Fishery Data Series No. 13-15

Sockeye Salmon Smolt Enumeration on the Karluk River, 2012

by

Mary Loewen

April 2013

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

The 2012 Karluk Sockeye Salmon Smolt Enumeration project was the revitalization of smolt enumeration on the Karluk River, which was discontinued in 2006. This report provides the daily and cumulative smolt outmigration estimates as well as biometric and age composition information, and when possible, comparisons with historical data. The research was designed to estimate smolt population size and age structure, assess fish body condition, and collect samples from the outmigrating smolt population for isotopic composition. The abundance of sockeye salmon smolt was estimated using Canadian fan traps and mark-recapture techniques. In 2012, a total of 888,658 sockeye salmon smolt were estimated to pass downstream of the traps from May 18 to June 29. Of these, the majority were freshwater-age-2 fish (85%) which signals a return to historical age composition estimates first. Length and weight of outmigrating smolt also indicated a healthy rearing environment for sockeye salmon in Karluk Lake prior to outmigration.

Key words: Sockeye salmon, smolt, *Oncorhynchus nerka,* Karluk River, mark-recapture

INTRODUCTION

Karluk Lake is located on the southwest side of Kodiak Island (Figure 1), and supports the largest sockeye salmon *Oncorhynchus nerka* run in the Kodiak Management Area (Foster 2010). Karluk Lake (57.442814°N, 154.112031°W) is approximately 19.5 km long, has a surface area of approximately 38.5 km^2 and maximum depth of over 130 m. Karluk Lake drains northwest into the approximately 35 km long Karluk River, which in turn flows into Karluk Lagoon, a semi-enclosed estuary with salinities ranging from full marine seawater at the outer spit to nearly freshwater conditions at the head of the lagoon. In addition to sockeye salmon, other fish species in the Karluk Lake drainage include pink salmon *Oncorhynchus gorbuscha*, Chinook *O. tshawytscha*, chum salmon *O. keta,* coho salmon *O. kisutch*, rainbow trout *O. mykiss*, Dolly Varden *Salvelinus malma*, three spine stickleback *Gasterosteus aculeatus*, and coastrange sculpin *Cottus aleuticus*.

Some of the earliest recorded Alaskan commercial harvests of sockeye salmon are from Karluk Lake, dating from the late 1800s (Bean 1891). In the early 1900s, sockeye salmon harvests and escapements at Karluk Lake were lightly regulated and overfishing is suspected to have occurred. A weir was established on the river in 1912 to enumerate escapement, and the White Act was implemented in 1924 to reserve 50% of the run for escapement. Despite these efforts, Karluk Lake sockeye salmon suffered a long-term decline in adult returns, which did not significantly increase until the late 1970s (Barnaby 1944; Schmidt et al. 1997, 1998).

There are two runs of sockeye salmon that spawn in the watershed. The majority of the early run enters the Karluk watershed in June and early July while the late run enters the system in late July, continuing through September. The early run has a sustainable escapement goal range of 110,000–250,000 fish, while the late-run sustainable escapement goal is 170,000–380,000 fish beginning on July 16 (Nemeth et al. 2010). From 1985 through 2007, Karluk sockeye salmon runs were consistently strong, averaging roughly 1.3 million sockeye salmon annually. Established early-run upper escapement goals were exceeded 16 years in the 22 year period, and late-run upper escapement goals were exceeded 8 years of the 22 year period. Sockeye salmon stocks in Karluk Lake experienced diminished adult returns from 2008 through 2011 which necessitated annual restrictions on the subsistence, sport, and commercial salmon fishery in order to conserve escapement.

Responding to the historically low runs of Karluk Lake sockeye salmon in 2008 and 2009, the Alaska Department of Fish & Game (ADF&G) conducted a series of investigations into the possible reasons for this decline. Between 2009 and 2011 ADF&G examined historical trends in escapement, run size, limnology, and climate, as well as trends in size, age, and growth rates for the Karluk Lake sockeye salmon. Additionally, with a growing concern about the low run strength of Karluk sockeye salmon, Kodiak National Wildlife Refuge hosted an interagency climate change forum in December 2009, with a focus on the poor returns of salmon at Karluk Lake. One outcome of the forum was discussion initiated by ADF&G and Kodiak Regional Aquaculture Association (KRAA) to attempt to reinitiate sockeye salmon smolt sampling at Karluk Lake.

Sockeye salmon typically spend anywhere from one to three years in freshwater before migrating to saltwater. The length of time spent in freshwater can be influenced by many things, including food availability, competition for space or food, genetics, and lake environmental conditions. Smolt outmigration studies can provide information on life history strategies, marine survival rates, and annual changes in outmigration timing. Combined with limnological investigations, this type of study can provide insight as to how environmental factors may influence food availability, juvenile outmigration timing, and general population health. Smolt data can also serve as an indicator of future run strength and overall stock status. Juvenile salmon are known to migrate to sea after certain size thresholds are met, during specific seasons, and under certain environmental conditions (Clarke and Hirano 1995). Salmon smolt outmigration may be triggered by warming springtime water temperatures (>4°C) and increased photoperiod (Clarke and Hirano 1995). Variables affecting growth in juvenile salmon include temperature, competition, food quality and availability, and water chemistry characteristics (Moyle and Cech 1988). Because of these dynamic factors, annual growth and survival from egg to smolt of sockeye salmon often varies among lakes, years, and within individual populations.

Sockeye salmon smolt studies have been conducted sporadically on Karluk Lake since 1925. Previous smolt projects were conducted on Karluk Lake 1925–1936, 1961–1968, 1979–1992, 1994–1995, and 1997 (Figure 2) by a variety of agencies and employing a variety of methodologies. Beach seining at Karluk Lake outlet, sonar estimation, fyke nets, trawling in Karluk Lake, and Canadian fan traps have all been used in the Karluk watershed to assess smolt abundance and condition. Most recently, from 1999 to 2003, a smolt project funded by the KRAA and implemented by ADF&G used Canadian fan traps and mark-recapture techniques to estimate outmigration smolt populations and obtain biometrical data such as age, length, weight, and body condition factor (Duesterloh and Watchers 2007; Watchers and Duesterloh 2005). The smolt project was continued from 2004 to 2006 as part of a larger project funded by the Gulf of Alaska Ecosystem Monitoring (GEM) program. Funding from the GEM project enabled a collaborative study between ADF&G and the University of Alaska to study the role of marine derived nutrients in the Karluk watershed. Additionally, smolt age and size sampling were conducted in conjunction with stable isotope analysis. Findings from the studies conducted on Karluk River during GEM can be found in Watchers and Duesterloh (2005) and Duesterloh and Watchers (2007).

In the last year of the GEM smolt monitoring study (2006) the average size of outmigrating sockeye was the smallest in the dataset stretching back to 1925. Furthermore, the majority of the fish were freshwater-age-3 (Duesterloh and Watchers 2007); historically, freshwater-age-2 smolt have been the dominant outmigrating age class (Kyle et al. 1988; Rounsefell 1958). While it has been found that lake residence time of Karluk sockeye salmon juveniles is longer than most systems (Koenings and Burkett 1987), increased freshwater age is often associated with poorer rearing conditions that cause juvenile salmon to take longer to reach a minimum size needed for onset of smolting and migration to sea (Foerster 1968).

In May and June of 2010 ADF&G and KRAA conducted a pilot project to estimate size and body condition factor of outmigrating sockeye salmon smolt at the outlet of Karluk Lake. In the winter of 2010, ADF&G and KRAA successfully submitted a proposal to the Alaska Sustainable Salmon Fund to conduct grab sampling of sockeye salmon smolt in Karluk River for three years beginning in 2011. The project goal was to collect smolt age and size information from mid-May to mid-June at the outlet of Karluk Lake in 2011–2013. In addition, sockeye salmon smolt were to be collected to expand the time series of stable isotope analyses that began in 1999.

Analysis of stable isotopes ($\delta^{13}C$ and $\delta^{15}N$) is a way to assess the contribution of marine derived nutrients (Finney et al. 2000) and trophic level in juvenile salmon. Trophic level determination allows assessment of diet differences between age classes or populations. Additionally, $\delta^{13}C$ analysis and C:N ratios provide an index of lipid content (i.e., fitness), which can be compared to calculated condition factor. Stable isotope analysis may provide a more complete evaluation of condition compared to standard condition factor calculations which are based on length and weight samples. Isotope samples collected in years when AWL sampling was not conducted can still provide insight to fish health and fitness. Finally, the $\delta^{13}C$ ratios, once corrected for lipid contribution, provide a possible index of lake productivity.

In 2012, ADF&G was allocated funding from the Alaska legislature to reinstitute a more comprehensive sockeye salmon smolt enumeration project at Karluk Lake. The 2012 season was one in which the two different projects worked cooperatively to achieve the goals of both projects: sampling outmigrating smolt for age and size and estimating total smolt outmigration.

The 2012 field season was the first year of the ADF&G Karluk River sockeye salmon smolt monitoring and enumeration project after a six-year period of limited or no data collection. The long-term goal of this project is to obtain reliable estimates of smolt production over time for Karluk Lake. Data collected from this project enables researchers to better identify what factors are specifically affecting and controlling sockeye salmon production within the freshwater environment which can help refine escapement goals and improve pre-season run forecasts. This information allows managers to better manage for maximum sustainable yield. This report presents data collected in 2012, compares the results to previous years when possible, and provides guidance for future seasons based on protocols and outcomes of the 2012 season.

OBJECTIVES

The objectives for the 2012 season were to

1. estimate the total number of outmigrating sockeye salmon smolt, by age class, from Karluk Lake from May 10 to June 30.
2. describe outmigration timing and growth characteristics (length, weight, and condition factor) by age class for Karluk Lake sockeye salmon smolt. Sample size is constructed such that the estimated mean weight of the major age class per strata will be within 5% and the mean length within 2% of the true value with 95% confidence (Thompson 1992).
3. determine the stable isotopic composition ($\delta^{15}N$ and $\delta^{13}C$) of a subsample of juvenile sockeye salmon corresponding to the sampling in objective 1.
4. build a smolt database to estimate smolt-to-adult survival and to forecast future runs of Karluk sockeye salmon.

METHODS

STUDY SITE AND TRAP DESCRIPTION

Two Canadian Fan traps were operated in an upstream-downstream array to capture smolt outmigrating from Karluk Lake (Figure 3). The downstream trap was installed approximately 0.6 km downstream from the lake outlet (57.4430°N, 154.1158°W) and was the primary site utilized for smolt enumeration and the recapture of marked fish (Figure 4). The upstream trap was installed approximately 0.1 km downstream from the lake outlet (57.4413°N, 154.1094°W) and was utilized to capture smolt for dye release testing (Figure 5). Capturing smolt at the upstream trap for marking and release was intended to reduce potential high mortality rates encountered in past project years when only one trap was in operation and transportation of the smolt upstream for release incurred heavy mortality.

Both traps were positioned towards the middle of the river at each location, where water velocity was great enough to make it difficult for smolt to avoid capture. The upper trap was approximately 6m from shore, while the lower trap was approximately 12m from shore. A live box (1.2 m x 0.9 m x 0.6 m) was attached to the outlet of each trap. Hand-powered cable winches ("come-alongs") attached to the rear of the trap allowed for adjustment of the trap vertically in the water column. Both traps were supported by aluminum Rackmaster pipe frame. Perforated aluminum plate supported by additional Rackmaster pipe frame was installed as wings on either side of the trap at a 45°-60° degree angle to river flow depending on river condition to improve flow and increase capture efficiency (Figure 5). Each trap had a separate live box for holding fish captured during the night.

The downstream trap was installed on May 18 and fished continuously through June 29. The trap was removed for the season on June 30, after the number of captured smolt dropped to less than 100 smolt per day for 3 consecutive days. Detailed methods of trap installation, operation, and maintenance are described in the 2012 Karluk Lake Operational Plan (Foster and Finkle 2012).

The upstream trap was installed on May 27 and was fished for four mark-recapture trials. Additionally, smolt were collected in the upstream trap for two consecutive nights following each mark-recapture trial for age-weight-and-length (AWL) sampling. At the completion of the project, both traps were disassembled and stored on site.

SMOLT ENUMERATION

Because smolt primarily outmigrate at night, sampling days extended for a 24-hour period from noon to noon and were identified by the date of the first noon-to-midnight period. The traps were checked a minimum of five times each day beginning at noon, at 1600, between 1900 and 2200 hours, between midnight and 0300, and no later than 0800 hours the next morning. Traps were checked more frequently during periods of increased smolt outmigration. For example, during the night (2200 to 0600 hours) between May 20 and June 14, the traps were monitored continuously. The upper trap was fished only when fish were needed for mark-recapture trials, and for the following two nights after a mark-recapture trial to obtain sockeye salmon smolt for AWL sampling.

Juvenile sockeye salmon greater than 45 mm fork length (FL; measured from tip of snout to fork of tail) were considered smolt (Thedinga et al. 1994). All fish were netted out of the traps' live boxes, identified (McConnell and Snyder 1972; Pollard et al. 1997), enumerated and released, except for those sockeye salmon retained for AWL samples and smolt to be used for mark-recapture tests.

TRAP EFFICIENCY AND SMOLT POPULATION ESTIMATES

Mark-recapture experiments were scheduled once a week to estimate trap efficiency when a sufficient number of smolt were captured to conduct a marking event. Between approximately 500 and 1,000 sockeye salmon smolt for each experiment were collected from the upper trap and transferred to an instream holding box. Smolt were retained in the live box for no more than three nights if sufficient numbers were not initially captured to perform a mark-recapture experiment.

The marking event was performed so that the marked fish were released before midnight and coincided with the start of the evening's outmigration. Sockeye salmon smolt were netted from the live box, counted, and transferred into two aerated repositories containing a Bismarck Brown-Y dye solution (4.6 g of dye to 92 L of water) for 20 minutes. Fresh water was then pumped into the container for 90 minutes to flush out the dye and allow the smolt a recovery period in circulating fresh river water. At the end of the marking process, any dead or stressed smolt were removed, counted, and disposed of downstream of the traps. Fish were released from the dye site by hand across the width of the river. The number of smolt recaptured in the traps was recorded for several days until recoveries ceased. Sockeye salmon smolt recaptured during mark-recapture experiments were recorded separately from unmarked smolt and excluded from daily total catch to prevent double counting.

Additionally, 100 marked smolt and 100 unmarked smolt were held at the upper trap in an instream live box for five days following the release event to ensure assumptions of the mark-recapture experiments were validated. If significant mortality was observed in the marked, held fish that was not observed in the unmarked, held fish, it is likely that the dyeing process had affected the viability of the smolt released for recapture, and would reduce the number of marked fish available for recapture at the lower trap. Any mortality observed in the marked, held smolt was incorporated into daily population estimates by reducing the actual number of smolt released by the percentage of mortality observed in the marked, held fish. Furthermore, technicians were tested daily on visual identification of retained marked and unmarked smolts, to ensure that smolt were recognized correctly as dyed or undyed when examined.

The trap efficiency *E* was calculated by

$$E_h = \frac{m_h + 1}{(M_h + 1)}, \tag{1}$$

where

h = stratum or time period index (release event paired with a recapture period),

M_h = the total number of marked smolt released in stratum *h*,

and

m_h = the total number of marked smolt recaptured in stratum *h*.

The population size of outmigrating sockeye salmon smolt was estimated using methods described in Carlson et al. (1998). The approximately unbiased estimator of the total population within each stratum ($\hat{N}_h$) was calculated by

$$\hat{N}_h = \frac{(n_h + 1)(M_h + 1)}{m_h + 1} - 1, \tag{2}$$

where

n_h = the number of unmarked smolt captured in stratum *h,*

Variance was estimated by

$$v(\hat{N}_h) = \frac{(M_h + 1)(n_h + 1)(M_h + m_h)(n_h - m_h)}{(m_h + 1)^2 (m_h + 2)}. \tag{3}$$

The estimate of $\hat{N}$ for all strata combined was estimated by

$$\hat{N} = \sum_{h=1}^{L} \hat{N}_h , \tag{4}$$

where L was the number of strata. Variance for $\hat{N}$ was estimated by

$$v(\hat{N}) = \sum_{h=1}^{L} v(\hat{N}_h), \tag{5}$$

and 95% confidence intervals (CI) were estimated from

$$\hat{N} \pm 1.96\sqrt{v(\hat{N})}, \tag{6}$$

which assumed that $\hat{N}$ was asymptotically normally distributed.

The estimate of outmigrating smolt by age class for each stratum *h* was determined by first calculating the proportion of each age class of smolt in the sample population as:

$$\hat{\theta}_{jh} = \frac{A_{jh}}{A_h}, \tag{7}$$

where

A_{jh} = the number of age *j* smolt sampled in stratum *h,* and

A_h = the number of smolt sampled in stratum *h*

with the variance estimated as

$$v(\hat{\theta}_{jh}) = \frac{\hat{\theta}_{jh}(1 - \hat{\theta}_{jh})}{A_h}. \tag{8}$$

For each stratum, the total population by age class was estimated as

$$\hat{N}_{jh} = N_j \hat{\theta}_{jh}, \tag{9}$$

where $\hat{N}_j$ was the total population size of age j smolt, excluding the marked releases (= $\sum N_{jh}$). The variance for $\hat{N}_{jh}$, ignoring the covariance term, was estimated as

$$v\left(\hat{N}_{jh}\right) = \hat{N}_h^{\,2} v\left(\hat{\theta}_{jh}\right) + \hat{N}_h v\left(\hat{\theta}_{jh}\right)^2. \tag{10}$$

The total population size of each age class over all strata was estimated as

$$\hat{N}_j = \sum_{h=1}^{L} \hat{N}_{jh}, \tag{11}$$

with the variance estimated by

$$v\left(\hat{N}_j\right) = \sum_{h=1}^{L} v\left(\hat{N}_{jh}\right). \tag{12}$$

AGE, WEIGHT, AND LENGTH SAMPLING

Smolt were collected throughout the night's migration and held in an instream live box. On five days per statistical week, 40 sockeye salmon smolt were randomly collected from the accumulated fish in the live box, anesthetized with Tricaine methanesulfonate (MS-222), and sampled for AWL data. During the two days immediately following a mark-recapture event, 40 smolt were also collected on each day from the upper trap and sampled for AWL data. Paired t-tests were used to test for differences in size and age class of smolt caught in each trap on nights when both traps were fishing. All smolt sampling data reflected the smolt day in which the fish were captured, and samples were not mixed between days.

Fork length (FL) was measured to the nearest 1 mm, and each smolt weighed to the nearest 0.1 g. Scales were removed from the preferred area (INPFC 1963) and mounted on a microscope slide for age determination. Whole fish were collected for isotopic signature from AWL-sampled fish and frozen until shipped to town.

After sampling, fish were held in aerated water until they completely recovered from the anesthetic, and were released downstream from the traps upon revival. Age was estimated from scales under 60X magnification and described using the European notation (Koo 1962).

Condition factor (Bagenal and Tesch 1978), which is a quantitative measure of the isometric growth of a fish and a relative index of robustness of fish health, was determined for each smolt sampled using

$$K = \frac{W}{L^3} 10^5, \tag{13}$$

where K is smolt condition factor, W is weight in g, and L is FL in mm.

CLIMATE AND HYDROLOGY

Water depth (cm), air and water temperature (°C), estimated cloud cover (%), estimated wind velocity (mph) and wind direction were recorded daily at 1200 hours.

RESULTS

TRAPPING EFFORT AND CATCH

Trapping took place for a total of 42 days beginning on May 18 and ending on June 29 (Appendix A1). A total of 108,023 sockeye salmon smolt were captured in the traps in 2012. In addition to sockeye salmon smolt, 199 sockeye salmon fry, 12,487 juvenile coho salmon, 6 juvenile Chinook salmon, 3,596 Dolly Varden, 858 stickleback, and approximately 41,502 sculpin were captured (Appendix A1).

SMOLT OUTMIGRATION TIMING AND POPULATION ESTIMATES

An estimated 888,658 (95% CI 730,373-1,046,941) sockeye salmon smolt outmigrated in 2012 (Table 1; Figure 6) based upon mark-recapture estimates and trap counts. The majority of these fish outmigrated between May 22 and June 5 (Table 2; Figure 7). Peak outmigration was the last week of May, with 60% of the outmigrating population leaving Karluk Lake between May 21 and May 28, and 41% of the total outmigration population estimated to have left the lake on a single night, May 28 (Figure 7).

TRAP EFFICIENCY ESTIMATES

Mark-recapture experiments were conducted on four occasions beginning on May 29 and ending on June 15. A total of 2,623 smolt, were captured in the upstream trap, marked and released. Adjusting for delayed mortality resulted in a total seasonal release of 1,993 smolt. Ninety-four smolt were recaptured, and trap efficiency estimates per stratum ranged from 7.9% to 13.4% (Table 3; Appendix A1). The majority of marked smolt were recaptured within two days of being released. Efficiencies from the first test conducted on May 29 were applied to all smolt counts beginning May 18 at initial project trapping (80.3% of total estimated outmigration). Tests were not conducted after June 15 because trap catches were below the minimum sample size needed. Therefore, the efficiencies from the June 15 test were applied to all smolt outmigrating after June 15 (4.1% of the total outmigration).

Delayed mortality experiments showed mortality was greatest within the first three days of holding fish. The first delayed mortality experiment was discontinued when the fish were inadvertently released after two days. Overall, delayed mortality ranged from 9% for unmarked fish to 24% for marked fish over five days.

AGE, WEIGHT, AND LENGTH DATA

A total of 1,419 legible samples were collected from sockeye salmon smolt for AWL data. While freshwater-age-2 fish comprised the majority of the outmigrating population all season, older fish (freshwater-age-3) were present in a greater proportion early in the season (May 18-30) while freshwater-age-1 smolt increased as a proportion of the population later in the season (23% between June 21-27; Table 2). The 2012 outmigration estimate consisted of 26,611 freshwater-age-1 (3% of total estimated outmigration), 753,793 freshwater-age-2 (85%) 108,219 freshwater-age-3 (12%), and approximately 35 age-4 (<1%) sockeye salmon smolt (Tables 1 and 2; Figure 8).

Of the sampled smolt, the mean length, weight, and condition factor of freshwater-age-1 smolt (n = 185) were 118 mm, 14.7 g, and 0.86. The mean length, weight, and condition factor of freshwater-age-2 smolt (n = 1117) were 132 mm, 20.3 g, and 0.86. The mean length, weight and condition factor of freshwater-age-3 smolt (n =116) were 144 mm, 25.6 g, and 0.85 (Table 4; Figure 9). Length frequency histograms showed that larger smolt (> 120 mm) composed the majority of the catch throughout the season in both traps (Figure 10).

Additionally, 275 samples were collected from the upper trap for AWL data. For these samples, the mean length, weight and condition factor of freshwater-age-1 smolt (n = 74) were 119 mm, 13.9 g, and 0.84. The mean length, weight, and condition factor of freshwater-age-2 smolt (n = 192) were 133 mm, 20.1 g, and 0.84. The mean length, weight and condition factor of freshwater-age-3 smolt (n = 9) were 139 mm, 22.3 g, and 0.82 (Table 5).

Paired t-test showed significant differences in mean length of smolt captured in the two different traps on June 7 with the lower trap catching larger smolt ($\bar{x}$ = 137 mm) than the upper trap ($\bar{x}$ = 130 mm; p-val <0.001) and on June 17, when the lower trap again caught larger fish ($\bar{x}$ = 134 mm) than the upper trap ($\bar{x}$ = 130 mm; p-val = 0.043).

161 whole fish were retained for isotopic sampling, and frozen for analysis at a later date.

PHYSICAL DATA

The absolute water depth at the trap location varied from 47cm to 66cm during the season. Water temperatures averaged near 3.2°C during the first few days the traps were installed (May 18 through May 21) and increased steadily throughout the season to a maximum of 10.0°C (Appendix C1 and C2). The season began with low water levels that increased steadily with gradual snow melt throughout the season. Warm temperatures, little precipitation, and light winds generally characterized the 2012 season.

DISCUSSION

SMOLT OUTMIGRATION TIMING

The lower trap was installed on May 18 and appeared to encompass the beginning of the smolt outmigration as only six fish were captured the first night of fishing. Previous project deployment timing had varied from early May to late May, and the timing of trap installment in 2012 was similar to trap deployments in 1999 and 2006, when similar small catches were recorded in the initial few days of trapping (Duesterloh and Watchers 2007). The outmigration was determined to have concluded when catches were <100 fish per night for three consecutive nights, which indicated the majority of the outmigration was complete. Historically, the majority of sockeye salmon smolt leave Karluk Lake in a compressed time frame with the majority of outmigration occurring between May 20 and June 3 in a single peak or with a smaller second peak occurring in the second week of June (Watchers and Duesterloh 2005; Duesterloh and Watchers 2007). While the project was deployed later than planned in 2012 due to personnel timing and a lack of available materials, a late spring and extended period of ice cover on Karluk Lake likely meant that the majority of the smolt outmigration was encompassed by the project timing.

The 2012 outmigration was extremely compressed, with an estimated 360,322 fish leaving Karluk Lake on May 28. This constitutes approximately 41% of the total outmigration population estimate and was calculated using the catch-weight method. This single-night estimate is considered conservative because the trap and catch box filled so rapidly that it was necessary to release fish without netting them out of the catch box and weighing them. While this number is larger than any single-night estimate previously reported, the estimate is considered reasonable and consistent with historical run timing when compared to previous years daily counts. In 2001 a daily catch of over 42,000 smolt was estimated, and in 2000, 37% of the total estimated population outmigrated in one night. The total number of smolt caught by the lower trap (108,023 fish) is comparable to cumulative season catches in 2000 and 2002, and smaller than cumulative catches in 2001 and 2004 (Duesterloh and Watchers 2007).

OUTMIGRATING POPULATION ESTIMATES AND MARK-RECAPTURE EXPERIMENTS

The 2012 point estimate of 888,658 smolt is lower than any population estimate reported between 1999 and 2006, as well as the 1999–2006 average of 1,872,174.

Though small compared to historical outmigration estimates, the 2012 estimate may be reasonable, since low escapements in 2008 and 2009 (brood year for freshwater-age-2 and -3) would be reflected in lower smolt outmigration numbers. If the 2012 age composition is reflective of an average age composition, in which the freshwater-age-2 component is approximately 85% of the total smolt produced from a brood year, the smolt to spawner ratio would be approximately 2.6, which is in line with historical averages.

Outmigration timing and magnitude in 2012 allowed for four mark-recapture events during the season with approximately 2,000 smolt marked and released throughout the season. The upper trap was installed in the river after the outmigration had begun, due to a lack of available materials in the field. Therefore, specific trap efficiencies during the peak of smolt outmigration were unknown. The first mark-recapture test took place on May 29, and the trap efficiency rate from this test applied to catches from the beginning of the season in order to calculate population estimates during the first ten days of the field season. The lower trap configuration (perf plate wings and trap height), as well as water flow and height before May 29 were similar to their configuration during the first mark-recapture test; therefore, applying the trap efficiency rate from the May 29 mark-recapture test to earlier dates is reasonable. In future years, the upper trap should be operational earlier in the season, and mark-recapture tests will allow for more precise estimation of trap efficiencies during the peak of the outmigration.

Trap efficiency estimates in 2012 were consistent with or higher than previous years, which historically have ranged between 4.5% and 10.1% (Duesterloh and Watchers 2007). Interannual variation in trap efficiency is expected because the traps were located in different areas of the river in different years, and environmental conditions in certain years (such as high water in 2005) can affect trap efficiencies.

Although the point estimate is low compared to estimates from 1999-2006, it is considered a conservative estimate. Even with consistent and frequent mark-recapture experiments, smolt population estimates from Karluk River appear to be especially susceptible to underestimation. Population estimates of the Karluk River, especially of 1999, 2005, and 2006, resulted in unrealistic marine survival rates, suggesting they underestimated the total smolt outmigration (Appendix C1). Historically, sockeye salmon smolt outmigrating from Karluk Lake are much larger compared to similarly-aged sockeye salmon smolt from other Kodiak Management Area systems. Due to their large size and swimming ability, Karluk smolt may be able to avoid traditional smolt traps better than smolt from other systems, leading to unrealistic population estimates. Methods which do not require trapping of individual fish or provide a census count, such as smolt weirs or sonar enumeration of the total outmigrating population might provide a more robust estimate of outmigration. However, these methods are likely not feasible on the Karluk River due to the river size and limited accessibility to areas which might be bathymetrically appropriate for sonar enumeration. In the future, underwater cameras or use of an observer stationed on the river bank opposite of the trap may provide insight into frequency and magnitude of trap avoidance.

The magnitude and compressed timing of smolt outmigration in the Karluk River means that catch-weight methods are often used to estimate the largest nights of catch, further compounding the imprecision of population estimates. During catch-weight estimation, some marked smolts may be released unidentified due to the nature of the methodology. Although the catch-weight method was used during the largest night of outmigration, no catch-weight analysis was used after the first mark-recapture event. Therefore, each smolt was netted out and individually examined for marks, which should have prevented most misidentification or unnoticed marks, resulting in a robust trap efficiency and population estimate for the duration of the season after May 29. Changes in mark-recapture techniques in 2012 compared to previous years (two-site recapture, increased duration of marking and recovery period of marked smolt) were incorporated to provide marks that would be easily identifiable to technicians, even during periods of high outmigration. Furthermore, mark-retention tests after each dye test showed the marks were easily and correctly identifiable by technicians. Additionally, the placement of the lower trap in 2012 was directly in the thalweg, which should have reduced trap avoidance throughout the season, and no modifications to the trap setup due to environmental conditions were required.

SMOLT AGE STRUCTURE

The 2012 outmigration population, as determined from scale samples, was comprised of 85% freshwater-age-2, 12% freshwater-age-3, and 3.0% freshwater-age-1 smolt. Historically, freshwater-age-2 smolt have been the dominant outmigrating age class followed by freshwater-age-3 (Kyle et al. 1988; Rounsefell 1958, Appendix C1 and C2). In 2006, the last year of a fully operational smolt project, the estimated proportion of freshwater-age-3 sockeye smolt in the outmigration population was an unprecedented 66%. While it has been found that lake residence time of Karluk sockeye salmon juveniles is longer than most systems, in 2009 the freshwater-age-3 component of the adult escapement was an extraordinary 90% (Koenings and Burkett 1987; Foster 2010). Extended residency in freshwater may indicate inadequate forage availability for juvenile salmon. For example, if growth rates are not sufficient to achieve the threshold size necessary to outmigrate in the spring, juvenile fish may stay in a lake to feed for another year (Burgner 1991). Extended freshwater residence for sockeye salmon often also signifies decreased overall lake productivity and subsequent adult salmon returns (Foerster 1968), such as the adult returns experienced at Karluk Lake from 2008-2011. The return to a predominantly freshwater-age-2 outmigrating smolt population composition suggests that lake rearing conditions have improved compared to those from 2004-2009.

Freshwater-age-2 fish comprised the majority of the outmigration, with freshwater-age-3 smolt present in larger proportions earlier in the season, and freshwater-age-1 smolt increasing in relative proportion later in the season (Table 2). This is in keeping with Barnaby (1944) in which larger smolt leave the lake first, with smaller fish leaving later in the season, and also reflected in historical outmigration patterns of age composition throughout the 1999-2005 seasons (Figure 8).

LENGTH AND WEIGHT COMPOSITION

The Karluk sockeye smolt dataset includes age, weight, and length data dating back to the 1920s. On average, sockeye salmon smolt within each age class were larger in 2012 than any in the historical dataset since 1925, and by weight were nearly 3.5 times heavier than the average weight of freshwater-age-2 smolt collected in 2006 (Appendix C3). No correlation between outmigration population size and adult returns has been found for Karluk River, but the average size of outmigrating freshwater-age-2 sockeye salmon smolt has a strong positive correlation with magnitude of outmigration returns (total returns from an outmigration, Appendix C4). The small size and low body condition of outmigrating smolt in 2005 and especially 2006 likely played a major role in determining marine survival and subsequent run strength (Foster and Finkle, unpublished memo). However, if the observed positive correlation between size-at-outmigration and adult returns continues, the adult returns of smolt enumerated in 2012 should be strong compared to recent (2008–2011) adult returns. The size and condition of freshwater-age-2 smolt leaving Karluk Lake in 2012 is likely more significant, and a better indicator of future run strength, than the overall population estimate from this season.

Statistically significant differences in the mean length of fish were found in fish collected when the upper and lower trap were both fished on June 7 and June 17. These differences in mean length are explained by the fact that larger (freshwater-age-3) fish were more often trapped at the lower site than the upper site when the two traps were both fishing. If large fish avoid the upper trap at a rate higher than the lower trap, this could potentially skew trap efficiency measurements. This may be due to either selectivity of the different traps, site specific differences in abundance of smaller and larger fish within the river, or nightly outmigration timing. Given that the lower trap caught larger fish, and that the trap is stationed in the middle of the river, the trap should have been able to catch smaller fish as well. The river width at the upper trap, just below the lake outlet, is much narrower than at the lower trap, and all fish may be moving out together in a school as they leave the lake. By the time the smolt travel further downstream to the lower trap, it is possible they dissipate into less dense schools. If smaller fish travel along shore, while older larger fish travel in the main thalweg, it is possible the lower trap will catch larger fish because of its placement in the main current of the river. Another possible scenario is that the upstream trap, located only 125 meters from the lake, might capture some juvenile sockeye salmon that were not intending to outmigrate from the lake; a mistake that might not have been corrected in that short distance, but would have resulted in eventually upstream migration prior to traveling the 0.6 km to the downstream trap. Alternatively, the timing of outmigration within a night may vary by age class. The upper trap was only fished in the evening until an adequate number of smolt for AWL had been captured, and then was raised out of the water. In contrast, the lower trap fished continuously, and fish retained for AWL would have represented the entire night's outmigration. If smaller, younger fish leave the lake earlier in the night than older, larger fish, it is possible the upper trap was not fishing when larger fish would have been passing by, and therefore was not available to catch those smaller smolt.

DELAYED MORTALITY EXPERIMENTS

The dye process is stressful to smolt, and delayed mortality experiments revealed high mortality rates in dyed smolt held over the next five days. Catch rates in the upper trap were such that several nights of collection were required to reach a sufficient number for dyeing. This handling and retention over several nights may have further stressed the fish and impaired their ability to recover from the dye process. Additionally, late in the season high flow rates in the catch box may have injured or stressed some fish held for mark-recapture, further increasing mortality rates. Though all efforts were made to prevent injury to the smolt, such as relocation of the trap in the river at times of high water, or adjustments of baffles inside the catch boxes, further modifications may be needed in future seasons to ensure mortality of handled fish remains as low as possible.

ADDITIONAL AVAILABLE DATA

In a series of ADF&G memorandums regarding the reduced runs to Karluk Lake, biologists postulated that large escapements from 2000 to 2003 and favorable spawning conditions produced large numbers of fry for numerous years, which eventually overgrazed and reduced the number of zooplankton available to sockeye salmon fry. Sockeye salmon fry then experienced slow growth and increased mortality, which led to fewer smolts and smolts in poorer condition. Limnological investigations have been conducted in Karluk Lake for many years, and also provide some insight to the rearing habitat and health of sockeye salmon smolt. The zooplankton biomass estimated in Karluk Lake in 2009 through 2011 was substantially greater than that from 2004 to 2008, increasing from near-starvation to above satiation levels for rearing salmon (Appendix D).

While the point estimate of the outmigrating population in 2012 is reasonable given the low escapements to Karluk Lake between 2008 and 2011, assuming a relatively high marine survival rate of 30% still suggests that adult returns in the near future will be small compared to those from 2000 to 2007. However, the total estimated smolt outmigration number may not be the best indicator of future run strength. No relationship between the estimated number of outmigrating sockeye salmon smolt and the number of adult returns from that outmigration year has been determined; however a positive relationship between the size of freshwater-age-2 outmigrants and subsequent adult returns has been explored. If the size and condition of smolt at outmigration is indicative of future returns, the overall biomass of sockeye smolt leaving Karluk Lake in a given year may also have utility as a predictive indicator of future salmon returns. Based on the estimated number of each age class and the average weight of that age class, almost 20 tons of sockeye smolt left Karluk in 2012 (Appendix C5). Compared to recent years, the biomass leaving Karluk Lake as outmigrating smolt was greater than either 2005 or 2006, and may be a better indicator of future adult returns than outmigration number.

Stable isotope samples from 2012 have not yet been processed, but will help to assess the level of marine-derived nutrients in juvenile sockeye salmon (i.e., Finney et al. 2000). C/N ratios provide an index of lipid content and thus fitness of fish and can be compared to calculated condition factor. The data from these samples will also allow for determination of any trophic level differences between age classes. In addition, the $\delta^{13}C$ ratios, once corrected for lipid contribution, provide a possible index of lake productivity that can supplement ongoing limnological investigations in Karluk Lake.

CONCLUSION

The continued collection of smolt outmigration data aids with investigations of changes in life history strategies in the Karluk watershed caused by changes in environmental conditions, such as fluctuating levels of zooplankton forage in Karluk Lake. While smolt investigations have been undertaken at Karluk Lake many times in the past, the sporadic nature and timing of projects makes it difficult to draw long-term conclusions and comparisons with this initial return to smolt trapping in the Karluk watershed. Methods employed to enumerate smolt in Karluk may not be directly comparable (for example beach seining and fin clipping at the lake outlet may have different biases than sonar estimation) to one another, further making population estimate comparisons difficult.

However, smolt projects increase in importance and value over the long term, because population estimates can be used as indices. The age, length, and weight data that has been collected over many years is a valuable source of directly comparable interannual data. These data show encouraging signs that present conditions indicate favorable rearing lake habitat for Karluk Lake sockeye salmon. All age classes of smolt were larger than any reported since the 1920s and 1930s, and condition factor among all age classes was also high. The continued collection of age, length, and weight data, together with smolt enumeration, will aid in further understanding the freshwater ecosystem dynamics of Karluk lake and river, and the effects on sockeye salmon run health.

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TABLES AND FIGURES

Table 1.–Karluk Lake sockeye salmon smolt population estimates, by freshwater age, 1991 to 2012.

	Number of Smolt						95% C.I.	
Year	Age 0	Age 1	Age 2	Age 3	Age 4	Total	Lower	Upper
1961	6,419	134,811	1,444,399	109,132	0	1,694,761	na	na
1962	0	18,653	1,010,144	406,067	0	1,434,864	na	na
1963	0	3,079	709,755	826,765	0	1,539,599	na	na
1964	0	0	385,593	1,152,095	23,417	1,561,105	na	na
1965	0	0	717,022	733,184	19,101	1,469,307	na	na
1966	0	0	661,593	398,519	20,838	1,080,950	na	na
1967	0	203,736	1,134,127	20,374	0	1,358,237	na	na
1968	0	171,158	2,250,549	1,219,958	0	3,641,665	na	na
1980	0	494,500	1,060,800	131,200	0	1,686,500	na	na
1981	0	219,500	1,561,300	260,900	0	2,041,700	na	na
1982	0	14,000	698,800	108,400	0	821,200	na	na
1983	0	13,000	781,000	147,000	0	941,000	na	na
1984	0	74,000	857,000	143,000	0	1,074,000	na	na
1991	0	108,123	2,392,324	1,640,374	0	4,140,821	2,809,914	5,471,727
1992	0	28,189	2,039,222	1,415,788	10,797	3,493,996	2,780,674	4,207,319
1999	0	35,196	531,134	487,406	12,798	1,066,534	717,152	1,415,915
2000	0	9,441	1,263,785	402,919	0	1,676,502	1,328,451	2,024,553
2001	2,838	238,271	3,062,597	436,469	80	3,740,255	3,136,398	4,344,111
2002	791	11,482	1,072,906	195,323	1,468	1,281,971	1,130,721	1,433,221
2003	0	16,445	1,712,969	501,816	4,205	2,235,435	1,673,898	2,796,972
2004	533	26,479	1,420,076	633,039	186	2,080,339	1,764,223	2,396,454
2005	0	47,834	1,227,246	218,243	2,264	1,494,818	725,956	2,263,680
2006	0	0	393,039	773,173	6,906	1,173,252	965,308	1,381,196
2012	0	26,611	753,793	108,219	35	888,658	730,373	1,046,941

Table 2.–Estimated sockeye salmon smolt outmigration from Karluk Lake in 2012 by freshwater age and statistical week.

Statistical	Start	Number of Smolt								
Week	Date	Age 1	%	Age 2	%	Age 3	%	Age 4	%	Total
21	5/17	3,952	2.0	171,900	88.4	18,698	9.6	-	0.0	194,550
22	5/24	319	0.1	440,281	84.4	80,951	15.5	35	0.0	521,586
23	5/31	6,948	9.8	59,641	84.2	4,282	6.0	-	0.0	70,871
24	6/7	3,343	7.1	41,463	87.8	2,428	5.1	-	0.0	47,234
25	6/14	2,537	8.5	25,673	85.8	1,704	5.7	-	0.0	29,915
26	6/21	5,249	22.6	17,858	76.9	123	0.5	-	0.0	23,231
27	6/28	311	24.5	929	73.0	32	2.5	-	0.0	1,272
Total		26,611	3%	753,793	85%	108,219	12%	35	0%	888,658

Table 3.–Results from mark-recapture tests performed on sockeye salmon smolt migrating from Karluk Lake, 2012.

Date	No. Released[a]	Total Recaptures	Trap efficiency[b]
5/29	557	68	12.4%
6/4	575	76	13.4%
6/9	456	35	7.9%
6/15	405	52	13.1%

[a] Number of released fish is adjusted for delayed mortality

[b] Calculated by: E = {(R+1)/(M+1)}*100 where: R = number of marked fish recaptured, and; M = number of marked fish (Carlson et al. 1998).

Table 4.–Length, weight, and condition factor of Karluk Lake sockeye salmon smolt samples from the lower trap in 2012, by freshwater age and statistical week.

	Stat	Sample	Length (mm)		Weight (g)		Condition	
Age	Week	Size	Mean	Std. Err	Mean	Std. Err	Mean	Std. Err
1	21	1	115	na	13.1	na	0.86	0.00
1	22	2	106	0.5	10.2	0.40	0.87	0.02
1	23	30	117	1.1	14.1	0.37	0.80	0.01
1	24	48	117	1.1	13.7	0.42	0.83	0.01
1	25	30	119	1.8	14.9	0.62	0.86	0.02
1	26	54	118	1.2	15.1	0.45	0.89	0.01
1	27	20	123	2.3	16.8	0.95	0.89	0.02
Totals		185	118	0.6	14.7	0.24	0.86	0.01
2	21	79	138	0.8	21.3	0.36	0.81	0.01
2	22	130	137	0.7	21.8	0.35	0.83	0.01
2	23	221	132	0.6	19.3	0.24	0.83	0.00
2	24	253	133	0.5	20.1	0.25	0.85	0.00
2	25	234	130	0.5	20.3	0.23	0.89	0.00
2	26	142	129	0.6	19.3	0.25	0.90	0.00
2	27	58	134	0.7	22.1	0.33	0.91	0.01
Totals		1,117	132	0.3	20.3	0.11	0.86	0.00
3	21	13	147	3.1	26.5	1.63	0.82	0.01
3	22	46	147	1.6	27.3	0.79	0.85	0.01
3	23	21	140	1.5	23.0	0.71	0.83	0.01
3	24	18	141	1.6	24.2	0.83	0.86	0.02
3	25	14	141	2.1	24.5	1.03	0.87	0.01
3	26	2	145	1.0	27.5	0.45	0.90	0.03
3	27	2	148	1.5	28.4	0.65	0.88	0.05
Totals		116	144	0.9	25.6	0.45	0.85	0.01
4	22	1	168	na	33.8	na	0.71	na
Totals		1	168	na	33.8	na	0.71	na

Table 5.–Length, weight, and condition factor of Karluk Lake sockeye salmon smolt samples from the upper trap in 2012, by age and statistical week.

Age	Stat Week	Sample Size	Length (mm)		Weight (g)		Condition	
			Mean	Std. Err	Mean	Std. Err	Mean	Std. Err
1	23	14	119	2.0	13.8	0.64	0.82	0.02
1	24	38	117	1.2	13.3	0.43	0.82	0.01
1	25	22	119	2.1	15.0	0.67	0.87	0.02
Totals		74	118	1.0	13.9	0.33	0.84	0.01
2	23	57	134	1.1	19.9	0.46	0.83	0.01
2	24	78	134	0.9	20.3	0.41	0.84	0.01
2	25	57	130	0.8	20.1	0.39	0.87	0.01
Totals		192	133	0.5	20.1	0.24	0.84	0.01
3	23	6	138	3.8	22.0	1.50	0.83	0.02
3	24	3	141	5.2	22.9	2.78	0.82	0.06
Totals		9	139	2.9	22.3	1.27	0.82	0.022

Note: The trap was only fished on two consecutive nights following a mark-recapture trial.

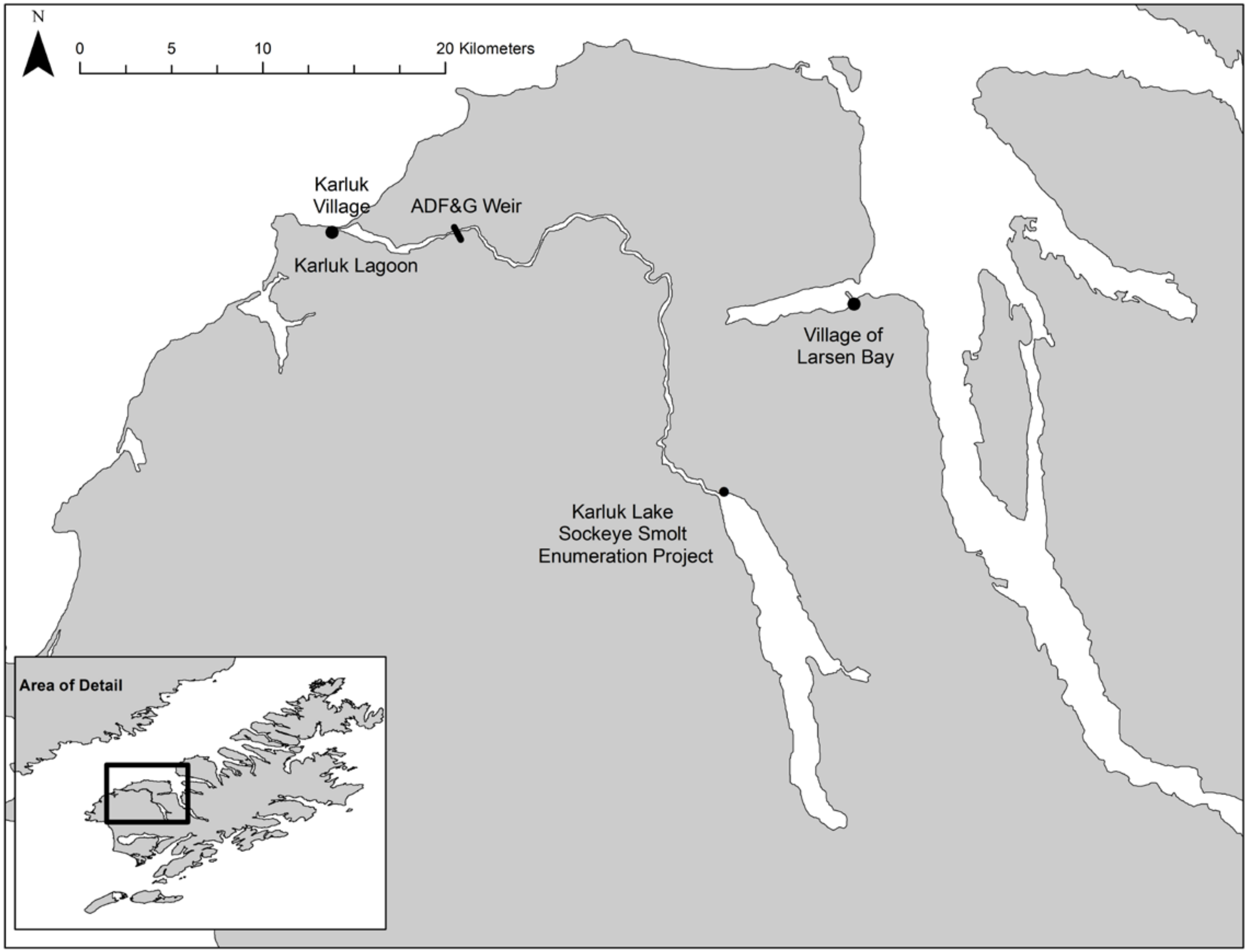


Figure 1.–Map of the Karluk lake and river, showing local communities and ADF&G projects.

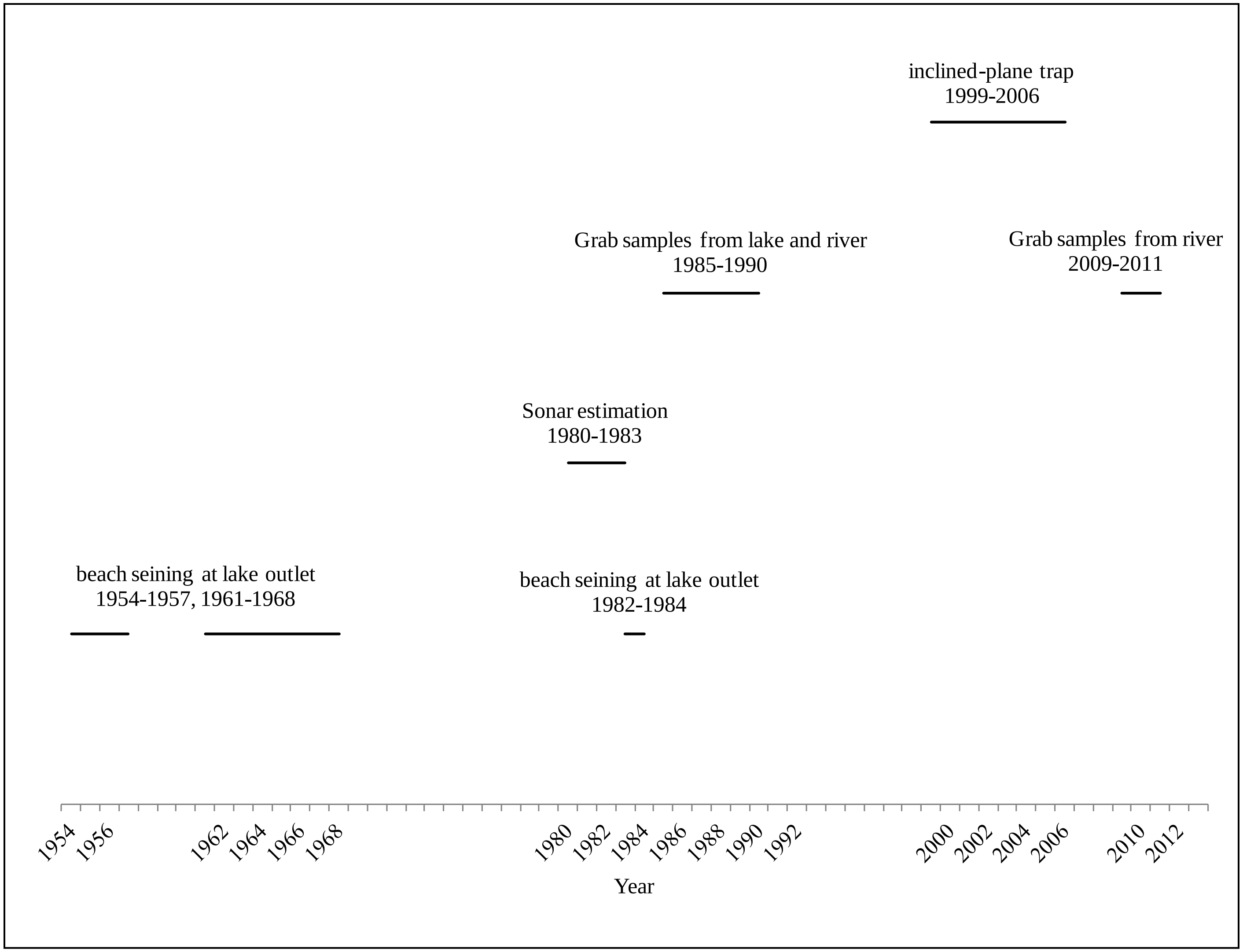


Figure 2.–Timeline depicting historical smolt investigations on the Karluk River.

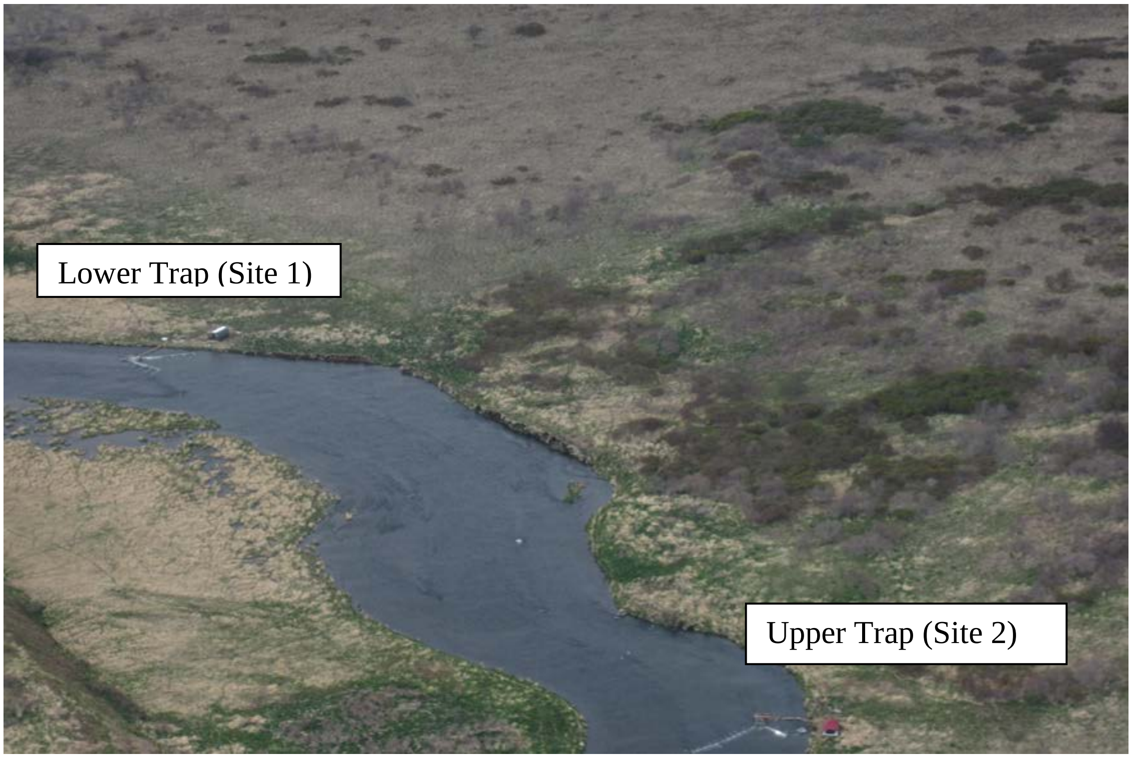


Figure 3.–Canadian Fan traps in the Karluk River, Alaska, 2012.

Figure 4.–The Lower Smolt Trap, Karluk River, Alaska, 2012.

Figure 5.–Aerial and ground view of the Upper Smolt Trap, Karluk River, Alaska, 2012.

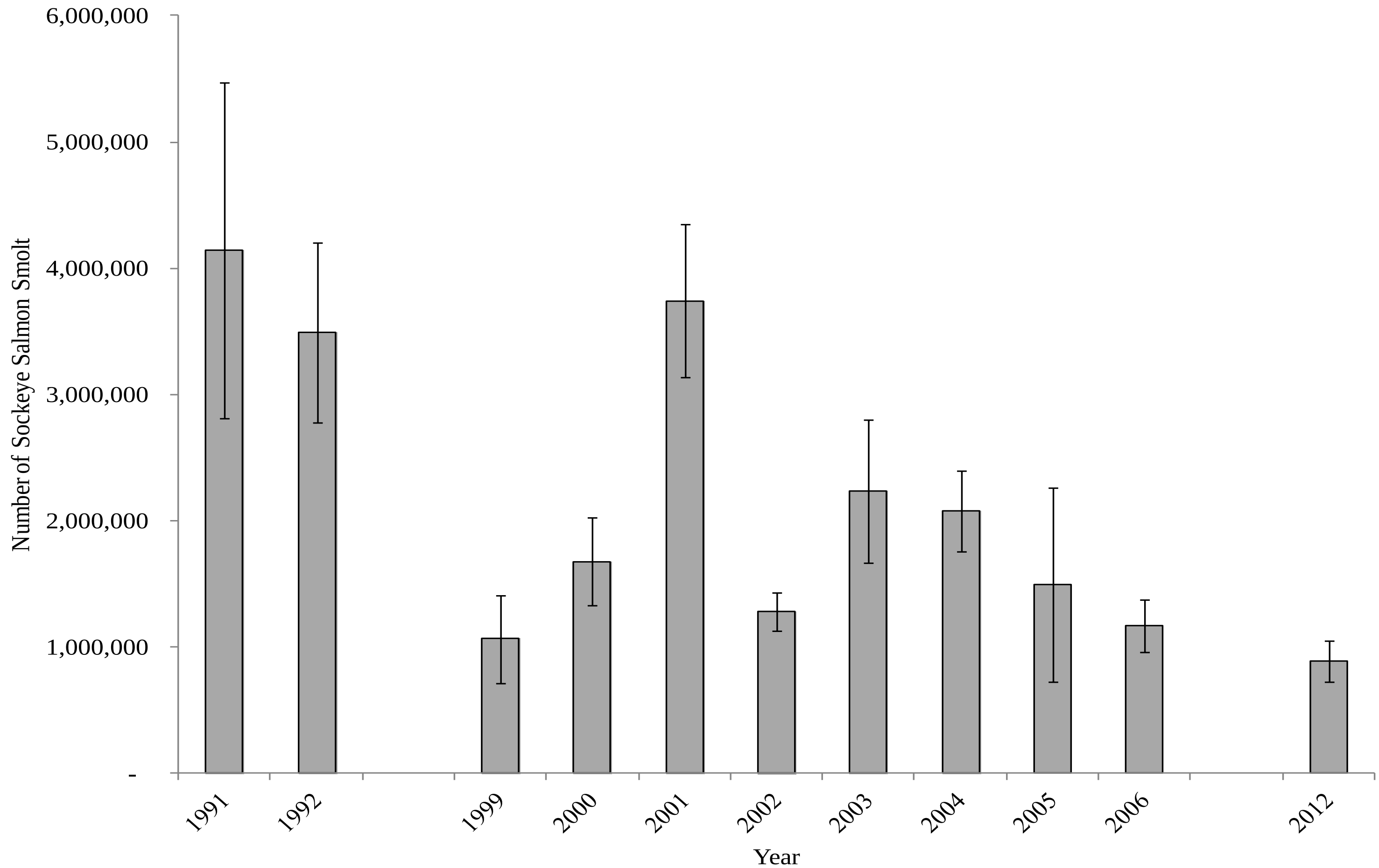


Figure 6.–Reported annual sockeye salmon smolt outmigration estimates and corresponding 95% confidence intervals, Karluk River, for years with population estimates, 1991–2012.

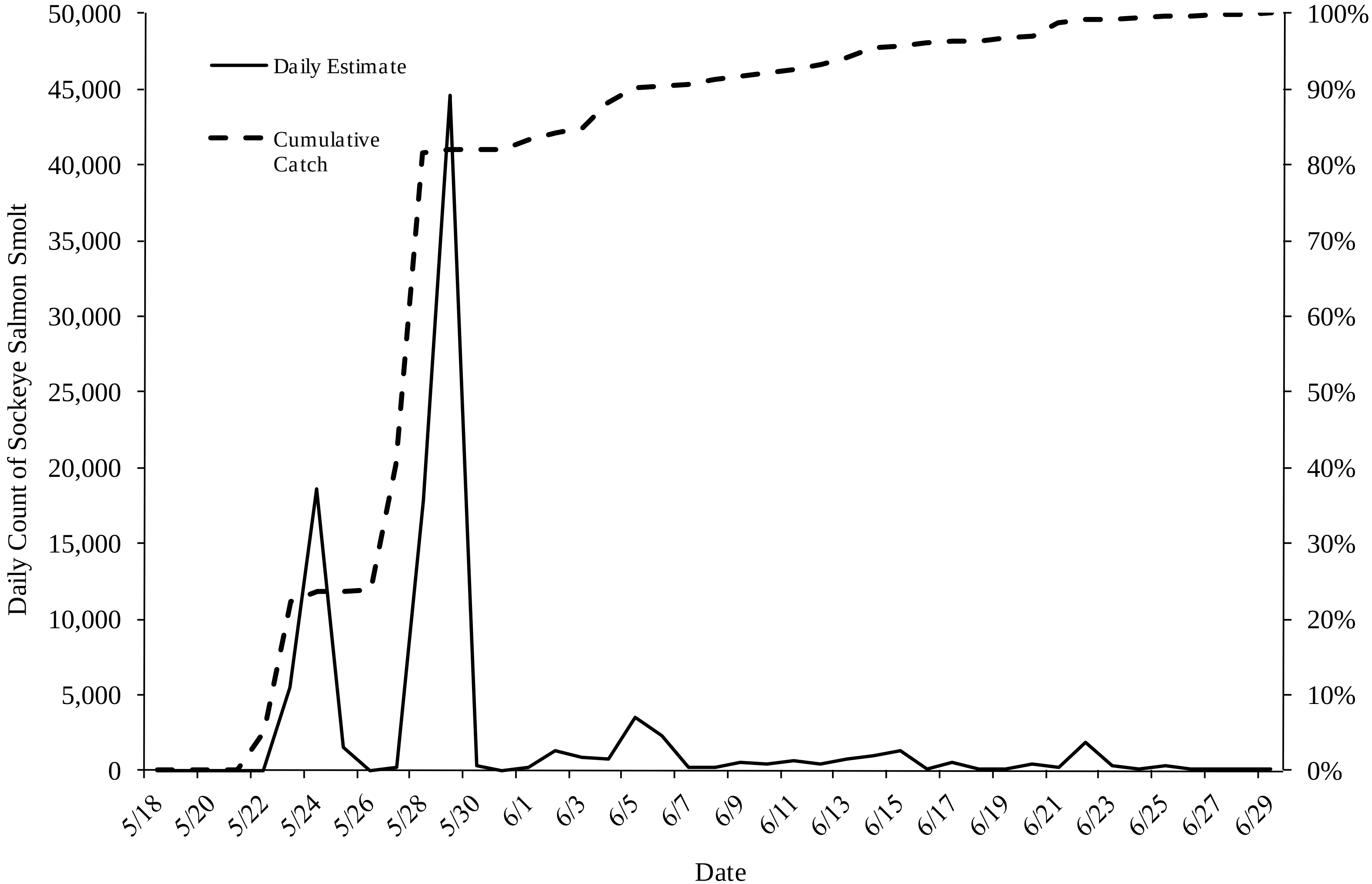


Figure 7.–Daily counts and cumulative percentage of the sockeye salmon smolt outmigration from Karluk Lake in 2012.

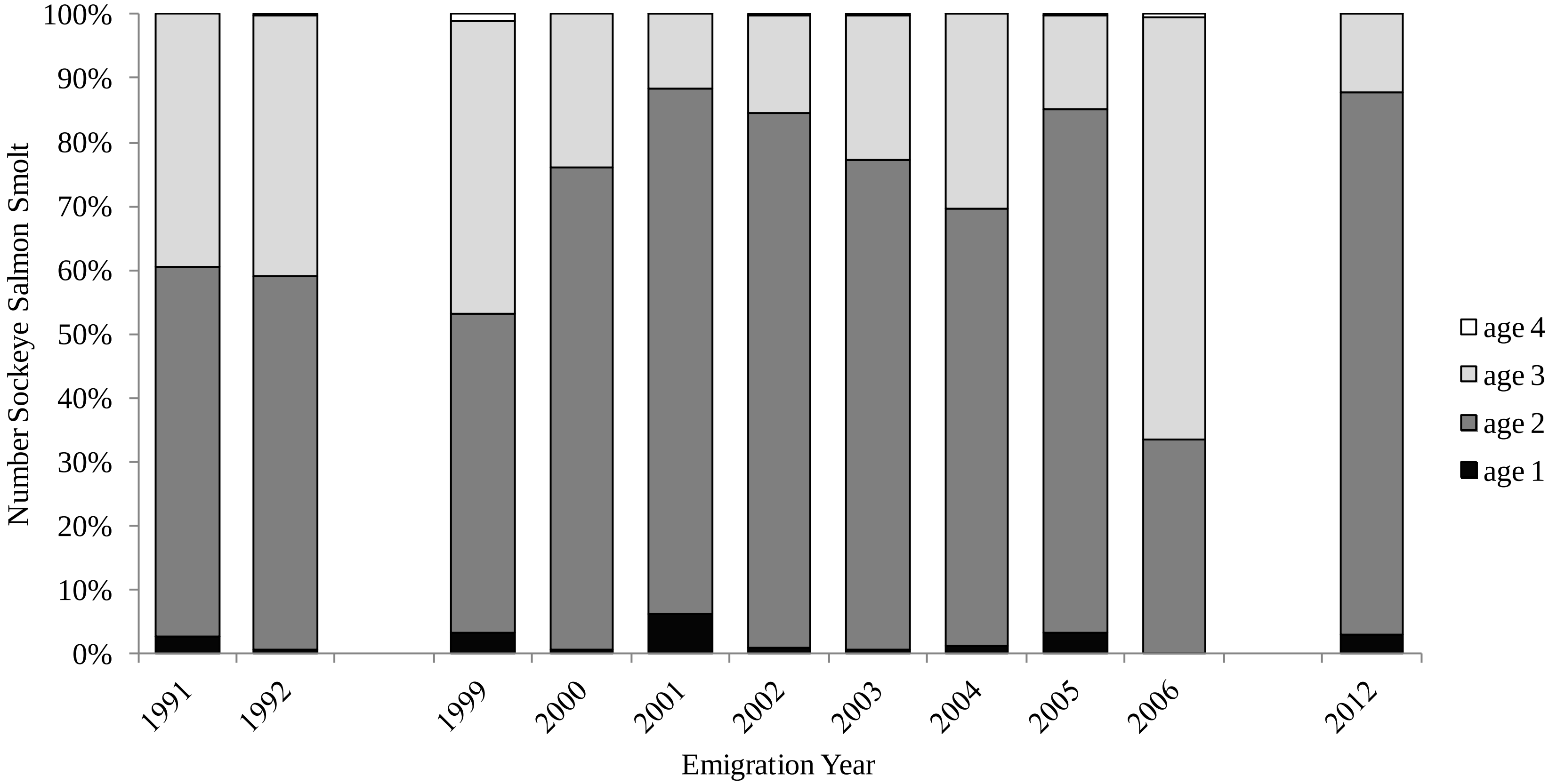
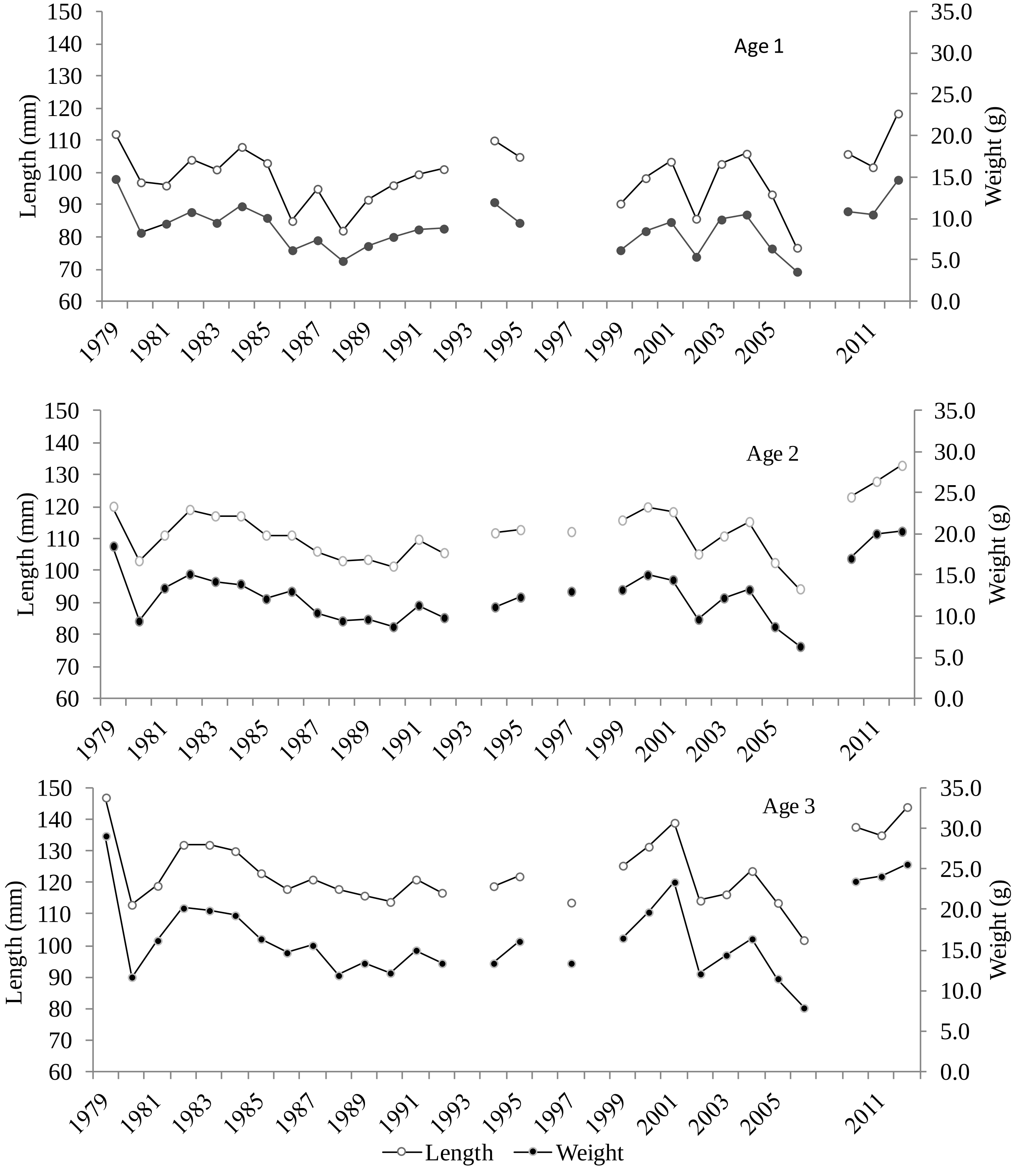


Figure 8.–A comparison of the estimated age structure of freshwater-age-0 to freshwater-age-4 sockeye salmon smolt outmigrations from the Karluk Lake, for years with population estimates, 1991–2012.



Note: Freshwater-age-0 and freshwater-age-4 smolt comprise such a small percentage of the yearly population as to be negligible.

Figure 9.–Average length and weight of sampled freshwater-age-1, -2, and -3 sockeye salmon smolt, by year from 1979 to 2012.

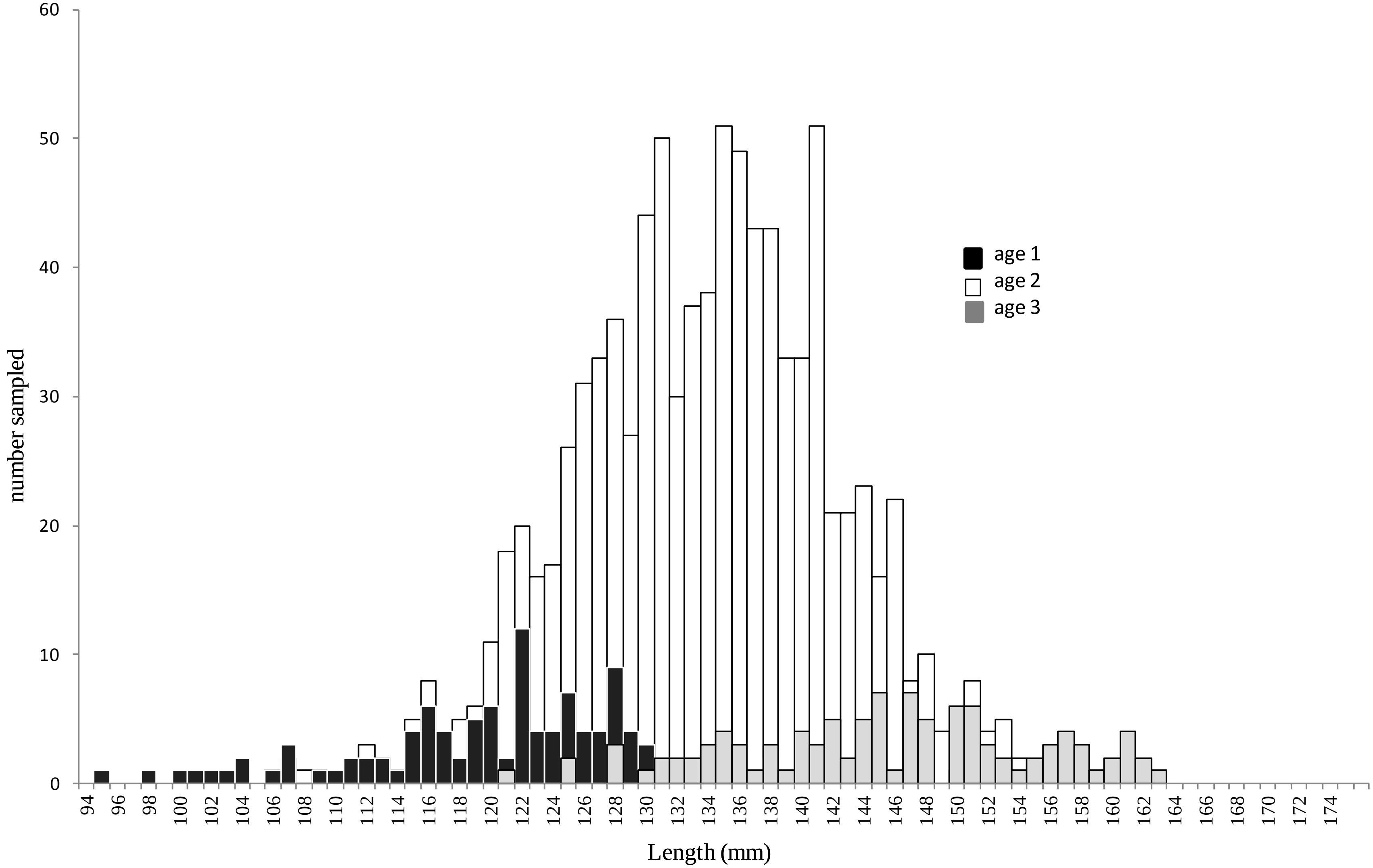


Figure 10.–Length frequency histogram of sockeye salmon smolt outmigrating from Karluk Lake in 2012 by age class.

APPENDIX A. SMOLT TRAP CATCHES BY DAY

Appendix A1.–Actual daily counts and trap efficiency data of the Karluk River sockeye salmon smolt project, 2012.

	Sockeye Smolt			Trap efficiency tests				Incidental catch[a]					
Date	Daily	Cum.	Daily Mortality	Marked[b]	Daily recoveries	Cum. recoveries	Efficiency[c]	Sock fry	Coho	Chnk	Dolly Varden	SB	SC
18-May	6	6	1					20	54	0	103	75	448
19-May	6	12	0					15	59	0	127	53	2805
20-May	5	17	0					36	147	0	147	39	2822
21-May	5	22	0					8	115	0	125	16	2357
22-May	5,467	5,489	9					19	186	0	129	16	397
23-May	18,568	24,057	12					3	75	0	73	16	124
24-May	1,514	25,571	5					12	45	0	122	22	80
25-May	32	25,603	3					0	45	1	171	16	1374
26-May	173	25,776	0					0	52	0	164	17	2761
27-May	17,861	43,637	10					0	21	0	141	8	677
28-May	44,556	88,193	29					2	631	0	200	5	216
29-May	328	88,521	3	557	32	32	12.4%	0	115	0	76	12	2530
30-May	33	88,554	1	0	28	60	12.4%	0	22	0	56	8	1220
31-May	172	88,726	1	0	7	67	12.4%	0	59	0	80	11	1975
1-Jun	1,303	90,029	6	0	1	68	12.4%	0	263	0	56	5	562
2-Jun	925	90,954	17	0	0	68	12.4%	0	274	0	86	9	225
3-Jun	789	91,743	2	0	0	68	12.4%	0	487	0	90	14	347
4-Jun	3,474	95,217	11	575	56	56	13.4%	13	1,319	0	142	15	62
5-Jun	2,310	97,527	8	0	12	68	13.4%	1	861	0	190	18	715
6-Jun	245	97,772	1	0	6	74	13.4%	2	120	0	68	46	545
7-Jun	201	97,973	2	0	2	76	13.4%	0	106	0	51	3	3100
8-Jun	567	98,540	4	0	0	76	13.4%	0	450	0	95	9	850

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Appendix A1.–Page 2 of 2.

	Sockeye Smolt			Trap efficiency tests				Incidental catch[a]					
Date	Daily	Cum.	Daily Mortality	Marked[b]	Daily recoveries	Cum. recoveries	Efficiency[c]	Sock fry	Coho	Chnk	Dolly Varden	SB	SC
9-Jun	443	98,983	12	456	29	29	7.9%	2	211	0	62	14	265
10-Jun	647	99,630	10	0	5	34	7.9%	2	136	0	85	19	770
11-Jun	416	100,046	10	0	1	35	7.9%	0	237	0	54	12	774
12-Jun	722	100,768	3	0	0	35	7.9%	0	378	0	35	22	366
13-Jun	1,043	101,811	5	0	0	35	7.9%	7	327	0	58	31	381
14-Jun	1,358	103,169	9	0	0	35	7.9%	0	198	0	73	16	121
15-Jun	156	103,325	3	405	41	41	13.1%	0	252	0	35	8	284
16-Jun	519	103,844	3	0	9	50	13.1%	2	446	0	51	14	1134
17-Jun	157	104,001	7	0	2	52	13.1%	6	478	0	37	6	709
18-Jun	121	104,122	7	0	0	52	13.1%	0	1,290	0	82	19	1092
19-Jun	464	104,586	1	0	0	52	13.1%	5	551	0	133	30	831
20-Jun	239	104,825	0	0	0	52	13.1%	3	362	0	91	33	554
21-Jun	1,892	106,717	1	0	0	52	13.1%	7	564	0	68	38	519
22-Jun	366	107,083	3	0	0	52	13.1%	6	447	0	37	46	331
23-Jun	138	107,221	4	0	0	52	13.1%	5	262	1	29	26	825
24-Jun	307	107,528	5	0	0	52	13.1%	3	189	3	23	11	1044
25-Jun	118	107,646	0	0	0	52	13.1%	1	67	0	27	7	2572
26-Jun	138	107,784	2	0	0	52	13.1%	5	137	1	26	16	1413
27-Jun	73	107,857	2	0	0	52	13.1%	8	104	0	11	13	739
28-Jun	74	107,931	0	0	0	52	13.1%	6	245	0	60	34	309
29-Jun	92	108,023	5	0	0	52	13.1%	0	100	0	27	10	277
Total		108,023		1993	231	231	11.7%[d]	199	12,487	6	3,596	858	41,502

[a] Soc Fry = sockeye salmon fry, Coho = juvenile coho salmon, Chnk = juvenile Chinook salmon, DV = Dolly Varden, SB = stickleback, SC = sculpin.

[b] Number marked has been adjusted from actual released to account for delayed mortality.

[c] Calculated by: = {(R+1)/(M+1)}*100 where: R = number of marked fish recaptured, and M = number of marked fish (Carlson et al. 1998).

[d] Average of trap efficiency trials throughout the season.

APPENDIX B. CLIMATOLOGICAL OBSERVATIONS

Appendix B1.–Daily climatological observations for the Karluk Lake sockeye salmon smolt project, 2012.

Date[a]	Time	Air (°C)	Water (°C)	Cloud cover[b]	Wind direction[b]	Velocity (mph)[b]	Stream depth (in)	Comments
20-May	12:00	NA	4.0	100%	NE	0-5		Small breaks in cloud cover, dry
21-May	4:30	-2.0	NA	30%	-	0		frost& clear
21-May	12:00	11.1	3.0	90%	NE	5-10		breezy, dry
22-May	13:00	13.0	4.0	85%	NE	0-5		breezy, dry, pleasant day
23-May	13:00	NA	NA	80%	NE	0-5		water thermometer broken
24-May	4:00	NA	NA	10%	-	0-5		calm & freezing
24-May	22:00	NA	NA	20%	NE	10-20		sunny
25-May	13:00	NA	4.5	90%	NE	10-20	18.5	breezy, cloudy
26-May	12:15	13.0	4.0	90%	SW	10	19.5	
27-May	12:18	13.0	5.0	45%	NE	0-5	20.5	sunny
28-May	13:00	NA	5.0	85%	NNE	20	21.5	sunny
29-May	12:25	NA	5.0	100%	N	15	20.5	light mist
30-May	12:01	11.0	4.0	100%	NE	5-10	21.0	light mist
31-May	11:30	9.0	4.0	65%	SW	5-10	22.0	rain on & off
1-Jun	12:00	9.0	4.0	90%	W	10-15	22.0	
2-Jun	14:20	15.0	5.0	75%	NE	0-5	22.0	partly sunny and warm
3-Jun	10:50	11.0	5.0	60%	NW	5-10	22.0	sunny, cool , breezy
4-Jun	10:45	10.0	5.0	95%	NE	0-5	23.0	cool, low clouds, signs of overnight rainfall
5-Jun	12:00	11.0	5.5	85%	-	0	23.5	mostly cloudy no wind
6-Jun	12:09	14.0	5.0	0%	NE	0-5	24.0	beautiful day
7-Jun	11:00	9.0	5.0	100%	-	0	23.5	misty & still
8-Jun	11:30	11.0	5.0	95%	NE	5-10	23.5	cloudy & cool
9-Jun	11:00	9.0	5.0	100%	NE	0-5	23.5	cloudy & cool, little to no breeze

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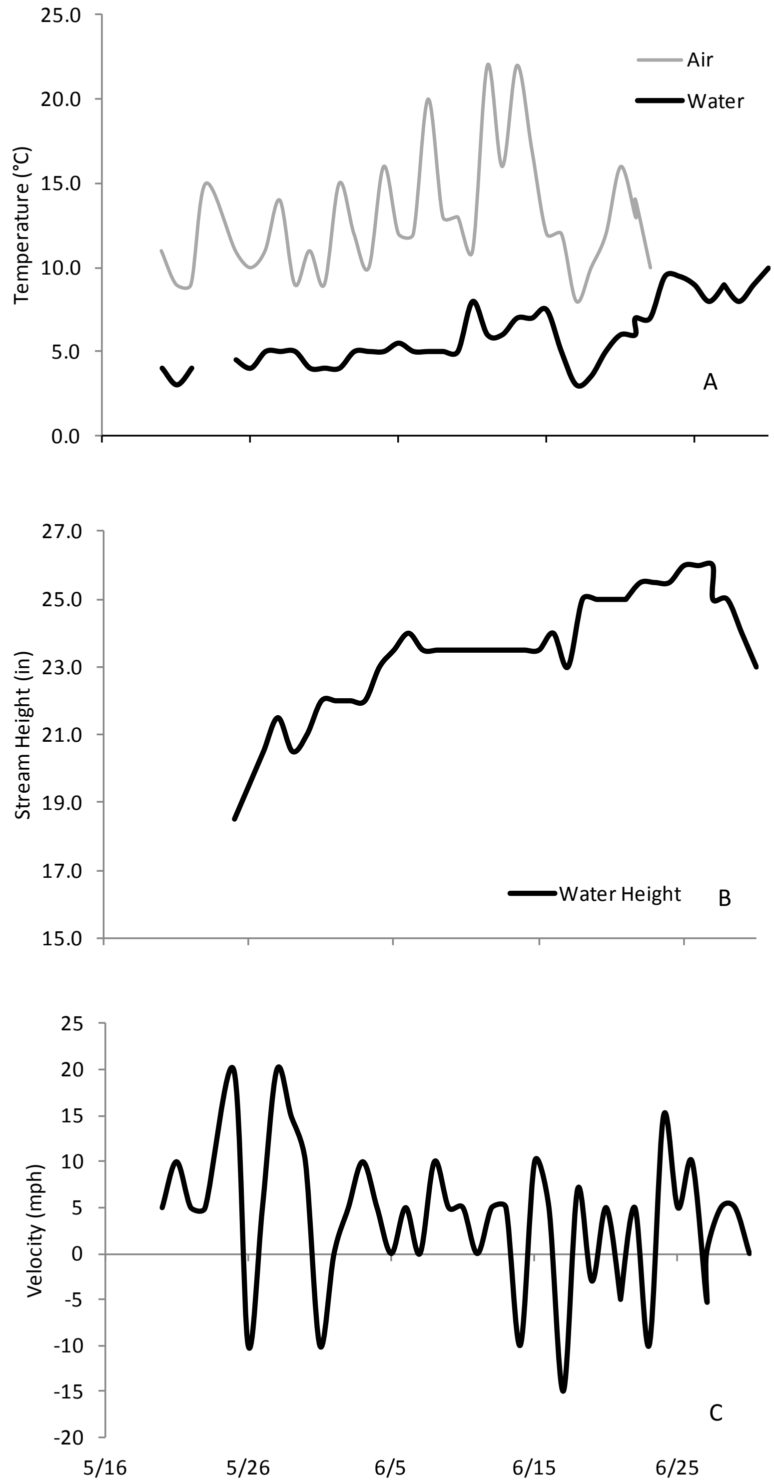
Date[a]	Time	Air (°C)	Water (°C)	Cloud cover[b]	Wind direction[b]	Velocity (mph)[b]	Stream depth (in)	Comments
10-Jun	11:00	15.0	8.0	80%	NE	0-5	23.5	cloudy, calm, warm, somesunshine
11-Jun	12:00	12.0	6.0	100%	-	0	23.5	cloudy, calm, humid
12-Jun	10:30	10.0	6.0	90%	NE	0-5	23.5	clearing up from morning rain
13-Jun	13:10	16.0	7.0	90%	NE	0-5	23.5	cloudy, warm day
14-Jun	11:57	12.0	7.0	100%	SW	5-10	23.5	cloudy, cool
15-Jun	9:57	12.0	7.5	70%	NE	5-10	23.5	breezy, cool
16-Jun	11:27	20.0	5.0	30%	NE	0-5	24.0	sunny & warm
17-Jun	9:18	13.0	3.0	25%	SW	10-15	23.0	beautiful
18-Jun	10:45	13.0	3.5	5%	ENE	10-15	25.0	sunny & windy
19-Jun	11:23	11.0	5.0	20%	W	0-15	25.0	sunny & windy with gusts
20-Jun	0:05	5.0	5.0	2%	-	0	25.0	gorgeous evening
20-Jun	12:00	22.0	6.0	30%	NE	0-5	25.0	warm & sunny, occasional light breeze
21-Jun	11:40	16.0	6.0	0%	SE	0-5	25.0	warm , sunny, no clouds, light breeze
21-Jun	14:03	22.0	7.0	0%	SE	0-5	25.0	warm, clear sky
22-Jun	0:09	8.0	6.0	2%	-	0	25.0	beautiful & calm evening
22-Jun	11:00	17.0	7.0	5%	NE	0-5	25.5	sunny & warm
23-Jun	12:00	12.0	9.5	100%	SW	5-10	25.5	low ceiling
24-Jun	11:10	12.0	9.5	95%	NE	10-15	25.5	windy & cool, light drizzle @ 22:30
25-Jun	11:45	8.0	9.0	100%	N	0-5	26.0	low ceiling
26-Jun	11:40	10.0	8.0	100%	NE	5-10	26.0	low ceiling, occasional gusts
27-Jun	12:05	12.0	9.0	100%	SSW	0-5	26.0	low ceiling
27-Jun	13:45	16.0	9.0	95%	-	0	25.0	cloudy, no wind, most clouds are dark
28-Jun	11:45	13.0	8.0	85%	NW	0-5	25.0	clouds lifting with a bit of sunshine
29-Jun	11:50	14.0	9.0	80%	NW	0-5	24.0	warm
30-Jun	11:50	10.0	10.0	100%	-	0	23.0	rainy & cool

[a] Actual calendar dates.

[b] Based on observer estimates.

Appendix B2.–Air and water temperature (A), stream gauge height (B), and wind velocity and direction (C) data gathered at the Karluk River smolt trap, 2012.



APPENDIX C. SUPPLEMENTAL HISTORICAL DATA

Appendix C1.–Estimated age composition of Karluk River sockeye salmon smolt samples, 1961–2012.

	Number of Smolt						95% C.I.	
Year	Age 0	Age 1	Age 2	Age 3	Age 4	Total	Lower	Upper
1961	6,419	134,811	1,444,399	109,132	0	1,694,761	na	na
1962	0	18,653	1,010,144	406,067	0	1,434,864	na	na
1963	0	3,079	709,755	826,765	0	1,539,599	na	na
1964	0	0	385,593	1,152,095	23,417	1,561,105	na	na
1965	0	0	717,022	733,184	19,101	1,469,307	na	na
1966	0	0	661,593	398,519	20,838	1,080,950	na	na
1967	0	203,736	1,134,127	20,374	0	1,358,237	na	na
1968	0	171,158	2,250,549	1,219,958	0	3,641,665	na	na
1980	0	494,500	1,060,800	131,200	0	1,686,500	na	na
1981	0	219,500	1,561,300	260,900	0	2,041,700	na	na
1982	0	14,000	698,800	108,400	0	821,200	na	na
1983	0	13,000	781,000	147,000	0	941,000	na	na
1984	0	74,000	857,000	143,000	0	1,074,000	na	na
1991	0	108,123	2,392,324	1,640,374	0	4,140,821	2,809,914	5,471,727
1992	0	28,189	2,039,222	1,415,788	10,797	3,493,996	2,780,674	4,207,319
1999	0	35,196	531,134	487,406	12,798	1,066,534	717,152	1,415,915
2000	0	9,441	1,263,785	402,919	0	1,676,502	1,328,451	2,024,553
2001	2,838	238,271	3,062,597	436,469	80	3,740,255	3,136,398	4,344,111
2002	791	11,482	1,072,906	195,323	1,468	1,281,971	1,130,721	1,433,221
2003	0	16,445	1,712,969	501,816	4,205	2,235,435	1,673,898	2,796,972
2004	533	26,479	1,420,076	633,039	186	2,080,339	1,764,223	2,396,454
2005	0	47,834	1,227,246	218,243	2,264	1,494,818	725,956	2,263,680
2006	0	0	393,039	773,173	6,906	1,173,252	965,308	1,381,196
2012	0	26,611	753,793	108,219	35	888,658	730,373	1,046,941

Appendix C2.–Karluk River sockeye salmon escapement, estimated number of smolt by freshwater age, smolt per spawner, adult return by freshwater age, return per spawner, and marine survival, by brood year, from 1994 to 2006.

Brood		Smolt Produced					Total	Smolt/	Adult Returns							Marine
Year	Esc	Age 0	Age 1	Age 2	Age 3	Age 4	Smolt	Spawner	fw-age 0	fw-age 1	fw-age 2	fw-age 3	fw-age 4	Run Total	R/S	Survival
1994						12,798										
1995	743,056	NA	NA	NA	487,406	0										
1996	574,326	NA	NA	531,134	402,919	80	934,133	1.6								
1997	564,761	NA	35,196	1,263,785	436,469	1,468	1,736,918	3.1	3,210	33,519	465,318	319,931	4,377	826,355	1.5	48%
1998	637,146	0	9,441	3,062,597	195,323	4,205	3,271,567	5.1	2,348	53,150	770,870	226,219	3,199	1,055,785	1.7	32%
1999	981,538	0	238,271	1,072,906	501,816	186	1,813,179	1.8	3,759	131,143	1,265,274	178,577	247	1,579,000	1.6	87%
2000	736,744	2,838	11,482	1,712,969	633,039	2,264	2,362,591	3.2	0	40,710	934,711	238,917	437	1,214,775	1.6	51%
2001	863,538	791	16,445	1,420,076	218,243	6,906	1,662,462	1.9	1,838	8,798	1,208,387	293,366	2,602	1,514,991	1.8	91%
2002	865,576	0	26,479	1,227,246	773,173	NA	2,026,898	2.3	155	12,724	1,148,082	327,698	1,240	1,489,899	1.7	74%
2003	1,078,710	533	47,834	393,039	NA	NA	NA									
2004	719,934	0	0	NA	NA	NA										
2005	781,962	0														
2006	490,373															

Appendix C3.–Mean length, weight, and condition factor of sockeye salmon smolt samples from the Karluk River by year and freshwater age, 1925–2012.

	Age 1					Age 1			
Year	n	Length (mm)	Wt. (g)	Cond. (K)	Year	n	Length (mm)	Wt. (g)	Cond. (K)
1925	3	113	na	na	1993	-	-	-	-
1926	5	100	na	na	1994	1	110	12.0	0.9
1927	5	116	na	na	1995	7	105	9.5	0.8
1928	6	111	na	na	-				
1929	0	na	na	na	1997	0	na	na	na
1930	24	110	na	na	-				
1931	16	111	na	na	1999	40	90	6.2	0.8
1932	16	105	na	na	2000	16	98	8.5	0.9
1933	43	114	na	na	2001	459	103	9.6	0.9
1934	7	123	na	na	2002	33	86	5.4	0.8
1935	16	113	na	na	2003	17	103	9.9	0.9
1936	60	111	na	na	2004	30	106	10.5	0.9
-					2005	4	93	6.4	0.8
1961	na	110	13.1	1.0	2006	3	77	3.6	0.8
1962	na	108	11.3	0.9	-				
1963	na	110	14.5	1.1	2010	46	106	10.9	0.9
1964	0	na	na	na	2011	29	102	10.5	0.9
1965	0	na	na	na	2012	185	118	14.7	0.9
1966	0	na	na	na					
1967	na	102	10.7	1.0					
1968	na	104	9.9	0.9					
-									
1979	66	112	14.8	1.1					
1980	300	97	8.3	0.9					
1981	77	96	9.4	1.1					
1982	8	104	10.8	1.0					
1983	17	101	9.5	0.9					
1984	165	108	11.5	0.9					
1985	227	103	10.1	0.9					
1986	426	85	6.2	1.0					
1987	43	95	7.4	0.8					
1988	8	82	4.9	0.8					
1989	5	92	6.7	0.8					
1990	30	96	7.8	0.9					
1991	166	100	8.7	0.8					
1992	59	101	8.8	0.8					

-continued-

	Age 2			
Year	n	Length (mm)	Wt. (g)	Cond. (K)
1925	563	136	22.8	0.9
1926	445	136	22.9	0.9
1927	212	134	21.2	0.9
1928	494	128	19.9	0.9
1929	418	130	20.0	0.9
1930	1,145	127	18.5	0.9
1931	1,795	130	20.0	0.9
1932	1,358	133	20.9	0.9
1933	685	136	23.9	1.0
1934	822	140	24.8	0.9
1935	1,520	142	26.3	0.9
1936	744	133	21.3	0.9
-				
1961	na	115	13.7	0.9
1962	na	113	12.4	0.9
1963	na	119	14.6	0.9
1964	na	128	21.0	1.0
1965	na	127	19.1	0.9
1966	na	115	13.2	0.9
1967	na	113	13.8	1.0
1968	na	113	12.4	0.9
-				
1979	201	120	18.5	1.1
1980	496	103	9.4	0.9
1981	600	111	13.4	1.0
1982	413	119	15.1	0.9
1983	1,014	117	14.2	0.9
1984	670	117	13.9	0.9
1985	541	111	12.1	0.9
1986	1,184	111	13.0	1.0
1987	1,776	106	10.4	0.9
1988	800	103	9.4	0.9
1989	828	103	9.6	0.9
1990	270	101	8.7	0.8
1991	1,584	110	11.3	0.8
1992	1,340	106	9.8	0.8
1993	-	-	-	-
1994	167	112	11.1	0.8
1995	79	113	12.3	0.8
-				
1997	157	112	13.0	0.9
-				
1999	598	116	13.2	0.8
2000	963	120	15.0	0.9
2001	1,565	118	14.4	0.9
2002	1,610	105	9.6	0.8
2003	1,130	111	12.2	0.9
2004	1,082	115	13.2	0.9
2005	941	102	8.7	0.8
2006	439	94	6.3	0.8
-				
2010	306	123	17.0	0.9
2011	138	128	20.0	0.9
2012	1,117	133	20.3	0.9

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Appendix C3.–Page 3 of 4.

	Age 3					Age 3			
		Length	Wt.	Cond.			Length	Wt.	Cond.
Year	n	(mm)	(g)	(K)	Year	n	(mm)	(g)	(K)
1925	84	145	28.5	0.9	1993	-	-	-	-
1926	156	144	28.5	1.0	1994	129	119	13.4	0.8
1927	144	147	27.3	0.9	1995	2	122	16.1	0.9
1928	225	141	28.4	1.0	-				
1929	603	143	25.2	0.9	1997	83	114	13.4	0.9
1930	625	137	25.0	1.0	-				
1931	247	138	26.8	1.0	1999	549	125	16.5	0.8
1932	634	139	29.5	1.1	2000	268	131	19.7	0.9
1933	521	144	29.6	1.0	2001	313	139	23.4	0.9
1934	75	148	33.3	1.0	2002	262	114	12.1	0.8
1935	286	152	26.6	0.8	2003	271	116	14.4	0.9
1936	233	143	18.2	0.6	2004	616	124	16.4	0.9
-					2005	207	114	11.5	0.8
1961	na	124	16.6	0.9	2006	565	102	7.9	0.7
1962	na	123	15.8	0.8	-				
1963	na	129	18.5	0.9	2010	43	138	23.5	0.9
1964	na	136	24.1	1.0	2011	33	135	24.1	1.0
1965	na	142	26.7	0.9	2012	116	144	25.6	0.9
1966	na	131	18.9	0.8					
1967	na	133	23.1	1.0					
1968	na	124	15.3	0.8					
-									
1979	11	147	29.1	0.9					
1980	80	113	11.7	0.8					
1981	83	119	16.2	1.0					
1982	64	132	20.2	0.9					
1983	149	132	19.9	0.9					
1984	63	130	19.3	0.9					
1985	37	123	16.4	0.9					
1986	28	118	14.7	0.9					
1987	316	121	15.6	0.9					
1988	10	118	11.9	0.8					
1989	149	116	13.4	0.9					
1990	709	114	12.2	0.8					
1991	654	121	15.0	0.8					
1992	565	117	13.4	0.8					

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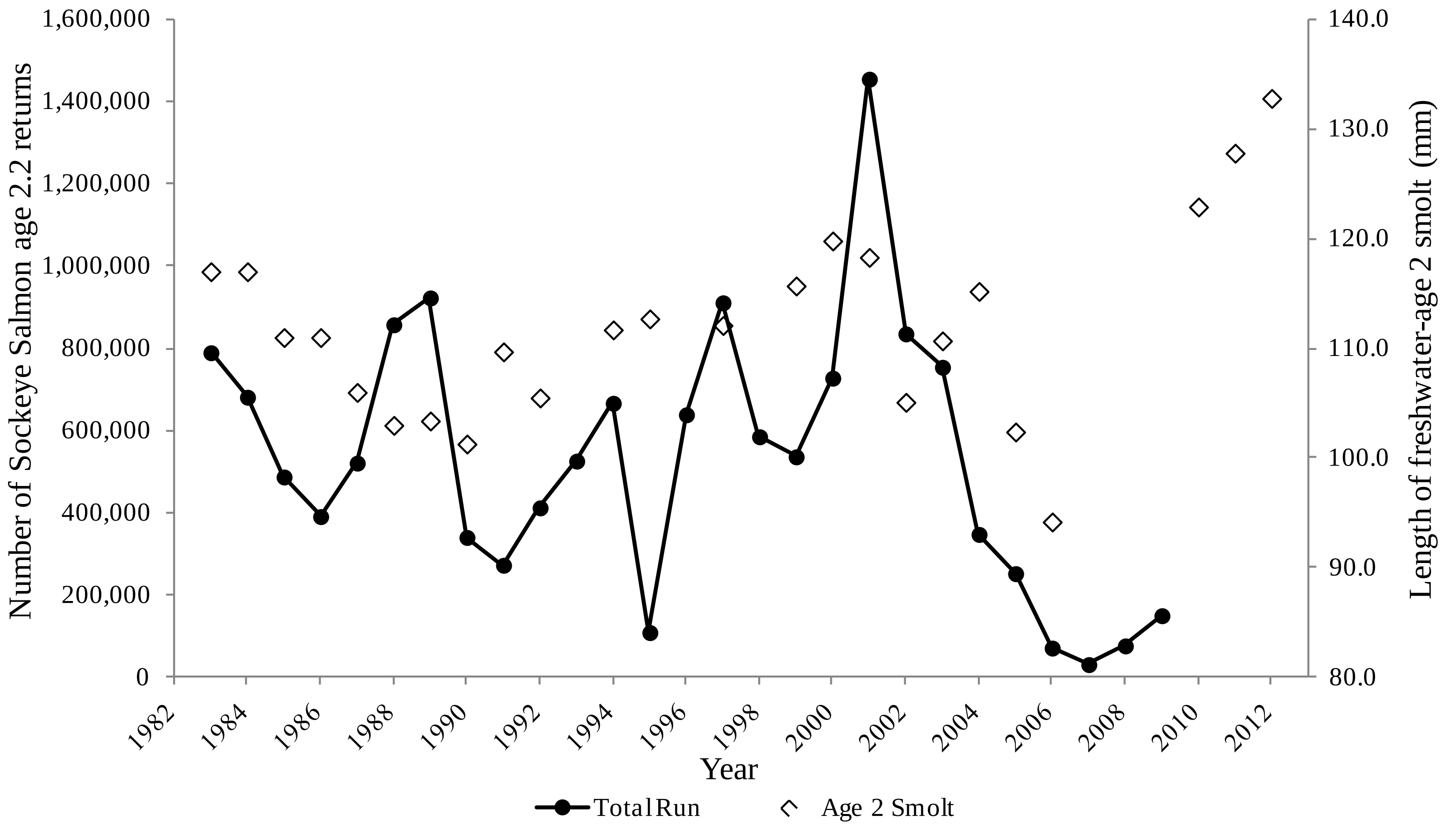
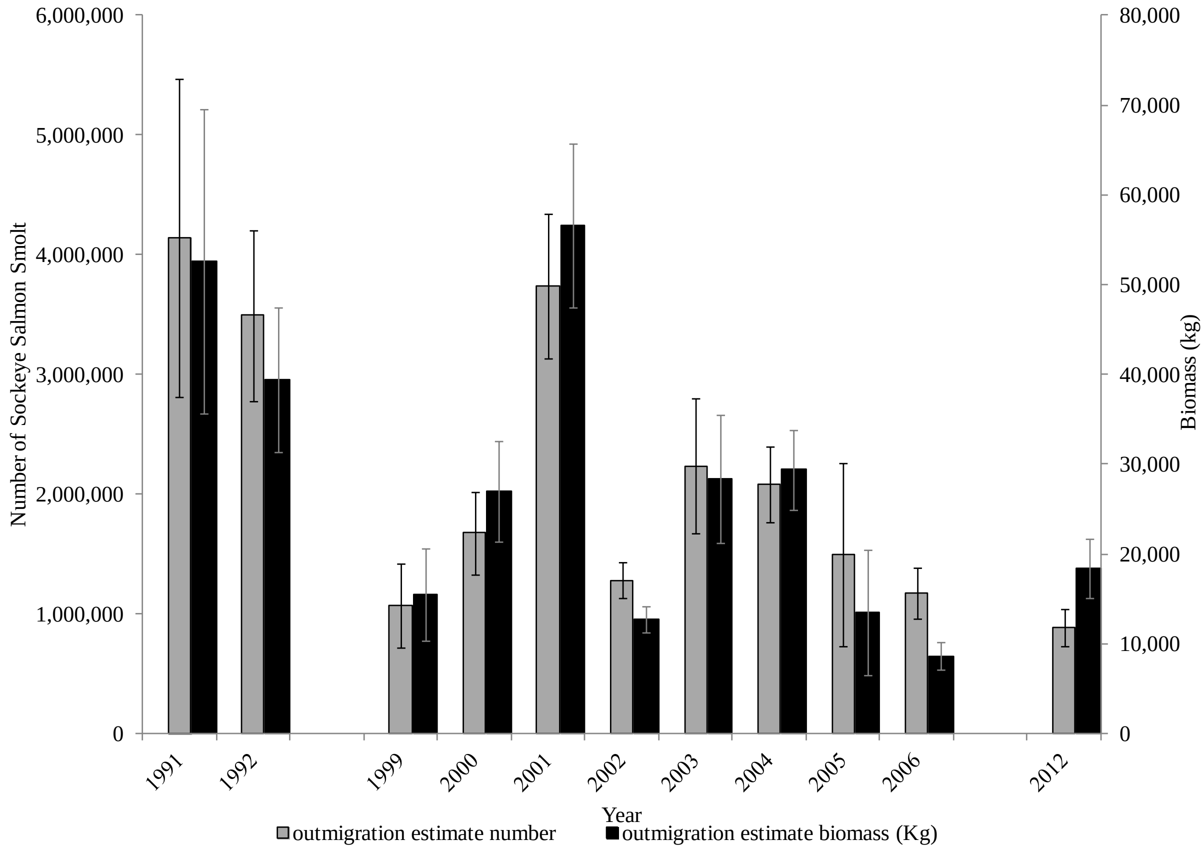
	Age 4					Age 4			
		Length	Wt.	Cond.			Length	Wt.	Cond.
Year	n	(mm)	(g)	(K)	Year	n	(mm)	(g)	(K)
1925	0	na	na	na	1993	-	-	-	-
1926	3	164	na	na	1994	0	na	na	na
1927	0	na	na	na	1995	0	na	na	na
1928	4	151	na	na	-				
1929	12	155	na	na	1997	1	109	12.3	1.0
1930	20	143	na	na	-				
1931	14	145	na	na	1999	15	132	18.9	0.8
1932	20	146	na	na	2000	0	na	na	na
1933	23	147	na	na	2001	1	140	23.7	0.9
1934	6	161	na	na	2002	2	105	10.2	0.9
1935	2	146	na	na	2003	4	113	12.5	0.9
1936	9	151	na	na	2004	2	134	21.3	0.9
-					2005	1	120	11.9	0.7
1961	0	na	na	na	2006	6	104	8.2	0.7
1962	0	na	na	na	-				
1963	0	na	na	na	2010	2	151	31.6	0.9
1964	na	149	33.7	1.0	2011	1	164	38.4	0.9
1965	na	145	28.7	0.9	2012	1	168	33.8	0.7
1966	na	137	21.4	0.8					
1967	0	na	na	na					
1968	0	na	na	na					
-									
1979	0	na	na	na					
1980	0	na	na	na					
1981	0	na	na	na					
1982	0	na	na	na					
1983	0	na	na	na					
1984	0	na	na	na					
1985	0	na	na	na					
1986	0	na	na	na					
1987	0	na	na	na					
1988	0	na	na	na					
1989	0	na	na	na					
1990	1	121	14.4	0.8					
1991	0	na	na	na					
1992	4	127	18.0	0.9					

Appendix C4.–Average length of outmigrating freshwater-age 2 smolt and subsequent number of adult age 2.2 returns.

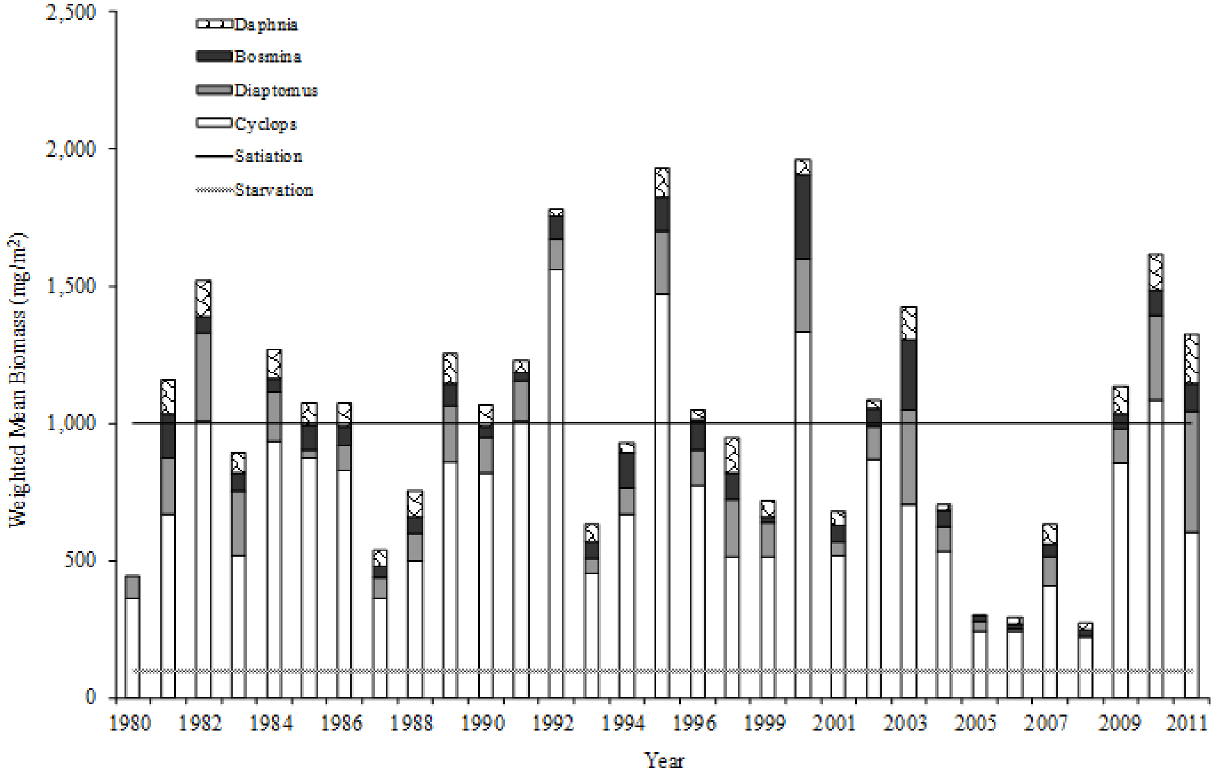


Appendix C5.–Annual sockeye salmon smolt outmigration estimates by number and biomass (Kg) and corresponding 95% confidence intervals, Karluk River, for years with population estimates, 1991–2012.



APPENDIX D. ZOOPLANKTON DATA

Appendix D1.–Karluk Lake weighted mean zooplankton biomass (mg/m^2) from 1980 to 2011.



Source: Reduced sockeye salmon runs at Karluk Lake (III) Jan 24, 2011, Alaska Department of Fish and Game.