JUVENILE SOCKEYE SALMON POPULATION ESTIMATES IN SKILAK AND KENAI LAKES, ALASKA, BY USE OF SPLIT-BEAM HYDROACOUSTIC TECHNIQUES IN SEPTEMBER 2003.

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ABSTRACT

During 15-17 September 2003, hydroacoustic surveys were conducted on Skilak and Kenai Lakes using split-beam sonar. We chose to conduct a second hydroacoustic survey of Skilak Lake on 24 September, because the first population estimate for this lake appeared low and a full moon during the first survey could have biased the estimate. The population estimates for Skilak Lake totaled 10,170,000 and 12,058,000 fish respectively. The two population estimates were not significant ($F = 1.198$; $P = 0.388$) and the estimates pooled. The population estimates for Skilak and Kenai Lakes were 11,115,000 and 2,235,000 fish. Annual midwater trawls were conducted to obtain information on age, weight, and length (AWL) of fall fry. For Skilak Lake, age-0 sockeye salmon composed 96 % of the total population estimate. The mean population size of this cohort was 1.31 g and 51.6 mm. In comparison, age-0 sockeye salmon accounted for 99 % of the total fish population in Kenai Lake. The age-0 fry in Kenai Lake were slightly larger in size compared to that of Skilak Lake and averaged 55.8 mm and 1.82 g.

KEY WORDS: Alaska, Cook Inlet, hydroacoustics, Kenai River, salmon, *Oncorhynchus nerka*, split–beam, sonar.

INTRODUCTION

In September 2003, the Alaska Department of Fish and Game (ADF&G) conducted hydroacoustic and townet surveys in Skilak and Kenai lakes (Kenai River drainage) to determine population abundance, age distribution, and size of juvenile sockeye salmon, *Oncorhynchus nerka*. These surveys have been performed annually since 1986 (DeCino 2001, DeCino and Degan 2000, Tarbox and King 1988a, 1988b, Tarbox, et. al. 1993, Tarbox and Brannian 1995, Tarbox et. al. 1996). The information obtained on fall fry rearing in these major nursery lakes are used to help biologists forecast the number of sockeye salmon returning to the Kenai River. Moreover, the biological basis of the brood interaction spawner-recruit model and cyclic pattern in sockeye salmon returns to the Kenai River (Carlson et al. 1999; Edmundson et al. 2003) is thought to be that heavy grazing on cyclopoid copepods from large fry populations causes the survival of the year class that follows the more abundant line to be reduced. Thus, a major goal of this project, coupled with limnological studies, is to gain a better understanding of the factors regulating the production of sockeye salmon in the Kenai River, which supports the largest runs of sockeye in Upper Cook Inlet (Fox and Shields 2002).

For the 2003 fish surveys, population sizes were estimated using an echo integration (MacLennan and Simmonds 1992) procedure of data captured from use of split-beam sonar. The condition of the juvenile sockeye was based on the size and age of fish captured in mid-water trawls. In addition, transects across each lake were geo-referenced during the hydroacoustic surveys (DeCino and Degan 2000). In this report, we describe the nature of our lake surveys, and we provide (1) abundance estimates of juvenile sockeye salmon rearing in Skilak and Kenai lakes, (2) distributions of age, weight and length of fall fry, and (3) assessments of the pre-winter condition of fry.

METHODS

Hydroacoustic Surveys

We used a stratified- random sampling design for the hydroacoustic surveys to distribute sampling effort in proportion to abundance and reduce the variance of the population estimate. Each lake was divided into areas or sub-basins and survey transects were randomly selected within each area. The number of transects were chosen to reduce relative error to ~25% for Skilak Lake and 30% for Kenai Lake. This sample size was based on recommendations in Tarbox et al (1996). Because of the configuration of Skilak Lake, transects perpendicular to shore were surveyed within three sub-basins (Figure 1), whereas in Kenai Lake, transects were surveyed within five sub-basins (Figure 2). Transects were chosen based on a stratified- random design (DeCino and Degan 2000, Tarbox et. al. 1996, Jolly and Hampton 1990, Figures 1 & 2). Transects were traversed at approximately 2 m/s. The acoustic vessel (7.2 m long) was powered by two 2-stroke outboard engines. The transducer/sled was attached to a cable, ("come-along"), connected to a boom and towed off the boat's starboard side approximately 1-m below the water surface.

Juvenile sockeye salmon were sampled acoustically at night with a BioSonics DT-60001 split beam echosounder. A 6.6° circular split-beam transducer was mounted to a 1.5-m long aluminum sled. The transducer transmitted digital data via a 15-m long cable to the echosounder. The echosounder was connected to a laptop computer via pcmcia data connection. For geo-referenced transect routes, we used a Garmin[1] GMAP model 175 global positioning system (GPS). Acoustic digital data were collected and stored on a laptop computer hard-drive. Configuration parameters were input into BioSonics[1] Visual Acquisition data collection software. Environmental variables (temperature) were measured with an YSI[1] model 58 digital thermistor and input to the environmental variables of the program. Fish were acoustically sampled at 2 pings/sec, 1-51 m depth, 0.2 ms pulse width and a –65dB data threshold. Twelve-volt batteries 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 Area office network for access by analysis programs. The acoustic data were edited by use of BioSonics[1] Visual Analyzer program. 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 and sigma (σ) the backscattering coefficient.

Target strength and σ computations were performed using a macro built by Aquacoustics Inc[1]. For each lake, this macro appended all transects and calculated in-situ target strengths and σ's from each detected target. Targets were filtered to include only those echoes near the beam center (0 to –4dB off axis). The entire lake average σ was input to BioSonics1 Visual Analyzer program for echo-integration.

A fish density estimate was computed for each transect and expanded for each area from which they were collected. The echo integrator compiled data in 20 report sequences along each transect and sent outputs to computer files for further reduction and analysis. The total number of fish (N_{ij}) for area stratum i based on transects j was estimated across depth stratum k. N_{ij} consisted of an estimate of the number of fish detected by hydroacoustic gear in the mid-water (1-51 m) layer (M_{ij}) and an estimate of the number of fish in the surface layer (0-2 m). In order to estimate the number of fish unavailable to the hydroacoustic gear because of their location near the surface (S_{ij}), the fish density in the upper stratum was assumed equal to the density in the first stratum echo integrated in the lake. That assumption is based on lake morphometry and percent volume sampled in post-processing analysis

$$\hat{N}_{ij} = \hat{S}_{ij} + \hat{M}_{ij} \tag{1}$$

[1] Use of a company name does not constitute endorsement by ADF&G

The mid-water component was estimated as

$$\hat{M}_{ij} = a_i \sum_{k=1}^{K} M_{ijk} \tag{2}$$

where a_i represented the surface area (m2) of area stratum i which was estimated using a planimeter and USGS maps of Skilak and Kenai Lakes, and m_{ijk} (number/m2) was the estimated mean fish density in area i depth k across transect j. The depth would be less than the maximum 51 m if the bottom was detected within depth stratum k anytime along a transect. The estimated numbers of fish near the surface (0–2 m) in area i was

$$S_{ij} = a_{ij} m_{ij} \tag{3}$$

where a_{is} was the estimated area (m2) of the surface stratum (0–2 m), and m_{ijk} is 2/5 the mean fish density for in the first ensonified depth stratum (1–5 m below transducer) of transect j.

Fish abundance in area i (N_i) was estimated from the mean abundance for all transects j in the area, or

$$\hat{N}_i = J^{-1} \sum_{j=1}^{J} N_{ij} \tag{4}$$

and its variance was estimated as

$$v(\hat{N}_i) = \sum (\hat{N}_{ij} - \hat{N}_i)^2 (J-1)^{-1} J^{-1} \tag{5}$$

Total fish abundance (N) for each lake was estimated as the sum of the area estimates and the variance of N was estimated as the sum of the area variance estimates.

The abundance of juvenile sockeye salmon in each lake (N_s) was estimated as

$$N_s = \hat{N}\hat{P} \tag{6}$$

where $\hat{P}$ was the estimated proportion of total fish targets that were juvenile sockeye salmon in the lake. Age-specific numbers of juvenile sockeye salmon (N_{sa}) were estimated as

$$N_{sa} = \hat{N}\hat{P}_a \tag{7}$$

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

Variance estimates were calculated as

$$v(\hat{N}_s) = \hat{N}^2 v(\hat{P}) + P^2 v(\hat{N}) - v(\hat{P})v(\hat{N}) \quad (8)$$

$$v(\hat{N}_{sa}) = \hat{N}^2 v(\hat{P}_a) + P_a^2 v(\hat{N}) - v(\hat{P}_a)v(\hat{N}) \quad (9)$$

Two surveys were completed in Skilak Lake on 15 and 24 September 2003. These two surveys were done in full moon and new moon conditions. A randomized block ANOVA with moon as the treatment and the three areas as the blocks was utilized to test for significance in population estimate differences.

Age, Weight, and Length (AWL) surveys

Mid-water trawls (tow netting) were taken in both lakes to determine species composition of the targets and age composition, wet weight (g), and fork length (mm) of juvenile sockeye. Sampling in Skilak Lake utilized a stratified cluster and stratified two-stage sampling technique (Scheaffer et al. 1986, Cochran 1977). Areas were the same as those used in the hydroacoustic sampling. Depth strata were developed to account for potential vertical variation in species and age composition. Three depth strata were defined: surface (0-10 m), mid-depth (15-25 m) and deep (30-40 m). Each tow was defined as a primary sampling unit and a minimum of three tows were conducted in each stratum. All fish captured in each tow were identified to species. A sample of sockeye fry was collected from each tow to estimate age composition and average length and weight.

We used the same stratified random sampling technique in Kenai Lake; however, three areas and two depth intervals were defined. The three sampling areas consisted of area one (identical to the hydroacoustic area one), area two (combining hydroacoustic areas two and three) and area three (combining hydroacoustic areas four and five). Two depth strata were defined: surface (0-10 m) and mid-depth (15-25 m).

Fish captured in Skilak Lake were measured to the nearest 1 mm in the field. Scales were removed from sockeye juveniles greater than 55 mm and placed into individual pre-weighed scintillation vials. Vials were returned to the laboratory in Soldotna where they were weighed and frozen for subsequent lipid analysis. Fresh wet-weights were converted to formalin-fixed weight based on the Shields and Carlson (1996) conversion data. All fish collected from Kenai Lake were enumerated, identified, and preserved in 10% formalin. In the laboratory juvenile sockeye salmon were measured to the nearest millimeter (fork length), weighed (wet) to the nearest 0.1 g, and the age determined from scale samples using criteria outlined by Mosher (1969).

RESULTS

Skilak Lake

In Skilak Lake, two hydroacoustic surveys were performed; one in full moon (September 15, 2003) and one without full moon (September 24, 2003) conditions. The purpose of doing two surveys was based on the assumption that a larger population could be detected in the absence of moonlight. Two surveys were conducted because the first survey resulted in a population estimate that was lower than expected based upon the number of spawners observed the previous year. We felt that the full moon that occurred during the first survey could have biased the estimate if fish were more surface oriented under these conditions.

For target strength estimation, a total of 17,878 and 23,846 echoes were used to calculate target strengths of –52.7 and –53.5 dB with a standard deviation's (SD) of 4.05 and 3.78 dB for survey 1 and 2, respectively. The mean and standard deviation for the sigma (σ) used for echo integration equaled 9.14 × 10-6 ± 3.36 × 10-5 and 6.33 × 10-6 ± 9.13 × 10-6 (Table 1). The population estimates were 10,170,00 and 12,058,000. The two surveys were not significantly different from each other based on a randomized block ANOVA with the moon as the treatment and lake area as the block ($F = 1.198$; $P = 0.388$). Therefore, the surveys were combined and the estimated fish abundance was 11,115,000 with a standard error (SE) of 1,312,000 fish. Of the estimated total population of juvenile sockeye salmon, approximately 44% were detected in Area 1 (Table 2, Figure 3). In addition, the largest proportion of total fish targets in the 1-6 m depth strata was detected in Area 1 (Table 2), causing our estimate of the fish population in the surface layer (0-2 m) to also be greatest in this area. We estimated the total fish population in the upper 2 m of the water column in Skilak Lake was approximately 1,205,800 fish.

During our tow-net survey, 1,295 fish were captured of which 1,276 fish or 98.5 % were juvenile sockeye salmon. Of these, 1,000 were subsampled for wet weight, and fork length (AWL). From the 1000 fish, 300 were subsampled for age. Age-0 juvenile sockeye salmon accounted for 95 % (SE = 0.016 %) of the total sockeye population estimate. The remaining 5 % (SE = 0.015 %) were age-1 sockeye salmon. Therefore, approximately 10,614,825 (SE = 1,254,363) and 500,175 (SE = 178,376) sockeye salmon were aged 0 and 1+ fish, respectively (Table 3). The mean population weight and length of age-0 sockeye salmon was 1.18 g (SE = 0.01 g) and 51.6 mm (SE = 0.77 mm). In comparison, age-1 juvenile sockeye averaged 2.57 g (SE = 0.09 g) and 65.7 mm (SE = 1.37 mm, Table 4, Figure 3).

Kenai Lake

A total of 11,281 echoes were used to estimate target strengths in Kenai Lake. The mean target strength was –52.05 dB with a SD of 4.41 dB. The mean σ was 9.74 × 10-6 with a SD of 1.38 × 10-6. This σ produced a population estimate of 2,235,000 (SE = 171,505) fish. Of the 2,235,000 fish, 66,700 fish were estimated to occur in the surface layer (upper 0-2 m) (Table 2). The greatest proportion of the total fish population was located in Area 4 and 5 with the largest density in Area 4 (Table 2).

Based on our mid-water trawls conducted in Kenai Lake, sockeye salmon accounted for 99.5 % of the population. Thus, the population estimate of juvenile sockeye salmon was 1,963,168 (SE = 194,452). Of the apportioned juvenile sockeye, 99.1 % (SE = 0.24 %) were age-0, which accounted for approximately 1,945,452 (SE = 192,797) fish (Table 3). The mean population weight and length of the age-0 cohort was 1.53 g (SE = 0.02 g) and 51.8 mm (SE = 0.24 mm), respectively. The age-1 cohort population estimate was 17,221 (SE = 5,011) fish. Only six age-1 fish were captured in the midwater trawl and these averaged 64.5 mm (SE = 2.23) and 3.03 g (SE = 0.32, Table 4, Figure 3).

DISCUSSION

The 2003 population estimates of juvenile sockeye salmon in both Skilak and Kenai lakes ranked the 10th largest since surveys were initiated in 1986 (Figure 4). These juvenile sockeye salmon abundance estimates exhibit considerable year-to-year variation and there appears to be little overall trend in the time series (Figure 4). However, the combined lake 2003 population estimate is about 5 million less than the 18.3 million 17-year mean.

Skilak Lake consistently supports more sockeye salmon fry than Kenai Lake. The Skilak Lake population estimate is 4.6 million fish less than the historical mean. The highest population estimate (1993) was approximately 33 million fry (Tarbox et al 1996), and the lowest population estimate (1996) was 5.2 million fish. The average population size since 1986 is 15.7 million fish with a SD of 8.41 million fish. This 2003 estimate is about 4.6 million less than the historical average.

The 2003 Kenai Lake population estimate of 2.2 million fish is the tenth highest since inception of acoustic estimates in 1986 (Figure 4). Juvenile sockeye salmon estimates have ranged from 768,000 in 1996 to 6.2 million in 1988 (Tarbox et al 1996). The average population since 1986 is 2.67 million fish with a SD of 1.03 million. The 2003 sockeye salmon population estimate for Kenai Lake is about 430,000 fish below the historical mean population size.

The 2003 sockeye salmon population estimate for these two lakes combined was lower than predicted from the number of spawners enumerated in the summer of 2002. Edmundson et al (2003) presented a regression analysis relating number of spawners to fall fry abundance. Approximately 750,000 sockeye salmon spawners entered the Kenai River watershed in 2002. Given this spawner abundance, one would predict approximately 20+ million fry would be present these two lakes in the fall of 2003. But, this did not occur. The 2003 fall fry estimate lies within the lower range of the scatter of historical data at this level of spawner abundance (Edmundson et al 2003). A flood that occurred in the Kenai River watershed in fall of 2002 could have scoured redds reducing the number of fry that recruited to the lakes in the spring of 2003.

The target strengths of the juvenile sockeye salmon measured with the split-beam transducer in 2003 were within reported ranges of target strengths measured using a dual-beam hydroacoustic system (see Tarbox et al 1996). In addition, juvenile sockeye salmon lengths and weights followed historical trends. Kenai Lake, on average, has produced larger fish in both length and weight compared with Skilak Lake. Juvenile sockeye salmon in Kenai Lake were both significantly longer ($F = 320.4$, $p = 0.00$) and heavier ($F = 549.3$, $p = 0.00$) than the Skilak Lake fish in 2003.

Similar to the historical population estimates, historical length and weight measurements show considerable year to year variation in Skilak Lake (Figure 7). For age-0 sockeye salmon in Skilak Lake, the2003 mean length and weight were three and five percent greater, respectively, than the historical means. A regression equation relating fall fry weight to their abundance (Edmundson et al 2003) predicted a 1.23 g mean weight for sockeye fry in Skilak Lake, whereas actual mean weight was 1.31 g. The larger than predicted size observed in 2003 fall fry is consistent with a smaller population size and the potential for less density-dependent rearing conditions. In as much, the sockeye salmon fry in Skilak and Kenai Lakes are some of the smallest in Alaska (Edmundson and Mazumder 2001). Given the harsh rearing conditions these fish experience, long-term data sets will be needed for managers and researchers to better forecast runs of sockeye salmon to the Kenai River.

In 2002, we detected larger "acoustic" sized targets in Skilak Lake than in Kenai Lake. In 2003, we minimized acoustic sampling error by working in calm conditions in both lakes. We also minimized bias in sampling error with respect to target strength measurements and townetting data by having the acoustic vessel direct the townet vessel to sample locations in the lake where fry were more abundant. This allowed the townet crew to catch fish in a more cost effective manner.

In 2003, we conducted two acoustic surveys on Skilak Lake, because the population estimate from the first survey was lower than predicted from a regression relating fall fry abundance to number of spawners. This observation led us to speculate that the population estimate from the first survey could have been biased low, because fry were feeding in the surface layer under the full moon that occurred during this survey and this layer (0-2 m) was not ensonified. In fact, we observed more targets in the upper three depth strata during the first survey compared to the second survey (Appendix A1 and A2; Figure 6). This could be due to greater light penetration (Gliwicz 1986) and possible foraging behavior in full moonlight conditions (Gliwicz 1986). During the second survey, greater numbers of targets were observed and their distribution was shifted more toward the middle of the water column compared to the first survey. This change in vertical distribution may have been due to differences in fish behavior or perhaps sampling error.

Nevertheless, our population estimates of juvenile sockeye salmon obtained from the two surveys in Skilak Lake were remarkably similar. That is, the abundance estimates differed by approximately 2 million fish. In addition, the results of randomized block ANOVA suggested that the population estimates were not significantly different. Since these estimates appear equally consistent, we pooled the two surveys. MacLennon and Simonds (1992) suggested that population estimates from replicate surveys can be used and in doing so the sample variance from our two surveys was halved. Although, conducting multiple acoustic surveys is more costly, this approach allows us to better understand effects of survey conditions on the estimate and increase the precision of the estimate. However, fish targets also appear to "clump" in certain areas of the lake, particularly near shore. More intensive sampling in areas of greater abundance may allow us to further reduce the variance of population estimates. Using an adaptive sampling strategy to sample fish concomitant with limnological studies would also provide robust data sets to help us better understand abiotic and biotic factors influencing the distribution, behavior and ecology of juvenile sockeye salmon.

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TABLES

Table 1. Target strength (dB) and sigma (σ) the mean backscattering coefficient for echo integration used to estimate population of juvenile sockeye salmon *O. nerka*.

Lake	n	Target Strength (dB)	σ
Skilak 1*	17,878	-52.73(4.05)	9.14×10^{-6} (3.36×10^{-5})
Skilak 2**	23,846	-53.50(3.78)	6.33×10^{-6} (9.13×10^{-6})
Kenai	11,281	-52.05(4.27)	9.74×10^{-6} (6.13×10^{-6})

* survey 1 September 15, 2003
** survey 2 September 24, 2003

Table 2 Estimated number of total fish in Skilak and Kenai Lakes, Alaska in September 2003.

Lake	Area	Transect	Surface	Midwater	Total	Mean	Area Variance
			Estimated Number of Fish				
Skilak	1-1*	1	2.1205E+05	3.3766E+06	3.5887E+06		
		2	4.6882E+05	4.3485E+06	4.8173E+06		
		3	2.5056E+05	2.3111E+06	2.5617E+06	3.6161E+06	3.6235E+11
		4	3.1779E+05	2.6767E+06	2.9945E+06		
		5	2.8450E+05	1.6126E+06	1.8971E+06		
		6	1.3533E+06	5.5493E+06	6.9026E+06		
	1-2*	1	5.8856E+04	1.6880E+06	1.7469E+06		
		2	2.5643E+04	8.2220E+05	8.4784E+05		
		3	1.5395E+04	6.8534E+06	6.8688E+06		
		4	2.0954E+04	1.2055E+06	1.2265E+06		
		5	1.0445E+06	3.8391E+06	4.8836E+06		
		6	5.2322E+05	4.5343E+06	5.0576E+06		
	2-1	1	1.5227E+05	1.9917E+06	2.1440E+06		
		2	1.8112E+05	2.4167E+06	2.5978E+06	2.6173E+06	2.9681E+10
		3	1.2467E+05	2.1989E+06	2.3235E+06		
		4	4.3051E+04	2.1466E+06	2.1896E+06		
	2-2	1	1.2312E+04	3.5189E+06	3.5313E+06		
		2	2.2787E+04	2.2877E+06	2.3105E+06		
		3	3.2295E+04	2.7227E+06	2.7550E+06		
		4	8.5635E+04	3.0009E+06	3.0865E+06		
	3-1	1	3.4877E+05	1.1421E+06	1.4909E+06		
		2	3.5536E+05	2.0379E+06	2.3932E+06	4.8812E+06	1.3002E+12
		3	1.6158E+06	8.4935E+06	1.0109E+07		
		4	4.9609E+04	2.2104E+06	2.2600E+06		
	3-2	1	2.2713E+06	6.5869E+06	8.8583E+06		
		2	9.8411E+05	5.4712E+06	6.4553E+06		
		3	1.1476E+05	3.5055E+06	3.6202E+06		
		4	2.0479E+05	3.6573E+06	3.8620E+06		
	TOTAL					1.1115E+07	1.6922E+12
Kenai	1	1	3.5225E+03	2.9135E+05	2.9488E+05		
		2	3.0470E+03	7.5069E+05	7.5374E+05		
		3	3.0951E+04	7.3474E+05	7.6569E+05		
		4	0.0000E+00	2.0044E+05	2.0044E+05	4.6301E+05	7.0217E+09
		5	2.9850E+04	3.3545E+05	3.6530E+05		
		6	3.8377E+04	3.2177E+05	3.6014E+05		
		7	2.7941E+04	4.7295E+05	5.0089E+05		
	2	1	1.3028E+04	3.5321E+05	3.6624E+05		
		2	3.4438E+03	5.4813E+05	5.5158E+05		
		3	2.6635E+04	3.5092E+05	3.7755E+05	5.4502E+05	6.1525E+09
		4	0.0000E+00	7.6635E+05	7.6635E+05		
		5	1.6285E+03	6.6176E+05	6.6339E+05		
	3	1	0.0000E+00	2.0503E+05	2.0503E+05		
		2	0.0000E+00	1.1418E+05	1.1418E+05		
		3	0.0000E+00	3.2765E+05	3.2765E+05	3.1583E+05	6.5216E+09
		4	3.7527E+03	3.3559E+05	3.3934E+05		
		5	7.0194E+03	5.8594E+05	5.9296E+05		
	4	1	3.5254E+03	4.4031E+05	4.4384E+05		
		2	7.7356E+03	3.3089E+05	3.3863E+05		
		3	1.8648E+03	5.3536E+05	5.3723E+05	3.7897E+05	2.3795E+09
		4	0.0000E+00	2.8628E+05	2.8628E+05		
		5	2.7045E+04	2.6183E+05	2.8888E+05		
	5	1	5.0878E+04	4.6182E+05	5.1270E+05		
		2	1.2352E+04	8.8819E+05	9.0054E+05		
		3	9.4320E+03	4.1220E+05	4.2164E+05	5.3218E+05	7.3388E+09
		4	2.5760E+04	5.6910E+05	5.9486E+05		
		5	4.9237E+04	4.3885E+05	4.8808E+05		
		6	2.3137E+04	2.5213E+05	2.7527E+05		
	TOTAL					2.2350E+06	2.9414E+10
	TOTAL FOR BOTH LAKES					1.3350E+07	1.7216E+12

*11 = area 1 survey 1, 12= area 1 survey 2

Table 3. Estimated fish population and contribution of age-0 and age-1 sockeye salmon to the total fish population in Kenai and Skilak Lakes, Alaska, night surveys. September 2003.

Lake	Estimated Total Fish	Standard Error (SE)	Estimated Juvenile Sockeye	Standard Error (SE)	% Age-0	Total Age-0	Standard Error (SE)	% Age-1	Total Age-1	Standard Error (SE)
Skilak	11,115,000	1,300,846	10,953,172	1,282,629	96.1	10,520,947	1,243,480	3.9	432,225	175,910
Kenai	2,235,000	171,505	2,231,816	171,638	99.9	2,229,481	171,480	0.1	2,335	2,744
Total	13,350,000	1,312,103	13,184,989	1,294,062		12,750,429	1,255,248		434,560	175,931
Variance	1.7×10^{12}		2.0×10^{12}			1.2×10^{12}			4.4×10^{11}	

Table 4. Age, weight and length of juvenile sockeye salmon from midwater trawl surveys September 2003.

	Age-0			Age-1		
Lake	n	mean l (mm)	mean wt (g)	n	mean l (mm)	mean wt (g)
Skilak*	955	51.6 (0.77)	1.18 (0.01)	45	65.7 (1.37)	2.57 (0.09)
Skilak**	955	51.6 (0.77)	1.31 (0.07)	45	65.7 (1.37)	2.77 (0.13)
Kenai	907	55.8 (0.55)	1.82 (0.06)	1	79.0	5.00

Standard Errors (SE) are in parenthesis.

* fresh weight

** formalin adjusted weight after Shields and Carlson 1996

FIGURES

Skilak Lake Transects September 15th and 24th, 2003

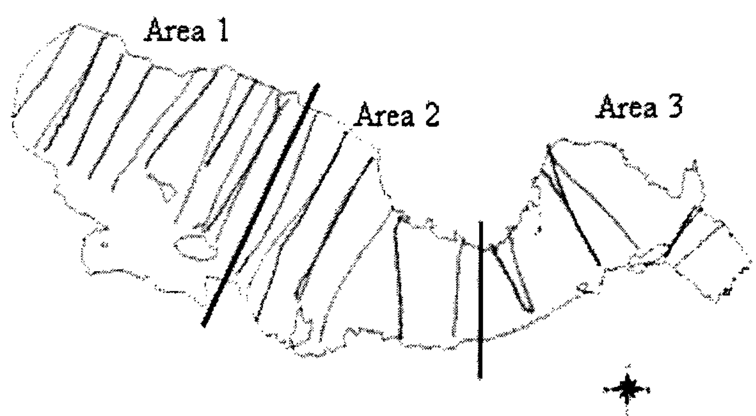

Figure 1. Skilak Lake transects and areas.

Kenai Lake Transects September 16, 2003

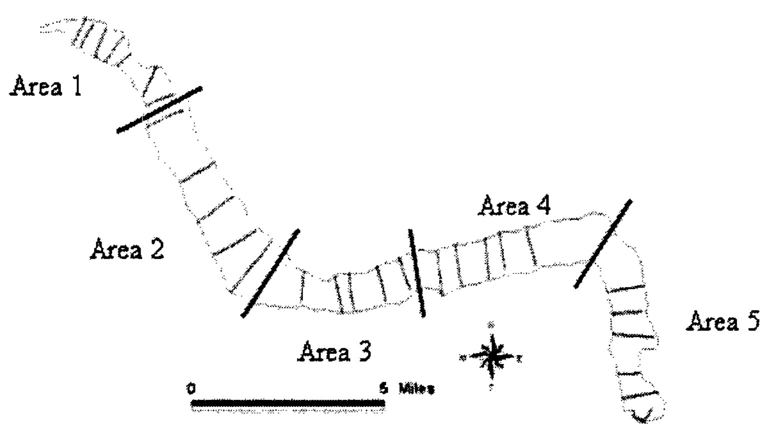

Figure 2. Kenai Lake transects and areas.

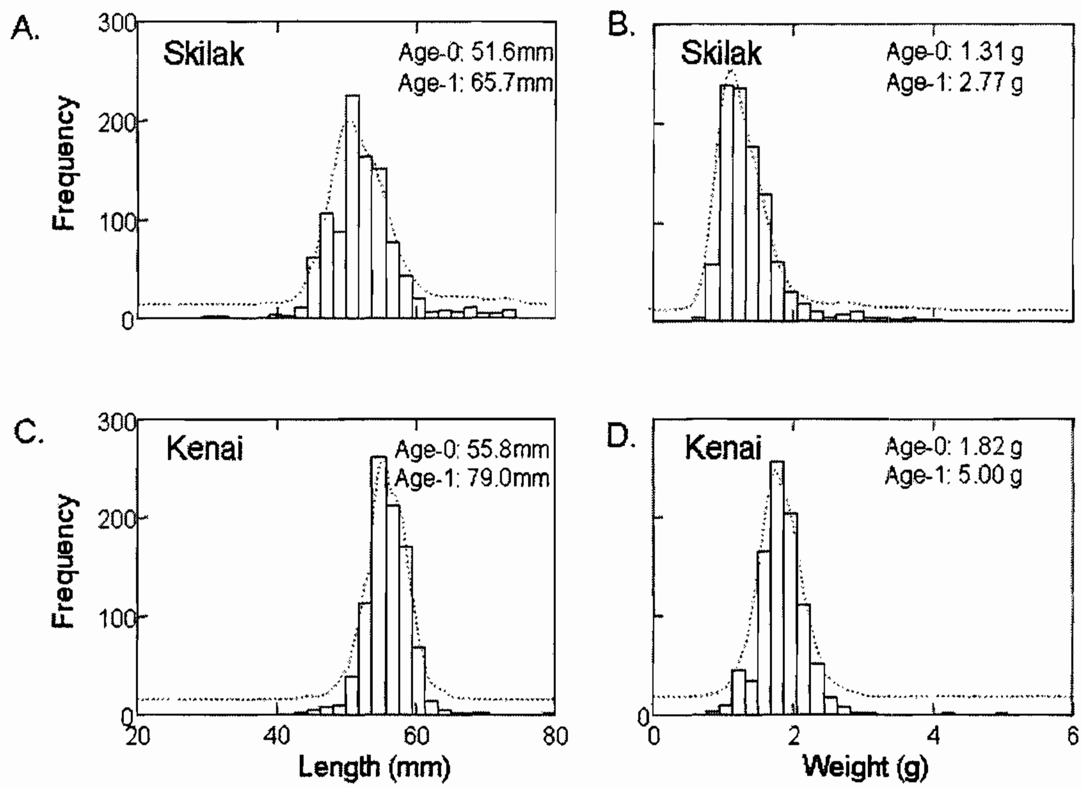

Figure 3. Kenai and Skilak Lake age-weight and length distribution.

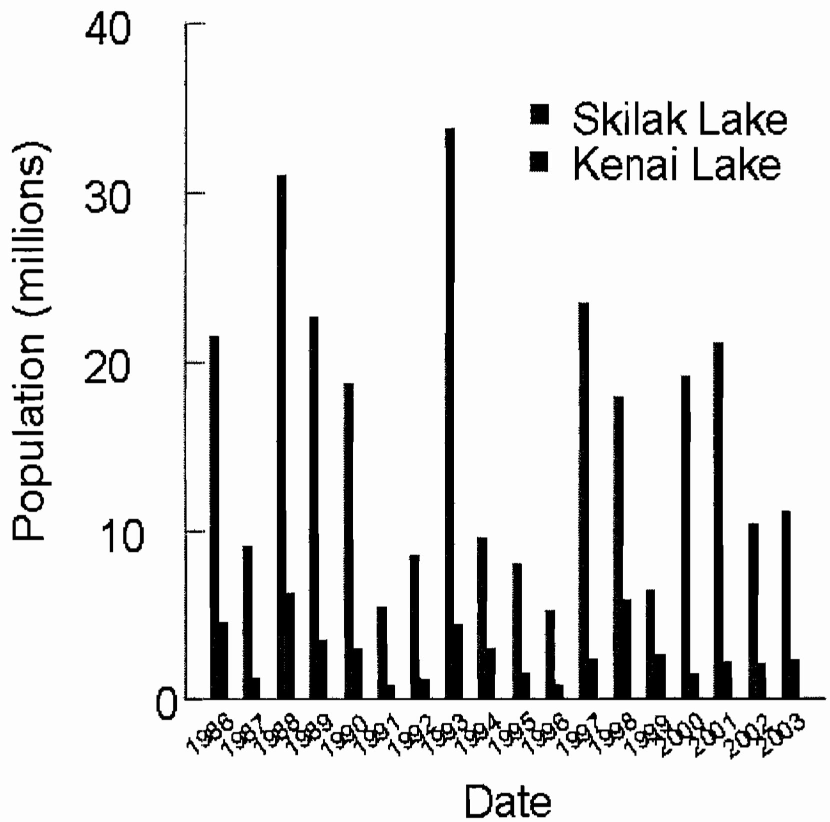

Figure 4. Skilak and Kenai historical population estimates.

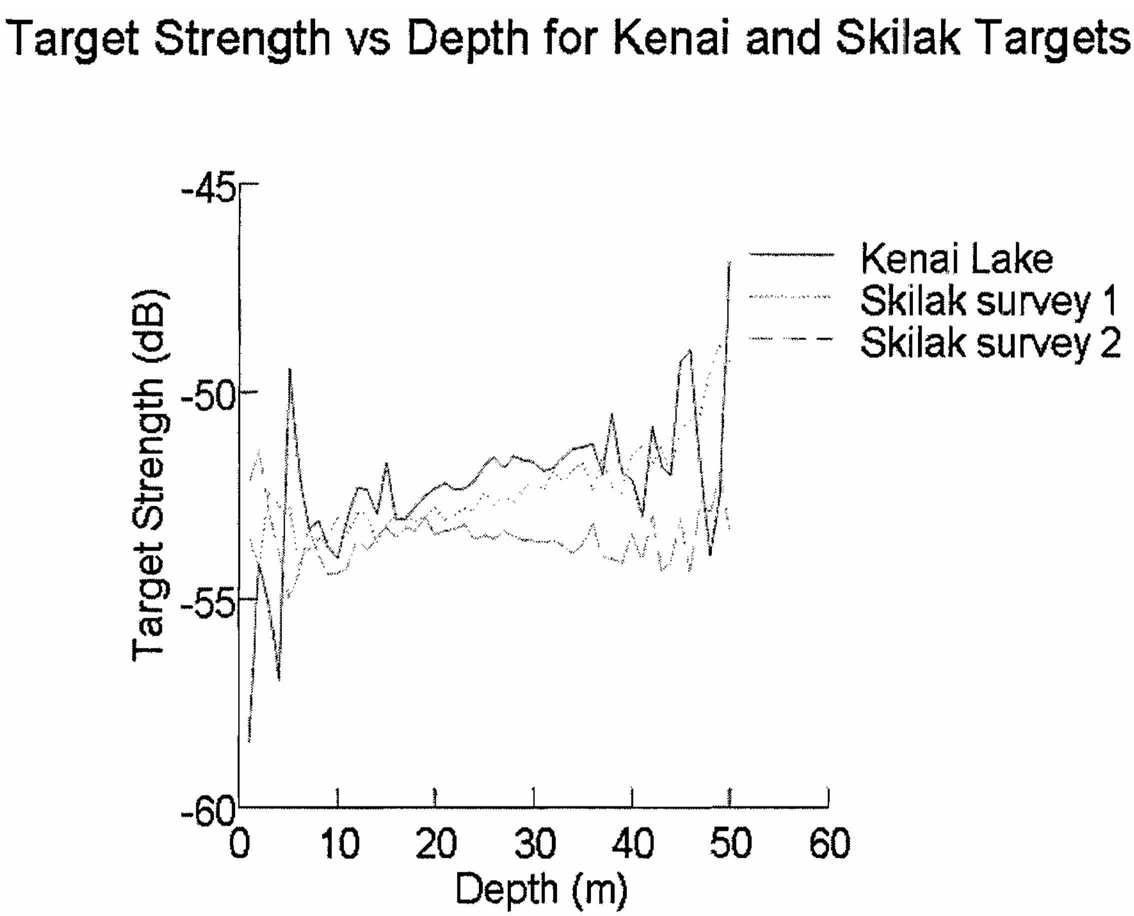

Figure 5. Target strength vs. depth for Kenai and Skilak Lake hydroacoustic surveys in September 2003.

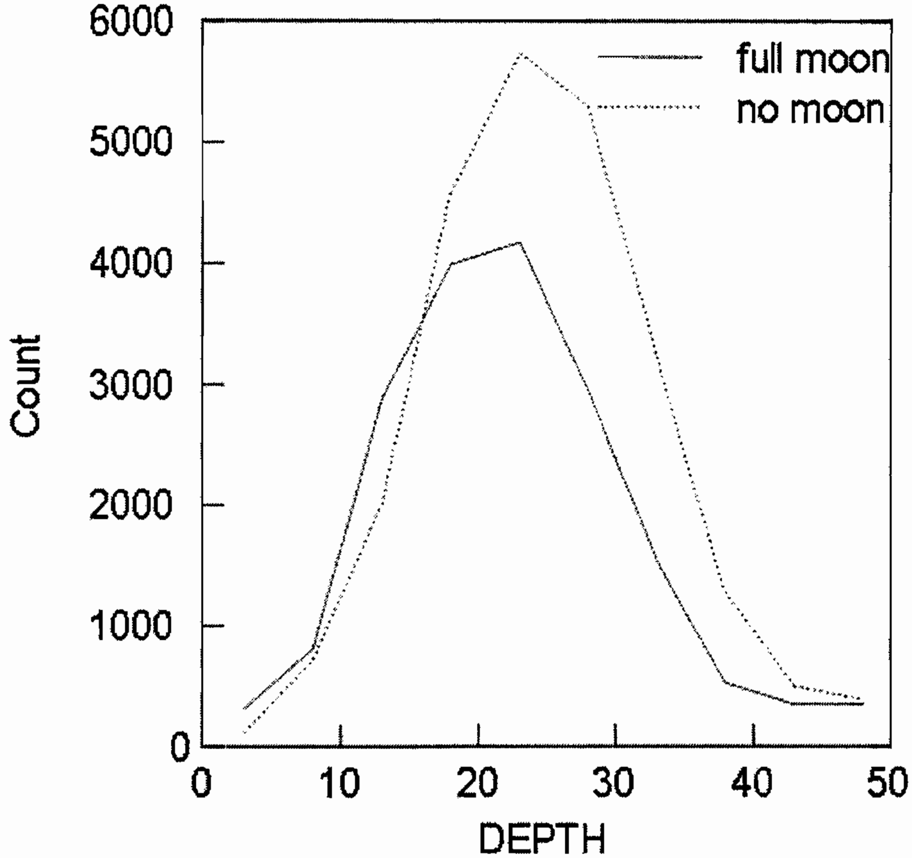

Figure 6. Target distribution at depth for Skilak Lake acoustic surveys September 2003.

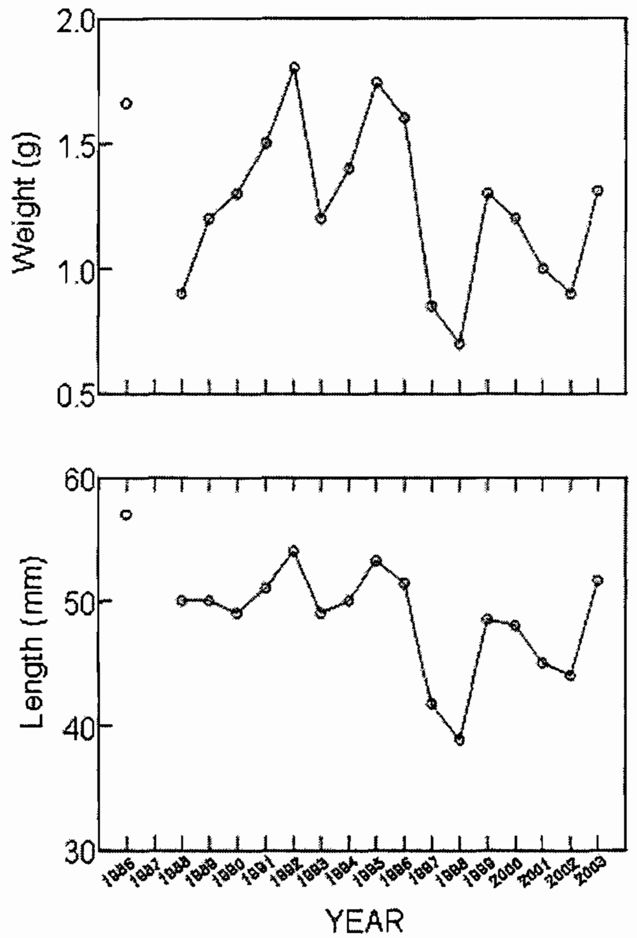

Figure 7. Historical mean lengths and weights for age-0 Skilak Lake sockeye salmon.

APPENDICES

Appendix A 1. Mean σ for the September 2003 hydroacoustic survey in Skilak Lake with the full moon.

Skilak Strata	Number	σ	Mean σ / Depth σ
1 –6 m	312	1.19E-05	1.02
6 – 11 m	813	8.07E-06	0.99
11 – 16 m	2886	9.40E-06	1.00
16 – 21 m	3989	8.98E-06	1.00
21 – 26 m	4171	7.76E-06	0.99
26 – 31 m	2958	8.45E-06	0.99
31 – 36 m	1541	9.91E-06	1.01
36 – 41 m	522	1.17E-05	1.02
41 – 46 m	340	1.41E-05	1.04
46 – 51 m	346	1.94E-05	1.07
Grand Total	17878	9.14E-06	1.00

Appendix A 2. Mean σ for the September 2003 hydroacoustic survey in Skilak Lake without the full moon.

Skilak Strata	Number	σ	Mean σ / Depth σ
1 –6 m	116	1.00E-05	1.04
6 – 11 m	719	5.96E-06	0.99
11 – 16 m	2011	7.30E-06	1.01
16 – 21 m	4583	6.62E-06	1.00
21 – 26 m	5738	6.35E-06	1.00
26 – 31 m	5297	5.96E-06	0.99
31 – 36 m	3232	5.74E-06	0.99
36 – 41 m	1274	5.89E-06	0.99
41 – 46 m	493	6.67E-06	1.00
46 – 51 m	383	8.34E-06	1.02
Grand Total	23846	6.33E-06	1.00

Appendix A 3. Mean target strength, σ for the September 2002 hydroacoustic survey in Kenai Lake.

Kenai Strata	Number	σ	Mean σ / Depth σ
1 -6 m	33	7.58E-06	0.98
6 – 11 m	194	7.76E-06	0.98
11 – 16 m	741	1.08E-05	1.01
16 – 21 m	2011	9.23E-06	1.00
21 – 26 m	3175	9.51E-06	1.00
26 – 31 m	2756	9.97E-06	1.00
31 – 36 m	1677	9.75E-06	1.00
36 – 41 m	551	1.09E-05	1.01
41 – 46 m	107	1.13E-05	1.01
46 – 51 m	36	8.89E-06	0.99
Grand Total	11281	9.74E-06	1.00