out and there is more water which will lead to fewer competitive interactions and predation is likely to be decreased. This ultimately may lead to an ontogenetic shift from deeper water as juveniles and small adults to shallow more productive water as larger adults (Werner and Hall 1977; Dahlgren and Eggleston 2000).

Length frequency histograms of gillnet fish versus acoustic fish show what is typical in the literature (Mehner and Schulz 2002), that acoustic surveys suggest larger targets and more widely distributed sizes than those derived from gillnets. For the Ugashik Lakes, I eliminated fish below 175 mm (-53.67 dB for 70 kHz and -53.88 dB for 120 kHz, using the TS to length equation from Chapter 2), from analysis to avoid inflated density estimates caused by immature salmon, so the trend of gillnets missing these fish is not evident in this study. The larger individuals, however, are absent from the gillnet distribution. This could be a matter of not having a net strong enough to hold these larger individuals, net selectivity, or lack of fish >600 mm. There is anecdotal evidence of sturgeon (*Acipenser sp*.) in these lakes which would give very large target strengths and such fish would be unlikely to be captured in gillnets. In addition, there is some anecdotal evidence, from local residents of the area, of some very large Arctic char and lake trout individuals in the lakes although none were captured in our study. Although the distributions do not have identical modes, the core of the lengths in gillnets and acoustics match up well.

The difference in modes for gillnet and acoustic target size distribution is most likely caused by a combination of gillnet catch bias and acoustic "rounding" of target strengths. The bias can come from a number of variables. The most noted one is the size of the various meshes in the net (Finstad and Berg 2004). Certain size and shaped fish (Kurkilahti et al. 2002) are captured better than others for a given size mesh. Some size classes can be missed if there is not a mesh size to efficiently capture these individuals. Extreme sizes of fish make capture in gillnets difficult as well. Small fish often lack the power necessary to become entangled in gillnets. Also, very large fish are strong enough to break the fine mesh of many gillnets preventing the capture of large individuals. Gillnets are a passive gear meaning the movement of the fish is the cause of contact and subsequent capture with a gillnet. Thus, fish mobility, water clarity, and temperature can all affect gillnet capture success. In clear water, fish may see and avoid a net. Water temperature affects fish movement. Temperatures that restrict fish movement will decrease gillnet catches simply by decreasing encounter probability (Hansson and Rudstam 1995; Bromaghin 2005).

Acoustic measures of target strengths are also prone to “rounding”. Measures of individual target strength results in normal distributions of TS for tethered individual fish (Hartman and Nagy 2005). Therefore, it is expected that measures of TS on wild individuals will result in rounding and blending of fish population size distributions. In all likelihood, a combination of this “rounding” and gillnet size bias resulted in the incomplete agreement of size distributions in the two gears as is commonly reported in acoustic comparisons (Hartman et al. 2000).

Future Research

It is important to highlight areas of a research experiment that need further clarification. The most important area that I think needs further research is with the further development of a TS to length relationship for the species in this lake system. The relationship I created in Chapter 2 has limitations such as small sample size, small range of sizes, and only three individuals less than 100 mm in length. Using a large sample size and a large range of sizes will help to create a more accurate relationship between size and TS and decrease the bias this inaccuracy leaves on density estimates.

Another form of likely bias in estimating fish density in these lakes is fish movement. Experiments should be performed to determine what, if any movements occur in these lakes. Emphasis should be put on Dolly Varden and Arctic char migrations into and out of the lakes. In addition, movements from the lake body into surrounding tributaries may also prove to be a form of movement bias and should be tested for using weirs or stationary receivers and tagged individuals. This movement may be species specific and it will prove important to know which of the species in the lakes are making this movement. Knowing this may allow acoustic surveys to be performed before these fish make any movements that would make them undetectable to hydroacoustics. Lastly, fish movement should be investigated in relation to patch dynamics. Knowing if patch dynamics are influencing fish congregation and/or movement could lead to more precise density estimates from hydroacoustic surveys in the future. Patches may form only during parts of the year based on forage or other variables. These patches may also be in a permanent geographic area of the lakes making it important to insonify that area during every acoustic survey in order to get an unbiased estimate.

Management Implications

Findings in this paper emphasize the degree of difficulty of managing and monitoring the Ugashik Lakes. Their remote setting makes even the most typical data collection difficult. In addition, the system is unique in its lack of thermal stratification during the summer which affects fish distribution. This novelty alone makes these lakes important candidates for research as there are other similar lake systems in southwest Alaska. This lack of thermal stratification could affect the way these lakes are managed compared to other large lake systems. The limnological characteristics make for low productivity in these lakes creating minimal food resources and likely enhancing competition among the fish populations (Edmundson and Todd 2000). This lack of resources creates a patchy low density population that is difficult to quantify with a reasonable measure of precision. The difficulty in precision stems from high variances that are a result of fish patches with high density values separated by small or zero values in between (Pennington 1983). This lack of precision creates large confidence intervals making significant changes in fish populations difficult to detect annually. However, changes over time can still be determined. High variances between years make determining any significant differences difficult, but there may be a significant trend over multiple years. Changes in density over multiple years, though not statistically significant, can still reveal important trends in fish population dynamics. Managers can determine an overall increase, decrease, or stability in fish density over time. From this, investigations can be made to determine specifically what may be causing changes, if any. Overall changes in fish density may be caused by a decline in a specific species, or in a specific habitat. The research done here is an excellent starting point for monitoring fish density trends over time. This especially pertains to significant recreational fishing pressure increases that are possible in the future. For instance, Figure 6, using our 2001-06 dataset, shows a general decrease of overall fish density in the lower lake for depth strata 0-4 m. From here a manager can then break down the 0-4 m stratum into density for each species found (Figure 7). The decrease for overall density may be carried by a specific species in decline. In this example all species show a decline except for round whitefish with Arctic char showing the largest decline over time. There could also be significant movements between the upper and lower lakes via the Narrows. From a management perspective if this decline continues over time it may be important to investigate the cause.

Down-looking hydroacoustics is best suited for pelagic fish or fish sufficiently off the bottom of the lake enough to be detected by the gear. It also requires a minimum depth to gain a valid amount of sampled water. The evidence from gillnet and hydroacoustic surveys shows a large proportion of the larger individuals reside in the shallow littoral zone of the lakes making them nearly impossible to detect with acoustic gear. This could prove to be a significant difficulty in abundance estimation for this shallow water. I overcame this limitation by using gillnet CPUE to calibrate density estimates based on 4-20 m deep littoral water sampled with hydroacoustics as explained in the methods. However, there is no simple way to determine the accuracy of this estimation procedure. The acoustic surveys proved valid for deeper offshore water in this lake system which represents a large proportion of the lake's volume. Here large amounts of water are being sampled much faster than conventional data collection techniques (Thorne 1983).

The low density, patchy populations of fish in the Ugashik Lakes make for large variations in estimates of density. This in turn leads to difficulty in comparing any changes that occur annually with these fish populations, but is still useful in determining population change over multiple years. Other means of determining density such as mark-recapture, would require much more time, labor, and money with likely similar or less precise results than absolute abundance (Crocket et al. 2006; McInerny and Cross 2005). Add to this, the remoteness of the Ugashik Lakes and hydroacoustic surveys still are the best means of acquiring density estimates for the lakes. The large variance values would likely carry over to any other method used such as mark and recapture. So, low precision of abundance estimates would not likely be attributed to hydroacoustics only. In conclusion, the low precision estimates of density are unavoidable. Hydroacoustics is a valid means of estimating fish density for the Ugashik Lakes, Alaska.

In closing it is important to address the shortcomings this dataset may possess. As an example I used all 6 years of hydroacoustic data to show trends in fish density over time. However, the hydroacoustic data collected from 2001-2004 has severe limitations.

The coverage of the lakes was minimal for these years as a result of inclimate weather and variable power sources. In addition, no gillnet data was collected in 2001-02 so species apportionment for these years in questionable. The littoral areas of the Ugashik Lakes saw very little coverage from 2001-04 as well making the estimates of this area's bias undetermined. So, I warn against the validity of using 2001-04 hydroacoustic data. The years 2005-06 had very good coverage of both lakes with little weather or power source problems to combat. The smaller variation between these years is also likely an indicator of less bias in estimation. I suggest at least two more years of data collected in the manner outlined in Chapter 3 before making any assessment on the fish populations. Lastly, there were areas in both lakes that had pelagic targets. Our assumption is that those fish caught in bottom set gillnets represent fish at the same depth but in pelagic regions of the lake. An attempt was made to capture these fish with pelagic horizontal and vertical gillnets. Over 40 hours of effort yielded only 4 individuals that were lake trout.

References

Aglen, A. 1983. Random errors of acoustic fish abundance estimates in relations to the survey grid density applied. FAO Fisheries Report. 300, 293-298.

Aglen, A. 1989. Empirical results on precision-effort relationships for acoustic surveys. International Council for the Exploration of the Sea B:30: 28.

Baldwin, C.,M., D.A. Beauchamp, Gubala, C.P. 2002. Seasonal and diel distribution and movement of Cutthroat trout from ultrasonic telemetry. Transactions of the American Fisheries Society 131: 143-158.

Bernard, D.R., Hepler, K.R., Jones, J.D., Whalen, M.E., McBride, D.N. 1995. Some tests of the "migration hypothesis" for anadromous Dolly Varden (southern form). Transactions of the American Fisheries Society 124: 297-307.

Biro, P. A. 1998. Staying Cool: Behavioral Thermoregulation during Summer by Young-of-Year Brook Trout in a Lake. Transactions of the American Fisheries Society 127: 212-222.

Brandt, S. B. 1996. Acoustic assessment of fish abundance and distribution. Pages 385-419. in Murphy, B. R., and D. W. Willis, editors. Fisheries Techniques. American Fisheries Society, Bethesda, Maryland.

Bromaghin, A.F. 2005. A versatile net selectivity model, with application to Pacific salmon and freshwater species of the Yukon River, Alaska. Fisheries Research 74: 157-168.

Bromaghin, J.F. 1993. Sample size determination for interval estimation of multinomial probabilities. The American Statistician 47: 203-206.

Cochran, W.G. 1977. Sampling techniques, 3rd edition. Wiley, New York.

Cole, G.A. 1994. Textbook of Limnology. 4th edition. Waveland Press, Inc. Prospect Heights, Illinois.

Crockett, H. J., Johnson, B. M., Martinez, P. J., Brauch, D. 2006. Modeling Target Strength Distributions to Improve Hydroacoustic Estimation of Lake Trout Population Size. Transactions of the American Fisheries Society 135: 1095-1108.

Dahlgren, C. P. and Eggleston, D. B. 2000. Ecological Processes Underlying Ontogenetic Habitat Shifts in a Coral Reef Fish. Ecology 81: 2227-2240.

Dunaway, D.O. and Jaenicke, M.J. 2000. Area management report for the recreational fisheries of the Southwest Alaska Sport Fish Management Area, 1998. Alaska Department of Fish and Game, Fishery Management Report No. 00-3, Anchorage.

Dill, L.M., 1983. Adaptive flexibility in the foraging behavior of fishes. Canadian Journal of Fisheries and Aquatic Sciences 40: 398-408.

Edmundson, J.A. and Todd, G.L. 2000. Limnological perspectives on stock and recruitment for Egegik and Ugashik river sockeye salmon. Regional information report, No. 2A00-33. Alaska Department of Fish and Game.

Encina, L. and Rodriguez-Ruiz, A. 2003. Abundance and distribution of a brown trout population in a remote high mountain lake. Hydrobiologia 493: 35-42.

Finstad, A.G. and Berg, O.K. 2004. Bimodal population size distributions and biased gillnet sampling. Canadian Journal of Fisheries and Aquatic Sciences 61: 2151-2157.

Foote, K.G. 1990. Spheres for calibrating an eleven-frequency acoustic measurement system. ICES Journal of Marine Science 46: 284-286.

Foote, K. G. 1980a. Effect of fish behavior on echo energy: the need for measurements of orientation distributions. ICES Journal of Marine Science 39: 193-201.

Foote, K. G. 1980b. Importance of the swimbladder in acoustic scattering by fish: a comparison of gadoid and mackerel target strengths. Journal of the Acoustical Society of America 67: 2084-2089.

Gauthier, S, and Rose, G. A. 2002. *In situ* target strength studies on Atlantic Redfish (*Sebastes* spp.). Journal of Marine Science 59: 805-815.

Hansson, S. and Rudstam, L.G. 1995. Gillnet catches as an estimate of fish abundance: a comparison between vertical gillnet catches and hydroacoustic abundances of Baltic Sea herring and sprat. Canadian Journal of Fisheries and Aquatic Sciences 52: 75-82.

Hartman , K. J. and Nagy, B. 2005. A target strength and length relationship for striped bass and white perch. Transactions of the American Fisheries Society 134: 375-380.

Hartman, K.J., Nagy, B., Tipton, R.C., Morrison, S. 2000. Verification of Hydroacoustic Estimates of Fish Abundance in Ohio River Lock Chambers. North American Journal of Fisheries Management 20: 1049-1056.

Harvey, M.C. and Brown, G.E. 2004. Dine or dash?: Ontogenetic shift in the response of yellow perch to conspecific alarm cues. Environmental biology of fishes 70: 345-352.

Heales, D.S., Brewer, D.T., Kuhnert, P.M., Jones, P.N. 2007. Detecting declines in catch rates of diverse trawl by-catch species, and implications for monitoring. Fisheries Research 84: 153-161.

Horne, J. K., Barbee, D., Sawada, K., Abe, K., Sadayasu, K., Takao, Y. 2006. Swim bladders under pressure: Anatomical and acoustic responses by walleye Pollock. Journal of the Acoustical Society of America 120: 3105.

Huntingford, F.A., Metcalfe, N.B., Thorpe, J.E. 1988. Feeding motivation and response to predation risk in Atlantic salmon parr adopting different life history strategies. Journal of Fish Biology 32: 777-782.

Jeppesen, E., Pekcan-Hekim, Z., Lauridsen, T.L., Soendergaard, M., Jensen, J.P. 2006. Habitat distribution of fish in late summer: changes along a nutrient gradient in Danish lakes. Ecology of Freshwater Fish 15: 180-190.

Jobling, M. 1995. Environmental Biology of Fishes. Chapman and Hall, London.

Johnson, L. 1980. The arctic charr, *Salvelinus alpinus*. Pages 15-98. in Balon, E. K., editor. Charrs: Salmonid fishes of the genus *Salvelinus*. Dr. W. Junk Publishers, The Hague, Netherlands.

Jurvelius, J., Heikkinen, T., Valkeajaervi, P., Lindem, T. 1987. Fish density and fish species composition in relation to the phosphorus concentration in some pelagic areas of Lake Paeijaenne. Biological Research Reports from the University of Jyvaskyla.

Jurvelius, J., Torfinn, L., Louhimo, J. 1984. The number of pelagic fish in Lake Paasivesi, Finland, monitored by hydroacoustic methods. Fisheries Research 2: 273-283.

Krieger, K. A. 1992. The Ecology of Invertebrates in Great Lakes Coastal Wetlands: Current Knowledge and Research Needs. Journal of Great Lakes Research 18: 634-650.

Kurkilahti, M., Appelberg, M., Hesthagen, T., Rask, M. 2002. Effect of fish shape on gillnet selectivity: a study with Fulton's condition factor. Fisheries Research 54: 153-170.

Langeland, A., L'Abee-Lund, J. H., Jonsson, B., Jonsson, N. 1991. Resource Partitioning and Niche Shift in Arctic Charr *Salvelinus alpinus* and Brown Trout *Salmo trutta*. The Journal of Animal Ecology 60: 895-912.

Lemberg, N. A. and O. A. Mathisen. 1975. Hydro-acoustic fish stock assessment survey in Becharof and Ugashik lakes, 1975. Report 1735 of Alaska Department of Fish and Game, Anchorage, Alaska.

MacLennan, D.N. and Simmonds, E.J. 2005. Fisheries Acoustics. Chapman and Hall, London.

Martin, N. V. and C. H. Olver. 1980. The lake charr, *Salvelinus namaycush*. Pages 205-280. in Balon, E. K. editor. Charrs: Salmonid fishes of the genus *Salvelinus*. Dr. W. Junk Publishers, The Hague, Netherlands.

Masahiko, F. and Kazuo, A. 2006. Robust analysis of single echo trace obtained by split beam sounder. Journal of the Acoustical Society of America 120: 3060.

McInerny, M. C. and Cross, T. K. 2005. An Evaluation of Mark-Recapture Estimates of Black Crappie Population Size Determined by Trap-Netting during Fall and Spring in Minnesota Lakes. North American Journal of Fisheries Management 25: 475-490.

Meka, J.M., Knudsen, E.E., Douglas, D.C., Benter, RB. 2003. Variable Migratory Patterns of Different Adult Rainbow Trout Life History Types in a Southwest Alaska Watershed. Transactions of the American Fisheries Society 132: 717-732.

Mehner, T. 2006. Individual variability of diel vertical migrations in European vendace (*Coregonus albula*) explored by stationary vertical hydroacoustics. Ecology of Freshwater 15: 146-153.

Mehner, T. and Schulz, M. 2002. Monthly variability of hydroacoustic fish stock estimates in a deep lake and its correlation to gillnet catches. Journal of Fish Biology 61: 1109-1121.

Midttun, L. 1984. Fish and other organisms as acoustic targets. Rapports et Procès-Verbaux des Réunions du Conseil International pour l'Exploration de la Mer 184:25–33.

Nordeng, H. 1983. Solution to the "char problem" based on Arctic char (*Salvelinus alpinus*) in Norway. Canadian Journal of Fisheries and Aquatic Sciences 40: 1372-1387.

Ona, E., and R.B. Mitson. 1996. Acoustic sampling and signal processing near the seabed: the dead zone revisited. ICES Journal of Marine Science 53: 677-690.

Ona, E. 1990. Physiological factors causing natural variations in acoustic target strength of fish. Journal of Marine Biology 70: 107-127.

Ostrovsky, L.A., Sutin, A.M., Soustova, I.A., Matveyev, A.L., Potapov, A.I., Kluzek, Z. 2003. Nonlinear scattering of acoustic waves by natural and artificially generated subsurface bubble layers in sea. Journal of the Acoustical Society of America 113: 741-749.

Parks, J. R. 1998. Noise in acoustic systems. Canadian technical report of fisheries and aquatic sciences.

Pennington, M. 1983. Efficient estimators of abundance, for fish in plankton surveys. Biometrics 39: 281-286.

Plumb, M. 2006. Ecological factors influencing fish distribution in a large sub-arctic lake system. Master's thesis. University of Alaska in Fairbanks.

Rudstam, L.G., Magnuson, J.J., Tonn, W.M. 1984. Size selectivity of passive fishing gear: A correction for encounter probability applied to gill nets. Canadian Journal of Fisheries and Aquatic Sciences 41: 1252-1255.

SAS Institute Inc., SAS 9.1.3 Help and Documentation, Cary, NC: SAS Institute Inc., 2000-2004.

Sass, G.G., Gille, C.M., Hinke, J.T., Kitchell, J.F. 2006. Whole-lake influences of littoral structural complexity and prey body morphology on fish predator-prey interactions. Ecology of Freshwater Fish 15: 301-308.

Scheaffer, R.L., W. Mendenhall III, and R.L. Ott. 1996. Elementary Survey Sampling 5th Edition. Duxbury Press.

Sellers, T., J., B. R. Parker, D. W. Schindler, Tonn W.M. 1998. Pelagic distribution of lake trout (*Salvelinus namaycush*) in small Canadian shield lakes with respect to temperature, dissolved oxygen, and light. Canadian Journal of Aquatic Science 55: 170-179.

Stanton, T. K. 1982. Effects of transducer motion on echo integration techniques. Journal of the Acoustical Society of America 72: 947-949.

Takao, Y.,Furusawa, M. 1996. Dual-beam echo integration method for precise acoustic surveys. Fisheries and Plankton Acoustics. Proceedings of an ICES International Symposium held in Aberdeen, Scotland, 12-16 June 1995. 53: 351-358

Thedinga, J. F., Murphy, M. L., Johnson, S. W., Lorenz, J. M., Koski, K. V. 1994 Determination of Salmonid Smolt Yield with Rotary-Screw Traps in the Situk River, Alaska, to Predict Effects of Glacial Flooding. North American Journal of Fisheries Management 14: 837–851.

Thorne, R.E. 1983. Assessment of population abundance by hydroacoustics. Biological Oceanography 2: 253-262.

Trzcinski, M.K., Mohn, R., Bowen, W.D. 2006. Continued decline of an Atlantic cod population: How important is gray seal predation? Ecological Applications 16: 2276-2292.

USFWS. 2003. Quantification of Resident Fish Populations in the Ugashik Lakes Using Hydroacoustics. Research Proposal. Prepared by KSFO. ID number 04-R7-XX.

Vagle, S., and Burch, H. 2005. Acoustic measurements of the sound-speed profile in the bubbly wake formed by a small motor boat. Journal of the Acoustical Society of America 117: 153-163.

Wanzenböck, J., Mehner, T., Schulz, M., Gassner, H. Winfield, I.J. 2003. Quality assurance of hydroacoustic surveys: the repeatability of fish-abundance and biomass estimates in lakes within and between hydroacoustic systems. ICES Journal of Marine Science 60: 486-492.

Wellenreuther, M. and Connel, S. D. 2002. Response of predators to prey abundance: separating the effects of prey density and patch size. Journal of Experimental Marine Biology and Ecology 273: 61-71.

Werner, E. E. and Hall, D. J. 1977. Competition and habitat shift in two sunfishes. Ecology 58: 869-876.

Williams D. D., Heege N., Magnusson K. A. 2007. Habitat background selection by colonizing intermittent pond invertebrates. Hydrobiologia 592: 487-498.

Williamson, N. J. 1982. Cluster Sampling Estimation of the Variance of Abundance Estimates Derived from Quantitative Echo Sounder Surveys. Canadian Journal of Fisheries and Aquatic Sciences 39: 229-231.

Yuma, M., Timoshkin, O, A, Melnik, N. G, Khanaev, I. V, Ambali, A. 2006. Biodiversity and food chains on the littoral bottoms of Lakes Baikal, Biwa, Malawi and Tanganyika: working hypotheses. Hydrobiologia 568: 95-99.

Table 1. Acoustic effort and gillnet catches for each lake separated by year. Low acoustic effort numbers from 2001 to 2004 are due to inclimate weather and electrical noise contamination of collected data from low battery power.

Lake	Year	Acoustic Effort (min)	Gillnet Effort (# of Nets)	Gillnet Effort (# of Fish)
Lower	2001	180	0	0
	2002	660	0	0
	2003	360	21	212
	2004	240	40	327
	2005	1980	19	51
	2006	540	20	178
Upper	2001	0	0	0
	2002	240	0	0
	2003	240	24	313
	2004	300	45	505
	2005	2460	23	107
	2006	540	11	206

Table 2. Transducer and transceiver settings for the EY500, 120 kHz and EK60, 70 kHz split-beam system used for Ugashik Lakes surveys.

	2001-05	2005	2006
Frequency (kHz)	120	70	70
Bandwidth (kHz)	1.2	4.69	6.82
Pulse Length (ms)	0.30	0.512	0.128
Maximum Power (W)	63.00	500.00	500.00
Two-way beam angle (degrees)	-20.80	-21.00	-21.00
Sv transducer gain (dB)	26.10	24.15	25.42
TS transducer gain (dB)	26.10	24.15	25.42
Angle sensitivity alongship (degrees)	21.00	23.00	23.00
Angle sensitivity athwartship (degrees)	21.00	23.00	23.00
3 dB beam width alongship (degrees)	6.90	7.12	6.41
3 dB beam width athwartship (degrees)	7.00	6.58	6.42
Minimum echo level (dB)	-53.88	-53.67	-53.67
Maximum echo length (dB)	1.00	1.00	1.00
Minimum echo length (dB)	0.500	0.500	0.500
Maximum gain compensation (dB)	12.00	12.00	12.00
Maximum phase deviation (dB)	0.600	0.600	0.600

Table 3. Gillnet catch composition by species by year and by depth strata. Years 2005 and 2006 were combined because no near-shore nets were set in 2005 to minimize impact to adult sockeye salmon.

Year	Lake	N (net sets)	N (# of fish)	Strata	Artic char	Arctic grayling	Dolly Varden	lake trout	round whitefish
2003	Lower	21	195	0-4	0.329	0.105	0.132	0.118	0.316
				4-20	0.341	0	0	0.146	0.512
				20-80	0.075	0	0	0.925	0
				>80	0	0	0	1	0
	Upper	24	269	0-4	0.258	0.269	0.097	0.140	0.237
				4-20	0.129	0.258	0	0.183	0.430
				20-80	0.167	0	0	0.833	0
				>80	0	0	0	1	0
2004	Lower	40	327	0-4	0.269	0.010	0.154	0.019	0.548
				4-20	0.241	0.036	0.060	0.205	0.458
				20-80	0.309	0	0	0.691	0
				>80	0	0	0	1	0
	Upper	45	506	0-4	0.200	0.325	0.130	0.180	0.165
				4-20	0.245	0.027	0.045	0.245	0.436
				20-80	0.186	0	0	0.814	0
				>80	0	0	0	1	0
2005-06	Lower	39	228	0-4	0.071	0	0.048	0.071	0.810
				4-20	0.163	0.023	0	0.023	0.791
				20-80	0.026	0	0	0.974	0
					0	0	0	1	0
	Upper	34	313		0	0.313	0	0.469	0.219
					0.063	0.125	0	0.375	0.438
					0.110	0	0	0.890	0
					0	0	0	1	0

Table 4. Catch per unit effort (CPUE) data used to calibrate 0-4 m deep water using 4-20 m deep water. The ratio of CPUE between 0-4 and 4-20 m deep water was used to determine fish density in 0-4 m deep water where acoustics were unable to sample.

Lake	Year	Ratio (0-4 to 4-20)	Strata	CPUE
Lower	2003	1.85	0-4	19.00
			4-20	10.25
	2004	1.25	0-4	26.00
			4-20	20.75
	2005/06	0.98	0-4	11.08
			4-20	11.35
Upper	2003	1.00	0-4	23.25
			4-20	23.25
	2004	1.81	0-4	50.00
			4-20	27.50
	2005	1.00	0-4	7.31
			4-20	7.31

Table 5. Lower lake fish densities (fish / 100,000 m ^{3}) by depth strata by year with 95% confidence intervals computed using cluster sampling. Year 2004 in 80+ depth strata had only one sample so no confidence interval could be constructed.

Strata	Year	Density	Lower 95%	Upper 95%
0-4	2001	11.41	6.57	16.25
	2002	6.01	3.78	8.25
	2003	0.00	0.00	0.00
	2004	9.34	8.02	10.65
	2005	7.31	2.93	11.70
	2006	6.83	5.36	8.31
4-20	2001	3.37	1.75	4.99
	2002	1.79	1.05	2.53
	2003	0.31	0.30	0.32
	2004	5.16	4.01	6.31
	2005	5.76	2.82	8.70
	2006	3.65	2.66	4.64
20-80	2001	10.30	7.87	12.73
	2002	0.92	0.69	1.15
	2003	0.13	0.11	0.15
	2004	2.63	2.34	2.92
	2005	7.07	4.19	9.95
	2006	1.42	1.10	1.74
80+	2001	3.05	2.70	3.40
	2002	0.43	0.37	0.49
	2003	0.59	0.46	0.72
	2004	1.21	N/A	N/A
	2005	17.60	13.84	21.36
	2006	1.75	1.24	2.26

Table 6. Upper lake fish densities (fish / 100,000 m ^{3}) by depth strata by year with 95% confidence intervals. No data was collected in the Upper lake in 2001 due to inclement weather.

Strata	Year	Density	Lower 95%	Upper 95%
0-4	2002	4.51	3.22	5.80
	2003	0.00	0.00	0.00
	2004	9.28	7.67	10.90
	2005	20.72	4.93	36.51
	2006	31.65	27.98	35.31
4-20	2002	3.33	2.59	4.07
	2003	0.21	0.12	0.30
	2004	3.38	2.59	4.17
	2005	14.2	4.24	24.16
	2006	16.20	13.8	18.6
20-80	2002	2.07	1.52	2.62
	2003	0.84	0.63	1.05
	2004	6.57	5.00	8.14
	2005	16.4	11.28	21.52
	2006	13.80	11.08	16.52
80+	2002	0.49	0.32	0.66
	2003	0.29	0.24	0.34
	2004	2.28	2.04	2.52
	2005	26.3	18.09	34.51
	2006	0.24	0.15	0.33

Table 7. Lower lake fish densities (fish / 100,000 m ^{3}) for Arctic char by depth strata by year with 95% confidence intervals computed using cluster sampling. Years within the same strata with the same letter are not significantly different.

Strata	Year	Density	Lower 95%	Upper 95%	
0-4	2001	3.75	1.87	5.63	A
	2002	1.98	1.14	2.82	A
	2003	0.00	0.00	0.00	A
	2004	2.51	1.73	3.29	A
	2005	0.52	0.21	0.83	A
	2006	0.49	0.35	0.62	A
4-20	2001	0.52	0.30	0.74	A
	2002	0.29	0.19	0.39	A
	2003	0.18	0.13	0.23	A
	2004	0.94	0.73	1.15	A
	2005	0.98	0.51	1.45	A
	2006	0.21	0.12	0.29	A
20-80	2001	0.77	0.59	0.95	AB
	2002	0.07	0.05	0.09	C
	2003	0.01	0	0.02	C
	2004	0.81	0.72	0.90	A
	2005	0.18	0.11	0.26	BC
	2006	0.04	0.03	0.05	C

Table 8. Lower lake fish densities (fish / 100,000 m ^{3}) for Arctic grayling by depth strata by year with 95% confidence intervals computed using cluster sampling. Years within the same strata with the same letter are not significantly different.

Strata	Year	Density	Lower 95%	Upper 95%	
0-4	2001	1.20	0.60	1.80	A
	2002	2.00	1.14	2.82	B
	2003	0.00	0.00	0.00	C
	2004	0.09	0.07	0.11	C
	2005	0.00	0.00	0.00	C
	2006	0.00	0.00	0.00	C
4-20	2001	0.00	0.00	0.00	A
	2002	0.00	0.00	0.00	A
	2003	0.00	0.00	0.00	A
	2004	0.14	0.11	0.17	B
	2005	0.02	0.01	0.03	A
	2006	0.03	0.02	0.04	A

Table 9. Lower lake fish densities (fish / 100,000 m ^{3}) for Dolly Varden by depth strata by year with 95% confidence intervals computed using cluster sampling. Years within the same strata with the same letter are not significantly different.

Strata	Year	Density	Lower 95%	Upper 95%	
0-4	2001	1.51	0.76	2.26	A
	2002	0.79	0.46	1.13	A
	2003	0.00	0.00	0.00	A
	2004	1.44	1.11	1.77	A
	2005	0.35	0.14	0.56	A
	2006	0.33	0.24	0.42	A
4-20	2001	0.00	0.00	0.00	A
	2002	0.00	0.00	0.00	A
	2003	0.00	0.00	0.00	A
	2004	0.23	0.18	0.29	B
	2005	0.00	0.00	0.00	A
	2006	0.00	0.00	0.00	A

Table 10. Lower lake fish densities (fish / 100,000 m ³) for lake trout by depth strata by year with 95% confidence intervals computed using cluster sampling. Years within the same strata with the same letter are not significantly different. Year 2004 in 80+ depth strata had only one sample so no confidence interval could be constructed.

Strata	Year	Density	Lower 95%	Upper 95%	
0-4	2001	1.35	0.68	2.02	A
	2002	0.71	0.41	1.01	A
	2003	0.00	0.00	0.00	A
	2004	0.18	0.14	0.22	A
	2005	0.52	0.21	0.83	A
	2006	0.49	0.35	0.62	A
4-20	2001	0.22	0.13	0.32	A
	2002	0.13	0.08	0.17	A
	2003	0.08	0.05	0.11	A
	2004	0.80	0.62	0.98	B
	2005	0.14	0.07	0.20	A
	2006	0.03	0.02	0.04	A
20-80	2001	9.54	7.31	11.77	A
	2002	0.85	0.65	1.05	A
	2003	0.12	0.10	0.14	A
	2004	1.82	1.62	2.02	A
	2005	6.89	4.09	9.69	A
	2006	1.38	1.07	1.69	A
>80	2001	3.05	2.70	3.40	A
	2002	0.43	0.36	0.50	A
	2003	0.59	0.45	0.74	A
	2004	1.21	NA	NA	A
	2005	17.6	13.51	21.69	B
	2006	1.75	1.24	2.26	A

Table 11. Lower lake fish densities (fish / 100,000 m ^{3}) for round whitefish by depth strata by year with 95% confidence intervals computed using cluster sampling. Years within the same strata with the same letter are not significantly different.

Strata	Year	Density	Lower 95%	Upper 95%	
0-4	2001	3.61	1.81	5.41	A
	2002	1.90	1.10	2.70	A
	2003	0.00	0.00	0.00	A
	2004	5.12	3.95	6.29	A
	2005	5.92	2.37	9.47	A
	2006	5.54	4.04	7.04	A
4-20	2001	0.79	0.46	1.12	A
	2002	0.44	0.28	0.59	A
	2003	0.27	0.18	0.36	A
	2004	1.79	1.39	2.19	A
	2005	4.75	2.48	7.02	A
	2006	1.00	0.57	1.42	A

Table 12. Upper lake fish densities (fish / 100,000 m ^{3}) for Arctic char by depth strata by year with 95% confidence intervals computed using cluster sampling. Years within the same strata with the same letter are not significantly different. No data was collected in the Upper lake in 2001 due to inclement weather.

Strata	Year	Density	Lower 95%	Upper 95%	
0-4	2002	1.16	0.69	1.63	A
	2003	0.00	0.00	0.00	A
	2004	1.86	1.46	2.26	A
	2005	0.00	0.00	0.00	A
	2006	0.00	0.00	0.00	A
4-20	2002	0.36	0.25	0.47	A
	2003	0.04	0.02	0.06	A
	2004	0.56	0.45	0.66	A
	2005	0.61	0.29	0.93	A
	2006	0.34	0.27	0.41	A
20-80	2002	0.35	0.25	0.44	A
	2003	0.14	0.11	0.17	A
	2004	0.56	0.45	0.67	A
	2005	0.61	0.29	0.93	A
	2006	0.34	0.27	0.41	A

Table 13. Upper lake fish densities (fish / 100,000 m ^{3}) for Arctic grayling by depth strata by year with 95% confidence intervals computed using cluster sampling. Years within the same strata with the same letter are not significantly different. No data was collected in the Upper lake in 2001 due to inclement weather.

Strata	Year	Density	Lower 95%	Upper 95%	
0-4	2002	1.21	0.72	1.70	A
	2003	0.00	0.00	0.00	A
	2004	3.02	2.36	3.68	A
	2005	6.49	1.55	11.43	A
	2006	9.91	8.48	11.34	A
4-20	2002	0.72	0.60	0.84	A
	2003	0.08	0.05	0.11	A
	2004	0.06	0.05	0.07	A
	2005	1.21	0.58	1.84	A
	2006	0.67	0.53	0.81	A

Table 14. Upper lake fish densities (fish / 100,000 m ^{3}) for Dolly Varden by depth strata by year with 95% confidence intervals computed using cluster sampling. Years within the same strata with the same letter are not significantly different. No data was collected in the Upper lake in 2001 due to inclement weather.

Strata	Year	Density	Lower 95%	Upper 95%	
0-4	2002	0.44	0.26	0.62	AB
	2003	0.00	0.00	0.00	B
	2004	1.21	0.95	1.47	A
	2005	0.00	0.00	0.00	B
	2006	0.00	0.00	0.00	B
4-20	2002	0.00	0.00	0.00	A
	2003	0.00	0.00	0.00	A
	2004	0.10	0.08	0.12	B
	2005	0.00	0.00	0.00	A
	2006	0.00	0.00	0.00	A

Table 15. Upper lake fish densities (fish / 100,000 m ³) for lake trout by depth strata by year with 95% confidence intervals computed using cluster sampling. Years within the same strata with the same letter are not significantly different. No data was collected in the Upper lake in 2001 due to inclement weather.

Strata	Year	Density	Lower 95%	Upper 95%	
0-4	2002	0.63	0.38	0.89	A
	2003	0.00	0.00	0.00	A
	2004	1.67	1.31	2.03	A
	2005	9.72	2.31	17.13	A
	2006	14.80	12.65	16.95	A
4-20	2002	0.51	0.42	0.60	A
	2003	0.06	0.03	0.09	A
	2004	0.56	0.46	0.66	A
	2005	3.63	1.74	5.52	A
	2006	2.01	1.59	2.43	A
20-80	2002	1.72	1.26	2.18	B
	2003	0.70	0.53	0.87	B
	2004	5.34	4.01	6.61	AB
	2005	14.60	10.05	19.15	A
	2006	12.30	9.89	14.71	AB
>80	2002	0.49	0.31	0.66	A
	2003	0.29	0.22	0.35	A
	2004	2.28	2.04	2.52	A
	2005	26.3	17.54	35.06	B
	2006	0.24	0.15	0.33	A

Table 16. Upper lake fish densities (fish / 100,000 m^3) for round whitefish by depth strata by year with 95% confidence intervals computed using cluster sampling. Years within the same strata with the same letter are not significantly different. No data was collected in the Upper lake in 2001 due to inclement weather.

Strata	Year	Density	Lower 95%	Upper 95%	
0-4	2002	1.07	0.64	1.50	A
	2003	0.00	0.00	0.00	A
	2004	1.53	1.20	1.86	A
	2005	4.54	1.09	7.99	A
	2006	6.93	5.93	7.93	A
4-20	2002	1.20	1.00	1.40	A
	2003	0.13	0.08	0.18	A
	2004	0.99	0.81	1.17	A
	2005	4.24	2.03	6.45	A
	2006	2.34	1.85	2.83	A

Table 17. Lower lake total fish densities (fish / 100,000 m ^{3}) for each depth strata with 95% confidence intervals. Strata with the same letter are not significantly different.

Strata	Density	Lower 95%	Upper 95%	
0-4	7.49	4.30	10.68	A
4-20	5.09	3.49	6.69	A
20-80	5.72	4.23	7.21	A
>80	10.43	9.03	11.83	A

Table 18. Upper lake total fish densities (fish / 100,000 m ^{3}) for each depth strata with 95% confidence intervals. Strata with the same letter are not significantly different.

Strata	Density	Lower 95%	Upper 95%	
0-4	17.00	10.45	23.55	A
4-20	8.17	6.91	9.43	B
20-80	13.47	11.52	15.42	AB
>80	16.98	13.99	19.57	A

Table 19. Lower lake total abundance estimates for each species by year.

Species	Year	Abundance Est.	Lower 95%	Upper 95%
Artic char	2001	61,790	36,306	87,274
	2002	24,474	14,561	54,387
	2003	2,051	1,303	2,799
	2004	54,560	42,420	66,701
	2005	19,473	9,930	29,263
	2006	8,002	5,451	10,353
Arctic grayling	2001	12,024	6,012	18,036
	2002	20,040	11,423	28,257
	2003	0	0	0
	2004	2,305	1,804	2,806
	2005	201	101	301
	2006	301	201	401
Dolly Varden	2001	15,131	7,616	22,646
	2002	7,916	4,610	11,323
	2003	0	0	0
	2004	16,734	12,926	20,642
	2005	3,507	1,403	5,612
	2006	3,307	2,405	4,209
lake trout	2001	252,553	189,743	315,461
	2002	29,589	21,114	37,963
	2003	4,030	3,172	4,892
	2004	55,283	47,598	61,878
	2005	184,580	109,828	233,232
	2006	40,058	30,674	49,341
round whitefish	2001	44,088	22,746	65,431
	2002	23,447	13,828	32,966
	2003	2,706	1,804	3,608
	2004	69,239	53,507	84,870
	2005	106,914	48,597	165,230
	2006	65,531	46,193	84,770

Table 20. Upper lake total abundance estimates for each species by year.

Species	Year	Abundance Est.	Lower 95%	Upper 95%
Artic char	2002	30,684	19,848	41,260
	2003	4,208	3,144	5,272
	2004	48,924	38,822	58,884
	2005	24,522	11,658	37,386
	2006	13,668	10,854	16,482
Arctic grayling	2002	27,406	18,744	36,068
	2003	1,136	710	1,562
	2004	43,736	34,222	53,250
	2005	109,340	30,246	188,434
	2006	150,236	127,942	172,530
Dolly Varden	2002	6,248	3,692	8,804
	2003	0	0	0
	2004	18,602	14,626	22,578
	2005	0	0	0
	2006	0	0	0
lake trout	2002	61,487	44,486	78,617
	2003	19,395	14,466	24,311
	2004	173,197	131,802	213,032
	2005	600,204	339,508	860,901
	2006	558,786	459,525	658,046
round whitefish	2002	32,234	23,288	41,180
	2003	1,846	1,136	2,556
	2004	35,784	28,542	50,694
	2005	124,676	44,304	205,048
	2006	131,634	110,476	152,792

Table 21. Total abundance estimates for each species for lakes combined. 2001 is absent because no upper lake data was collected due to inclimate weather.

Species	Year	Abundance Est.	Lower 95%	Upper 95%
Artic char	2002	55,158	34,409	95,647
	2003	6,259	4,447	8,071
	2004	103,484	81,242	125,585
	2005	43,995	21,588	66,649
	2006	21,670	16,305	26,835
Arctic grayling	2002	47,446	30,167	64,325
	2003	1,136	710	1,562
	2004	46,041	36,026	56,056
	2005	109,541	30,347	188,735
	2006	150,537	128,143	172,931
Dolly Varden	2002	14,164	8,302	20,127
	2003	0	0	0
	2004	35,336	27,552	43,220
	2005	3,507	1,403	5,612
	2006	3,307	2,405	4,209
lake trout	2002	91,076	65,600	116,580
	2003	23,425	17,638	29,203
	2004	228,480	179,400	274,910
	2005	784,784	449,336	1,094,133
	2006	598,844	490,199	707,387
round whitefish	2002	55,681	37,116	74,146
	2003	4,552	2,940	6,164
	2004	105,023	82,049	135,564
	2005	231,590	92,901	370,278
	2006	197,165	156,669	237,562

Table 22. Lower lake fish densities (fish / 100,000 m ^{3}) for all species within depth strata with years combined with 95% confidence intervals computed using cluster sampling. Strata within species with the same letter are not significantly different.

Species	Strata	Density	Lower 95%	Upper 95%	
Arctic char	0-4	0.90	0.20	1.61	AB
	4-20	0.59	0.31	0.87	A
	20-80	0.31	0.12	0.51	B
Arctic grayling	0-4	0.16	0.00	0.36	A
	4-20	0.02	0.00	0.04	A
Dolly Varden	0-4	0.46	0.14	0.78	A
	4-20	0.02	0.00	0.06	B
lake trout	0-4	0.45	0.17	0.74	A
	4-20	0.19	0.14	0.33	A
	20-80	4.36	1.75	6.98	C
	>80	11.10	5.56	16.70	D
round whitefish	0-4	3.86	1.44	6.29	A
	4-20	2.03	0.85	3.21	A

Table 23. Upper lake fish densities (fish / 100,000 m ^{3}) for all species within depth strata with years combined with 95% confidence intervals computed using cluster sampling. Strata within species with the same letter are not significantly different.

Species	Strata	Density	Lower 95%	Upper 95%	
Arctic char	0-4	0.29	0.00	0.63	A
	4-20	0.70	0.28	1.13	B
	20-80	1.43	0.82	2.04	C
Arctic grayling	0-4	6.08	0.39	11.80	A
	4-20	1.29	0.44	2.14	B
Dolly Varden	0-4	0.16	0.00	0.35	A
	4-20	0.01	0.00	0.02	B
lake trout	0-4	8.73	0.21	17.20	A
	4-20	3.81	1.27	6.35	B
	20-80	10.70	5.83	15.50	C
	>80	20.10	9.36	30.90	D
round whitefish	0-4	4.22	0.23	8.20	A
	4-20	4.52	1.56	3.48	A

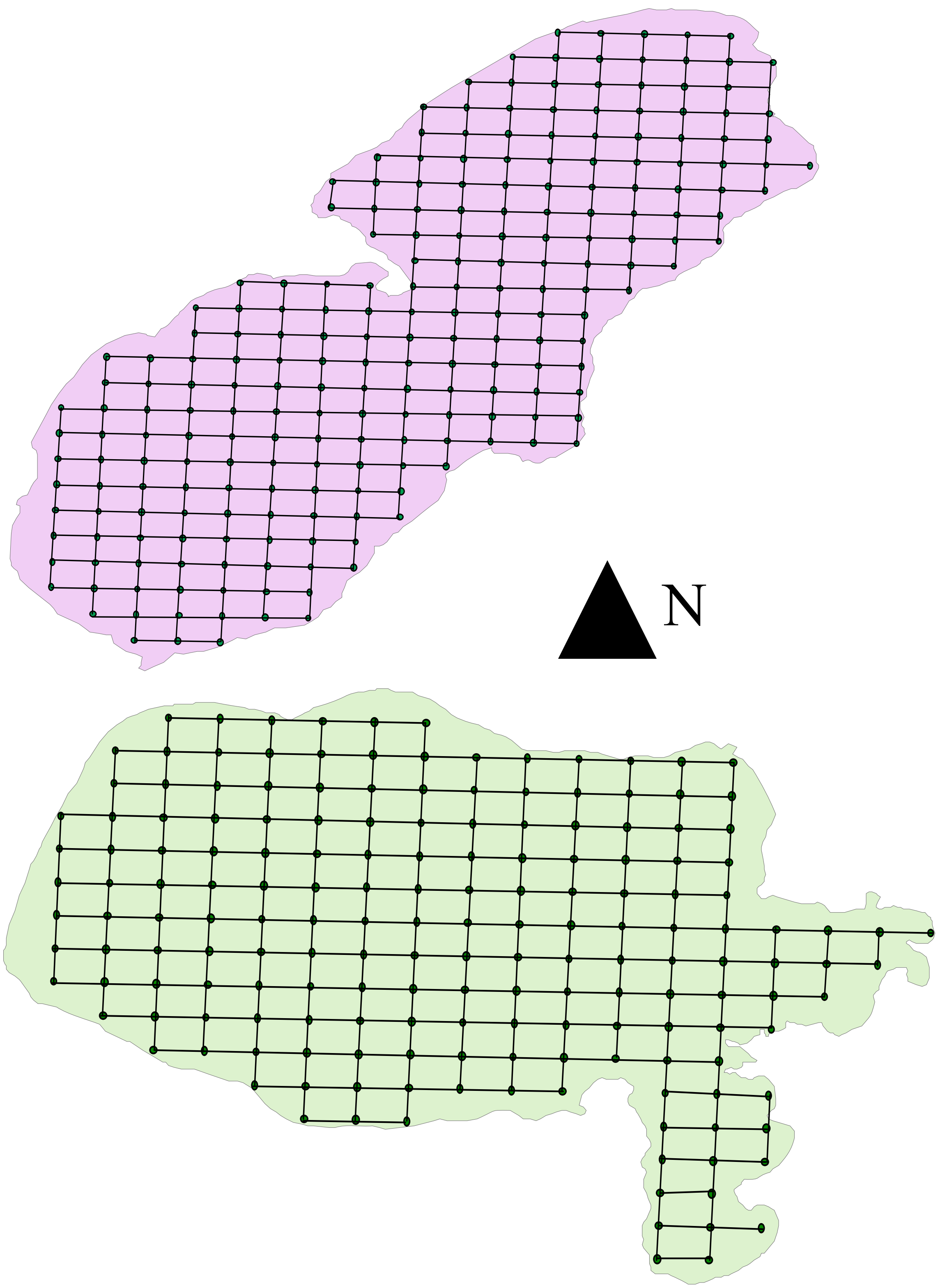


Figure 1. Maps of upper and lower Ugashik Lakes, AK showing how acoustic transects were run in both lakes north/south and east/west in 2005. Parallel transects are 1 km apart. Drawing is not to scale.

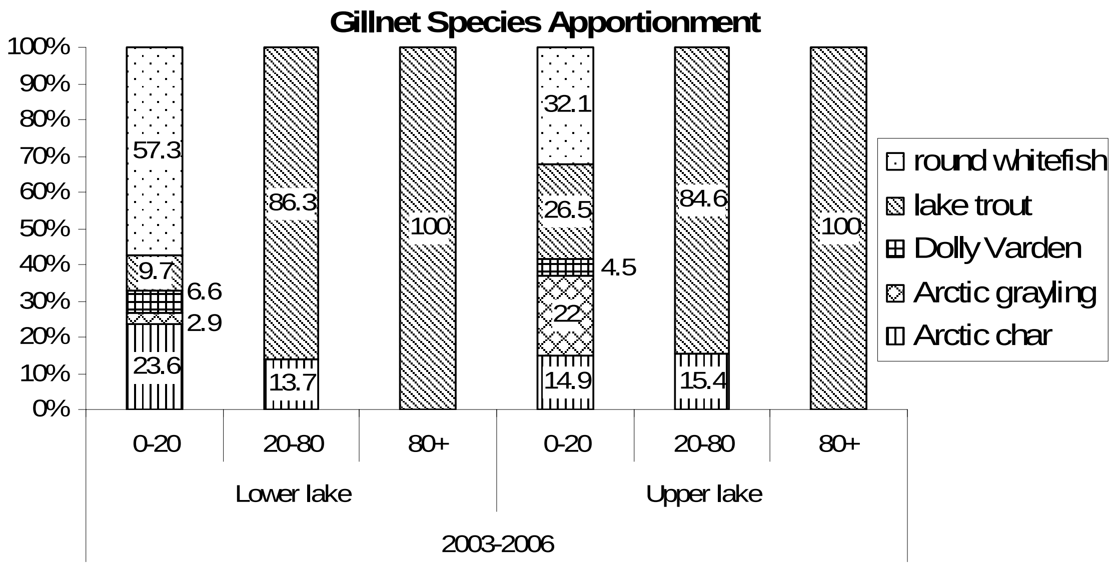


Figure 2. Gillnets were used to apportion species by percentages caught in nets set within the three depth strata.

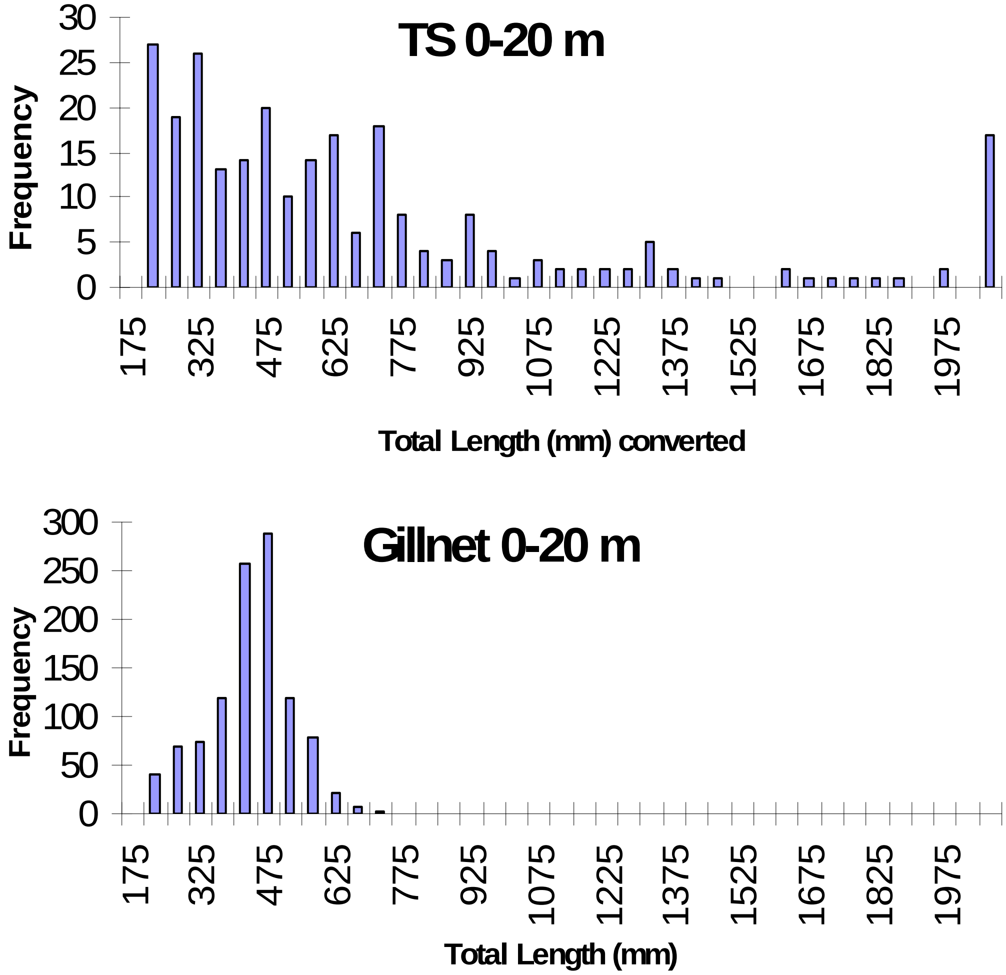
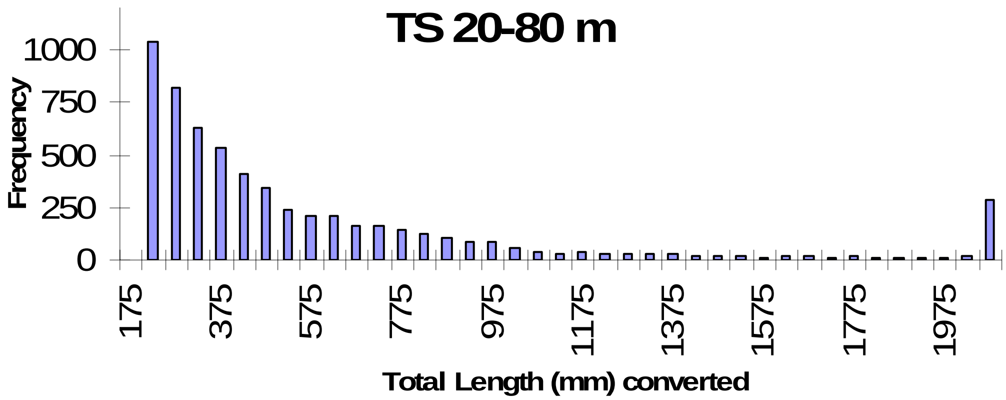


Figure 3. Comparison of 0-20 m depth stratum of length distributions between hydroacoustic and gillnet gears. Hydroacoustic distribution lengths are converted from target strength (dB) using equation TS = 20 log (L) -78.53 from Chapter 2.



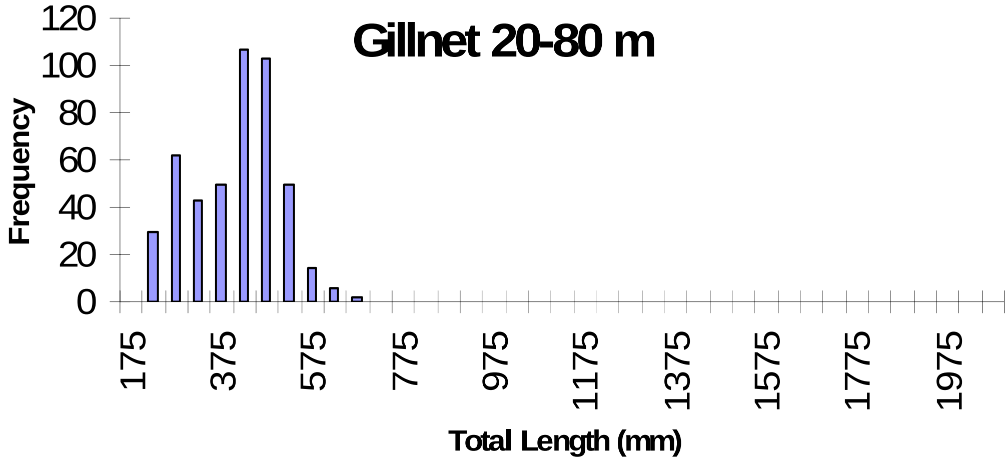


Figure 4. Comparison of 20-80 m depth stratum of length distributions between hydroacoustic and gillnet gears. Hydroacoustic distribution lengths are converted from target strength (dB) using equation TS = 20 log (L) -78.53 from Chapter 2.

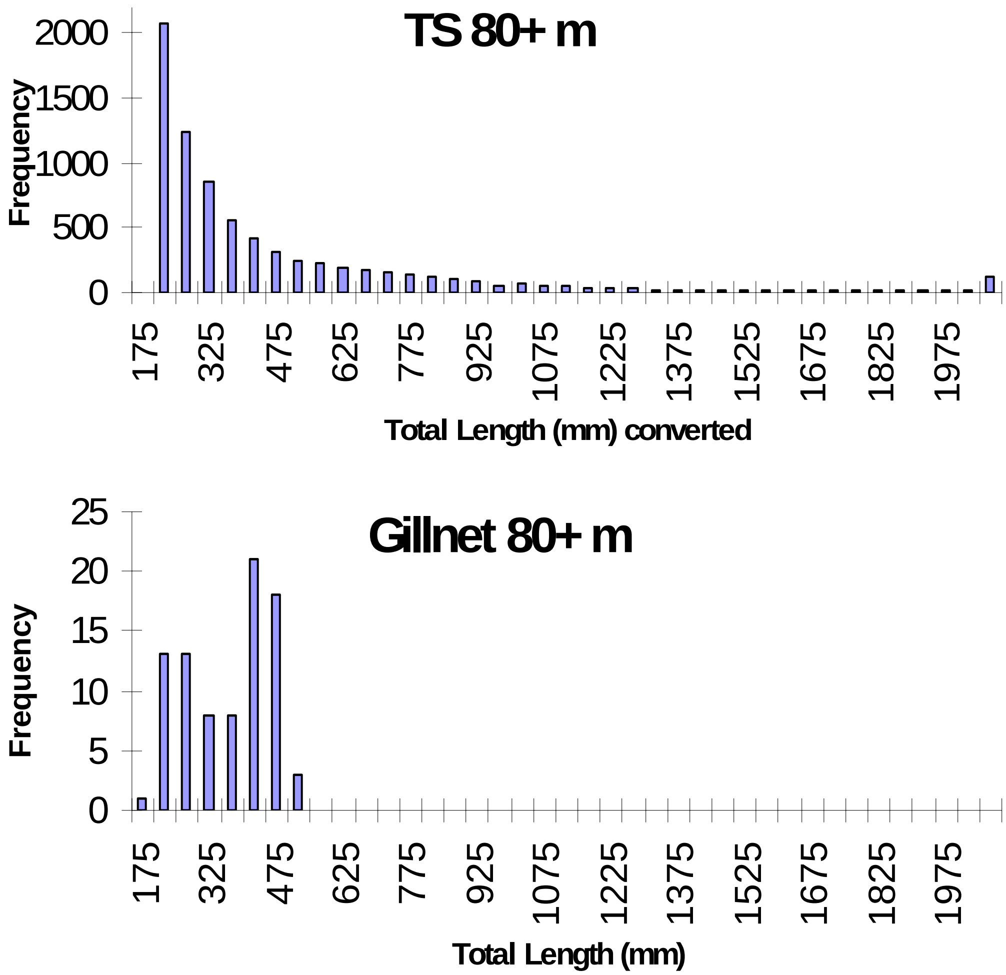


Figure 5. Comparison of 80+ m depth stratum of length distributions between hydroacoustic and gillnet gears. Hydroacoustic distribution lengths are converted from target strength (dB) using equation TS = 20 log (L) -78.53 from Chapter 2.

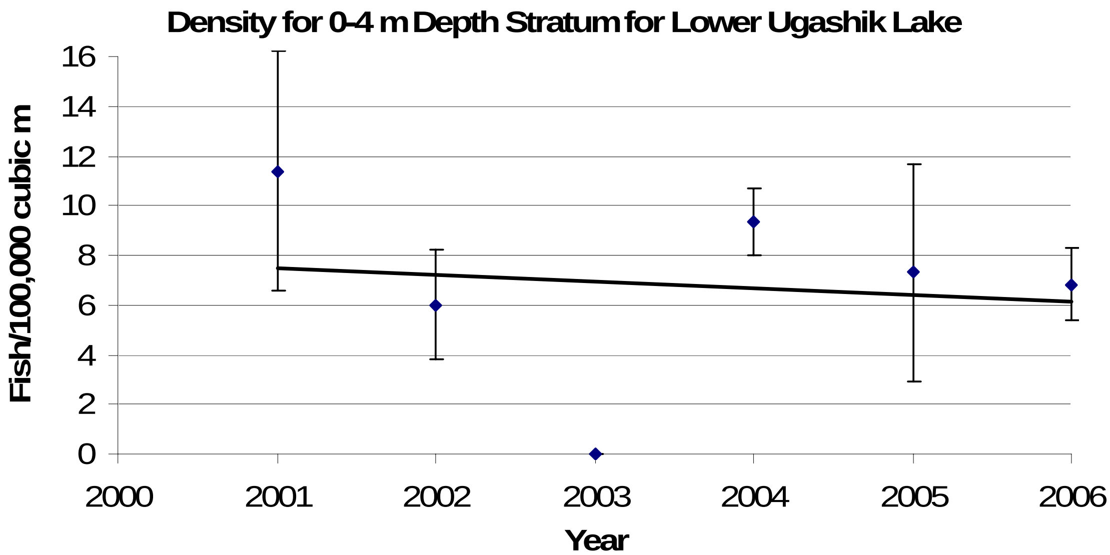


Figure 6. Total annual density estimates with all species combined for the 0-4 m depth stratum.

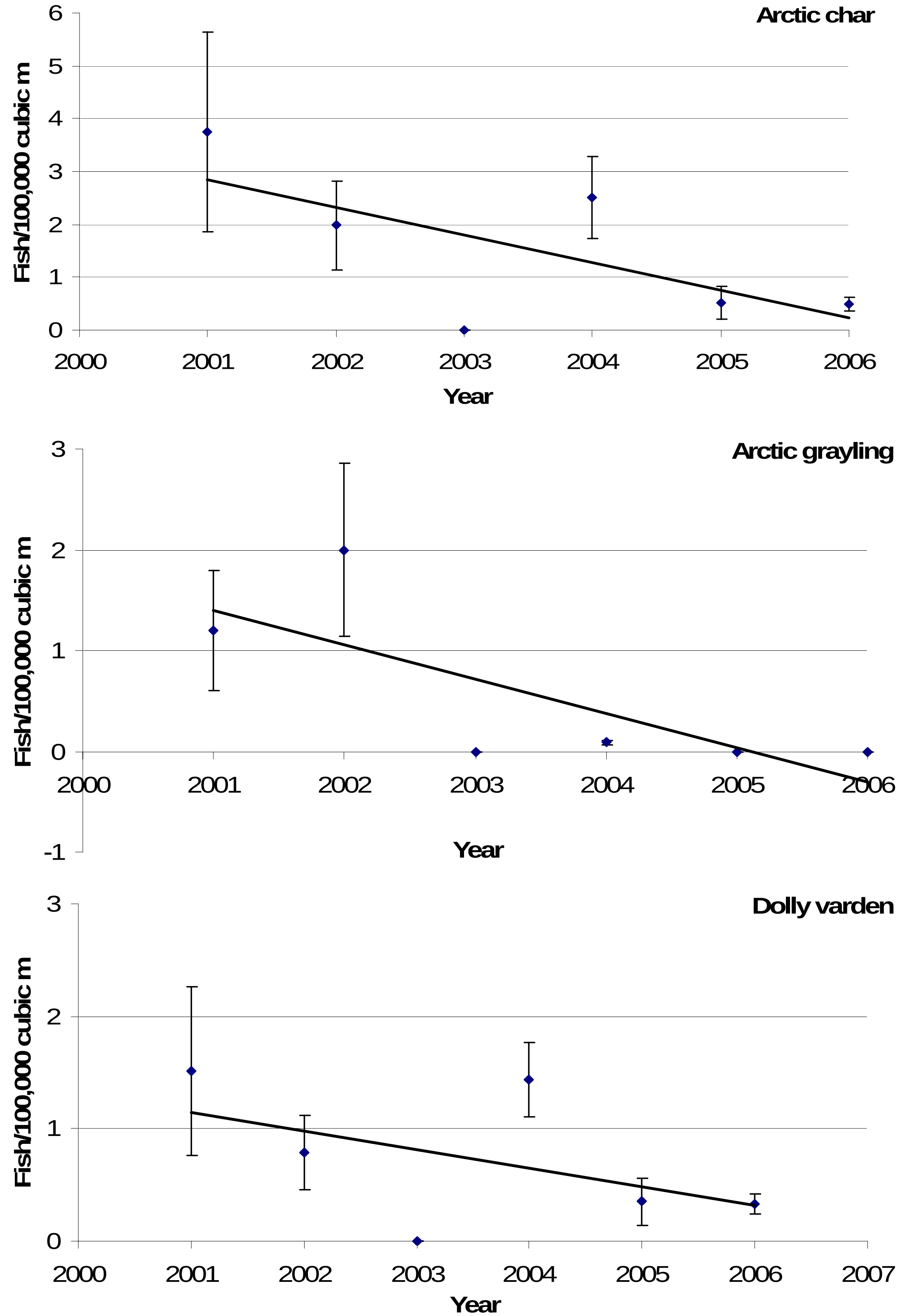


Figure 7. Annual density estimates for each species for the 0-4 m depth strata for the lower lake.

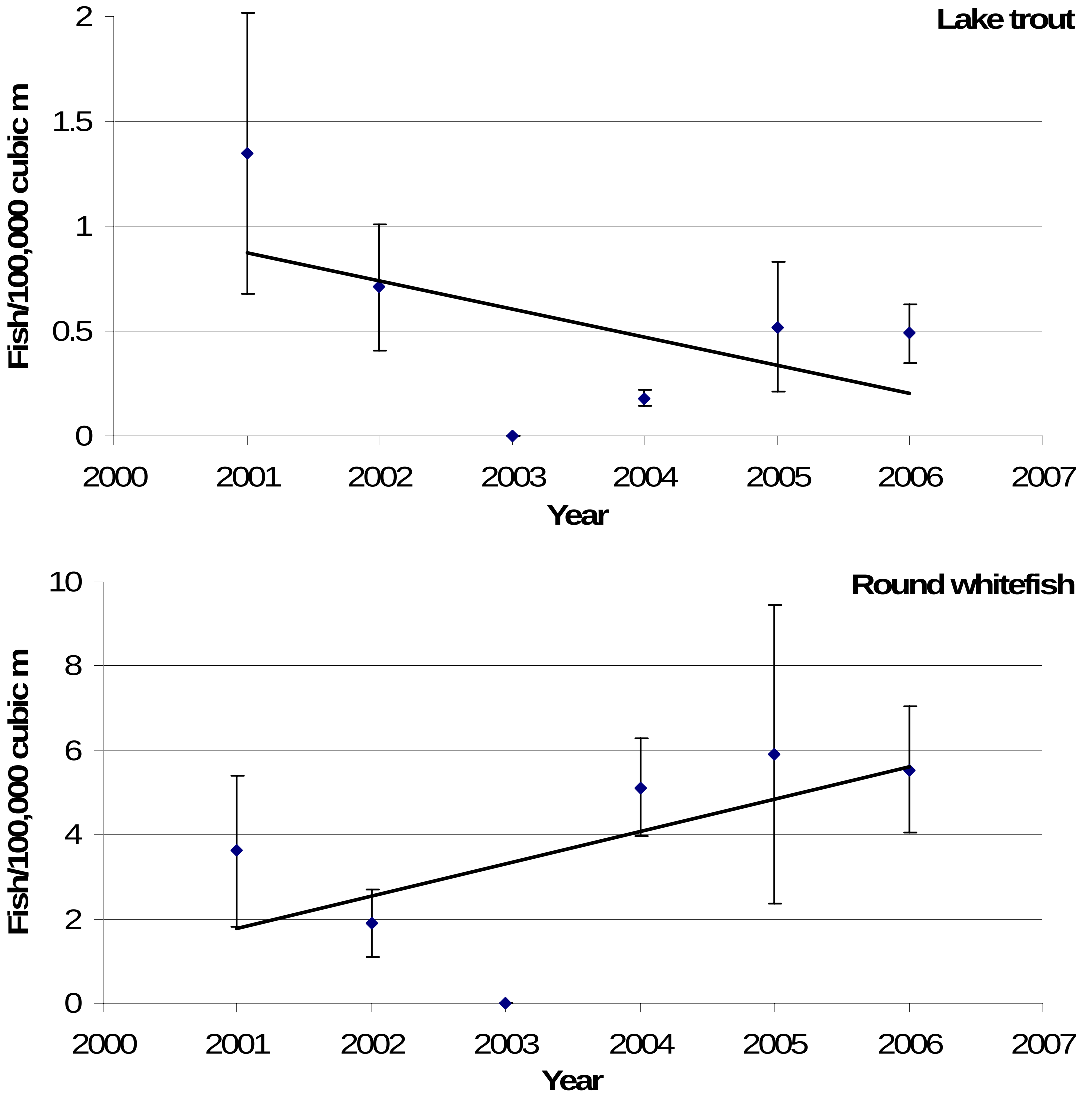


Figure 7. continued.

Chapter 4: Using GIS natural neighbor interpolation to produce bathymetrical and fish density maps for Ugashik Lakes, Alaska

Abstract: Visual representation of data analysis is often important to convey certain information about a system. This is especially important where global position of certain trends need to be emphasized. The Ugashik Lakes, Alaska represent a novel lake system in that they do not thermally stratify and are remote in location. Knowing geographical position of fish concentrations and depth variation makes decisions for data collection more informative and can give a more robust management plan in the long term. I used natural neighbor interpolation in GIS software to produce a map of fish density and lake depth (bathymetry).

Introduction

Hydroacoustic technology has seen major advancements in the last 20 years. Originally this sampling technique was primarily limited to use in the seas, but through the down-sizing of the equipment, its use in inland freshwaters and even remote areas has increased (MacLennan and Simmonds 2005). In addition, Geographic Information Systems (GIS) have also seen increased use in the field of natural resources. Together, these two technologies have a great potential for aiding researchers and managers in their duties (Kracker 2006). Visualization of acoustic data is quite problematic to those outside the field. Results are often grouped together as abundance estimates or densities of fish lacking any visual representation or appeal.

Geo-statistics is often a GIS based statistical approach to analyzing data. In fishery management it is often used in large bodies of water like the seas where most fish populations are pelagic and individuals are close together in shoals or schools (Paramo and Roa 2002; Taylor et al. 2005). Inland freshwater bodies often lack sufficient densities of fish to create a strong geo-statistical relationship (MacLennan and Simmonds 2005) and this is the case in the Ugashik Lakes, Alaska where this study was performed. However, the visual properties of spatial analytical techniques can still be used to aid in presenting results.

Interpolation of fisheries data can present a strong visual representation of the body of water being surveyed. Natural neighbor is an interpolation technique available in the ArcMap (Environmental Systems Research Institute Inc., Redlands, CA, USA) software product and is used extensively in the scientific community (Hajiraker et al. 1999; Riegl et al. 2005; Valley et al. 2005; Foster et al. 2006). I chose this technique of interpolation because it works well with the way my data was collected in grid layout. In addition, it is a deterministic approach rather than a true geo-statistical technique. This leads to less user specified parameters to fill in and speeds up computation.

A recent hydroacoustic survey of the Ugashik Lakes, Alaska was performed in 2005 resulting in an in-depth full survey grid of both lakes. This provided an opportunity to use natural neighbor to create detailed bathymetry maps and spatial fish density maps of both lakes showing areas of the lake that contain high densities of fish for possible future study. The natural neighbor method is simple and accounts for an unknown point weighting surrounding points based on how close they are. The equation is the same as inverse distance weighted interpolation (IDW), but the weighting of surrounding points is different by using polygons instead of search radii. Previous bathymetry maps of these lakes were produced from a more course dataset using depth soundings instead of hydroacoustics. This study will allow a better representation of the extreme variation in the bathymetry of these glacial lakes. Also, a short hydroacoustic survey was performed in 2006 using a zigzag pattern instead of the grid in 2005. This produced point depth data between the grid survey of 2005 which will allow testing of the accuracy of the interpolated bathymetry surface (Figure 1).

Methods

Study Area

The Ugashik Lakes are located in the Alaska Peninsula National Wildlife Refuge 120 km southwest of the town of King Salmon. The upper lake flows into the lower lake via the Ugashik Narrows. The majority of the fishing pressure is concentrated in the Narrows. Combined, both lakes are 342 km², have a max depth of 180 m and rarely stratify due to consistent high winds. The resident species are Dolly Varden (*Salvelinus malma*) (Walbaum), Arctic char (*Salvelinus alpinus*) (Linnaeus), lake trout (*Salvelinus namaycush*) (Walbaum), round whitefish (*Prosopium cylindraceum*) (Pallus), and Arctic grayling (*Thymallus arcticus*) (Pallus).

Acoustic Survey

All acoustic data were collected with a Simrad EK60 echo-sounder, with a 70 kHz split-beam transducer operating at a 7.1° beam angle in a vertical down-looking manner. The unit was calibrated with a 32.1 mm copper sphere (TS = -39.1 dB) in accordance with standard calibration procedures (Foote 1990) before the survey took place. Data were collected to a notebook computer at 0.512- ms for 2005 and 0.128 ms pulse duration for 2006. The transducer was towed one meter below the surface at ~5 knots. Table 1 displays acoustic settings used during surveying and processing. The lakes were surveyed in a grid pattern north/south and east/west in 2005 and a zig-zag pattern in 2006 (Figure 1). Acoustic fish density data was stratified into 300-m horizontal bins and a density estimate was computed for each bin. Bathymetry data was stored twice a second during data collection. This dataset was reduced in size to take a depth reading every five seconds to shorten software computation time of the interpolation.

Interpolation

Datasets were imported into ArcMap as x,y coordinate data and a point file of the points were produced. The next step is running the natural neighbor interpolation procedure in the spatial analyst extension of ArcMap found in the spatial analyst (Johnston et al. 2001). Once the surface was produced it was clipped to a shape file of the Ugashik Lakes creating an overall surface within the boundaries of the lakes edge. Natural neighbor requires no user specified parameters for point interpolation. Extent for the x,y coordinate data is for the lower lake is found in Table 2. Depth contours were separated by 20 m. Contour lines separated by less than 20 m had poor separation in highly variable bathymetry areas making visual representation difficult. Density contours were separated by 5 fish/100,000 m^3. This contour separation was chosen for its even interval and contours less than 5 fish/100,000 m^3 had poor separation as mentioned above. The last contour represents areas where density exceeds 40 fish/100,000 m^3. The contour range ceased here because there are several areas in the lakes that have densities exceeding 200 fish/100,000 m^3 and a legend with 5 fish increments up to 200 would be too large.

Statistics

Only the bathymetry surface was tested. Testing the density surface for accuracy was not possible due to the mobility of fish and the long time duration over which data were collected. The bathymetry surface created from the 2005 dataset was tested against known depth values from the 2006 dataset with a paired t-test. An interpolated value between actual points (2005) was compared to a known depth value at that point (2006). A total of 60 points from each lake were used for the test. An alpha value of 0.05 was used.

Results

The average depth in the lower lake is 47.00 m and 45.14 m for the upper lake. The interpolated surface of the upper lake is more accurate than the lower lake. The paired t-test results confirm this. The lower lake showed significant differences ($t=3.91$, $df=59$, $p<0.001$), but the upper lake did not. The bathymetry maps from interpolation are Figure 2 for the upper lake and Figure 3 for the lower lake.

The southeast area of the lower lake had the highest fish densities. The upper lake found its highest fish densities in the northern half. The fish density maps from interpolation are Figure 4 for the upper lake and Figure 5 for the lower lake.

Discussion

Bathymetry

The lower lake has a much more variable bathymetry with extreme changes. The lower lake has areas that change depth by 30-80 m in less than 20 m traveled horizontally. The majority of this extreme bathymetry change occurs in the island arm area of the lower lake (Figure 6) where multiple small islands crop up along with many underwater humps and ridges. The upper lake however has very little of this extreme bathymetry. Most upper lake variation is in two main basins; one in the lower (southern) and one in the upper (northern) region of the lake. However, the extreme depth changes found in the lower lake are absent in the upper lake. The paired t-test results show that the grid pattern used in 2005 to collect data was still too coarse to capture the extreme bathymetrical variation in the lower lake. A possible future solution is to collect data on a finer scale in the lower lake especially in the island arm area of the lake. Here it might be necessary to collect data on a grid using parallel transects that are 0.5 km apart instead of 1.0 km.

Using natural neighbor as the interpolation technique makes creating a bathymetrical map for a natural resource manager easier compared to other methods because it does not have any user specified parameters like inverse distance weighted (IDW) or kriging. Having an accurate bathymetrical map is important to management decisions for the Ugashik Lakes. The effect of depth on fish size and fish distribution has been shown in Chapter 3, where it is used to stratify the lakes for analysis. Depth determines what species are found, the size of the individuals, the density of the population, and spawning areas (Awulachew 2006; Janssen et al. 2006). Knowing the bathymetrical layout of a lake could aid in knowing where aquatic vegetation exists or in more turbid waters where light absorption reaches the point of preventing photosynthesis. Management of a particular species can be aided by an accurate bathymetrical map by knowing in advance where likely spawning and foraging habitats are found (Edsall 1992; Fee et al. 1996). Limnological studies will be easier to plan out knowing in advance a detailed bathymetry of the lakes. Models can even be created that describe shape and hydrology of the lake in the past and how that has changed up to the present. This can help determine the location of sediment loading which can alter and even destroy habitat (Cohen et al. 1993; Gunn and Sein 2000). Knowing such history can give clues as to what fish and other organisms are found there or were found there in the past (Yang and Teller 2005). This can help in future management decisions and how an investigative study is organized.

The method I employed is not without drawbacks. The shallow littoral areas of the lake are not accurately represented. Conducting hydroacoustics all the way up to shore was impossible with the equipment used and thus depth measurements less than four meters are absent from the dataset. I ceased surveying at 4 meters depth to eliminate sound and bubble layer noise. Also, the depth can decrease dramatically around the littoral areas of these lakes making contact with the transducer or the boat and the lake bottom a concern. A solution to this problem would be to take a random selection of sounding measurements with a smaller vessel to allow access to very shallow water so as to represent this area in the dataset.

Fish Density

Testing the accuracy of the fish density map was not possible due to fish mobility. Creating such a map does, however, offer a visual representation of areas where fish are likely to be concentrated during the summer time on the Ugashik Lakes. It is also a good way to cross reference the statistical testing of the distribution based on mean density values of individual transects. Those transects that are statistically significantly higher than the rest can be referenced to this density map for communication or presentation. In addition, there might be an area along a particular transect possessing very high density.

This can also be located using the fish density map. Having this knowledge can help in future acoustic surveys by knowing in advance areas where fish congregate. This may help develop a stratified random survey design which assures the research vessel passes over this area and insonifies those fish. This allows those areas of higher density to be sampled more thoroughly thus decreasing variance values (MacLennan and Simmonds 2005).

Other methods of interpolation are possible using our dataset. Each method has its advantages and disadvantages. Kriging, for example is an exact interpolation, but requires a multitude of various user settings. These settings can seem daunting to a natural resource manager with little or no experience in a GIS. It is a geostatistical interpolation technique that is based on statistics and can produce a more advanced prediction surface. The use of statistics allows a prediction of accuracy for the interpolated surface. Other methods also exist such as nearest neighbor, inverse distance weighted (IDW), and spline. Most of these use similar algorithms and their differences arise from how the weighting procedure of known points is implemented (Coley and Claburn 2005). However for ease of use, I chose natural neighbor as it is the simplest to compute and takes the least amount of time (Childs 2004).

References

Awulachew, S.B. 2006. Investigation of physical and bathymetric characteristics of lakes Abaya and Chamo, Ethiopia and their management implications. Lakes and Reservoirs: Research and Management 11: 133-140.

Childs, C. 2004. Interpolating surfaces in ArcGIS spatial analyst. ArcUser. July-Sept.

Cohen, A. S., Bills, R., Cocquyt, C. Z., Caljon, A. G. 1993. The impact of sediment pollution on biodiversity in Lake Tanganyika. Conservation Biology 7: 667-677.

Coley, A.R. and Claburn, P. 2005. GIS visualization and analysis of mobile hydroacoustic fisheries data: a practical example. Fisheries Management and Ecology 12: 361-367.

Edsall, T. A., Brown, C. L., Kennedy, G. W., French, J. R. P. 1992. Surficial substrates and bathymetry of five historical lake trout spawning reefs in near-shore waters of the Great Lakes. Technical report. Great Lakes Fishery Commission.

Fee, E. J., Hecky, R. E., Kasian, S. E. M., Cruikshank, D. R. 1996. Effects of Lake Size, Water Clarity, and Climatic Variability on Mixing Depths in Canadian Shield Lakes. Limnology and Oceanography 41: 912-920.

Foote, K.G. 1990. Spheres for calibrating an eleven-frequency acoustic measurement system. ICES Journal of Marine Science 46: 284-286.

Foster, J.G., Riegl, B., Purkis, S.J., Dodge, R.E. 2006. Mapping of Tropical Shallow Water Benthos (Algae, Seagrass, Corals) Using Three Single-Beam Acoustic Ground Discrimination Systems (QTCView, Echoplus, Biosonics). EOS, Transactions, American Geophysical Union Vol. 87.

Gunn, J. M. and Sein, R. 2000. Effects of forestry roads on reproductive habitat and exploitation of lake trout (*Salvelinus namaycush*) in three experimental lakes. Canadian Journal of Fisheries and Aquatic Sciences 57: 97-104.

Hajirakar, M., Kieser, R., Stanley, R.D. Cornthwaite, A.M., Huang, P.Y. 1999. Three-dimensional visualization of fishery acoustic data and bathymetry using IBM Visualization Data Explorer. Canadian Manuscripts and Reports for Fisheries and Aquatic Sciences 2486: 59.

Janssen, J., Jude, D.J., Edsall, T.A., Paddock, R.W., Wattrus, N., Toneys, M., and McKee, P. 2006. Evidence of lake trout reproduction at Lake Michigan's mid-lake reef complex. Journal of Great Lakes Research 32: 749-763.

Johnston, K., Ver Hoef, J.M., Krivoruchko, K. and Lucas, N. 2001. Using ArcGIS Geostatistical Analyst. Redlands: ESRI Press, pp. 300.

Kracker, L.M. 2006. Ten Years of GIS and Fisheries. Annual Conference on Great Lakes Research Vol. 49.

MacLennan, D. E. and E. J. Simmonds. 2005. Fisheries Acoustics. Chapman and Hall. London.

Paramo, J. and R. Roa. 2002. Acoustic-geostatistical assessment and habitat-abundance relations of small pelagic fish from the Colombian Caribbean. Fisheries Research. 60: 309-319.

Riegl, B.M., Moyer, R.P., Morris, L.J., Virnstein, R.W., Purkis, S.J. 2005. Distribution and seasonal biomass of drift macroalgae in the Indian River Lagoon (Florida, USA) estimated with acoustic seafloor classification (QTCView, Echoplus). Journal of Experimental Marine Biology and Ecology 326: 89-104.

Taylor, J.C.,Thompson, J.S., Rand, P.S., Fuentes, M. 2005. Sampling and Statistical Considerations for Hydroacoustic Surveys Used in Estimating Abundance of Forage Fishes in Reservoirs. North American Journal of Fisheries Management 25: 73-85.

Valley, R.D., Drake, M.T. and Anderson C.S. 2005. Evaluation of alternate interpolation techniques for the mapping of remotely-sensed submersed vegetation abundance. Aquatic Botany 81: 13-25.

Yang, Z. and Teller, J.T. 2005. Modelling the history of Lake Woods since 11,000 cal yr B.P. using GIS. Journal of Paleolimnology 33: 483-497.

Table 1. Transducer and transceiver settings for the 70 kHz split-beam system used for Ugashik Lakes surveys.

Setting	**2005**	**2006**
Frequency (kHz)	70	70
Bandwidth (kHz)	4.69	6.82
Pulse Length (ms)	0.512	0.128
Maximum Power (W)	500.00	500.00
Two-way beam angle (degrees)	-21.00	-21.00
Sv transducer gain (dB)	24.15	25.42
TS transducer gain (dB)	24.15	25.42
Angle sensitivity alongship (degrees)	23.00	23.00
Angle sensitivity athwartship (degrees)	23.00	23.00
3 dB beam width alongship (degrees)	7.12	6.41
3 dB beam width athwartship (degrees)	6.58	6.42
Minimum echo level (dB)	-53.67	-53.67
Maximum echo length (dB)	1.00	1.00
Minimum echo length (dB)	0.500	0.500
Maximum gain compensation (dB)	12.00	12.00
Maximum phase deviation (dB)	0.600	0.600

Table 2. Extent values for Ugashik Lakes bathymetry and fish density maps layers in decimal degrees.

Lower lake layer extent	Top	57.57
	Bottom	57.42
	Left	-157.03
	Right	-157.01
Upper lake layer extent	Top	57.79
	Bottom	57.56
	Left	-156.84
	Right	-156.53

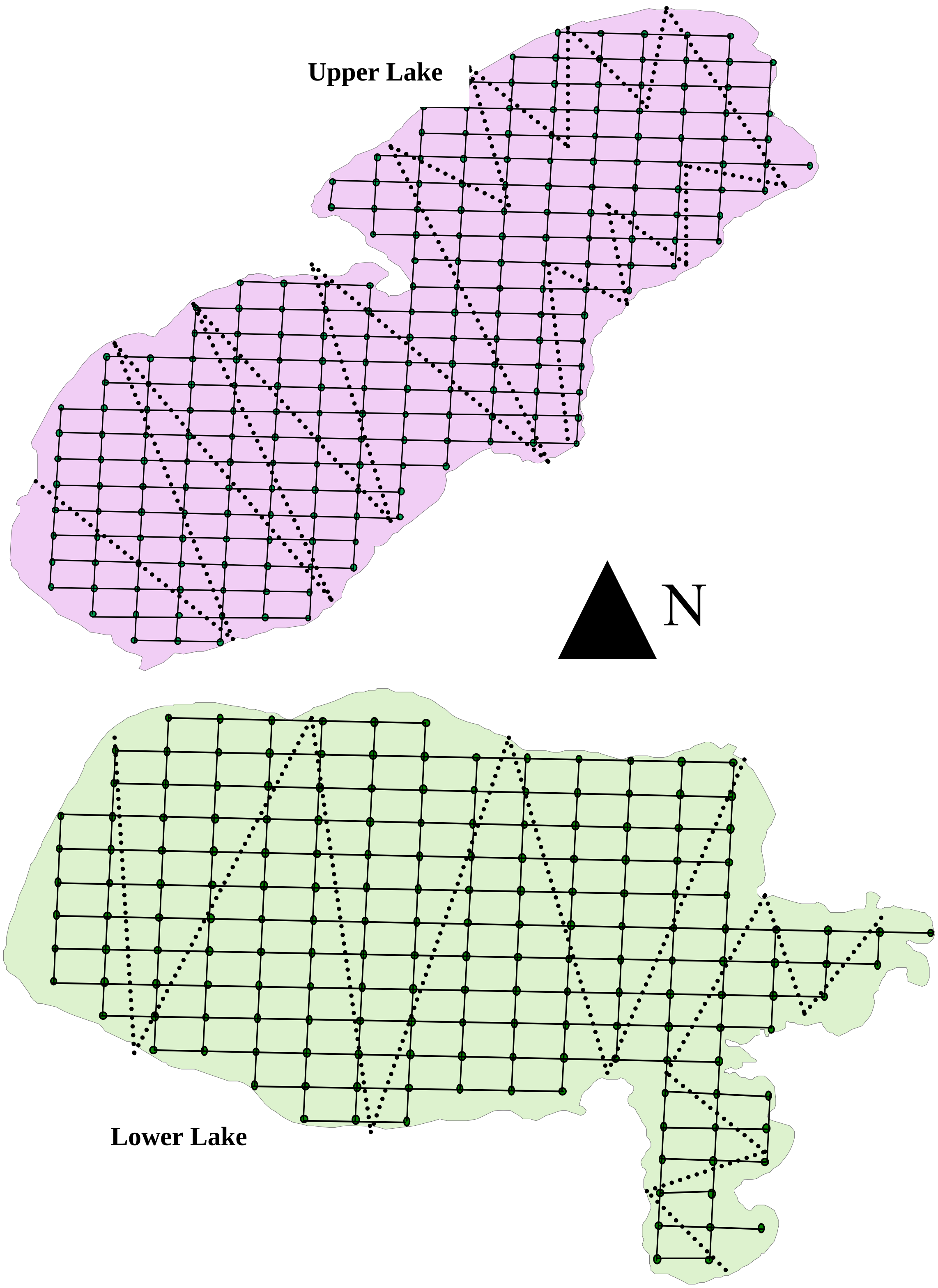


Figure 1. Maps of upper and lower Ugashik Lakes, AK showing how acoustic transects were run in both lakes north/south and east/west in 2005. Parallel transects are 1 km apart. The acoustic survey in 2006 (dotted line) was a zig-zag design.

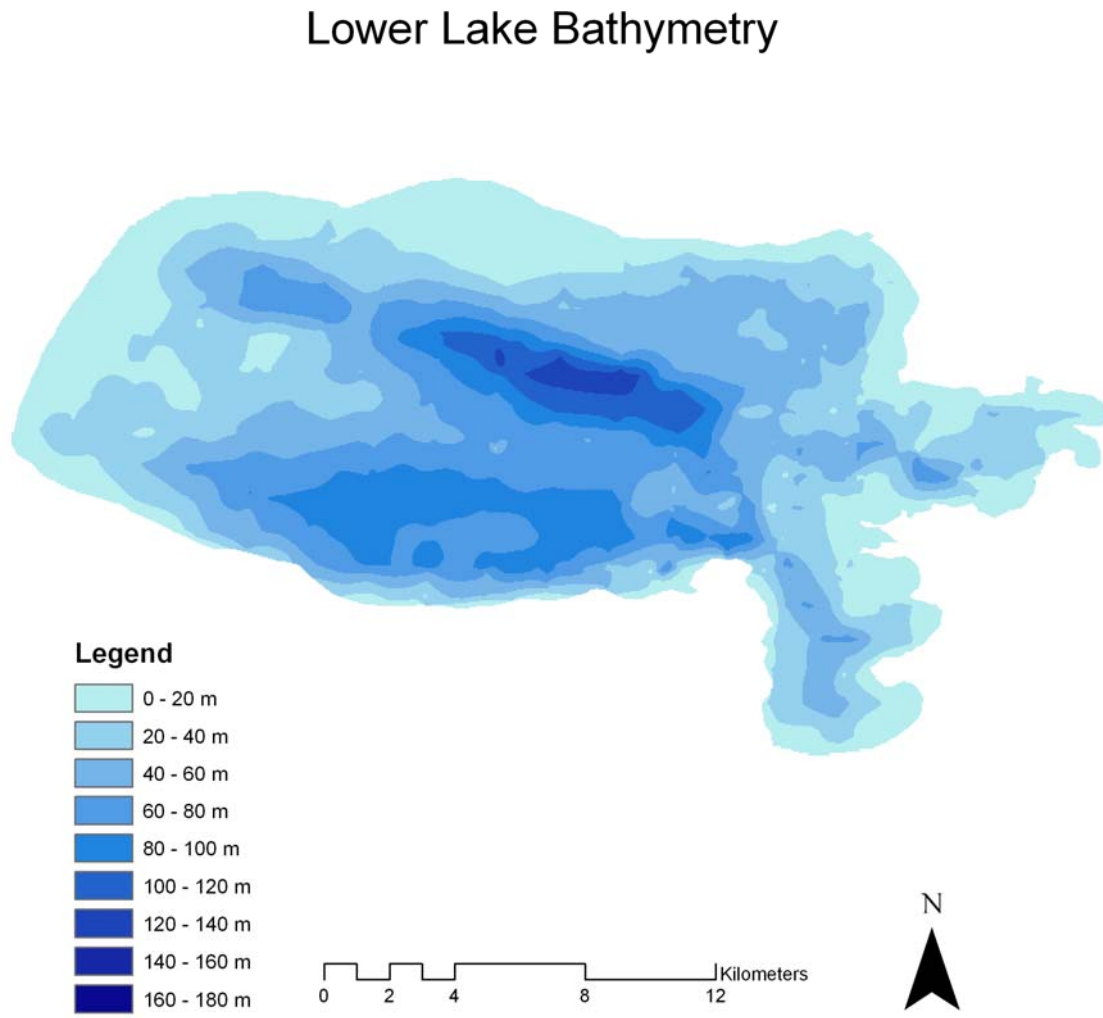


Figure 2. Bathymetry map of lower Ugashik lake. Maximum depth in this lake was 132.12 m.

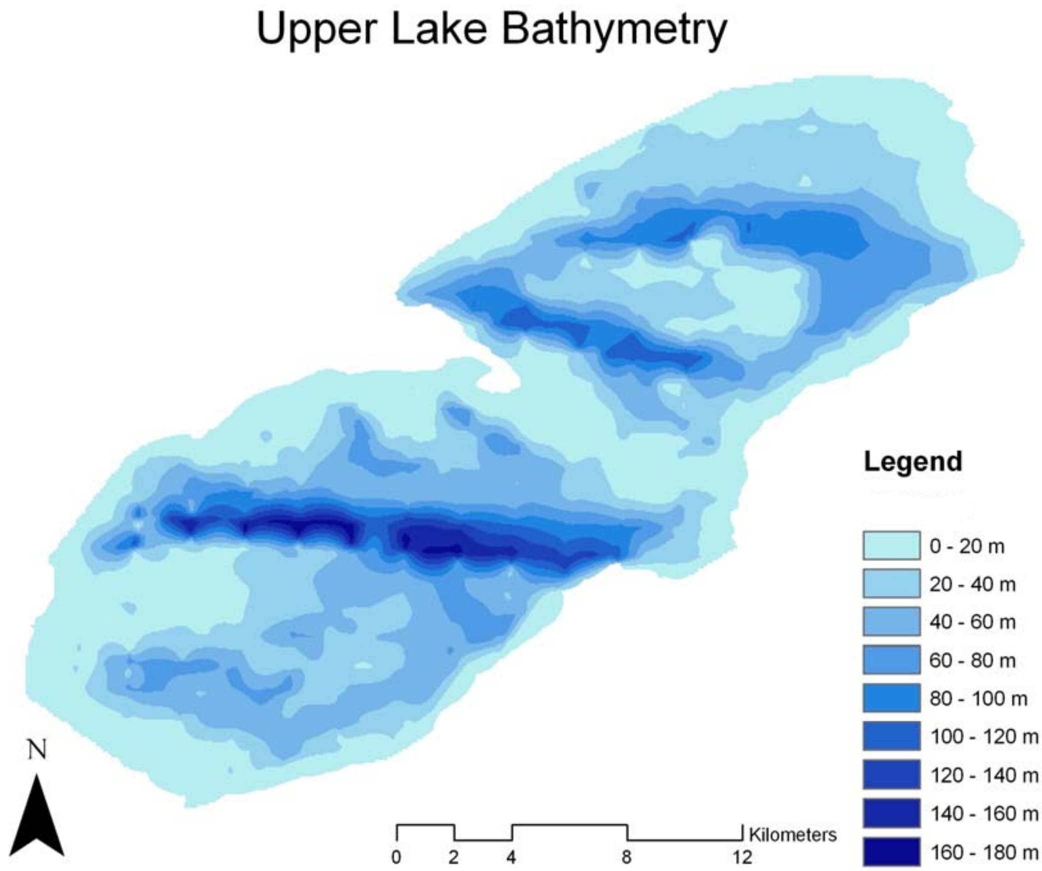


Figure 3. Bathymetry map of upper Ugashik lake. Maximum depth in this lake was 172.91 m.

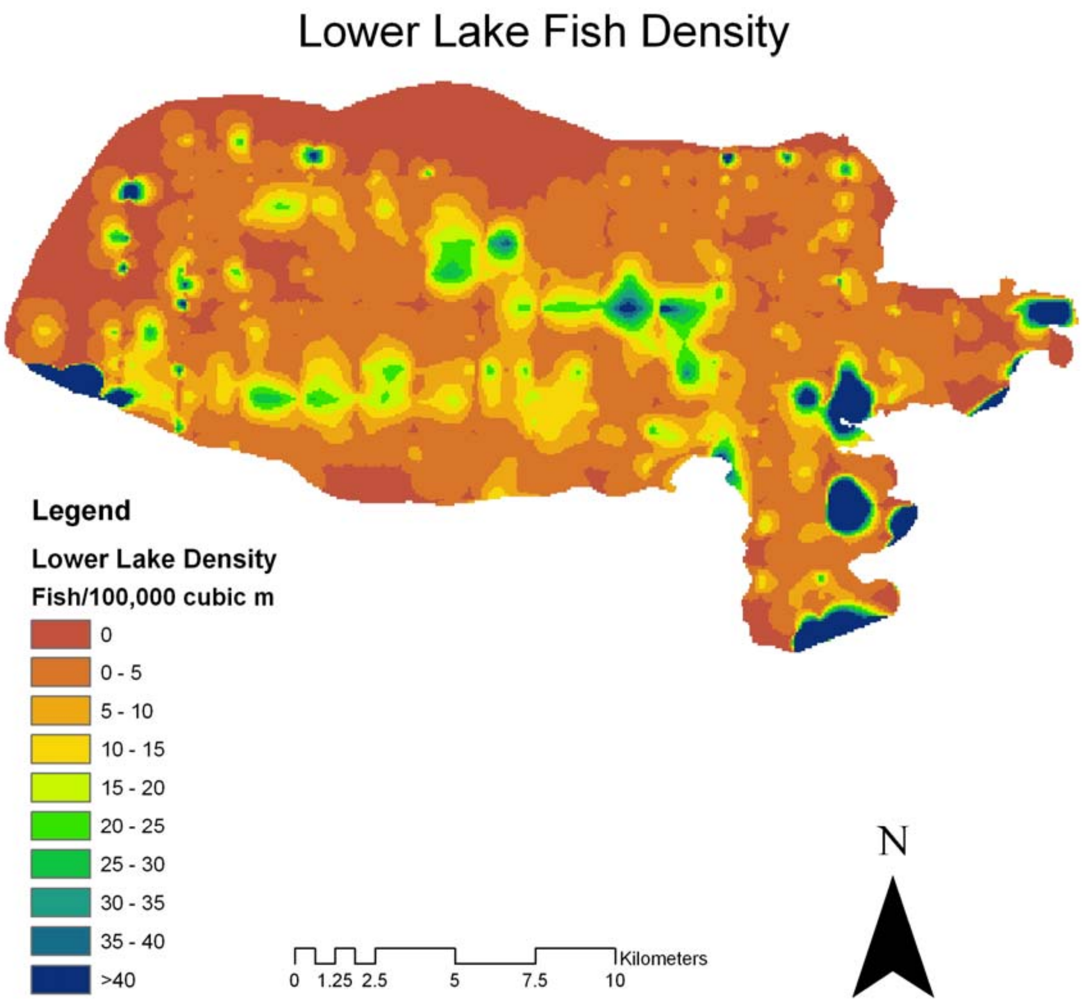


Figure 4. Map of fish density for lower Ugashik lake.

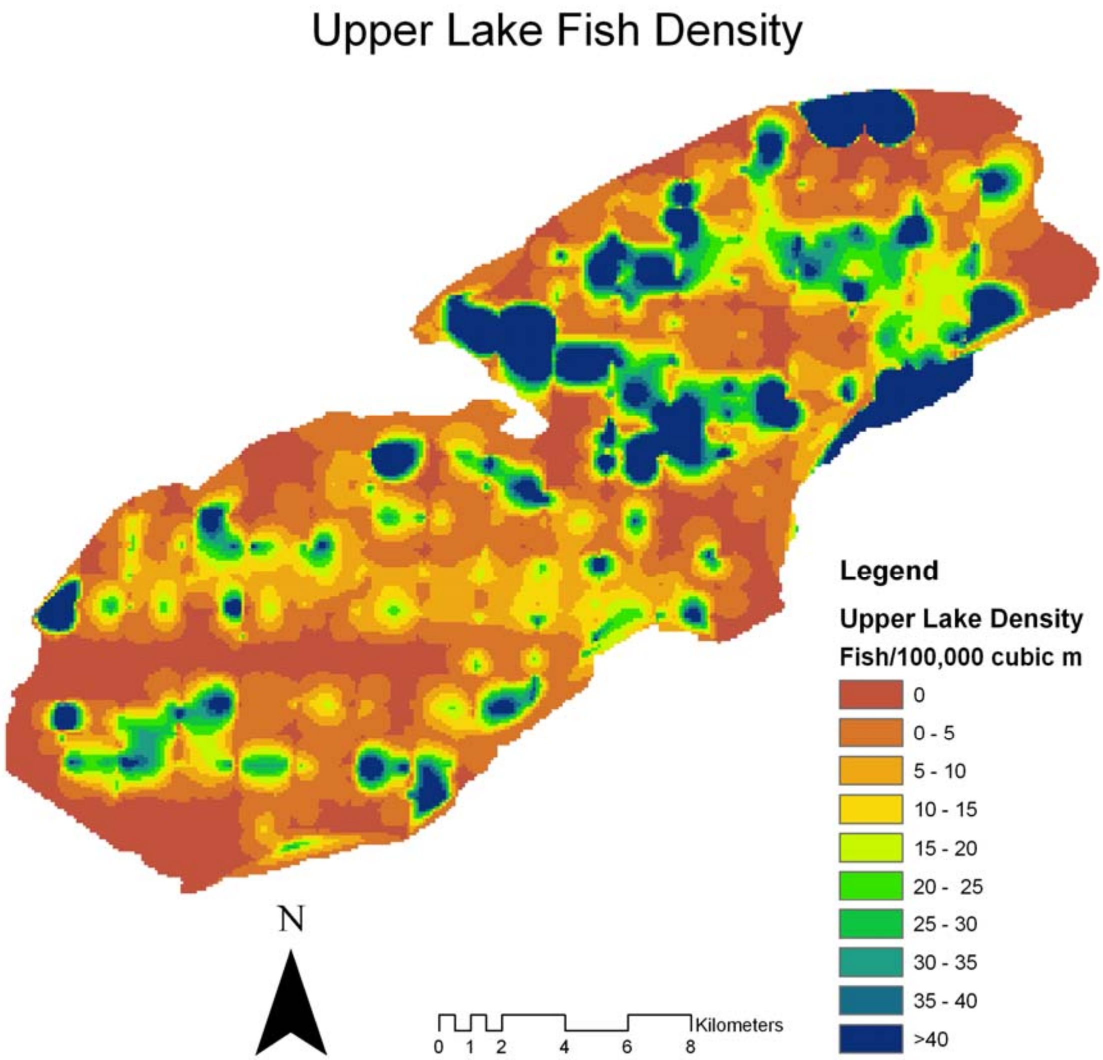


Figure 5. Map of fish density for upper Ugashik lake.

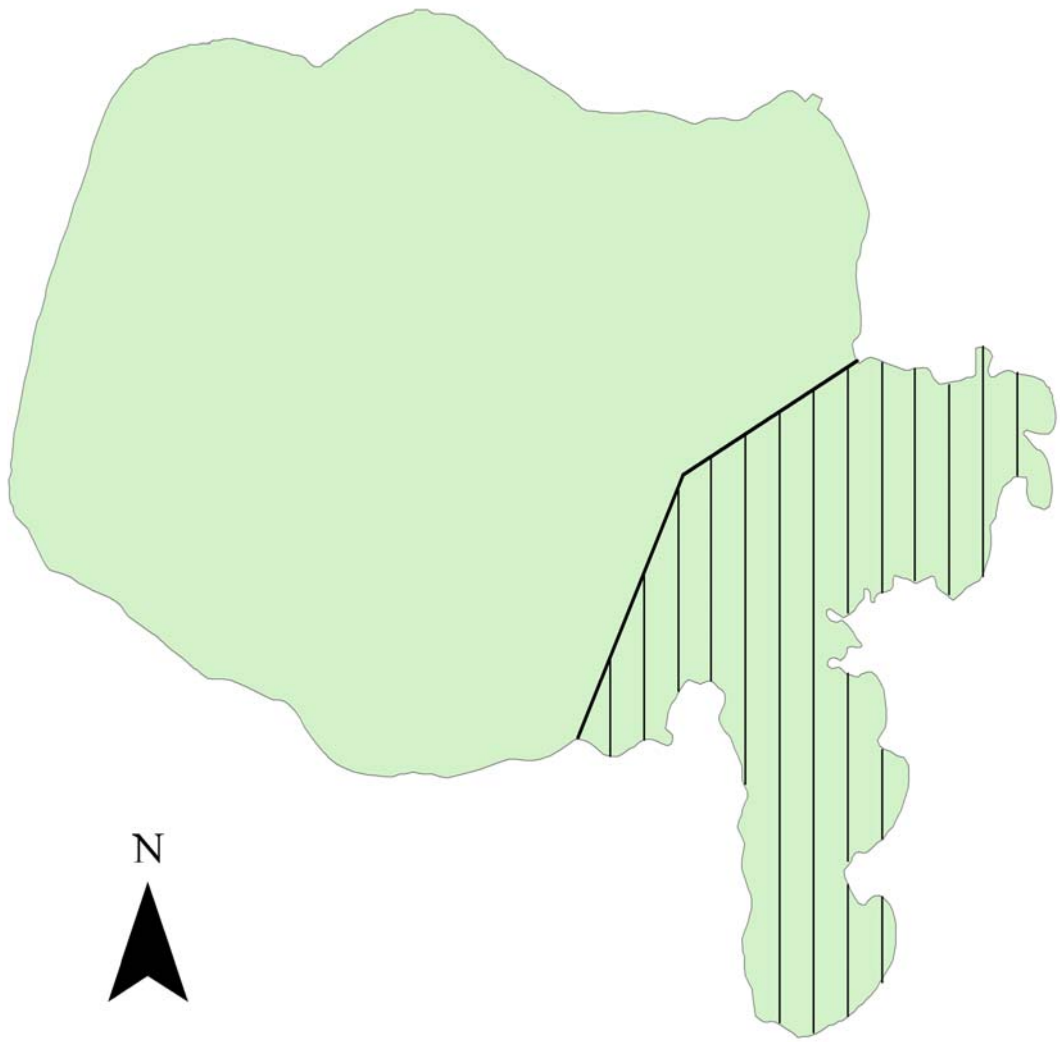


Figure 6. Map of lower lake showing island arm area (vertical lines) with extreme bathymetrical variation.

Appendix A: A resident fish monitoring protocol for the sub-arctic Ugashik Lakes on the Alaska Peninsula NWR.

Abstract: The Ugashik Lakes represent a sub-arctic lake system on the Alaska Peninsula. These lakes, like others in the area, lack thermal stratification due to high wind weather patterns. This lack of stratification prevents thermal heterogeneity that most large lake systems produce such as the thermocline and warm littoral areas. The remoteness of these lakes makes them difficult candidates for surveying and management for the United States Fish and Wildlife Service. The possibility of significant future increases in fishing pressure, make the management of these lakes important. I present here, an outline of the methods best used to sample this remote lake system for monitoring resident species fish populations and think it applies to other large sub-arctic systems in the area as well. The use of hydroacoustics along with gillnet surveys were used to produce a protocol to determine fish density, distribution, and species apportionment based on depth.

Introduction

The Ugashik Lakes in southwest Alaska represent remote, sub-arctic lakes that are cold, resource limited, and have little to no fishing pressure (United States Fish and Wildlife Service 2003). However, what makes these lakes unique is their lack of thermal stratification. The remoteness of these lakes as well as their extreme depths makes them difficult candidates for monitoring and management for the United States Fish and Wildlife Services (USFWS). Additionally, there is difficulty in maintaining separate management protocols for resident species and migratory species. These lakes are a major nursery for the Bristol Bay stocks of sockeye (*Oncorhynchus nerka*) and coho

(*Oncorhynchus kisutch*) salmon. The resident species are important to subsistence and recreational fishermen while the salmon are important to commercial fishermen. So from a management perspective it is important to maintain the recreational fishery, but it must not interfere with the salmon's use of these lakes as a nursery.

Future fishing pressure increases are a real possibility with some private land holdings still existing around the lake shore which could lead to possible fishing lodges. Also, recent communications with local Native organizations have discussed decreases in their round whitefish (*Prosopium cylindraceum*) and Arctic char (*Salvelinus alpinus*) subsistence catches (USFWS 2003). Such annual variation in catches could be attributed to annual differences in the hatching of fish, recruitment of fish into older age classes, emigration/immigration, and natural mortality. Knowledge of the trends in density estimates of resident fish species is necessary to take management actions. However, the remote nature of these lakes, their size, and depth present challenges for the fisheries management agencies in monitoring and managing their fish populations. This chapter details the approach I recommend the fisheries management agency employ in implementing an annual monitoring survey of the Ugashik Lakes that I believe could be adapted to other such lakes in Alaska.

Methods

Fish stock abundance estimates are difficult to determine. Passive gears, such as gillnets and trapnets depend on fish activity and give only relative abundance estimates (Rudstam et al. 1984). Also, many passive gears are simply avoided by fish in clear water, such as the Ugashik Lakes, leading to decreased catches and underestimation of relative abundance. If absolute abundance is the goal, active gears, such as seining and trawling require a large amount of the lake to be sampled, which leads to high labor costs (Heales et al. 2007). Mark-recapture is another possibility for absolute abundance, but labor costs are still an issue, and gaining a large enough sample size can often be problematic, especially in a system where fish densities are low like the Ugashik Lakes.

Hydroacoustics is a well established technique for quantifying fish density, abundance, and size distribution (Wanzenböck et al. 2003; Hartman et al. 2000). Hydroacoustics allows large areas of the lake to be sampled and has the advantages of: short duration; low impact on the fish studied; is independent of catch statistics and population history; and allows for absolute abundance estimates (Thorne 1983). New developments in software, ease of use, speed, and mainly smaller size of sonar equipment make it easy to use even in a remote setting. However, hydroacoustics is not without limitations.

A major problem with hydroacoustics is its inability to determine the various species encountered during a survey. Often there is previous information known about the structure of the fish population of a body of water. Thermal fronts such as thermoclines often spatially separate fish allowing biologists to speciate acoustic targets. Other bodies of water have only a few species present and these may differ significantly by size allowing easy determination of species. The Ugashik Lakes have multiple species all belonging to the same family *Salmonidae* and most overlap in size. This is a major difficulty for speciating acoustic targets. To overcome this, I captured physical samples of fish using gillnets to apportion species within the acoustic estimates. Much of the hydroacoustic literature cites using trawling gears for capture of fish. This was impractical for us because trawling requires a large vessel to tow the trawl nets. A large vessel was impossible to use in the Ugashik Lakes due to shallow water passage required from Bristol Bay to the Ugashik Lakes.

This paper describes how hydroacoustics were used to obtain density and abundance estimates for resident species of the Ugashik Lakes, Alaska. In addition, it also describes how to apportion species within this abundance estimate using gillnet surveys.

General Methodology

I conducted summer surveys at various times from May to September from 2001-06 to identify distribution and density of resident species in the Ugashik Lakes. Surveys were restricted to this time period because the summer is the only time that these lakes are ice free. Surveys consisted of mobile down-looking hydroacoustics and traditional fishery gears to identify species composition.

The Ugashik Lakes are located in the Alaska Peninsula National Wildlife Refuge 120 km southwest of the town of King Salmon. The lakes are classified as warm thereimictic (Cole 1994). The upper lake flows into the lower lake via the Ugashik Narrows. Combined, both lakes are 342 km^2, have a max depth of 180 m and rarely thermally stratify during ice-free periods due to consistent high winds (Edmundson and Todd 2000).

Fishery Gears

Multi-mesh gillnets were deployed to capture physical samples of fish to determine species composition and allow speciating acoustic targets. Gillnet surveys were performed only in years 2003-2006. In 2003-04, four types of floating and sinking multifilament nylon experimental gillnets were used as part of a study by the University of Alaska-Fairbanks (Plumb 2006). Two gill nets were 120-m long made up of six 20 m panels. The panels of one net were composed of 10-, 12.5-, 16-, 19-, 22-, and 25-mm bar mesh sizes. The panels of the other 120-m net were composed of 10-, 19-, 33-, 45-, 55-, and 60-mm bar mesh sizes. Two gill nets were 60-m long made up of six 10 m panels. The panels of one net were composed of 10-, 12.5-, 16-, 19-, 22-, and 25-mm bar mesh sizes. The panels of the other 60-m net was composed of 10-, 19-, 33-, 45-, 55-, and 60-mm bar mesh sizes. All gill nets were 1.8-m deep. In 2005, monofilament nets of bar mesh sizes 51-, 64-, 76-, 89-, 102-, 114-, 127-mm were used. The monofilament diameter was from 0.20-0.57-mm for these nets. In 2006, I used the large diameter monofilament nets from 2005, but added a new set of monofilament nets of smaller diameters from 0.10-0.25 mm with mesh sizes 10-, 19-, 33-, 45-, 55-, and 60-mm. The combination of these nets allowed us to capture the large numbers of the majority of fish sizes from 200-450 mm and the rare large individuals over 650 mm. Large diameter gillnets were purchased from Memphis Net and Twine Company. The small diameter nets were purchased from Lundgrens Fiskredskap. See Appendix B for specifications and contact information.

A total of 1,709 fish, in 161 net sets were caught from 2003-06 Sets were approximately 4 hours long and were placed in a stratified random design around the lake in three depth strata: 0-20 m, 20-80 m, and >80 m. The 0-20 m stratum was further split into 0-4 m and 4-20 m. In addition, gillnet catch per unit effort (CPUE) was calculated and used to calibrate an abundance estimate for water 4 m deep and less from the hydroacoustic data. This was necessary as there are large numbers of fish in this depth and acoustic sampling in this water depth is impossible due to small sample volume related to acoustic dead zones just in front of the transducer (near-field boundary) and near the bottom (Ona and Mitson 1996). Exclusion of this water would underestimate the population estimates of all species of fish. Gillnet CPUE from water 4-20 m deep was compared to CPUE of water 0-4 m deep. The ratio of CPUE of 4-20 m to 0-4 m was applied to 4-20 m sonar abundance data to determine estimates of 0-4 m water. For instance, if the CPUE ratio of 4-20 m to 0-4 m is 2 to 1, then for every two sonar targets in 4-20 m water it is assumed there is one in the 0-4 m water.

The target sample size of gillnet captured fish for speciation of acoustic targets was determined using a multinomial probability model from Bromaghin (1993). This paper models pre-determined sample size on the number of categories of capture. In this instance the categories are the different species of fish in the Ugashik Lakes. From this a target number of fish caught instead of a target number of nets set for each depth strata can be determined. The more categories and more confidence desired the larger the target sample sizes. From this information the target number of fish to be caught will be larger for the 0-20 m because it has all five species of interest where as 20-80 m has two species and >80 m has only one species (lake trout). Based on Bromaghin (1993), our target number of fish caught was 130 for 0-20 m stratum with a 90% confidence interval and 10% error. Our target number of fish caught was 64 for 20-80 m stratum with a 90% confidence interval and 10% error. The >80 m stratum has only one category (species) so this computation is impossible. Species were determined for netted fish and total length was measured to the nearest millimeter.

From our experience I recommend completing the gillnet survey in the near-shore region of the 0-20 m stratum first each summer. Having this complete before the adult sockeye salmon arrive will eliminate undesirable salmon catches in gillnets. The sockeye salmon are unwanted for resident species estimates, they saturate nets preventing resident species from encountering the nets, and worst of all they can destroy gillnets beyond repair. As for the 20-80 and >80 depth strata, I recommend letting gillnets fish for longer than the four hours I allotted to them. There is more water to sample so encounters will be decreased. To decrease labor and increase catch I recommend fishing nets for at least eight hours or more. Another thing to consider is how much netting effort should be devoted to the 80+ depth stratum. In our study as well as Plumb's (2006) only lake trout have been found in these depths, much of the time and labor spent gillnetting this water may be better spent elsewhere.

Acoustic survey

All acoustic data used in developing the monitoring protocol were collected with a Simrad EK60 echo-sounder, with a 70 kHz split-beam transducer operating at a 7.1° beam angle. The unit was calibrated with a 32.1 mm copper sphere [target strength (TS) = -39.1 dB] in accordance with standard calibration procedures (Foote 1990). The transducer was towed on an aluminum tow-body approximately 1 m below the surface to avoid noise from the boat and surface (Figure 1). Data were collected to a notebook computer at 0.512- ms pulse duration with the transducer set to pulse twice per second. The minimum threshold for acoustic data during collection was set to -70 decibels (dB). Single target detection parameters can be found in Table 1. Many settings used during collection of data can be changed later during processing. The pulse duration and number of pulses per second, however, cannot be changed. These parameters should be recorded for each survey to assure they can be retrieved for use in analysis software. I recommend using the fastest pulse duration available which is 0.128 ms. This allows the software to distinguish targets that are closer together. I recommend two pulses per second. This prevents large areas of acoustic dead zone at the bottom of the lake. The more overlapping pulses, the smaller the acoustic dead zone will be. Various locations of the boat were used for towing to maximize stability of the tow-body and transducer with no particular spot being best. The best assurance for stability during surveying is calm weather conditions. A very slight chop can be handled but more than that causes vertical movement of the transducer and negatively affects the bottom detection algorithm and ultimately will increase the acoustic dead-zone along the bottom (Figure 2). This can lead to fish missed by the survey because they are caught in the enlarged dead-zone (Ona and Mitson 1996; Jannsen and Brandt 1980; MacLennan and Simmonds 2005).

The survey design used must balance time available to perform the survey and include enough sampled water volume to obtain a valid abundance estimate. Our survey consisted of evenly spaced parallel transects going north to south and east to west. An attempt was made to randomize this, but was impractical due to time, weather, and fuel constraints. The most feasible survey design for short time duration is referred to as systematic sampling with parallel transects or a box design (Figure 3). This design ensures constant surveying of the vessel which allows large amounts of water to be sampled in a short time.

An attempt to determine various sample sizes were calculated based on differing levels of accuracy and acceptable error. The equation used was:

$$N = [(1.96 * \sigma) / E]^2$$

Where σ is standard deviation and E is the error term.

These calculations would let the management agency determine how accurate they want their estimates to be depending on how much effort or funding they are willing to put into a survey. However, the patchy distribution of the fish population, make for large sample sizes that are not practical given the size of the Ugashik Lakes.

An example of sample sizes based on differing error acceptance and differing confidence intervals for the 20-80 m depth stratum can be seen in Table 2. The sample sizes represent how many kilometers of acoustic data collection would be required for the shown error and confidence intervals. Any combination of error and confidence produce an impractical sample size for the size of these lakes and any time constraint that may be in place. For example, if one accepts 30 percent error and an 80 percent confidence interval the sample size would be 294 kilometers of acoustic data collection. If you steamed the entire upper lake north to south with transects one kilometer apart you would still only cover approximately 230 kilometers. Thus, the best sampling strategy is to cover as much water as is feasible with systematic sampling with parallel transects. The patchy distribution is responsible for large variance values, so drastically increasing sampling effort is unlikely to pay off in more accurate abundance estimates.

Fish abundance estimates and statistical analysis

Acoustic data was processed in EchoView® software version 4.0. Before density values can be used the data must be processed to ensure accurate results. This includes: creating echogram files with appropriate settings, ensuring the bottom line produced by the bottom-detection algorithm is correct, stratifying the water sampled vertically and horizontally (binning), creating a TS threshold to exclude unwanted size classes, exporting data in appropriate format for analysis, and finally producing a density estimate. These steps are discussed as follows:

Assuming data has been collected properly, the next step is to produce working files for use in EchoView® software. From here, it is assumed the reader has completed the "Getting Started" and "Introduction to Integration" tutorials. EchoView® uses template files to use for each batch of data. The web address for EchoView® is www.echoview.com. The template file stores settings that were used to collect the data. The most important settings are in the calibration windows that stores settings: absorption coefficient, sound speed, transmitted power, two way beam angle, transducer gain, Sa correction, transmitted pulse length, and frequency. These settings must be correct for proper analysis. These parameters are set during data collection and cannot be changed. They must be recorded during data collection in order to be manually transferred into the processing software. Every other aspect of processing can be changed. Once this information has been put into a template file, this template file is then used to process all data files that were collected with those settings.

The next step is to produce processing lines. The obvious ones are those that set the surface and bottom of the lake. These lines separate what data are analyzed and what is excluded. For analysis of the Ugashik Lakes I produced lines at 4 m, to eliminate surface disturbance and the acoustic dead zone near the transducer (near-field boundary), and 0.25 m above the bottom. I also created lines at 20 m, and 80 m to produce the depth strata that the lakes were separated into based on species apportionment of gillnet catches. Ultimately, these lines allow the water column to be separated and processed and analyzed separately. The automatic algorithms the software uses to make surface and bottom lines often make mistakes so the user must manually go through each echogram file to check and fix them. In addition, a number of fish in these lakes are below the 0.25-m line for the bottom of the lake. These fish must be manually included in the processed water column by going through each file and drawing the bottom line under the fish, but above the lake bottom so as to include these individuals.

The next step is to export values from a data file. The process of exporting is covered in the "Introduction to Integration" tutorial. Data is exported horizontally according to bin size and vertically according to the depth analysis lines were produced. For instance, if horizontal bins are 500 m and analysis lines are set every 10 m, then exported data will be in bins that are 500 m long by 10 m deep. The values given per bin can be number of single targets per bin with amount of water sampled to give density or number of fish per cubic meter. This is known as echo counting. The values given per bin can also be total backscatter (Sv) with mean target size per bin (TS) to give density or number of fish per cubic meter. This is known as echo integration.

From here, analysis is combined by bin or by transect in a typical spreadsheet format to come to an overall density estimate. Other analysis can be performed from this stage such as testing for differences in depth strata densities, annual densities, or distributions.

To determine the best approach for analyzing the acoustic data various statistical analyses were performed using the 2005 lower lake dataset for comparison. In the field of hydroacoustics there is no defined route of statistical analysis so I am presenting different analyses to allow the management agency to choose depending on their requirements. Each analysis has its strengths and weaknesses, both of which will be discussed to allow the management agency to choose a proper analysis for their needs.

There are two distinct methods of processing and analyzing hydroacoustic data (Figure 4). First, one can use each transect as a single independent sample. Second, one can take each transect and break it up into horizontal segments usually referred to as bins where each bin represents a single sample. Determining the size of the bins is usually done by testing for auto-correlation. The length of a bin is usually the minimum distance that avoids significant auto-correlation with its neighbors. This is tested for by using a correllogram or variogram. A correllogram or variogram tests for auto-correlation by measuring the correlation between consecutive sample bins of short duration. A typical bin size, referred to as lag, for hydroacoustic auto-correlation testing is 10 meters. The number of sample bins that represent a zero correlation value multiplied by the sample bin size, lag (10-m) is the size of the bin used for analysis. For example, if the correllogram shows zero correlation at the seventh bin with a lag of 10 meters then the analysis bin size would be 10 * 7 = 70 meters. So analysis bin size would be 70 meters. Statistical validity is often cited for not using the binning method. The binning method is criticized as being pseudo-replication (Dr. Patrick Sullivan, Cornell University, personal communication). This leads to arbitrarily inflating sample size. While it is true that the bins have been tested for correlation amongst neighboring bins, the bins themselves do not actually represent an independent dataset. The bins have been serially collected. This violates the assumption that the data have been collected as independent samples. This is usually justified by stating that each bin is not significantly correlated to the bins next to it (Cressie 1993; Rivoirard et al. 2000). I don't recommend this method because it violates the assumption of independent sample collection.

The next step is determining if the data will be processed and analyzed using echo integration or echo counting. Each has its limitations and advantages. Echo integration is the most commonly used approach to measuring fish abundance. It is used in cases where fish densities are too high to determine single individuals. The total reflected energy, or sound intensity, is summed. This total reflected energy is assumed to be directly proportional to total back scattering cross section of all fish in a volume of water. Fish density is then determined by dividing the total back scatter by the mean back scattered cross section of individual fish (Brandt 1996).

Echo counting is a simple procedure for determining fish densities. Fish must be sufficiently dispersed to determine individual fish. An echo count is registered if an echo voltage exceeds a predetermined threshold (size). Fish density is simply the number of fish divided by the volume of water sampled (Brandt 1996).

The next step after determining whether to use the whole transect or bins and whether to use echo integration or echo counting is what statistical analysis to perform to get a fish density estimate. I will discuss a multitude of combinations of analysis here in hopes of making it easy to visualize the pros and cons of each approach. For the Ugashik Lakes each analysis was split among the three depth strata of the lake; 4-20, 20-80, and >80 m. This depth stratification used was based on species found at depth from gillnet surveys in 2003-04 performed by Plumb (2006). The 4-20 m stratum found all fish species of interest. The 20-80 m stratum found only Arctic char and lake trout. The >80 m stratum has only lake trout present. Concurrent gillnet surveys in 2005-06 continued to find this trend of fish species at these depths. Density estimates are presented as fish per 100,000 m^3 with 95% confidence intervals.

To conclude analysis techniques, there are two primary approaches to processing acoustic data. The first is echo integration. Within this, I looked at binning transect acoustic data. The binned data is then statistically analyzed using simple arithmetic means and cluster sampling. Continuing within echo integration I looked at using the whole transect of acoustic data. The transect data was statistically analyzed using simple arithmetic mean and arithmetic bootstrap. The second processing approach is echo counting (Kieser and Ehrenberg 1990; Mulligan and Chen 1998)). Within this, I looked at binning. This was statistically analyzed using simple arithmetic mean, cluster sampling, Pennington estimator, Pennington bootstrap (Pennington 1983), and arithmetic bootstrap. Continuing with echo counting, I looked at the whole transect of acoustic data. The transect data was statistically analyzed using simple arithmetic mean and arithmetic bootstrap. A flow chart showing these analyses is in Figure 4.

Binning with echo integration

For this analysis I chose to simply take the arithmetic mean of all the density values for each bin. Bin size for analysis was determined using auto-correlation analysis. Horizontal bin size was 300 m. The number of pings per horizontal bin was 235. Vertical bin size is based on the depth stratification mentioned above.

Transects with echo integration

This analysis again used the arithmetic mean density values for all transects in the lake. In addition, another analysis performed was bootstrapping. A major advantage of bootstrapping is that it is not necessary to assume normality. The only assumption is that each sample was collected randomly (Buckland 1984). Each transect is its own sample with an overall mean density value for each depth strata. Producing a mean over the entire transect instead of comparing bins, eliminates zero values from being analyzed. The problem with using bins to produce means is with the low density and patchy distribution of the fish population in these lakes. With the use of bins the distribution is dominated by very low and zero density values with a few high values. This ultimately leads to the large variance values and the zeros make comparisons among years or depth strata very complicated. All transects from each lake for each year are re-sampled (bootstrapped) 2000 times to stabilize the distribution. Bootstrapping is also simple to implement compared to more complicated procedures for acoustic data analysis such as geo-statistics (Sheaffer et al. 1996; Robotham and Castillo 1990; Efron and Tibshirani 1986).

In addition, a method known as cluster sampling was also used. Cluster sampling uses the bins of each transect as elements and the transect itself is considered the cluster. The cluster (transect) is the unit being sampled even though the transect is split into bins based on auto-correlation. The mean density value for each cluster is the same as the arithmetic mean, but the number of elements in each cluster has a weighting affect on the variance values. This means shorter transects affect variance less than longer ones and as a result, likely decrease overall variance values. Cluster sampling is a preferred statistical analysis for binning of hydroacoustic data because the collection of data is continuous and serially correlated. Cluster sampling also eliminates the need for the use of complicated geo-statistical analysis such as variograms and correllograms which are difficult to fit a model to and interpret with such low densities of fish. Density estimates were then split into the varying depth strata and then apportioned among species captured at that depth in gillnets (Scheaffer et al. 1996; Williamson 1982).

Bins with echo counting

This aspect of analysis is the most complicated and has the most analyses. First, like all the other analyses I computed the arithmetic mean for all density values of all bins. The second analysis uses a zero inflation model based on Pennington (1983). Bins with echo counting produce a dataset with an inordinate amount of zeros. The Ugashik Lakes have very low fish densities so most of the bins contained no fish and therefore a value of zero for density. This large amount of zeros in the dataset causes problems with most statistical analysis. The Pennington zero inflation model separates zero and non-zero density values and transforms the non-zeros. The probability of a bin being a non-zero value is used to weight the non-zero values to produce a mean. This analysis is complicated and has some limitations. There is still the assumption of normality after the transformation of the non-zero values. Many of the Ugashik Lakes datasets still lack normality after the transformations are applied. The easiest way to avoid the zero inflated data set is to use either echo integration which rarely has a zero value for bins, or process and analyze the data as transects and not bins.

Lastly, there are two more analyses that can be run on the echo counting bin dataset. An arithmetic bootstrap and a Pennington bootstrap were both performed. The Pennington bootstrap uses the zero inflation model with the re-sampling technique of bootstrapping.

Transects with echo counting

This way of processing and analyzing eliminates the aforementioned zero inflation problem. It uses an overall mean of the entire transect and thus contains no bins with zero values. I simply took the arithmetic mean like the other three analyses and also performed an arithmetic bootstrap. Second, I computed mean density using cluster sampling as mentioned before.

Comparison of Approaches

The comparisons of the various approaches for processing and statistical analysis can be seen in Figure 5 for 0-20 m, Figure 6 for 20-80 m and Figure 7 for >80 m depth strata. This shows density estimates for 0-20, 20-80, and >80 m depth strata using the 2005 dataset. It also shows the inflated values for density estimates with echo integration. Echo integration results in density values were 20 times greater than echo counting. This difference is likely the result of large numbers of immature sockeye and coho salmon being included in the echo integration analysis. The bins with echo counting show the smallest confidence intervals across all statistical analyses, so that would be the most tempting to choose for analysis. However, I would like to stress the validity of using transect-based processing over binning. The confidence intervals are slightly larger but the estimator is more consistent and will be less biased by assumptions not met by binning.

In closing this section, I know that personnel new to hydroacoustics may have questions about some of the terms and conditions described above, so our recommendation is to visit the DNR/Cornell hydroacoustics website written by Dr. Patrick Sullivan and Dr. Lars Rudstam that covers many of these issues in much more detail. It is very informative and even contains programs to statistically analyze datasets. The site is: www.dnr.cornell.edu/acoustics. In addition the book "Fisheries Acoustics" by David MacLennan and John Simmonds (MacLennan and Simmonds 2005) is exceptional for the discussion of all aspects of hydroacoustics.

Transects with echo counting using cluster sampling is the approach I recommend for acoustic surveys (see chapter 4). By using the transect processing approach one avoids the problem of zero inflation that is found when the transect is divided into bins. The transect approach also avoids pseudo-replication criticism associated with dividing a transect into various parts. The echo counting approach is also important in that it prevents inflation of the resident species density estimates. The Ugashik Lakes are a nursery for sockeye and coho salmon and the immature individuals prior to migrating to sea make up a large portion of lake biomass. Echo counting allows these small immature salmon to be eliminated from analysis by setting a size threshold in the processing software. Performing this with echo integration would prove very difficult if not impossible. Also, echo integration had less consistent means across the different statistical analysis indicating a lack in precision. Lastly, cluster sampling was the approach for statistical analysis I recommend as it is the most valid by meeting the most assumptions about the data. It should be noted here that cluster sampling does use binning for the processing stage of analysis. However, when using cluster sampling, the whole transect mean is used. The main purpose of binning the transects is to have a weighting value for computation of variance and standard error values. The less bins in a transect, the shorter the transect is and thus, the less weight that transect will have in determining variance.

The dataset from 2005 was used for analysis comparison in this chapter. However, acoustic data were collected from 2001-06. Chapter four of this thesis compares annual differences in the Ugashik Lakes fish population using the binning with cluster sampling approach. I recommend using these past years of density estimates with 95% confidence intervals as a baseline and then subsequent monitoring years be used to look for trends referenced to this baseline. Density estimates by species with 95% confidence intervals for each depth strata, year, and lake are found in chapter 4.

The low density populations of fish in the Ugashik Lakes make for large variations in estimates of density. This leads to large confidence intervals that represent low precision for the density estimates. This in turn leads to difficulty in comparing any changes that occur annually with these fish populations. However, other methods of determining absolute abundance would require much more time, labor, and money with likely similar or lower precision results in absolute abundance. Add to this, the remoteness of the Ugashik Lakes and hydroacoustic surveys still are the best means of acquiring abundance estimates for the lakes. The large variance values would likely carry over to any other methods used such as mark and recapture. In conclusion, the low precision estimates of density are unavoidable. Even with large confidence intervals, a general trend could be detected over subsequent annual surveys even if comparison between individual gears is not statistically significant. Hydroacoustics is a valid means of estimating density and abundance for the Ugashik Lakes, Alaska.

Lastly, I want to discuss those areas where effort should be expanded due to limitations in these data. The first area I think should include more work is the relationship between total length and target strength of the fish in the Ugashik Lakes.

The major shortcoming of our experiment in Chapter 2 was the small sample size and the lack of a range of sizes for individual fish. Capturing salmonids less than 200 mm in this lake system proved very difficult. I resorted to using immature coho salmon to be able to include smaller individuals. Even then there was a large gap between the size of those fish and the majority of large individuals. There were only three small immature coho used to anchor the relationship. Future studies should try to include more individuals overall and more importantly more individuals less than 200 mm. I do believe the apparatus used was successful at collecting large numbers of individual target strength values for each fish measured.

The weather conditions from which acoustics data is collected has an effect on the outcome of analysis results. I collected data in the full spectrum of weather conditions. Collection was made when the lake was flat calm and in three foot high rolling waves. Our recommendation from this is to collect data on days with minimal or no wind. The rocking of the vessel in windy conditions adversely affects the bottom detection technique used in the collection software. Ultimately the bottom of the lake resembles valleys and peaks. This will also enlarge the acoustic dead zone (Figure 2) where fish will be missed for analysis. Processing of these data will be simplified if collection is done during calm weather conditions.

I noticed large numbers of pelagic fish in the deepest basins in both lakes. These schools or shoals represent the most dense aggregation of fish found in the lakes using hydroacoustics. An attempt to capture these individuals was made in 2005 using drifting gillnets, vertical gillnets, and enlarged minnow traps. Only two lake trout were caught from the upper lake (474 and 505 mm) and one lake trout from the lower lake (314 mm).

Knowing the species and size distributions of these fish would fill in some gaps in the data set. In addition, an *in situ* relationship between fish length and target strength could be developed if a sample of the same fish insonified by acoustics could be captured by some method such as gillnets. Then a comparison could be made with the *ex situ* method I produced in Chapter 2.

References

Brandt, S. B. 1996. Acoustic assessment of fish abundance and distribution. Pages 385-419. in Murphy, B. R., and D. W. Willis, editors. Fisheries Techniques. American Fisheries Society, Bethesda, Maryland.

Bromaghin, J.F. 1993. Sample size determination for interval estimation of multinomial probabilities. The American Statistician 47: 203-206.

Buckland, S. T. 1984. Monte Carlo confidence intervals. Biometrics 40: 811-817.

Cole, G.A. 1994. Textbook of Limnology. 4th edition. Waveland Press, Inc. Prospect Heights, Illinois.

Cressie, N.A.C. 1993. Statistics for Spatial Data. Revised Edition. Wiley.
Del Grosso, V. A., and C. W. Mader. 1972. Speed of sound in pure water. Journal of the Acoustical Society of America 52: 1442-1446.

Edmundson, J.A. and Todd, G.L. 2000. Limnological perspectives on stock and recruitment for Egegik and Ugashik river sockeye salmon. Regional information report, No. 2A00-33. Alaska Department of Fish and Game.

Efron, B. and Tibshirani, B. 1986. Bootstrap methods for standard errors, confidence intervals, and other measures of statistical accuracy. Statistical Science 2: 54-77.

Foote, K.G. 1990. Spheres for calibrating an eleven-frequency acoustic measurement system. ICES Journal of Marine Science 46: 284-286.

Hartman, K.J., Nagy, B., Tipton, R.C., Morrison, S. 2000. Verification of Hydroacoustic Estimates of Fish Abundance in Ohio River Lock Chambers. North American Journal of Fisheries Management 20: 1049-1056.

Heales, D.S., Brewer, D.T., Kuhnert, P.M., Jones, P.N. 2007. Detecting declines in catch rates of diverse trawl by-catch species, and implications for monitoring. Fisheries Research 84: 153-161.

Janssen, J.J., and S.B. Brandt. 1980. Feeding ecology and vertical migration of adult alewives (*Alosa pseudoharengus*) in Lake Michigan. Canadian Journal of Fisheries and Aquatic Sciences 37: 177-184.

Kieser, R. and Ehrenberg, J. E. 1990. An unbiased, stochastic echo-counting model. International Council for the Exploration of the Sea, France. 189: 65-72.

MacLennan, D.N. and Simmonds, E.J. 2005. Fisheries Acoustics. Chapman and Hall, London.

Mulligan, T. J. and Chen, D. G. 1998. A split-beam echo counting model: development of statistical procedures. ICES Journal of Marine Science. 55: 905-917.

Ona, E., and R.B. Mitson. 1996. Acoustic sampling and signal processing near the seabed: the dead zone revisited. ICES Journal of Marine Science 53: 677-690.

Pennington, M. 1983. Efficient estimators of abundance, for fish and plankton surveys. Biometrics 39: 281-286.

Plumb, M. P. 2006. Ecological factors influencing fish distribution in a large sub-arctic lake system. Master's Thesis. University of Alaska Fairbanks.

Rivoirard, J., J. Simmonds, K.G. Foote, P. Fernandes, and N. Bez. 2000. *Geostatistics for* Estimating Fish Abundance. Blackwell Science. 206 pp.

Robotham, H. and Castillo, J. 1990. The bootstrap method: an alternative for estimating confidence intervals of resources surveyed by hydroacoustic techniques. Investigacion Pesquera 34:79-83.

Rudstam, L.G., Magnuson, J.J., Tonn, W.M. 1984. Size selectivity of passive fishing gear: A correction for encounter probability applied to gill nets. Canadian Journal of Fisheries and Aquatic Sciences 41: 1252-1255.

Scheaffer, R.L., W. Mendenhall III, and R.L. Ott. 1996. Elementary Survey Sampling 5th Edition. Duxbury Press.

Thorne, R.E. 1983. Assessment of population abundance by hydroacoustics. Biological Oceanography 2: 253-262.

USFWS. 2003. Quantification of Resident Fish Populations in the Ugashik Lakes Using Hydroacoustics. Research Proposal. Prepared by KSFO. ID number 04-R7-XX.

Wanzenböck, J., Mehner, T., Schulz, M., Gassner, H. Winfield, I.J. 2003. Quality assurance of hydroacoustic surveys: the repeatability of fish-abundance and biomass estimates in lakes within and between hydroacoustic systems. ICES Journal of Marine Science 60: 486-492.

Williamson, N. J. 1982. Cluster Sampling Estimation of the Variance of Abundance Estimates Derived from Quantitative Echo Sounder Surveys. Canadian Journal of Fisheries and Aquatic Sciences 39: 229-231.

Table 1. Single target detection parameters for the Ugashik Lakes. The threshold value coincides with fish of total length 200 mm based on TS-total length relationship for salmonids determined in chapter 2.

TS threshold (dB)	-53.67
Pulse length determination level (dB)	6.00
Minimum normalized pulse length	0.50
Maximum normalized pulse length	1.00
Beam compensation model	Simrad LOBE
Maximum beam compensation (dB)	12.00
Maximum standard deviation of:	
Minor axis angles (degrees)	0.600
Major axis angles (degrees)	0.600

Table 2. Sample size determination of 20-80 m depth stratum from the lower lake in 2005. This shows the large sample sizes produced at varying accuracies. The sample sizes are too large to be practical due to the large inherent population variance of the Ugashik Lakes.

Error (% of mean)	Confidence Interval	Sample Size (km)
10%	95%	6,191
	90%	4,335
	80%	2,641
20%	95%	1,548
	90%	1,084
	80%	661
30%	95%	688
	90%	482
	80%	294

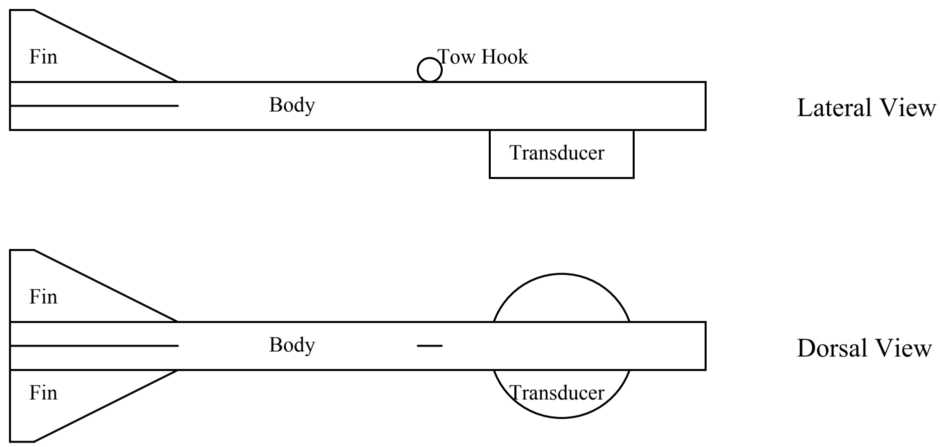


Figure 1. Views of tow-body that transducer was attached to used for hydroacoustic survey.

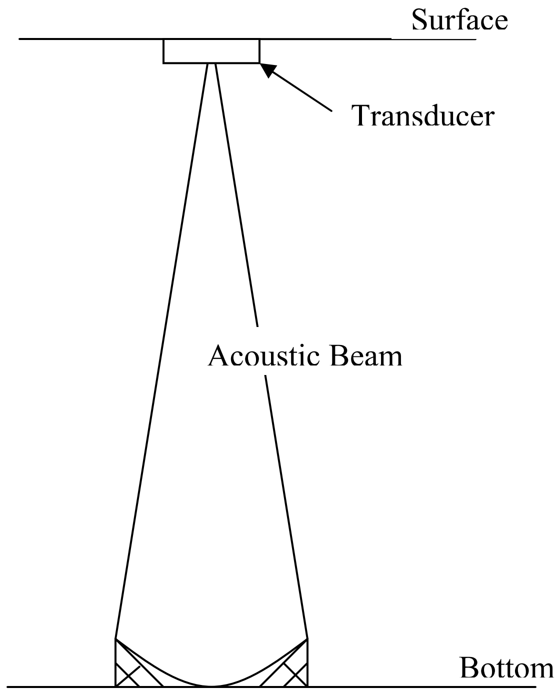


Figure 2. The acoustic dead zone (cross hatch).

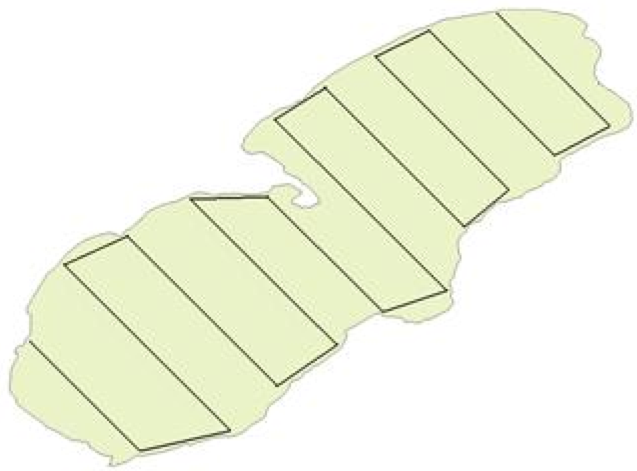


Figure 3. Example of systematic sampling with parallel transects in the upper Ugashik Lake. This is also known as a box survey design.

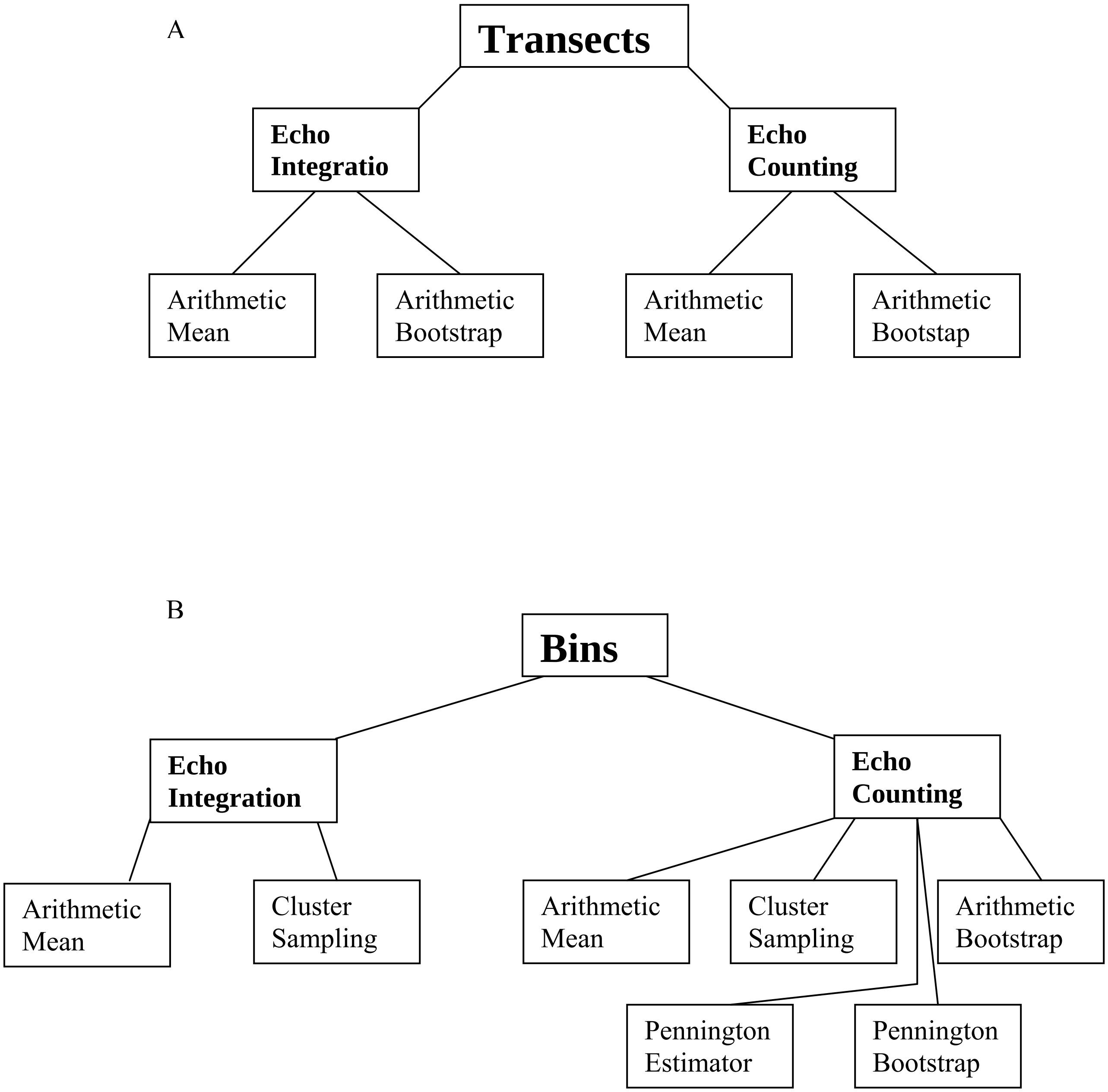
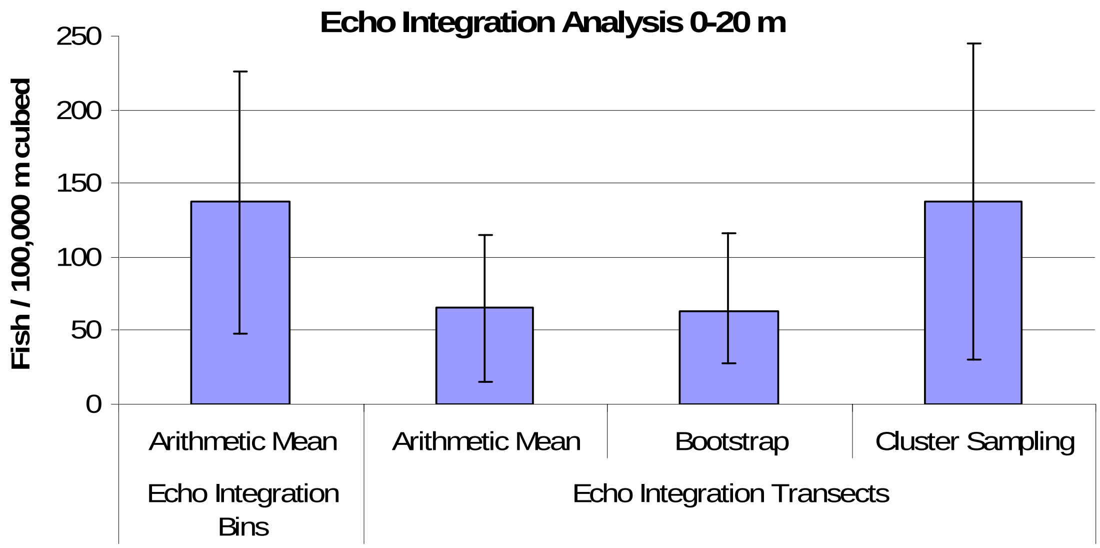


Figure 4. Flow charts showing the processing and statistical analysis performed on the 2005 lower lake data set. The two processing options are to use whole transects (A) or binning (B). Then fish densities are produced from either echo integration or echo counting. Within each of these various statistical analyses was used to produce overall density estimates.



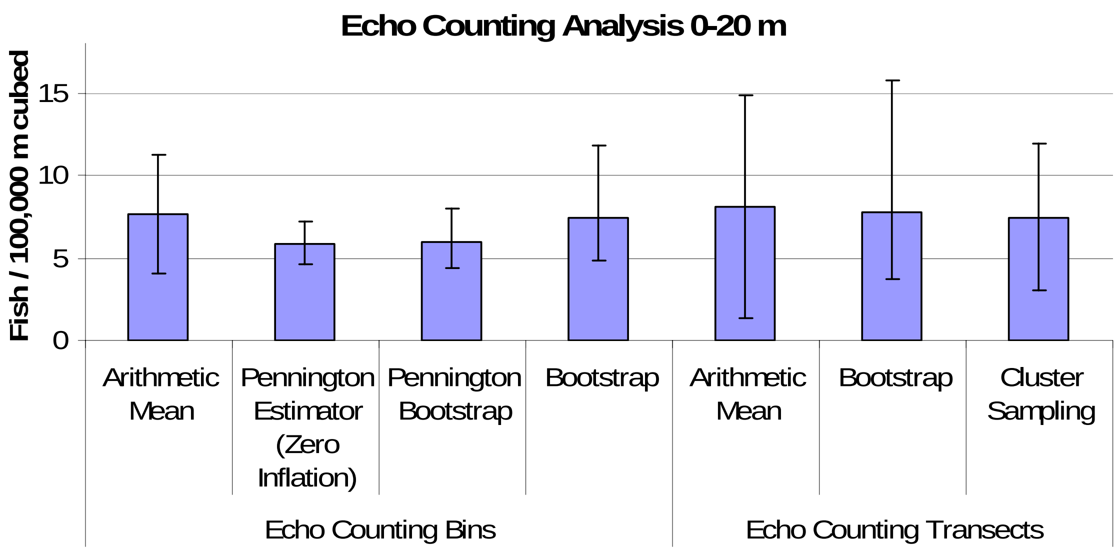


Figure 5. Mean density values with 95% confidence intervals for the 0-20 m depth stratum showing the differences between various processing and statistical analysis of hydroacoustic data for (a) echo integration and (b) echo counting.

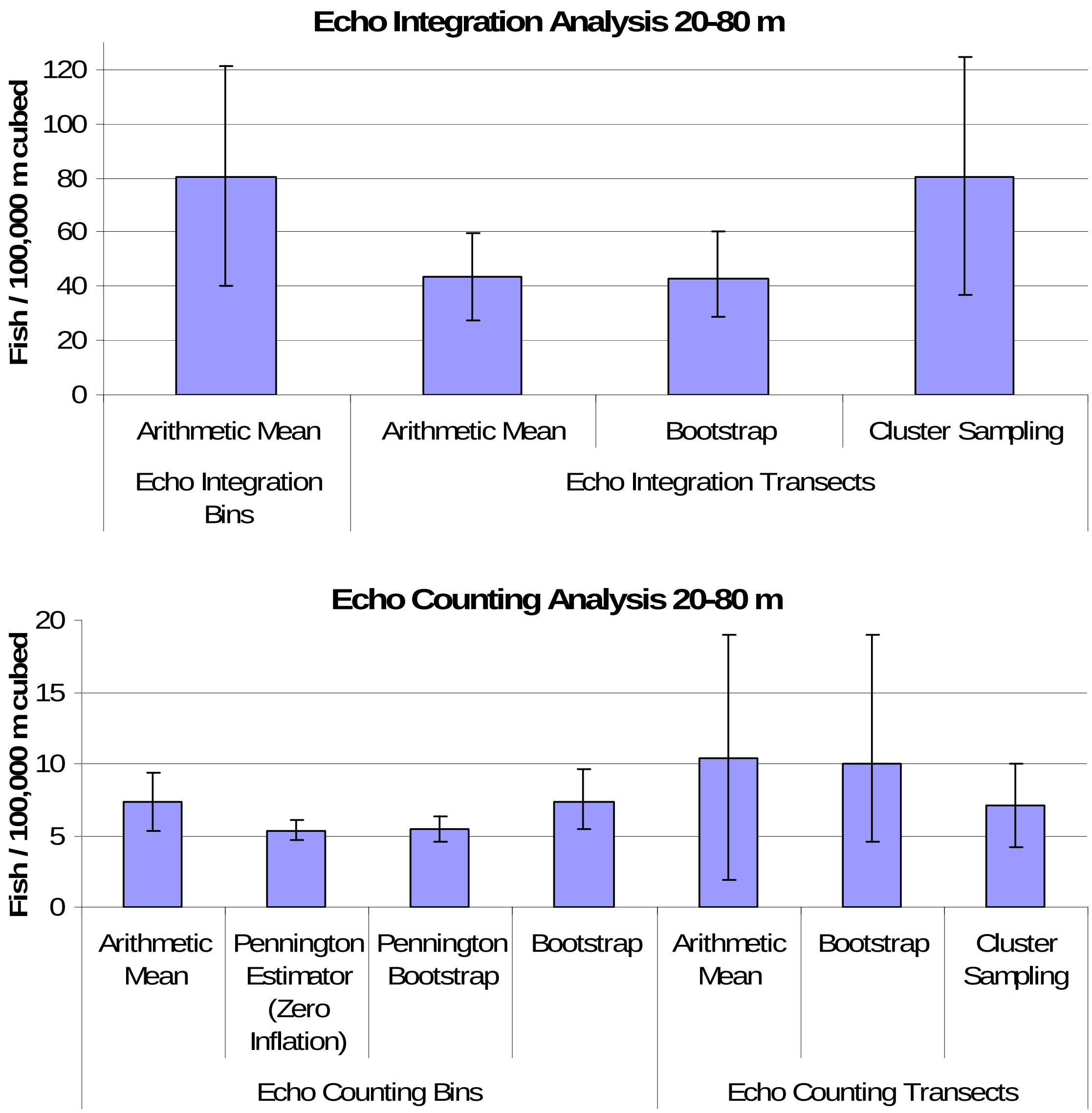


Figure 6. Mean density values with 95% confidence intervals for the 20-80 m depth stratum showing the differences between various processing and statistical analysis of hydroacoustic data for (a) echo integration and (b) echo counting.

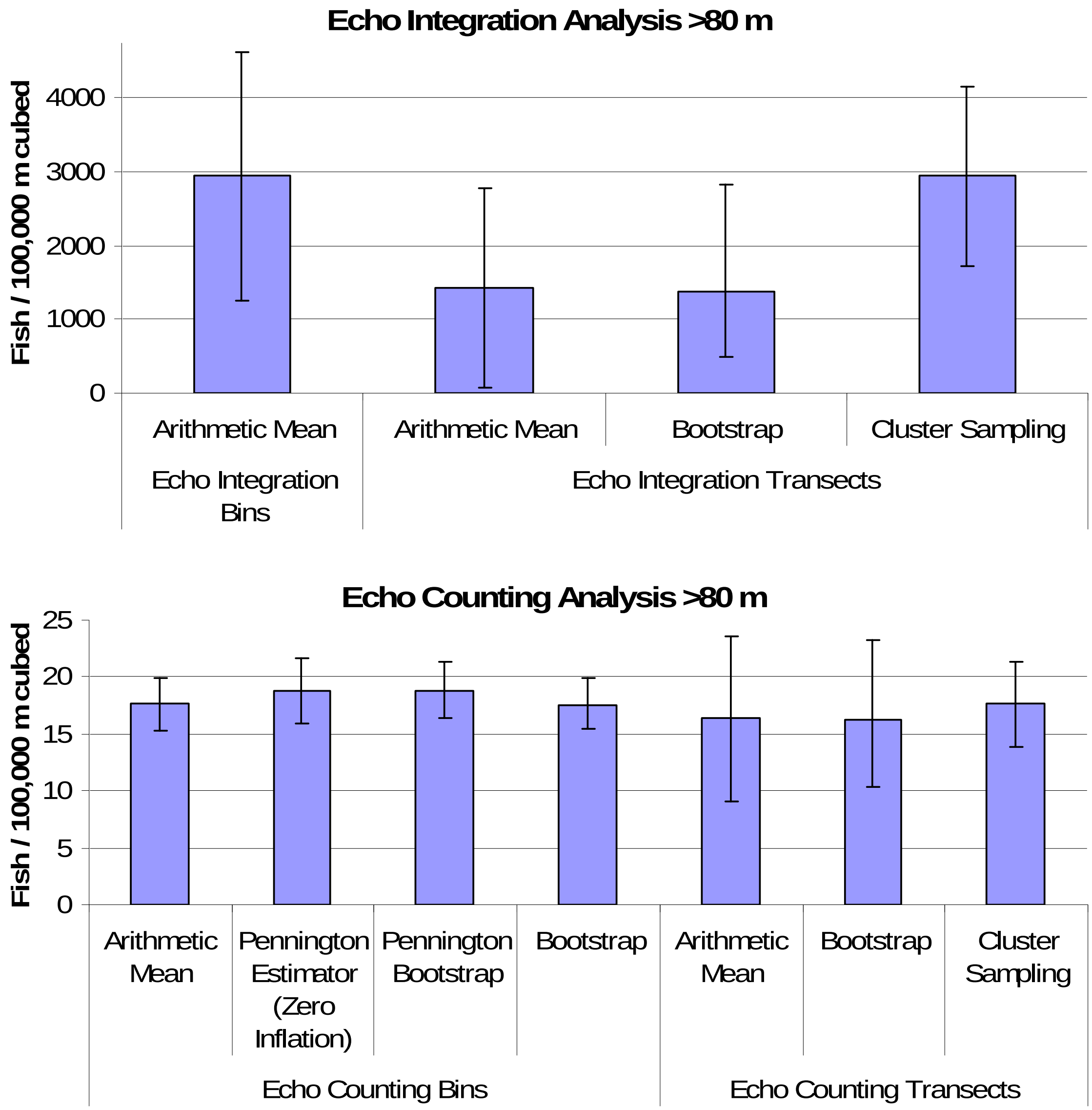


Figure 7. Mean density values with 95% confidence intervals for the >80 m depth stratum showing the differences between various processing and statistical analysis of hydroacoustic data for (a) echo integration and (b) echo counting.

Appendix B. Monofilament gillnet specifications and companies contact information from where they were purchased. Specifications are bar mesh measurements. Multi-filament gillnets were used from 2003-04, but I recommend using monofilament nets for their durability and invisibility to fish.

Memphis Net and Twine Company Incorporated
888-674-7638 www.memphisnet.net

Mesh	51 mm	64 mm	76 mm	89 mm	102 mm	114 mm	127 mm
Diameter	0.20 mm	0.28 mm	0.33 mm	0.40 mm	0.47 mm	0.52 mm	0.57 mm

Lundgrens Fiskredskap
www.lungrensfiske.com

Mesh	10 mm	19 mm	33 mm	45 mm	55 mm	60 mm
Diameter	0.12 mm	0.15 mm	0.15 mm	0.17 mm	0.25 mm	0.25 mm
