JUVENILE SOCKEYE SALMON POPULATION ESTIMATES IN SKILAK AND KENAI LAKES, ALASKA, BY USE OF SPLIT-BEAM HYDROACOUSTIC TECHNIQUES IN SEPTEMBER 1999.

by

Robert D. DeCino

Donald Degan

Regional Information Report[1] No. 2A00-6

Alaska Department of Fish and Game
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[1]The Regional Information Report Series was established in 1987 to provide an information access system for all unpublished divisional reports. These reports frequently serve diverse ad hoc informational purposes or archive basic uninterpreted data. To accommodate timely reporting of recently collected information, reports in this series undergo only limited internal review and may contain preliminary data; this information may be subsequently finalized and published in the formal literature. Consequently, these reports should not be cited without prior approval of the author or of the Division of Commercial Fisheries.

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ABSTRACT

From September 20-24, 1999 hydroacoustic surveys were completed on Skilak and Kenai Lakes using split-beam sonar. This is the first time split-beam sonar has been used to estimate juvenile sockeye salmon, *Oncorhynchus nerka,* for these two lakes. The population estimates for Skilak and Kenai Lakes were approximately 6,400,000 and 2,500,000 fish. In early September 1999, annual midwater trawls were conducted on both lakes for age, weight, and length (AWL) studies. In Skilak Lake, 92% of juvenile sockeye were age-0 with a mean weight of 1.3 g, and 49 mm long. In Kenai Lake the age-0 fish accounted for 95.5% of the sample. Mean length of these fish was 43 mm with an average weight of 0.9 g.

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

INTRODUCTION

In September 1999, the Alaska Department of Fish and Game (ADF&G) conducted its annual juvenile sockeye salmon, *O nerka*, population estimates along with age, weight and length (AWL) sampling. These population estimates and midwater trawls have been performed since 1986. These techniques are used to add information to a time series of juvenile sockeye salmon population estimates (Tarbox and King 1988a, 1988b, Tarbox, et. al. 1993; Tarbox and Brannian 1995, Tarbox et. al.1996) and the population's autumn condition factor.

The objectives for the 1999 hydroacoustic population surveys were to enumerate juvenile salmon and assess the population pre-winter condition. Population estimates were completed by use of split-beam sonar. The condition of the juvenile sockeye was based on captured fish from mid-water trawls. In addition, transects across each lake were geo-referenced during the hydroacoustic survey. Prior to the 1999 hydroacoustic surveys, surveys were conducted with dual-beam sonar (Tarbox et al. 1999).

METHODS

Hydroacoustic Surveys

We used a stratified random sampling design for the hydroacoustic surveys to distribute sampling effort and provide an appropriate estimation of total fish abundance and variance. 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. The sample size was based on Tarbox et al (1999). Because of the configuration of Skilak Lake transects perpendicular to shore were surveyed within three sub-basins (Figure 1). In Kenai Lake, transects were surveyed within five sub-basins (Figure 2).

Juvenile sockeye salmon were sampled, acoustically, at night with a BioSonics DT-6000[1] split beam echosounder. A 6.6^{0} circular split-beam transducer was mounted to a 1.5-m long steel 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 a Garmin[1] GMAP model 175 global positioning system (GPS) was differentially corrected with a Garmin[1] model CBR-21 receiver tuned to the Kenai land station (output correction at 310kHz, 100bps). Differentially corrected latitude and longitude coordinates were input through the echosounder to the computer.

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

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variables (temperature) were measured with YSI[1] model 58 digital thermistor and input to the environmental variables of the program. Fish were acoustically sampled at 1-5 pings/sec, 0-60 m depth, 0.4 ms pulse width and a –65dB data threshold. Twelve-volt batteries powered the acoustic system and the laptop computer operated on power supplied by a Honda[1] generator.

Transects were chosen based on a stratified random design (Tarbox 1999, Jolly and Hampton 1990, Figures 1 & 2). Transects were traversed at approximately 2m/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-a-long"), connected to a boom and towed off the boats starboard approximately 1-m below the water surface.

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 *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 BioSonics[1] *Visual Analyzer* program for echo-integration.

Fish density estimates were performed on each transect. In Skilak Lake individual transects were made up of partial cross-lake transects. That is, any one transect that traversed the entire lake width could have been comprised of up to three smaller transects. Fish densities were calculated for each transect and weighted based on distance traveled. Distance traveled was determined from beginning and ending latitude and longitude coordinates.

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. It consisted of an estimate of the number of fish detected by hydroacoustic gear in the mid-water section (M_{ij}). In order to estimate fish unavailable to the hydroacoustic gear because of their location near the surface (S_{ij}), the upper stratum was assumed equal to the first stratum echo integrated in the lake. That assumption is based on lake morphometry and percent volume sampled in post-processing analysis

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

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

The mid-water component was estimated as

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

where a_i represented the surface area (m^2) of area stratum i which was estimated using a planimeter and USGS maps of Skilak and Kenai Lakes. The depth would be less than the maximum 5 m if the bottom was detected within depth stratum k anytime along a transect. The estimated mean fish density in area i depth k across transect j was m_{ijk} in number/m^2.

The estimated number of fish near the surface (0–2 m) in area i was

$$\hat{S}_{ij} = a_{is} m_{ij1} \,,$$

where a_{is} was the estimated area (m^2) of the surface stratum (0–2 m), and m_{ij1} 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) became the mean abundance estimated by each transect j, or

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

and its variance was estimated as

$$v(\hat{N}_i) = \sum_{j=1}^{J} (\hat{N}_{ij} - \hat{N}_i)^2 (J - 1)^{-1} J^{-1} \,.$$

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

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

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

$$\hat{N}_{sa} = \hat{N} \hat{p}_a \,,$$

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

Variance estimates were calculated as

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

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

Age, Weight, and Length (AWL) surveys

Mid-water trawls (tow netting) were undertaken 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). Area and depth defined strata. 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.

In Kenai Lake, the same stratified random sampling technique was used (Scheaffer et al. 1986, Cochran 1977). 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).

All captured fish 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

For target strength estimation a total of 14,660 echoes were used to calculate target strenth of –53.73 dB with a standard deviation (SD) of 4.14 dB. The mean σ used for echo integration equaled 6.51×10^{-6} with a SD of 9.8×10^{-6} (Table 1). As a result, the estimated fish population was approximately 6,427,700 with a standard error (SE) of about 880,000 fish. Of the estimated population of juvenile sockeye salmon approximately 45 percent were detected in Area 1 (Table 2, Figure 1). In addition, the largest portion of juvenile sockeye salmon not available to hydroacoustic sampling techniques (estimated in the upper 2 m of the water column) were detected in Area 1 (Table 2). Skilak Lake's total contribution of fish in the upper 2 m accounted for approximately 273,000 fish.

From the tow-net survey, 1,063 total fish were captured of which 1,062 fish or 99.91 % (SE = 0.17 %) were juvenile sockeye salmon. Nine hundred juvenile sockeyes were subsampled for age, wet weight, and fork length (AWL). Of the total sockeye captured, age-0 juvenile sockeye accounted for 92% (SE = 2.54%). The remaining 8% (SE = 2.53 %) were apportioned to age-1 fish. Therefore, approximately 5,907,000 (SE = 826,000) and 514,000 (SE = 176,000) fish were aged 0 and 1+ years, respectively. Age-0 juvenile sockeye salmon had an average weight of 1.3 g (SE = 0.03g) with an average length of 48.52 mm (SE = 0.22mm). The age-1 juvenile sockeye mean weight of 4.0 g (SE = 0.05g) and a mean length were 70.5 mm (SE = 0.36mm).

Kenai Lake

A total of 16,334 echoes were used for estimating target strengths in Kenai Lake. The mean target strength was –54.38 dB with a SD of -3.72 dB. The mean σ was 5.21 X 10^{-6} with a SD of 5.60 X 10^{-6}. Unlike Skilak Lake, two different σ's were used for echo integrating the water column. From 1 to 31m depth σ = 5.64 X 10^{-6} (92.4 % of average σ) and from 31 to 51 m depth σ = 4.38 X 10^{-6} (118.9 % of average σ). These σ's resulted in a population estimate of approximately 2,551,000 (SE = 354,669) fish. Of the 2,551,000 fish, approximately 281,000 fish were accounted from the lake surface (upper 2-m) not sampled by the hydroacoustic gear (Table 2).

From the mid-water trawls conducted in Kenai Lake, the proportion of juvenile sockeye salmon accounted for 99.5 % (SE = 0.17%) of the catch. This proportion resulted in a population estimate of approximately 2,539,000 (SE = 353,000) sockeye salmon. Of the apportioned juvenile sockeye, 95.5 % (SE = 1.89 %) were age-0 which accounted for approximately 2,423,000 (SE = 340,000) fish. The mean age-0 fish weighed 0.91 g (SE =0.03g) and were 42.9 mm (SE = 0.5mm) long. The remaining age-1 fish population was approximately 114,000 fish (SE = 50,000). The average age-1 fish weight and length were 3.5 g (SE = 0.1g) and 67.4 mm (SE = 0.2 mm), respectively.

DISCUSSION

In September 1999, the ADF&G used a 200 kHz split-beam sonar configuration for echo integrating juvenile sockeye salmon in Kenai and Skilak Lakes. There were about three times fewer juvenile sockeye salmon in 1999 as compared to either the 1997 or 1998 population estimates for both lakes. The 1999 population estimate falls within ranges of the 1991, 1992, and 1995, 1996 population estimates. In addition, the target strengths of the sockeye salmon occur within reported target strengths from the historical use of dual-beam hydroacoustic surveys (see Tarbox et al. 1996).

The juvenile sockeye salmon population estimate in Skilak Lake has followed a similar trend since 1986 (Tarbox et al. 1999), that is, a greater abundance of fish in Skilak Lake compared to Kenai Lake. The 1999 Skilak Lake population of juvenile sockeye salmon is the third lowest estimate since 1986. The highest population estimate occurred in 1993, and consisted of approximately 33 million fry (Tarbox et al 1996). The lowest population estimate (1996) totaled 5.2 million fish. The average population estimates since 1986 is equal to 15.9 million fish with a SD of 9.1 million fish. This estimate is much lower than the historical average.

In addition to the population structure observed in both systems, target strengths behaved similarly to historical acoustically sampled targets. That is, target strength decreased with depth (Figure 3). Kenai Lake's target strength exhibited a greater degree of decline when compared with Skilak Lake. This response is most likely due to signal scattering in glacial systems. Kenai Lakes turbidity (9 NTU) is, on average, approximately two times greater than Skilak Lake's (5 NTU) turbidity (Schmidt et al. 1994).

The 1999 Kenai Lake population estimate of 2.5 million fish is seventh highest since inception of acoustic estimates starting in 1986. Juvenile sockeye salmon estimates range from 760,000 in 1996 to 6.2 million in 1988 (Tarbox et al 1996). The average population since 1986 is 2.8 million fish with a SD of 1.7 million. The population of Kenai Lake appears consistent with historical populations.

Conversely, juvenile sockeye salmon lengths and weights did not follow historical trends. Kenai Lake, on average, produces slightly larger fish in both length and weight compared with Skilak Lake. However, the size of juvenile sockeye salmon is consistent with respect to fish sampled from mid-water trawls compared with fish sampled with hydroacoustic techniques.

The split-beam sonar configuration gives results similar to those obtained with dual-beam sonar. The compact digital sonar system (transducer, sounder, DGPS and laptop computer) simplifies equipment preparation, setup and deployment. The ability to collect and store data on the computer hard drive eliminated use of digital-audio tapes, providing a more reliable and user friendly system. Post process editing of the data was more accurate by zooming into bottom structure and separating bottom signals from target echoes. This utility enabled more data to be included into the data set.

Use of the split-beam system provided new abilities such as the use of a DGPS to input and store transect location to recorded echoes. Using a DGPS transects we were able to recreate exact location of transects on digitized maps of the lakes. This ability will enable researches to build a database of transects to chart the lakes biological and morphological characteristics inter-annually. Furthermore hydroacoustics survey techniques that have DGPS input coupled with digitized lakes provides the opportunity to estimate entire lake sockeye salmon populations. For a description of Skilak and Kenai Lakes estimated population by use of these techniques see Appendix II.

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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	14,660	-53.73 (-4.14)	6.51×10^{-6} (9.8×10^{-6})
Kenai all targets	16,334	-54.38 (-3.72)	5.21×10^{-6} (5.6×10^{-6})
Kenai 1 – 31 m	12,026	-54.14 (-3.82)	5.64×10^{-6} (6.1×10^{-6})
Kenai 31 – 60 m	4,308	-55.04 (-3.31)	4.38×10^{-6} (3.6×10^{-6})

Standard Deviations are in parenthesis

Table 2. Estimated number of total fish in Skilak and Kenai Lakes, Alaska in September 1999.

			Estimated Number of Fish				
Lake	Area	Transect	Surface	Midwater	Total	Mean	Variance
Skilak	1	1	2.3657E+04	4.7533E+06	4.7769E+06		
		2	6.1512E+04	2.1444E+06	2.2059E+06		
		3	5.4453E+05	2.7299E+06	3.2744E+06	2.8757E+06	5.7329E+11
		4	1.6701E+05	1.0786E+06	1.2456E+06		
	2	1	4.3188E+04	2.5145E+06	2.5577E+06		
		2	6.7402E+04	1.3207E+06	1.3881E+06	2.0344E+06	1.1270E+11
		3	3.7620E+04	1.4869E+06	1.5245E+06		
		4	2.7554E+04	2.6399E+06	2.6675E+06		
	3	1	5.9697E+04	7.6156E+05	8.2125E+05		
		2	3.9109E+04	2.1207E+06	2.1598E+06	1.5175E+06	9.0563E+10
		3	1.6701E+04	1.2212E+06	1.2379E+06		
		4	5.1798E+03	1.8460E+06	1.8512E+06		
	TOTAL					6.4277E+06	7.7655E+11
Kenai	1	1	8.4539E+03	7.5412E+04	8.3866E+04		
		2	3.2168E+03	1.40E+05	1.4310E+05		
		3	3.7918E+04	1.8340E+05	2.2132E+05	1.7636E+05	2.4017E+09
		4	5.3614E+04	3.4047E+05	3.9408E+05		
		5	2.2844E+03	6.3240E+04	6.5525E+04		
		6	2.2689E+02	1.5005E+05	1.5028E+05		
	2	1	7.4274E+03	4.7368E+05	4.8111E+05		
		2	3.6536E+04	2.3294E+05	2.6948E+05		
		3	1.9758E+03	1.1197E+05	1.1395E+05	2.3979E+05	8.0014E+09
		4	6.1294E+03	8.8519E+04	9.4648E+04		
	3	1	1.0281E+05	6.2992E+05	7.3274E+05		
		2	1.1456E+05	6.1029E+05	7.2485E+05		
		3	2.8252E+03	4.1790E+05	4.2072E+05	6.1830E+05	1.0102E+10
		4	9.8775E+03	3.3376E+05	3.4364E+05		
		5	6.3726E+04	8.06E+05	8.6954E+05		
	4	1	6.2015E+04	5.2560E+05	5.8762E+05		
		2	2.4700E+04	5.2322E+05	5.4792E+05		
		3	0.0000E+00	3.6667E+05	3.6667E+05	7.4730E+05	7.0412E+10
		4	2.1138E+04	4.1610E+05	4.3723E+05		
		5	4.2322E+05	1.3738E+06	1.7970E+06		
	5	1	2.5328E+05	1.2432E+06	1.4965E+06		
		2	7.7967E+04	1.2616E+06	1.3396E+06		
		3	4.3609E+04	5.4884E+05	5.9245E+05		
		4	1.0616E+05	7.2758E+05	8.3374E+05	7.6929E+05	3.4876E+10
		5	1.1629E+04	3.0660E+05	3.1823E+05		
		6	1.0109E+05	5.2754E+05	6.2864E+05		
		7	4.2287E+03	1.7168E+05	1.7591E+05		
	TOTAL					2.5510E+06	1.2579E+11
	TOTAL FOR BOTH LAKES					8.9787E+06	9.0235E+11

file name: 99totalestimatetable.xls

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 1999.

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	6,427,700	881,221	6,421,658	880,421	91.9	5,908,100	825,782	8.0	514,216	176,070
Kenai	2,551,000	354,669	2,539,112	353,042	95.0	2,424,841	340,305	4.5	114,795	50,223
Total	8,978,700	949,916	8,960,770	948,567		8,332,941	893,153		629,011	183,092
Variance	9.0×10^{11}		9.0×10^{11}			8.0×10^{11}			3.4×10^{11}	

Table 4. Age, weight and length of juvenile sockeye salmon from midwater trawl surveys September 1999.

	Age-0			Age-1		
Lake	n	mean l (mm)	mean wt (g)	n	mean l (mm)	mean wt (g)
Skilak	828	48.5 (0.26)	1.3 (0.03)	72	70.5 (0.36)	4.0 (0.05)
Kenai	612	42.9 (0.52)	0.9 (0.03)	29	67.4 (0.24)	3.5 (0.06)

Standard Errors (SE) are in parenthesis.

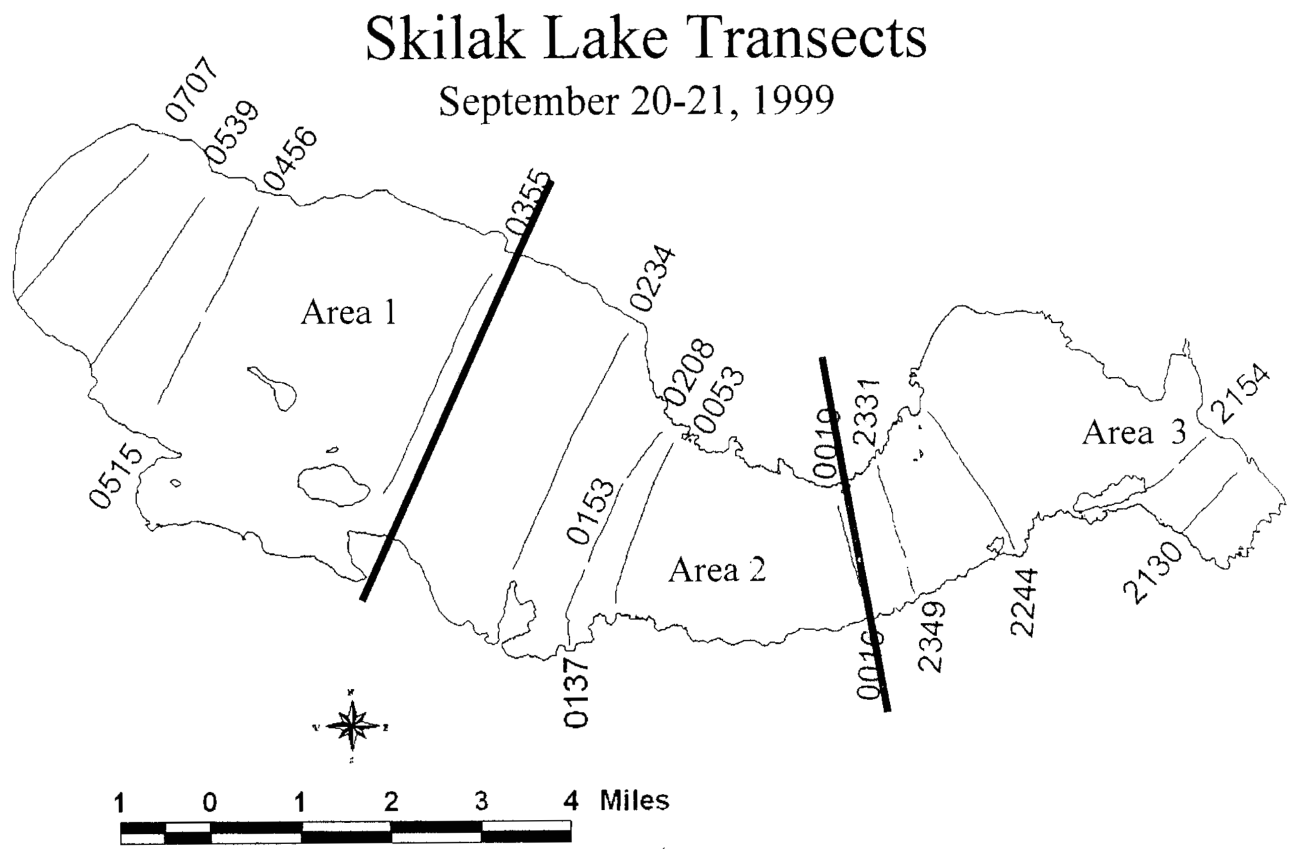


Figure 1. Skilak Lake transects and areas.

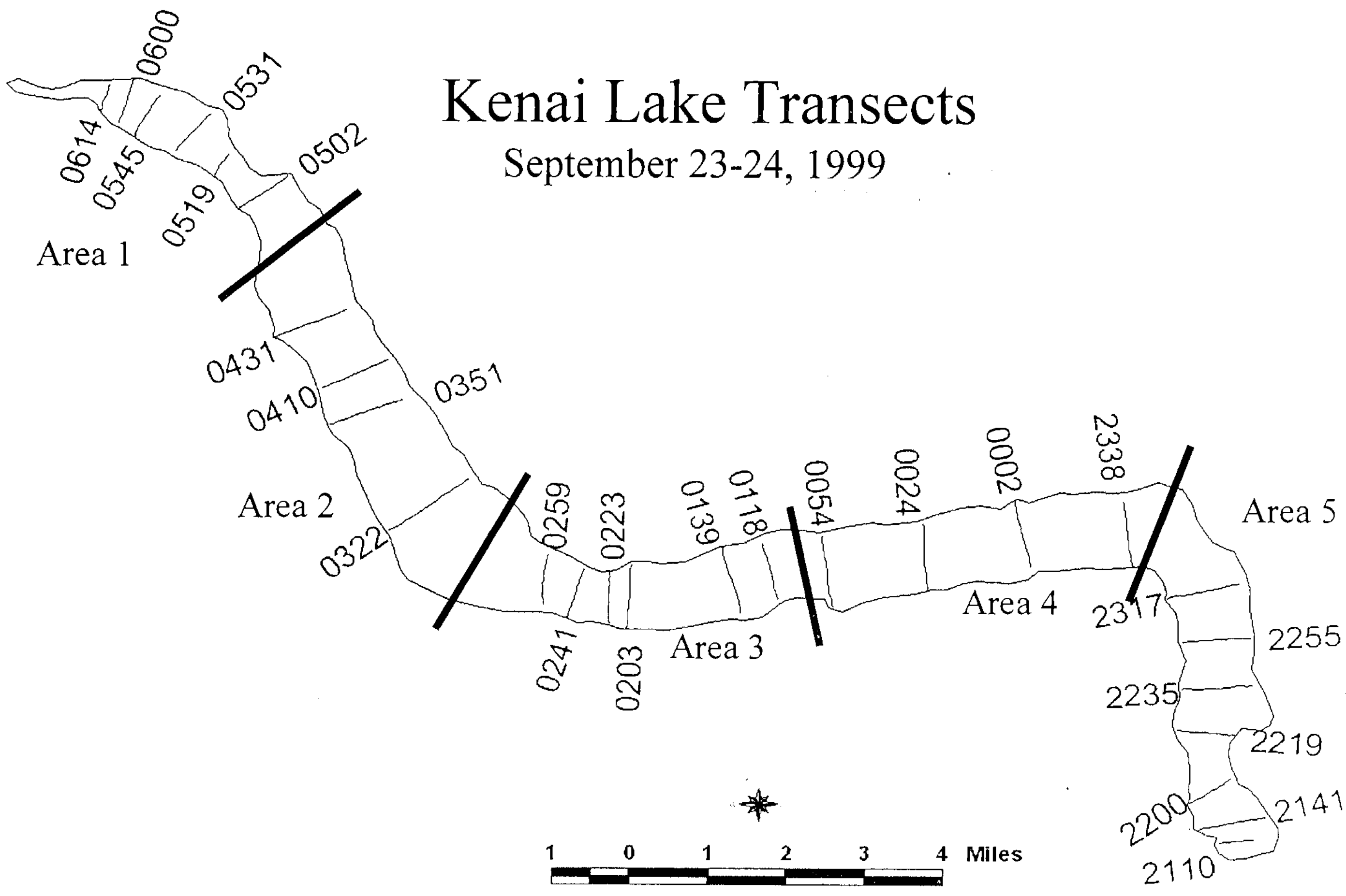


Figure 2. Kenai Lake transects and areas.

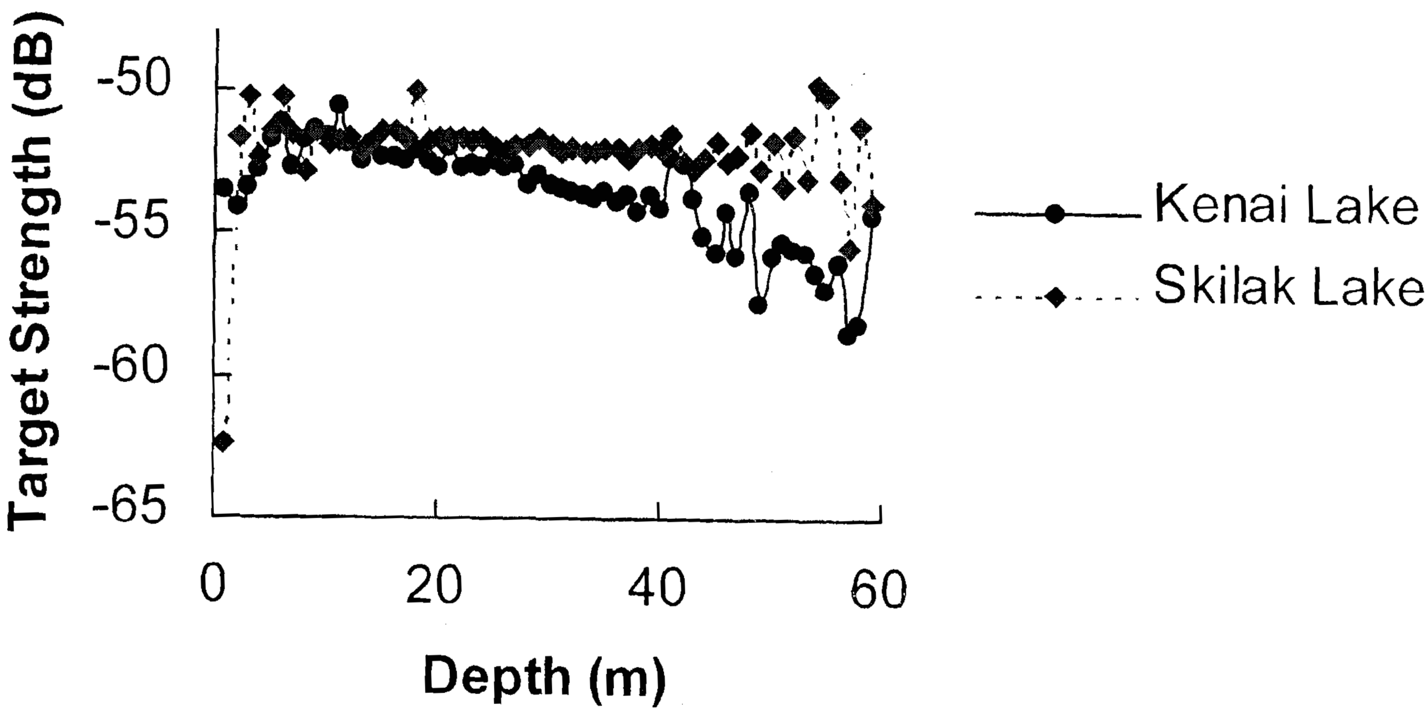


Figure 3. Target strength vs depth for Kenai and Skilak Lake hydroacoustic surveys in September 1999

APPENDIX A

Appendix A1. Mean σ for September 1999 hydroacoustic survey in Skilak Lake.

Skilak Strata	Number	σ	Mean σ / Depth σ
0 –5 m	46	6.65E-06	0.98
5 – 10 m	308	7.11E-06	0.91
10 – 15 m	695	6.54E-06	0.99
15 – 20 m	1368	7.58E-06	0.86
20 – 25 m	2501	6.77E-06	0.96
25 – 30 m	2859	6.43E-06	1.01
30 – 35 m	2788	6.18E-06	1.05
35 – 40 m	1877	6.23E-06	1.04
40 – 45 m	1173	6.10E-06	1.07
45 – 50 m	595	6.22E-06	1.05
50 – 55 m	353	6.44E-06	1.01
55 – 60 m	97	6.11E-06	1.07
Grand Total	14660	6.51E-06	1.00

Appendix A 2. Mean target strength, σ for September 1999 hydroacoustic survey in Kenai Lake.

Kenai Strata	Number	σ	Mean σ / Depth σ
0 -5 m	71	4.65E-06	1.12
5 – 10 m	292	6.66E-06	0.78
10 – 15 m	1046	6.74E-06	0.77
15 – 20 m	2074	5.82E-06	0.90
20 – 25 m	3716	5.61E-06	0.93
25 – 30 m	4126	5.26E-06	0.99
30 – 35 m	2795	4.46E-06	1.17
35 – 40 m	1333	4.17E-06	1.25
40 – 45 m	398	4.58E-06	1.14
45 – 50 m	196	3.17E-06	1.64
50 – 55 m	150	2.70E-06	1.93
55 – 60 m	137	2.28E-06	2.28
Grand Total	16334	5.21E-06	1.00

Strata	Number	σ	% of mean
0 – 30 m	11325	5.64E-06	0.92
30 – 45 m	4526	4.38E-06	1.19
45 – 60 m	483	2.77E-06	1.88
Grand Total	16334	5.21E-06	1.00

APPENDIX B

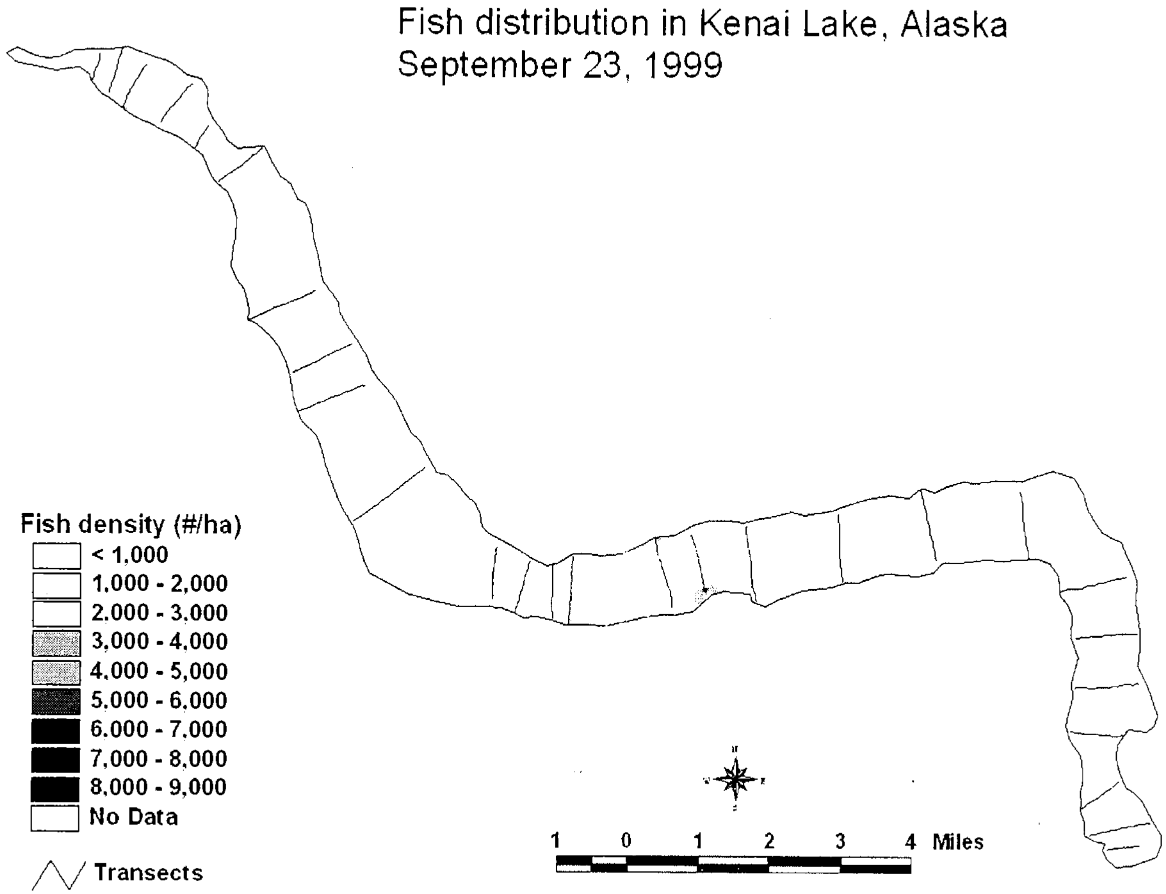
Population estimates were for both lakes were computed using a GIS program. Fish density by transect and report was plotted as an overlay on each lake outline. The density was then interpolated between the data points by Inverse Weighted Distance with the distance expanded for each point to 2000 meters so that many points were used to calculate a density for each cell. A grid was generated for density within the lake and a map displaying this is provided (Appendix B 1, 2). The density was blocked by 405 square meter cells and grouped into 60 equal intervals (resulting in-groups with min and max, range, mean, and stdev in tables for each lake (Appendix A 3, 4). The count of the number of cells with each density value is summed, divided by 10,000 to convert to hectares, then multiplied by the mean density for each cell range. These fish numbers are then summed for the entire lake to generate a population estimate. These numbers look similar between methods (Tables 1, 2, 3; Appendix A 3, 4). However, these values do not reflect the expansion for densities near the surface not sampled with acoustics.

Appendix B.1. Skilak Lake estimates using GIS method.

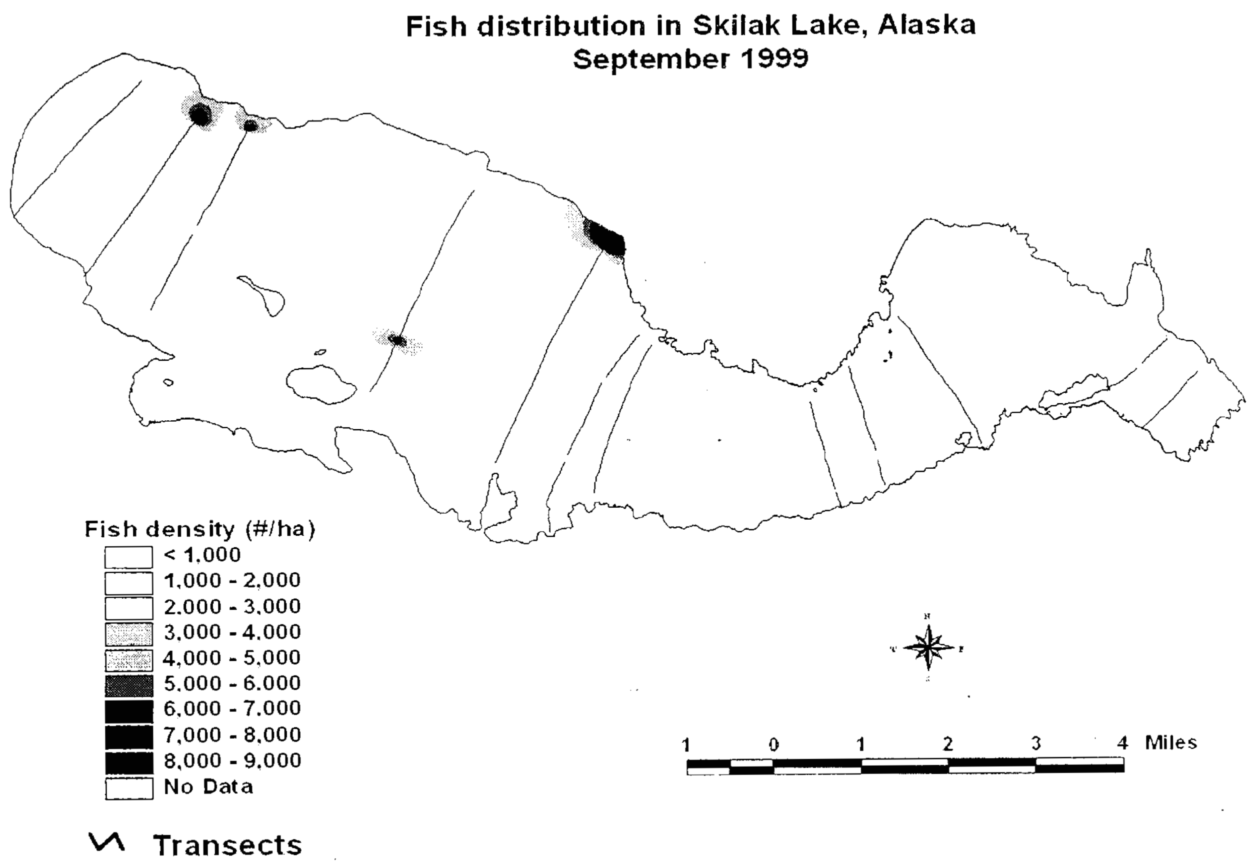
Value	Count	Area(m)	Min	Max	Range	Mean	Std	Sum	Number	
1	15436	4,233,388	0.00	148.08	148.08	98.15	37.14	1,515,004	41,550	
2	61218	16,789,292	148.09	296.16	148.08	228.70	42.31	14,000,319	383,965	
3	71374	19,574,616	296.17	444.25	148.08	363.37	43.11	25,934,874	711,275	
4	49075	13,459,023	444.25	592.33	148.08	518.64	43.59	25,452,264	698,039	
5	52372	14,363,239	592.33	740.42	148.08	669.90	42.78	35,084,140	962,197	
6	36938	10,130,400	740.42	888.49	148.08	809.04	43.08	29,884,140	819,585	
7	24154	6,624,335	888.51	1036.58	148.07	961.15	42.70	23,215,674	636,700	
8	15978	4,382,033	1036.59	1184.66	148.07	1101.95	42.55	17,607,034	482,880	
9	9087	2,492,148	1184.68	1332.70	148.02	1252.32	42.47	11,379,840	312,097	
10	6168	1,691,600	1332.76	1480.80	148.03	1403.65	42.67	8,657,744	237,442	
11	5182	1,421,185	1480.84	1628.88	148.03	1552.65	42.66	8,045,840	220,661	
12	3914	1,073,431	1628.93	1776.98	148.05	1698.89	42.86	6,649,448	182,364	
13	3077	843,880	1777.03	1925.02	147.99	1847.53	42.32	5,684,865	155,910	
14	2254	618,169	1925.12	2073.10	147.98	1994.88	42.56	4,496,456	123,317	
15	1667	457,182	2073.24	2221.23	147.99	2145.05	43.33	3,575,805	98,068	
16	1497	410,559	2221.32	2369.27	147.96	2294.89	42.21	3,435,455	94,219	
17	1200	329,105	2369.57	2517.41	147.85	2440.36	42.54	2,928,430	80,313	
18	940	257,799	2517.49	2665.02	147.53	2590.62	43.15	2,435,187	66,786	
19	893	244,909	2665.52	2813.40	147.88	2735.16	42.48	2,442,497	66,986	
20	649	177,991	2813.68	2961.46	147.78	2883.62	41.30	1,871,472	51,326	
21	544	149,194	2962.09	3109.70	147.60	3032.26	42.74	1,649,548	45,240	
22	466	127,802	3109.90	3257.13	147.23	3181.90	42.57	1,482,766	40,665	
23	386	105,862	3257.87	3405.91	148.04	3332.55	42.98	1,286,366	35,279	
24	356	97,634	3406.52	3553.93	147.40	3480.90	43.12	1,239,199	33,986	
25	304	83,373	3554.09	3702.05	147.95	3626.23	42.64	1,102,373	30,233	
26	288	78,985	3702.57	3849.85	147.28	3776.71	42.94	1,087,694	29,830	
27	259	71,032	3851.42	3998.01	146.59	3925.13	43.71	1,016,610	27,881	
28	232	63,627	3999.26	4145.84	146.58	4072.44	41.22	944,805	25,912	
29	223	61,159	4147.66	4294.13	146.46	4216.78	40.91	940,343	25,789	
30	219	60,062	4294.85	4442.37	147.52	4369.78	40.75	956,983	26,246	
31	186	51,011	4444.91	4589.84	144.94	4515.67	41.03	839,915	23,035	
32	178	48,817	4590.77	4736.66	145.89	4663.64	44.28	830,128	22,767	
33	161	44,155	4739.24	4886.71	147.46	4812.08	43.73	774,744	21,248	
34	154	42,235	4887.40	5033.76	146.36	4962.23	43.24	764,184	20,958	
35	136	37,299	5037.10	5182.44	145.34	5110.88	40.07	695,079	19,063	
36	125	34,282	5183.12	5329.69	146.57	5260.34	44.40	657,542	18,033	
37	125	34,282	5331.85	5478.98	147.13	5402.36	45.37	675,295	18,520	
38	120	32,911	5479.64	5625.22	145.58	5547.61	42.21	665,713	18,257	
39	121	33,185	5627.82	5774.80	146.98	5707.06	41.59	690,554	18,939	
40	115	31,539	5775.98	5922.93	146.96	5853.16	43.07	673,114	18,460	
41	116	31,813	5926.59	6071.04	144.46	6001.75	41.74	696,203	19,094	
42	147	40,315	6074.28	6218.34	144.07	6147.87	38.89	903,736	24,785	
43	75	20,569	6219.52	6367.50	147.98	6297.28	42.74	472,296	12,953	
44	80	21,940	6371.91	6513.82	141.91	6435.31	42.55	514,825	14,119	
45	82	22,489	6516.31	6660.76	144.45	6588.41	45.08	540,250	14,817	
46	86	23,586	6667.58	6810.94	143.37	6743.58	42.47	579,948	15,905	
47	100	27,425	6815.21	6956.61	141.40	6899.00	43.12	689,900	18,921	
48	41	11,244	6963.16	7105.80	142.65	7033.60	45.14	288,378	7,909	
49	46	12,616	7109.86	7248.60	138.74	7175.25	40.40	330,062	9,052	
50	41	11,244	7258.79	7400.31	141.52	7337.84	43.14	300,852	8,251	
51	42	11,519	7405.35	7543.04	137.69	7476.95	40.03	314,032	8,612	
52	42	11,519	7554.94	7699.83	144.90	7625.19	44.85	320,258	8,783	
53	41	11,244	7711.56	7847.78	136.22	7787.53	37.36	319,289	8,757	
54	49	13,438	7851.36	7994.66	143.30	7926.29	41.47	388,388	10,652	
55	52	14,261	7998.58	8142.59	144.01	8071.05	42.58	419,695	11,510	
56	66	18,101	8145.70	8289.93	144.23	8227.33	43.17	543,004	14,892	
57	74	20,295	8294.28	8438.15	143.86	8366.67	43.15	619,134	16,980	
58	82	22,489	8441.01	8588.09	147.09	8516.00	45.33	698,312	19,151	
59	85	23,312	8589.08	8735.65	146.56	8664.53	45.12	736,485	20,198	
60	146	40,041	8737.54	8884.99	147.45	8829.33	45.61	1,289,082	35,354	
	369,264								**7,246,715**	Population estimate

Appendix B.2. Kenai Lake population estimate using GIS method.

Value	Count	Area	Min	Max	Range	Mean	Std	Sum	Number	
1	34724	14,073,386	0	148	148	81	38	2,802,397	113,579	
2	39179	15,878,965	148	297	148	215	40	8,429,587	341,645	
3	34573	14,012,187	297	445	148	368	41	12,739,805	516,335	
4	12074	4,893,505	445	594	148	498	40	6,009,284	243,552	
5	5339	2,163,858	594	742	148	656	41	3,501,861	141,928	
6	2593	1,050,924	742	891	148	821	45	2,129,945	86,325	
7	4186	1,696,556	891	1,039	148	978	45	4,093,449	165,905	
8	2621	1,062,272	1,039	1,188	148	1,107	49	2,900,769	117,566	
9	1492	604,697	1,188	1,336	148	1,248	46	1,861,444	75,443	
10	844	342,067	1,336	1,485	148	1,407	42	1,187,205	48,117	
11	516	209,131	1,485	1,633	148	1,553	44	801,472	32,483	
12	435	176,302	1,633	1,781	148	1,708	45	743,158	30,120	
13	375	151,985	1,782	1,929	148	1,855	42	695,510	28,189	
14	404	163,738	1,930	2,078	148	2,011	44	812,409	32,926	
15	409	165,765	2,079	2,227	148	2,148	43	878,561	35,607	
16	257	104,160	2,227	2,374	147	2,289	43	588,305	23,844	
17	131	53,093	2,376	2,523	147	2,445	43	320,275	12,980	
18	110	44,582	2,524	2,672	147	2,599	45	285,895	11,587	
19	84	34,045	2,676	2,819	142	2,752	42	231,147	9,368	
20	92	37,287	2,821	2,966	145	2,892	43	266,053	10,783	
21	78	31,613	2,972	3,116	145	3,054	40	238,179	9,653	
22	84	34,045	3,118	3,259	142	3,188	42	267,811	10,854	
23	54	21,886	3,274	3,414	141	3,336	39	180,137	7,301	
24	32	12,969	3,415	3,558	143	3,486	48	111,545	4,521	
25	23	9,322	3,566	3,707	141	3,648	40	83,895	3,400	
26	22	8,916	3,716	3,810	94	3,757	27	82,653	3,350	
27	10	4,053	3,872	3,980	108	3,924	43	39,244	1,591	
28	18	7,295	4,010	4,137	127	4,080	44	73,434	2,976	
29	10	4,053	4,158	4,268	110	4,200	36	42,003	1,702	
30	15	6,079	4,312	4,453	141	4,389	41	65,837	2,668	
31	9	3,648	4,493	4,569	77	4,529	20	40,760	1,652	
32	8	3,242	4,616	4,739	122	4,673	47	37,387	1,515	
33	6	2,432	4,753	4,892	139	4,816	54	28,894	1,171	
34	4	1,621	4,972	5,019	47	4,999	17	19,995	810	
35	1	405	5,105	5,105	0	5,105	0	5,105	207	
36	4	1,621	5,281	5,319	39	5,300	18	21,201	859	
37	3	1,216	5,382	5,477	95	5,425	39	16,275	660	
38	1	405	5,586	5,586	0	5,586	0	5,586	226	
39	4	1,621	5,651	5,767	116	5,713	41	22,852	926	
40	2	811	5,860	5,877	17	5,869	8	11,737	476	
41	1	405	5,995	5,995	0	5,995	0	5,995	243	
42	1	405	6,130	6,130	0	6,130	0	6,130	248	
43	3	1,216	6,266	6,333	67	6,302	28	18,906	766	
45	1	405	6,663	6,663	0	6,663	0	6,663	270	
46	2	811	6,686	6,710	24	6,698	12	13,397	543	
47	1	405	6,845	6,845	0	6,845	0	6,845	277	
48	1	405	6,978	6,978	0	6,978	0	6,978	283	
49	1	405	7,145	7,145	0	7,145	0	7,145	290	
50	2	811	7,372	7,415	43	7,393	22	14,787	599	
54	1	405	7,942	7,942	0	7,942	0	7,942	322	
56	1	405	8,245	8,245	0	8,245	0	8,245	334	
57	1	405	8,353	8,353	0	8,353	0	8,353	339	
58	2	811	8,510	8,606	95	8,558	48	17,116	694	
60	1	405	8,907	8,907	0	8,907	0	8,907	361	
	140,845								**2,140,370**	Population estimate



Appendix B.3. Kenai Lake fish distribution using GIS.



Appendix B.4. Skilak Lake distribution using GIS.