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Juvenile Sockeye Salmon Population Estimates in Skilak and Kenai Lakes, Alaska, by Use of Split-beam Hydroacoustic Techniques, 2005 through 2010

by

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and

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

Symbols and Abbreviations

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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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ABSTRACT

In the autumn of 2005 through 2010, we conducted autumn nighttime hydroacoustic surveys on Skilak and Kenai lakes to estimate the abundance of juvenile sockeye salmon *Oncorhynchus nerka* using split-beam sonar. Typically, a second hydroacoustic survey was conducted on Skilak Lake to provide for an evaluation of sampling error. Skilak Lake always had the larger population of the 2 lakes and the population estimates over these years at Skilak Lake ranged from 8.3 to 39.6 million juvenile sockeye. Kenai Lake juvenile population estimates ranged from 1.2 to 3.3 million fish. Annual midwater trawl surveys were also conducted to estimate age composition, mean weight, and mean length of juvenile sockeye salmon. For Skilak Lake, age-0 sockeye salmon comprised from 47% to 99.6% of the total population estimates. The mean weight and length of these cohorts ranged from 0.55 g and 39.9 mm to 1.64 g and 56.2 mm, with the smallest weight being the lowest on record since 1986. In comparison, Kenai Lake age-0 sockeye salmon accounted for greater than 97% of the total fish population. The age-0 fry in Kenai Lake were always larger than Skilak Lake fry, ranging from 1.81 g to 2.36 g weight and from 55.1 mm to 60.3 mm length.

Key words: Alaska, Cook Inlet, Skilak Lake, Kenai River, juvenile, salmon, sockeye salmon *Oncorhynchus nerka*, hydroacoustics, split-beam, sonar.

INTRODUCTION

In the autumn seasons from 2005 through 2010 the Alaska Department of Fish and Game (ADF&G) conducted hydroacoustic and tow-net surveys in Skilak and Kenai lakes (Kenai River drainage, Figure 1) to estimate abundance, age distribution, and size of juvenile sockeye salmon *Oncorhynchus nerka*. These surveys have been performed annually since 1986 (DeCino 2002; 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 is used to help biologists forecast the number of sockeye salmon returning to the Kenai River (Eggers 2013) and evaluate sustainable escapement goals (Fair et al. 2010). Information about juvenile abundance is important for separating freshwater production from marine production.

In this report, we describe the methods used in our lake surveys, and we provide (1) abundance estimates for the fall juvenile sockeye salmon rearing in Skilak and Kenai lakes, and (2) distributions of age, weight, and length of fry.

OBJECTIVES

This annual project has 2 primary objectives:

1. Conduct hydroacoustic population estimates in Kenai and Skilak lakes; and
2. Collect juvenile sockeye salmon with a midwater trawl to assess age, weight, and length prior to winter.

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 based on previous research findings (Tarbox and King 1988a and b; Tarbox and Brannian 1995; Tarbox et al. 1993; Tarbox et al. 1994; Tarbox et at. 1996 and 1999). Each lake was divided into areas or sub-basins and survey transects were randomly selected within each area based on a stratified-random design (DeCino and Degan 2000; Tarbox et. al. 1996; Jolly and Hampton 1990; Figures 2 and 3). 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 historical findings (Tarbox and Brannian 1995; Tarbox et al. 1993; Tarbox et al. 1994, 1996, and 1999). Because of the configuration of Skilak Lake, transects perpendicular to shore were surveyed within 3 sub-basins (Figure 2), whereas in Kenai Lake, transects were surveyed within 5 sub-basins (Figure 3). Transects were traversed at approximately 2 m/s. The acoustic vessel (7.2 m long) was powered by two 2-stroke outboard engines in years 2005 through 2007 and one 4-stroke engine in 2008 through 2010. Two hydroacoustic surveys were completed in Skilak Lake, and a single survey was conducted in Kenai Lake.

For these 2005–2010 fish surveys, population sizes were estimated using an echo integration (MacLennan and Simmonds 1992; Simmonds and MacLennan 2005) procedure applied to data obtained using split-beam sonar. For all hydroacoustic surveys, juvenile sockeye salmon were sampled acoustically at night with a BioSonics DTx-6000[1] split-beam echosounder. For specific data collection parameters on all surveys see Appendix A1. A down-looking transducer was mounted to a 1.5 m long aluminum towbody. The towbody was attached to a cable 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 geo-referenced transect routes, we used a Garmin Legend global positioning system (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. Environmental variables (temperature) were measured with an YSI[1] model 58 digital thermistor and input to the environmental variables section of the program. Twelve-volt batteries powered the acoustic system and the laptop computer.

The stored acoustic data were transported to the area office where they were uploaded into the office network for access by analyses programs. The acoustic data were edited by use of SonarData Echoview analysis software. Acoustic data were first edited to remove bottom echoes. After bottom editing was complete, water column "noise" was also removed (excluded by encapsulating noise inside a polygon and culling from analyses data sets), and then the individual target information was processed and saved for estimation of in situ target strength (TS) and sigma (σ), the area backscattering coefficient.

TS and σ computations were performed using a macro built by Aquacoustics Inc. For each lake, this macro appended all transects and calculated in situ TSs and σ's from each detected target. Targets were filtered to include only those echoes near the beam center (0 to -3 dB [decibels] off axis). Average σ's were derived from individual targets and both were put into 5 m depth strata. Generally, the entire lake average σ was input to a spreadsheet to compute densities for each transect using echo-integration. However, if a stratum differed by more than 20% of the mean σ computed for the entire lake, and target density was greater than 5% of total targets used to compute average σ, then a different σ was used to compute densities of the fish targets contained in that stratum (Appendix A2 and A3). TS and σ were processed from the same data collection threshold of -65 dB.

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

A fish density estimate was computed for each transect by echo integration and expanded for each area from which they were collected. The echo integrator compiled data in one report along each transect and sent outputs to computer files for further reduction and analysis. The total number of fish ($\hat{N}_{ij}$) for area stratum *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 the midwater depth intervals as described in DeCino and Degan (2000) and DeCino and Willette (2011). The population estimate of the area is based on the density of transect *j* component 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 area stratum *i* which was estimated using a planimeter and USGS maps of Skilak and Kenai lakes, and $\hat{M}_{ijk}$ (number/m^2) was the estimated mean fish density in area *i* depth *k* across transect *j*. The depth will be less than the maximum 52 m if the bottom is detected within depth stratum *k* at any point along the transect.

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

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

and its variance was estimated as

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

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

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* (age-0 or age-1) sockeye salmon in the fish population derived from the tow netting operation. Variance estimates were calculated as described in Appendix B and DeCino and Willette (2011).

Two surveys were completed in Skilak Lake in 2005, 2007, 2008, 2009, and 2010. These surveys were done at night in dark conditions to assess the potential of "missing" fish detected by the hydroacoustic gear (DeCino et al. 2004). A randomized block ANOVA with survey as the treatment and the 3 areas as the blocks was utilized to test whether the 2 population estimates differed. In addition, Bartlett's test for homogeneity of variance (Zar 1984) was used to test whether the variance of the surveyed populations was the same for each independent acoustic survey (DeCino and Willette 2011). If the population estimates were not significantly different from each other, transects from each survey area were pooled and population estimates and variances were calculated as above.

Skilak and Kenai lake fish abundance estimates were graphically displayed using Arc/View software to interpolate fish densities between transects (DeCino and Degan 2000). The ensonified water column was echo-integrated; however, as noted above, data outputs were produced into 250 m long by 50 m deep bins. The binned echo-integrated data (number per hectare) were $\log_{10}$ transformed and input into the Arc/View software program. The $\log_{10}$ transformed spatial data were interpolated using an inverse distance weighted (IDW) algorithm for each binned data point and a constant radius and power were used to visualize densities (ArcView 3D Analyst 1997) across years.

AGE, WEIGHT, AND LENGTH (AWL) SURVEYS

Mid-water trawl (tow netting) surveys were conducted in both lakes, during day time hours, to estimate the species composition of acoustic targets and the age composition, mean wet weight (g), and mean fork length (mm) of juvenile sockeye salmon. The tow net was 3 m wide by 7 m deep with graduated mesh sizes that ranged from 10.2 cm at the net opening to 3 mm at the cod end for a total length of 18 m. The tow net's ground speed was approximately 0.8 m/s.

Sampling in Skilak Lake utilized a stratified cluster and stratified 2-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). However, in 2008 through 2010, only surface tows were done because new motor restrictions required the use of 4-stroke outboard motors to be used in the Kenai River watershed. Our tow net boat, which is equipped with hydraulic power to haul the tow net from depths, could not be used because it was powered with 2-stroke outboard engines, and thus we had to retrieve this heavy tow net by hand from surface tows by a boat powered with a 4-stroke engine. Each tow was defined as a primary sampling unit and a minimum of 3 tows were conducted in each stratum. All fish captured in each tow were identified to species.

We used the same stratified random sampling technique in Kenai Lake; however, only 2 depth strata were sampled: surface (0–10 m) and mid-depth (15–25 m), because historically very few fish were captured in the 30–40 m stratum. Like Skilak Lake in 2008 through 2010, juvenile fish were only collected from surface tows.

Generally, a minimum subsample size of approximately 1,000 and 500 sockeye salmon fry were collected from Skilak and Kenai lakes, respectively. Scales were collected from fish > 50 mm between years 2005 and 2008 and from all subsampled fish thereafter. Fish captured in Skilak Lake were measured to the nearest 1 mm in the field, and all fry were placed into individual pre-weighed scintillation vials. Vials were returned to the laboratory in Soldotna where they were weighed and frozen for subsequent lipid and bomb calorimetry analysis. Fresh wet weights were converted to formalin-fixed weight based on 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

Two hydroacoustic surveys were conducted on Skilak Lake in each autumn sampling season except for 2006. For TS estimation, the average size of individual targets in Skilak Lake increased each year from a low of -56.11 dB in 2005 to a high of -50.83 dB in 2009 (Table 1). In 2010, TS decreased and for the 9 September 2010 survey, 2 TSs were reported because the rule was invoked on splitting the detected targets in the water column (Table 1).

The numbers of echoes used to estimate TS and σ generally decreased from 2005 to 2010. However, the lowest number of echoes used occurred in 2009 and the highest number of 62,571 in 2005. The mean and SD for σ also generally increased between 2005 and 2010, varying from a low of $3.18 \times 10^{-6} \pm 5.31 \times 10^{-6}$ on 14 September 2005 to a high of $1.1 \times 10^{-5} \pm 1.28 \times 10^{-5}$ on 28 September 2008 (Table 1).

The 2 population estimates obtained each autumn were not significantly different from each other ($p < 0.05$) for all dual surveys except 2009, based on a randomized block ANOVA with date as the treatment and area as the block (Table 2), and all variances were similar from each independent surveyed population. Although the 2009 dual population estimates were significantly different from each other, we were not able to determine which estimate was true, so we still averaged the 2 estimates. During this 6-year span the estimated fish populations decreased from a high in 2005 of 39,619,000 with a SE of 4,037,945 fish, to a low of 8,736,048 with a SE of 716,688 fish in 2009 (Table 3; Figure 4; Appendices A4–A9).

Fish densities decreased from 2005 through 2009 and then increased in 2010. The $\log_{10}$ transformed densities (number of fish per hectare) depicted this declining trend (Figure 5). These units are intended to simply show structure of the possible densities interpolated between transects and are not meant for quantitative analysis. However, fish densities were generally higher along the shorelines from 2007 to 2010. In 2005 and 2006, fish densities were generally higher and more uniform throughout the entire lake.

During our tow-net surveys, total catch of juvenile fish generally decreased each year from a high of 6,258 fish captured in 2005 to a low of approximately 1,000 fish in 2009 (Table 4). From all midwater trawls, juvenile sockeye salmon comprised greater than 95.1% of the catch in each year sampled (Table 4) and greater than 90% of the trawls were performed near the surface (Appendix A9). Of the total juvenile sockeye salmon captured, the age-0 fish percentages decreased in 3 consecutive years (2005 to 2007) from 99.6% in 2005 to 47.0% in 2007. However, in 2008 to 2010, the age-0 sockeye fry increased to over 93% (Table 4). In contrast, age-1 juvenile sockeye salmon increased from 2005 through 2007 with the greatest percentage of age-1 in 2007 accounting for 53.0% of the estimated population (Table 4). Similarly, in 2008 through 2010, the age-1 sockeye fry decreased to less than 10%, which corresponds to a typical Skilak historical age structure (Table 4; Figure 6).

The mean weight (converted to a formalin-preserved weight) and length of age-0 sockeye salmon ranged from a historical low of 0.55 g (SE = 0.01) with a corresponding length of 39.9 mm (SE = 0.25) in 2005 (Table 4; Figures 7 and 8), to 1.64 g (SE = 0.05) and 56.2 mm (0.72 mm) in 2009. In comparison, the age-1 juvenile sockeye salmon averaged 1.54 g (SE = 0.14g) and 56.5 mm (SE = 1.09 mm) in 2005, to 4.83 g (SE = 0.11 g) and 80.7 mm (0.38 g) in 2009 (Table 4; Figure 7). In 2006, 2007, and to a lesser extent 2009, length and weight distributions were bimodal (Figure 7). In 2007 the second peak shifted more strongly to the right, indicating more age-1 fish.

When we add the 2005–2010 age-0 fry weight and abundance to the density dependent regression (fry weight against fry population) in Edmundson et al. (2003), we slightly improved the fit of the regression line to the data (R^2 = 0.512; Figure 9).

KENAI LAKE

Kenai Lake single target echoes decreased yearly from 2005 to 2008 and then increased in 2010 (Table 1). The average TSs calculated from the echoes indicated no apparent trend and ranged from a high of -53.21 dB (SE = 5.87 dB) to a low of -54.52 dB (SE = 4.57 dB) in 2009 and 2006, respectively (Table 1). The average σ's ranged from 5.81×10^{-6} with a SD of 6.29×10^{-6} to 8.16×10^{-6} with a SD of 1.04×10^{-5}. These σ's produced juvenile population estimates that ranged from a low of 1.2 million fish to a high of approximately 3.5 million juvenile fish (Table 3).

Like Skilak Lake, we visualized the densities of juvenile fish in Kenai Lake and used the same procedure and values for interpolation. The distribution of juvenile sockeye salmon in Kenai Lake varied over these 6 years with no apparent trend (Figure 10).

Based on our mid-water trawl sampling in Kenai Lake, sockeye salmon accounted for > 99% of the total pelagic fish population in all years, except 2010, when it was 97.4%. All of the estimated juvenile sockeye salmon population consisted of age-0 fish in 4 of 6 years sampled (Table 3). The mean population weight and length of the age-0 cohort ranged from 1.81 g (SE = 0.04 g) and 54.9 mm (SE = 1.48 mm), to 2.36 g (SE = 0.08g) and 60.3 mm (SE = 0.60 mm), respectively (Table 4; Figure 11). Length and weight distributions were typically unimodal.

When we regressed fry weight against fry abundance (Figure 12) from Kenai Lake, we found a similar negative relationship to Skilak Lake that was strong (R^2 = 0.338; P = 0.006). When we examined the relationship between age-0 juvenile sockeye salmon density and weight for both lakes combined, we found that juvenile sockeye salmon weight was more strongly density dependent in Skilak Lake (Figure 13).

DISCUSSION

In the span of 6 years between 2005 and 2010, Skilak Lake experienced both the 2 greatest population abundance estimates and the first and fourth smallest weights of juvenile sockeye salmon recorded since inception of this project in 1986. These large juvenile sockeye salmon populations and small weights were most likely due, in large part, to the large escapements (>1 million fish) in 2004–2009 (Westerman and Willette 2012). During this 25-year project history, large escapements in 1987 and 1989 resulted from oil spills and subsequent closures of the drift gill net fishery to prevent harvest of potentially tainted fish. However, the large escapements in 2004–2009 resulted from restrictive management plans and later run timings. For instance, prior to 2004, approximately 80% (on average) of the escapement entered the Kenai River by July 31, contrasted with approximately 66% for the 2004–2009 escapements (Westerman and Willette 2012). As a result, a larger than normal fraction of the run entered the river in August after the fishery closed by regulation. For this report we examined multiple years of hydroacoustic population estimates for Kenai and Skilak lakes, which allowed comparison of very different population sizes and juvenile sockeye salmon conditions concurrently.

The juvenile sockeye salmon abundance estimates in 2005 through 2010 exhibited 2 high years (2005 and 2006), 3 near-average (2007, 2008, and 2010) years, and 1 below-average year (2009). Historically there is considerable year-to-year variation, and there appears to be little overall trend in the time series (Figure 4). However, one of the most striking results was that the Skilak Lake population estimates for 2005 and 2006 were about 2 times greater than their historical average of approximately 18 million fish. Concomitantly, the juvenile sockeye salmon average weight was more than 2 times less than the average weight. Similar to the historical population estimates, historical length and weight measurements show considerable year-to-year variation in Skilak Lake (Figure 8). In 2005 and 2006, the above-average population abundance years, mean weights of age-0 sockeye salmon in Skilak Lake were 53% and 31% less than historical averages, respectively. A regression equation relating fall fry weight to their abundance predicted 0.67 g and 0.77 g mean weight for sockeye salmon fry in Skilak Lake in 2005–2006, whereas actual mean weights were 0.55 g and 0.81 g.

Three Skilak Lake sockeye salmon fry abundance estimates (2007, 2008, and 2010) were at or slightly below the historical average. The 2007 mean weight was 21% less than the average weight. Conversely, the 2008 juvenile sockeye weight was 23% greater than the historical mean weight. For 2007, the regression equation (Figure 9) predicted a mean weight of 1.2 g, whereas the actual mean weight of 0.91g was 25% less than predicted. For 2008, the regression equation predicted a mean weight of 1.17 g, whereas the actual weight of 1.45 g was 23% greater than predicted. The small size of the sockeye salmon fry in Skilak Lake for 2005 was likely due in part to the low total copepod biomass in the lake. We are concerned that these small fry suffered elevated overwinter mortality, if they lack sufficient energy reserves to survive the winter fast. We are developing an overwinter mortality model employing measurements of whole body energy content of juvenile sockeye salmon sampled in the fall. In a later report we will detail the findings of the overwinter mortality model.

These large juvenile sockeye salmon populations and small sizes have led us to further evaluate overwinter survival. In 2005, we developed a method for estimating abundances of sockeye salmon smolt emigrating from the Kenai River watershed (Willette and DeCino 2009). Smolting the Kenai River is a reasonable method to estimate overwinter mortality of the fall fry populations rearing in Skilak and Kenai lakes. For the 2005 sockeye fry populations in the Kenai river watershed, we estimated the sockeye smolt populations at 9.3 million and 15.0 million using mark–recapture and inriver hydroacoustics (Willette and DeCino 2009), respectively. Given those estimates, the overwinter survival of the Kenai River watershed sockeye salmon smolt population would be approximately 29–54%. Similarly, for 2006 sockeye salmon fry, the overwinter survival would be about 47–80% using the same methodology for smolt estimation in 2007. These comparisons indicate that the fall fry populations of 2005 and 2006 potentially exceeded 70% and 50% overwinter mortality, respectively.

Additionally, the presence of 2 consecutive years of 2 times greater-than-average fall fry population estimates could be responsible for the age structure shift noted in 2007. We have documented the first time age-1 fry were in greater abundance in Skilak Lake than age-0 fry in 2007 (Table 4). This is particularly interesting due to implications for the brood year interaction (Carlson et al. 1999; Edmundson et al. 2003) model where consecutive large juvenile sockeye salmon populations can compete for less food. Did the large juvenile population in 2005 cause delayed smoltification of the age-0 lake fish in Skilak, leading to a cascade in the age structure? Surely the hold over age-1 fish in 2006 contributed to an increased competition for the new fry entering the system, which then continued until the next year when a greater percentage of age-1 fry were estimated in the lake. Certainly, long-term data sets are important to understanding mechanisms causing changes in age structure.

Historically, Skilak Lake has consistently supported more and smaller sockeye salmon fry than Kenai Lake (Tarbox and King 1988a and b; Tarbox and Brannian 1995; Tarbox et al. 1993, 1996, and 1999; DeCino 2002; DeCino and Degan 2000; DeCino et al. 2004; DeCino and Willette 2011), and these years were no different. The average Kenai Lake juvenile sockeye population estimate is approximately 2.6 million fish, which is roughly 14% of the average Skilak juvenile sockeye salmon fry population. In Kenai Lake, the 2005 and 2008 surveys indicated about average numbers. The 2006 survey was approximately 0.5 million fish less than the historical average, but the 2007 population was more than 47% less than average and the fifth lowest on record. However, these populations are within the range previously reported in both number and size of fish, unlike the 2005 and 2006 Skilak Lake estimates.

The TSs of all the juvenile sockeye salmon measured with the split-beam transducer from 2005 to 2010 were within reported ranges of TSs measured using both a dual-beam hydroacoustic system (see Tarbox et al. 1996) and the split-beam system used the previous 10 years (DeCino 2001, 2002; DeCino and Degan 2000; DeCino and Willette 2011; DeCino et al. 2004).

Kenai Lake, like Skilak Lake, has a similar density-dependent negative relationship of fry number to fry weight. The relationship is slightly less robust when compared with the Skilak Lake density-dependent function. In Kenai Lake, predominately age-0 fish are captured and are often larger for each given year compared to Skilak Lake age-0 fish (DeCino 2001, 2002; DeCino and Degan 2000; DeCino et al 2004; DeCino and Willette 2011). Kenai Lake had only one year in this reported time span when age-1 fish were captured but they represented less than 1%. This may indicate that either the population of juvenile sockeye salmon has not exceeded the carrying capacity of the lake and the juvenile fish attained a minimum threshold size to smolt (Koenings and Burkett 1987), or larger age-1 fish have avoided capture in the tow net. Limnological parameters have not been measured in Kenai Lake in several years, so we do not have the complement of limnological data to examine the carrying capacity, but clearly the fish are greater than the minimum threshold size (Koenings and Burkett 1987) for smolting. Next season, we plan to conduct a study to compare catches of fall fry in Kenai Lake between our tow net and a new high-speed trawl that should reduce net avoidance by larger fry.

The 2 population estimates of juvenile sockeye salmon in Skilak Lake often differed by several million fish, but 4 of the 5 dual estimates were not significantly different from each other, so the data were pooled. MacLennon and Simmonds (1992) suggested that data from replicate surveys can be pooled. We also chose to pool the 2 surveys in 2009 because we do not know which one would be the most reasonable. Although conducting multiple acoustic surveys is more costly, this approach allows us to better understand effects of survey conditions on the estimates and increases the precision of the estimates. Conducting 2 acoustic surveys is now a standard operating procedure, because it allows more accurate point estimates of the juvenile sockeye salmon population in Skilak Lake, the largest contributor of sockeye salmon fry in the Kenai watershed.

ADF&G should adopt the use of an adaptive sampling strategy to sample fish concomitant with limnological studies to provide robust data sets to help us better understand abiotic and biotic factors influencing the distribution, behavior, and ecology of juvenile sockeye salmon. Questions about age structure in Skilak Lake, carrying capacity in Kenai Lake, and the influence of large escapements on juvenile sockeye salmon survival should be further studied and documented. Questions remain today on the patchiness of juvenile sockeye salmon distributions. Not only are the juvenile sockeye salmon potentially affected by increased escapement levels, but resident predator populations of rainbow trout (*O. mykiss*), Dolly Varden (*Salvelinus malma*), and lake trout (*S. namaycush*) may have also been affected with possibly wide-ranging ecological effects not previously seen.

ACKNOWLEDGEMENTS

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REFERENCES CITED

ArcView 3D Analyst. 1997. 3D surface creation, visualization, and analysis. ESRI 1997, 1999. Redlands, California.

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.

Cochran, W. G. 1977. Sampling techniques, third edition. John Wiley & Sons, New York.

DeCino R. D. 2001. Juvenile sockeye salmon population estimates in Skilak and Kenai lakes, Alaska, by use of split-beam hydroacoustic techniques in September 2000. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 2A01-03, Anchorage.

DeCino, R. D. 2002. Juvenile sockeye salmon population estimates in Skilak and Kenai lakes, Alaska, by use of split-beam hydroacoustic techniques in September 2001. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 2A02-3, Anchorage.

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 2A00-6, 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., T. M. Willette, and J. A., Edmundson. 2004. 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, Division of Commercial Fisheries, Regional Information Report 2A04-07, 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 over escapement (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., C. Tide, and A. M. Carroll. 2013. Run forecasts and harvest projections for 2013 Alaska salmon fisheries and review of the 2012 season. Alaska Department of Fish and Game, Special Publication No. 13-03, Anchorage.

Fair, L. F., T. M. Willette, J. W. Erickson, R. J. Yanusz, and T. R. McKinley. 2010. Review of salmon escapement goals in Upper Cook Inlet, Alaska, 2011. Alaska Department of Fish and Game, Fishery Manuscript Series No. 10-06, Anchorage.

Jolly, G. M., and I. Hampton. 1990. A stratified random transect design for acoustic surveys of fish stocks. Canadian Journal of Fisheries and Aquatic Sciences 47:1282-1291.

Koenings, J. P., and R. D. Burkett. 1987. Population characteristics of sockeye salmon (*Oncoryhynchus nerka*) smolts relative to temperature regimes, euphotic volume, fry density, and forage base within Alaskan Lakes. [*In*]: H.D. Smith, L Margolis, and C. C. Wood, editors, Sockeye Salmon (*Oncorhynchus nerka*) Canadian Special Publication of Fish and Aquatic Science 96.

.MacLennan D. N., and E. J. Simmonds. 1992. Fisheries acoustics. 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.

Scheaffer, R. L., W. Mendenhall, and L. Ott. 1986. Elementary survey sampling, third edition. Duxbury Press, Boston.

REFERENCES CITED (Continued)

Shields, P. A., and S. R. Carlson. 1996. Effects of formalin and alcohol preservation on lengths and weights of juvenile sockeye salmon. Alaska Fishery Research Bulletin 3(2):81-93.

Simmonds, J., and D. MacLennan. 2005. Fisheries acoustics: theory and practice, second edition. Blackwell Science Ltd. Oxford, UK.

Tarbox, K. E., and B. E. King. 1988a. An estimate of juvenile sockeye salmon (*Oncorhynchus nerka*) densities in Skilak and Kenai lakes, Alaska through the use of dual beam hydroacoustic techniques. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 2S88-2, Anchorage.

Tarbox, K. E., and B. E. King. 1988b. An estimate of juvenile fish densities in Skilak and Kenai lakes, Alaska through the use of dual beam hydroacoustic techniques in 1987. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 2S88-4, Anchorage.

Tarbox, K. E., B. E. King, and L. K. Brannian. 1993. An estimate of juvenile fish densities in Skilak and Kenai lakes, Alaska, through the use of dual beam hydroacoustic techniques in 1991. Alaska Department of Fish and Game, Technical Fishery Report 93-01, Juneau.

Tarbox, K. E., B. E. King, and L. K. Brannian. 1994. An estimate of juvenile fish densities in Skilak and Kenai lakes, Alaska, through the use of dual beam hydroacoustic techniques in 1992. Alaska Department of Fish and Game, Technical Fishery Report 94-14, Juneau.

Tarbox, K. E., and L. K. Brannian. 1995. An estimate of juvenile fish densities in Skilak and Kenai lakes, Alaska, through the use of dual beam hydroacoustic techniques in 1993–1994. Alaska Department of Fish and Game, Regional Information Report 2A95-31, Anchorage.

Tarbox, K. E., D. Waltemyer, and S. R. Carlson. 1996. An estimate of juvenile fish densities in Skilak and Kenai lakes, Alaska, through the use of dual-beam hydroacoustic techniques in 1995. Alaska Department of Fish and Game, Regional Information Report 2A96-35, Anchorage.

Tarbox, K. E., D. Waltemyer, and S. R. Carlson. 1999. An estimate of juvenile fish densities in Skilak and Kenai lakes, Alaska, through the use of dual-beam hydroacoustic techniques in 1995. Alaska Department of Fish and Game, Regional Information Report 2A99-29, Anchorage.

Westerman, D. L., and T. M. Willette. 2012. Upper Cook Inlet salmon escapement studies, 2011. Alaska Department of Fish and Game, Fishery Data Series No. 12-83, Anchorage.

Willette, T. M., and R. D. DeCino. 2009. Improving preseason forecasts of Kenai River sockeye salmon runs through salmon smolt monitoring – technology development. Exxon Valdez Oil Spill Gulf Ecosystem Monitoring and Research Project Final Report (GEM project 050675), Alaska Department of Fish and Game, Commercial Fisheries Division, Soldotna, Alaska.

Zar, J. H. 1984. Biostatistical analysis, second edition. Prentice Hall, Inc. Englwood Cliffs, New Jersey.

TABLES AND FIGURES

Table 1.–Average target strength (decibels) and mean areal backscattering coefficient (σ) for echo integration used to estimate the population size of juvenile sockeye salmon in Skilak and Kenai lakes.

Lake	Year	Sample Date	*n*	Target Strength (dB)	σ
Skilak	2005	14 Sep	62,571	-56.11 (3.15)	3.18×10^{-6} (5.31×10^{-6})
	2005	3 Oct	55,032	-55.87 (3.27)	3.61×10^{-6} (1.24×10^{-5})
	2006	20 Oct	55,689	-55.58 (4.04)	4.12×10^{-6} (4.97×10^{-6})
	2007	17 Sep	18,250	-54.37 (4.52)	5.94×10^{-6} (6.09×10^{-6})
	2007	8 Oct	41,069	-54.39 (4.39)	5.82×10^{-6} (6.12×10^{-6})
	2008	5 Sep	31,638	-53.28 (5.63)	9.97×10^{-6} (1.23×10^{-5})
	2008	28 Sep	39,211	-52.52 (5.47)	1.10×10^{-5} (1.28×10^{-5})
	2009	8 Sep	11,564	-50.83 (4.95)	1.43×10^{-5}(1.42×10^{-5})
	2009	30 Sep	25681	-50.95 (4.70)	1.31×10^{-5} (1.21×10^{-5})
	2010[a]	9 Sep	10,607	-54.33 (4.97)	6.54×10^{-6} (7.16×10^{-6})
	2010[b]	9 Sep	1,308	-53.5 (5.23)	8.94×10^{-6} (1.14×10^{-5})
	2010	28 Sep	26,908	-54.17 (4.72)	6.46×10^{-6} (6.84×10^{-6})
Kenai	2005	3 Oct	20,796	-53.88 (4.77)	7.14×10^{-6} (1.43×10^{-5})
	2006	26 Oct	17,688	-54.52 (4.57)	5.81×10^{-6} (6.29×10^{-6})
	2007	20 Sep	5,188	-54.14 (4.98)	7.30×10^{-6} (1.87×10^{-5})
	2008[c]	4 Sep	4,089	-53.51 (5.35)	7.20×10^{-6} (8.97×10^{-6})
	2008[d]	4 Sep	2,144	-59.32 (2.34)	1.41×10^{-6} (1.22×10^{-6})
	2009	14 Sep	7,865	-53.21 (5.87)	1.10×10^{-5} (81.44×10^{-5})
	2010	18 Sep	11,789	-53.98 (5.43)	8.16×10^{-6} (1.04×10^{-5})

Note: Standard deviation in parenthesis.

[a] 0–35 m strata.

[b] >35 m strata.

[c] 0–30 m strata.

[d] > 30 m strata.

Table 2.–Skilak Lake randomized block ANOVA statistics for testing the difference between 2 population estimates.

	Date			
Year	Survey 1	Survey 2	*F*-ratio	*P*
2005	14 Sep	3 Oct	0.533	0.472
2006	20 Oct			
2007	17 Sep	9 Oct	0.956	0.338
2008	3 Sep	29 Sep	3.369	0.079
2009	8 Sep	30 Sep	7.861	0.010
2010	3 Sep	29 Sep	1.490	0.245

Table 3.–Estimated fall fish populations and contributions of age-0 and age-1 sockeye salmon to the total fish population in Kenai and Skilak lakes, night surveys.

Lake	Year	Estimated Total Fish Population	Standard Error (SE)	Estimated Juvenile Sockeye	Standard Error (SE)	Age-0	Standard Error (SE)	Age-1	Standard Error (SE)
Skilak	2005	39,619,000	4,037,945	39,600,007	4,036,079	39,493,199	4,034,410	106,808	106,971
	2006	35,500,396	4,438,468	35,396,745	4,425,624	27,535,941	3,952,408	7,860,805	2,175,925
	2007	16,875,000	2,574,762	16,744,001	2,554,872	7,796,250	1,443,667	8,940,375	1,590,585
	2008	18,139,999	2,629,924	17,718,531	2,568,677	17,531,464	2,542,931	187,067	81,938
	2009	8,736,048	716,688	8,268,320	678,561	7,582,889	645,997	688,401	183,061
	2010	15,008,695	1,579,189	14,939,504	1,571,934	14,498,399	1,531,000	435,252	137,268
Kenai	2005	2,356,800	266,064	2,336,351	264,067	2,336,351	264,067	0	0
	2006	1,866,954	232,486	1,852,915	260,166	1,852,915	260,166	0	0
	2007	1,260,171	192,417	1,250,367	191,090	1,250,266	191,137	9,903	5,221
	2008	2,713,369	333,940	2,694,782	331,685	2,694,375	331,635	0	0
	2009	3,220,035	1,259,067	3,199,395	1,251,005	3,199,395	1,251,005	0	0
	2010	3,476,204	294,959	3,387,561	289,476	3,361,489	287,513	26,072	12,323

Table 4.–Average age, weight, and length of juvenile sockeye salmon captured in midwater trawls.

Lake	Year	Total Catch	Sockeye Catch	Percent Sockeye	AWL sample	Age-0				Age-1			
						n	%	Length (mm)	Wt (g)	n	%	Length (mm)	Wt (g)
Skilak	2005	6,258	6,255	99.95	1,000	996	99.6	39.9 (0.25)	0.55 (0.01)	4	0.4	56.5 (1.09)	1.54 (0.14)
	2006	1,370	1,366	99.71	967	755	78.1	44.6 (1.09)	0.81 (0.01)	212	21.9	60.8 (1.15)	2.03 (0.04)
	2007	1,417	1,406	99.22	999	470	47.0	46.6 (0.68)	0.90 (0.02)	529	53.0	60.6 (0.49)	1.98 (0.02)
	2008	1,076	1,051	97.68	791	785	99.2	52.4 (0.42)	1.45 (0.04)	6	0.8	73.7 (0.70)	4.02 (0.09)
	2009	1,000	951	95.10	829	774	93.4	56.2 (0.72)	1.64 (0.05)	55	6.6	80.7 (0.38)	4.83 (0.11)
	2010	1,954	1,945	99.54	1,000	977	97.7	52.3 (0.13)	1.21 (0.02)	23	2.3	74.4 (1.04)	3.40 (0.12)
Kenai	2005	461	457	99.13	457	457	100.0	57.2 (0.49)	2.05 (0.05)	0	0.0	0	0
	2006	532	528	99.25	520	520	100.0	55.1 (0.52)	1.81 (0.05)	0	0.0	0	0
	2007	514	510	99.22	509	505	99.2	56.8 (0.36)	1.81 (0.04)	4	0.8	84.0 (3.81)	6.13 (0.89)
	2008	292	290	99.32	290	290	100.0	56.8 (1.61)	1.89 (0.15)	0	0.0	0	0
	2009	624	620	99.36	620	620	100.0	60.3 (0.60)	2.36 (0.08)	0	0.0	0	0
	2010	903	880	97.45	786	781	99.4	54.9 (1.48)	1.85 (0.16)	5	0.6	93.8 (7.15)	9.18 (1.72)

Note: Standard errors are in parentheses.

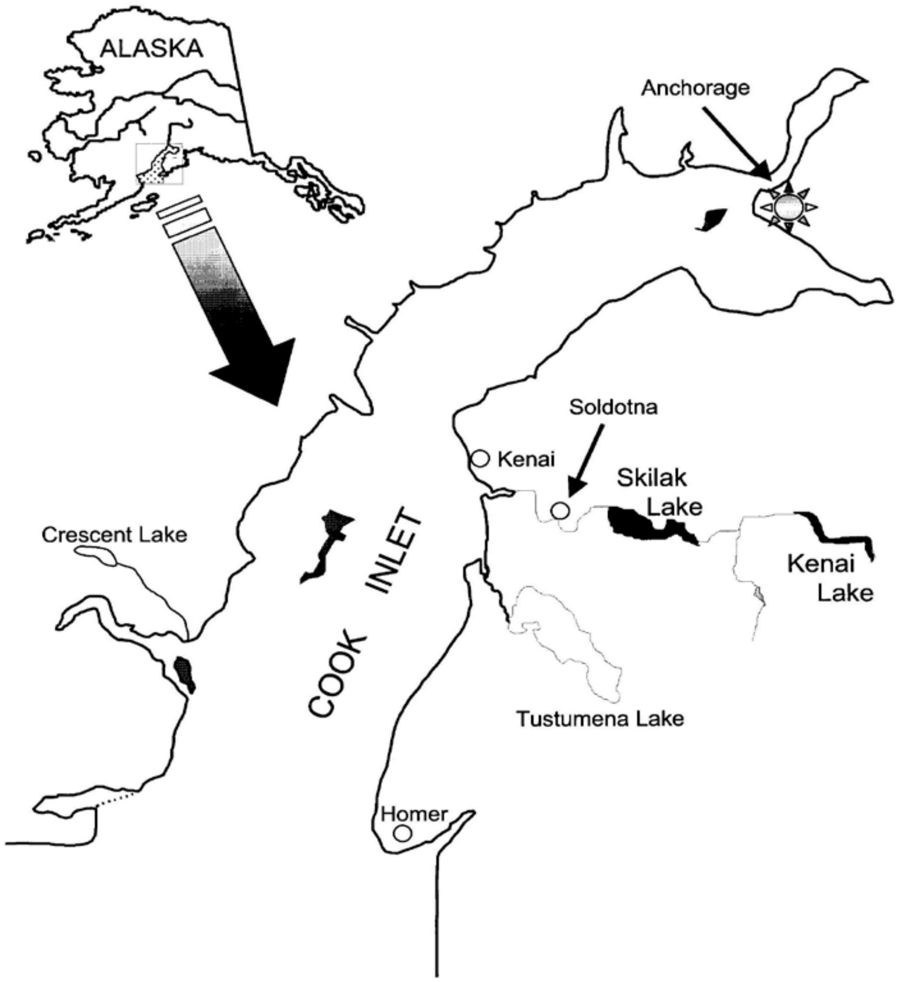

Figure 1.–Location of Skilak and Kenai lakes, Alaska.

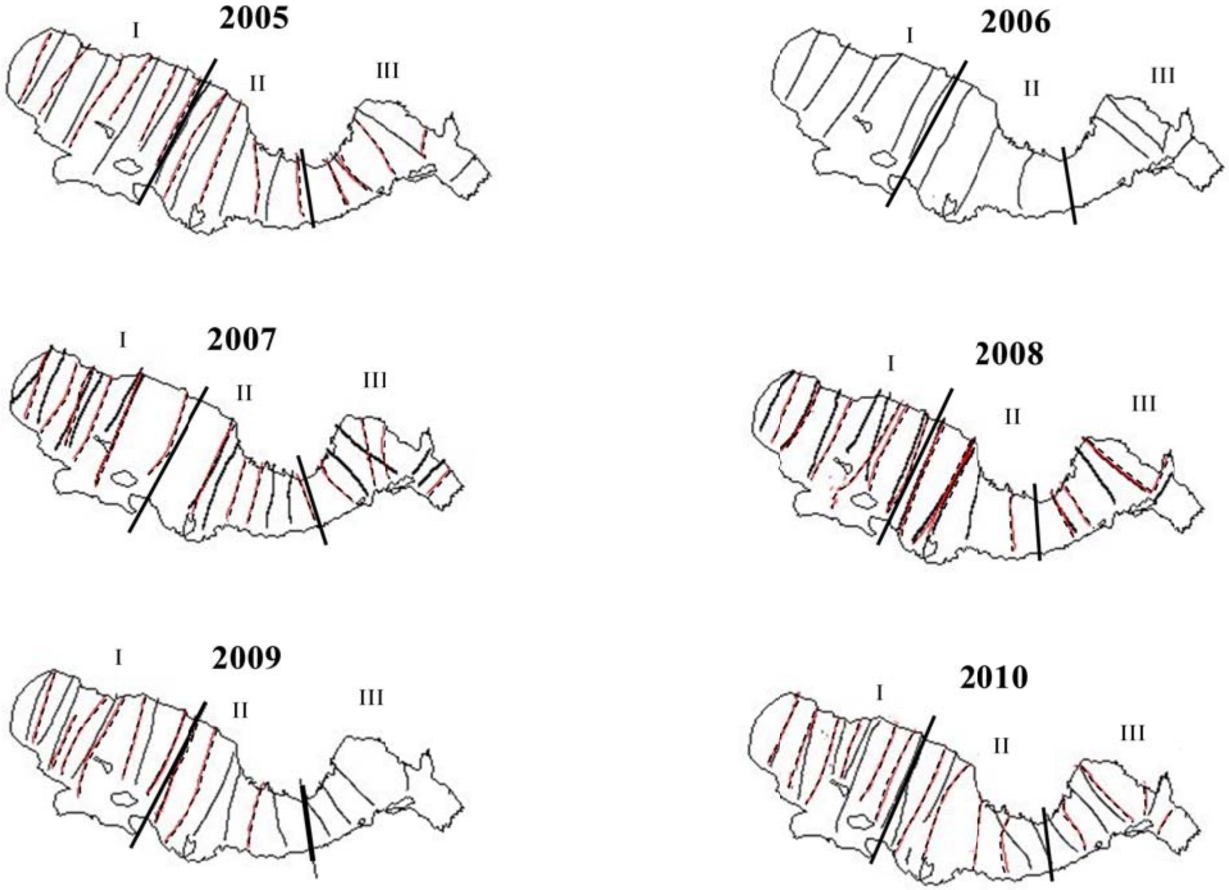

Figure 2.–Skilak Lake fall transects.

Note: Solid lines indicate first fall survey, dashed lines second fall survey. Roman numerals indicate lake area.

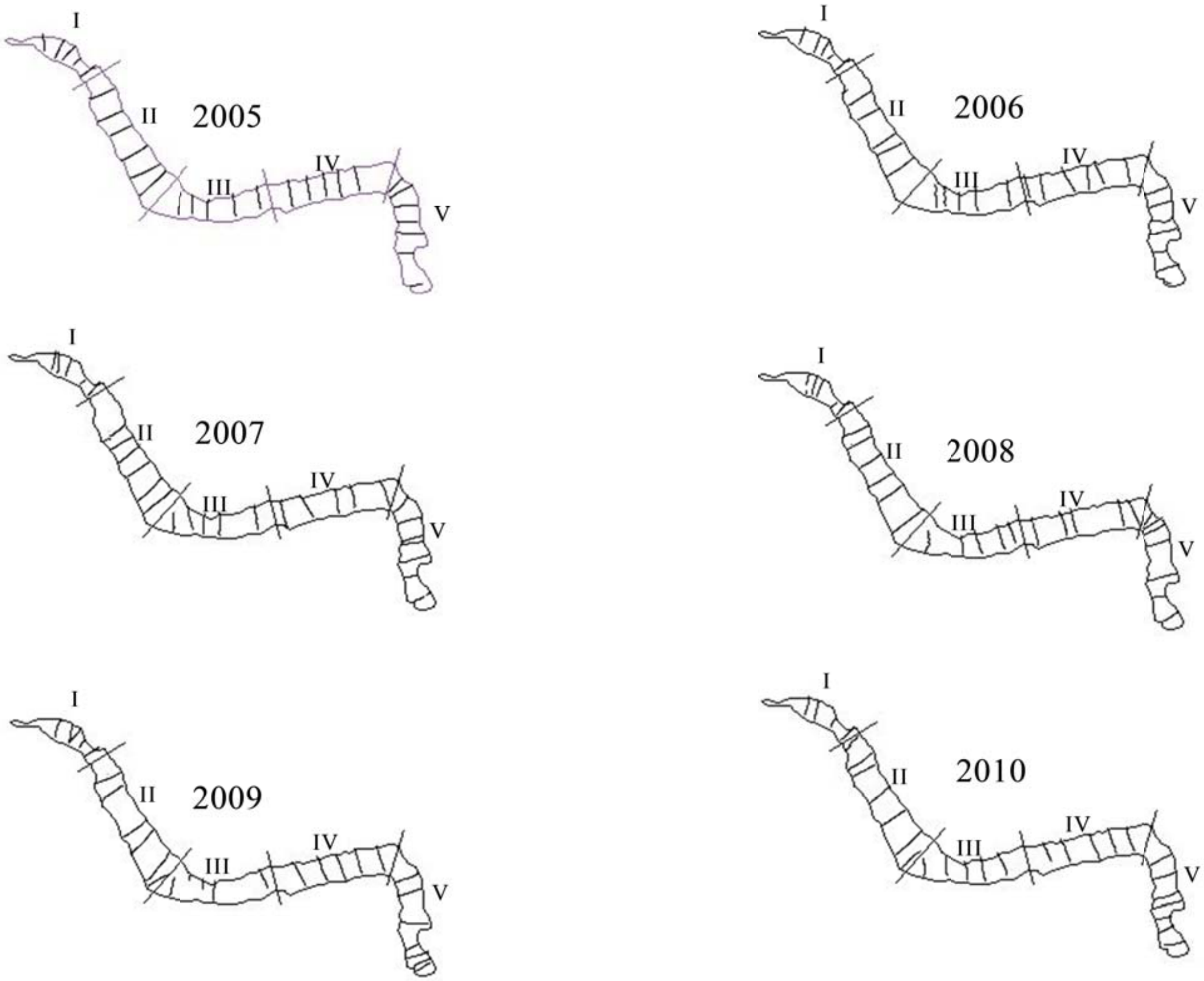

Figure 3.–Kenai Lake fall transects.

Note: Roman numerals indicate lake area.

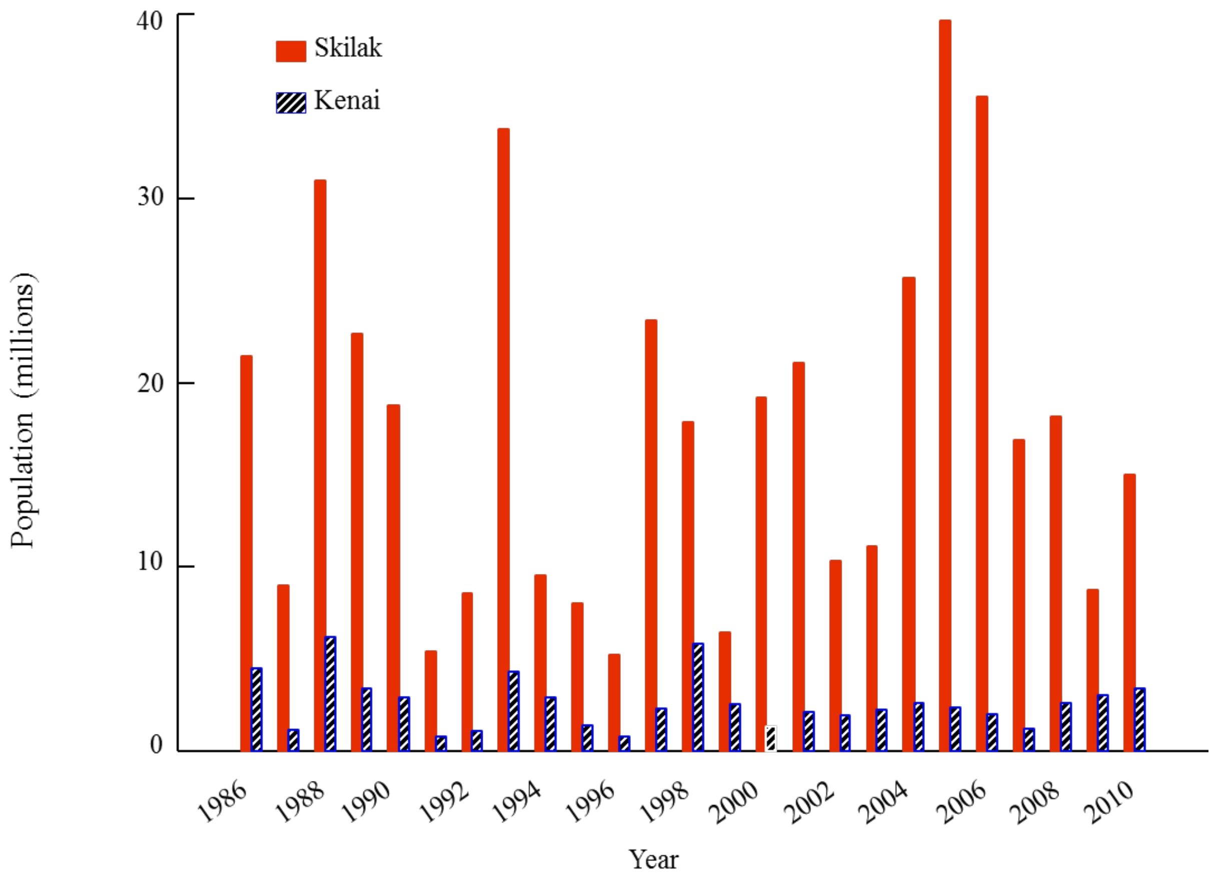

Figure 4.–Historical juvenile sockeye salmon population estimates of Skilak and Kenai lakes from 1986 to 2010.

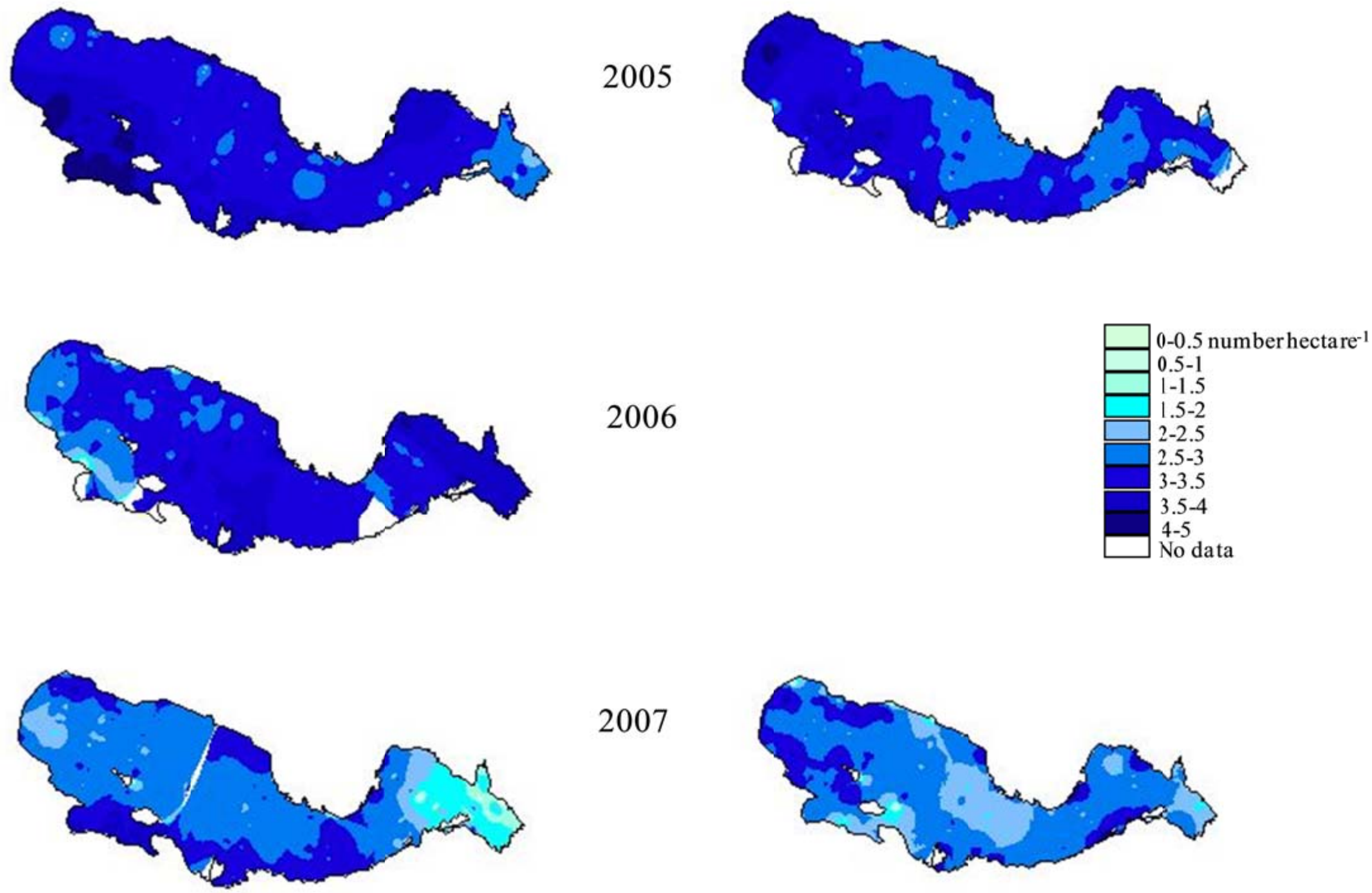

Figure 5.–Skilak lake transformed fry population densities.

Note: Number per hectare compiled in 250 m linear bins figures on left are for survey 1, and figures on right are for survey 2.

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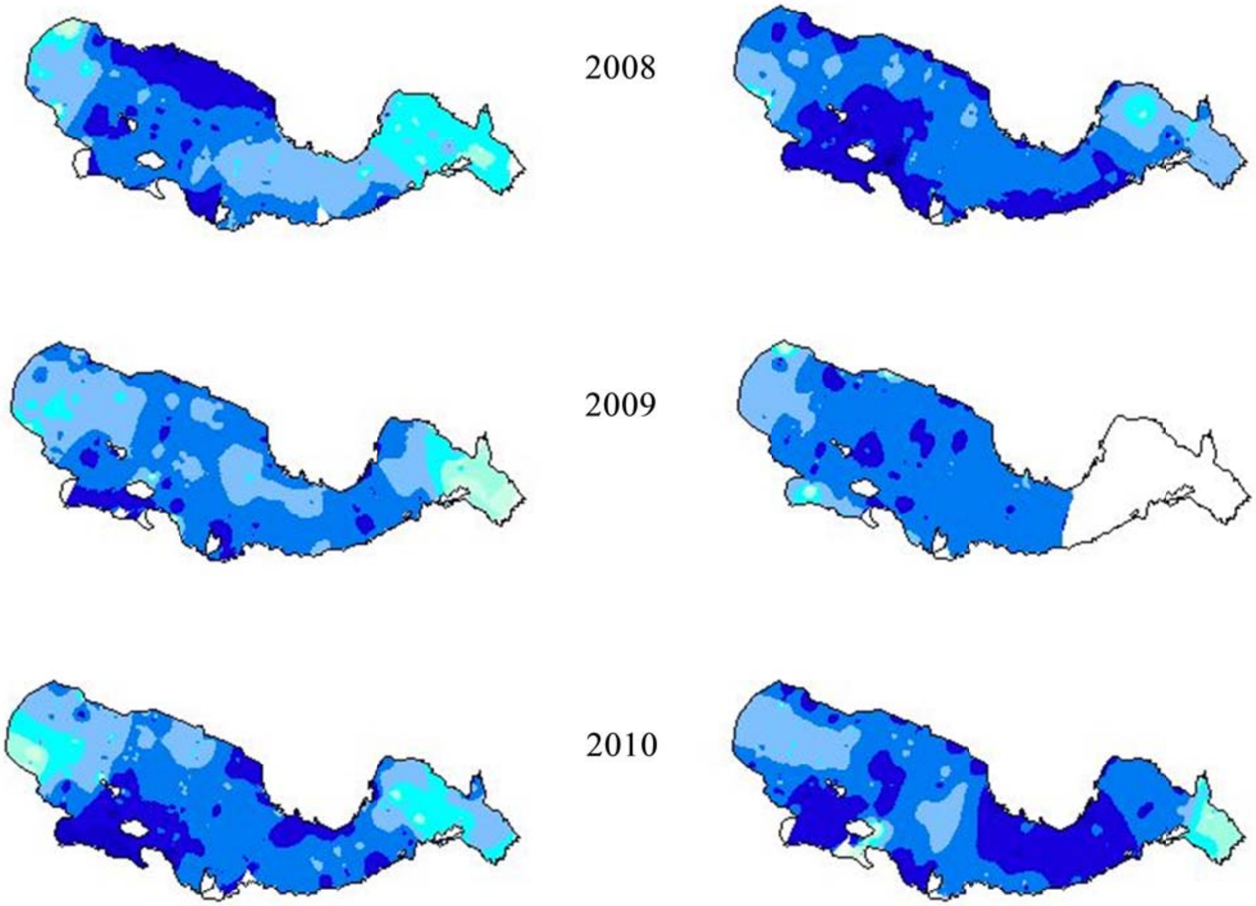

Figure 5.–Page 2 of 2.

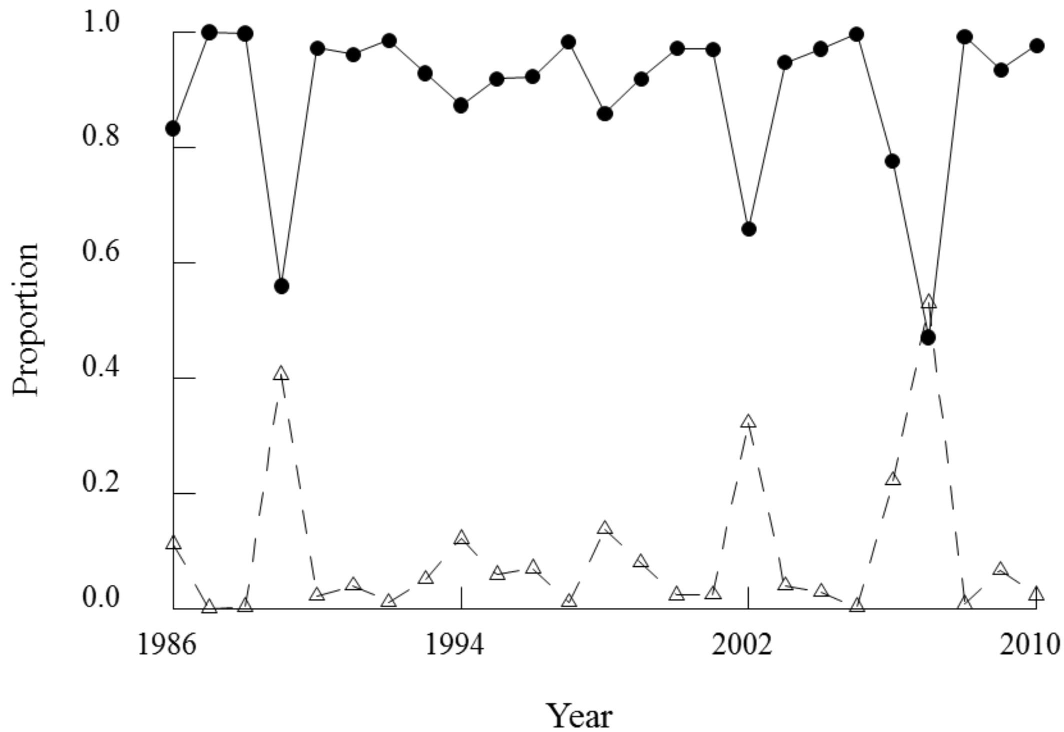

Figure 6.–Historical age-0 and age-1 proportion of sockeye salmon sampled in Skilak Lake.

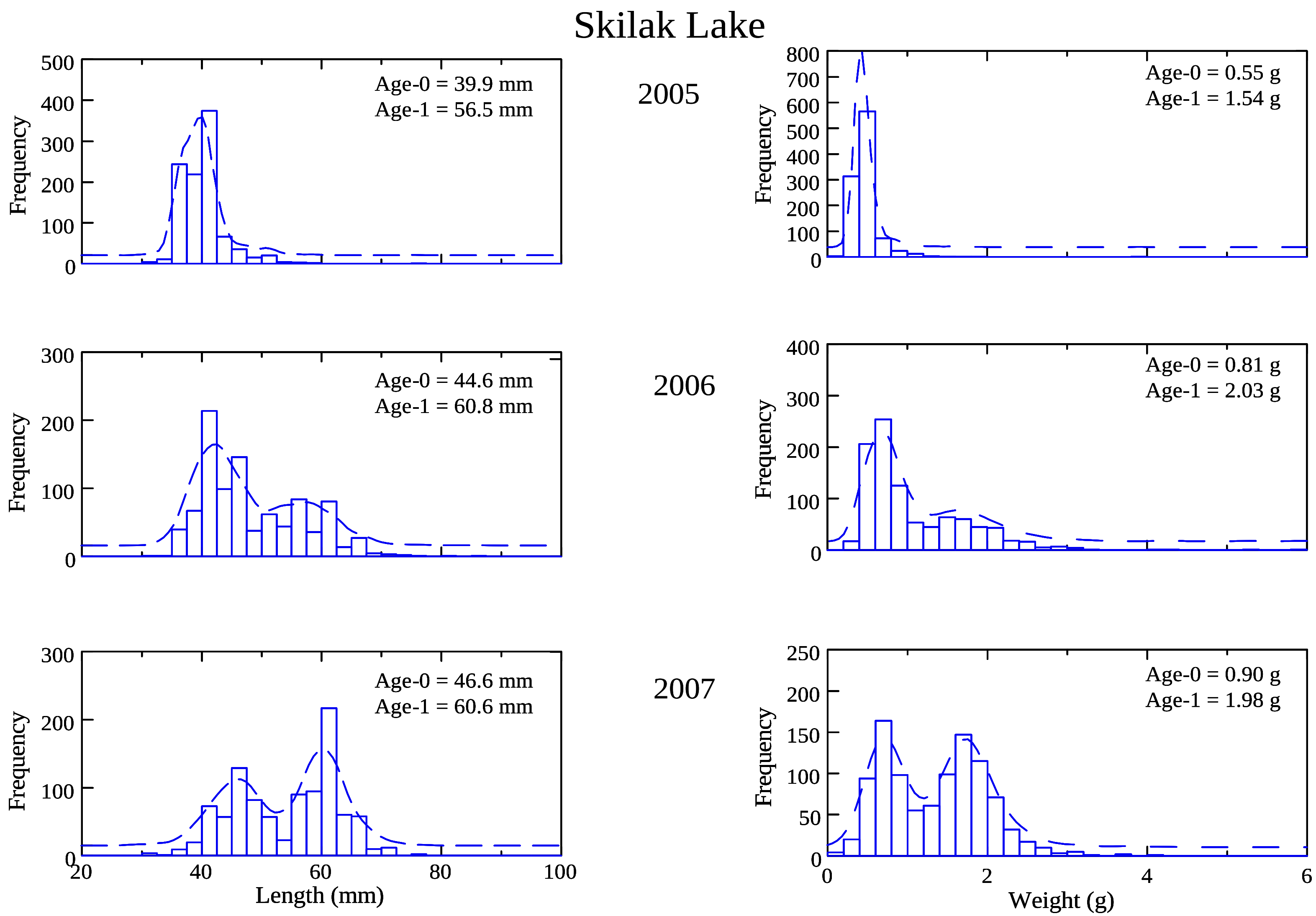

Figure 7.–Age-0 and age-1 length (mm) and weight (g) of juvenile sockeye salmon fry in Skilak Lake.

Note: Dashed line is the non-parametric (kernel) density function. Weights and lengths in upper right corner of plots are the averages.

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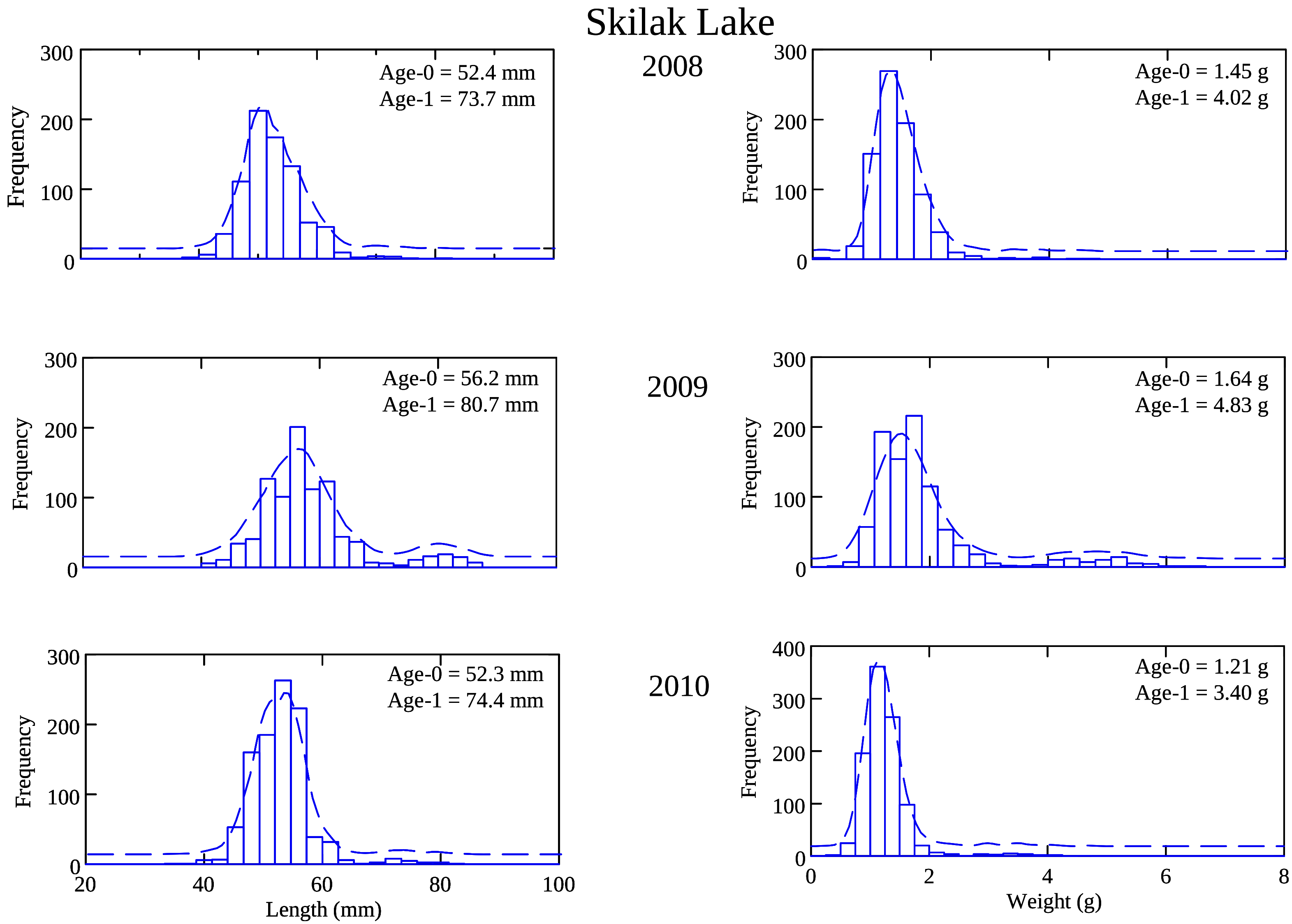

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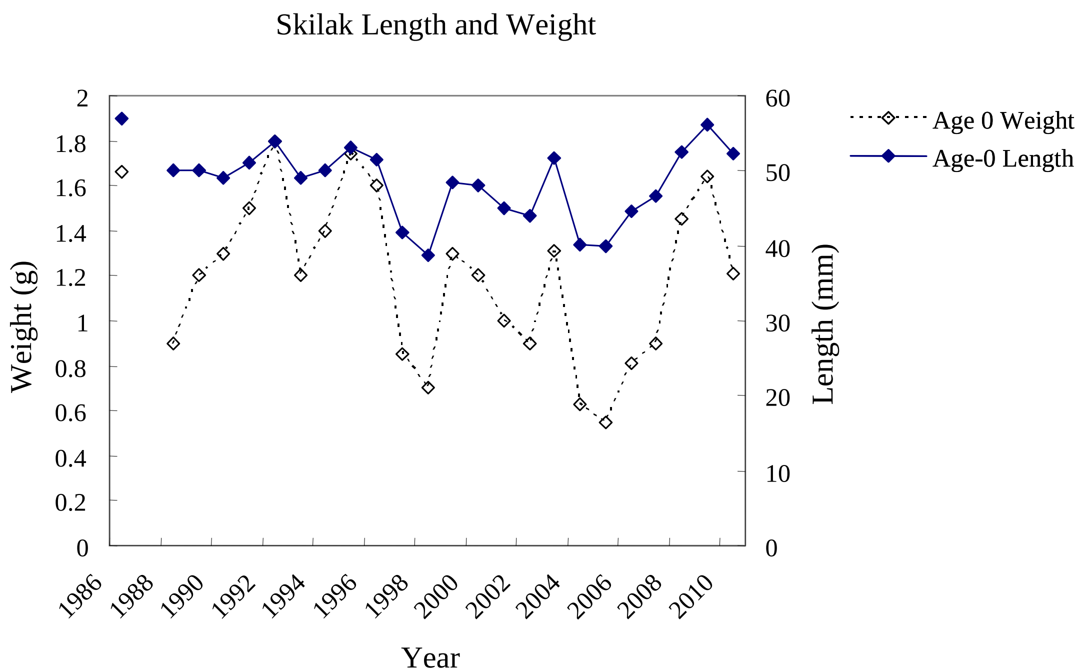

Figure 8.–Historical age-0 fry weight (g) and length (mm) of Skilak Lake sockeye salmon fry.

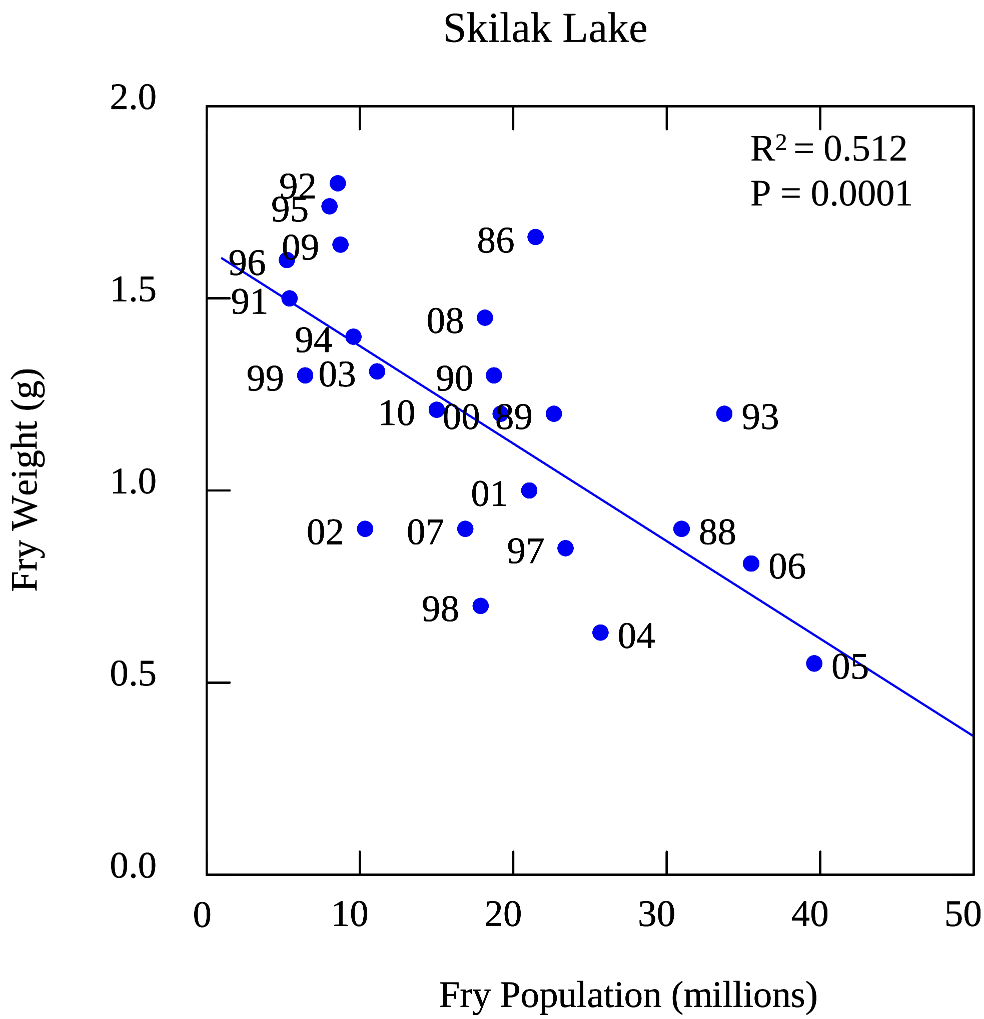

Figure 9.–Age-0 fry weight (g) vs abundance modeled after Edmundson et al. (2003) density dependent function.

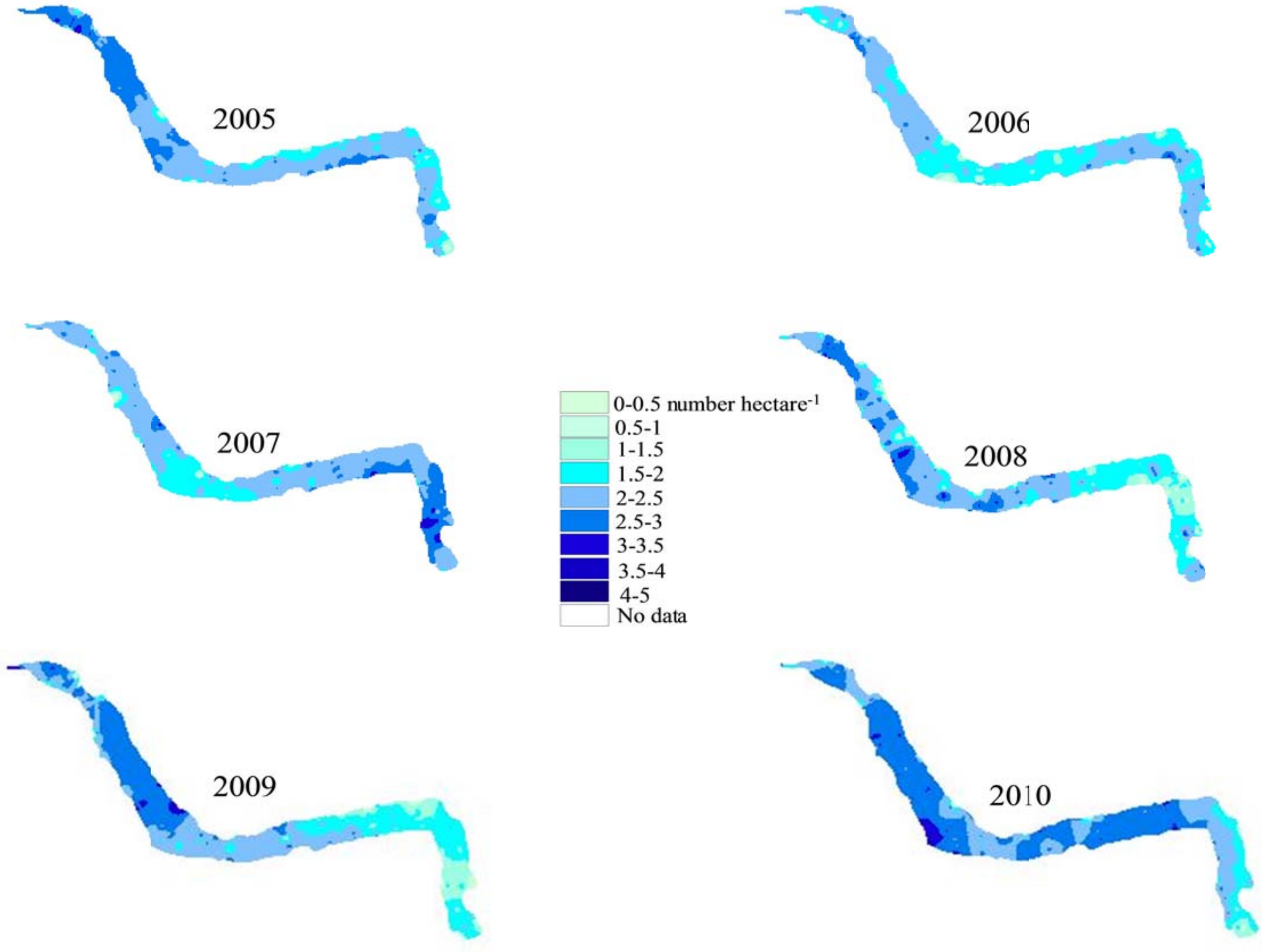

Figure 10.–Kenai Lake $\log_{10}$ transformed population densities (number per hectare) compiled in 250 m bins.

Kenai Lake

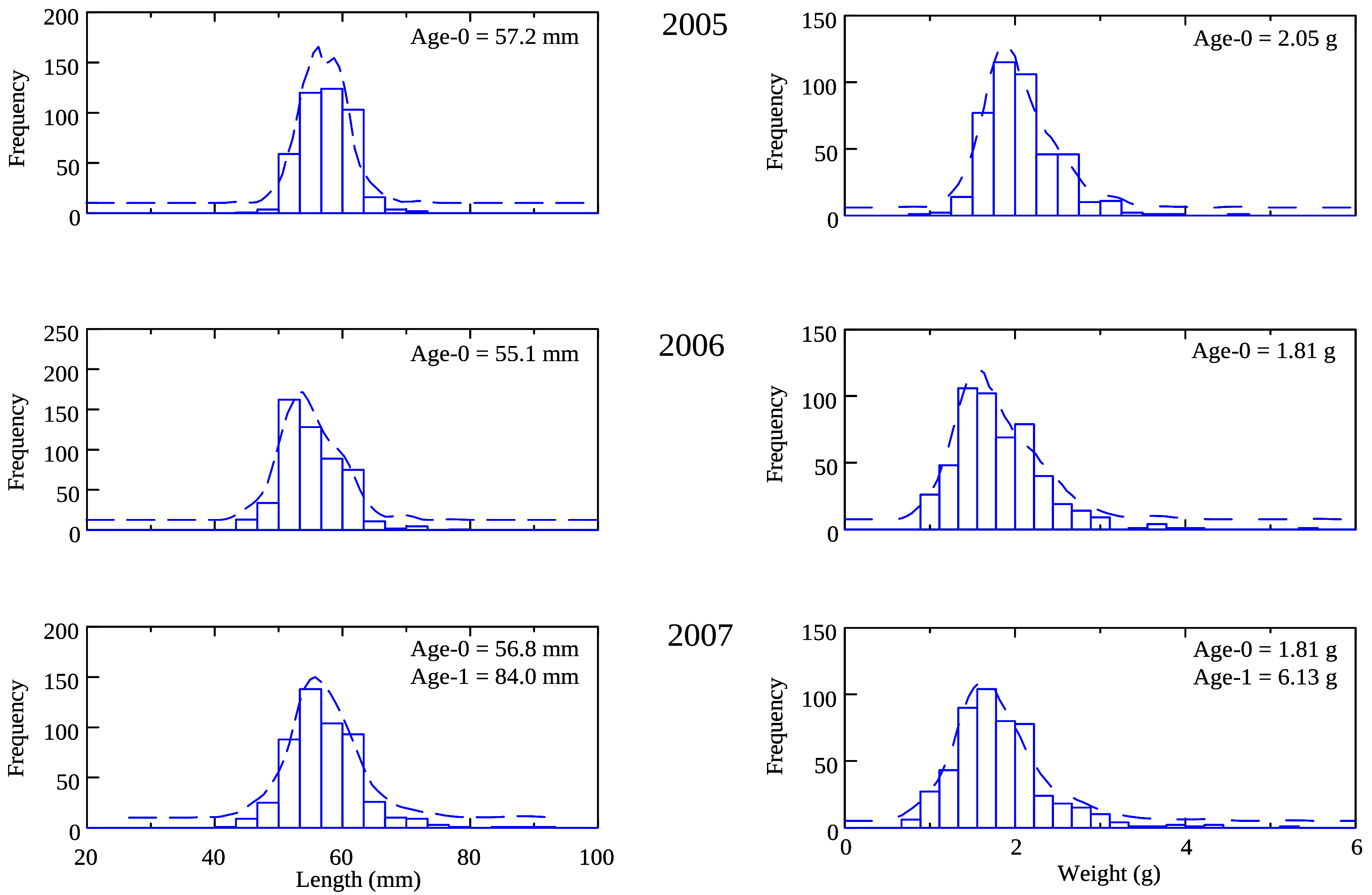

Figure 11.–Age-0 and age-1 length (mm) and weight (g) of juvenile sockeye salmon fry in Kenai Lake.

Note: Dashed line is the non-parametric (kernel) density function. Weights and lengths in upper right corner of plots are the averages.

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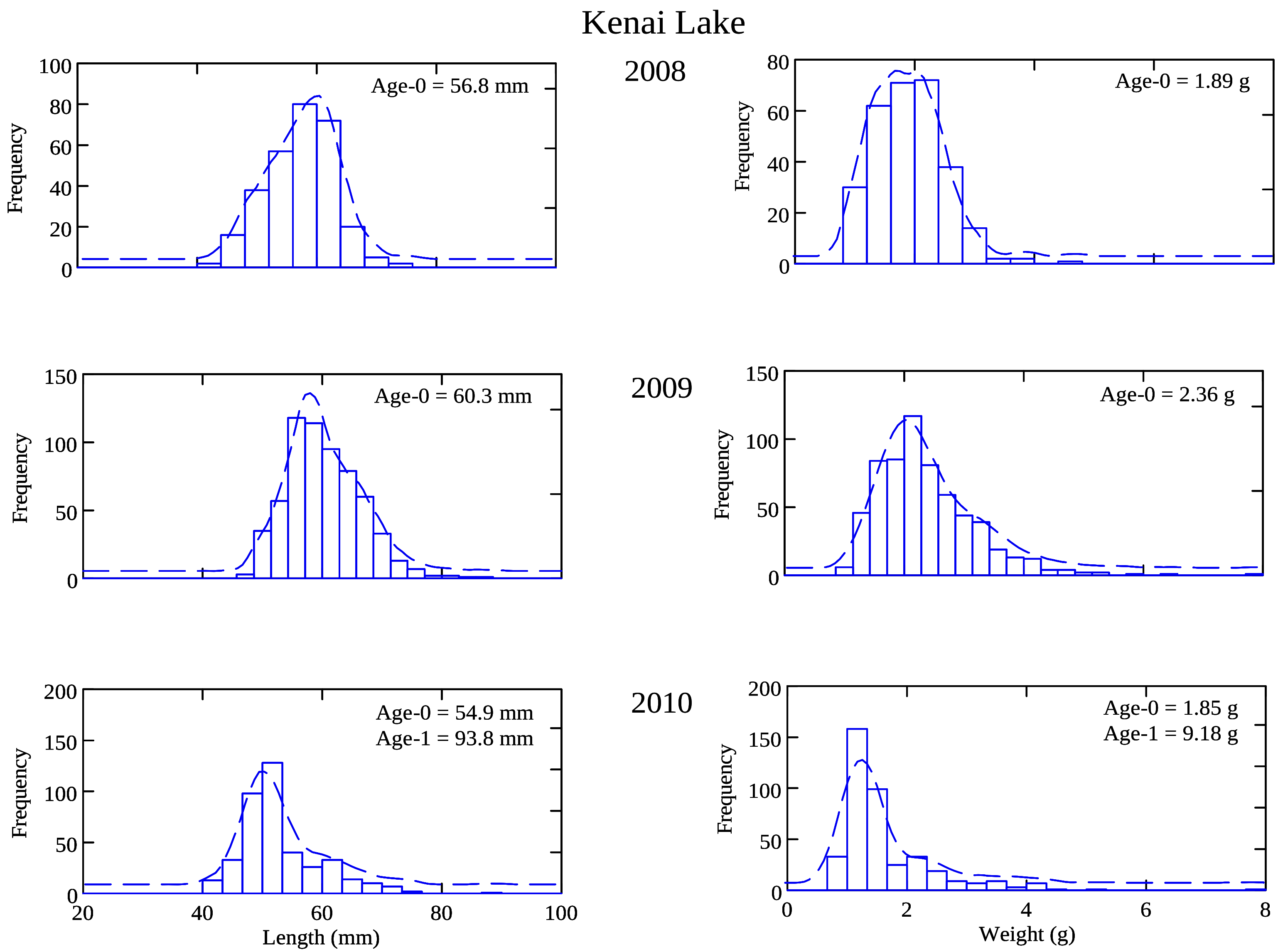

Figure 11.–Page 2 of 2.

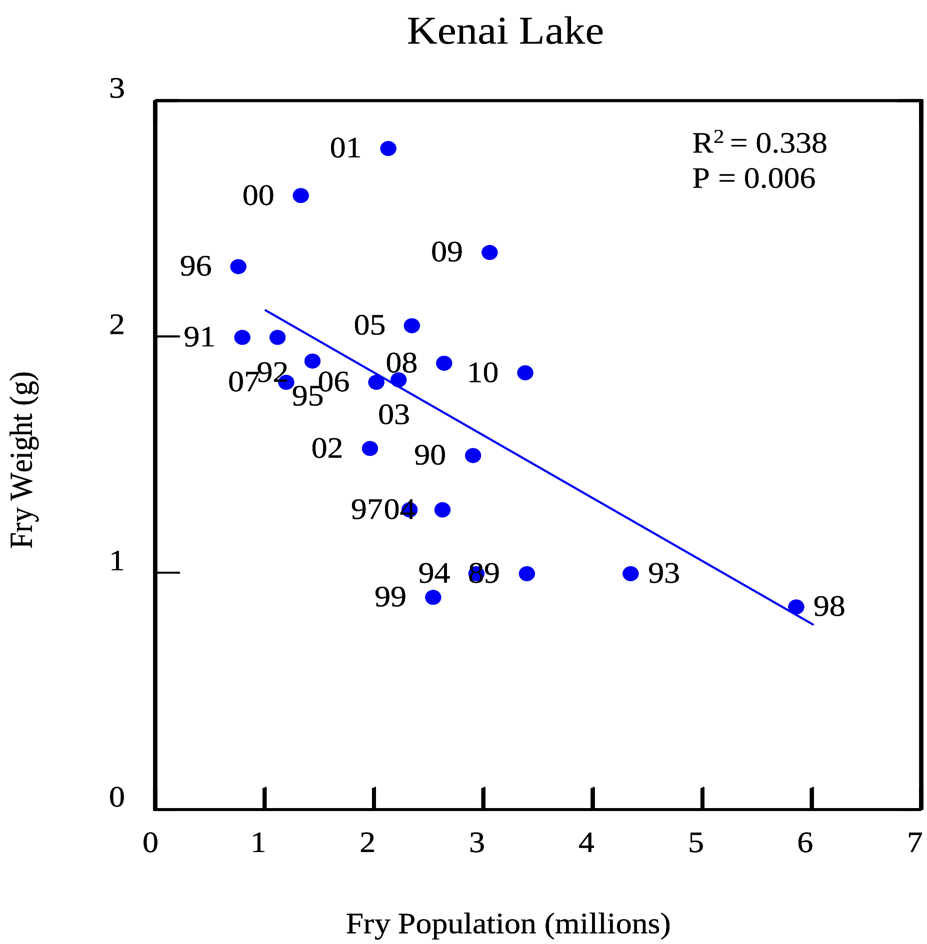

Figure 12.–Age-0 fry weight (g) vs abundance modeled after Edmundson et al (2003) density dependent function.

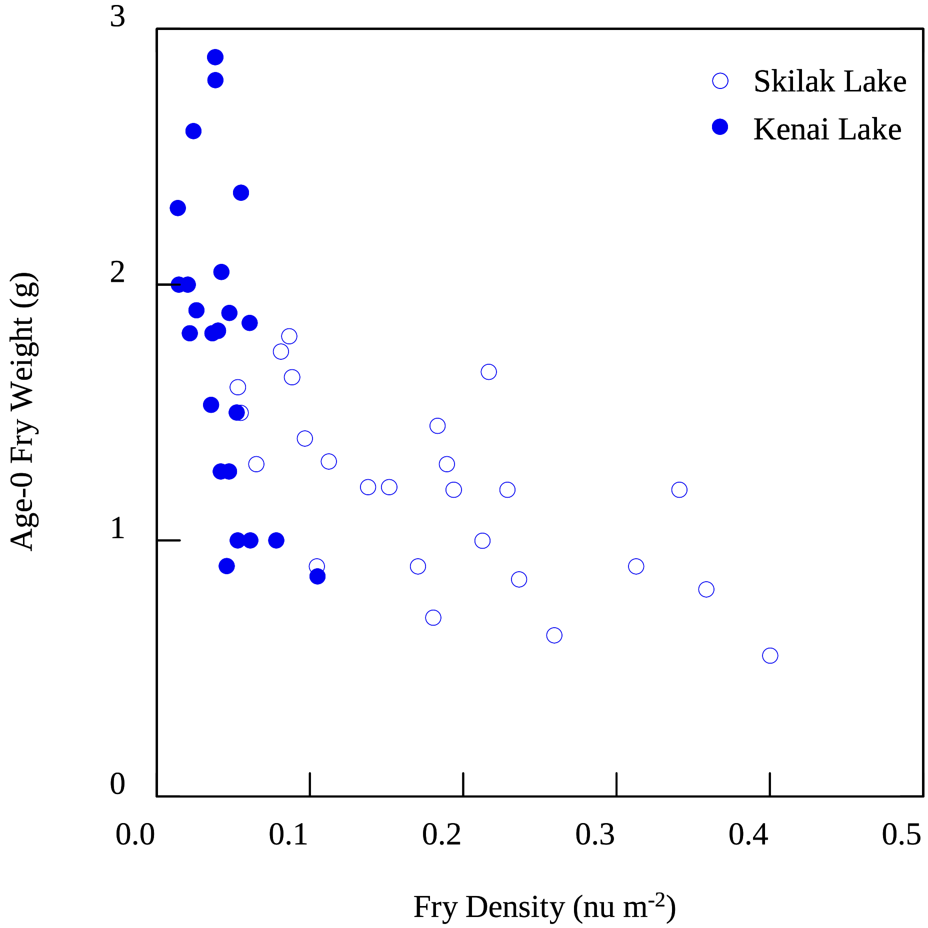

Figure 13.–Age-0 fry weight (g) vs fry density (number m^{-2}) for Skilak and Kenai lakes.

APPENDIX A

Appendix A1.–Hydroacoustic data collection parameters for autumn populations surveys.

	2005			2006		2007		
Lake	Skilak		Kenai	Skilak	Kenai	Skilak		Kenai
Date	14 Sep	3 Oct	19 Sep	20 Oct	26 Oct	17 Sep	9 Oct	20 Sep
Frequency (kHz)	208	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	6.6 Circular
Mode	Split	Split	Split	Split	Split	Split	Split	Split
Pulse duration (ms)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Sample range (m)	1 to 65	1 to 65	1 to 65	1 to 65	1 to 65	1 to 65	1 to 65	1 to 65
Water temperature (C)	10	9.4		10	6	10	6.5	7
Transducer depth (m)	1	1	1	1	1	1	1	1
Threshold (dB)	-65	-65	-65	-65	-65	-65	-65	-65
Ping rate (pps)	4	4	4	3	4	3	3	4

	2008			2009			2010		
Lake	Skilak		Kenai	Skilak		Kenai	Skilak		Kenai
Date	3 Sep	29 Sep	4 Sep	8 Sep	30 Sep	14 Sep	10 Sep	28 Sep	17 Sep
Frequency (kHz)	208	208	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	6.6 Circular	6.6 Circular
Mode	Split	Split	Split	Split	Split	Split	Split	Split	Split
Pulse duration (ms)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Sample range (m)	1 to 65	1 to 65	1 to 65	1 to 65	1 to 65	1 to 65	1 to 65	1 to 65	1 to 65
Water temperature (C)	8.5	7.5	8	10	9.4		9	8.2	9.6
Transducer depth (m)	1	1	1	1	1	1	1	1	1
Threshold (dB)	-65	-65	-65	-65	-65	-65	-65	-65	-65
Ping rate (pps)	3	3	4	4	4	4	3	3	4

Appendix A2.–Number of individual targets, mean backscattering coefficient (σ), and strata sigma ratio of whole water column sigma for hydroacoustic surveys conducted in Skilak Lake.

14 Sep 2005

Skilak Strata	Individual Targets	σ	Mean σ / Strata σ
0–5 m	73	3.39×10^{-6}	107
5–10 m	2,053	3.86×10^{-6}	121
10–15 m	5,198	3.58×10^{-6}	113
15–20 m	8,521	3.68×10^{-6}	116
20–25 m	12,484	3.22×10^{-6}	101
25–30 m	13,151	3.04×10^{-6}	96
30–35 m	10,297	2.91×10^{-6}	92
35–40 m	5,763	2.72×10^{-6}	86
40–45 m	3,108	2.62×10^{-6}	82
45–50 m	1,269	3.50×10^{-6}	110
50–51 m	654	3.65×10^{-6}	115
Total	62,571	3.18×10^{-6}	100

4 Oct 2005

Skilak Strata	Individual Targets	σ	Mean σ / Strata σ
0–5 m	18	3.07×10^{-6}	85
5–10 m	623	3.41×10^{-6}	95
10–15 m	2,161	4.16×10^{-6}	115
15–20 m	5,634	3.49×10^{-6}	97
20–25 m	11911	3.66×10^{-6}	102
25–30 m	14,984	3.55×10^{-6}	99
30–35 m	11,978	3.44×10^{-6}	95
35–40 m	5,569	3.21×10^{-6}	89
40–45 m	1,611	3.50×10^{-6}	97
45–50 m	385	1.02×10^{-5}	282
50–55 m	158	1.31×10^{-5}	364
Total	55,032	3.61×10^{-6}	100

19 Oct 2006

Skilak Strata	Individual Targets	σ	Mean σ / Strata σ
0–5 m	449	4.00×10^{-6}	97
5–10 m	2,114	4.39×10^{-6}	107
10–15 m	5,482	4.17×10^{-6}	101
15–20 m	9,277	4.14×10^{-6}	100
20–25 m	12,292	4.11×10^{-6}	100
25–30 m	12,539	4.05×10^{-6}	98
30–35 m	8,750	4.01×10^{-6}	97
35–40 m	3,451	3.85×10^{-6}	93
40–45 m	1,032	5.13×10^{-6}	124
45–50 m	303	7.26×10^{-6}	176
Total	55,689	4.12×10^{-6}	100

-continued-

17 Sep 2007

Skilak Strata	Individual Targets	σ	Mean σ / Strata σ
0–5 m	34	7.72×10^{-6}	130
5–10 m	1,031	5.82×10^{-6}	98
10–15 m	2,837	6.02×10^{-6}	101
15–20 m	3,310	5.84×10^{-6}	98
20–25 m	3,400	6.01×10^{-6}	101
25–30 m	3,304	5.73×10^{-6}	97
30–35 m	2,391	5.64×10^{-6}	95
35–40 m	1,122	5.46×10^{-6}	92
40–45 m	443	6.69×10^{-6}	113
45–50 m	216	8.70×10^{-6}	147
50–55 m	162	1.15×10^{-5}	193
Total	18,250	5.93×10^{-6}	100

8 Oct 2007

Skilak Strata	Individual Targets	σ	Mean σ / Strata σ
0 –5 m	4	7.50×10^{-6}	129
5–10 m	667	6.48×10^{-6}	111
10–15 m	2,479	6.54×10^{-6}	112
15–20 m	4,454	6.47×10^{-6}	111
20–25 m	7,352	6.20×10^{-6}	107
25–30 m	8,505	5.54×10^{-6}	95
30–35 m	8,775	5.48×10^{-6}	94
35–40 m	5,530	5.10×10^{-6}	88
40–45 m	2,409	5.16×10^{-6}	89
45–50 m	673	7.58×10^{-6}	130
50–55 m	221	1.34×10^{-5}	231
Total	41,069	5.82×10^{-6}	100

5 Sep 2008

Skilak Strata	Individual Targets	σ	Mean σ / Strata σ
0 –5 m	46	9.11×10^{-6}	91
5–10 m	996	8.74×10^{-6}	88
10–15 m	2,921	9.77×10^{-6}	98
15–20 m	4,298	1.07×10^{-5}	108
20–25 m	4,623	9.60×10^{-6}	96
25–30 m	5,593	1.10×10^{-5}	110
30–35 m	5,562	9.85×10^{-6}	99
35–40 m	3,435	1.02×10^{-5}	102
40–45 m	1869	9.85×10^{-6}	99
45–50 m	2,295	7.72×10^{-6}	77
Total	31,638	9.97×10^{-6}	100

28 Sep 2008

Skilak Strata	Individual Targets	σ	Mean σ / Strata σ
0 –5 m	34	8.02×10^{-6}	73
5–10 m	1,642	1.01×10^{-5}	91
10–15 m	5,697	1.07×10^{-5}	97
15–20 m	6,897	1.15×10^{-5}	104
20–25 m	7,541	1.11×10^{-5}	100
25–30 m	7,911	1.13×10^{-5}	102
30–35 m	5,038	1.11×10^{-5}	100
35–40 m	2,513	1.15×10^{-5}	104
40–45 m	1,157	1.07×10^{-5}	97
45–50 m	781	7.43×10^{-6}	97
Total	39,211	1.10×10^{-5}	100

-continued-

Appendix A2.–Page 3 of 3.

8 Sep 2009

Skilak	Individual		Mean σ
Strata	Targets	σ	Strata σ
0–5 m	12	7.88×10^{-6}	71
5–10 m	284	1.28×10^{-5}	103
10–15 m	996	1.25×10^{-5}	102
15–20 m	1,948	1.30×10^{-5}	99
20–25 m	2,827	1.36×10^{-5}	99
25–30 m	2120	1.46×10^{-5}	100
30–35 m	1,609	1.50×10^{-5}	98
35–40 m	917	1.55×10^{-5}	98
40–45 m	366	1.83×10^{-5}	103
45–50 m	321	1.69×10^{-5}	96
50–55 m	164	2.34×10^{-5}	105
Total	11,564	1.43×10^{-5}	100

30 Sep 2009

Skilak	Individual		Mean σ
Strata	Targets	σ	Strata σ
0–5 m	5	7.58×10^{-6}	64
5–10 m	336	1.16×10^{-5}	103
10–15 m	1,462	1.28×10^{-5}	102
15–20 m	2,854	1.30×10^{-5}	104
20–25 m	5541	1.31×10^{-5}	103
25–30 m	6,014	1.28×10^{-5}	99
30–35 m	5,054	1.32×10^{-5}	97
35–40 m	2,626	1.26×10^{-5}	96
40–45 m	1,091	1.40×10^{-5}	95
45–50 m	492	1.69×10^{-5}	104
50–55 m	206	1.60×10^{-5}	93
Total	25,681	1.31×10^{-5}	100

9 Sep 2010

Skilak	Individual		Mean σ
Strata	Targets	σ	Strata σ
0–5 m	45	7.09×10^{-6}	104
5–10 m	1,074	6.40×10^{-6}	94
10–15 m	2,418	6.34×10^{-6}	93
15–20 m	2,462	6.21×10^{-6}	91
20–25 m	2,108	6.62×10^{-6}	97
25–30 m	1,680	7.15×10^{-6}	105
30–35 m	820	6.80×10^{-6}	100
35–40 m	458	8.18×10^{-6}	120
40–45 m	329	9.89×10^{-6}	145
45–50 m	313	9.17×10^{-6}	135
50–55 m	208	8.68×10^{-6}	128
Total	11,915	6.80×10^{-6}	100

28 Sep 2010

Skilak	Individual		Mean σ
Strata	Targets	σ	Strata σ
0–5 m	24	3.10×10^{-6}	48
5–10 m	536	5.33×10^{-6}	83
10–15 m	1,941	5.72×10^{-6}	89
15–20 m	4,141	5.86×10^{-6}	91
20–25 m	7,143	6.25×10^{-6}	97
25–30 m	5,586	6.64×10^{-6}	103
30–35 m	3,782	6.67×10^{-6}	103
35–40 m	2,075	6.54×10^{-6}	101
40–45 m	897	7.23×10^{-6}	112
45–50 m	411	8.97×10^{-6}	139
50–55 m	372	1.26×10^{-5}	195
Total	26,908	6.46×10^{-6}	100

Appendix A3.–Estimated number of total fish in Skilak and Kenai lakes, Alaska, in autumn 2005.

			Estimated Number of Fish				
Lake	Area[a]	Transect	Surface	Midwater	Total	Mean	Area Variance
Skilak	1-1	1	1,563,228	10,978,456	12,541,684	23,920,143	26,241,012,895,933
		2	1,568,074	13,225,593	14,793,668		
		3	330,782	38,546,823	38,877,605		
		4	689,881	24,028,942	24,718,823		
		5	2,390,019	43,321,312	45,711,331		
		6	1,212,217	14,861,119	16,073,336		
	1-2	1	134,236	7,423,850	7,558,085		
		2	87,376	15,043,628	15,131,004		
		3	398,750	9,787,333	10,186,083		
		4	225,338	20,005,962	20,231,300		
		5	786,774	13,497,733	14,284,507		
		6	1,614,409	65,319,879	66,934,288		
	2-1	1	962,914	9,412,115	10,375,028	10,189,821	2,195,484,970,457
		2	1,054,728	12,365,752	13,420,480		
		3	703,595	9,146,627	9,850,222		
		4	1,385,500	13,371,000	14,756,501		
	2-2	1	312,194	5,399,451	5,711,645		
		2	92,476	5,036,556	5,129,033		
		3	324,446	6,120,690	6,445,136		
		4	1,342,397	14,488,124	15,830,522		
	3-1	1	497,686	3,827,145	4,324,831	5,509,195	969,558,704,857
		2	1,145,872	9,202,096	10,347,969		
		3	820,232	7,944,625	8,764,858		
		4	348,304	4,945,407	5,293,712		
	3-2	1	253,630	4,962,938	5,216,568		
		2	286,894	3,375,708	3,662,602		
		3	25,460	1,630,957	1,656,417		
		4	106,370	4,700,233	4,806,603		
	TOTAL					39,619,158	29,406,056,571,247

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			Estimated Number of Fish				
Lake	Area[a]	Transect	Surface	Midwater	Total	Mean	Area Variance
Kenai	1	1	0	272,608	272,608	845,499	52,048,563,952
		2	502	720,591	721,093		
		3	24,591	1,650,319	1,674,910		
		4	9,811	787,522	797,333		
		5	8,134	753,415	761,549		
	2	1	0	435,074	435,074	536,462	9,675,133,301
		2	3,361	448,085	451,445		
		3	6,976	236,712	243,687		
		4	0	464,261	464,261		
		5	31,247	658,830	690,077		
		6	27,292	906,937	934,230		
	3	1	0	317,744	317,744	245,405	746,079,054
		2	3,544	186,313	189,857		
		3	359	300,827	301,186		
		4	0	188,404	188,404		
		5	0	229,833	229,833		
	4	1	0	392,360	392,360	400,556	2,353,173,441
		2	3,534	535,022	538,556		
		3	801	478,141	478,942		
		4	8,867	295,867	304,734		
		5	0	288,190	288,190		
	5	1	94,468	356,476	450,944	328,837	5,967,278,287
		2	86,520	612,409	698,929		
		3	5,084	194,715	199,798		
		4	0	152,837	152,837		
		5	8,635	245,284	253,919		
		6	12,896	119,805	132,701		
		7	3,114	409,619	412,733		
TOTAL						2,356,759	70,790,228,035
TOTAL FOR BOTH LAKES						41,975,918	29,476,846,799,283

[a] 1-1 represents the first survey of Area 1; 1-2 represents the second survey of Area 1.

Appendix A4.–Estimated number of total fish in Skilak and Kenai lakes, Alaska, in autumn 2006.

			Estimated Number of Fish				
Lake	Area	Transect	Surface	Midwater	Total	Mean	Area Variance
Skilak	1	1	95,928	12,182,531	12,278,459	9,354,026	1,129,057,924,365
		2	110,474	9,476,132	9,586,606		
		3	47,293	8,677,593	8,724,886		
		4	121,910	7,160,190	7,282,100		
		5	311,127	12,014,355	12,325,481		
		6	345,916	5,580,706	5,926,622		
	2	1	47,613	8,399,592	8,447,205	11,933,754	3,992,744,593,784
		2	128,054	17,541,810	17,669,864		
		3	57,159	11,154,119	11,211,279		
		4	92,996	10,313,674	10,406,670		
	3	1	70,212	18,483,598	18,553,810	14,212,616	14,583,912,805,994
		2	7,840	19,167,574	19,175,413		
		3	103,337	16,099,929	16,203,266		
		4	6,537	2,911,437	2,917,974		
	TOTAL					35,500,396	19,705,715,324,143
Kenai	1	1	10,156	281,089	291,245	214,633	1,818,690,884
		2	11,215	71,497	82,712		
		3	3,130	231,360	234,490		
		4	6,374	148,273	154,647		
		5	11,587	298,486	310,073		
	2	1	17,830	178,328	196,158	328,381	5,325,471,019
		2	2,871	282,640	285,510		
		3	110,540	565,847	676,387		
		4	9,779	261,345	271,124		
		5	0	202,110	202,110		
		6	23,950	315,046	338,996		
	3	1	3,552	234,964	238,516	159,097	1,134,685,642
		2	3,552	234,964	238,516		
		3	0	72,895	72,895		
		4	12,862	112,182	125,045		
		5	0	120,516	120,516		
	4	1	0	464,708	464,708	417,452	2,902,534,598
		2	1,301	451,443	452,744		
		3	16,450	379,118	395,568		
		4	77,363	532,650	610,013		
		5	10,697	363,744	374,440		
		6	5,105	202,135	207,241		
	5	1	6,508	282,837	289,345	911,266	55,494,911,069
		2	14,485	291,311	305,796		
		3	0	1,810,439	1,810,439		
		4	83	1,139,685	1,139,767		
		5	0	486,909	486,909		
		6	53,423	536,771	590,193		
		7	0	609,281	609,281		
	TOTAL					1,866,954	66,676,293,212
	TOTAL FOR BOTH					37,531,226	19,772,391,617,354

Appendix A5.–Estimated number of total fish in Skilak and Kenai lakes, Alaska, in autumn 2007.

			Estimated Number of Fish				
Lake	Area[a]	Transect	Surface	Midwater	Total	Mean	Area Variance
Skilak	1-1	1	187,972	8,532,097	8,720,069	8,311,022	1,688,964,814,515
		2	354,604	3,930,170	4,284,774		
		3	382,229	3,523,502	3,905,731		
		4	327,675	4,541,709	4,869,384		
		5	278,262	7,959,633	8,237,894		
		6	1,708,322	9,844,135	11,552,458		
	1-2	1	57,980	2,862,398	2,920,378		
		2	230,841	10,290,446	10,521,287		
		3	85,920	8,517,639	8,603,559		
		4	196,255	4,985,042	5,181,297		
		5	160,026	18,352,359	18,512,385		
		6	272,116	12,150,934	12,423,050		
	2-1	1	982,575	9,442,126	10,424,701	4,211,984	926,036,178,082
		2	320,639	3,728,590	4,049,229		
		3	267,753	4,127,801	4,395,554		
		4	320,249	4,535,476	4,855,726		
	2-2	1	107,262	2,306,798	2,414,060		
		2	196,021	2,452,622	2,648,643		
		3	48,480	1,724,374	1,772,854		
		4	242,077	2,893,031	3,135,108		
	3-1	1	92,813	837,044	929,857	4,352,353	3,844,287,141,016
		2	150,293	473,063	623,356		
		3	544,977	1,920,011	2,464,988		
		4	168,474	3,179,088	3,347,562		
	3-2	1	13,402	778,901	792,303		
		2	127,625	6,173,280	6,300,905		
		3	147,584	2,936,659	3,084,244		
		4	560,299	16,715,309	17,275,608		
	TOTAL					16,875,359	6,459,288,133,613

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Appendix A5.–Page 2 of 2.

Lake	Area	Transect	Estimated Number of Fish: Surface	Midwater	Total	Mean	Area Variance
Kenai	1	1	6,082	271,295	277,377	262,143	13,407,082,571
		2	12,111	691,319	703,430		
		3	5,053	86,849	91,902		
		4	26,820	132,280	159,100		
		5	2,732	76,174	78,906		
	2	1	2,529	94,072	96,602	233,782	1,194,604,464
		2	28,246	277,006	305,252		
		3	355	315,790	316,146		
		4	8,420	261,230	269,650		
		5	3,214	239,397	242,610		
		6	0	172,435	172,435		
	3	1	8,564	93,103	101,667	129,610	583,158,459
		2	9,289	104,292	113,581		
		3	3,734	132,048	135,782		
		4	49,339	169,430	218,769		
		5	0	78,249	78,249		
	4	1	103,770	829,068	932,839	404,941	19,940,973,725
		2	15,939	381,095	397,034		
		3	10,921	290,610	301,532		
		4	52,313	250,677	302,990		
		5	0	90,308	90,308		
	5	1	2,191	293,685	295,877	229,695	1,898,516,985
		2	10,217	148,652	158,869		
		3	10,145	252,119	262,264		
		4	0	239,652	239,652		
		5	2,563	147,742	150,305		
		6	0	74,355	74,355		
		7	1,947	424,594	426,541		
	TOTAL					1,260,171	37,024,336,205
	TOTAL FOR BOTH LAKES					18,135,530	6,496,312,469,818

[a] 1-1 represents the first survey of Area 1; 1-2 represents the second survey of Area 1.

Appendix A6.–Estimated number of total fish in Skilak and Kenai lakes, Alaska, in autumn 2008.

			Estimated Number of Fish				
Lake	Area[a]	Transect	Surface	Midwater	Total	Mean	Area Variance
Skilak	1	1	498,870	6,178,461	6,677,331	9,680,817	4,563,669,170,851
		2	335,165	12,545,716	12,880,881		
		3	1,049,142	14,595,774	15,644,916		
		4	479,555	8,419,384	8,898,939		
		5	118,128	3,369,489	3,487,617		
		6	1,324	625,503	626,827		
	1, 2	1	2,198,726	25,282,798	27,481,524		
		2	375,709	11,937,981	12,313,690		
		3	610,101	13,665,807	14,275,908		
		4	208,774	6,254,577	6,463,351		
		5	122,152	3,747,159	3,869,311		
		6	30,074	3,519,431	3,549,504		
	2	1	100,936	1,293,500	1,394,436	6,324,185	1,853,583,914,832
		2	82,474	1,529,769	1,612,243		
		3	814,670	11,954,063	12,768,733		
		4	807,642	6,217,452	7,025,094		
	2,2	1	220,851	5,531,356	5,752,207		
		2	415,025	4,324,462	4,739,487		
		3	558,993	8,988,637	9,547,630		
		4	228,905	7,524,747	7,753,652		
	3	1	18,039	165,098	183,136	2,134,997	499,238,264,320
		2	49,869	256,863	306,732		
		3	297,522	907,088	1,204,609		
		4	175,419	2,001,909	2,177,328		
	3,2	1	162,802	942,600	1,105,401		
		2	414,952	2,575,570	2,990,522		
		3	351,009	5,997,029	6,348,038		
		4	80,934	2,683,279	2,764,212		
	TOTAL					18,139,999	6,916,491,350,003

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Appendix A6.–Page 2 of 2.

			Estimated Number of Fish				
Lake	Area	Transect	Surface	Midwater	Total	Mean	Area Variance
Kenai	1	1	84,196	498,210	582,406	645,769	9,595,913,229
		2	69,005	583,448	652,453		
		3	53,342	675,648	728,990		
		4	62,077	870,904	932,981		
		5	10,907	321,107	332,014		
	2	1	12,847	449,985	462,831	796,435	35,389,573,683
		2	206,013	1,503,849	1,709,862		
		3	23,317	531,126	554,443		
		4	99,328	697,702	797,030		
		5	81,079	556,643	637,721		
		6	78,982	537,743	616,725		
	3	1	435	189,379	189,814	574,068	22,179,113,535
		2	10,624	347,090	357,714		
		3	34,718	601,158	635,876		
		4	7,439	612,258	619,697		
		5	33,276	1,033,965	1,067,241		
	4	1	88,467	445,335	533,803	390,363	26,298,071,103
		2	0	72,526	72,526		
		3	1,245	152,257	153,502		
		4	9,736	223,148	232,884		
		5	210,977	748,125	959,102		
	5	1	82,030	352,267	434,297	306,733	18,053,310,293
		2	19,228	116,905	136,133		
		3	278,864	779,260	1,058,124		
		4	25,531	139,388	164,919		
		5	9,778	36,101	45,879		
		6	5,295	66,757	72,052		
		7	22,254	213,475	235,729		
	TOTAL					2,713,369	111,515,981,842
	TOTAL FOR BOTH LAKES					20,853,369	7,028,007,331,845

[a] 1-1 represents the first survey of Area 1; 1-2 represents the second survey of Area 1.

Appendix A7.–Estimated number of total fish in Skilak and Kenai lakes, Alaska, in autumn 2009.

			Estimated Number of Fish				
Lake	Area[a]	Transect	Surface	Midwater	Total	Mean	Area Variance
Skilak	1	1	304,517	2,551,323	2,855,840	3,624,662	230,475,138,370
		2	177,940	4,760,381	4,938,321		
		3	77,163	3,841,116	3,918,279		
		4	230,868	1,434,683	1,665,551		
		5	55,417	976,102	1,031,519		
		6	203,231	1,902,594	2,105,825		
	1, 2	1	155,858	4,290,579	4,446,437	4,496,768	352,897,886,586
		2	306,139	5,393,204	5,699,342		
		3	365,489	4,726,060	5,091,548		
		4	200,360	4,082,791	4,283,151		
		5	98,441	5,576,250	5,674,691		
		6	20,305	1,765,131	1,785436		
	2	1	22,787	1,627,469	1,650,256	2,845,350	129,826,089,659
		2	169,523	2,610,719	2,780,242		
		3	33,282	2,348,835	2,382,118		
		4	244,302	2,851,391	3,095,692		
	2,2	1	5,913	1,940,339	1,946,252	3,213,624	418,167,926,187
		2	9,137	2,939,719	2,948,856		
		3	55,050	2,883,502	2,938,551		
		4	127,053	4,893,783	5,020,836		
	3	1	36,853	166,110	202,963	2,266,036	153,340,598,356
		2	115,719	1,150,910	1,266,629		
		3	347,654	2,293,252	2,640,906		
		4	115,337	2,926,941	3,042,278		
	3,2	1	67,232	1,903,183	1,970,415	2,743,877	139,631,484,088
		2	92,168	2,898,657	2,990,825		
		3	97,166	3,572,443	3,669,608		
		4	67,370	2,277,292	2,344,661		
	TOTAL					8,736,048	513,641,826,385

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Appendix A7.–Page 2 of 2.

Lake	Area	Transect	Estimated Number of Fish: Surface	Midwater	Total	Mean	Area Variance
Kenai	1	1	2,271	326,311	328,582	1,800,185	1,560,783,665,380
		2	1,348	1,016,696	1,018,044		
		3	9,652	464,154	473,806		
		4	2,382	404,284	406,666		
		5	1,550	6,772,279	6,773,829		
	2	1	38	337,024	337,061	788,061	17,977,415,939
		2	994	960,795	961,790		
		3	119	1,318,804	1,318,923		
		4	8,181	659,912	668,093		
		5	9,706	694,140	703,846		
		6	8,633	730,020	738,653		
	3	1	59,273	493,531	552,804	313,177	4,109,879,838
		2	0	240,587	240,587		
		3	0	281,064	281,064		
		4	29,270	284,906	314,176		
		5	0	177,255	177,255		
	4	1	5,377	57,441	62,818	223,823	1,951,165,711
		2	5,445	199,818	205,264		
		3	49,400	201,358	250,758		
		4	4,214	282,089	286,303		
		5	9,190	304,783	313,973		
	5	1	192	48,698	48,890	94,789	427,285,181
		2	24,981	177,037	202,017		
		3	13,996	100,709	114,705		
		4	8,151	67,900	76,051		
		5	1,169	39,221	40,390		
		6	6,384	67,008	73,393		
		7	13,192	94,883	108,075		
TOTAL						3,220,035	1,585,249,412,049
TOTAL FOR BOTH LAKES						11,956,083	2,098,891,238,434

[a] 1-1 represents the first survey of Area 1; 1-2 represents the second survey of Area 1.

Appendix A8.–Estimated number of total fish in Skilak and Kenai lakes, Alaska, in autumn 2010.

			Estimated Number of Fish				
Lake	Area	Transect	Surface	Midwater	Total	Mean	Area Variance
Skilak	1	1	312,416	6,423,789	6,736,205	5,723,352	1,161,329,885,789
		2	197,510	14,350,856	14,548,365		
		3	414,146	4,288,430	4,702,576		
		4	269,513	1,262,692	1,532,205		
		5	192,847	5,092,650	5,285,498		
		6	191,836	1,433,869	1,625,706		
	1, 2	1	249,164	6,415,287	6,664,451		
		2	377,916	9,024,071	9,401,987		
		3	163,681	2,314,427	2,478,108		
		4	131,148	7,961,896	8,093,045		
		5	199,404	4,270,503	4,469,907		
		6	226,744	2,915,427	3,142,170		
	2	1	520,978	4,625,662	5,146,640	5,903,830	534,238,254,368
		2	407,647	5,040,838	5,448,485		
		3	977,682	4,910,973	5,888,655		
		4	452,543	6,753,719	7,206,262		
	2,2	1	76,529	7,129,255	7,205,784		
		2	394,638	8,909,918	9,304,556		
		3	195,783	2,142,844	2,338,627		
		4	212,820	4,478,815	4,691,635		
	3	1	567,659	1,641,329	2,208,988	3,381,512	798,269,871,592
		2	92,815	708,360	801,175		
		3	1,314,753	5,893,954	7,208,707		
		4	653,320	4,421,934	5,075,253		
	3,2	1	4,090	107,516	111,605		
		2	316,621	2,145,889	2,462,511		
		3	123,659	2,937,436	3,061,095		
		4	208,817	5,913,947	6,122,764		
	TOTAL					15,008,695	2,493,838,011,748

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Lake	Area	Transect	Estimated Number of Fish: Surface	Midwater	Total	Mean	Area Variance
Kenai	1	1	11,714	409,581	421,295	367,820	3,871,587,945
		2	13,467	226,322	239,789		
		3	739	205,581	206,320		
		4	21,516	418,306	439,822		
		5	18,063	513,812	531,874		
	2	1	22,400	2,497,069	2,519,469	1,457,301	50,003,417,286
		2	12,001	1,514,491	1,526,491		
		3	6,124	1,195,654	1,201,778		
		4	30,815	1,004,186	1,035,001		
		5	10,978	1,117,972	1,128,950		
		6	47,271	1,284,847	1,332,118		
	3	1	12,686	548,610	561,295	534,310	11,012,669,791
		2	10,645	501,220	511,866		
		3	24,084	368,873	392,957		
		4	0	294,754	294,754		
		5	82,253	828,426	910,679		
	4	1	12,513	404,093	416,606	921,579	21,208,585,231
		2	2,169	1,279,159	1,281,328		
		3	16,817	953,773	970,590		
		4	12,217	829,554	841,771		
		5	4,430	1,093,169	1,097,599		
	5	1	2,696	51,492	54,188	195,194	904,740,532
		2	38,390	216,244	254,634		
		3	21,727	208,682	230,409		
		4	27,175	258,707	285,881		
		5	486	126,190	126,675		
		6	1,027	198,141	199,169		
		7	9,963	205,440	215,403		
	TOTAL					3,476,204	87,001,000,785
	TOTAL FOR BOTH LAKES					18,484,899	2,580,839,012,534

Appendix A9.–Number of midwater trawls by depth by area and by year for Skilak lake.

	Area					
	1		2		3	
Year	surface	>10m	surface	>10m	surface	>10m
2005	2	1	1	0	1	0
2006	3	1	2	1	1	2
2007	5	7	3	5	2	4
2008	24	0	32	0	32	4
2009	34	0	17	0	21	0
2010	48	0	8	0	3	0

APPENDIX B

Appendix B1.–Two-stage sampling method. Cluster and 2-Stage Sampling (lake sockeye fry).

Notation

j indexes the tow; *k* indexes the age class; *i* indexes an individual fish

N = total number of tows in the lake (calculated by volume)
n = number of tows sampled (assumed random)
m_j = number of fish in tow *j*
m $= \sum_{j=1}^{n} m_j$ = number of fish sampled in the tows
$\bar{m}$ $= \frac{m}{n}$ = average number of fish per sampled tow
M $= \sum_{j=1}^{N} m_j$ = number of fish in the lake (hydroacoustic estimate)
$\bar{M}$ $= \frac{M}{N}$ = average number of fish per tow for the lake population
o_j = number of sockeye fry in tow *j*
o $= \sum_{j=1}^{n} o_j$ = number of sockeye fry sampled
$\bar{o}$ $= \frac{o}{n}$ = average number of sockeye fry per sampled tow
O $= \sum_{j=1}^{N} o_j$ = number of sockeye fry in the lake
$\bar{O}$ $= \frac{O}{N}$ = average number of sockeye fry per tow for the lake population
L = proportion of sockeye fry in the fish population
L_k = proportion of age-*k* sockeye fry in the fish population
P_k = proportion of age-*k* fry in the sockeye population
l_j = sample proportion of sockeye fry in tow *j*
a_j = number of sockeye fry in tow *j* sampled for age, weight, and length (AWL)
a_{jk} = number of age-*k* sockeye fry sampled for AWL in tow *j*
l_{jk} = sample proportion of age-*k* sockeye fry of the fish in tow *j*
P_{jk} = sample proportion of age-*k* sockeye fry of the sockeye in tow *j*
Y_j = total of *y* in tow *j*, for all sockeye fry
Y $= \sum_{j=1}^{N} Y_j$ = total of *y*, for all sockeye fry
Y_{jk} = total of *y* in tow *j*, for age-*k* sockeye fry
Y_k $= \sum_{j=1}^{N} Y_{jk}$ = total of *y* for age-*k* sockeye fry
y_{ijk} = measurement of *y* (weight or length) on the i^{th} sockeye fry

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A. Whole Fish Population (cluster sampling).

a. The estimate of the proportion of sockeye fry in the fish population is

$$\hat{L} = \frac{\sum_{j=1}^{n} o_j}{\sum_{j=1}^{n} m_j} = \frac{o}{m},$$

with variance estimate

$$v(\hat{L}) = \left(\frac{N-n}{N}\right)\left(\frac{1}{n\bar{\bar{M}}^2}\right)\frac{\sum_{j=1}^{n}(o_j - \hat{L}m_j)^2}{n-1}.$$

b. The estimated proportion of age-*k* sockeye fry in the fish population is

$$\hat{L}_k = \hat{L}(\hat{P}_k),$$

with variance estimate

$$v(\hat{L}_k) = \hat{L}^2 v(\hat{P}_k) + \hat{P}_k^2 v(\hat{L}) - v(\hat{L})v(\hat{P}_k),$$

where the estimate of P_k and the variance estimate of P_k is given below.

B. Sockeye Salmon Population (2-stage sampling).

a. The estimated proportion of age-*k* fry in the sockeye population is

$$\hat{P}_k = \frac{\sum_{j=1}^{n} o_j p_{jk}}{\sum_{j=1}^{n} o_j},$$

which is a ratio estimator, where $p_{jk} = \frac{a_{jk}}{a_j}$. The variance estimate is

$$v(\hat{P}_k) = \left(\frac{N-n}{N}\right)\left(\frac{S_r^2}{n\bar{o}^2}\right) + \left(\frac{1}{nN\bar{o}^2}\right)\sum_{j=1}^{n} o_j^2 \left(\frac{o_j - a_j}{o_j}\right)\left[\frac{p_{jk}(1-p_{jk})}{a_j - 1}\right],$$

where $S_{kr}^2 = \frac{\sum_{j=1}^{n} o_j^2 (p_{jk} - \hat{P}_k)^2}{n-1}$.

C. Sockeye Fry Abundance Estimates.

a. Estimated total sockeye fry abundance is

$$\hat{O} = \hat{L}(\hat{M}),$$

with variance estimate

-continued-

$$v(\hat{O}) = \hat{L}^2 v(\hat{M}) + \hat{M}^2 v(\hat{L}) - v(\hat{L}) v(\hat{M}),$$

where $\hat{M}$ is the total fish population estimate (obtained hydroacoustically).

b. Estimated age-*k* sockeye fry abundance is

$$\hat{O}_k = \hat{L}_k(\hat{M}),$$

with variance estimate

$$v(\hat{O}_k) = \hat{L}_k^2 v(\hat{M}) + \hat{M}^2 v(\hat{L}_k) - v(\hat{L}_k) v(\hat{M}).$$

D. Sockeye Fry W-L Estimates (2-stage sampling).

a. The estimated average weight or length for the whole fry population is

$$\hat{\hat{Y}} = \frac{\sum_{j=1}^{n} o_j \bar{y}_j}{\sum_{j=1}^{n} o_j},$$

which is a ratio estimator, where $\bar{y}_j = \frac{\sum_{j=1}^{a_j} y_{ij}}{a_j}$. The variance estimate is

$$v(\hat{\hat{Y}}) = \left(\frac{N-n}{N}\right)\left(\frac{S_r^2}{n\bar{o}^2}\right) + \left(\frac{1}{nN\bar{o}}\right)\sum_{j=1}^{n} o_j^2 \left(\frac{o_j - a_j}{o_j}\right)\left(\frac{S_j^2}{o_j}\right),$$

where $S_r^2 = \frac{\sum_{j=1}^{n} o_j^2 (\bar{y}_j - \hat{\hat{Y}})^2}{n-1}$ and $S_j^2 = \frac{\sum_{j=1}^{a_j} (y_{ij} - \bar{y}_j)^2}{a_j - 1}$.

b. The estimated average weight or length of age-*k* sockeye fry is

$$\bar{Y}_k = \frac{\sum_{j=1}^{n} o_{jk} \bar{y}_{jk}}{\sum_{j=1}^{n} o_j k},$$

which is a subpopulation ratio estimator, where $o_{jk} = o_j(p_{jk})$ and $\bar{y}_{jk} = \frac{\sum_{j=1}^{a_{jk}} y_{ij}}{a_{jk}}$.

An approximate variance estimate is

$$v(\bar{Y}_k) \approx \left(\frac{N-n}{N}\right)\left(\frac{S_{kr}^2}{n\bar{o}_k^2}\right) + \left(\frac{1}{nN\bar{o}_k}\right)\sum_{j=1}^{n} o_{jk}^2 \left(\frac{o_j - a_j}{o_j}\right)\left(\frac{S_{jk}^2}{o_{jk}}\right),$$

where $S_{kr}^2 = \frac{\sum_{j=1}^{n} o_{jk}^2 (\bar{y}_{jk} - \hat{\hat{Y}}_k)^2}{n-1}$ and $S_{jk}^2 = \frac{\sum_{j=1}^{a_{jk}} (y_{ijk} - \bar{Y}_{jk})}{a_{jk} - 1}$.