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Susitina Drainage Lakes Pelagic Fish Estimates, Using Split-beam Hydroacoustic and Midwater Trawl Sampling Techniques, 2005–2008

by

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and

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Alaska Department of Fish and Game **Divisions of Sport Fish and Commercial Fisheries**

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat or long
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	$\log_{2,}$ etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

Acoustic and midwater trawl surveys were conducted in September 2005 to 2008 to estimate the abundance of juvenile sockeye salmon (*Oncoryhnchus nerka*) and other juvenile pelagic fishes rearing in Susitna River drainage lakes. The population estimates from these surveys varied dramatically between each lake and year. Total fish densities ranged from 0.02 to 6.96 fish per m^2 with corresponding populations of approximately 83,000 to 19.6 million fish. Juvenile sockeye salmon densities ranged from 0 to 1.48 fish per m^2 with corresponding populations of approximately 0 to 1.9 million fish. Threespine sticklebacks (*Gasterosteus aculeatus*) were the predominant species in more than half of the lakes studied each year. Stickleback average sizes ranged from 26.5 to 38.9 mm and mean age-0 sockeye salmon fry sizes ranged from 37.2 to 83.5 mm. Although their mean sizes barely overlapped, acoustic separation of these species was impossible. Townet surveys were conducted to apportion acoustic targets to species and estimate age composition, mean weight, and length of juvenile sockeye salmon. Sockeye salmon abundance estimates for some lakes may have been biased low due to net avoidance by larger juvenile sockeye salmon.

Key words: sockeye salmon, *Oncorhynchus nerka*, hydroacoustics, split–beam, sonar, Susitna River, Cook Inlet, Alaska.

INTRODUCTION

In September 2005–2008, the Alaska Department of Fish and Game (ADF&G) conducted hydroacoustic and midwater trawl surveys on 7 lakes located in the Susitna River drainage (Figure 1) to estimate abundance, age distribution, and size of juvenile sockeye salmon (*Oncorhynchus nerka*). Similar surveys were conducted in the early 1990s (King and Walker 1997). King and Walker (1997) also presented similar data from historical studies of Susitna drainage lakes. The information obtained on fall fry rearing in these nursery lakes in the Susitna drainage were previously used to help forecast the number of sockeye salmon returning to the Susitna River system, in addition to the euphotic volume method (Tarbox and Kyle 1989). Moreover, these studies begin to help us understand the ecological linkages that could limit or influence sockeye salmon freshwater production. If studies in these lakes continue, we may be able to develop sockeye salmon production models similar to those developed for other systems in the Cook Inlet watershed (i.e., the brood interaction spawner-recruit model of Carlson et al. 1999 and Edmundson et al. 2003). These acoustic surveys and midwater trawl studies are part of a more comprehensive series of studies of limnological conditions, smolt production, and escapement enumeration designed to gain a better understanding of the factors regulating the freshwater production of sockeye salmon in the Susitna drainage, which supports 1 of the 3 largest runs of sockeye salmon in Upper Cook Inlet (Shields 2009; Westerman and Willette 2010).

OBJECTIVES

The objectives of this study were to (1) estimate the abundance of juvenile sockeye salmon rearing in Susitna drainage lakes, (2) estimate the distributions of age, weight, and length of fall sockeye salmon fry, and (3) estimate the abundance and size of other pelagic fish captured in the Susitna drainage lakes.

METHODS

HYDROACOUSTIC SURVEYS

We used a systematic parallel transect sampling design for the hydroacoustic surveys (MacLennan and Simmonds 1992). Transects were chosen, conceptually, based on previous studies (King and Walker 1997). Transects were evenly spaced on maps in the area office before traveling to the field during the first year of the study. In the field, transect end points were affixed with a flashing strobe light prior to the night time hydroacoustic survey. In addition, transect end points were saved as waypoints on a handheld global positioning system (GPS) in order to replicate survey design in subsequent years. During the hydroacoustic survey, transects were traversed at approximately 2 m s^{-1}. The acoustic vessel (4.6 m long rubber raft) was powered by one 2-stroke outboard engine.

For all the hydroacoustic surveys, pelagic fish communities were sampled acoustically at night with a BioSonics DTx-6000[1] split-beam echosounder. The down-looking transducer was mounted to a 1.5 m long aluminum tow body. The tow body was attached to a polypropylene rope connected to a boom and towed off the boat's starboard side approximately 1 m below the water surface. The transducer transmitted digital data via a direct connection data cable to the echosounder. The echosounder was connected to a laptop computer via ethernet data connection. For georeferenced transect routes, we used a Garmin eTrex Legend GPS. Acoustic digital data were collected and stored on a laptop computer hard drive. Configuration parameters (Appendix A1) were input into BioSonics Visual Acquisition data collection software. Temperature was measured with a YSI model-58 digital thermistor and input to the environmental variables of the program. A 12V battery powered the acoustic system and the laptop computer.

Acoustic data were stored (hard drive) and transported to the area office where they were uploaded into the office network for access by analysis programs. The acoustic data were edited using SonarData Echoview analysis software. Acoustic data were first bottom edited to remove bottom echoes. After bottom editing was complete, individual target information was processed and saved for estimation of in-situ target strength (TS) and sigma (σ), the area backscattering coefficient.

TS and sigma computations were performed using a macro built by Aquacoustics Inc. For each lake, this macro appended all transects and calculated in-situ TSs and sigmas from each detected target. Targets were filtered to include only those echoes near the beam center (+3 to –3dB off axis) and the largest sigmas were removed (> -40dB) to compute the average sigma. Target number and average sigma were calculated and assembled into 1 m depth strata (Appendices A2–A8). The following rule was used to determine the in-situ sigma to use for calculating target densities in any particular depth stratum. If the stratum sigma differed by more than 20% of the mean sigma computed for the entire lake and target density was greater than 5% of total targets used to compute average sigma, then the stratum sigma was used to compute target densities in that stratum, otherwise a sigma averaged over several similar depth strata was used (DeCino and Willette 2011). Typically, 2 to 3 sigmas averaged over different depth strata were input to a spreadsheet to compute fish densities for each transect using echo integration.

A fish density estimate was computed for each transect and expanded for each lake from which they were collected. The echo integrator compiled data in 1 report along each transect and sent outputs to computer files for further reduction and analysis. The total number of fish ($\hat{N}_{ij}$) for a lake i based on transects j was estimated across depth stratum k. $\hat{N}_{ij}$ consisted of an estimate of the number of fish detected by hydroacoustic gear in both the surface and midwater depth

[1] Product names used in this report are included for scientific completeness, but do not constitute a product endorsement.

intervals as described in DeCino and Degan (2000) and DeCino and Willette (2011). The population estimate of the lake based on the density of transect j component was estimated as:

$$\hat{N}_{ij} = a_i \sum_{k=1}^{K} \hat{M}_{ijk} , \tag{1}$$

where a_i represented the surface area (m^2) of the lake stratum i, which was estimated using a planimeter and USGS maps of each Susitna drainage lake (King and Walker 1997), and $\hat{M}_{ijk}$ (number/m^2) was the estimated mean fish density in area i depth k across transect j. The depth would be less than the maximum 52 m if the bottom was detected within depth stratum k anytime along the transect.

Using transects as the sampling unit (Burczynski and Johnson 1986), fish abundance in lake i ($\hat{N}_i$) was estimated from the mean abundance for all transects j in the lake, i.e.,

$$\hat{N}_i = J^{-1} \sum_{j=1}^{J} \hat{N}_{ij} , \tag{2}$$

and its variance was estimated as

$$v(\hat{N}_i) = \sum (\hat{N}_{ij} - \hat{N}_i)^2 (J-1)^{-1} J^{-1} . \tag{3}$$

The abundance of juvenile sockeye salmon in each lake ($\hat{N}_s$) was estimated as:

$$\hat{N}_s = \hat{N}\hat{P}_s , \tag{4}$$

where $\hat{P}_s$ was the estimated proportion of total fish targets that were juvenile sockeye salmon in the lake. Age-specific numbers of juvenile sockeye salmon, $\hat{N}_{sa}$, were estimated as:

$$\hat{N}_{sa} = \hat{N}_s \hat{P}_a . \tag{5}$$

where $\hat{P}_a$ was the estimated proportion of age; a sockeye salmon in the fish population.

Variance estimates were calculated as described in DeCino and Willette (2011, 2014) and Glick and Willette (2014).

AGE, WEIGHT, AND LENGTH (AWL) SURVEYS

Midwater trawl surveys were conducted in all lakes after acoustic surveys were completed to estimate the species composition of acoustic targets. The age composition (sockeye salmon only), mean wet weight (g), and mean fork length (mm) were estimated from a subsample of all pelagic fishes. The trawl was 4 m by 2 m wide and 7.6 m long. Mesh opening was 6 cm at the opening and decreased to 4 mm at the cod end. Midwater trawl sampling consisted of surface and depth tows. Each trawl consisted of towing the net between two 4.6 m long rafts at 1–2 m s^{-1} for 30 minutes. Two rafts were attached together by aluminum poles configured in a cross pattern (i.e., port side, fore gunwale, of raft 1 attached to starboard side aft gunwale of raft 2, plus its correlate). The trawl net was stretched open with aluminum poles on both the head rope and foot rope. The depth of each net tow was set by attaching buoys on both ends of the head rope using various lengths of line. The maximum depth of the net opening was obtained by attaching 15 kg of lead weight to each end of the foot rope. The areas to trawl were identified from hydroacoustic surveys to maximize catch using observed target information. Fish captured in each tow were identified and enumerated to species. If greater than 200 individuals of any non-salmonid species were captured in a tow, their numbers were estimated, visually in 2005 and by number per minnow net removal iterations from 2006 through 2008, and recorded on data sheets. All juvenile sockeye salmon captured were saved to estimate age, mean length, and weight. From 2005 to 2006 a subsample of about 100 non-salmonid fish were saved for later length and weight measurement. In 2007 the subsample size was increased to 200 non-salmonid fishes.

All fish saved in this study were preserved in a 10% formalin solution and transported to the laboratory. All sockeye salmon fry were enumerated, measured to the nearest 1 mm, and weighed to the nearest 0.1 g. Scales were removed from sockeye fry greater than 50 mm and their age determined from scale samples using criteria outlined by Mosher (1969).

RESULTS

2005

For the 2005 acoustic studies, we collected the data at a -77dB threshold (Appendix A1). Our TS data collected with the -77 dB threshold were comparable to King and Walker's (1997) in Hewitt, Judd, and Shell lakes only. Hewitt Lake exhibited the smallest overall TS of -57.2 dB, followed by Shell, Judd, Larson, and Chelatna lakes, respectively (Table 1). However, when the mean TSs were examined in the "upper" water column, Hewitt Lake's -60.1 dB was followed by Larson, Shell, Judd, and Chelatna lakes, respectively (Table 1). The sigmas used to echo integrate different depth strata varied from 9.78×10^{-7} in Hewitt Lake to 1.26×10^{-5} in Chelatna Lake (Table 1). For all lakes, except Shell Lake, at least 2 sigmas were used to echo integrate the data in different depth strata. All lakes exhibited slight bimodal distributions in both TS (Figures 2–6) and length frequency of the abundant pelagic fish captured (Figures 7–11).

The total number of fish estimated using the acoustic gear ranged from approximately 1.3 million fish in Chelatna Lake to 19.6 million fish in Hewitt Lake (Table 2). Likewise, the total estimated target densities ranged from 0.08 to 6.96 fish per m^2 (Table 2). Generally, each lake had the greatest density of targets in the top 20 m (Figures 12–16). The surface population estimates ranged from 52,388 in Larson Lake to over 1.9 million fish in Hewitt Lake (Table 2).

Sockeye salmon fry populations ranged from approximately 58,000 fish in Shell Lake to 1.9 million in Judd Lake. Judd Lake had the highest sockeye salmon density of 1.48 fish per m^2. The sockeye salmon fry densities in Judd Lake were nearly 4 times greater than those in Hewitt Lake and 133 times greater than those in Shell Lake (0.01 fish per m^2; Table 2).

During our midwater trawl surveys, approximately 4,993 fish were captured, and the total ranged from 155 at Chelatna Lake to 2,762 fish at Hewitt Lake (Table 3). Juvenile sockeye salmon fry captured ranged from 12 at Shell Lake to 617 at Judd Lake (Table 4). Juvenile sockeye were predominantly caught in Judd Lake 96.7%, followed by Chelatna Lake 38.6% (Table 3). Age-0 juvenile sockeye salmon were most common in trawl samples with the largest residing in Shell Lake at 66.7 mm and 3.5 g, to the smallest sampled in Hewitt Lake at 37.2 mm and 0.7 g (Table 4). Age-1 sockeye salmon fry were only captured in Hewitt and Judd lakes, respectively (Table 4).

Non-salmonid trawl catches were predominantly stickleback in Hewitt Lake (94.4%), Larson Lake (90.7%), and Shell Lake (96.1%), followed by whitefish (*Prosopium* sp.) in Chelatna Lake (49%; Table 3). Stickleback mean lengths were smallest in Larson Lake (29.8 mm), but sticklebacks in Hewitt Lake exhibited the lowest body weight (0.3 g; Table 5). In Chelatna Lake, whitefish were the next most abundant species and their average lengths and weights were 43.1 mm and 0.8 g, respectively (Table 5). The only other fish caught in the Susitna Lake studies were sculpin, which is not a typical pelagic fish.

Stickleback mean lengths were smallest in Larson Lake (29.8 mm), but sticklebacks in Hewitt Lake exhibited the lowest body weight (0.3 g; Table 5). In Chelatna Lake, whitefish were the next most abundant species, and their average lengths and weights were 43.1 mm and 0.8 g, respectively (Table 5). The only other fish caught in the Susitna Lake studies were sculpin, which is not a typical pelagic fish.

Sticklebacks were the most abundant species present in Hewitt, Larson, and Shell lakes, with estimates ranging from approximately 1.9 to 18.5 million fish. Whitefish estimates totaled 647,287 in Chelatna Lake, and a few coho salmon (*O. kisutch*) were present in Larson Lake (Table 6).

2006

From 2006 to 2008, we collected targets using a -65 dB threshold. Two additional lakes, Byers and Stephan, were sampled in 2006 (Figure 1). Hewitt Lake exhibited the smallest overall mean TS of -55.5 dB, followed by Judd, Shell, Larson, Stephan, Chelatna, and Byers lakes (Table 1). Likewise, when targets were examined in the "upper" water column, Hewitt Lake exhibited the smallest mean TS (-57.3 dB), followed by Shell, Judd, and Larson lakes (Table 1). Sigma values varied from the smallest in the top 5 meters at Hewitt Lake (1.85×10^{-6}) to the largest below 20 meters in Chelatna Lake (1.47×10^{-5}, Table 1). In all lakes except Stephan Lake, 2 or more sigmas were used to generate the respective lakes population estimates (Table 1). TS bimodality was evident in Chelatna, Larson, Shell, and (Figures 2, 5, and 6) Judd lakes (Figure 4). Multiple modes were evident in Byers Lake (Figure 17) and Hewitt Lake appeared unimodal (Figure 3). Length frequency distributions of all pelagic fish appeared bimodal in all lakes (Figures 8–11), except Chelatna (Figure 7) and Stephan lakes (Figure 18).

The total number of fish detected by the acoustic gear ranged from approximately 82,093 fish in Stephan Lake to over 12.5 million fish in Hewitt Lake. Fish target estimates, not available to the acoustic gear in the 0–2 m layer, were greatest in Hewitt Lake at 681,845 fish to 8,160 fish in Stephan Lake. Likewise, fish densities were greatest in Hewitt Lake and smallest in Stephan Lake (Table 2). Fish densities were greatest in the upper 20 m and decreased from surface to bottom for all lakes (Figures 12–16, 19 and 20).

Sockeye salmon fry populations ranged from approximately 14,000 fish in Shell Lake to 1.1 million for Chelatna Lake (Table 2). Juvenile sockeye fish densities ranged from a high 0.359 fish m^{-2} in Judd Lake to 0.002 fish m^{-2} in Shell Lake. The greatest number of sockeye salmon not available to direct acoustic measurement was located in Chelatna Lake, followed by Judd and Hewitt lakes. The large number of sockeye salmon fry in Chelatna Lake is most likely due to other species being unrepresented in the midwater trawl surveys because weather conditions did not allow more townet sets to be conducted.

During our midwater trawl surveys, approximately 5,072 fish were captured, and the total ranged from 5 at Stephan Lake to 3,751 fish at Hewitt Lake (Table 3). Juvenile sockeye salmon fry captured ranged from 4 at Stephan Lake to 105 at Judd Lake. Juvenile sockeye were exclusively caught in Chelatna Lake (100%) and were predominantly caught in Stephan Lake (80%). In Judd Lake, one-half of the midwater trawl catch were juvenile sockeye salmon, followed by less than 20% for all other lakes (Table 3). Of the juvenile sockeye salmon captured in midwater trawls, age-0 were the most common, with the largest residing in Stephan Lake at 83.5 mm and 8.2 g and the smallest sampled in Chelatna Lake at 50.8 mm and 1.7 g (Table 4). Age-1 sockeye salmon were captured in both Hewitt and Judd lakes, and both lengths and weights were similar (Table 4). However, there was a greater proportion of age-1 fish in Judd Lake (~41%) in 2006 compared to either 2005 or 2007 (Table 4).

Non-salmonid trawl catches were predominantly sticklebacks in Shell (99.0%), Hewitt (98.3%), Larson (95.4%), Byers (73.5%), and in Judd lakes (50.7%; Table 3). Sticklebacks were most abundant in Judd Lake at greater than 12 million fish followed by Shell, Larson, and Chelatna lakes (Table 6). Stickleback lengths and weights were smallest in Judd Lake at 26.5 mm and 0.3 g (Table 5). Lake Trout, *Salvelinus namaycush,* and coho salmon juveniles were present in Byers, Larson, and Shell lakes.

2007

In Shell Lake, the average whole water column TS was the smallest at -56.2 dB, and the largest at -49.1 dB occurred in Byers Lake. In all lakes except Hewitt Lake, more than 1 sigma was used to integrate the acoustic data in different water column strata, and the sigmas ranged from 1.61×10^{-6} in Stephan Lake to 1.37×10^{-5} in Byers Lake (Table 1). TS distributions were similar to those in previous years with bimodal distributions in Chelatna, Larson, Shell, and Stephan lakes (Figures 2, 5, 6, and 21). Likewise, length frequency distributions were bimodal in all lakes except Judd Lake (Figures 7, 8, 10, 11, 18 and 22). Judd Lake pelagic fish populations indicated a slight bimodal length frequency distribution (Figure 9).

The total number of fish estimated using the acoustic gear ranged from 322,678 in Byers Lake to approximately 9.7 million fish in Hewitt Lake (Table 2). Shell Lake had the largest number of estimated targets in the surface layer, followed by Larson and Hewitt lakes (Table 2). Fish densities ranged from 0.079 to 3.447 fish per m^2. Fish densities decreased with depth in all lakes, with peak densities occurring in the top 20 m except for Judd Lake (Figures 7–11, 14 and 15).

Sockeye salmon fry populations ranged from just over 24,000 fish in Larson Lake to greater than 1 million fish in Judd Lake (Table 2). Age-0 sockeye fry were predominant in 5 lakes; however, age-1 sockeye fry were approximately one third of the total sockeye salmon fry captured in Larson Lake (Table 2).

During our midwater trawl surveys, approximately 6,660 fish were captured and the total ranged from 116 fish at Judd Lake to 2,770 fish at Hewitt Lake (Table 3). Captured juvenile sockeye salmon fry ranged from 12 at Larson Lake to 554 at Judd Lake (Table 4). The proportion of sockeye salmon fry in townet catches was greatest in Judd Lake (89.7 %), followed by Chelatna Lake at 63.4% (Table 3). Age-0 juvenile sockeye salmon were most common in townet samples, with the largest residing in Stephan Lake at 74.8 mm and 5.2 g and the smallest sampled residing in Hewitt Lake at 43.9 mm and 1.1 g. Age-1 sockeye salmon were captured in both Chelatna and Larson lakes (Table 4).

Non-salmonid trawl catches were predominantly stickleback in Byers, Hewitt, Larson, and Shell lakes, followed by whitefish (*Prosopium* sp.) in Chelatna Lake (Table 3). Stickleback lengths were smallest in Hewitt Lake at 28.5 m, but their body weights were lowest in both Hewitt and Shell lakes at 0.2 g. In Chelatna Lake, whitefish average length and weight were 43.8 mm and 0.9 g. In Stephan Lake, 107 sculpin were captured, and their mean lengths and weights were 29.4 mm and 0.5 g (Table 5).

2008

Only Chelatna and Judd lakes were sampled in 2008. Chelatna Lake had the largest overall TS of -53.4 dB. Chelatna Lake also had the largest sigma for echo integration (Table 1). Chelatna Lake TS distribution was more bimodal (Figure 2) compared to Judd Lake (Figure 4). TS distributions for Chelatna Lake were similar in shape over all the years (Figure 2). The shape of TS distributions were also similar each year at Judd Lake, but total target counts varied considerably with the lowest counts in 2008 (Figure 4). Acoustic TSs were lower in all lakes compared to previous years. Length frequency distributions of pelagic juvenile fish were somewhat bimodal in Chelatna Lake (Figure 7) compared to Judd Lake (Figure 9).

Both total fish and juvenile sockeye salmon populations were approximately 10 times greater in Chelatna Lake compared to Judd Lake (Table 2). Juvenile sockeye salmon were the most abundant fish captured in the midwater trawls (Table 3). On the other hand, the juvenile sockeye salmon were the smallest size in 2008 compared to other years sampled. Juvenile sockeye salmon in Judd Lake were smaller than in Chelatna Lake in 2008 (Table 4).

DISCUSSION

Between 2005 and 2008, Judd Lake was the only lake that had more than 50% juvenile sockeye salmon present. These studies corroborated similar findings from King and Walker (1997). King and Walker (1997) also found that more than one-half of the lakes they examined contained large populations of sticklebacks. In all years of our studies, fish species other than sockeye salmon were the most abundant fish in most of these lakes. Sticklebacks were most abundant in Byers, Hewitt, Larson, and Shell lakes for each year studied. Hewitt Lake had exceptionally high numbers of sticklebacks compared to previous studies and other lakes in this study. In Chelatna Lake, whitefish were the most abundant fish species in 2005.

Juvenile sockeye salmon were the most abundant species each year in Judd Lake. However, in Chelatna Lake juvenile sockeye were the most abundant species sampled in 2006, 2007, and 2008. Townetting in Chelatna Lake in 2006 was cut short due to weather, which most likely biased the results for species apportionment because whitefish were present in all other years sampled.

We initially collected fish TSs using a -77dB threshold in 2005 to compare with the King and Walker (1997) study. This threshold entrained noise at depths greater than 30 m at the smallest TS range (-77dB to -70dB), possibly biasing the average TS and skewing the TS distribution. Our TS data collected at -77 dB were, however, comparable to some lakes sampled in the King and Walker (1997) study. After 2005, we changed our data collection threshold because of the noise issue and to standardize with the minimum thresholds used in other Upper Cook Inlet lake studies (e.g., DeCino and Willette 2014), especially in deeper lakes like Byers and Chelatna. When we changed the threshold to a -65 dB, our TS data between lakes and years were similar when compared with the 2005 data set (Table 1). However, when comparing the peaks of the TS histograms for Hewitt Lake, the 2005 data is bimodal and not similar to the TS peaks in the 2006 and 2007 data (Figure 4). This suggests the TS of smaller/younger age classes of sticklebacks were not being sampled acoustically after the threshold was raised. Threespine sitcklebacks typically have a 3-year life cycle, and other researchers have found similar findings of multiple year classes of stickleback inhabiting subarctic lake ecosystems (Greenbank and Nelson 1959).

The smaller TS noted in Chelatna Lake in 2005 could be from sculpin (*Cottus* sp.), which were captured in the midwater trawls. Wurtsbaugh and Neverman (1988) noted that larval sculpin migrated at night from bottom substrates to digest food. However, we did not collect any larval scuplin, and the sizes of the sculpin we captured were similar to the sticklebacks in the other lakes. For an unknown reason, more noise was present during the 2005 acoustic survey in Chelatna Lake on the lower dB collection level, but the authors suspect the cable may have been too tight when connected to the transducer and suspended from the davit. Generally for all the other lakes, the shape and peak of the histogram were similar between all years sampled.

We estimated that more than 5 times as many sticklebacks were present in 2005 than previously measured. Even when we chose to collect data using a -65 dB threshold, our results were 4 to 5 times greater than the early 1990s studies. We therefore feel that collecting data using a -65 dB threshold was reasonable for the current study questions, but we could have missed the younger year classes of stickleback.

Generally, our population estimates fell within the historical ranges previously reported (King and Walker 1997). Exceptions to this observation were in Chelatna, Hewitt, Byers, and Shell lakes. In Chelatna Lake there were greater numbers of both individual fish targets and sockeye salmon fry in the historical surveys compared with our most recent population estimates. In Hewitt Lake, the total estimated targets were 5 to 19 times greater than the historical estimates from the mid-1990s. But, Hewitt Lake's estimated juvenile sockeye salmon population in 2005 was 19% larger than the 1994 population estimate, and it was the largest sockeye salmon fry population for that lake during 2005–2008. The juvenile sockeye salmon abundance estimates for Hewitt Lake in 2006–2007 were much smaller than in the historical estimates (King and Walker 1997). In both Byers and Shell lakes, no juvenile sockeye salmon were captured in the midwater trawls in 2007. This was most likely due to sampling error, lack of effort to collect juvenile sockeye salmon, and net avoidance.

We feel the trawling effort needs to be increased to better estimate the species and size composition of pelagic juvenile fish populations in these lakes and provide more accurate acoustic abundance estimates. Acoustic abundance estimates are sensitive to target apportionment and will tend to be biased low with respect to sockeye salmon fry when zero juvenile sockeye salmon are captured, but there is a distinct possibility that sockeye salmon reside in the lake. For instance, 69,800 and 3,150 adult sockeye salmon passed the adult weirs at Shell (Weber 2009) and Byers lakes in 2006 (Weber 2009), respectively. With this many returning adults we would expect to catch greater numbers of sockeye salmon fry in the midwater trawls. We towed the net through what appeared to be the greatest fish densities observed in the acoustic echograms in 2007 but did not capture any sockeye salmon fry. The most likely source of error in target apportionment in these 2 lakes is trawl net avoidance. The mean smolt lengths for 2006 were 110 mm and 99 mm for both Shell and Byers lakes, respectively (Weber 2009). The average lengths of age-0 sockeye fry for 2006 were 74.7 mm for Byers Lake and 73.7 mm for Shell Lake. The largest sockeye salmon fry we captured was 82 mm and 6.5 g and that was the only fish captured in Chelatna Lake, an occluded system (Table

4). These data indicate that larger juvenile sockeye salmon are avoiding our townet in clear water lakes, causing our abundance estimates to be biased low.

Another problem with species apportionment from net catches is target depth. For instance, in 2007, Judd Lake fish densities increased with depth (Figure 14). We could only fish at a maximum depth of approximately 11 m because of the trawl buoy line length. These buoy lines were attached to the cork line of the townet, and the net was towed at speeds previously described in the methods. As the boat sped up to towing speed, the friction on the buoys, net, and rigging most likely caused the net to rise in the water column, so we did not know the true towing depth. After 2008, depth sensors were purchased to measure the depth the trawl net fished. In addition, we could invest in a different towing platform that would give the researchers a better opportunity to tow at greater depths, but this would entail use of hydraulics and a high speed midtrawl like that currently used in Skilak Lake research (DeCino and Willette 2014).

Juvenile sockeye salmon tend to exhibit a diel vertical migration (Narver 1978; Clarke 1978; Eggers 1978; Clark and Levy 1988), which could affect capture in townets. Juvenile sockeye salmon that coexist with adult or subadult predators typically migrate to near surface depths at sunset to feed. As darkness ensues, the juvenile fish cannot detect their prey, so they settle to greater depths and suspend feeding. As dawn approaches, the fish tend to migrate once again to shallow depths to feed, after which they swim to greater depths to avoid predation (Narver 1978; Eggers 1978; Clark and Levy 1988). During these migrations we could potentially miss fish with our midwater trawl while fishing at night. We therefore need to spend more effort to fish at more depth intervals, so we can adequately obtain replicate samples in the townet when fish are not available in the shallower depths.

These studies demonstrated the variability of fish assemblages in the Susitna drainage lakes. These lake fish assemblages are more diverse compared to Kenai and Skilak lakes, which are nearly monospecies lake systems. The Susitna drainage lakes had greater numbers of sticklebacks compared with Kenai Peninsula sockeye salmon lakes. In addition, Susitna drainage lakes are generally smaller, have different limnological characteristics, and many contain the highly predatory northern pike (*Esox lucius*), which is an invasive species that can dramatically alter a lake's fish assemblages. Susitna lakes also differ from Kenai Peninsula lakes in the number of competing fish species. For instance, in Hewitt Lake we noted that there was an anoxic bottom layer limiting all fish to a shallow layer above the anoxic water. Hewitt Lake has very high numbers of sticklebacks that likely consume large numbers of zooplankton. Depressed zooplankton stocks may have allowed algal blooms in this lake, which were evident when zooplankton nets were retrieved.

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REFERENCES CITED

Burczynski, J. J., and R. L. Johnson. 1986. Application of dual-beam acoustic survey techniques to limnetic populations of juvenile sockeye salmon (Oncorhynchus nerka). Canadian Journal of Fisheries and Aquatic Sciences 43: 1776–1788.

Carlson, S. R., K. E. Tarbox, and B. G. Bue. 1999. The Kenai sockeye salmon simulation model: a tool for evaluating escapement and harvest levels. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 2A99-08, Anchorage.

Clark, W. C. 1978. Growth of underyearling sockeye salmon (Oncorhynchus nerka) on diel temperature cycles. Fisheries and Marine Service Technical Report No. 780.

Clark, C. W., and D. A. Levy. 1988. Diel vertical migrations by juvenile sockeye salmon and the antipredation window. American Naturalist 133: 271–290.

DeCino, R. D. and D. J. Degan. 2000. Juvenile sockeye salmon population estimates in Skilak and Kenai lakes, Alaska, by use of split-beam hydroacoustic techniques in September 1999. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 2A00-06, Anchorage.

DeCino, R. D., and T. M. Willette. 2011. Juvenile sockeye salmon population estimates in Skilak and Kenai lakes, Alaska, by use of split-beam hydroacoustic techniques in September 2004. Alaska Department of Fish and Game, Fishery Data Series No. 11-13, Anchorage.

DeCino, R. D., and T. M. Willette. 2014. Juvenile sockeye salmon population estimates in Skilak and Kenai lakes, Alaska, by use of split-beam hydroacoustic techniques in autumn 2005-2010. Alaska Department of Fish and Game, Fishery Data Series No. 14-17, Anchorage.

Edmundson, J. A., T. M. Willette, J. M. Edmundson, D. C. Schmidt, S. R. Carlson, B. G. Bue and, K. E. Tarbox. 2003. Sockeye salmon overescapement, (Kenai River Component), Exxon Valdez Oil Spill Restoration Project Final Report (Restoration Project 96258A-1), Alaska Department of Fish and Game, Division of Commercial Fisheries, Anchorage, Alaska.

Eggers, D. M. 1978. Limnetic feeding behavior of juvenile sockeye salmon in Lake Washington and predator avoidance. Limnology and Oceanography 23: 1114–1125.

Glick, W. J., and T. M. Willette. 2014. Juvenile sockeye salmon population estimates using split-beam hydroacoustics in Susitna drainage lakes, Alaska, 2009 to 2012. Alaska Department of Fish and Game, Fishery Data Series No. 14-48, Anchorage.

Greenbank J., and P. R. Nelson. 1959. Life history of threespine stickleback Gasterosteus aculeatus Linnaeus in Karluk lake and Bare Lake Kodiak, Island, Alaska. Fishery Bulletin 153, 59:537–559

King, B. E., and S. C. Walker. 1997. Susitna river sockeye salmon fry studies, 1994 and 1995. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 2A97-26, Anchorage.

MacLennan D. N., and E. J. Simmonds. 1992. Fisheries acoustics, first edition. St. Edmundsbury Press, Great Britain.

Mosher, K. H. 1969. Identification of Pacific salmon and steelhead trout by scale characteristics. U.S. Department of the Interior, Circular 317, Washington, D.C.

Narver, D. W. 1978. Diel vertical movements and feeding of underyearling sockeye salmon and the limnetic zooplankton on Babine Lake, British Columbia. Journal of the Fishery Research Board of Canada 27: 281–316.

Shields, P. 2009. Upper Cook Inlet commercial fisheries annual management report, 2008. Alaska Department of Fish and Game, Fishery Management Report No. 09-22 Anchorage.

Tarbox, K, and G. Kyle. 1989. An estimate of adult sockeye salmon, Oncorhynchus nerka, production based on eupohitic volume, for the Susitna River drainage, Alaska. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 2S89-01, Soldotna.

Weber, N. 2009. Shell Lake sockeye salmon final report 2006–2009. Cook Inlet Aquaculture Association, Kenai, Alaska.

Westerman, D. L. and T. M. Willette. 2010. Upper Cook Inlet salmon escapement studies, 2008. Alaska Department of Fish and Game, Fishery Data Series No. 11-33, Anchorage.

Wurstbaugh, W. A. and D. Neverman. 1988. Post-feeding thermotoaxis and daily vertical migration in a larval fish. Nature 333: 846–848.

TABLES AND FIGURES

Table 1.–Target strength (TS) and mean backscattering coefficient, sigma (σ), used to echo integrate defined depth strata, 2005–2008.

	2005			2006			2007			2008		
Lake	Depth strata	Sigma	TS	Depth strata	Sigma	TS	Depth strata	Sigma	TS	Depth strata	Sigma	TS
Byers				0 to 5 m	7.13×10^{-6}	-51.5	0 to 5m	2.41×10^{-6}	-56.2			
				5 - 35 m	1.24×10^{-5}	-49.1	5 m to 15m	1.01×10^{-5}	-50.0			
				35 - bottom	8.40×10^{-6}	-50.8	15 m to bottom	1.37×10^{-5}	-48.6			
				whole water column	1.21×10^{-6}	-49.2	whole water column	1.22×10^{-5}	-49.1			
Chelatna	0 to 30 m	5.99×10^{-6}	-52.2	0 to 20 m	7.79×10^{-6}	-51.1	0 to 15 m	1.06×10^{-5}	-49.8	0 to 30 m	1.01×10^{-5}	-53.8
	30 m to bottom	1.26×10^{-5}	-49.0	20 m to bottom	1.47×10^{-6}	-48.3	15 m to 40 m	9.28×10^{-6}	-50.3	30 m to 40 m	1.58×10^{-5}	-51.9
	whole water column	8.53×10^{-6}	-50.7	whole water column	1.05×10^{-5}	-49.8	40 m to bottom	1.21×10^{-5}	-49.2	40 m to bottom	1.01×10^{-5}	-53.8
							whole water column	1.06×10^{-5}	-49.7	whole water column	1.15×10^{-6}	-53.36
Hewitt	0 to 5m	9.78×10^{-7}	-60.1	0 to 5m	1.85×10^{-6}	-57.3	whole water column	2.58×10^{-6}	-55.9			
	5 m to bottom	2.11×10^{-6}	-56.8	5 m to bottom	3.11×10^{-6}	-55.1						
	whole water column	1.92×10^{-6}	-57.2	whole water column	2.80×10^{-6}	-55.5						
Judd	0 to 25 m	2.94×10^{-6}	-55.3	0 to 15m	2.68×10^{-6}	-55.7	0 to 20 m	2.58×10^{-6}	-55.9	0 - bottom	3.25×10^{-6}	-56.4
	25 m to bottom	5.78×10^{-6}	-52.4	15 m to bottom	3.33×10^{-6}	-54.8	20 m to bottom	4.41×10^{-6}	-53.6			
	whole water column	3.52×10^{-6}	-54.5	whole water column	3.06×10^{-6}	-55.1	whole water column	3.58×10^{-6}	-54.5			
Larson	0 to 8m	2.54×10^{-6}	-56.0	0 to 20m	3.44×10^{-6}	-54.6	0 - 10 m	2.42×10^{-6}	-56.2			
	9 m to 11 m	5.59×10^{-6}	-52.5	20 m to bottom	5.39×10^{-6}	-52.7	10 m to 15 m	7.66×10^{-6}	-51.2			
	12 m to bottom	8.52×10^{-6}	-50.7	whole water column	3.95×10^{-6}	-54.0	15 m to 40 m	1.29×10^{-5}	-48.9			
	whole water column	7.18×10^{-6}	-51.4				whole water column	1.02×10^{-5}	-49.9			
Stephan				0 to bottom	7.43×10^{-6}	-51.3	0 to 15 m	1.61×10^{-6}	-57.9			
							15 m to bottom	1.02×10^{-5}	-49.9			
							whole water column	2.91×10^{-6}	-55.4			
Shell	0-bottom	2.71×10^{-6}	-55.7	0 - 5 m	2.10×10^{-6}	-56.8	0 to 10 m	1.77×10^{-6}	-57.5			
				5 m - bottom	4.29×10^{-6}	-53.7	10 m to bottom	2.73×10^{-6}	-55.6			
				whole water column	3.98×10^{-6}	-54.0	whole water column	2.42×10^{-6}	-56.2			

Table 2.–Population estimates for total targets and sockeye salmon fry in Susitna River drainage lakes, 2005–2008.

		Total estimated targets					Estimated juvenile sockeye fry						
	Lake	Surface	Midwater	Total	SE	Density (n/m2)	Surface	Midwater	Total	SE	Density (n/m2)	Age 0	Age 1
2005	Chelatna	72,428	1,247,698	1,320,126	138,931	0.0835	27,569	474,930	502,499	52,883	0.0317	502,499	
	Hewitt	1,946,184	17,699,708	19,645,892	2,998,277	6.9650	109,541	996,231	1,105,773	168,759	0.3900	1,020,628	85,144
	Judd	220,378	1,732,711	1,953,089	420,959	1.5273	213,124	1,675,678	1,888,802	407,103	1.4770	1,698,033	196,435
	Larson	52,388	2,073,772	2,126,160	322,901	1.2023	4,832	191,270	196,102	29,782	0.1108	196,102	
	Shell	224,911	1,743,356	1,968,267	226,077	0.3762	6,615	51,275	57,890	6,649	0.0111	57,890	
2006	Byers	25,079	173,400	198,479	35,503	0.1333	4,426	30,600	35,026	6,265	0.0235	35,026	
	Chelatna	129,926	1,009,278	1,139,204	376,726	0.0727	129,926	1,009,278	1,139,204	376,726	0.0727	1,139,204	
	Hewitt	681,845	11,822,649	12,504,494	2,406,409	4.4332	11,634	201,719	213,353	41,058	0.0756	56,667	156,687
	Judd	83,047	665,602	748,650	197,941	0.5854	50,909	408,023	458,933	121,340	0.3589	269,210	189,723
	Larson	101,690	963,050	1,064,740	151,956	0.6021	3,968	37,582	41,551	5,930	0.0235	41,551	
	Shell	182,261	1,279,292	1,461,553	140,916	0.2793	1,844	12,941	14,784	1,425	0.0028	14,784	
	Stephan	8,160	73,933	82,093	40,136	0.0226	6,528	59,146	65,674	32,109	0.0181	65,674	
2007	Byers	70,092	252,586	322,678	74,709	0.2167	0	0	0				
	Chelatna	35,150	1,213,279	1,248,429	195,407	0.0790	22,271	768,719	790,990	123,808	0.0500	781,419	9,492
	Hewitt	569,826	9,153,016	9,722,842	1,044,191	3.4470	3,291	52,869	56,161	6,031	0.0199	56,161	
	Judd	67,907	1,144,109	1,212,016	212,295	0.9478	60,882	1,025,753	1,086,635	190,336	0.8498	1,086,635	
	Larson	597,338	2,079,731	2,677,069	633,425	1.5138	5,369	18,694	24,064	5,694	0.1362	15,040	9,024
	Shell	722,140	2,498,857	3,220,998	999,442	0.6156	0	0	0				
	Stephan	83,458	757,294	840,753	495,789	0.2311	3,185	28,904	32,090	18,923	0.0088	32,090	
2008	Chelatna	93,425	1,406,957	1,500,382	383,779	0.0949	89,314	1,345,051	1,434,365	366,893	0.0906	1,434,365	0
	Judd	13,509	152,529	166,038	32,585	0.1298	11,915	134,531	146,446	28,740	0.1145	143,195	3,251

Table 3.–Percentage of all species captured in midwater trawls in Susitna drainage lake townet studies, 2005–2008.

Year	Lake	Chinook	Sockeye	Coho	Lake trout	Whitefish	Stickleback	Sculpin	Other	Total fish	Total min fished	No tows
2005	Chelatna	0.0	38.1	0.0	0.0	49.0	0.0	12.9	0.0	155	240	8
	Hewitt	0.0	5.6	0.0	0.0	0.0	94.4	0.0	0.0	2,762	53	4
	Judd	0.0	96.7	0.0	0.0	0.0	3.3	0.0	0.0	638	60	4
	Larson	0.0	9.2	0.1	0.0	0.0	90.7	0.0	0.0	1,030	120	6
	Shell	0.0	2.9	0.0	0.0	0.0	96.1	1.0	0.0	408	120	4
2006	Byers	0.0	17.6	2.9	2.9	0.0	73.5	2.9	0.0	34	60	4
	Chelatna	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	19	95	4
	Hewitt	0.0	1.7	0.0	0.0	0.0	98.3	0.0	0.0	3,751	50	5
	Judd	0.0	49.1	0.0	0.0	0.0	50.7	0.3	0.0	375	100	5
	Larson	0.0	4.1	0.5	0.0	0.0	95.4	0.0	0.0	196	205	5
	Shell	0.0	1.0	0.0	0.0	0.0	99.0	0.0	0.0	692	110	4
	Stephan	0.0	80.0	20.0	0.0	0.0	0.0	0.0	0.0	5	60	3
2007	Byers	0.0	0.0	0.0	0.0	0.0	99.6	0.4	0.0	260	149	7
	Chelatna	0.0	63.4	0.0	0.0	36.6	0.0	0.0	0.0	131	180	6
	Hewitt	0.0	0.6	0.0	0.0	0.0	99.2	0.2	0.0	2,770	92	6
	Judd	0.0	89.7	0.0	0.0	0.0	10.3	0.0	0.0	116	137	5
	Larson	0.0	0.9	0.0	0.0	0.0	99.0	0.1	0.0	890	90	4
	Shell	0.0	0.0	0.0	0.0	0.0	99.1	0.8	0.0	2,362	93	6
	Stephan	1.5	3.8	1.5	0.0	0.0	0.0	92.4	0.8	131	93	6
2008	Chelatna	0	95.6	0	0	4.4	0	0	0	114	540	18
	Judd	0	88.2	0	0	0	11.8	0	0	406	390	13

Table 4.–Age, weight, and length of sockeye salmon fry captured in midwater trawls, 2005–2008.

Year	Lake	Sockeye Age-0					Sockeye Age-1				
		n	l (mm)	SE	w (g)	SE	*n*	l (mm)	SE	w (g)	SE
2005	Chelatna	59	57.5	1.74	2.7	0.23					
	Hewitt	228	37.2	0.50	0.7	0.03	19	63.2	0.86	2.8	0.14
	Judd	554	43.8	0.28	1.0	0.02	63	61.5	0.47	2.5	0.05
	Larson	95	58.9	0.85	2.5	0.10					
	Shell	12	66.7	1.83	3.5	0.26					
2006	Byers	6	74.7	3.61	5.5	0.89					
	Chelatna	19	50.8	1.92	1.7	0.17					
	Hewitt	17	54.0	2.89	2.2	0.25	47	71.6	0.52	4.4	0.10
	Judd	105	53.8	0.50	2.1	0.05	74	66.0	0.68	3.7	0.07
	Larson	8	62.4	2.78	2.9	0.40					
	Shell	7	73.7	3.88	5.2	0.91					
	Stephan	4	83.5	5.39	8.2	1.68					
2007	Byers	0									
	Chelatna	82	68.5	1.43	4.0	0.23	1	82.0		6.5	
	Hewitt	16	43.9	3.21	1.1	0.22					
	Judd	104	47.6	1.01	1.3	0.07					
	Larson	5	51.6	4.17	1.7	0.37	3	78.0	3.79	5.2	0.85
	Shell	0									
	Stephan	4	74.8	3.84	5.2	1.00					
2008	Chelatna	109	45.6	3.26	1.34	1.1					
	Judd	308	37.6	2.19	0.7	0.55	7	64.6	2.44	3.2	0.93

Table 5.–Weight (W) and lengths (L) of Chinook, coho, lake trout, whitefish, stickleback, and sculpin from midwater trawl catches, 2005–2008.

		Chinook					Coho					Lake Trout					Whitefish				
Lake	Year	*n*	l (mm)	SE	w (g)	SE	*n*	l (mm)	SE	w (g)	SE	*n*	l (mm)	SE	w (g)	SE	*n*	l (mm)	SE	w (g)	SE
Chelatna	2005																76	43.1	0.81	0.8	0.06
Hewitt	2005																				
Judd	2005																				
Larson	2005						1	76		5.6											
Shell	2005																				
Byers	2006						1	67		4.1		1	64		2.4						
Chelatna	2006																				
Hewitt	2006																				
Judd	2006																				
Larson	2006						1	100		14.2											
Shell	2006																				
Stephan	2006						1	111		19.1											
Byers	2007																				
Chelatna	2007																48	43.8	0.97	0.9	0.06
Hewitt	2007																				
Judd	2007																				
Larson	2007																				
Shell	2007						1	64		2.7											
Stephan	2007	2	43	5	0.9	0.3	2	111.5	7.5	17.0	3.05										
Chelatna	2008																5	37.6	1.5	0.6	0.086
Judd	2008																				

-continued-

Table 5.–Page 2 of 2.

		Stickleback					Sculpin				
Lake	Year	*n*	l (mm)	SE	w (g)	SE	*n*	l(mm)	SE	w (g)	SE
Chelatna	2005						20	33.5	1.66	0.6	0.09
Hewitt	2005	100	30.5	0.63	0.3	0.02					
Judd	2005	21	37.6	1.8	0.6	0.09					
Larson	2005	101	29.8	0.73	0.4	0.06					
Shell	2005	99	36.9	0.65	0.6	0.03	1	39.0		0.8	
Byers	2006	25	34.0	1.88	0.5	0.11					
Chelatna	2006										
Hewitt	2006	102	32.4	0.7	0.4	0.02					
Judd	2006	108	26.5	0.86	0.3	0.03					
Larson	2006	100	31.9	0.58	0.4	0.02					
Shell	2006										
Stephan	2006										
Byers	2007	200	38.9	0.38	0.5	0.02					
Chelatna	2007										
Hewitt	2007	247	28.5	0.33	0.2	0.01					
Judd	2007	12	29.5	2.64	0.4	0.10					
Larson	2007	199	30.8	0.36	0.3	0.01	1	23.0		0.1	
Shell	2007	200	30.8	0.24	0.2	0.01	19	28.4	2.46	0.4	0.16
Stephan	2007						107	29.4	0.89	0.5	0.07
Chelatna	2008										
Judd	2008	44	36.8	1.30	0.7	0.08					

Table 6.–Population estimates of non-sockeye salmon targets based on midwater trawl apportionment, 2005–2008.

	Chinook	SE	Coho	SE	Lake Trout	SE	Whitefish	SE	Stickleback	SE	Sculpin	SE	other	SE
2005														
Chelatna							647,287	68,121			170,339	17,927		
Hewitt									18,540,119	2,829,518				
Judd									64,287	13,856				
Larson			2,064	313					1,927,994	292,805				
Shell									1,891,080	217,211	19,297	2,216		
2006														
Byers			5,838	1,044	5,838	2,240			145,940	26,105	5,838	1,044		
Chelatna														
Hewitt									12,291,141	2,365351				
Judd									289,717	76,600				
Larson			5,194	741					1,017,995	145,284				
Shell									1,446,769	139,490				
Stephan			16,419	8,027										
2007														
Byers									321,437	74,422	1,241	287		
Chelatna							457,440	71,600						
Hewitt									9,645,621	1,035,898	21,060	2,262		
Judd									125,381	21,962				
Larson									2,649,998	627,019	3,008	712		
Shell			1,364	423					3,192,360	990,556	27,273	8,463		
Stephan	12,836	7,569	12,836	7,569							776,573	457,943	6,418	3,785
2008														
Chelatna							66,017	16,886						
Judd									19,593	3,845				

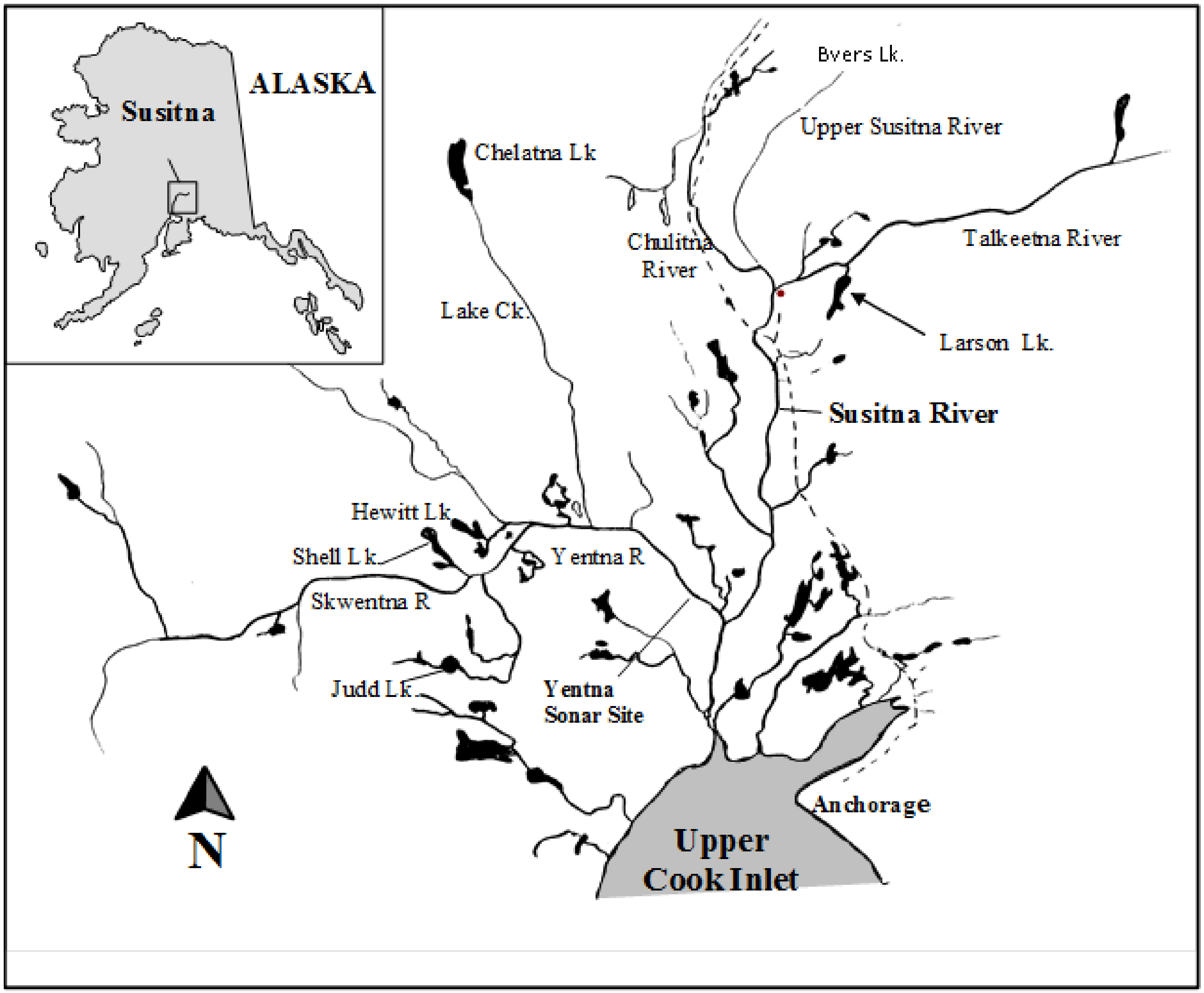

Figure 1.–Map of Susitna River drainage lakes.

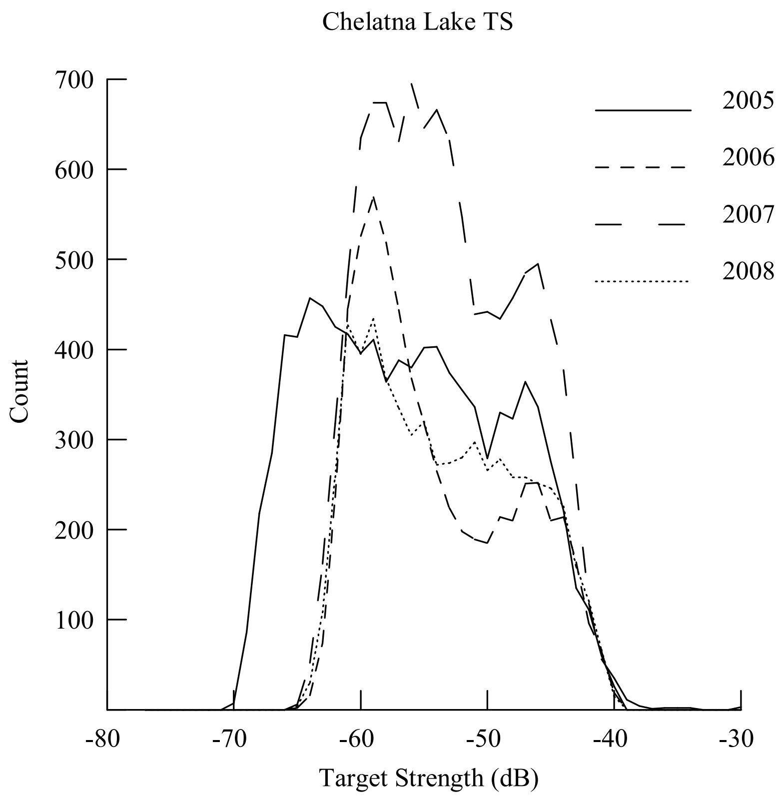

Figure 2.–Chelatna Lake target strength (TS) distributions, 2005–2008.

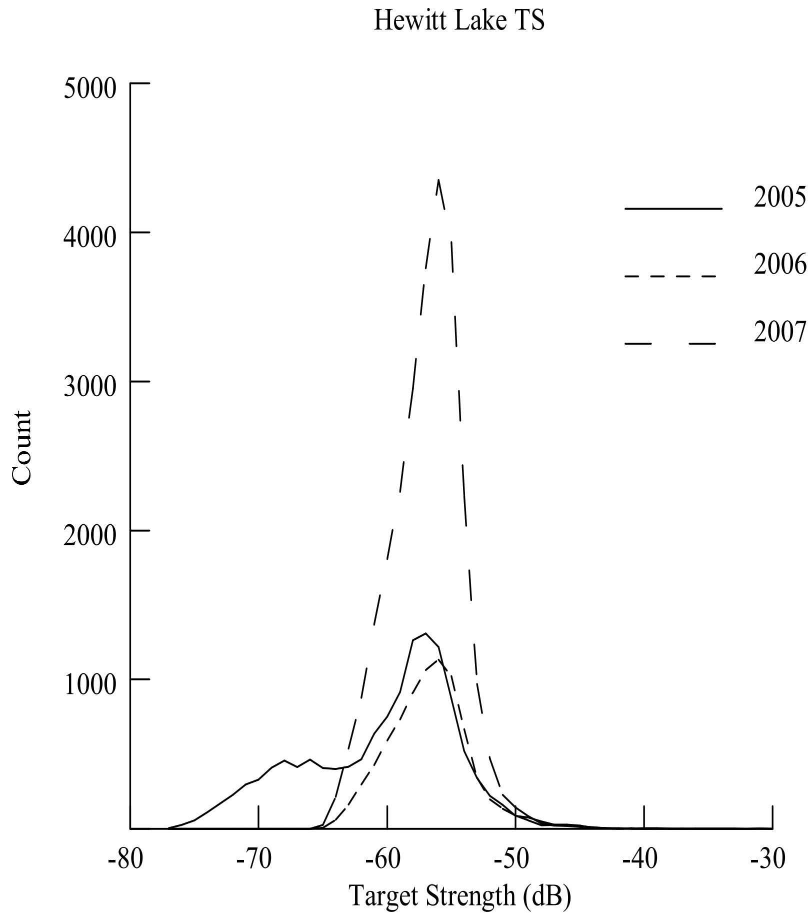

Figure 3.–Hewitt Lake target strength (TS) distributions, 2005–2007.

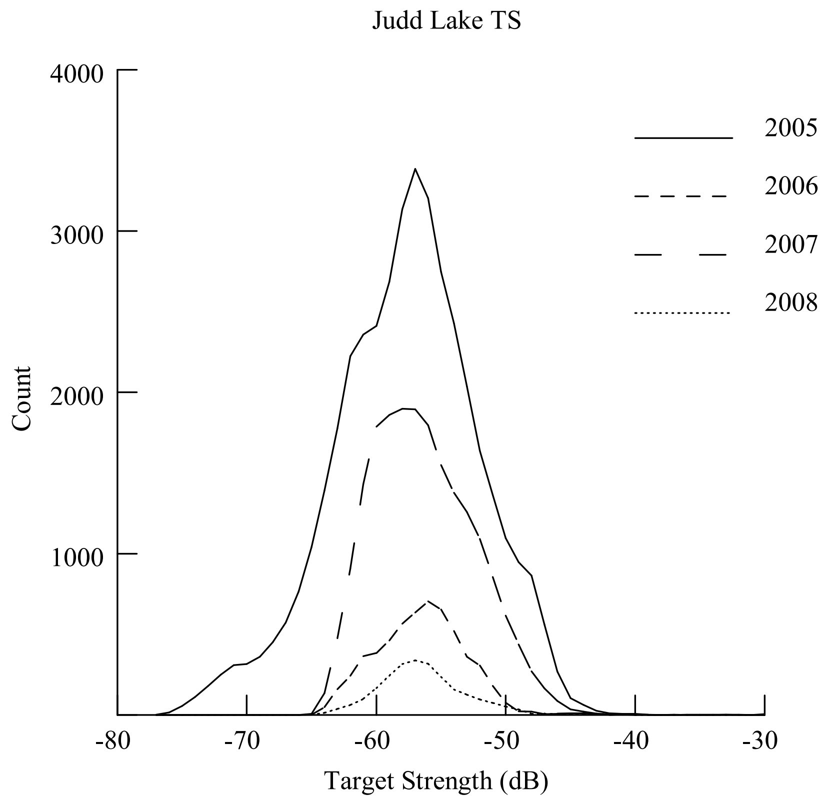

Figure 4.–Judd Lake target strength (TS) distributions, 2005–2008.

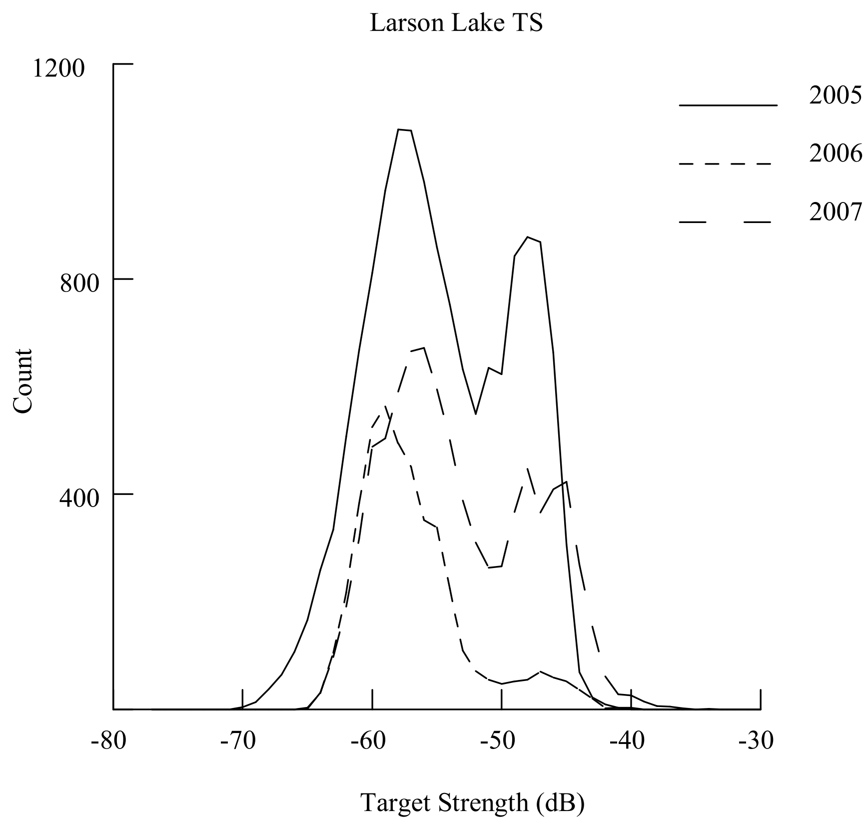

Figure 5.–Larson Lake target strength (TS) distributions, 2005–2007.

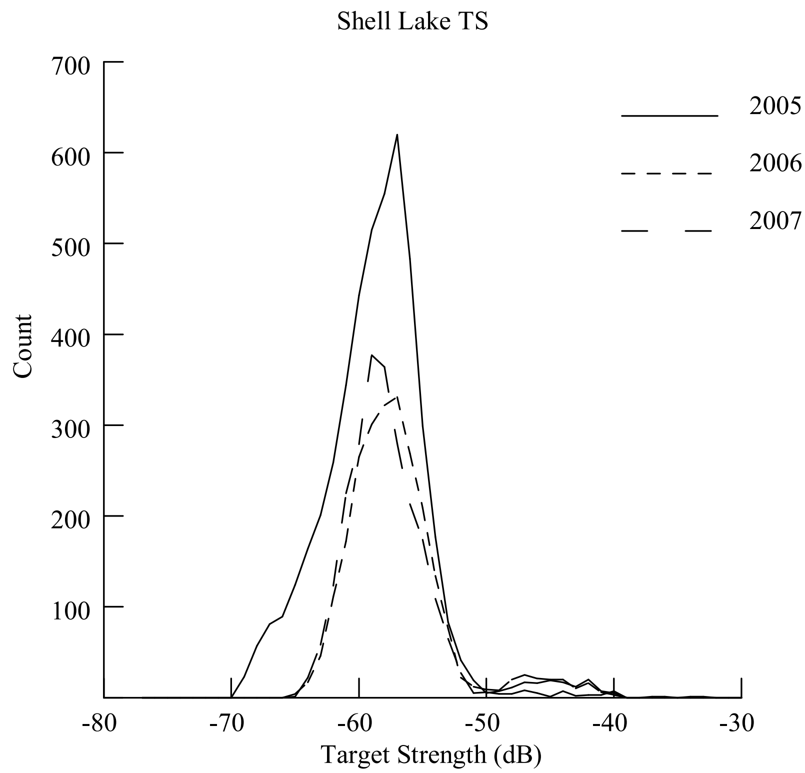

Figure 6.–Shell Lake target strength (TS) distributions, 2005–2007.

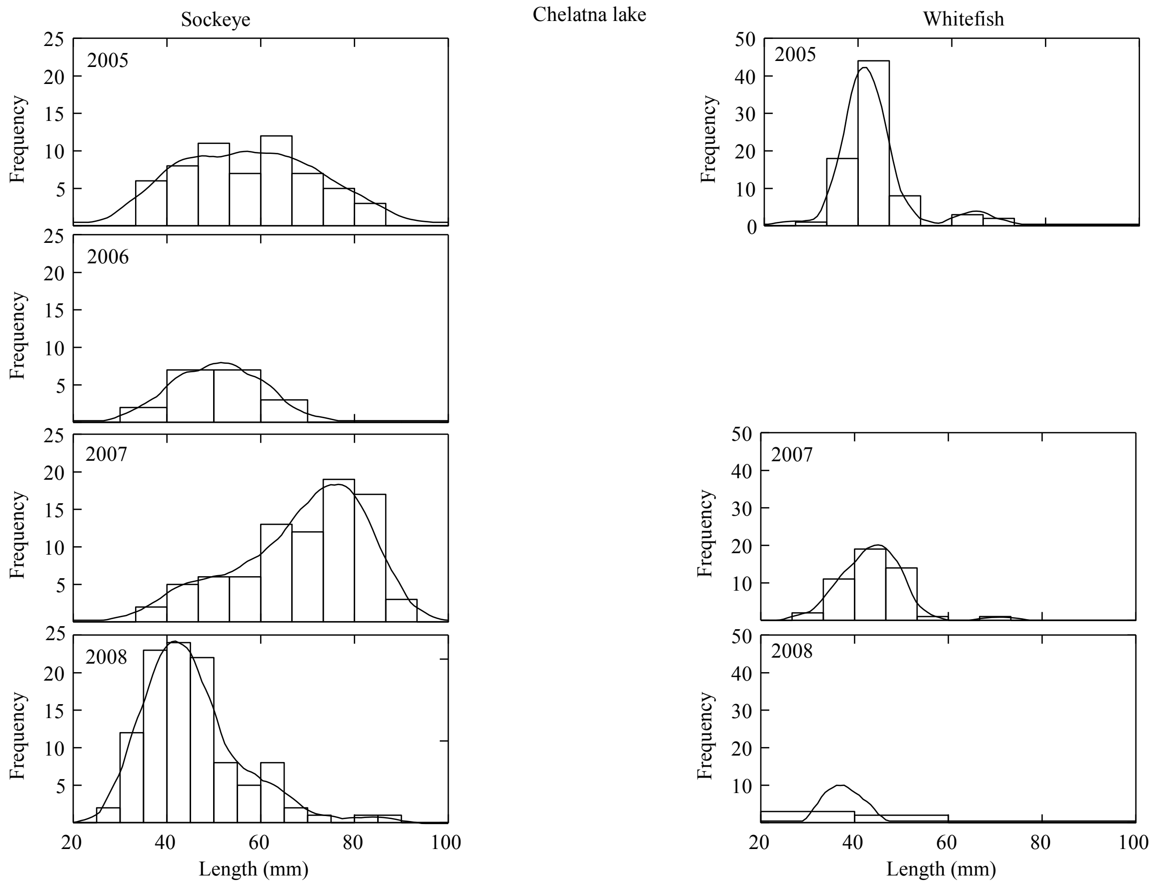

Figure 7.–Chelatna Lake length frequency histograms for juvenile sockeye salmon and whitefish.

Note: Curved line is a non-parametic (kernel) density function. No whitefish were captured in 2006.

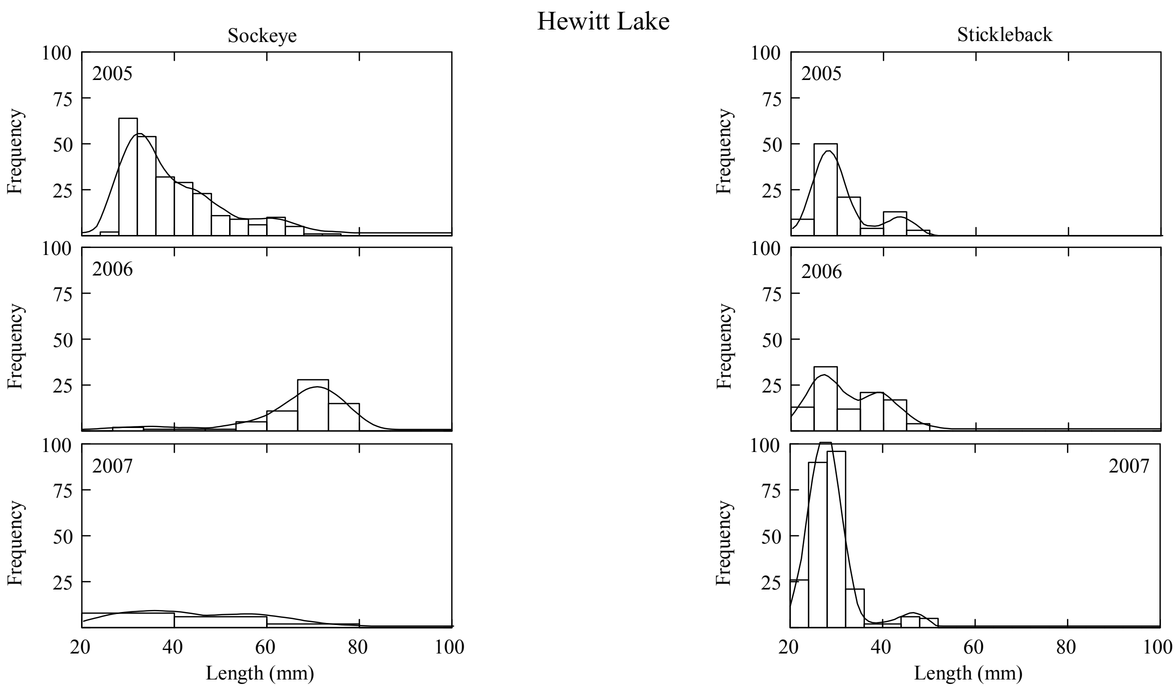

Figure 8.–Hewitt Lake length frequency histograms for juvenile sockeye salmon and threespine stickleback.

Note: Curved line is a non-parametic (kernel) density function.

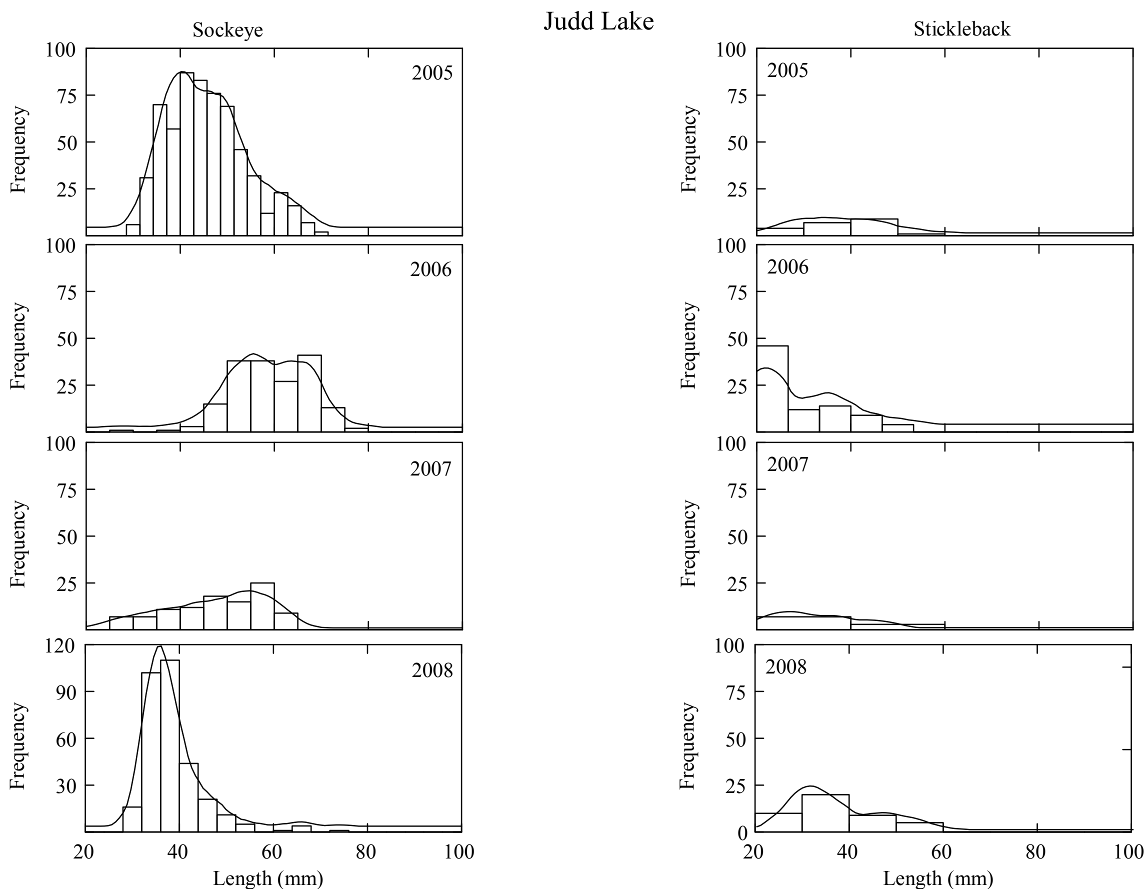

Figure 9.–Judd Lake length frequency histograms for juvenile sockeye salmon and threespine stickleback.

Note: Curved line is a non-parametic (kernel) density function.

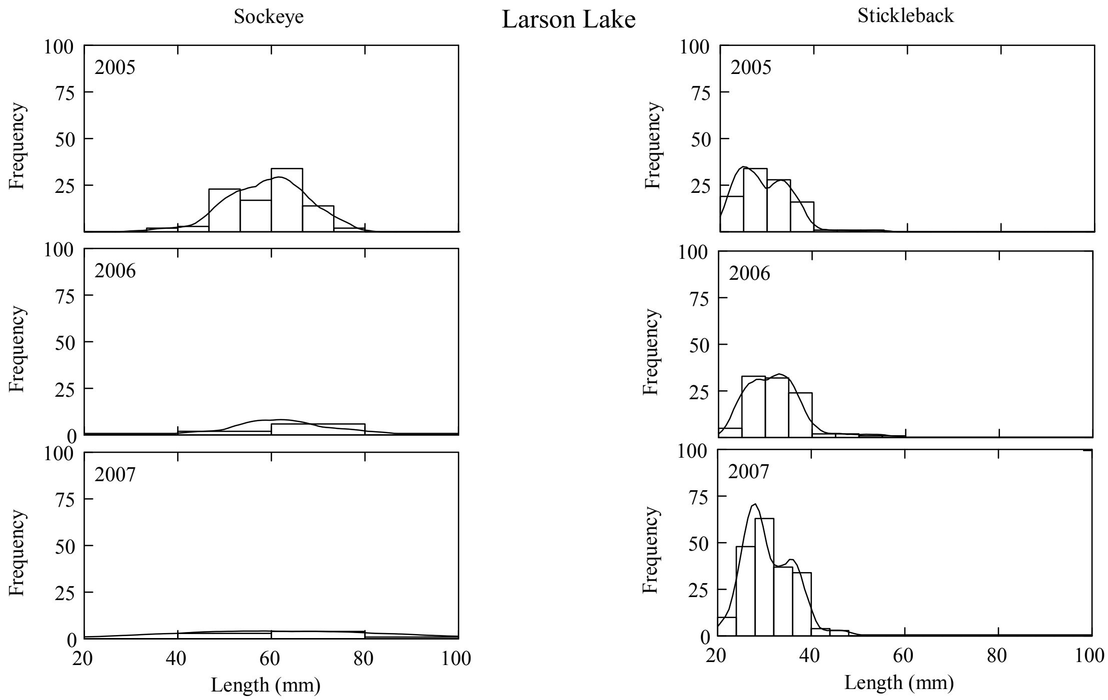

Figure 10.–Larson Lake length frequency histograms for juvenile sockeye salmon and threespine stickleback.

Note: Curved line is a non-parametic (kernel) density function.

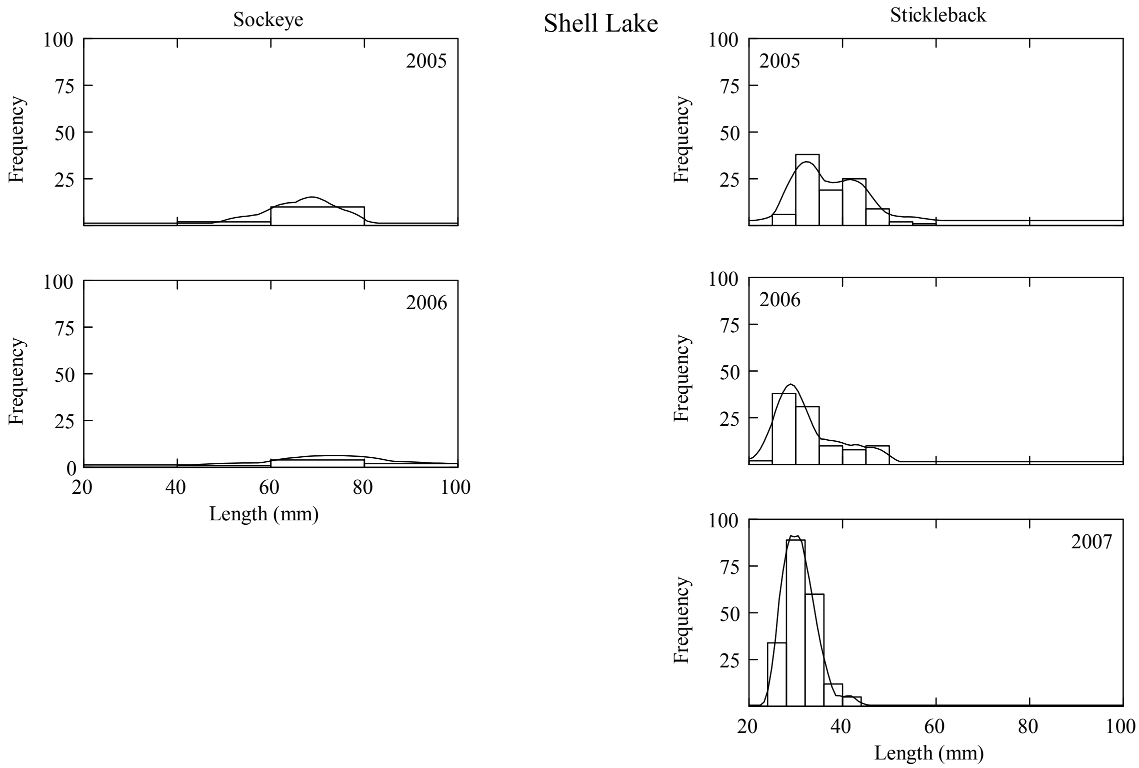

Figure 11.–Shell Lake length frequency histograms for juvenile sockeye salmon and threespine stickleback.

Note: Curved line is a non-parametic (kernel) density function. No juvenile sockeye salmon were captured in 2007.

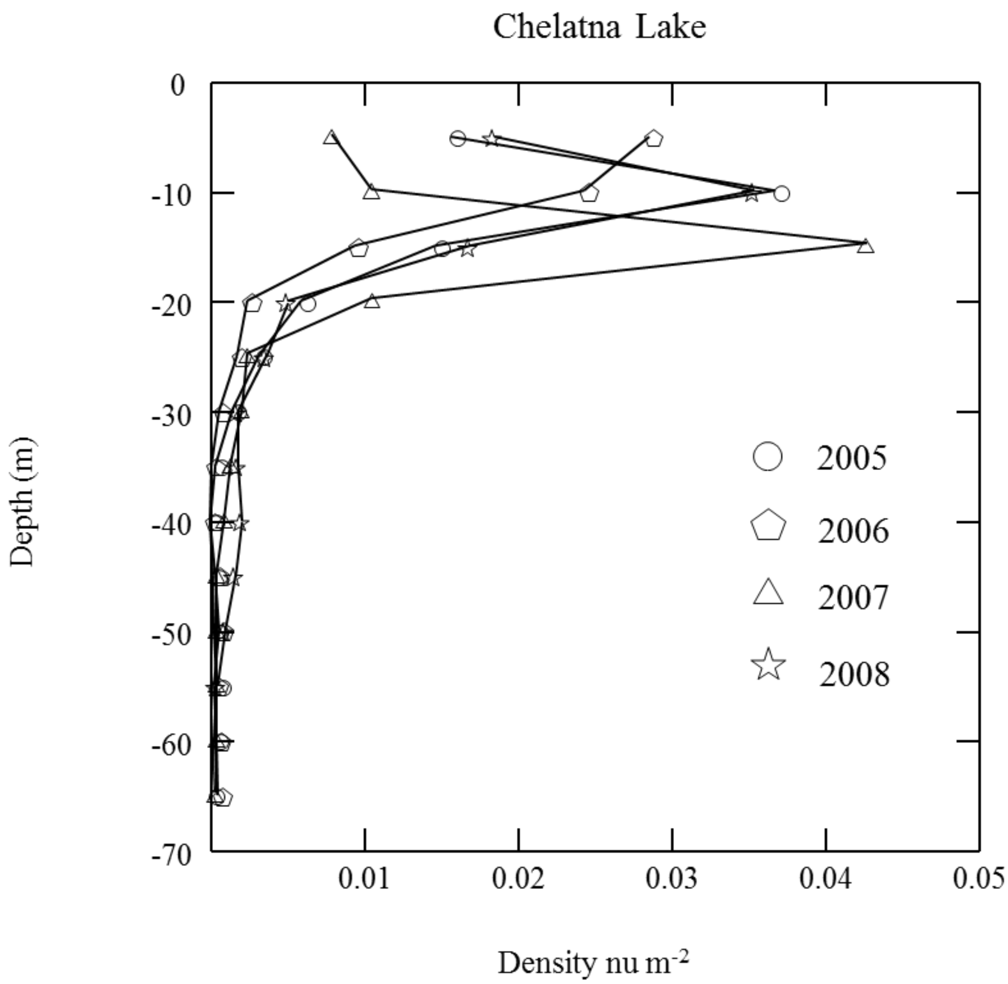

Figure 12.–Chelatna Lake density (number $^{-2}$) of all pelagic fish targets by depth (m).

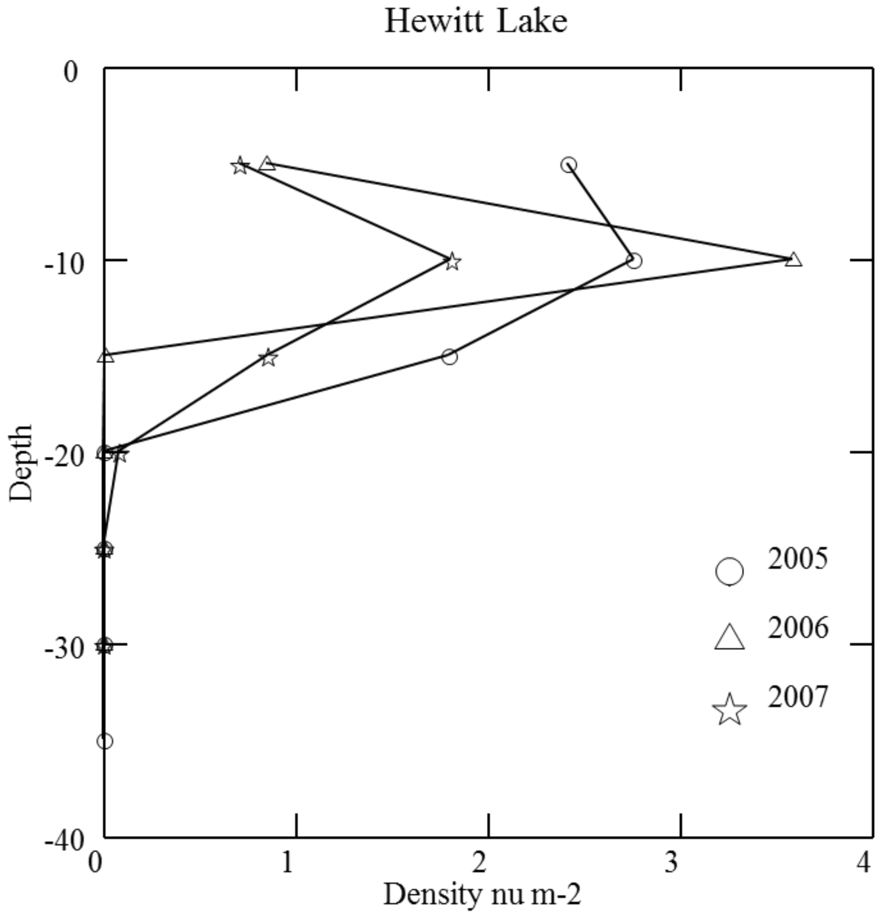

Figure 13.–Hewitt Lake density (number $^{-2}$) of all pelagic fish targets by depth (m).

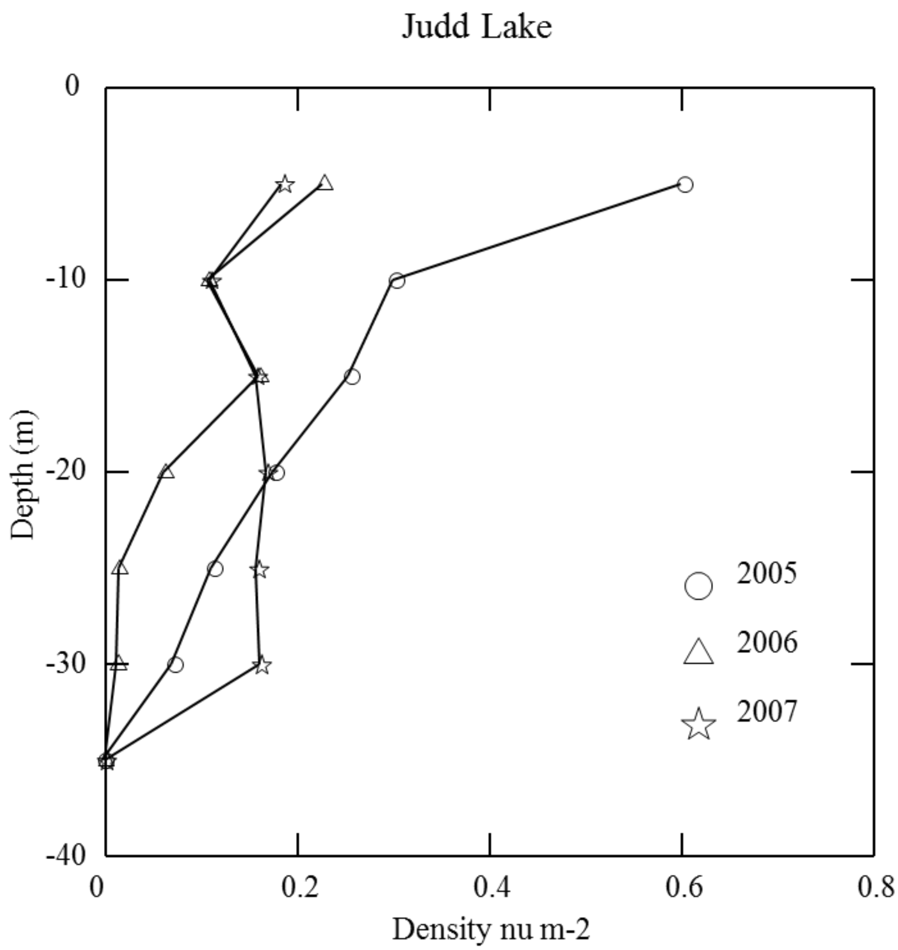

Figure 14.–Judd Lake density (number $^{-2}$) of all pelagic fish targets by depth (m).

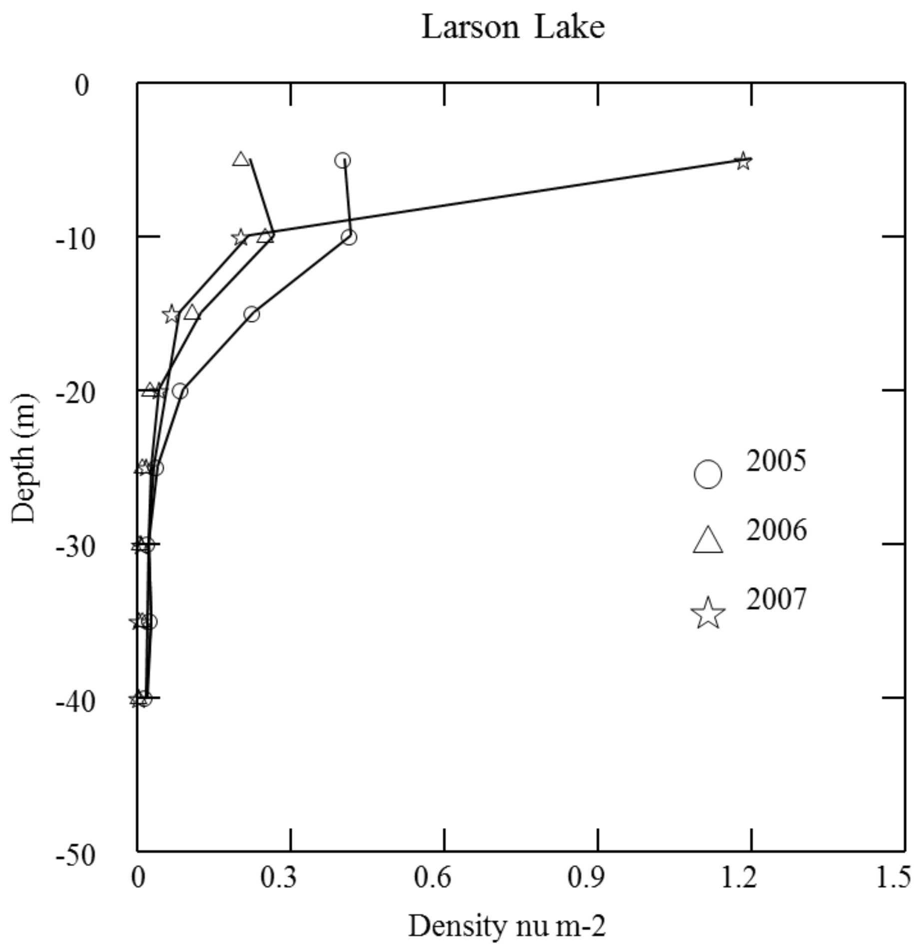

Figure 15.–Larson Lake density (number $^{-2}$) of all pelagic fish targets by depth (m).

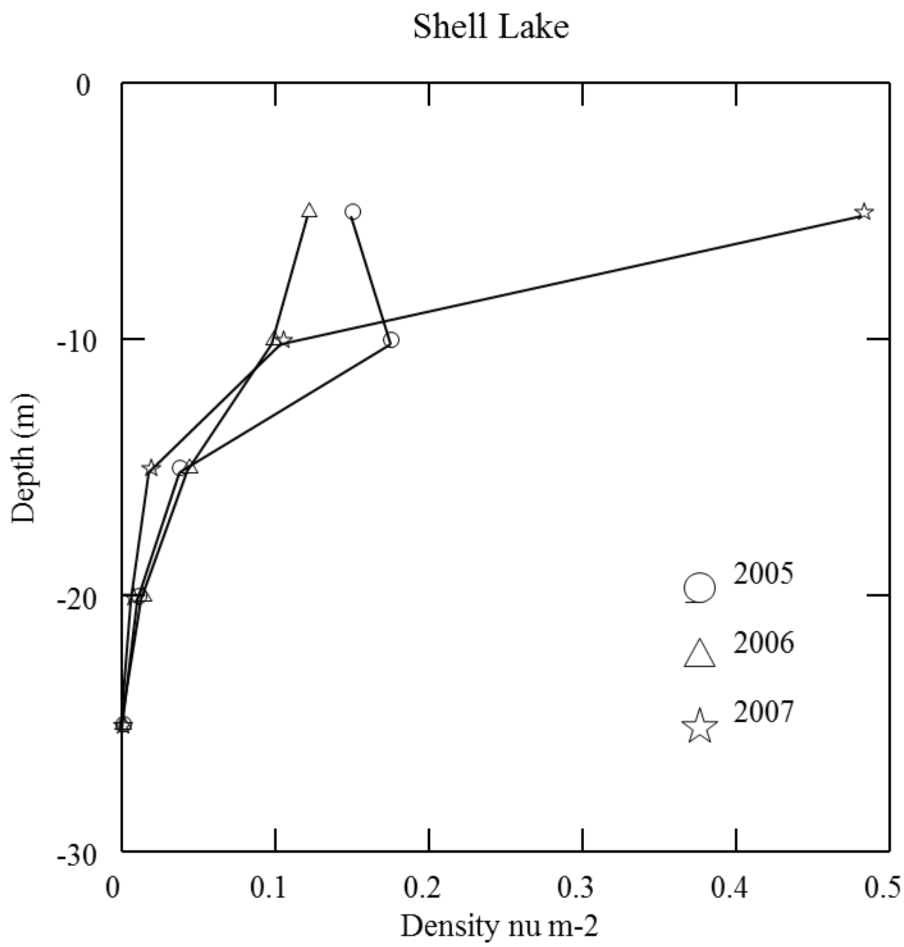

Figure 16.–Shell Lake density (number $^{-2}$) of all pelagic fish targets by depth (m).

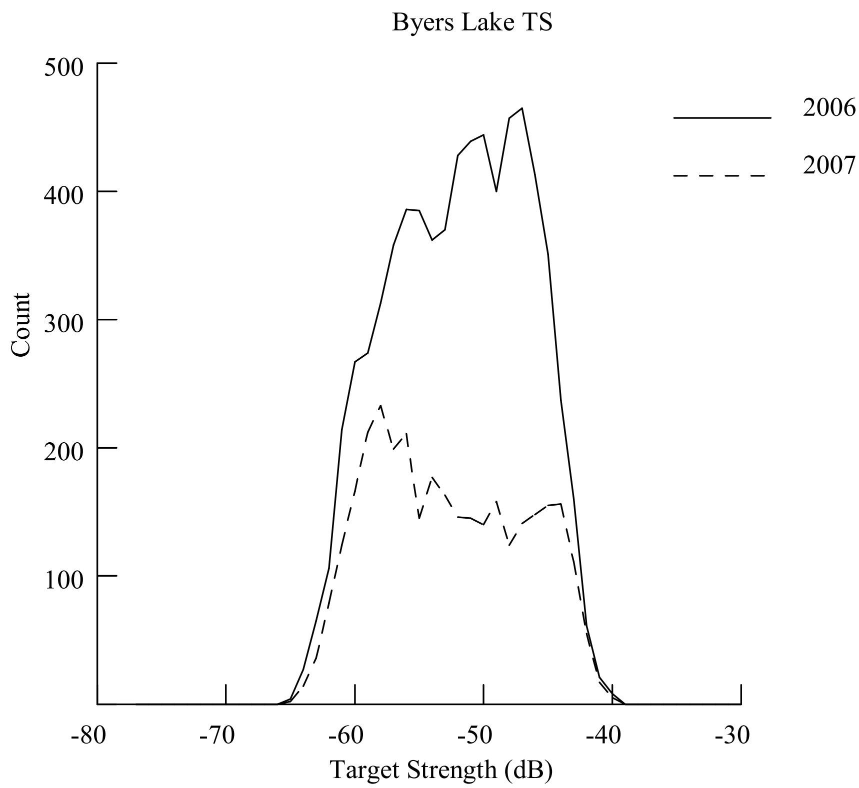

Figure 17.–Byers Lake target strength (TS) distributions, 2006–2007.

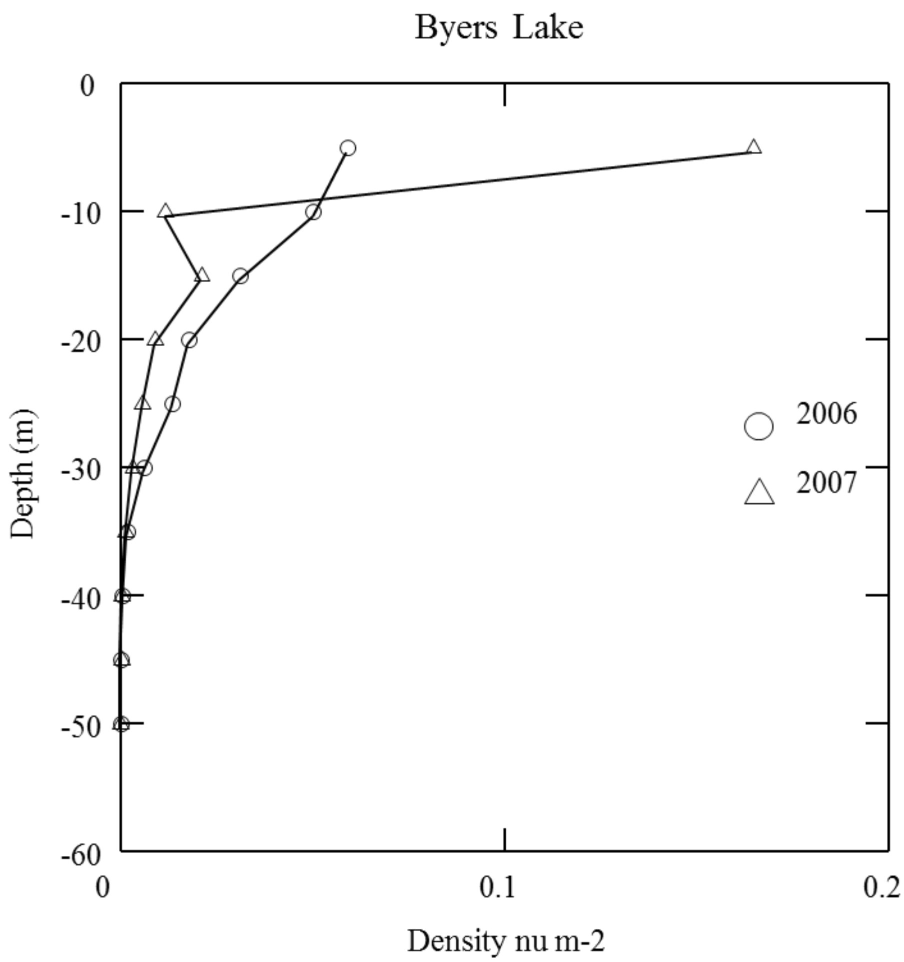

Figure 18.–Byers Lake density (number $^{-2}$) of all pelagic fish targets by depth (m).

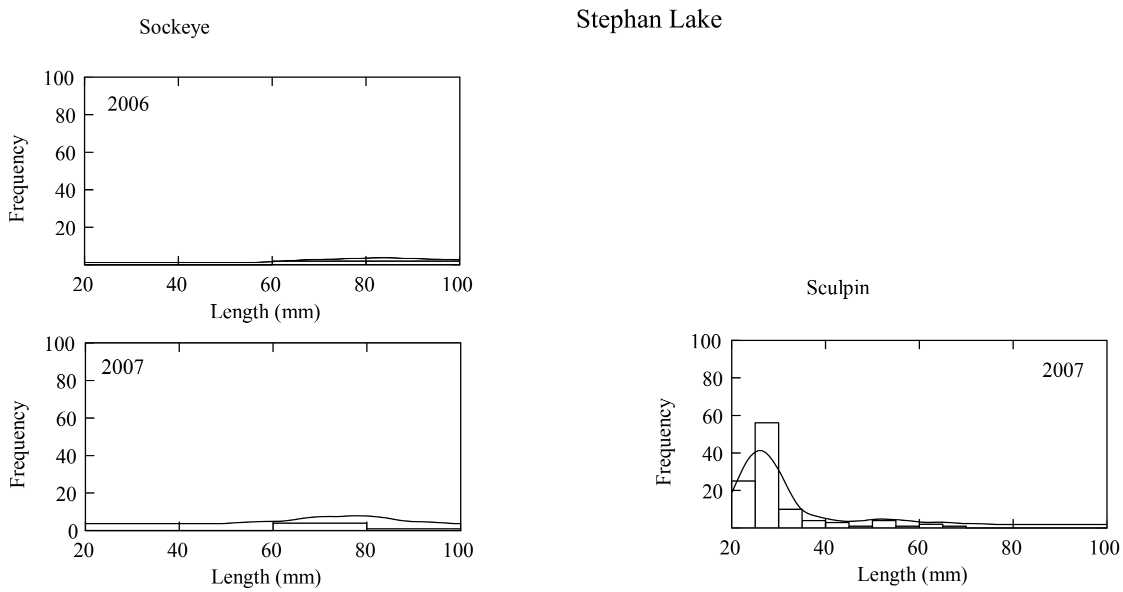

Figure 19.–Stephan Lake length frequency histograms for juvenile sockeye salmon and sculpin.

Note: Curved line is a non-parametic (kernel) density function. Sculpin were not captured in 2006.

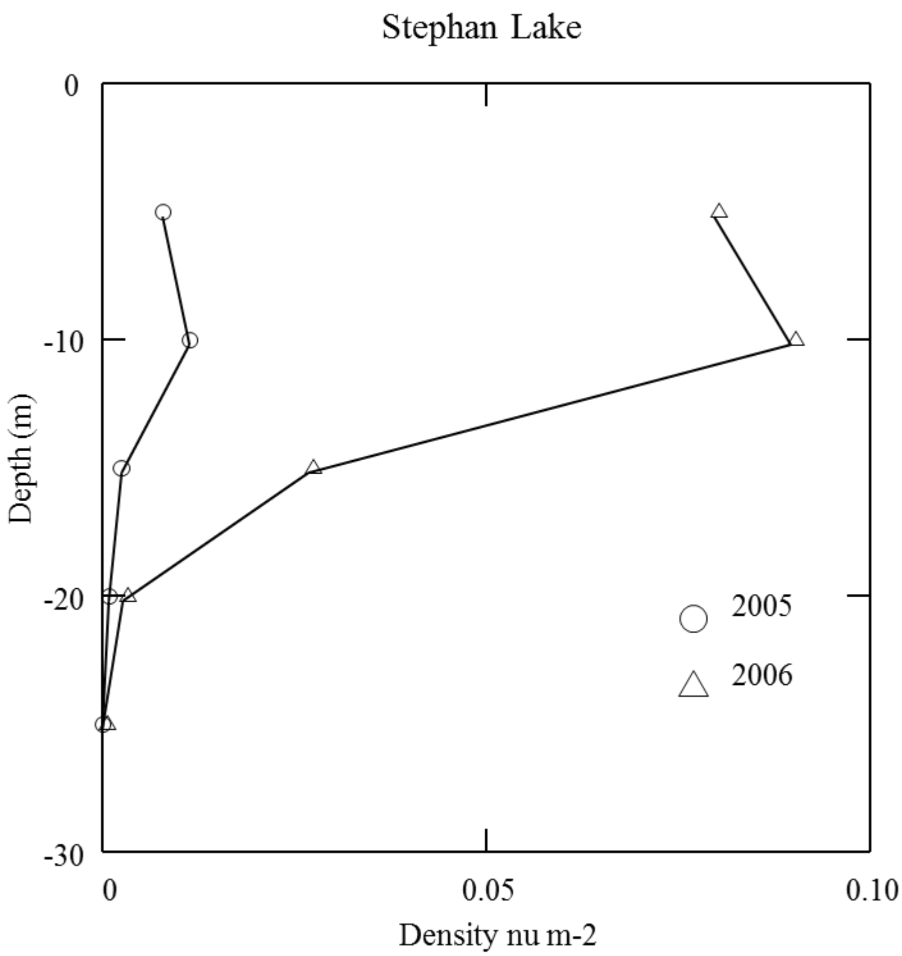

Figure 20.–Stephan Lake density (number $^{-2}$) of all pelagic fish targets by depth (m).

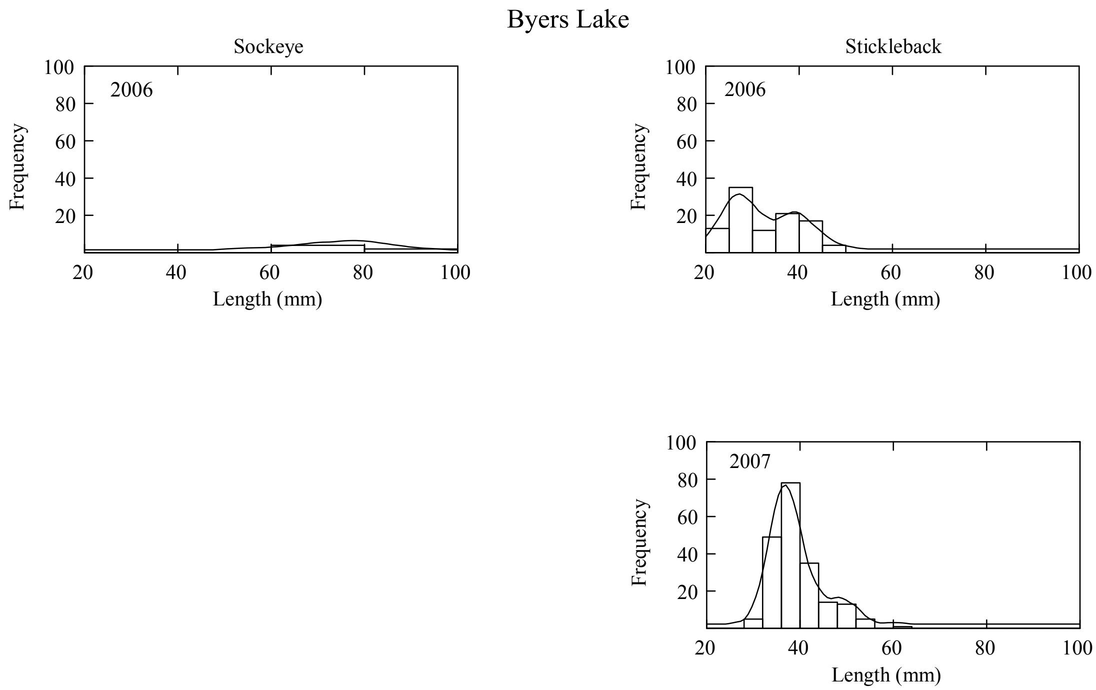

Figure 21.–Byers Lake length frequency histograms for juvenile sockeye salmon and threespine stickleback.

Note: Curved line is a non-parametic (kernel) density function. No juvenile sockeye were captured in 2007.

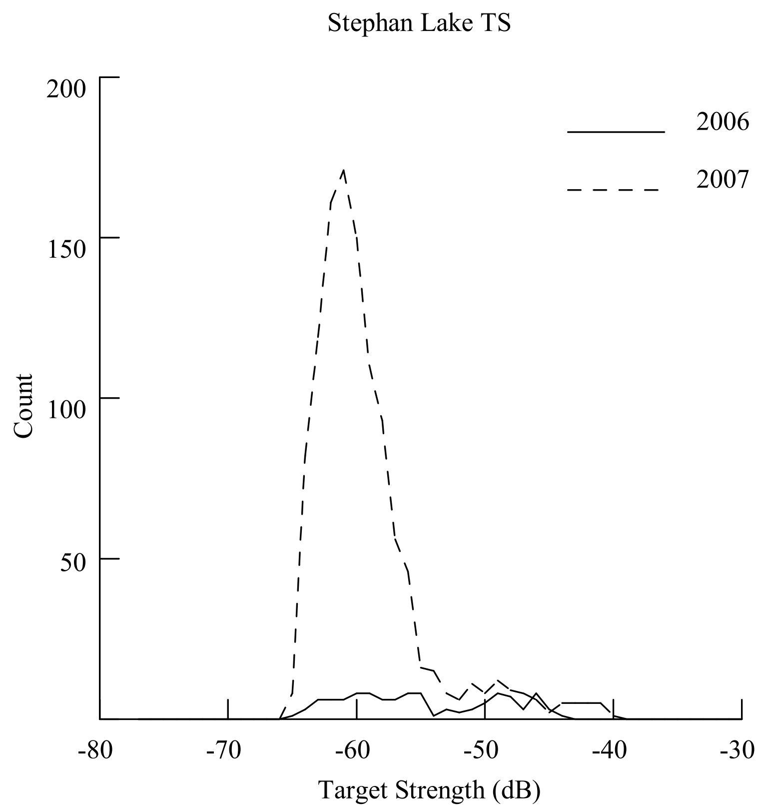

Figure 22.–Stephan Lake target strength (TS) distributions, 2006–2007.

APPENDIX A

Appendix A1.–Acoustic data collection parameters for Susitna drainage lake surveys, 2005–2008.

Parameter	Year	Byers	Chelatna	Hewitt	Judd	Larson	Shell	Stephan
Frequency (kHz)	2005		208	208	208	208	208	
Beam size (degree)			6.6 Circular	6.6 Circular	6.6 Circular	6.6 Circular	6.6 Circular	
Mode			Split	Split	Split	Split	Split	
Pulse duration (ms)			0.4	0.2	0.2	0.2	0.2	
Sample range (m)			1 to 65	1 to 35	1 to 42	1 to 42	1 to 32	
Water temperature (C)			8.5	11	8.8	9.6	11	
Transducer depth (m)			1	1	1	1	1	
Threshold (dB)			-77	-77	-77	-77	-77	
Ping rate (pps)			4	4	4	4	4	
Frequency (kHz)	2006	208	208	208	208	208	208	208
Beam size (degree)		6.6 Circular	6.6 Circular	6.6 Circular	6.6 Circular	6.6 Circular	6.6 Circular	6.6 Circular
Mode		Split	Split	Split	Split	Split	Split	Split
Pulse duration (ms)		0.2	0.2	0.2	0.2	0.2	0.2	0.2
Sample range (m)		1 to 60	1 to 65	1 to 35	1 to 42	1 to 42	1 to 32	1 to 30
Water temperature (C)		9	8.5	11	8.8	9.6	11	10
Transducer depth (m)		1	1	1	1	1	1	1
Threshold (dB)		-65	-65	-65	-65	-65	-65	-65
Ping rate (pps)		4	4	4	4	4	4	4
Frequency (kHz)	2007	208	208	208	208	208	208	208
Beam size (degree)		6.6 Circular	6.6 Circular	6.6 Circular	6.6 Circular	6.6 Circular	6.6 Circular	6.6 Circular
Mode		Split	Split	Split	Split	Split	Split	Split
Pulse duration (ms)		0.2	0.2	0.2	0.2	0.2	0.2	0.2
Sample range (m)		1 to 60	1 to 65	1 to 35	1 to 42	1 to 42	1 to 32	1 to 30
Water temperature (C)		9.5	9	11	9.4	11.9	11.9	10
Transducer depth (m)		1	1	1	1	1	1	1
Threshold (dB)		-65	-65	-65	-65	-65	-65	-65
Ping rate (pps)		4	4	4	4	4	4	4
Frequency (kHz)	2008		208		208			
Beam size (degree)			6.6 Circular		6.6 Circular			
Mode			Split		Split			
Pulse duration (ms)			0.2		0.2			
Sample range (m)			1 to 65		1 to 42			
Water temperature (C)			9.6		10			
Transducer depth (m)			1		1			
Threshold (dB)			-65		-65			
Ping rate (pps)			4		4			

Appendix A2.–Byers Lake target strengths by depth and year.

Depth (m)	2006			2007		
	Number of targets	σ	TS	Number of targets	σ	TS
1	2	1.93×10^{-6}	-57.1	15	1.37×10^{-6}	-58.6
2	9	5.74×10^{-6}	-52.4	33	2.31×10^{-6}	-56.4
3	31	6.66×10^{-6}	-51.8	26	3.34×10^{-6}	-54.8
4	53	6.13×10^{-6}	-52.1	27	2.48×10^{-6}	-56.1
5	86	8.18×10^{-6}	-50.9	17	1.95×10^{-6}	-57.1
6	111	9.75×10^{-6}	-50.1	17	4.50×10^{-6}	-53.5
7	123	1.11×10^{-6}	-49.6	36	1.24×10^{-5}	-49.1
8	164	1.09×10^{-6}	-49.6	46	6.03×10^{-6}	-52.2
9	226	1.07×10^{-5}	-49.7	45	8.41×10^{-6}	-50.8
10	223	1.30×10^{-5}	-48.8	111	7.99×10^{-6}	-51.0
11	210	1.07×10^{-5}	-49.7	191	9.53×10^{-6}	-50.2
12	249	1.08×10^{-5}	-49.7	143	8.77×10^{-6}	-50.6
13	259	1.08×10^{-5}	-49.7	145	1.18×10^{-5}	-49.3
14	226	9.58×10^{-6}	-50.2	137	1.27×10^{-5}	-49.0
15	280	8.24×10^{-6}	-50.8	164	1.14×10^{-5}	-49.4
16	270	1.13×10^{-5}	-49.5	177	1.01×10^{-6}	-50.0
17	250	1.32×10^{-5}	-48.8	115	1.07×10^{-5}	-49.7
18	278	1.31×10^{-5}	-48.8	111	1.20×10^{-5}	-49.2
19	357	1.35×10^{-5}	-48.7	137	1.31×10^{-5}	-48.8
20	279	1.17×10^{-5}	-49.3	118	1.13×10^{-5}	-49.5
21	338	1.33×10^{-5}	-48.8	102	1.28×10^{-5}	-48.9
22	356	1.54×10^{-5}	-48.1	118	1.65×10^{-5}	-47.8
23	305	1.70×10^{-5}	-47.7	111	1.35×10^{-5}	-48.7
24	320	1.20×10^{-5}	-49.2	118	1.39×10^{-5}	-48.6
25	285	1.07×10^{-5}	-49.7	135	1.91×10^{-5}	-47.2
26	256	1.38×10^{-5}	-48.6	128	1.44×10^{-5}	-48.4
27	237	1.39×10^{-5}	-48.6	83	1.02×10^{-5}	-49.9
28	201	1.47×10^{-5}	-48.3	141	1.29×10^{-5}	-48.9
29	192	1.20×10^{-5}	-49.2	86	1.45×10^{-5}	-48.4
30	185	1.35×10^{-5}	-48.7	61	1.20×10^{-5}	-49.2
31	96	9.79×10^{-6}	-50.1	102	1.97×10^{-5}	-47.1
32	110	9.77×10^{-6}	-50.1	54	1.16×10^{-5}	-49.3
33	105	1.58×10^{-5}	-48.0	51	2.12×10^{-5}	-46.7
34	91	1.16×10^{-5}	-49.4	20	9.98×10^{-6}	-50.0
35	53	1.41×10^{-5}	-48.5	29	7.22×10^{-6}	-51.4
36	51	1.29×10^{-5}	-48.9	30	1.93×10^{-5}	-47.1
37	20	8.24×10^{-6}	-50.8			
38	19	9.34×10^{-6}	-50.3	13	1.37×10^{-5}	-48.6
39	13	6.46×10^{-6}	-51.9	9	1.72×10^{-5}	-47.7
40	31	7.82×10^{-6}	-51.1	13	1.48×10^{-5}	-48.3
41	8	1.25×10^{-5}	-49.0	3	2.19×10^{-6}	-56.6
42	4	1.57×10^{-6}	-58.0	7	1.27×10^{-5}	-49.0
43	14	4.39×10^{-6}	-53.6	10	7.15×10^{-6}	-51.5
44	1	8.61×10^{-7}	-60.7	15	3.23×10^{-5}	-44.9
46	7	3.79×10^{-6}	-54.2	12	1.23×10^{-5}	-49.1
47	21	3.74×10^{-6}	-54.3			
48	4	9.23×10^{-6}	-50.3			
50	5	6.69×10^{-6}	-51.7			
51	1	9.97×10^{-7}	-60.0			
Grand total	7015	1.21×10^{-5}	-49.2	3262	1.22×10^{-5}	-49.1

Appendix A3.–Chelatna Lake target strengths by year and by depth.

Depth (m)	2005 Number of targets	2005 σ	2005 TS	2006 number of targets	2006 σ	2006 TS	2007 Number of targets	2007 σ	2007 TSs
1	1	6.25×10^{-7}	-62.0						
2	4	5.78×10^{-7}	-62.4	4	1.16×10^{-5}	-49.4	4	9.51×10^{-6}	-50.2
3	13	3.19×10^{-6}	-55.0	9	3.35×10^{-6}	-54.7	7	3.44×10^{-6}	-54.6
4	37	7.30×10^{-6}	-51.4	13	1.66×10^{-6}	-57.8	7	9.04×10^{-6}	-50.4
5	70	7.83×10^{-6}	-51.1	35	5.34×10^{-6}	-52.7	19	1.24×10^{-5}	-49.1
6	106	8.71×10^{-6}	-50.6	56	8.18×10^{-6}	-50.9	39	5.30×10^{-6}	-52.8
7	174	9.06×10^{-6}	-50.4	84	1.08×10^{-5}	-49.7	61	7.61×10^{-6}	-51.2
8	202	7.35×10^{-6}	-51.3	94	8.52×10^{-6}	-50.7	106	6.38×10^{-6}	-52.0
9	239	6.80×10^{-6}	-51.7	102	1.18×10^{-5}	-49.3	158	7.75×10^{-6}	-51.1
10	199	4.96×10^{-6}	-53.0	113	8.27×10^{-6}	-50.8	253	1.15×10^{-5}	-49.4
11	249	5.99×10^{-6}	-52.2	112	8.27×10^{-6}	-50.8	473	1.12×10^{-5}	-49.5
12	226	6.31×10^{-6}	-52.0	54	9.17×10^{-6}	-50.4	705	1.15×10^{-5}	-49.4
13	260	6.26×10^{-6}	-52.0	45	6.92×10^{-6}	-51.6	874	1.15×10^{-5}	-49.4
14	241	5.54×10^{-6}	-52.6	77	7.18×10^{-6}	-51.4	886	1.08×10^{-5}	-49.7
15	299	5.44×10^{-6}	-52.6	87	5.62×10^{-6}	-52.5	691	1.00×10^{-5}	-50.0
16	226	4.68×10^{-6}	-53.3	74	4.63×10^{-6}	-53.3	456	9.03×10^{-6}	-50.4
17	230	4.12×10^{-6}	-53.9	56	5.16×10^{-6}	-52.9	293	1.14×10^{-5}	-49.4
18	178	3.26×10^{-6}	-54.9	59	5.68×10^{-6}	-52.5	175	7.96×10^{-6}	-51.0
19	205	3.51×10^{-6}	-54.6	50	9.13×10^{-6}	-50.4	151	5.53×10^{-6}	-52.6
20	221	7.35×10^{-6}	-51.3	46	7.05×10^{-6}	-51.5	136	5.92×10^{-6}	-52.3
21	206	6.55×10^{-6}	-51.8	33	3.58×10^{-6}	-54.5	142	6.48×10^{-6}	-51.9
22	214	6.28×10^{-6}	-52.0	56	3.43×10^{-6}	-54.6	138	8.43×10^{-6}	-50.7
23	143	3.83×10^{-6}	-54.2	36	1.01×10^{-5}	-50.0	140	8.95×10^{-6}	-50.5
24	145	6.34×10^{-6}	-52.0	33	5.58×10^{-6}	-52.5	127	9.13×10^{-6}	-50.4
25	137	2.67×10^{-6}	-55.7	38	1.81×10^{-5}	-47.4	152	7.85×10^{-6}	-51.1
26	174	5.11×10^{-6}	-52.9	42	1.06×10^{-5}	-49.8	98	9.58×10^{-6}	-50.2
27	178	4.42×10^{-6}	-53.5	61	7.32×10^{-6}	-51.4	135	7041×10^{-6}	-51.3
28	200	8.00×10^{-6}	-51.0	55	1.36×10^{-5}	-48.7	170	1.16×10^{-5}	-49.4
29	199	5.02×10^{-6}	-53.0	28	1.76×10^{-5}	-47.5	163	1.04×10^{-5}	-49.8
30	207	9.81×10^{-6}	-50.1	36	1.47×10^{-5}	-48.3	149	1.14×10^{-5}	-49.4
31	150	7.72×10^{-6}	-51.1	31	3.64×10^{-6}	-54.4	94	4.70×10^{-6}	-53.3
32	196	6.88×10^{-6}	-51.6	25	1.52×10^{-5}	-48.2	100	1.14×10^{-5}	-49.4
33	116	7.17×10^{-6}	-51.4	34	1.33×10^{-5}	-48.8	118	7.77×10^{-6}	-51.1
34	114	5.32×10^{-6}	-52.7	26	1.60×10^{-5}	-48.0	136	1.75×10^{-5}	-47.6
35	134	4.26×10^{-6}	-53.7	13	3.15×10^{-6}	-55.0	107	1.53×10^{-5}	-48.1

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Appendix A3.–Page 2 of 3.

Depth (m)	2005 Number of targets	2005 σ	2005 TS	2006 Number of targets	2006 σ	2006 TS	2007 Number of targets	2007 σ	2007 TS
36	94	3.41×10^{-6}	-54.7	22	1.39×10^{-5}	-48.6	137	1.43×10^{-5}	-48.4
37	122	6.28×10^{-6}	-52.0	28	1.12×10^{-5}	-49.5	62	9.81×10^{-6}	-50.1
38	91	4.80×10^{-6}	-53.2	38	1.50×10^{-5}	-48.2	56	8.83×10^{-6}	-50.5
39	113	7.84×10^{-6}	-51.1	23	4.72×10^{-6}	-53.3	71	8.78×10^{-6}	-50.6
40	84	8.21×10^{-6}	-50.9	41	2.10×10^{-5}	-46.8	71	5.74×10^{-6}	-52.4
41	133	8.37×10^{-6}	-50.8	58	1.50×10^{-5}	-48.2	46	3.97×10^{-6}	-54.0
42	76	9.68×10^{-6}	-50.1	44	1.99×10^{-5}	-47.0	77	7.38×10^{-6}	-51.3
43	133	1.45×10^{-6}	-48.4	87	1.22×10^{-5}	-49.1	47	5.73×10^{-6}	-52.4
44	136	1.14×10^{-6}	-49.4	111	1.23×10^{-5}	-49.1	115	1.13×10^{-5}	-49.5
45	134	7.22×10^{-6}	-51.4	99	1.92×10^{-5}	-47.2	67	2.17×10^{-5}	-46.6
46	104	7.82×10^{-6}	-51.1	106	2.39×10^{-5}	-46.2	85	2.26×10^{-5}	-46.5
47	95	1.54×10^{-6}	-48.1	89	2.32×10^{-5}	-46.3	67	1.66×10^{-5}	-47.8
48	150	1.40×10^{-5}	-48.6	62	1.62×10^{-5}	-47.9	65	2.24×10^{-5}	-46.5
49	156	1.61×10^{-5}	-47.9	92	1.96×10^{-5}	-47.1	83	1.20×10^{-5}	-49.2
50	151	1.30×10^{-5}	-48.9	64	1.42×10^{-5}	-48.5	74	7.76×10^{-6}	-51.1
51	154	1.56×10^{-5}	-48.1	86	1.35×10^{-5}	-48.7	98	1.25×10^{-5}	-49.0
52	209	1.79×10^{-5}	-47.5	104	1.87×10^{-5}	-47.3	61	1.09×10^{-5}	-49.6
53	137	1.28×10^{-5}	-48.9	121	1.85×10^{-5}	-47.3	91	1.82×10^{-5}	-47.4
54	121	8.81×10^{-6}	-50.6	82	1.40×10^{-5}	-48.5	100	1.41×10^{-5}	-48.5
55	120	1.01×10^{-5}	-50.0	133	1.21×10^{-5}	-49.2	123	1.92×10^{-5}	-47.2
56	164	2.27×10^{-5}	-46.4	183	1.09×10^{-5}	-49.6	139	1.52×10^{-5}	-48.2
57	126	1.20×10^{-5}	-49.2	222	9.73×10^{-5}	-50.1	140	1.20×10^{-5}	-49.2
58	113	1.69×10^{-5}	-47.7	273	1.13×10^{-5}	-49.5	190	1.06×10^{-5}	-49.7
59	115	1.34×10^{-5}	-48.7	236	1.14×10^{-5}	-49.4	159	9.76×10^{-6}	-50.1
60	158	1.57×10^{-5}	-48.0	323	8.01×10^{-6}	-51.0	182	9.65×10^{-6}	-50.2
61	84	1.05×10^{-5}	-49.8	321	6.93×10^{-6}	-51.6	168	6.26 x 10-6	-52.0
62	74	2.04×10^{-5}	-46.9	386	8.23×10^{-6}	-50.8	210	1.09×10^{-5}	-49.6
63	75	1.14×10^{-5}	-49.4	537	8.28×10^{-6}	-50.8	243	6.96×10^{-6}	-51.6
64	113	1.91×10^{-5}	-47.2	506	7.15×10^{-6}	-51.5	284	1.08×10^{-5}	-49.7
65	14	1.62×10^{-5}	-47.9	80	6.25×10^{-6}	-52.0	53	1.28×10^{-5}	-48.9
Grand total	9,442	8.53×10^{-6}	-50.7	6,274	1.05×10^{-5}	-49.8	10,827	1.06×10^{-5}	-49.7

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Appendix A3.–Page 3 of 3.

Depth (m)	2008			depth (m)	2008		
	Number of targets	σ	TS		Number of targets	σ	TS
1	1	5.89×10^{-7}	-62.3	27	56	5.45×10^{-6}	-54.8
2	9	6.51×10^{-6}	-55.7	28	85	1.46×10^{-5}	-53.1
3	25	1.21×10^{-5}	-53.4	29	96	1.30×10^{-5}	-53.9
4	38	9.96×10^{-6}	-53.1	30	88	1.41×10^{-5}	-53.0
5	56	8.38×10^{-6}	-53.5	31	75	1.87×10^{-5}	-51.2
6	75	1.16×10^{-5}	-52.4	32	45	1.15×10^{-5}	-53.0
7	112	9.01×10^{-6}	-53.7	33	66	2.12×10^{-5}	-51.1
8	159	9.94×10^{-6}	-53.1	34	137	1.51×10^{-5}	-52.0
9	168	1.03×10^{-5}	-52.8	35	99	1.40×10^{-5}	-52.1
10	173	1.08×10^{-5}	-53.0	36	106	1.52×10^{-5}	-51.9
11	167	1.07×10^{-5}	-52.7	37	122	1.27×10^{-5}	-52.2
12	246	1.04×10^{-5}	-53.0	38	99	2.23×10^{-5}	-50.5
13	288	1.39×10^{-5}	-51.3	39	112	1.30×10^{-5}	-52.7
14	297	1.04×10^{-5}	-53.0	40	109	2.43×10^{-5}	-49.6
15	213	1.15×10^{-5}	-52.7	41	133	1.76×10^{-5}	-50.7
16	157	1.15×10^{-5}	-52.6	42	113	1.05×10^{-5}	-52.9
17	112	9.55×10^{-6}	-52.8	43	112	1.21×10^{-5}	-52.0
18	110	7.50×10^{-6}	-54.4	44	94	1.62×10^{-5}	-51.2
19	73	8.06×10^{-6}	-54.6	45	136	1.08×10^{-5}	-53.3
20	86	9.99×10^{-6}	-54.0	46	106	1.37×10^{-5}	-54.2
21	76	6.68×10^{-6}	-54.3	47	158	7.31×10^{-6}	-55.8
22	53	1.08×10^{-5}	-54.1	48	231	6.65×10^{-6}	-56.5
23	68	8.18×10^{-6}	-54.0	49	318	9.86×10^{-6}	-55.4
24	89	1.36×10^{-5}	-52.8	50	410	8.30×10^{-6}	-56.1
25	58	1.65×10^{-5}	-52.5	51	200	5.94×10^{-6}	-56.6
26	37	1.98×10^{-5}	-51.1	Grand Total	6,252	1.15×10^{-5}	-53.4

Appendix A4.–Hewitt Lake mean sigma, target strength by depth and year.

	2005			2006			2007		
Depth (m)	Number of targets	σ	TS	Number of targets	σ	TS	Number of targets	σ	TS
1	78	5.86×10^{-7}	-62.3	15	1.07×10^{-6}	-59.7	18	9.75×10^{-7}	-60.1
2	433	6.30×10^{-7}	-62.0	154	1.53×10^{-6}	-58.2	188	1.23×10^{-6}	-59.1
3	534	7.83×10^{-7}	-61.1	308	1.64×10^{-6}	-57.9	670	1.21×10^{-6}	-59.2
4	447	9.65×10^{-7}	-60.2	404	1.70×10^{-6}	-57.7	861	4.09×10^{-6}	-53.9
5	645	1.43×10^{-6}	-58.5	1072	2.03×10^{-6}	-56.9	976	1.68×10^{-6}	-57.8
6	1382	1.68×10^{-6}	-57.7	3367	3.08×10^{-6}	-55.1	1901	2.23×10^{-6}	-56.5
7	1730	1.84×10^{-6}	-57.4	2425	3.16×10^{-6}	-55.0	3591	2.53×10^{-6}	-56.0
8	1797	2.19×10^{-6}	-56.6	198	2.64×10^{-6}	-55.8	3254	2.68×10^{-6}	-55.7
9	1765	2.11×10^{-6}	-56.8	18	4.08×10^{-6}	-53.2	2801	2.62×10^{-6}	-55.8
10	1460	2.37×10^{-6}	-56.3	13	3.94×10^{-6}	-54.0	2279	2.72×10^{-6}	-55.6
11	1065	2.59×10^{-6}	-55.9	4	1.61×10^{-6}	-57.9	1805	2.79×10^{-6}	-55.5
12	765	2.65×10^{-6}	-55.8				1654	2.85×10^{-6}	-55.4
13	306	1.27×10^{-6}	-59.0				1590	2.75×10^{-6}	-55.6
14	64	3.91×10^{-7}	-64.1				1656	2.59×10^{-6}	-55.9
15	19	6.23×10^{-7}	-62.1	3	2.14×10^{-6}	-56.7	1533	2.58×10^{-6}	-55.9
16	6	2.36×10^{-7}	-66.3				963	2.57×10^{-6}	-55.9
17	3	1.03×10^{-5}	-49.9				458	2.45×10^{-6}	-56.1
18	12	2.08×10^{-7}	-66.8				106	2.28×10^{-6}	-56.4
19	5	1.37×10^{-7}	-68.6				16	1.39×10^{-6}	-58.6
22	3	2.21×10^{-7}	-66.6						
23	2	6.75×10^{-6}	-51.7						
25				5	4.35×10^{-6}	-53.6			
26	7	3.07×10^{-6}	-55.1						
27	2	7.52×10^{-8}	-71.2						
28	4	9.74×10^{-6}	-50.1						
29	2	4.52×10^{-7}	-63.4						
30	1	7.33×10^{-8}	-71.3						
Grand total	12537	1.92×10^{-6}	-57.2	7986	2.80×10^{-6}	-55.5	26320	2.58×10^{-6}	-55.9

Appendix A5.–Judd Lake mean sigma and target strength (TS) by depth and year.

	2005			2006			2007			2008		
Depth (m)	Number of targets	σ	TS	Number of targets	σ	TS	Number. of targets	σ	TS	Number of targets	σ	TS
1	25	2.20×10^{-6}	-56.6	1	2.02×10^{-6}	-56.9	6	1.29×10^{-6}	-58.9			
2	105	1.52×10^{-6}	-58.2	6	8.65×10^{-6}	-50.6	17	3.64×10^{-6}	-54.4			
3	162	2.38×10^{-6}	-56.2	39	6.49×10^{-6}	-51.9	38	3.00×10^{-6}	-55.2			
4	244	2.26×10^{-6}	-56.5	39	9.05×10^{-6}	-50.4	48	1.78×10^{-6}	-57.5	7	5.42×10^{-6}	-58.1
5	300	2.44×10^{-6}	-56.1	43	3.52×10^{-6}	-54.5	76	2.67×10^{-6}	-55.7	6	1.09×10^{-6}	-60.6
6	311	2.03×10^{-6}	-56.9	42	2.65×10^{-6}	-55.8	111	2.56×10^{-6}	-55.9	6	1.56×10^{-6}	-59.6
7	363	2.67×10^{-6}	-55.7	107	2.38×10^{-6}	-56.2	134	1.98×10^{-6}	-57.0	14	2.76×10^{-6}	-58.0
8	414	2.16×10^{-6}	-56.7	148	1.73×10^{-6}	-57.6	198	2.87×10^{-6}	-55.4	13	1.97×10^{-6}	-58.3
9	360	2.25×10^{-6}	-56.5	182	2.67×10^{-6}	-55.7	284	2.27×10^{-6}	-56.4	11	2.71×10^{-6}	-57.1
10	415	3.12×10^{-6}	-55.1	241	1.92×10^{-6}	-57.2	344	1.90×10^{-6}	-57.2	22	3.19×10^{-6}	-57.2
11	424	2.92×10^{-6}	-55.3	242	1.95×10^{-6}	-57.1	362	1.97×10^{-6}	-57.1	16	2.65×10^{-6}	-56.7
12	483	3.16×10^{-6}	-55.0	263	2.82×10^{-6}	-55.5	449	2.28×10^{-6}	-56.4	25	2.73×10^{-6}	-56.9
13	484	2.91×10^{-6}	-55.4	312	2.69×10^{-6}	-55.7	468	1.91×10^{-6}	-57.2	31	2.69×10^{-6}	-56.1
14	553	3.09×10^{-6}	-55.1	365	2.43×10^{-6}	-56.1	496	2.15×10^{-6}	-56.7	23	6.15×10^{-6}	-56.0
15	610	2.98×10^{-6}	-55.3	386	2.96×10^{-6}	-55.3	512	2.47×10^{-6}	-56.1	36	1.91×10^{-6}	-58.0
16	595	3.20×10^{-6}	-54.9	398	3.35×10^{-6}	-54.8	677	2.88×10^{-6}	-55.4	64	3.26×10^{-6}	-56.3
17	676	2.92×10^{-6}	-55.3	345	3.01×10^{-6}	-55.2	768	2.79×10^{-6}	-55.5	57	3.02×10^{-6}	-56.4
18	679	3.15×10^{-6}	-55.0	197	3.09×10^{-6}	-55.1	816	2.56×10^{-6}	-55.9	73	2.61×10^{-6}	-57.2
19	830	2.50×10^{-6}	-56.0	146	3.15×10^{-6}	-55.0	716	2.61×10^{-6}	-55.8	76	3.27×10^{-6}	-56.6
20	1,140	2.73×10^{-6}	-55.6	189	2.88×10^{-6}	-55.4	667	2.54×10^{-6}	-55.9	53	8.10×10^{-6}	-54.2
21	1,222	2.64×10^{-6}	-55.8	188	3.30×10^{-6}	-54.8	837	3.05×10^{-6}	-55.2	43	4.89×10^{-6}	-55.2
22	1,036	2.56×10^{-6}	-55.9	136	2.80×10^{-6}	-55.5	970	3.13×10^{-6}	-55.0	73	4.74×10^{-6}	-56.1
23	1,031	2.94×10^{-6}	-55.3	179	4.36×10^{-6}	-53.6	1,372	3.69×10^{-6}	-54.3	67	3.45×10^{-6}	-56.9
24	1,039	3.84×10^{-6}	-54.2	238	3.11×10^{-6}	-55.1	1,585	3.82×10^{-6}	-54.2	117	3.72×10^{-6}	-56.4
25	1,102	4.15×10^{-6}	-53.8	251	3.84×10^{-6}	-54.2	1,942	4.28×10^{-6}	-53.7	161	2.83×10^{-6}	-56.8
26	1,232	5.79×10^{-6}	-52.4	318	3.39×10^{-6}	-54.7	1,717	4.30×10^{-6}	-53.7	170	3.24×10^{-6}	-56.4

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Appendix A5.–Page 2 of 2.

Depth (m)	2005			2006			2007			2008		
	Number of targets	σ	TS	Number of targets	σ	TS	Number of targets	σ	TS	Number of targets	σ	TS
27	1,058	6.02×10^{-6}	-52.2	271	3.69×10^{-6}	-54.3	1,602	4.90×10^{-6}	-53.1	183	3.20×10^{-6}	-56.2
28	932	5.62×10^{-6}	-52.5	287	3.21×10^{-6}	-54.9	1,501	4.73×10^{-6}	-53.3	226	2.87×10^{-6}	-56.9
29	459	6.03×10^{-6}	-52.2	130	3.32×10^{-6}	-54.8	897	5.29×10^{-6}	-52.8	325	2.89×10^{-6}	-56.3
30	100	3.45×10^{-6}	-54.6	43	3.58×10^{-6}	-54.5	346	5.24×10^{-6}	-52.8	479	3.01×10^{-6}	-56.2
31							2	1.08×10^{-5}	-49.7	15	3.95×10^{-6}	-55.4
Grand total	18,384	3.52×10^{-6}	-54.5	5,732	3.06×10^{-6}	-55.1	19,958	3.58×10^{-6}	-54.5	2,392	3.25×10^{-6}	-56.4

Appendix A6.–Larson Lake mean sigma and target strength (TS) by depth and year.

Depth (m)	2005			2006			2007		
	Number of targets	σ	TS	Number of targets	σ	TS	Number of targets	σ	TS
1	7	1.21×10^{-6}	-59.2	3	1.22×10^{-6}	-59.1	15	1.99×10^{-6}	-57.0
2	62	1.59×10^{-6}	-58.0	40	2.31×10^{-6}	-56.4	208	2.24×10^{-6}	-56.5
3	163	2.17×10^{-6}	-56.6	79	2.08×10^{-6}	-56.8	320	2.16×10^{-6}	-56.7
4	322	2.11×10^{-6}	-56.8	143	2.28×10^{-6}	-56.4	362	2.09×10^{-6}	-56.8
5	380	1.96×10^{-6}	-57.1	176	1.81×10^{-6}	-57.4	295	2.43×10^{-6}	-56.1
6	382	2.42×10^{-6}	-56.2	223	1.91×10^{-6}	-57.2	227	2.47×10^{-6}	-56.1
7	532	2.89×10^{-6}	-55.4	273	2.31×10^{-6}	-56.4	257	3.34×10^{-6}	-54.8
8	573	3.12×10^{-6}	-55.1	354	3.02×10^{-6}	-55.2	227	4.60×10^{-6}	-53.4
9	527	4.74×10^{-6}	-53.2	346	3.97×10^{-6}	-54.0	193	6.67×10^{-6}	-51.8
10	588	5.30×10^{-6}	-52.8	327	6.77×10^{-6}	-51.7	193	9.65×10^{-6}	-50.2
11	684	6.49×10^{-6}	-51.9	226	4.93×10^{-6}	-53.1	170	1.02×10^{-5}	-49.9
12	748	8.40×10^{-6}	-50.8	116	2.87×10^{-6}	-55.4	189	8.05×10^{-6}	-50.9
13	710	8.36×10^{-6}	-50.8	105	2.80×10^{-6}	-55.5	275	1.45×10^{-5}	-48.4
14	627	8.91×10^{-6}	-50.5	105	2.43×10^{-6}	-56.1	279	1.16×10^{-5}	-49.4
15	520	8.45×10^{-6}	-50.7	124	2.18×10^{-6}	-56.6	345	1.42×10^{-5}	-48.5
16	483	9.12×10^{-6}	-50.4	108	2.26×10^{-6}	-56.5	337	1.27×10^{-5}	-48.9
17	442	8.77×10^{-6}	-50.6	119	3.82×10^{-6}	-54.2	458	1.49×10^{-5}	-48.3
18	390	9.20×10^{-6}	-50.4	124	3.39×10^{-6}	-54.7	469	1.48×10^{-5}	-48.3
19	381	8.78×10^{-6}	-50.6	101	4.20×10^{-6}	-53.8	448	1.37×10^{-5}	-48.6
20	391	7.70×10^{-6}	-51.1	104	5.39×10^{-6}	-52.7	423	1.38×10^{-5}	-48.6
21	506	7.13×10^{-6}	-51.5	71	4.30×10^{-6}	-53.7	328	1.00×10^{-5}	-50.0
22	410	6.28×10^{-6}	-52.0	109	3.40×10^{-6}	-54.7	346	1.16×10^{-5}	-49.3
23	403	7.79×10^{-6}	-51.1	126	4.62×10^{-6}	-53.4	277	1.03×10^{-5}	-49.9
24	302	6.88×10^{-6}	-51.6	29	5.51×10^{-6}	-52.6	236	1.35×10^{-5}	-48.7
25	239	8.32×10^{-6}	-50.8	36	7.62×10^{-6}	-51.2	141	1.99×10^{-5}	-47.0
26	277	6.31×10^{-6}	-52.0	58	4.31×10^{-6}	-53.7	150	1.50×10^{-5}	-48.2
27	282	8.67×10^{-6}	-50.6	19	3.31×10^{-6}	-54.8	201	1.18×10^{-5}	-49.3
28	255	8.19×10^{-6}	-50.9	20	5.61×10^{-6}	-52.5	125	1.12×10^{-5}	-49.5
29	315	7.03×10^{-6}	-51.5	54	9.95×10^{-6}	-50.0	123	1.77×10^{-5}	-47.5
30	305	8.84×10^{-6}	-50.5	48	7.96×10^{-6}	-51.0	100	1.13×10^{-5}	-49.5
31	348	8.46×10^{-6}	-50.7	64	8.99×10^{-6}	-50.5	120	9.30×10^{-6}	-50.3
32	344	9.11×10^{-6}	-50.4	76	5.79×10^{-6}	-52.4	103	7.65×10^{-6}	-51.2
33	404	1.06×10^{-5}	-49.8	110	4.06×10^{-6}	-53.9	148	8.60×10^{-6}	-50.7
34	473	9.12×10^{-6}	-50.4	117	4.91×10^{-6}	-53.1	87	1.1×10^{-5}	-49.6
35	465	9.62×10^{-6}	-50.2	115	3.18×10^{-6}	-55.0	144	1.14×10^{-5}	-49.4
36	357	1.02×10^{-5}	-49.9	60	7.83×10^{-6}	-51.1	62	1.25×10^{-5}	-49.0
37	181	1.19×10^{-5}	-49.3	9	1.51×10^{-5}	-48.2	31	7.59×10^{-6}	-51.2
38	9	1.04×10^{-5}	-49.8				3	1.35×10^{-5}	-48.7
Grand total	14,787	7.18×10^{-6}	-51.4	4,317	3.95×10^{-6}	-54.0	8,415	1.02×10^{-5}	-49.9

Appendix A7.–Shell Lake mean sigma and target strength (TS) by depth and year.

	2005			2006			2007		
Depth (m)	Targets	σ	TS	Targets	σ	TS	Targets	σ	TS
1	4	7.65×10^{-7}	-61.2	3	9.70×10^{-7}	-60.1	28	1.80×10^{-6}	-57.4
2	25	1.62×10^{-6}	-57.9	15	1.53×10^{-6}	-58.2	84	1.53×10^{-6}	-58.2
3	80	1.71×10^{-6}	-57.7	66	1.64×10^{-6}	-57.8	160	1.63×10^{-6}	-57.9
4	189	2.38×10^{-6}	-56.2	113	1.71×10^{-6}	-57.7	147	1.44×10^{-6}	-58.4
5	269	2.27×10^{-6}	-56.4	149	2.68×10^{-6}	-55.7	111	2.00×10^{-6}	-57.0
6	328	2.88×10^{-6}	-55.4	192	2.44×10^{-6}	-56.1	103	2.31×10^{-6}	-56.4
7	387	2.73×10^{-6}	-55.6	227	3.04×10^{-6}	-55.2	129	1.81×10^{-6}	-57.4
8	454	2.78×10^{-6}	-55.6	283	5.51×10^{-6}	-52.6	184	2.64×10^{-6}	-55.8
9	431	2.34×10^{-6}	-56.3	304	3.47×10^{-6}	-54.6	191	1.78×10^{-6}	-57.5
10	442	2.32×10^{-6}	-56.3	282	5.08×10^{-6}	-52.9	200	2.01×10^{-6}	-57.0
11	422	2.27×10^{-6}	-56.4	201	5.48×10^{-6}	-52.6	219	2.03×10^{-6}	-56.9
12	249	3.47×10^{-6}	-54.6	200	4.54×10^{-6}	-53.4	169	1.84×10^{-6}	-57.3
13	191	4.00×10^{-6}	-54.0	86	4.90×10^{-6}	-53.1	160	3.00×10^{-6}	-54.2
14	181	3.51×10^{-6}	-54.5	61	4.71×10^{-6}	-53.3	126	3.15×10^{-6}	-55.0
15	189	2.29×10^{-6}	-56.4	34	6.47×10^{-6}	-51.9	124	2.59×10^{-6}	-55.9
16	181	1.88×10^{-6}	-57.3	28	4.18×10^{-6}	-53.8	87	2.60×10^{-6}	-55.9
17	161	4.18×10^{-6}	-53.8	46	2.27×10^{-6}	-56.4	36	4.83×10^{-6}	-53.2
18	133	2.11×10^{-6}	-56.8	57	6.62×10^{-6}	-51.8	29	3.17×10^{-6}	-55.0
19	126	4.25×10^{-6}	-53.7	11	4.31×10^{-6}	-53.7	20	1.07×10^{-5}	-49.7
20	92	5.06×10^{-6}	-53.0	54	2.87×10^{-6}	-55.4	26	2.58×10^{-6}	-55.9
21	74	1.62×10^{-6}	-57.9	23	2.00×10^{-6}	-57.0	14	1.82×10^{-5}	-47.4
22	77	1.93×10^{-6}	-57.2	12	2.34×10^{-6}	-56.3	8	2.24×10^{-6}	-56.5
23	14	1.72×10^{-6}	-57.6	2	1.67×10^{-6}	-57.8	6	2.26×10^{-6}	-56.5
24	14	1.33×10^{-6}	-58.7				6	1.42×10^{-6}	-58.5
Grand total	4713	2.71×10^{-6}	-55.7	2449	3.98×10^{-6}	-54.0	2367	2.42×10^{-6}	-56.2

Appendix A8.–Stephan Lake mean sigma and target strength (TS) by depth and year.

	2006			2007		
Depth (m)	Targets	σ	TS	Targets	σ	TS
1	1	8.22×10^{-7}	-60.9	6	1.57×10^{-6}	-58.1
2	1	1.71×10^{-6}	-57.7	13	5.14×10^{-6}	-52.9
3	8	2.12×10^{-6}	-56.7	41	1.24×10^{-6}	-59.1
4	4	1.78×10^{-6}	-57.5	55	1.92×10^{-6}	-57.2
5	9	2.22×10^{-6}	-56.5	79	1.65×10^{-6}	-57.8
6	10	7.65×10^{-6}	-51.2	104	2.16×10^{-6}	-56.7
7	5	8.14×10^{-6}	-50.9	118	1.14×10^{-6}	-59.4
8	12	1.07×10^{-5}	-49.7	111	1.49×10^{-6}	-58.3
9	12	1.19×10^{-5}	-49.3	125	1.26×10^{-6}	-59.0
10	6	1.32×10^{-5}	-48.8	120	1.91×10^{-6}	-57.2
11	11	6.12×10^{-6}	-52.1	89	1.09×10^{-6}	-59.6
12	4	1.54×10^{-6}	-58.1	83	1.41×10^{-6}	-58.5
13	5	3.21×10^{-6}	-54.9	44	6.82×10^{-6}	-51.7
14	5	2.55×10^{-6}	-55.9	22	8.04×10^{-6}	-50.9
15	3	1.35×10^{-5}	-48.7	23	1.16×10^{-5}	-49.4
16	2	2.06×10^{-5}	-46.9	15	5.62×10^{-6}	-52.5
17				22	4.63×10^{-6}	-53.3
18				15	1.80×10^{-5}	-47.4
19	6	1.36×10^{-5}	-48.7	12	2.80×10^{-6}	-45.5
20	3	1.01×10^{-5}	-50.0	5	6.71×10^{-6}	-51.7
21	3	2.66×10^{-6}	-55.8	9	6.86×10^{-6}	-51.6
22				7	1.99×10^{-5}	-47.0
Grand total	110	7.43×10^{-6}	-51.3	1118	2.91×10^{-6}	-55.4