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Chignik River Sockeye Salmon Smolt Outmigration: An Analysis of the Population and Lake Rearing Conditions in 2012

by

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and

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May 2013

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

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

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

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ABSTRACT

This report describes the results of the sockeye salmon *Oncorhynchus nerka* smolt monitoring and enumeration project conducted by the Alaska Department of Fish and Game (ADF&G) in the Chignik River system in 2012. The research was designed to estimate smolt population size and age structure, assess fish body condition, describe limnetic habitat conditions and forage base, collect samples for genetic stock identification, and provide data for the Chignik River preseason adult sockeye salmon forecast. The abundance of sockeye salmon smolt was estimated using a rotary-screw trap array and mark-recapture techniques. In 2012, a total of 39,945,197 sockeye salmon smolt were estimated to have outmigrated from May 20 to July 10. Of these, 685,707 (1.7%) were freshwater age-0, 16,328,172 (40.9%) were freshwater age-1, 22,734,743 (56.9%) were freshwater age-2, and 196,575 (0.5%) were freshwater age-3 smolt. Limnology surveys were conducted in Chignik and Black lakes each month from June to August 2012 to describe physical characteristics, nutrient availability, primary production, and zooplankton forage available to rearing juvenile sockeye salmon. Smolt were under weight and zooplankton levels were low suggesting the food base was taxed and rearing conditions were less favorable than in recent years. The smolt-based forecast predicts a total adult run of 3.29 million sockeye salmon in 2013. Findings from this project are vital for understanding effects of the commercial fishery and environmental changes occurring in the Chignik River system on the sockeye salmon population.

Key words: sockeye salmon, smolt, *Oncorhynchus nerka*, Chignik River, limnology, mark-recapture, zooplankton, forecast

INTRODUCTION

The Alaska Department of Fish and Game (ADF&G) has monitored the sockeye salmon *Oncorhynchus nerka* smolt outmigration in the Chignik River annually since 1994 to gauge the health of smolt leaving the system, estimate marine survival, and estimate age composition of the outmigrating population. In recent years, the data have been used to provide a preseason forecast of the Chignik River adult sockeye salmon run.

The Chignik River system produces the vast majority of the sockeye salmon in the Chignik Management Area (CMA; Bouwens 2004). It consists of a large shallow lagoon, two large lakes, and several tributaries that provide spawning and rearing habitat for sockeye salmon (Figure 1). Black Lake, at the head of the system, has a surface area of approximately 35.7 km^2, is shallow (maximum depth 4.2 m), turbid, and surrounded by low relief. In contrast, Chignik Lake is smaller (22 km^2), deeper (maximum depth 64 m), and surrounded by mountains. Black Lake drains via the Black River into Chignik Lake, which drains via the Chignik River into Chignik Lagoon, and then into the Gulf of Alaska (Narver 1966; Dahlberg 1968; Chasco et al. 2003). Chignik Lagoon is 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 (Simmons 2009).

Both lakes are considered oligotrophic (Kyle 1992) and each maintains its own genetically distinct, though temporally overlapping, runs of adult sockeye salmon (Templin et al. 1999). Early-run sockeye salmon enter the river from June through early July and spawn in Black Lake and its tributaries. Late-run sockeye salmon return from early July through the late fall and spawn in the tributaries and shoals of Chignik Lake. The early run has a sustainable escapement goal range of 350,000 to 400,000 fish through July 4. The late run has an sustainable escapement goal range of 200,000 to 400,000 fish beginning on July 5 with an additional 50,000 fish in-river run goal in August and September (Nemeth et al. 2010).

Typically, juvenile salmon migrate to sea after certain size thresholds are met, during specific seasons, and under certain environmental conditions. Salmon smolt outmigration may be triggered by warming springtime water temperatures (>4°C), increased photoperiod (Clarke and

Hirano 1995), and smolt size (Rice et al. 1994). 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 (Bumgarner 1993).

Smolt outmigration studies provide information on life history strategies and annual changes in outmigration timing. Combined with limnology investigations, this type of study can provide insight as to how environmental and anthropogenic factors may influence food availability, juvenile outmigration timing, and overwintering habitat selection. Sockeye salmon rearing in Chignik and Black lakes are exposed to different types and levels of environmental stress which may influence their life history strategies. 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), possibly increasing competition among age classes. Conversely, stressed smolt may use an entirely different strategy and outmigrate early in order to take advantage of better rearing conditions in the marine environment (Rice et al. 1994). From 1960 to the present, mean annual temperature and precipitation (Cold Bay, Alaska; Alaska Climate Research Center 2012) has increased, while Black Lake water levels have decreased since the 1960's. Reported decreases in water surface elevation range from 1 to 6.5 feet resulting in volume reductions of 23 to 44%. There is some uncertainty in the measurements due to differences in datums used, but it is widely accepted that a decrease has occurred (Dahlberg 1968; CH2MHILL n.d.; Griffiths et al. 2011; U.S. Army Corps of Engineers 2012). Loss of Black Lake volume might lead to a reduction in rearing habitat and forage, intensifying competition and top-down pressure on zooplankton by juvenile salmon.

Competition for food and habitat can influence growth and survival rates as well as migratory behavior of juvenile sockeye salmon (Rice et al. 1994). Several studies indicate Black Lake juveniles move into Chignik Lake to overwinter, with possible deleterious effects on Chignik Lake juveniles (Finkle 2004; Westley and Hilborn 2006; Simmons 2009). Top-down pressures have been indicated by decreased zooplankton size of *Bosmina* from Chignik and Black lakes (Kerfoot 1987; Kyle 1992; Bouwens and Finkle 2003). Interactions between the Black Lake (early run) and Chignik Lake (late run) stocks and their habitat use are not completely understood, but these topics have been the focus of numerous studies (Bumgarner 1993; Ruggerone 2003; Westley et al. 2008; Simmons 2009; Westley et al. 2009). In particular, the influence of changing physical and environmental factors upon the outmigration of juvenile sockeye salmon merits continued investigation. Other past studies have also suggested that a component of juvenile sockeye salmon rear in the Chignik River and Chignik Lagoon during the summer to avoid overtaxed Chignik Lake rearing habitat and subsequently return to Chignik Lake in the fall of the same year (Roos 1957, 1959; Iverson 1966; Phinney 1968). Information derived from smolt and lake-assessment monitoring is crucial for understanding changes in the production capacity of the salmon habitat of both Black and Chignik lakes.

Since the inception of the sockeye salmon smolt enumeration project in 1994, estimates of sockeye salmon smolt outmigrations from the Chignik River have ranged from 2 to 40 million sockeye salmon. Chignik sockeye salmon smolt generally have been observed to outmigrate beginning in early May, peak in late May, and are predominantly composed of age-1 and -2 smolt (St. Saviour and Hunt 2012). Smolt outmigration data can serve as an indicator of future run strength and overall stock status. In recent years, abundance and age data from the enumeration project have been used to generate an adult sockeye salmon forecast for the Chignik River. Harvesters use the forecast to make economic decisions including gear purchases, vessel repairs, and their time of arrival to the fishing grounds. Processors use it to estimate their supply and production needs. Forecast methods use historic age class relationships and smolt outmigration estimates to predict adult runs.

The Chignik smolt enumeration project has also supplied samples for genetic analysis since 2006. Genetic analyses have provided valuable information about stock-specific run timing and age composition. One of these studies indicated migration timing of each stock varied by year. In 2006 and 2008, Black Lake juveniles outmigrated in the early part of the season relative to the Chignik Lake stock. However in 2007 the opposite pattern occurred, where Chignik Lake smolt made up the majority of the early outmigration and Black Lake smolt dominated the late period. Additionally, smolt age was not a consistent indicator of stock origin as previously thought (Creelman 2010). In 2008, smolt ages were similar to those of returning adults, where the vast majority of Black Lake stock were freshwater age-1 and Chignik Lake stock were freshwater age-2 (Creelman 2010; Narver 1966; Witteveen and Botz 2004). However in 2006 and 2007, the proportions of age-1 and age-2 sockeye salmon smolt were more evenly distributed among stocks (mean 44 to 57%; Creelman 2010).

Information on rearing conditions is also needed to determine what factors may affect sockeye salmon production and life-history traits in the Chignik River system. ADF&G has conducted comprehensive limnology studies of Chignik and Black lakes since 2000. In 2008 limnology was formally incorporated into the smolt enumeration project. To date, limnology and smolt data from the Chignik system have been used to describe top-down pressures on the Chignik Lake aquatic community and trends in the life history strategies of juvenile sockeye salmon relative to recent physical changes (Buffington 2001; Bouwens and Finkle 2003; Finkle 2004; U.S. Army Corps of Engineers 2012). The limnology portion of this project is used to identify and understand the relationships among juvenile sockeye salmon and zooplankton relative to physical conditions such as temperature, turbidity, dissolved oxygen, and nutrients.

The 2012 field season was the nineteenth year of the ADF&G Chignik River sockeye salmon smolt monitoring and enumeration project. The sampling protocol has been consistent for these 19 years. This report presents data collected in 2012, compares the results of 2012 to previous years, and provides the 2013 adult sockeye salmon forecast based on smolt data.

OBJECTIVES

The objectives for the 2012 season were to

1. estimate the total number of outmigrating sockeye salmon smolt, by age, from the Chignik River system;
2. describe outmigration timing and growth characteristics (length, weight, and condition factor) of sockeye salmon smolt by age for the Chignik River system;
3. describe the physical characteristics of Black and Chignik lakes including: temperature, dissolved oxygen, and light penetration profiles;
4. describe the nutrient availability and primary productivity of Black and Chignik lakes;
5. quantify the zooplankton forage base available to juvenile sockeye salmon in Black and Chignik lakes;
6. estimate Chignik sockeye salmon marine survival and build a smolt-based forecast model to estimate future runs;

7. collect genetic samples from outmigrating sockeye salmon smolt for use in a stock identification study; and
8. present a stewardship-building sockeye salmon smolt presentation to students at CMA schools.

METHODS

STUDY SITE AND TRAP DESCRIPTION

Two rotary-screw traps were operated side by side to capture smolt outmigrating from the Chignik River system. Another trap was modified and used as a live box and work station platform. The live box was placed behind the small trap, which was closest to shore. The trapping site was located 8.6 km upstream from Chignik Lagoon and 1.9 km downstream from the outlet of Chignik Lake (56°15'26" N lat, 158°43'49" W long [NAD 1983]; Figure 2). The traps were located near a bend in the river with relatively high current velocity and narrow span.

Each trap was secured to shore with highly visible polypropylene line. The line and a red strobe light attached to the safety railing of the offshore trap were employed to facilitate safe navigation around the traps and anchor lines for local boat traffic. The strobe was positioned far enough behind the mouth of the large trap to minimize trap avoidance by sockeye salmon smolt.

Each trap consisted of a cone constructed of perforated aluminum sheet (5-mm holes) mounted on two aluminum pontoons, with the large open end of the cone pointed upstream. The cone mouth diameter of the small trap was 1.5 m, and 2.4 m for the large trap. The small trap sampled an area of 0.73 m^2, and the large trap sampled an area of 2.0 m^2 of the river's cross-sectional profile because only the bottom half of the cone was submerged. The river current rotated both cones from five to ten revolutions per minute (RPM) during average discharge. Ideal trap RPM is between six and seven; trap distance from shore was adjusted to obtain this speed. Fish were funneled through the cones into live boxes at the downstream end of the traps, each approximately 0.7 m^3 in volume. A pair of adjustable aluminum support legs were used to maintain and adjust the traps' positions from the shore and their orientation to the current. A floating platform supporting a 3 x 4 m weatherport was tied directly behind the live box work station, to provide a sheltered work station while sampling and maintaining the traps.

The 2012 field season started later than usual due to late winter conditions. A fyke net was placed above the Chignik weir site (Figure 2) on May 5 at 1300 hours to detect outmigrating smolt before screw trap installation and to collect age, weight, length (AWL), and genetic samples. Both screw traps began fishing at 1930 hours on May 20. On May 22, wind pushed remaining ice to the outlet of Chignik Lake and the traps had to be raised and stored in a protected eddy to prevent damage from ice. On May 27 at 1600 hours, the smolt traps were reinstalled at the trap site. Linear interpolation was used to estimate daily smolt outmigration during the seven days that the screw traps were out. Minor periods of fishing interruption occurred throughout the season to clear debris and for trap maintenance. These periods were limited to 1 hour or less and did not occur during primary outmigration hours. Both traps were disassembled and stored on July 10.

SMOLT ENUMERATION

Since smolt primarily outmigrate at night, sampling days occurred 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 three times each day beginning at noon, between 2000 and 2200 hours, and no later than 0800 hours the next morning. Traps were checked more frequently throughout the evening during periods of increased smolt outmigration.

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 retained for age-weight-length (AWL), genetic samples, and mark-recapture tests. Sockeye salmon fry (<45 mm FL), coho salmon *O. kisutch* juveniles, Chinook salmon *O. tshawytscha* juveniles, pink salmon *O. gorbuscha* juveniles, chum salmon *O. keta* juveniles, Dolly Varden *Salvelinus malma*, stickleback of the family Gasterosteidae, pond smelt *Hypomesus olidus*, pygmy whitefish *Prosopium coulteri*, starry flounder *Platichthys stellatus*, Coast Range sculpin *Cottus aleutus*, Alaska blackfish *Dallia pectoralis*, eulachon *Thaleichthys pacificus*, and isopod *Mesidotea entomon* (Merrit and Cummings 1984; Pennak 1989) were also identified and counted.

Smolt caught at the fyke net site were handled in the same fashion as those from the screw traps. Due to inconsistency between gear types and catch during overlap, fyke net catch data was not used in the smolt population estimate. Instead, linear interpolation of screw trap catch data was used to estimate the sockeye salmon smolt population for the seven days that the traps were out.

TRAP EFFICIENCY AND SMOLT POPULATION ESTIMATES

Mark-recapture experiments were conducted weekly to determine trap efficiency, provided a sufficient number of smolt were captured to conduct a marking event. Between 800 and 3,600 sockeye salmon smolt for each experiment were collected from the traps, counted, and transferred to the live box. If sufficient numbers of smolt were not initially captured to perform a mark-recapture experiment, they were cumulatively retained in the live box for a maximum of three nights. After three nights, all captured live smolt were released downstream of the traps if the minimum sample size was not met. Mortalities that occurred during the holding time were removed and subtracted from the total.

Sockeye salmon smolt were netted from the live box, counted, and transferred into two 24-gal aerated marking containers. After a 30 min resting period, Bismarck Brown-Y dye solution (4.6 g of dye to 92.4 L of water) was mixed into the containers and held for 15 min. Fresh water was then pumped into the containers to slowly flush out the dye for 90 min while smolt recovered. At the end of the marking process, any dead or stressed smolt were removed, counted, and disposed of downstream of the traps.

The remaining marked smolt were taken to the upriver release site (56°15'15" N lat, 158°44'51" W long), approximately 1.3 km upstream of the traps (Figure 2). The smolt were transported upstream in aerated containers and released evenly across the breadth of the river. The marking event was performed so that the marked fish were released before midnight. 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 traps in instream live boxes to ensure assumptions of the mark-recapture experiments were validated. Delayed mortality of smolt held for this purpose was incorporated into daily population estimates.

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 recovery period),

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

and

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

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

$$\hat{U}_h = \frac{u_h(M_h + 1)}{m_h + 1}, \tag{2}$$

where

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

Variance was estimated by

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

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

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

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

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

and 95% confidence intervals were estimated from

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

which assumed that $\hat{U}$ 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

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

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

$$\hat{U}_{jh}=\hat{U}_j\hat{\theta}_{jh} , \tag{9}$$

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

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

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

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

with the variance estimated by

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

AGE, WEIGHT, AND LENGTH SAMPLING

Sockeye salmon smolt were collected throughout the night's migration and held in an instream live box. Forty sockeye salmon smolt were randomly collected from the traps live boxes five days per statistical week, anesthetized with tricaine methanesulfonate (MS-222), and sampled for AWL; the remaining smolt were released downstream.

All AWL sampled smolt were anesthetized with either a non-lethal (smolt > 100mm) or lethal (smolt ≤ 100mm) amount of Tricaine methanesulfonate (MS-222). 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 (International North Pacific Fisheries Commission 1963) and mounted on a microscope slide for age determination. Fin clips were collected from all AWL-sampled fish for genetic analysis and stored in ethanol following ADF&G protocol.

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

Bagenal and Tesch 1978), which is a quantitative measure of the isometric growth of a fish, 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

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

MARINE SURVIVAL ESTIMATES AND RUN FORECASTING

The total sockeye salmon adult run to the Chignik River system was calculated by adding total Chignik River sockeye salmon escapement, total harvest from the CMA, 80% of the pre-July 26th sockeye salmon catch from the Southeastern District Mainland of the Alaska Peninsula Management Area, and 90% of the pre-July 26th catch from the Cape Igvak Section of the Kodiak Management Area (5 AAC 09.360(g); 5 AAC 18.360(d)). Marine survival by age and the number of smolt produced per spawner from their respective brood years (BYs) were also calculated.

The total 2013 Chignik early and late adult sockeye salmon run was forecast using a multiple regression model of total outmigrating smolt and June sea surface temperature (SST) anomalies of the outmigration year. SST anomalies were derived from the Kaplan SST model and were specific to the South Alaska Peninsula region (NOAA Earth System Research Laboratory 2012). Data from 1996 and 2008 were excluded due to unrealistic estimates of marine survival and anomalous adult runs. The model was evaluated using ANOVA significance *F* and AIC; autocorrelation was evaluated by examining residual plots, AR1, and Durbin-Watson statistics. This smolt-based forecast is separate from the formal forecast (Eggers et al. 2013) which uses age-class relationships and escapement data and is stock-specific.

LIMNOLOGY

Limnology data were collected at one sampling station on Black Lake (Figure 3) and at four sampling stations on Chignik Lake (Figure 3). Sampling occurred monthly from June through August. Each station's location was logged with a global positioning system (GPS, using NAD 1983 datum) and Chignik Lake stations were marked with a buoy. Zooplankton samples, temperature, dissolved oxygen, and light penetration data were gathered at all sampling stations. Water samples were collected at the Black Lake station and at Chignik Lake stations 2 and 4. Sampling was conducted following protocols established by Finkle and Bouwens (2001).

Dissolved Oxygen, Light, and Temperature

Water temperature (°C) and dissolved oxygen (mg/L) levels were measured with a YSI Pro ODO meter. Readings were recorded at half-meter intervals from 0–5 m, and then intervals increased to one meter. Upon reaching a depth of 25 m, the intervals increased to every five meters up to 50 m (the depth limit of the equipment). A mercury thermometer was used to ensure the meter's calibration. Measurements of photosynthetically active wavelengths (μmol/m^2/sec) were taken with a Li-Cor LI-250A photometer. Readings began above the surface, at the surface, and proceeded at half-meter intervals until reaching a depth of 5 m. Readings were then recorded at one-meter intervals until the lake bottom or light penetration reached zero. The mean euphotic zone depth (EZD) was calculated for each lake (Koenings et al. 1987; Koenings and Kyle 1997). One-meter temperature and dissolved oxygen measurements were compared to assess the physical conditions in the euphotic zones of each lake. Secchi disc readings were collected from each station to measure water transparency. The depths at which the Secchi disc disappeared when lowered into the water column and reappeared when raised were recorded and averaged.

Water Sampling

Seven to eight liters of water were collected with a Van Dorn sampler from a depth of 1 m from each lake and also from a depth of 29 m at Chignik Lake. Water sampling and processing techniques have been consistent since 2000 and follow protocols outlined in Finkle (2007). Water analyses were performed at the Chignik field laboratory for pH and alkalinity and at the ADF&G Near Island Laboratory (NIL) for total Kjeldahl nitrogen, total phosphorous (TP), total ammonia, nitrate + nitrite, total filterable phosphorous, filterable reactive phosphorous, chlorophyll *a*, and phaeophytin *a*. Nutrient and photosynthetic pigment analyses were conducted at NIL using a SEAL AutoAnalyser 3 (AA3) HR; methods followed the equipment protocol.

Zooplankton

One vertical zooplankton tow was made at each limnology station with a 0.2-m diameter, 153-micron net from one meter above the lake bottom to the surface. Each sample was placed in a 125-ml poly bottle containing 12.5 ml of concentrated formalin to yield a 10% buffered formalin solution. Samples were stored for analysis at the ADF&G NIL. Subsamples of zooplankton were keyed to genus or species and counted on a 1 mL Sedgewick-Rafter counting slide. This process was replicated a minimum of three times per sample to ensure the sample was accurately represented. The counts were averaged and extrapolated to the entire sample. For each plankton tow, mean length (±0.01 mm) was measured for each identifiable group with a sample size derived from a student's t-test to achieve a confidence level of 95% (Edmundson et al. 1994). Biomass was calculated via species-specific linear regression equations (Koenings et al. 1987).

RESULTS

TRAPPING EFFORT AND CATCH

The large and small traps were in place for a total of 47 days. The traps were operational on May 20. The duration of the 2012 trapping season was 19 days shorter than the 2011 season due to a late ice break up on Chignik Lake.

A total of 431,729 sockeye salmon smolt were captured in the traps during the 2012 season (Appendix A1 and B1). In addition to sockeye salmon smolt, 53,045 sockeye salmon fry, 1,580 coho salmon smolt, 192 coho salmon fry, 85 juvenile Chinook salmon, 70 juvenile pink salmon, 473 Dolly Varden char, 8,609 stickleback, 478 sculpin, 31 starry flounder, 171 pond smelt, 394 pygmy whitefish, 1 Alaskan blackfish, 279 isopods, and 2 eulachon were captured (Appendix A1). The small screw trap caught 19% of the trapped sockeye salmon smolt, and the large trap 81% (Appendix B1).

SMOLT OUTMIGRATION TIMING AND POPULATION ESTIMATES

An estimated 39,945,197 (95% CI 31,024,952 to 48,865,441) sockeye salmon smolt outmigrated in 2012 (Tables 1 and 2; Figure 4) based upon mark-recapture estimates and trap counts (Table 3). The majority of these fish outmigrated from the late May to mid-June (Table 2; Figure 5). The 2012 outmigration estimate comprised 685,707 age-0, 16,328,172 age-1, 22,734,743 age-2, and 196,575 age-3 sockeye salmon smolt (Tables 1 and 2; Figure 6). Age-1 and age-2 smolt comprised the majority of the outmigration at 40.9% and 56.9% respectively.

TRAP EFFICIENCY ESTIMATES

Mark-recapture experiments were conducted on seven occasions beginning May 29 and ending on July 5 (Table 3; Appendix A1). A total of 14,338 smolt, 4% of the total catch, were marked and released. One hundred ninety one smolt were recaptured and trap efficiency estimates per stratum ranged from 0.65% to 2.75% (Table 3; Appendix A1). The majority of marked smolt were recaptured within the first day of being released.

AGE, WEIGHT, AND LENGTH DATA

A total of 1,660 usable samples were collected from sockeye salmon smolt for AWL data. The mean length, weight, and condition factor of sampled age-0 smolt was 52 mm, 0.9 g, and 0.65 respectively. The mean length, weight, and condition factor of sampled age-1 smolt was 68 mm, 2.2 g, and 0.68 respectively. The mean length, weight, and condition factor of sampled age-2 smolt was 78 mm, 3.4 g, and 0.69 respectively. The mean length, weight, and condition factor of sampled age-3 smolt was 87 mm, 4.4 g, and 0.66 respectively (Tables 4 and 5; Figures 7 and 8). Sockeye salmon fry (<45 mm FL) were captured throughout the trapping season, but were most abundant in late May to mid-June (Appendix A).

PHYSICAL DATA

The absolute water depth at the trap location ranged from 47 cm to 93 cm. Peak river discharge occurred on June 24. Water temperature at the beginning of the season was 3.0°C. It did not rise above 5.0°C until June 13; then it increased steadily to a maximum of 9.5°C on July 9 (Appendix C1 and C2). Cool temperatures, light winds, and overcast skies dominated the 2012 season.

ADULT RUN FORECAST

The smolt-based regression model forecasted a 2013 total adult run of 3.29 million sockeye salmon (80% prediction interval 2.64 to 3.95 million; significance F= 0.06), compared to the formal adult forecast, which predicted a run of 3.82 million sockeye salmon (Eggers et al. 2013)

LIMNOLOGY

Sampling was conducted each month in both Black Lake (June 18, July 9, and August 24) and Chignik Lake (June 16, July 7, and August 21). Comparisons with historical limnology data can be found in Appendices D1 and D2.

Temperature and Dissolved Oxygen

Black Lake

The 1-m temperature in Black Lake in 2012 increased from 11.6°C on June 18, to 12.3°C on August 24 (Figure 9). Dissolved oxygen levels at the 1-m depth were steady, ranging from 11.7 to 11.4 mg/L over the same dates (Figure 9).

Chignik Lake

The average 1-m temperature in Chignik Lake increased from 6.0°C on June 16, to 11.0°C on August 21 (Figure 10). Dissolved oxygen levels decreased from 13.7 mg/L to 11.9 mg/L over the same dates (Figure 10). Temperature and dissolved oxygen levels were similar throughout the water column at each sampling date, with no more than 0.5°C and 0.6 mg/L difference between surface and deeper water.

Light Penetration and Water Transparency

Black Lake

Light penetrated the entire water column in Black Lake during the 2012 sampling season. The EZD (4.15m) of Black Lake was nearly the same as its maximum depth (4.2m) throughout the entire sampling season. The mean lake depth (1.9 m) was used to calculate the euphotic volume (EV) of 78.09 x 10^6 m^3 (Table 6; Figure 11). During the 2012 sampling season, Secchi disc depth readings averaged 1.43 m.

Chignik Lake

EZD was similar on each sampling date and averaged 8.38 m. The EV in Chignik Lake averaged 202.0 x 10^6 m^3 (Table 6; Figure 11). Mean Secchi disc readings were at a depth of 2.26 m.

Water Quality Parameters, Nutrient Levels, and Photosynthetic Pigments

Black Lake

In 2012, the pH in Black Lake averaged 7.7 and alkalinity averaged 26.7 mg/L $CaCO_3$ across stations and depth. TP averaged 11.0 µg/L P, ammonia averaged 6.0 µg/L, nitrate + nitrite averaged 1.1 µg/L, and silicon averaged 1,618.6 µg/L. Chlorophyll *a* averaged 5.8 µg/L and phaeophytin *a* had a seasonal mean of 0.8 µg/L. Nutrients increased over the course of the season. Chlorophyll *a* concentration was highest in August and phaeophytin *a* concentration was highest in July (8.1 and 1.2 µg/L respectively; Table 7).

Chignik Lake

During the 2012 season, the pH in Chignik Lake averaged 7.4 and alkalinity averaged 20.3 mg/L $CaCO_3$ across stations and depth. TP averaged 10.0 µg/L and filterable reactive phosphorous averaged 2.1 µg/L. Ammonia averaged 11.0 µg/L, nitrate + nitrite averaged 171.7 µg/L, and silicon averaged 5289.8 µg/L. Chlorophyll *a* averaged 2.9 µg/L and phaeophytin *a* averaged 0.3 µg/L. Phosphorus parameters decreased over the season whereas nitrogen parameters increased. Chlorophyll *a* decreased in July and returned to June levels in August and phaeophytin *a* did not fluctuate throughout the season (Table 8). Photosynthetic pigment levels were comparable to other years (Appendix D2).

ZOOPLANKTON

Black Lake

Cladocerans were the most abundant zooplankton measured in Black Lake (season average of 39,526 individuals/m^2) followed by copepods (season average of 35,403 individuals/m^2). On average, the most prevalent copepod genera in Black Lake was *Cyclops* (15,906/m^2; Table 9; Appendix D3). *Bosmina* were the most abundant cladoceran genera with a seasonal average of 27,995/m^2; abundance peaked in August (Table 9).

Copepod biomass was greatest in July and was composed predominantly of *Eurytemora* (20.36 mg/m^2 weighted season average). Cladoceran biomass was predominantly composed of *Bosmina* throughout the sampling season with a weighted seasonal average of 22.5 mg/m^2 and greatest biomass observed in August. The total weighted seasonal average copepod biomass (40.1 mg/m^2) was greater than cladoceran biomass (26.5 mg/m^2) and resulted in a total weighted average of 66.6 mg/m^2 for all the Black Lake zooplankton (Table 10; Appendix D4).

Average seasonal lengths of the major non-egg bearing zooplankton in Black Lake were 0.98 mm for *Eurytemora*, 0.49 mm for *Cyclops*, and 0.31 mm for *Bosmina* (Table 11).

Chignik Lake

Copepod abundance (season average of 158,700 individuals/m^2) was greater than the average seasonal cladoceran abundance (3,132 individuals/m^2). *Cyclops* (72,426/m^2) and nauplii (50,495/m^2) were the most abundant genera of copepods. Ovigerous *Bosmina* (1,407 individuals/m^2) and *Bosmina* (1,132 individuals/m^2) were the most common cladocerans in Chignik Lake (Table 12; Appendix D5).

Copepod biomass was composed predominantly of *Cyclops* in June and July (91.0 mg/m^2 weighted season average.) In August, *Eurytemora* had the greatest biomass (48.7 mg/m^2). Cladoceran biomass was composed primarily of *Bosmina* (45.9 mg/m^2 weighted season average) reaching highest biomass in August (124.8 mg/m^2). The total weighted seasonal average copepod biomass (166.4 mg/m^2) was greater than the cladoceran biomass (50.9 mg/m^2) resulting in a weighted average of 217.3 mg/m^2 for all Chignik Lake zooplankton (Table 13; Appendix D6).

Average seasonal lengths of the major non-egg bearing zooplankton in Chignik Lake were 0.63 mm for *Cyclops*, 0.99 mm for *Eurytemora*, and 0.62 mm for *Daphnia l*. Ovigerous zooplankton were generally longer than non-egg bearing individuals (Table 14).

DISCUSSION

SMOLT POPULATION ESTIMATES AND AGE STRUCTURE

The point estimate of the 2012 total smolt outmigration (39.9 million) was well above the 19 year average (14.5 million) and the highest on record. Outmigration timing was later than average, with the peak occurring at the on June 2. There were two large peaks in the 2012 outmigration on June 2 and 7 (Figure 5).

Outmigration timing and magnitude in 2012 allowed for seven mark-recapture events throughout the season with approximately 14,000 smolt marked and released. Trap efficiency estimates in 2012 were consistent with previous years. Historic efficiencies have generally averaged <2% annually and individual mark-recapture events often were <1%. Efficiencies are consistent throughout the season and have never been more than 3% in the history of the project (St. Saviour and Hunt 2012). Low trap efficiencies are expected considering the size of the Chignik River and small proportion that the traps cover. Although trap efficiency estimates result in wide confidence intervals around the population point estimate, the interannual trap efficiency consistency provides confidence that the yearly population estimates are generally robust and comparable among years.

The 2012 smolt population comprised approximately 2% age-0, 41% age-1, and 57% age-2 smolt. The large proportion of age-2 smolt in the 2012 outmigration was atypical (Figure 6) and the overall outmigration was the highest on record (Table 1). Condition factor among all age classes was the lowest on record (Table 5); however, K increased among all age classes over the course of the season (Table 4). These data suggest that the 2012 smolt population level reached or exceeded the current carrying capacity of the system. The high proportion of age-2 smolt may indicate that most Chignik sockeye salmon smolt exhibited the life history strategy where they do not outmigrate until a threshold size is met (Burgner 1991). It would take longer to meet this threshold with more intraspecific competition and less food resources available. More fish staying for an extra year in Chignik Lake could perpetuate the problem of high competition and low food resources.

Age-0 smolt made up a similar proportion of the population as in recent years (Table 1) and did not indicate anything unusual in 2012. Although age-0 smolt make up a small proportion of the population, fry, less than 45 mm have not been included the estimate of age-0's. Fry less than 45 mm are not considered smolt (Thedinga et al. 1994) as they are very difficult to remove scales from and age due to their small size. This inherently leads to a biased-high size estimate of the entire age-0 class. Age-0 smolt can reach lengths of over 50 mm in the productive rearing conditions of Black Lake (Finkle 2004). Some of these fish return as adults as evidenced by adult scales (Nemeth et al. 2010). Some rear in the lagoon or river for the summer (Simmons 2009) before outmigrating, and others may return to Chignik Lake as juveniles to overwinter. Ongoing otolith microchemistry work should shed light on the frequency of these different life-history strategies (Walsworth *In prep*).

Zooplankton

Black Lake zooplankton density and biomass was similar to recent years. Black Lake zooplankton levels during the recent seven years have been more stable and lower than the previous six years. May samples were not collected in 2012, but seasonal patterns of zooplankton density and biomass were similar to what has been observed historically. Zooplankton density in Black Lake is usually predominated by copepods early in the season, decreasing from May to June, then peaking in late July or August (Finkle and Ruhl 2008; St. Saviour and Hunt 2012). Cladocerans become the predominant zooplankton in Black Lake late in the summer when phytoplankton levels have increased (chlorophyll *a* 1.5 to 10.4µ/L) and many of the zooplanktivorous fish have left the lake. In 2012, cladoceran biomass peaked at the end of August. Since cladocerans are a preferred food source for juvenile sockeye salmon, their abundance may be a better indicator of potential juvenile sockeye salmon production than other genera (Koenings et al. 1987; Kyle 1992). The relationship between total smolt and Black Lake zooplankton density is not consistent interannually (Figure 4; Appendix D3). Chignik Lake zooplankton levels are probably equally or more important for Black Lake-stock juvenile sockeye salmon (Finkle 2005).

Chignik Lake zooplankton density and biomass were well below average in 2012. Of particular concern, cladoceran density was apporoximately 93% lower than the ten year average; however biomass was 45% lower than the ten year average (Appendices D5 and D6). Cladoceran levels in 2012 indicated depletion by a large population of juvenile sockeye salmon and strong top-down pressure on this aquatic community. Chignik Lake zooplankton seasonal patterns are usually similar to those found in Black Lake, with the exception that copepods remain predominate later into the season when overall zooplankton densities are greatest (Tables 9 and 12). Chignik Lake copepod populations historically are composed primarily of *Cyclops*, while the most abundant cladoceran is *Bosmina*.

Decreased competition among juveniles for food may allow them to successfully rear and overwinter in the lakes rather than migrate to the marine environment early. When competition is too great or rearing conditions are poor in the freshwater environment, the lagoon may provide important rearing habitat for juvenile sockeye salmon before continuing to the marine environment (Simmons 2009). Chignik Lake zooplankton biomass has tracked very closely with smolt K since 2000 (Figure 12). Smolt entering the marine in environment in good condition (high K) have been shown to have higher survival than those with lower K (Foerster 1954; Henderson and Cass 1991). Keeping the sockeye salmon smolt population and zooplankton levels, particularly Chignik Lake cladocerans, in balance will help promote productive adult returns in future years. This may be achieved by hitting the lower end of the escapement goals especially in the early-run, as was done from 2003 to 2009. These escapements have generally resulted in strong adult returns and high return/ spawner ratios (Anderson et al. *In prep.*).

LIMNOLOGY

Nutrient data can indicate limitations in aquatic environments. A ratio of total nitrogen (TN) to total phosphorous (TP) is commonly used to indicate nutrient status, and both are necessary for primary productio at specific ratios (Wetzel 1983; University of Florida 2000). Nitrogen-phosphorous ratios of less than 10:1 indicate nitrogen limitations (U.S. Environmental Protection Agency 2000). Water quality data from 2012 indicated nutrient levels in both lakes fell into low production (oligotrophic) levels as defined by several trophic state indices (Carlson 1977; Forsberg and Ryding 1980; Carlson and Simpson 1996) but were comparable to other Alaskan lakes in the region (Honnold et al. 1996; Schrof and Honnold 2003). Nitrogen limitation doesn’t necessarily mean that nitrogen levels are low, it simply means that the ratio to phosphorus is low relative to other systems and the needs of primary producers. Phosphorus levels are likely high in this region due to volcanic activity. Seasonally averaged TN:TP ratios for Black Lake were unusually low (0.8:1) this season. Of the two, nitrogen was certainly the limiting nutrient in Black Lake during the 2012 season. The seasonal average for Chignik Lake was 18.3:1. The highest ratio there occurred in July (20:1). This seasonally averaged ratio is greater than the 10-year average (10.3:1).

The quantity of photosynthetic pigments present in an aquatic system is related to the biomass of primary producers and the potential production level of the system. The ratio of chlorophyll *a* (associated with active cells) to phaeophytin *a* (the byproduct of photosynthesis associated with senescent cells) serves as an indicator of the algal community condition. High chlorophyll-*a* to phaeophytin-*a* ratios indicate there are adequate nutrients and suitable physical conditions for primary production within the lake. Conversely, low ratios may suggest that primary productivity is taxed. A comparison of the photosynthetic pigment, chlorophyll *a,* to its byproduct, phaeophytin *a*, showed that chlorophyll *a* concentrations (ratio 7.1:1) in Black Lake were similar to the 10-year average (5.3:1). The ratio of chlorophyll *a* was higher than average in Chignik Lake this season (2012 ratio 9.5:1; 10-year average 5.0:1). These ratios remained average to high despite a cool cloudy summer. Changes in nutrients and forage bases can significantly impact higher trophic levels such as secondary or tertiary consumers (Kyle et al. 1988; Milovskaya et al. 1998). Nutrient and photosynthetic pigment levels were unrelated to zooplankton levels in 2012, which serves as further evidence for top-down control. However, these relationships are not stationary. In years with fewer juvenile sockeye salmon rearing, bottom-up controls could become more important (Northcote 1988). Continued collection of limnology data is important to understand mechanisms driving resource abundance.

The seasonal pH levels in Black and Chignik lakes remained consistent with observations from recent years with slightly higher than seasonal averages from the 1960s (1960s Black Lake seasonal average pH = 7.42; 1960s Chignik Lake seasonal average pH = 7.27; Narver 1966). The current levels are well within a safe pH range for aquatic organisms of 4.5 to 9.5 (Wetzel 1983). Higher pH in 2004–2006 may have been the result of predation on zooplankton from increased densities of juvenile fish, which in turn resulted in increased phytoplankton production. Decreased grazing pressure by zooplankton allows phytoplankton biomass to increase and remove greater quantities of carbon dioxide from the water through photosynthesis, increasing the overall level of pH in each lake (Wetzel 1983).

OUTMIGRATION TIMING

An estimated 686,000 age-0 sockeye salmon, greater than 45 mm in length, outmigrated in 2012 (Table 2). Unlike other systems where smolt leave the freshwater environment and enter directly into entirely marine near-shore feeding areas, the Chignik system has a large lagoon which acts as a transition zone between the freshwater and saltwater ecosystems. This provides a forage base of amphipods, pericardians, and other small crustaceans which may alleviate some of the top-down pressure in Chignik Lake (Bouwens and Finkle 2003). Simmons (2009) found that sockeye salmon fry were abundant in Chignik Lagoon throughout the summer and that residency time was closely related to sockeye salmon length and age, with smaller fish remaining longer to achieve additional growth in body size before their migration to the marine environment. Under stressful environmental conditions, such as elevated temperatures and poor visibility, underyearling sockeye salmon may migrate to sea. In 2005, 2006, and 2008 a greater proportion of age-0 smolt were observed outmigrating, possibly using an alternative life history strategy of leaving poor lake rearing conditions in search of more productive lagoon or marine habitat (Rice et al. 1994; Simmons 2009). The low proportion of age-0 sockeye salmon that outmigrated in 2012 indicates this did not occur this year.

Temperature also has a strong effect on smolt outmigration. Long term data indicate the Alaska Peninsula has generally been warming since the 1960's (Alaska Climate Research Center 2012). However, the average annual temperature has been declining for the past 10 years, perhaps as a result of a shift back to colder regime in the Pacific Decadal Oscillation (NOAA Earth System Research Laboratory 2013). A shift in Chignik sockeye salmon smolt peak outmigration timing from about May 23 to June 3 since 1994 indicates recent colder conditions may be delaying the outmigration. Griffiths et al. (2011) showed air temperatures and water temperatures are closely coupled in Black Lake due to the shallow depth of the water body. Air temperatures may play a larger role in the condition and success of sockeye salmon juveniles in Black Lake. In warmer years, thermal stress may cause earlier outmigration of Black Lake juveniles into Chignik Lake (Finkle 2004). In 2012, air and water temperatures at the smolt traps were cooler later into the spring than recent years. 2012 monthly temperatures in both Chignik and Black lakes were as cool as or cooler than all years since 2000 and the water column was not stratified. Yet, very few juvenile sockeye salmon were captured in a beach seine at Black Lake after June suggesting water temperature is always limiting there or something else is controlling early outmigration from Black Lake. Water clarity is one possibility. Black Lake is susceptible to wind-mixing and has more-variable water clarity over the course of a season, whereas Chignik Lake tends to lose clarity over the course of the season due to increased phytoplankton biomass and runoff from the West Fork. Increased water clarity should provide better feeding conditions for both juvenile fishes and zooplankton.

MARINE SURVIVAL ESTIMATES

All adult sockeye salmon offspring from brood years (BYs) 1991 through 2004 and most offspring from BY 2005 have returned to the Chignik River; overall marine survival has ranged from 6% for BY 1999 to 67% for BY 1993 (mean survival 22%; Table 15). The estimation of the 1993 and 1994 BY marine survival includes a portion of the outmigration estimate from 1996, which is considered erroneous (Edwards and Bouwens 2002). When presented by outmigration year, marine survivals ranged from 5% for outmigration year 2001 to 84% for outmigration year 2007, with a mean survival rate of 22% (Table 16). The unrealistic marine survival estimate for outmigration year 2007 is likely due to truly high survival and a biased low smolt outmigration estimate. Smolt were much larger than average that year so they entered the ocean in good condition and likely had higher survival than average (Figure 7). They also may have been stronger swimmers and been able to avoid the traps resulting in a biased-low smolt population estimate. Efficiency estimates would not necessarily have accounted for trap avoidance because trap catches were low for much of 2007 and did not sufficient smolt sample sizes for consistent mark-recapture experiments. Variability in marine conditions, which can only be indexed indirectly, strongly influences variability in marine survival.

FORECASTS OF ADULT SALMON RETURNS

A smolt-based forecast has been developed annually since 2002. Since its inception, the smolt-based forecast has overestimated the actual total sockeye salmon adult return to the Chignik watershed by as much as 107% (2004 forecast) and underestimated it by as much as 53% (2011 forecast). However, the ten year forecast average is very close to the true return average, with an error of -1%. Forecast methods have included simple and multiple linear regressions of smolt outmigrants by age class to ocean-age class adult returns and multiple regressions of outmigrant-age class smolt and temperature to ocean-age class adult returns. The 2013 smolt-based forecast uses total smolt outmigration and regional SST anomaly data to predict a total adult run of 3.29 million. This model reflects more of the general trend in smolt to adult returns and it is corroborated by the formal forecast.

The smolt-based forecasting method does not currently have the resolution to forecast by run because stock-of-origin cannot yet be applied to the smolt outmigration data. However, current genetic analyses may provide a basis for Chignik sockeye salmon smolt stock separation. Genetic samples collected from 2006 through 2008 were analyzed by a graduate student. These initial results indicate that outmigration timing of Black and Chignik Lake stocks is not consistent year to year (Creelman 2010). A grant from Alaska Sustainable Salmon Fund has allowed analysis of samples from 2009 to 2012 to build on the Chignik smolt genetics data set. Collection and laboratory processing were completed but data analysis was ongoing at the time of this publication. Genetic identification of Chignik sockeye salmon smolt could lead to stock-based smolt forecasts and provide information on stock-specific life history traits of rearing and outmigrating juveniles.

STEWARDSHIP AND CMA SCHOOLS

In a public outreach effort, a presentation describing the sockeye salmon life cycle and the Chignik Sockeye Salmon Smolt Enumeration project and salmon food web interactions was given to students in Chignik Lagoon and Perryville. The goal of the presentations was to relay the value of the smolt project and foster stewardship in students for their resource and to help them learn about resource sustainability. By actively promoting community youth involvement, it is hoped the smolt project can foster a sense of inclusion in the many research and management projects the department oversees in the Chignik River system.

CONCLUSION

The continued collection of smolt outmigration data aids with investigations of changes in life history strategies by sockeye salmon in the Chignik River system caused by changes in environmental conditions, such as those seen in Black Lake. Reductions in Black Lake water volume and rearing habitat have occurred along with shifts in water temperatures since the 1960s. Timing of Black Lake smolt outmigration to Chignik Lake has shifted earlier in the summer relative to 1970s timing (Westley et al. 2008) whereas the peak system-wide outmigration has shifted later since 1994. Competition between Black Lake emigrants and Chignik Lake smolt has been demonstrated (Parr 1972; Ruggerone 2003) and is likely stronger in years when Black Lake is warmer. High escapement and recruitment also likely have an effect on competition between stocks as evidenced by top-down pressures on the Chignik Lake zooplankton community. Continued monitoring of smolt outmigration and limnology in the system is the best way to detect changes in early life history strategies that may be deleterious to this vital commercial fishery.

ADF&G has conducted the smolt enumeration project since 1994 and in 2008 formally incorporated the collection of valuable limnology samples from both lakes. This data set is now becoming a long enough time series useful for identifying longer-term changes that may be occurring in the system as well as quantifying long-term natural variation. It has proven instrumental in understanding the mechanisms behind freshwater production and for enhancing management of the system. For example, targeting the lower ends of the escapement goals in response to overescapement and decreased rearing habitat in Black Lake has likely contributed to strong returns in recent years. Data from this project are essential for monitoring the health of sockeye salmon in Chignik system because smolt outmigration information may be the only available means to link changes in run strength to freshwater, marine, or climate influences.

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TABLES AND FIGURES

Table 1.–Chignik River sockeye salmon smolt population estimates, by age class, 1994 to 2012.

		Number of Smolt							95% C.I.	
Year		Age-0	Age-1	Age-2	Age-3	Age-4	Total	S.E.	Lower	Upper
1994	Numbers	0	7,263,054	4,270,636	0	0	11,533,690	1,332,321	8,922,341	14,145,038
	Percent	0.0	63.0	37.0	0.0	0.0	100.0			
1995	Numbers	735,916	2,843,222	5,178,450	0	0	8,757,588	1,753,022	5,321,664	12,193,512
	Percent	8.4	32.5	59.1	0.0	0.0	100.0			
1996	Numbers	80,245	1,200,793	731,099	5,018	0	2,017,155	318,522	1,392,852	2,641,459
	Percent	4.0	59.5	36.2	0.2	0.0	100.0			
1997	Numbers	528,846	11,172,150	13,738,356	122,289	0	25,561,641	2,962,497	19,755,145	31,368,136
	Percent	2.1	43.7	53.7	0.5	0.0	100.0			
1998	Numbers	75,560	5,790,587	20,374,245	158,056	0	26,398,448	3,834,506	18,882,817	33,914,080
	Percent	0.3	21.9	77.2	0.6	0.0	100.0			
1999	Numbers	73,364	12,705,935	8,221,631	78,798	0	21,079,728	3,070,060	15,062,412	27,097,045
	Percent	0.3	60.3	39.0	0.4	0.0	100.0			
2000	Numbers	1,270,101	8,047,526	4,645,121	160,017	0	14,122,765	1,924,922	10,349,918	17,895,611
	Percent	9.0	57.0	32.9	1.1	0.0	100.0			
2001	Numbers	521,546	18,940,752	5,024,666	516,723	5,671	25,009,358	5,042,604	15,125,854	34,892,862
	Percent	2.1	75.7	20.1	2.1	0.0	100.0			
2002	Numbers	440,947	13,980,423	2,223,996	72,184	0	16,717,551	2,112,220	12,577,007	20,856,909
	Percent	2.6	83.6	13.3	0.4	0.0	100.0			
2003	Numbers	155,047	5,146,278	1,449,494	0	0	6,750,819	527,041	5,717,820	7,783,819
	Percent	2.3	76.2	21.5	0.0	0.0	100.0			
2004	Numbers	244,206	6,172,902	2,239,716	0	0	8,656,824	1,219,278	6,267,039	11,046,609
	Percent	2.8	71.3	25.9	0.0	0.0	100.0			

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Table 1.–Page 2 of 2.

Year		Number of Smolt							95% C.I.	
		Age-0	Age-1	Age-2	Age-3	Age-4	Total	S.E.	Lower	Upper
2005	Numbers	859,211	2,075,681	1,468,208	32,889	0	4,435,988	1,034,892	2,407,600	6,464,376
	Percent	19.4	46.8	33.1	0.7	0.0	100.0			
2006	Numbers	1,744,370	2,849,043	2,847,624	119,614	0	7,560,651	2,280,536	3,090,799	12,030,502
	Percent	23.1	37.7	37.7	1.6	0.0	100.0			
2007	Numbers	9,286	1,926,682	1,028,865	0	0	2,964,833	969,567	1,064,482	4,865,184
	Percent	0.3	65.0	34.7	0.0	0.0	100.0			
2008	Numbers	1,017,498	3,309,894	987,928	41,136	0	5,356,455	605,266	4,170,134	6,542,777
	Percent	19.0	61.8	18.4	0.8	0.0	100.0			
2009	Numbers	110,446	3,777,572	4,288,491	0	0	8,176,509	320,013	7,472,166	8,880,852
	Percent	1.4	46.2	52.4	0.0	0.0	100.0			
2010	Numbers	1,039,131	17,684,165	9,347,999	91,509	0	28,162,803	4,433,289	19,473,557	36,852,050
	Percent	3.7	62.8	33.2	0.3	0.0	100.0			
2011	Numbers	203,380	10,684,120	1,371,044	0	0	12,258,543	1,802,506	8,725,631	15,791,456
	Percent	1.7	87.2	11.2	0.0	0.0	100.0			
2012	Numbers	685,707	16,328,172	22,734,743	196,575	0	39,945,197	4,551,145	31,024,952	48,865,441
	Percent	1.7	40.9	56.9	0.5	0.0	100.0			

Table 2.–Estimated sockeye salmon smolt outmigration from the Chignik River in 2012 by age class and statistical week.

Statistical		Number of Smolt								
Week	Date	age-0	%	age-1	%	age-2	%	age-3	%	Total
21	5/17	0	0.0%	289,444	30.0%	627,129	65.0%	48,241	5.0%	964,814
22	5/24	0	0.0%	2,422,797	24.5%	7,317,836	74.0%	148,335	1.5%	9,888,967
23	5/31	85,388	0.5%	5,635,614	33.0%	11,356,616	66.5%	0	0.0%	17,077,618
24	6/7	131,955	1.5%	5,762,046	65.5%	2,903,015	33.0%	0	0.0%	8,797,016
25	6/14	80,174	4.0%	1,453,153	72.9%	461,000	23.1%	0	0.0%	1,994,327
26	6/21	45,480	12.0%	278,562	73.5%	54,954	14.5%	0	0.0%	378,996
27	6/28	318,042	46.3%	356,722	51.9%	12,894	1.9%	0	0.0%	687,658
28	7/5	24,668	15.8%	129,833	83.3%	1,298	0.8%	0	0.0%	155,800
Total		685,707	1.7%	16,328,172	40.9%	22,734,743	56.9%	196,575	0.5%	39,945,197

Note: Percentage values may not add up to 100% due to rounding.

Table 3.–Results from mark-recapture tests performed on sockeye salmon smolt outmigrating from the Chignik River, 2012.

Date	No. Marked	Total Recaptures	Trap Efficiency[a]
5/20 - 6/2	3,510	35	1.03%
6/3 - 6/8	2,536	54	2.17%
6/9 - 6/14	3,240	20	0.65%
6/15 - 6/21	2,232	33	1.52%
6/22 - 6/27	872	23	2.75%
6/28 - 7/4	1,246	10	0.88%
7/5 - 7/10	702	16	2.42%
Total	14,338	191	1.63%

[a] Calculated by: E = {(R+1)/(M+1)}*100 where: E = trap efficiency, R = number of marked fish recaptured, and M = number of marked fish (Carlson et al. 1998). The number marked accounts for delayed mortality.

Table 4.–Length, weight, and condition factor of Chignik River sockeye salmon smolt samples in 2012, by age and statistical week.

				Length (mm)		Weight (g)		Condition Factor	
Age	Stat Week	Starting Date	Sample Size	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
0	23	5/31	1	49	0.00	0.7	0.00	0.59	0.00
0	24	6/7	3	54	0.33	0.9	0.03	0.58	0.01
0	25	6/14	8	51	1.06	0.8	0.04	0.63	0.02
0	26	6/21	24	51	0.69	0.8	0.04	0.63	0.02
0	27	6/28	74	53	0.48	1.0	0.03	0.65	0.01
0	28	7/5	19	50	0.91	0.9	0.04	0.67	0.02
Total			129	52	0.35	0.9	0.02	0.65	0.01
1	21	5/17	12	74	2.40	2.9	0.28	0.69	0.01
1	22	5/24	49	73	1.05	2.7	0.15	0.68	0.01
1	23	5/31	66	71	0.53	2.3	0.06	0.65	0.01
1	24	6/7	131	70	0.36	2.2	0.03	0.65	0.01
1	25	6/14	145	69	0.62	2.3	0.11	0.68	0.01
1	26	6/21	147	67	0.66	2.2	0.11	0.70	0.01
1	27	6/28	83	65	0.51	1.9	0.05	0.68	0.01
1	28	7/5	100	65	0.66	2.1	0.07	0.71	0.01
Total			733	68	0.25	2.2	0.04	0.68	0.00
2	21	5/17	26	82	0.81	3.9	0.14	0.69	0.01
2	22	5/24	148	81	0.49	3.8	0.09	0.70	0.01
2	23	5/31	133	78	0.44	3.3	0.07	0.68	0.01
2	24	6/7	66	76	0.61	3.0	0.12	0.68	0.01
2	25	6/14	46	75	0.79	3.0	0.15	0.68	0.01
2	26	6/21	29	75	0.69	3.0	0.09	0.72	0.01
2	27	6/28	3	75	2.31	3.3	0.38	0.77	0.02
2	28	7/5	1	78	0.00	3.6	0.00	0.76	0.00
Total			452	78	0.27	3.4	0.05	0.69	0.00
3	21	5/17	2	88	4.50	4.4	0.55	0.65	0.02
3	22	5/24	3	87	1.53	4.4	0.37	0.66	0.04
Total			5	87	1.66	4.4	0.27	0.66	0.02

Table 5.–Mean length, weight, and condition factor of sockeye salmon smolt samples from the Chignik River, by year and age, 1994 to 2012.

		Length (mm)			Weight (g)			Condition Factor		
Year	Age	Sample Size	Mean	Standard Error	Sample Size	Mean	Standard Error	Sample Size	Mean	Standard Error
1995	0	272	46	0.18	272	0.7	0.01	272	0.74	0.01
1996	0	125	49	0.45	113	1.0	0.03	113	0.82	0.01
1997	0	195	46	0.22	195	0.8	0.01	195	0.83	0.01
1998	0	15	45	0.96	15	0.7	0.03	15	0.73	0.03
1999	0	40	52	0.79	40	1.3	0.06	40	0.97	0.03
2000	0	223	60	0.52	223	2.1	0.05	223	0.91	0.01
2001	0	96	56	0.51	96	1.5	0.04	96	0.88	0.01
2002	0	217	49	0.27	217	1.2	0.02	217	0.98	0.01
2003	0	149	56	0.53	149	1.5	0.05	149	0.79	0.01
2004	0	347	56	0.44	347	1.7	0.05	347	0.91	0.01
2005	0	652	56	0.28	649	1.5	0.03	649	0.83	0.01
2006	0	427	52	0.24	427	1.0	0.02	427	0.70	0.01
2007	0	6	64	2.47	6	2.5	0.08	6	1.03	0.16
2008	0	568	53	0.17	566	1.1	0.01	566	0.76	0.01
2009	0	198	53	0.39	196	1.4	0.04	196	0.93	0.01
2010	0	128	54	0.48	128	1.2	0.04	128	0.78	0.01
2011	0	100	49	0.41	100	1.0	0.03	100	0.86	0.01
2012	0	129	52	0.35	129	0.9	0.02	129	0.65	0.01
1994	1	1,715	67	0.16	1,706	2.3	0.02	1,706	0.75	0.00
1995	1	1,272	60	0.34	1,272	2.0	0.04	1,272	0.82	0.00
1996	1	1,423	68	0.29	1,356	2.7	0.04	1,356	0.81	0.00
1997	1	1,673	63	0.35	1,673	2.4	0.04	1,673	0.81	0.00
1998	1	785	69	0.38	780	2.7	0.06	780	0.78	0.01
1999	1	1,344	77	0.17	1,344	4.1	0.03	1,344	0.89	0.00
2000	1	1,175	72	0.22	1,175	3.3	0.04	1,175	0.86	0.00
2001	1	1,647	65	0.13	1,647	2.1	0.02	1,647	0.76	0.00
2002	1	1,588	65	0.18	1,588	2.3	0.02	1,588	0.83	0.00
2003	1	1,665	65	0.11	1,665	2.1	0.01	1,665	0.75	0.00
2004	1	1,030	69	0.20	1,030	2.8	0.03	1,030	0.83	0.00
2005	1	892	69	0.25	892	2.7	0.03	892	0.81	0.00
2006	1	662	68	0.28	662	2.4	0.03	662	0.76	0.00
2007	1	809	82	0.16	809	4.9	0.03	809	0.88	0.00
2008	1	844	65	0.17	817	2.1	0.02	817	0.76	0.00
2009	1	588	79	0.45	571	3.8	0.08	571	0.77	0.00
2010	1	1,205	69	0.17	1,205	2.6	0.02	1,205	0.76	0.00
2011	1	1,401	70	0.22	1,400	2.8	0.03	1,400	0.88	0.01
2012	1	733	68	0.25	733	2.2	0.04	733	0.68	0.00
1994	2	1,091	77	0.22	1,068	3.6	0.04	1,068	0.74	0.00
1995	2	1,008	75	0.23	1,008	3.5	0.04	1,008	0.80	0.00
1996	2	548	80	0.34	533	4.2	0.06	533	0.81	0.00
1997	2	772	83	0.25	772	4.7	0.05	772	0.80	0.00
1998	2	1,925	72	0.13	1,881	3.0	0.03	1,881	0.76	0.00
1999	2	784	81	0.28	784	4.8	0.07	784	0.89	0.00
2000	2	503	76	0.34	503	3.6	0.07	503	0.80	0.00
2001	2	389	75	0.45	387	3.4	0.09	387	0.77	0.01
2002	2	225	80	0.78	225	4.9	0.18	225	0.88	0.01
2003	2	279	76	0.48	279	3.5	0.09	279	0.76	0.01
2004	2	274	77	0.41	274	3.9	0.09	274	0.82	0.00
2005	2	397	76	0.33	397	3.5	0.06	397	0.79	0.00
2006	2	518	78	0.35	518	3.8	0.08	518	0.78	0.00
2007	2	272	90	0.36	272	6.6	0.09	272	0.91	0.00
2008	2	288	79	0.35	287	3.7	0.06	287	0.73	0.01
2009	2	413	80	0.31	411	4.0	0.05	411	0.76	0.00
2010	2	359	81	0.30	359	4.0	0.05	359	0.74	0.00
2011	2	159	78	0.71	158	4.1	0.16	158	0.82	0.01
2012	2	452	78	0.27	452	3.4	0.05	452	0.69	0.00

- continued -

Table 5.–Page 2 of 2.

		Length (mm)			Weight (g)			Condition Factor		
		Sample		Standard	Sample		Standard	Sample		Standard
Year	Age	Size	Mean	Error	Size	Mean	Error	Size	Mean	Error
1996	3	3	100	5.55	3	8.4	1.68	3	0.81	0.06
1997	3	12	87	1.34	12	5.2	0.35	12	0.77	0.02
1998	3	20	84	3.39	19	5.5	0.99	19	0.81	0.02
1999	3	7	90	5.76	7	6.8	1.66	7	0.85	0.03
2000	3	14	86	2.36	14	5.3	0.63	14	0.79	0.01
2001	3	62	90	1.60	61	6.9	0.42	61	0.86	0.01
2002	3	6	110	7.24	6	13.8	2.67	6	1.00	0.03
2005	3	7	108	4.35	7	11.4	1.21	7	0.89	0.02
2006	3	32	99	1.89	32	8.9	0.55	32	0.89	0.02
2008	3	17	91	2.54	17	6.1	0.70	17	0.77	0.02
2010	3	2	92	1.50	2	6.0	0.35	2	0.78	0.01
2012	3	5	87	1.66	5	4.4	0.27	5	0.66	0.02
2001	4	1	125	-	1	18.8	-	1	0.96	-

Table 6.–Euphotic Zone Depth (EZD) and Euphotic Volume (EV) of Chignik and Black lakes, by month, 2012.

		2012			
Lake		June	July	August	Average[a]
Chignik	EZD	8.49	8.65	7.98	8.38
	Mean EV[c]	204.6	208.5	192.3	202.0
Black[b]	EZD	4.87	4.13	3.47	4.15
	Mean EV[c]	78.09	78.09	78.09	78.09

[a] EZD calculated per station then averaged for the month (µmol/s/m^2).

[b] The mean depth of Black Lake is 1.9 m; this value was used for the EV calculations instead of the EZD's when the EZD exceeded 1.9 m.

[c] EV units = x 10^6 m^3

Table 7.–Water quality parameters, nutrient concentrations, and photosynthetic pigments by sample date for Black Lake, 2012.

	2012				
	May[a]	18-Jun	9-Jul	24-Aug	Average
pH		7.86	7.64	7.56	7.69
Alkalinity (mg/L $CaCO_3$)		27.0	26.0	27.0	26.7
Total phosphorous (µg/L P)		10.4	10.5	12.2	11.0
Total filterable phosphorous (µg/L P)		2.4	3.2	4.1	3.2
Filterable reactive phosphorous (µg/L P)		1.7	1.5	1.4	1.5
Total Kjeldhal nitrogen (µg/L N)[b]					
Ammonia (µg/L N)		4.7	5.4	8.0	6.0
Nitrate + Nitrite (µg/L N)		3.4	1.3		2.4
Silicon (µg/L)		253.0	1332.9	3269.8	1618.6
Chlorophyll a (µg/L)		5.5	3.9	8.1	5.8
Phaeophytin a (µg/L)		0.8	1.2	0.4	0.8

[a] Limnology sampling did not occur in May 2012.

[b] Total Kjeldhal nitrogen was not processed in 2012 .

Table 8.–Water-quality parameters, nutrient concentrations, and photosynthetic pigments by sample date for Chignik Lake, 2012. All stations and depths are averaged for each sample date.

	2012				
	May[a]	16-Jun	7-Jul	21-Aug	Average
pH		7.54	7.17	7.36	7.36
Alkalinity (mg/L $CaCO_3$)		27.3	22.9	10.8	20.3
Total phosphorous (µg/L P)		12.8	9.2	7.9	10.0
Total filterable phosphorous (µg/L P)		3.7	3.6	3.1	3.5
Filterable reactive phosphorous (µg/L P)		2.3	2.0	1.9	2.1
Total Kjeldhal nitrogen (µg/L N)[b]					
Ammonia (µg/L N)		5.6	9.1	18.4	11.0
Nitrate + Nitrite (µg/L N)		201.3	174.9	139.0	171.7
Silicon (µg/L)		5774.3	4860.0	5235.3	5289.8
Chlorophyll a (µg/L)		3.5	1.8	3.2	2.9
Phaeophytin a (µg/L)		0.3	0.3	0.3	0.3

[a] Limnology sampling did not occur in May 2012.

[b] Total Kjeldhal nitrogen was not processed in 2012 .

Table 9.–Average number of zooplankton by taxon per m^2 from Black Lake by sample date, 2012.

Taxon		Sample date 18-Jun	9-Jul	24-Aug	Seasonal average
Copepods					
	Epischura	3,716	6,210	5,573	5,166
	Cyclops	14,331	5,520	27,866	15,906
	Harpacticus	531	0	0	177
	Ovig. *Harpaticus*	531	0	0	177
	Eurytemora	2,123	7,590	1,592	3,769
	Nauplii	6,369	13,110	11,147	10,209
Total copepods		27,601	32,431	46,178	35,403
Cladocerans					
	Bosmina	11,147	24,151	48,567	27,955
	Ovig. *Bosmina*	531	0	6,369	2,300
	Daphnia L.	0	0	1,592	531
	Holopedium	0	0	1,592	531
	Chydorinae	2,123	690	796	1,203
	Immature Cladocera	1,592	8,280	11,147	7,006
Total cladocerans		15,393	33,121	70,064	39,526
Total copepods + cladocerans		42,994	65,552	116,242	74,929

Table 10.–Biomass estimates (mg dry weight/m^2) of the major Black Lake zooplankton taxa by sample date, 2012.

Taxon		Sample date			Seasonal average	Weighted average
		18-Jun	9-Jul	24-Aug		
Copepods						
	Epischura	4.04	5.05	4.55	4.55	4.52
	Eurytemora	17.47	38.25	6.06	20.59	20.36
	Cyclops	11.30	2.95	31.62	15.29	15.05
	Harpacticus	0.55	0.00	0.00	0.18	0.18
Total copepods		33.36	46.25	42.23	40.61	40.11
Cladocerans						
	Bosmina	11.18	22.08	34.52	22.59	22.47
	Ovig. Bosmina	0.66	0.00	8.32	2.99	2.99
	Daphnia l.	0.00	0.00	1.66	0.55	0.55
	Chydorinae	0.56	0.26	0.60	0.47	0.45
Total cladocerans		12.40	22.34	45.10	26.60	26.46
Total Biomass		45.76	68.59	87.33	67.21	66.57

Table 11.–Average length (mm) of zooplankton in Black Lake by sample date, 2012.

Taxon		Sample date			Seasonal
		18-Jun	9-Jul	24-Aug	average
Copepods					
	Epischura	0.61	0.55	0.55	0.57
	Harpacticus	0.56	0.00	0.00	0.56
	Ovig. *Harpacticus*	0.50	0.00	0.00	0.56
	Eurytemora	1.24	0.92	0.77	0.98
	Cyclops	0.49	0.41	0.58	0.49
Cladocerans					
	Bosmina	0.33	0.32	0.28	0.31
	Ovig. Bosmina	0.37	0.00	0.38	0.37
	Daphnia l.	0.00	0.00	0.50	0.50
	Chydorinae	0.18	0.21	0.29	0.23
	Holopedium	0.00	0.00	0.33	0.33

Table 12.–Average number of zooplankton by taxon per m^2 from Chignik Lake, by sample date, 2012.

Taxon		Sample date			Seasonal
		16-Jun	7-Jul	21-Aug	Average
Copepods					
	Epischura	7,046	8,041	32,378	15,822
	Eurytemora	1,539	4,100	20,581	8,740
	Ovig. *Eurytemora*	0	186	305	164
	Cyclops	53,278	65,977	98,023	72,426
	Ovig. *Cyclops*	0	557	5,202	1,920
	Harpacticus	0	119	876	332
	Ovig. *Harpacticus*	0	186	0	62
	Nauplii	24,867	14,411	134,966	50,495
	Immature Cladocera	0	4,100	20,581	8,740
Total copepods		86,730	97,678	312,911	158,700
Cladocerans	*Bosmina*	2,110	212	3,185	1,132
	Ovig. *Bosmina*	0	239	3,875	1,407
	Daphnia l.	106	372	265	212
	Ovig. *Daphnia l.*	0	0	305	102
	Chydorinae	372	0	265	88
	Ovig. *Chydorinae*	0	0	265	88
	Holopedium	0	0	305	102
Total cladocerans		2,588	823	8,466	3,132
Total copepods + cladocerans		89,318	98,501	321,377	161,832

Table 13.–Biomass estimates (mg dry weight/m^2) of the major zooplankton species in Chignik Lake by sample date, 2012.

Taxon		Sample date			Seasonal	Weighted
		16-Jun	7-Jul	21-Aug	Average	average
Copepods						
	Epischura	8.64	9.27	29.41	15.77	15.38
	Harpacticus	0.00	0.11	0.55	0.22	0.21
	Eurytemora	8.97	24.01	119.92	50.96	48.65
	Ovig. Eurytemora	0.00	1.94	2.80	1.58	1.58
	Cyclops	85.66	132.68	89.97	102.77	91.04
	Ovig. Cyclops	0.00	2.14	31.84	11.33	9.58
Total copepods		103.27	170.15	274.49	182.63	166.44
Cladocerans						
	Bosmina	2.56	13.61	124.79	46.99	45.93
	Ovig. Bosmina	0.00	0.46	3.66	1.37	1.48
	Daphnia l.	0.23	0.48	3.68	1.46	1.44
	Daphnia l. ovig	0.00	1.23	0.60	0.61	0.60
	Chydorinae	0.17	0.54	3.18	1.30	1.32
	Ovig. *Chydorinae*	0.00	0.00	0.26	0.09	0.09
	Holopedium	0.00	0.00	0.12	0.04	0.04
Total cladocerans		2.96	16.32	136.29	51.86	50.90
Total copepods + cladocerans		106.23	186.47	410.78	234.49	217.34

Table 14.–Average length (mm) of zooplankton from Chignik Lake by sample date, 2012.

Taxon		Sample date			Seasonal
		16-Jun	7-Jul	21-Aug	Average
Copepods					
	Epischura	0.62	0.61	0.57	0.60
	Harpacticus	0.00	0.53	0.44	0.48
	Ovig. *Harpacticus*	0.00	0.50	0.00	0.50
	Eurytemora	1.06	0.94	0.98	0.99
	Ovig. *Eurytemora*	0.00	1.44	1.33	1.38
	Cyclops	0.65	0.69	0.54	0.63
	Ovig. *Cyclops*	0.00	1.03	1.18	1.10
Cladocerans					
	Bosmina	0.36	0.33	0.32	0.33
	Ovig. *Bosmina*	0.00	0.48	0.37	0.43
	Daphnia l.	0.70	0.68	0.48	0.62
	Ovig. *Daphnia l.*	0.00	0.86	0.72	0.79
	Chydorinae	0.33	0.23	0.28	0.27
	Ovig. *Chydorinae*	0.00	0.00	0.33	0.33
	Holopedium	0	0.00	0.25	0.25

Table 15.–Chignik River sockeye salmon escapement, estimated number of smolt by freshwater age, smolt per spawner, adult return by freshwater age, return per spawner, marine survival, by brood year 1991 through 2005.

Brood		Smolt Produced					Smolt /	Adult Returns					Return /	Marine
Year	Escapement	Age-0.	Age-1.	Age-2.	Age-3.	Total Smolt	Spawner	Age-0.	Age-1.	Age-2.	Age-3.	Total	Spawner	Survival
1991	1,040,098	NA	NA	4,270,636	0	4,270,636	4.11	6,868	1,795,467	737,680	11,621	2,551,636	2.45	NA
1992	764,436	NA	7,263,054	5,178,450	5,018	12,446,522	16.28	152,005	649,920	1,159,871	93,372	2,055,168	2.69	17%
1993	697,377	0	2,843,222	731,099	122,289	3,696,610	5.30	16,270	457,189	1,998,416	7,265	2,479,140	3.55	67%
1994	966,909	735,916	1,200,793	13,738,356	158,056	15,833,121	16.37	251	1,818,410	1,483,548	2,467	3,304,676	3.42	21%
1995	739,920	80,254	11,172,150	20,374,245	78,798	31,705,447	42.85	36,053	2,391,218	942,680	17,366	3,387,317	4.58	11%
1996[a]	749,137	528,846	5,790,587	8,221,631	160,017	14,701,081	19.63	145,189	1,998,842	877,180	13,958	3,035,168	4.05	21%
1997	775,618	75,560	12,705,935	4,645,121	516,723	17,943,339	23.13	15,852	770,645	956,005	5,627	1,748,129	2.25	10%
1998	701,128	73,364	8,047,526	5,024,666	72,184	13,217,740	18.85	5,515	1,030,709	350,167	1,052	1,387,443	1.98	10%
1999	715,966	1,270,101	18,940,752	2,223,996	0	22,434,849	31.34	26,176	913,849	403,536	1,663	1,345,224	1.88	6%
2000	805,225	521,546	13,980,423	1,449,494	0	15,951,463	19.81	15,176	1,988,373	699,285	2,729	2,705,565	3.36	17%
2001	1,136,918	440,947	5,146,278	2,239,716	32,889	7,859,830	6.91	78,019	1,031,100	696,415	482	1,807,624	1.59	23%
2002	725,220	155,047	6,172,902	1,468,208	119,614	7,915,771	10.91	17,633	700,976	412,758	2,079	1,136,292	1.57	14%
2003	684,145	244,206	2,075,681	2,847,624	0	5,167,511	7.55	84,284	875,278	736,979	3,227	1,699,768	2.48	33%
2004	578,259	859,211	2,849,043	1,028,865	41,136	4,778,255	8.26	131,023	1,067,014	987,159	10,222	2,195,418	3.80	46%
2005	581,382	1,744,370	1,926,682	987,928	0	4,658,980	8.01	28,613	1,461,254	932,776	87,665	2,510,308	4.32	54%
2006	735,493	9,286	3,309,894	4,874,340	91,509	8,285,029	11.3	33,123	2,808,615	1,850,353				
2007	654,974	1,017,498	3,242,862	9,347,999	0	13,608,359	20.78	45,736	519,017					
2008	706,058	59,306	17,684,165	1,371,044	196,575	19,311,090	27.4	17,460						
2009	720,062	1,039,131	10,684,120	22,734,743										
2010	743,911	203,380	16,328,172											
2011	753,817	685,707												
2012	712,389													
1994-2005 Average, excluding 1996														22%

[a] 1996 data are presented, but considered erroneous due to unrealistic survival estimates and thus not used in subsequent calculations.

Table 16.–Chignik River sockeye salmon smolt estimates, ocean-age-class returns , and marine survival by outmigration years 1994 through 2008.

Emigration Year	Smolt estimates Age-0.	Age-1.	Age-2.	Age-3.	Total	Adult returns Age-.1	Age-.2	Age-.3	Age-.4	Total	Marine Survival
1994	0	7,263,054	4,270,636	0	11,533,690	4,063	208,548	1,207,343	9,782	1,429,736	12%
1995	735,916	2,843,222	5,178,450	0	8,757,588	14,186	343,315	1,267,456	3,975	1,628,932	19%
1996*	80,245	1,200,793	731,099	5,018	2,017,155	28,209	675,848	3,225,337	16,857	3,946,250	196%
1997	528,846	11,172,150	13,738,356	122,289	25,561,641	11,814	1,232,238	2,767,364	15,622	4,027,038	16%
1998	75,560	5,790,587	20,374,245	158,056	26,398,448	601	170,545	2,756,954	31,741	2,959,840	11%
1999	73,364	12,705,935	8,221,631	78,798	21,079,728	446	136,822	1,524,022	9,416	1,670,706	8%
2000	1,270,101	8,047,526	4,645,121	160,017	14,122,765	5,460	404,961	1,611,191	5,237	2,026,848	14%
2001	521,546	18,940,752	5,024,666	516,723	25,003,687	324	229,693	1,051,600	3,203	1,284,819	5%
2002	440,947	13,980,423	2,223,996	72,184	16,717,551	4,164	432,476	2,013,710	22,238	2,472,588	15%
2003	155,047	5,146,278	1,449,494	0	6,750,819	2,282	158,558	1,540,591	51,097	1,752,528	26%
2004	244,206	6,172,902	2,239,716	0	8,656,824	1,316	178,412	1,285,999	17,447	1,483,173	17%
2005	859,211	2,075,681	1,468,208	32,889	4,435,988	804	204,180	1,205,391	9,166	1,419,541	32%
2006	1,744,370	2,849,043	2,847,624	119,614	7,560,651	771	169,698	1,655,282	8,933	1,834,684	24%
2007	9,286	1,926,682	1,028,865	0	2,964,833	793	429,607	2,041,386	12,977	2,484,763	84%
2008	1,017,498	3,309,894	987,928	41,136	5,356,455	1,734	337,732	3,457,883	61,180	3,858,529	72%
2009	110,446	3,777,572	4,288,491	0	8,176,509	6,022	425,225	2,043,248			
2010	1,039,131	17,684,165	9,347,999	91,509	28,162,803	6,097	856,890				
2011	203,380	10,684,120	1,371,044	0	12,258,543	2,423					
2012	685,707	16,328,172	22,734,743	196,575	39,945,197						
1994-2007 Average, Excluding 1996											22%

[a] 1996 data are presented, but considered erroneous due to unrealistic survival estimates and thus not used in subsequent calculations.

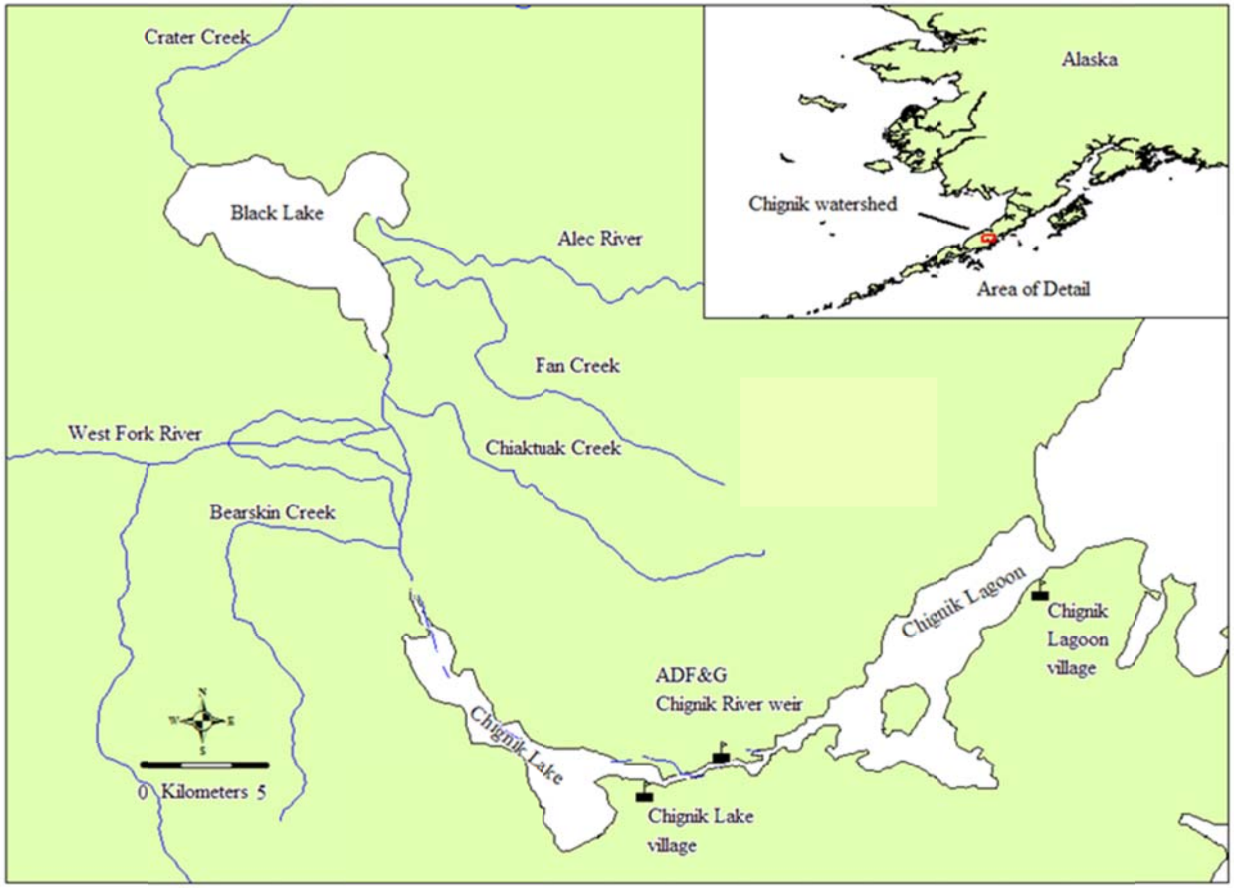

Figure 1.–Map of the Chignik River Basin.

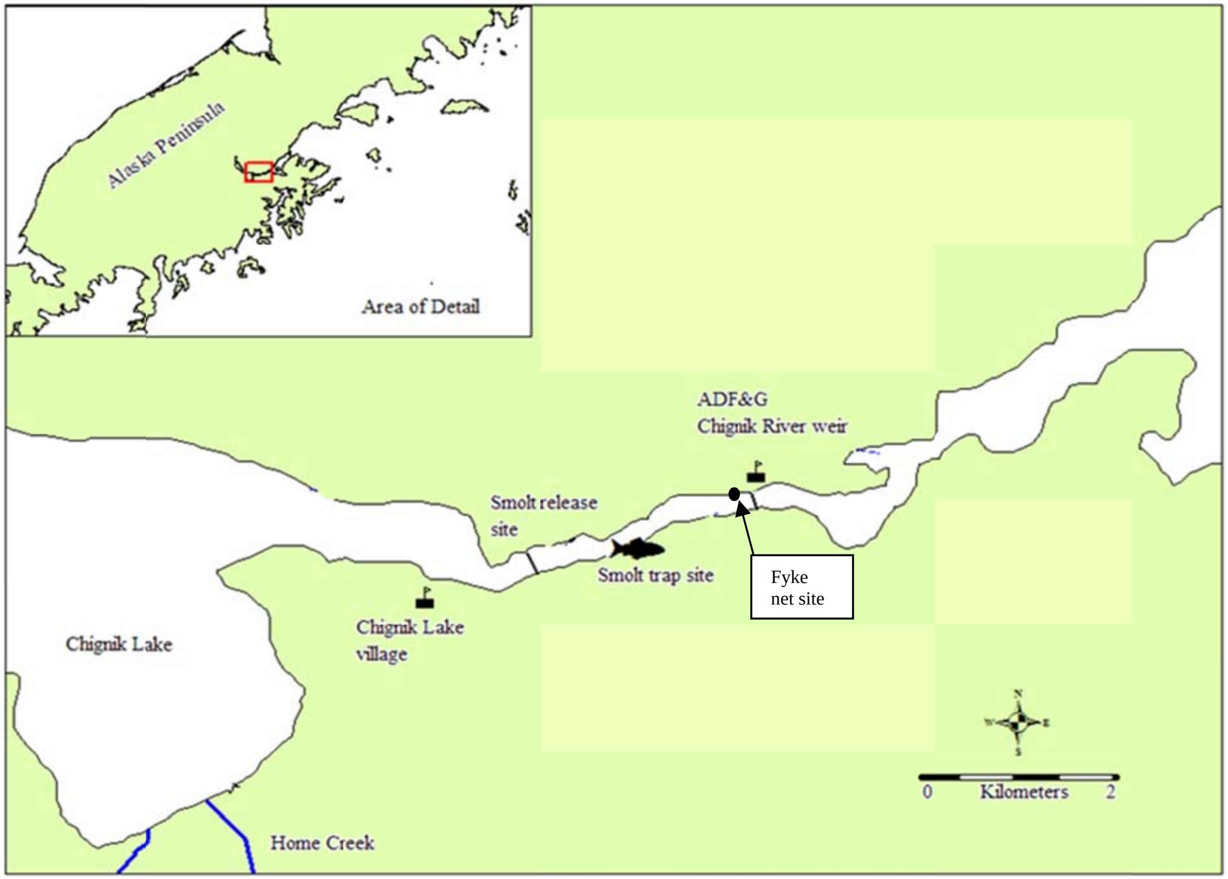

Figure 2.–Location of the traps and the release site of marked smolt in the Chignik River, Alaska, 2012.

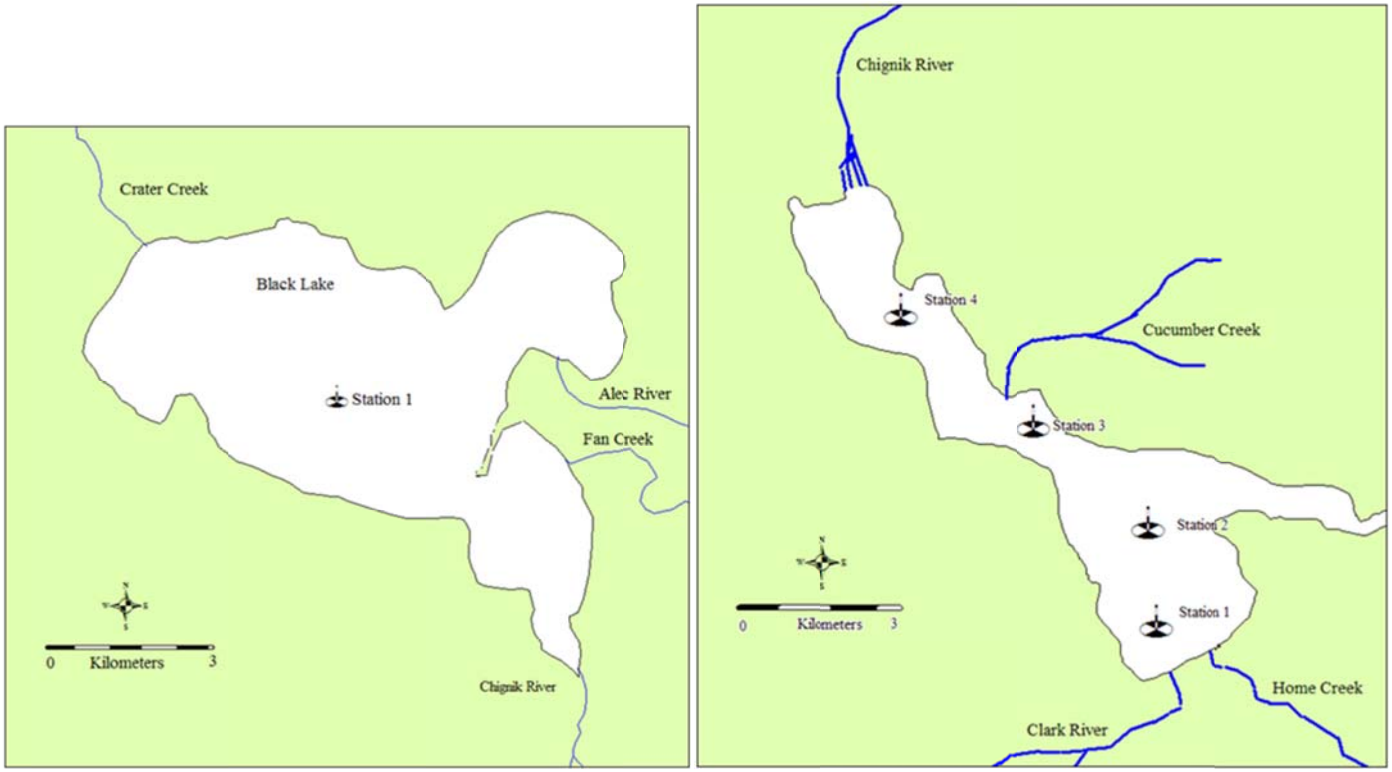

Figure 3.–Location of the Black Lake and Chignik Lake limnology sampling stations, 2012.

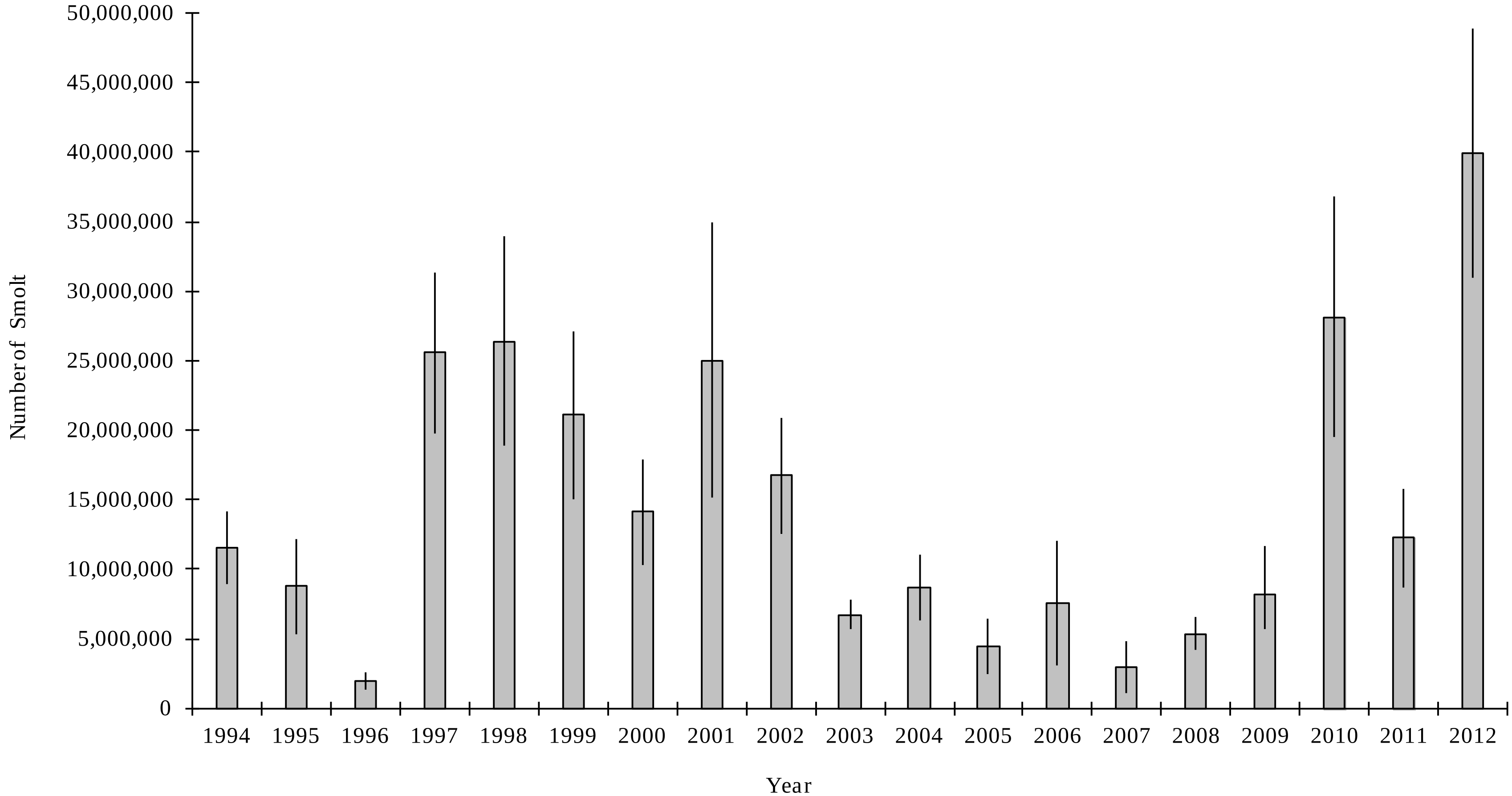

Figure 4.–Annual sockeye salmon smolt outmigration estimates and corresponding 95% confidence intervals, Chignik River, 1994–2012. Outmigration estimates from 1996 were underestimated.

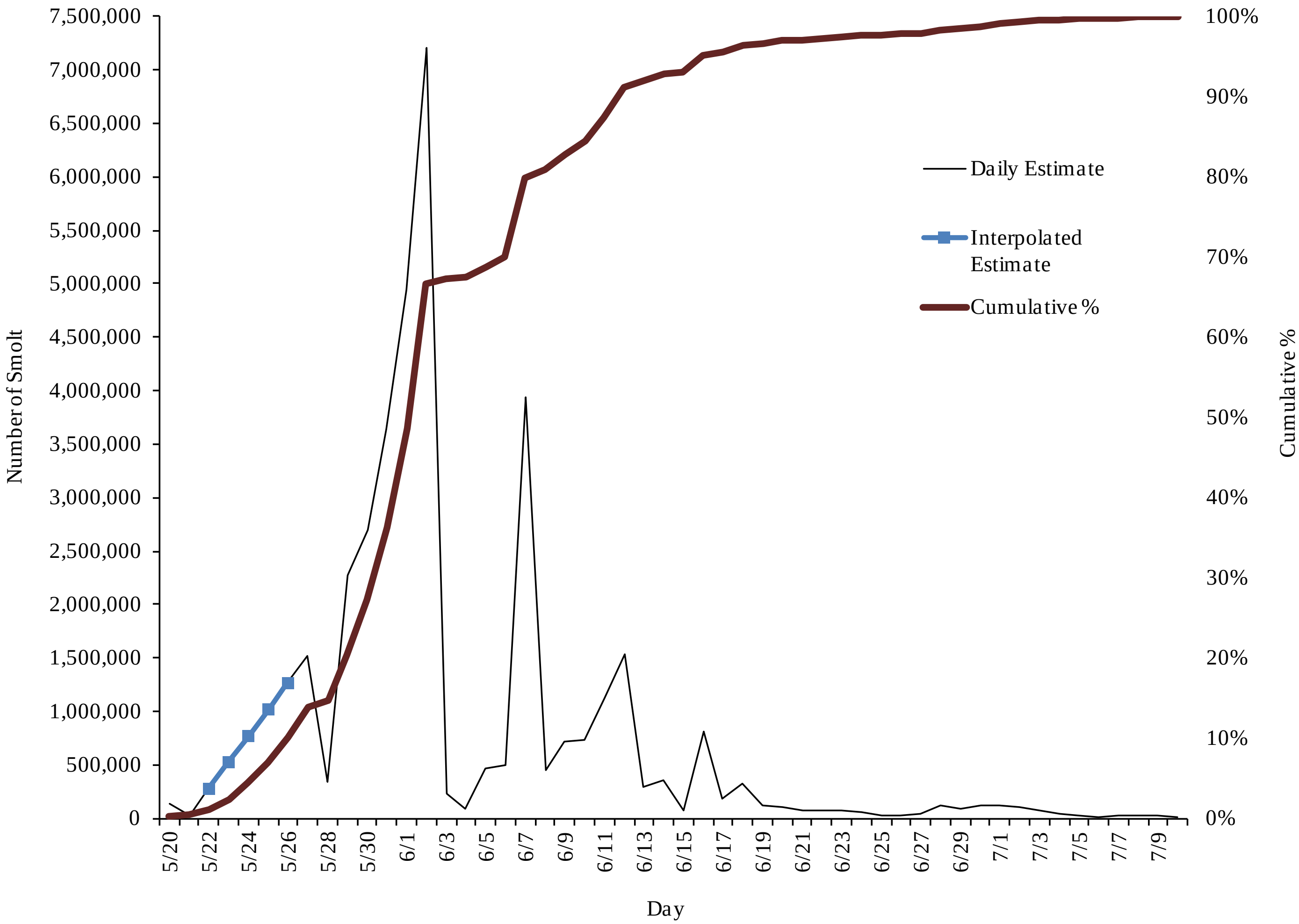

Figure 5.–Daily estimate and cumulative percentage of the sockeye salmon smolt outmigration from the Chignik River in 2012. The traps were removed from 5/22 - 5/26 and the daily estimate was derived by linear interpolation.

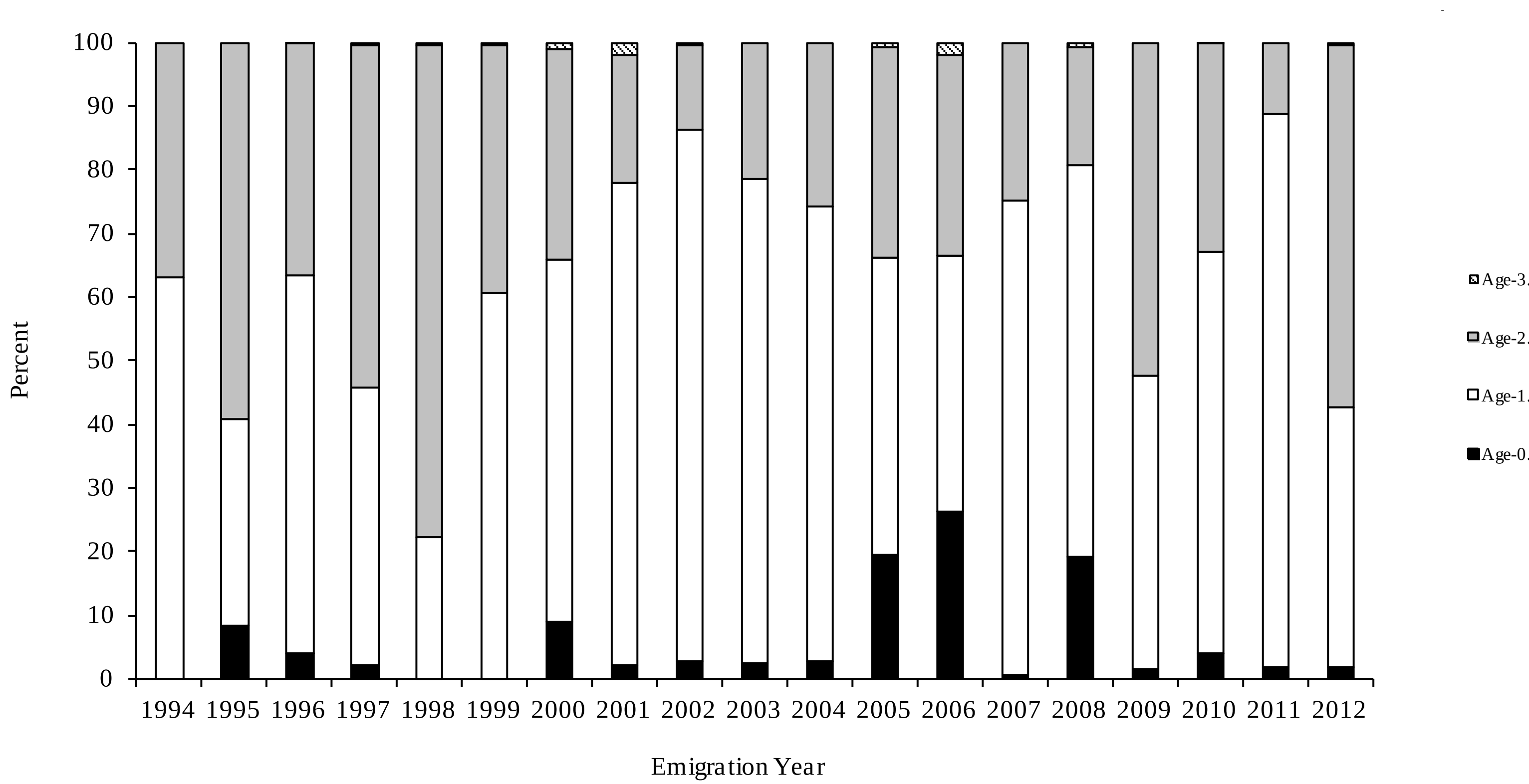

Figure 6.–A comparison of the estimated age structure of age-0. to age-3. sockeye salmon smolt outmigrations from the Chignik River, 1994–2012.

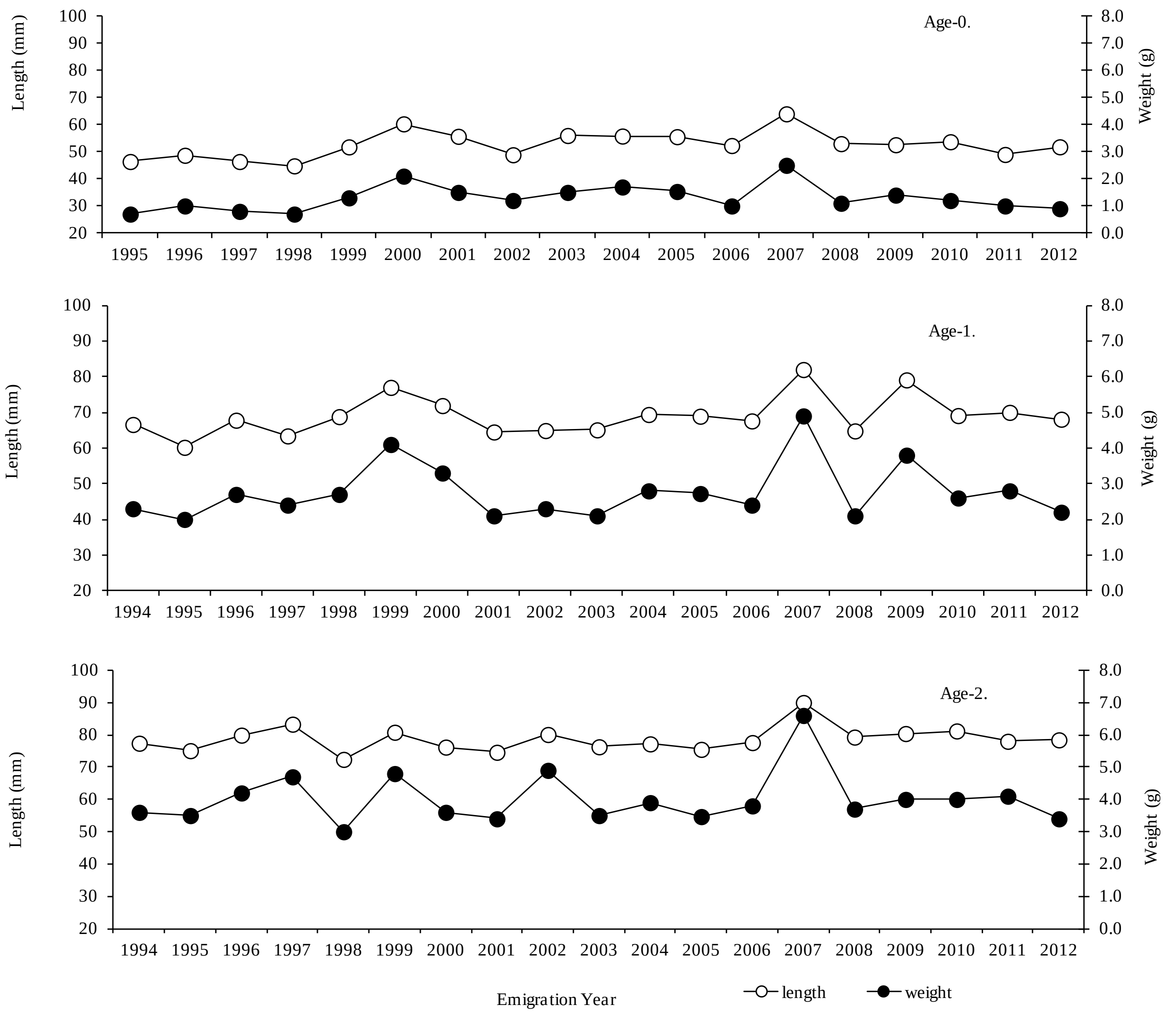

Figure 7.–Average length and weight of sampled age-0., age-1. and age-2. sockeye salmon smolt, by year from 1994 to 2012. Age-3. smolt comprise such a small percentage of the yearly population as to be negligible.

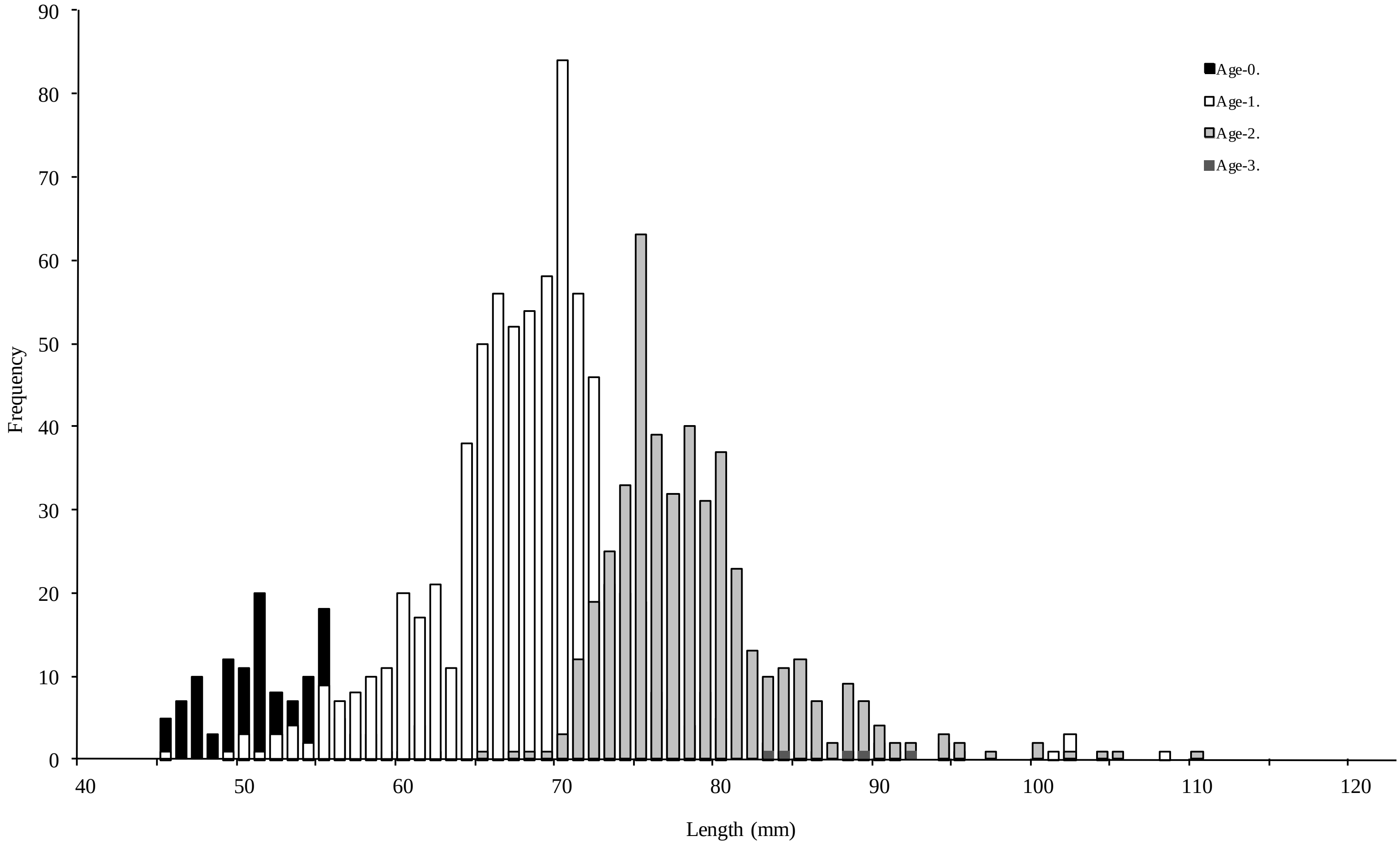

Figure 8.–Length frequency histogram of sockeye salmon smolt from the Chignik River in 2012 by age.

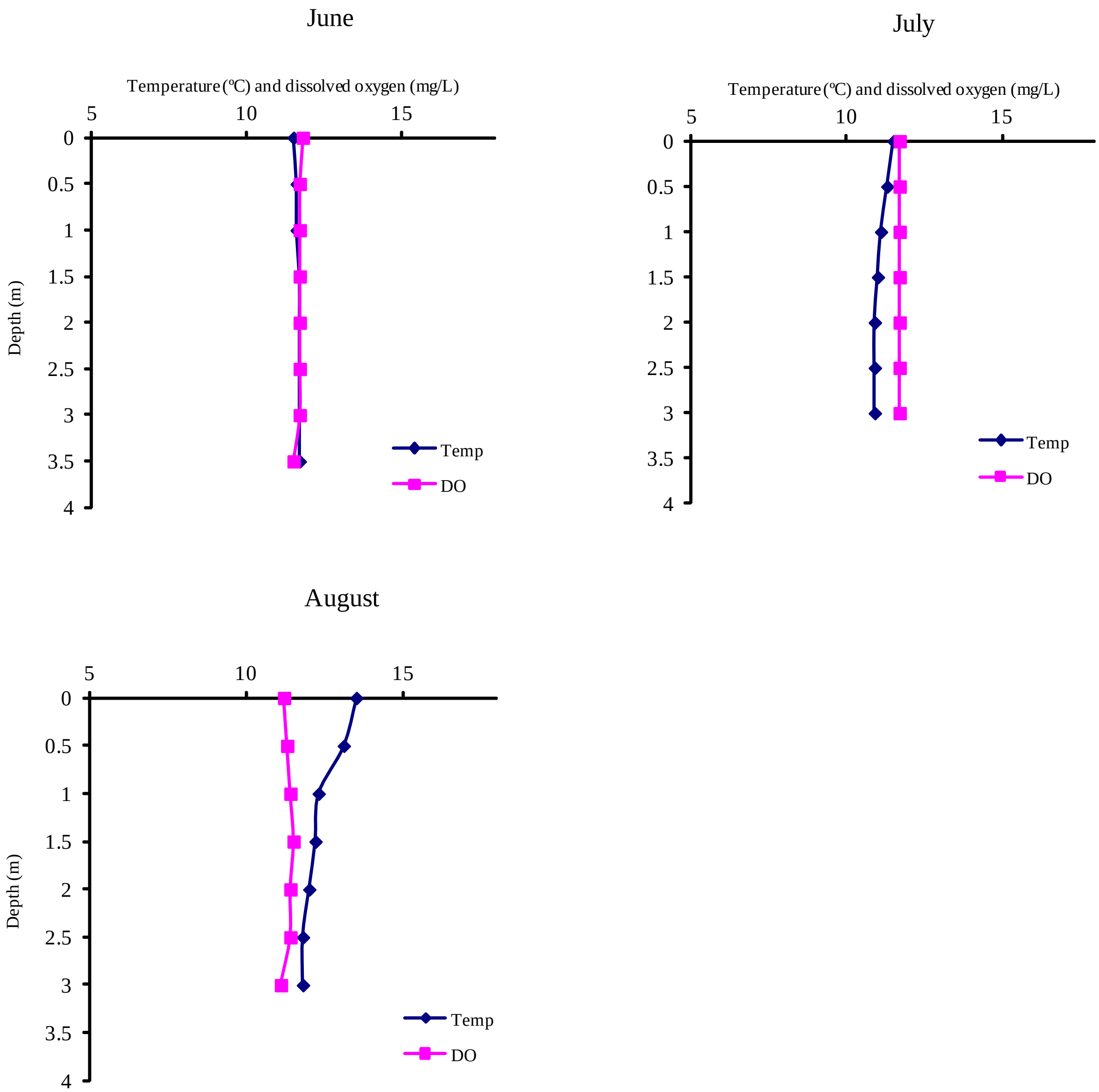

Figure 9.–Mean monthly temperature and dissolved oxygen profiles in Black Lake in 2012.

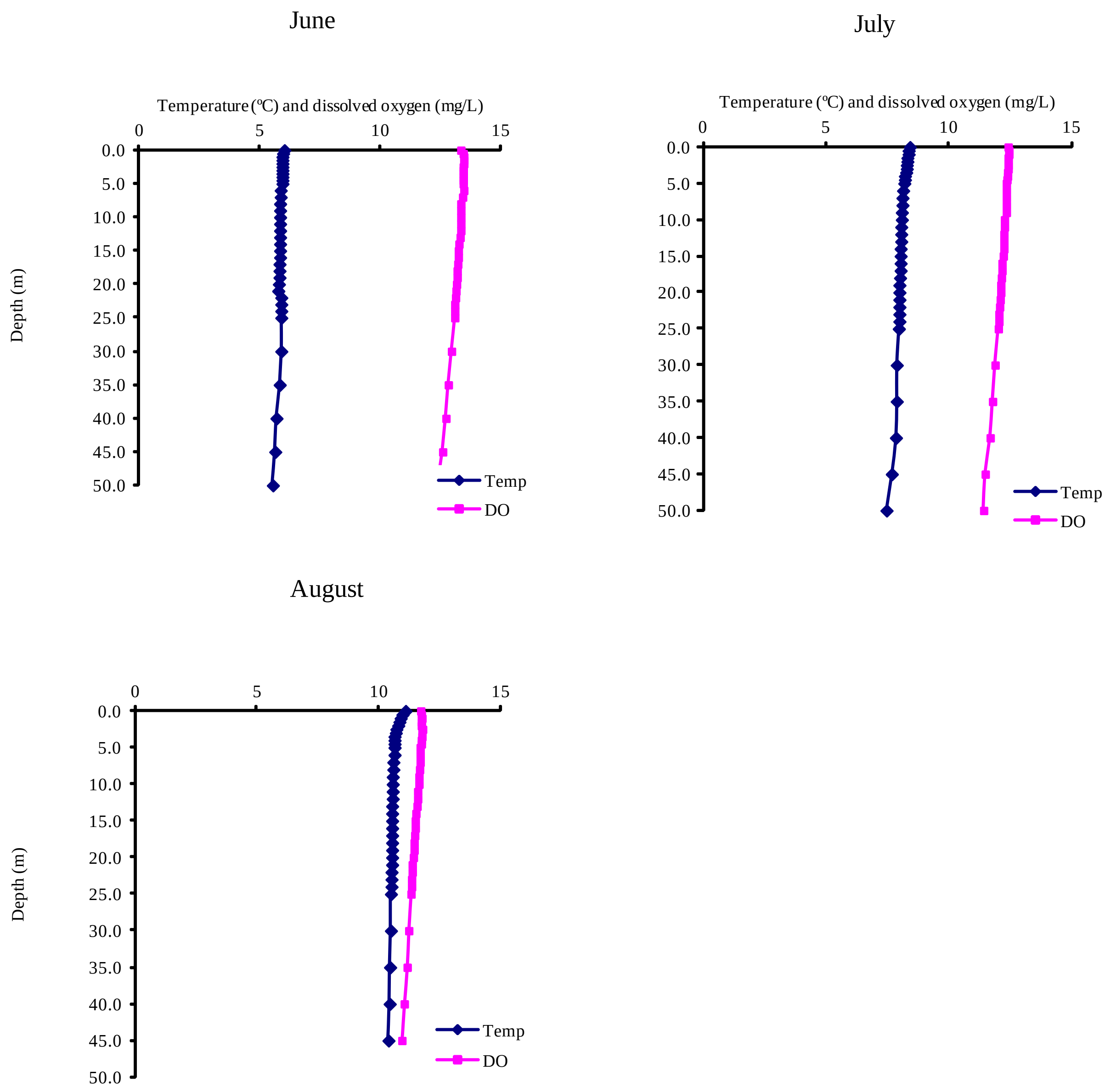

Figure 10.–Mean monthly temperature and dissolved oxygen profiles in Chignik Lake in 2012.

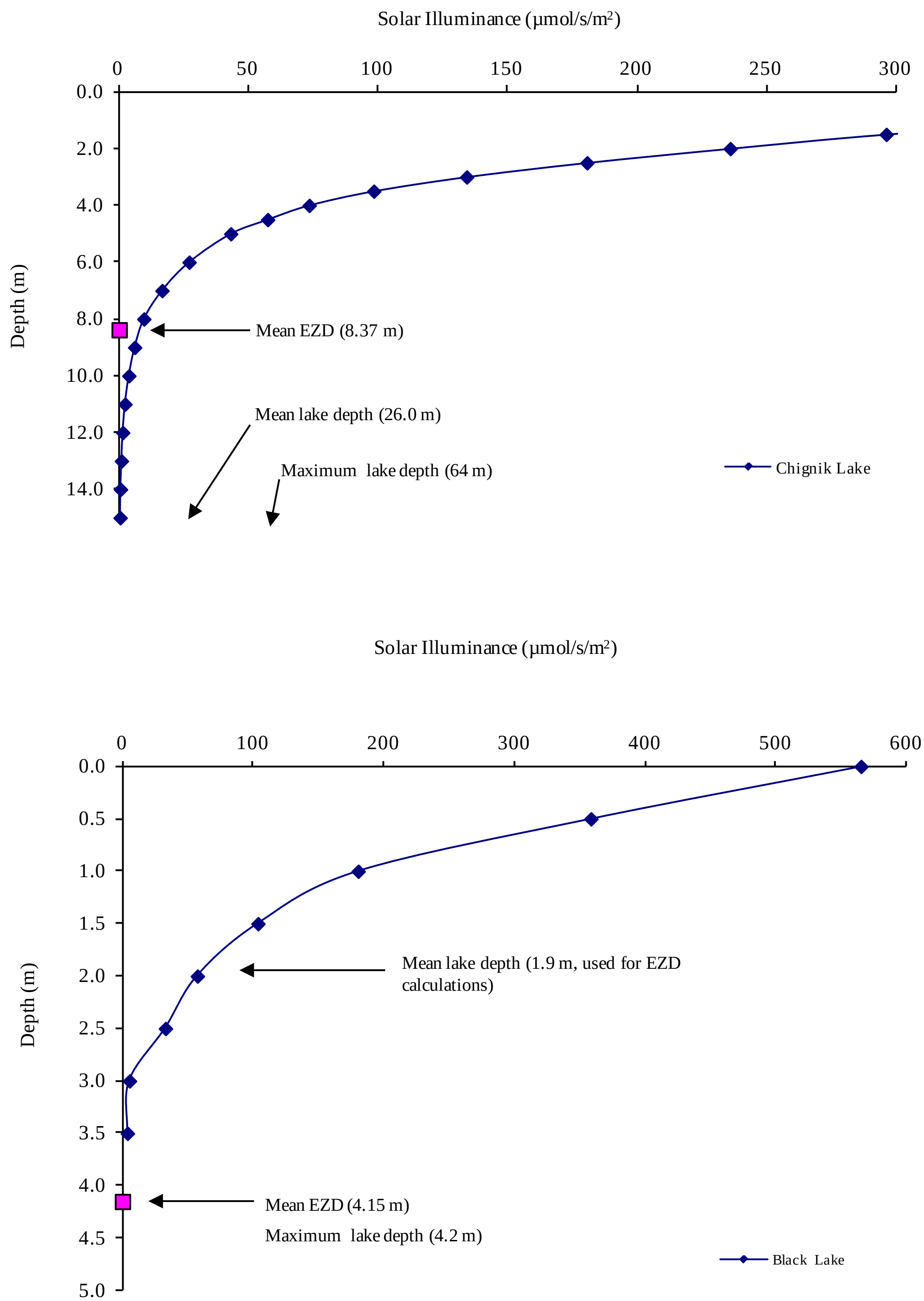

Figure 11.–Light penetration curves relative to mean depth, euphotic zone depth (EZD), and maximum depth in Chignik and Black lakes in 2012.

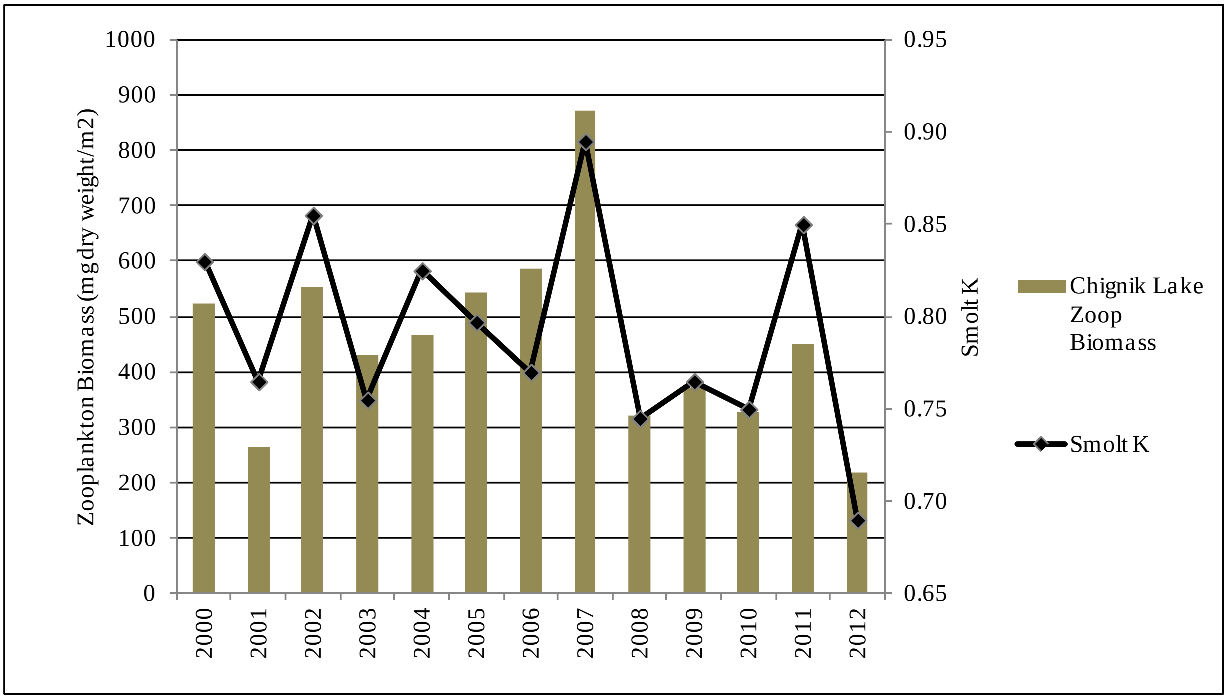

Figure12.–Annual Chignik Lake zooplankton biomass (mg dry weight/m^2) and sockeye salmon smolt condition (K).

APPENDIX A. SMOLT TRAP CATCHES BY DAY

Appendix A1.–2012 Daily trap catch and efficiency.

	Actual Sockeye Smolt		Trap Efficiency Test				Incidental Catch[c]														
Date[a]	Daily	Cum.	Marked	Daily Recoveries	Cum. Recoveries	Efficiency[b]	Fry Sockeye	Coho	Fry Coho	Pink	Chnk	Chum	DV	SB	SC	SF	PS	PW	AB	ISO	EU
20-May	1,341	1,341	0	0	0	1.03%	131	3	0	0	0	0	1	23	11	0	2	0	0	1	0
21-May	317	1,658	0	0	0	1.03%	1,155	1	0	0	0	0	2	47	14	2	6	0	0	0	0
27-May	15,516	17,174	0	0	0	1.03%	1,784	1	0	1	1	0	13	100	3	0	10	1	0	3	0
28-May	3,479	20,653	0	0	0	1.03%	2,004	3	1	0	1	0	7	86	18	3	3	0	0	1	0
29-May	23,343	43,996	3,510	27	27	1.03%	1,552	8	0	0	1	0	2	93	11	0	6	0	0	1	0
30-May	27,697	71,693	0	5	32	1.03%	939	3	2	0	0	0	6	82	7	0	8	1	0	1	0
31-May	37,286	108,979	0	3	35	1.03%	2,580	8	2	0	0	0	4	112	2	0	4	1	0	2	0
1-Jun	50,749	159,728	0	0	35	1.03%	2,345	9	0	0	0	0	15	86	4	0	2	0	0	1	0
2-Jun	73,895	233,623	0	0	35	1.03%	3,680	9	0	0	0	0	14	93	7	0	6	0	0	11	0
3-Jun	5,143	238,766	2,536	46	46	2.17%	2,703	13	0	0	0	0	10	141	3	2	3	1	0	6	0
4-Jun	1,942	240,708	0	4	50	2.17%	1,621	10	0	0	0	0	5	71	8	0	2	1	0	2	0
5-Jun	9,994	250,702	0	1	51	2.17%	1,587	10	0	0	0	0	8	60	9	0	1	0	0	8	0
6-Jun	10,738	261,440	0	2	53	2.17%	1,913	11	1	6	0	0	14	81	10	0	4	0	0	1	0
7-Jun	85,273	346,713	0	0	53	2.17%	2,134	22	7	20	0	0	9	250	11	1	2	0	0	6	0
8-Jun	9,672	356,385	0	1	54	2.17%	2,995	6	2	1	0	0	13	212	8	0	2	1	0	23	0
9-Jun	4,694	361,079	3,240	13	13	0.65%	1,692	5	2	1	0	0	6	158	12	1	1	1	0	6	0
10-Jun	4,757	365,836	0	1	14	0.65%	2,815	15	0	0	0	0	6	250	19	1	2	3	0	5	0
11-Jun	7278	373,114	0	2	16	0.65%	2,676	16	6	0	0	0	17	317	10	1	5	0	0	5	0
12-Jun	9,945	383,059	0	1	17	0.65%	3,994	15	1	0	0	0	14	397	21	0	5	1	0	16	0
13-Jun	1,947	385,006	0	3	20	0.65%	2,915	17	0	1	0	0	14	243	12	1	5	1	0	9	0
14-Jun	2,263	387,269	0	0	20	0.65%	984	17	5	1	0	0	18	171	23	0	6	0	0	8	0
15-Jun	1,191	388,460	2,232	29	29	1.52%	1,537	19	0	0	0	0	9	144	4	0	3	3	0	4	0
16-Jun	12,447	400,907	0	2	31	1.52%	455	32	4	0	0	0	21	142	4	1	5	2	0	6	0
17-Jun	2,848	403,755	0	0	31	1.52%	503	30	3	0	0	0	21	129	9	0	5	0	0	6	0
18-Jun	5,026	408,781	0	1	32	1.52%	489	48	13	14	0	0	21	435	7	0	4	0	0	6	0
19-Jun	1,873	410,654	0	1	33	1.52%	338	33	5	0	0	0	13	408	13	0	6	5	0	7	1
20-Jun	1,667	412,321	0	0	33	1.52%	668	36	12	3	0	0	31	518	5	0	6	5	0	3	0
21-Jun	1,051	413,372	0	0	33	1.52%	2,197	17	5	0	0	0	3	338	0	0	4	3	0	7	0
22-Jun	1,953	415,325	872	17	17	2.75%	188	63	6	0	0	0	6	235	12	1	7	12	0	15	0
23-Jun	1,900	417,225	0	4	21	2.75%	483	38	3	2	1	0	9	210	5	0	5	13	0	5	0

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Appendix A1.–Page 2 of 2.

	Actual Sockeye Smolt		Trap Efficiency Test				Incidental Catch[c]														
Date	Daily	Cum.	Marked	Daily Recoveries	Cum. Rec. Per Strata	Efficiency[b]	Fry Sockeye	Coho	Fry Coho	Pink	Chnk	Chum	DV	SB	SC	SF	PS	PW	AB	ISO	EU
24-Jun	1,555	418,780	0	0	21	2.75%	118	40	8	0	3	0	1	104	2	1	1	7	0	6	0
25-Jun	869	419,649	0	0	21	2.75%	150	75	22	1	2	0	12	222	11	2	1	17	0	13	0
26-Jun	900	420,549	0	2	23	2.75%	82	44	16	14	6	0	6	525	1	2	3	18	0	7	0
27-Jun	1,348	421,897	0	0	23	2.75%	47	89	8	0	3	0	12	311	19	1	4	34	0	12	0
28-Jun	1,015	422,912	1,246	3	3	0.88%	82	70	6	4	3	0	12	226	18	1	0	29	0	4	1
29-Jun	861	423,773	0	3	6	0.88%	94	30	3	0	4	0	0	231	10	2	2	26	0	1	0
30-Jun	1,042	424,815	0	1	7	0.88%	502	48	3	1	9	0	7	133	1	0	7	3	0	1	0
1-Jul	1,134	425,949	0	1	8	0.88%	319	42	2	0	5	0	12	123	13	1	2	10	0	3	0
2-Jul	958	426,907	0	2	10	0.88%	209	13	9	0	3	0	5	88	7	0	1	11	0	6	0
3-Jul	632	427,539	0	0	10	0.88%	67	54	10	0	5	0	5	163	5	1	3	13	0	2	0
4-Jul	422	427,961	0	0	10	0.88%	81	42	6	0	3	0	6	188	8	1	0	12	0	8	0
5-Jul	839	428,800	702	12	12	2.42%	42	105	5	0	4	0	11	206	19	1	2	25	0	9	0
6-Jul	406	429,206	0	0	12	2.42%	35	70	6	0	7	0	18	114	23	0	4	29	1	5	0
7-Jul	770	429,976	0	0	12	2.42%	77	56	3	0	3	0	12	96	11	1	2	18	0	6	0
8-Jul	673	430,649	0	3	15	2.42%	43	70	5	0	9	0	7	64	8	0	3	11	0	3	0
9-Jul	732	431,381	0	0	15	2.42%	23	95	0	0	6	0	7	85	17	1	1	36	0	9	0
10-Jul	348	431,729	0	1	16	2.42%	17	119	0	0	6	0	8	98	23	2	5	40	0	9	0
Total		431,729	14,338	191		1.63%	53,045	1,580	192	70	85	0	473	8,609	478	31	171	394	1	279	2

[a] Traps were removed May 22 – May 26. The table does not reflect the interpolated sockeye smolt counts used for the population estimate (Figure 5).

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

[c] Soc Fry = sockeye salmon fry, Coho = juvenile coho salmon, Pink = juvenile pink salmon, Chnk = juvenile Chinook salmon, Chum = juvenile chum salmon, DV = Dolly Varden, SB = stickleback, SC = sculpin, SF = starry flounder, PS = pond smelt, PW = pygmy whitefish, and AB = Alaskan blackfish, ISO = isopods, and EU = eulachon.

APPENDIX B. SMOLT CATCHES BY TRAP

Appendix B1.–Number of sockeye salmon smolt caught by trap, by day, from the Chignik River, May 20 through July 10, 2012.

	Small Trap		Large Trap		Combined		Daily Proportion	
Date[a]	Daily	Cumulative	Daily	Cumulative	Daily	Cumulative	Small	Large
5/20	320	320	1,021	1,021	1,341	1,341	23.9%	76.1%
5/21	93	413	224	1,245	317	1,658	29.3%	70.7%
5/27	4,017	4,430	11,499	12,744	15,516	17,174	25.9%	74.1%
5/28	1,068	5,498	2,411	15,155	3,479	20,653	30.7%	69.3%
5/29	8,403	13,901	14,940	30,095	23,343	43,996	36.0%	64.0%
5/30	6,071	19,972	21,626	51,721	27,697	71,693	21.9%	78.1%
5/31	12,236	32,208	25,050	76,771	37,286	108,979	32.8%	67.2%
6/1	8,512	40,720	42,237	119,008	50,749	159,728	16.8%	83.2%
6/2	9,266	49,986	64,629	183,637	73,895	233,623	12.5%	87.5%
6/3	1,526	51,512	3,617	187,254	5,143	238,766	29.7%	70.3%
6/4	459	51,971	1,483	188,737	1,942	240,708	23.6%	76.4%
6/5	707	52,678	9,287	198,024	9,994	250,702	7.1%	92.9%
6/6	2,144	54,822	8,594	206,618	10,738	261,440	20.0%	80.0%
6/7	12,489	67,311	72,784	279,402	85,273	346,713	14.6%	85.4%
6/8	1,456	68,767	8,216	287,618	9,672	356,385	15.1%	84.9%
6/9	653	69,420	4,041	291,659	4,694	361,079	13.9%	86.1%
6/10	591	70,011	4,166	295,825	4,757	365,836	12.4%	87.6%
6/11	904	70,915	6,374	302,199	7,278	373,114	12.4%	87.6%
6/12	989	71,904	8,956	311,155	9,945	383,059	9.9%	90.1%
6/13	556	72,460	1,391	312,546	1,947	385,006	28.6%	71.4%
6/14	365	72,825	1,898	314,444	2,263	387,269	16.1%	83.9%
6/15	204	73,029	987	315,431	1,191	388,460	17.1%	82.9%
6/16	1,314	74,343	11,133	326,564	12,447	400,907	10.6%	89.4%
6/17	464	74,807	2,384	328,948	2,848	403,755	16.3%	83.7%
6/18	989	75,796	4,037	332,985	5,026	408,781	19.7%	80.3%
6/19	616	76,412	1,257	334,242	1,873	410,654	32.9%	67.1%
6/20	485	76,897	1,182	335,424	1,667	412,321	29.1%	70.9%
6/21	323	77,220	728	336,152	1,051	413,372	30.7%	69.3%
6/22	236	77,456	1,717	337,869	1,953	415,325	12.1%	87.9%
6/23	436	77,892	1,464	339,333	1,900	417,225	22.9%	77.1%
6/24	197	78,089	1,358	340,691	1,555	418,780	12.7%	87.3%
6/25	237	78,326	632	341,323	869	419,649	27.3%	72.7%
6/26	212	78,538	688	342,011	900	420,549	23.6%	76.4%
6/27	257	78,795	1,091	343,102	1,348	421,897	19.1%	80.9%
6/28	255	79,050	760	343,862	1,015	422,912	25.1%	74.9%
6/29	189	79,239	672	344,534	861	423,773	22.0%	78.0%
6/30	259	79,498	783	345,317	1,042	424,815	24.9%	75.1%

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	Small Trap		Large Trap		Combined		Daily Proportion	
Date	Daily	Cumulative	Daily	Cumulative	Daily	Cumulative	Small	Large
7/1	201	79,699	933	346,250	1134	425,949	17.7%	82.3%
7/2	178	79,877	780	347,030	958	426,907	18.6%	81.4%
7/3	178	80,055	454	347,484	632	427,539	28.2%	71.8%
7/4	108	80,163	314	347,798	422	427,961	25.6%	74.4%
7/5	100	80,263	739	348,537	839	428,800	11.9%	88.1%
7/6	96	80,359	310	348,847	406	429,206	23.6%	76.4%
7/7	197	80,556	573	349,420	770	429,976	25.6%	74.4%
7/8	211	80,767	462	349,882	673	430,649	31.4%	68.6%
7/9	87	80,854	645	350,527	732	431,381	11.9%	88.1%
7/10	71	80,925	277	350,804	348	431,729	20.4%	79.6%
Total		80,925		350,804		431,729	18.7%	81.3%

[a] Traps were removed May 22 – May 26. The table does not reflect the interpolated sockeye smolt counts used for the population estimate (Figure 5).

APPENDIX C. CLIMATE OBSERVATIONS

Appendix C1.–Daily climatological observations for the Chignik River sockeye salmon smolt project, 2012.

Date[a]	Time	Air (°C)	Water (°C)	Cloud[b] Cover %	Wind[b] Dir	Vel.[b] (mph)	Trap Revolutions (rpm) Small	Trap Revolutions (rpm) Large	Stream Gauge (cm)	Comments
5/21	12:00	8.0	3.0	60%	NW	5	5.00	5.50		
5/22	13:30	4.0	3.0	60%	NW	0-5				traps removed due to ice movement
5/23	15:30	7.5	3.0	100%	NW	0-7				
5/24	9:30	6.0	3.2	100%	S	10				
5/25	11:30	7.0	3.9	100%	N	6				
5/26	9:30	10.0	3.5	10%	N	5-15				
5/27	16:00	12.0	4.5	5%	N	5-10	6.00	7.00	47	traps fishing; stream gauge placed
5/28	12:00	4.5	3.5	100%	S	5	6.50	7.00	49	
5/29	12:00	7.0	4.0	100%	SE	5-7	6.00	7.00	53	drizzle
5/30	12:00	5.8	3.8	100%	N	5-15	6.75	7.20	57	drizzle
5/31	12:30	7.0	3.5	90%	N	5	7.50	7.70	61	
6/1	12:00	5.5	3.5	95%	N	5-10	7.75	7.75	67	
6/2	10:00	2.0	3.0	85%	N	5-10	8.00	7.75	68	
6/3	12:00	7.0	3.8	0%	N	10-25	7.75	8.25	67	
6/4	12:00	7.5	4.0	95%	S	5	7.50	7.50	62	
6/5	12:00	8.0	4.1	95%	S	0-5	7.00	7.50	63	
6/6	11:00	10.0	4.2	50%	N	0-5	7.50	7.75	65	
6/7	13:00	7.5	5.0	100%	NW	27	7.50	8.00	66	
6/8	10:20	7.5	4.0	100%	WNW	5	7.75	7.80	68	rain, gusts to 15mph
6/9	12:20	5.5	4.5	100%	N	0-5	7.75	7.75	70	
6/10	12:00	7.0	5.0	100%	WNW	0-5	7.63	7.50	68	
6/11	12:45	8.0	5.0	20%	N	5-15	7.50	7.75	66	gusts to 23mph
6/12	10:00	3.8	4.0	5%	N	12	7.50	7.50	62	gusty
6/13	13:00	13.5	6.3	30%	NW	10-20	7.75	8.00	62	
6/14	13:00	9.0	6.0	60%	E	5	7.70	7.80	68	
6/15	12:10	7.5	5.7	100%	E	5-10	8.00	7.80	72	
6/16	12:00	12.0	5.8	60%	NW	5-15	8.30	8.00	76	
6/17	11:46	13.0	6.5	5%	W	5-10	8.13	8.40	82	
6/18	12:15	8.0	6.5	90%	W	5-10	8.75	8.40	86	
6/19	11:10	6.5	6.0	30%	W	15	9.00	8.70	87	
6/20	10:50	5.5	6.0	55%	W	15-20	9.00	8.75	85	
6/21	13:10	14.5	7.0	20%	W	7-15	9.13	8.50	88	
6/22	11:55	12.2	6.8	95%	NW	5	8.90	8.75	86	
6/23	12:40	11.5	7.2	50%	SE	8-15	9.00	8.75	87	
6/24	12:30	9.5	7.0	100%	calm	0	10.00	9.25	93	
6/25	12:15	8.5	6.5	95%	S	0-2	9.25	8.80	92	
6/26	13:17	9.5	7.0	100%	W	0-5	9.25	8.50	89	

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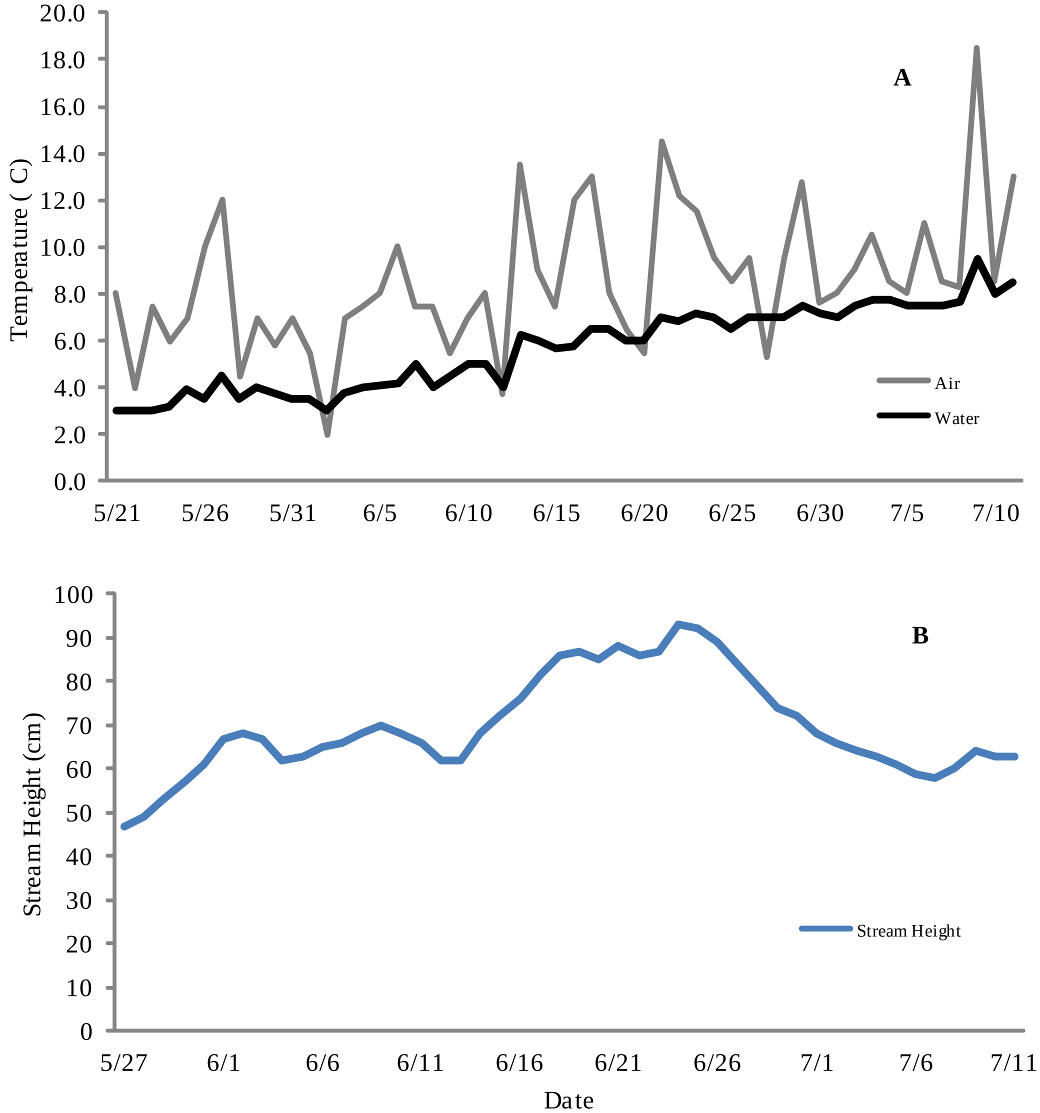
Appendix C1.–Page 2 of 2.

Date[a]	Time	Air (°C)	Water (°C)	Cloud[b] Cover (%)	Wind[b] Dir	Vel.[b] (mph)	Trap Revolutions (rpm) Small	Large	Stream Gauge (cm)	Comments
6/27	12:20	5.3	7.0	98%	W	10	9.20	8.75	84	
6/28	12:35	9.5	7.0	100%	W	0-2	8.50	8.13	79	
6/29	12:00	12.8	7.5	60%	calm	0	8.00	8.00	74	
6/30	13:24	7.6	7.2	100%	W	7-15	8.00	8.00	72	
7/1	12:00	8.0	7.0	80%	NW	5	8.00	7.50	68	
7/2	11:15	9.0	7.5	55%	calm	0	7.30	7.50	66	
7/3	11:16	10.5	7.8	100%	W	0-4	7.25	7.00	64	
7/4	11:15	8.5	7.8	80%	variable	0-5	7.20	7.35	63	drizzle
7/5	11:11	8.0	7.5	100%	W	0-5	7.25	7.25	61	
7/6	12:10	11.0	7.5	80%	W	0-7	7.50	7.10	59	
7/7	11:22	8.5	7.5	100%	NW	5	7.20	7.00	58	drizzle
7/8	11:15	8.3	7.7	100%	calm	0	7.40	7.25	60	drizzle
7/9	13:50	18.5	9.5	20%	calm	0	7.20	7.30	64	
7/10	10:30	8.5	8.0	60%	ENE	5-7	7.30	7.30	63	
7/11	13:00	13.0	8.5	75%	W	0-5	7.50	7.50	63	

[a] Actual calendar dates. Records from 5/23 - 5/26 were gathered at the fyke net site near the Chignik Weir (Figure 2).

[b] Based on observer estimates.

Appendix C2.–Air and water temperature (A) gathered at the Chignik River smolt traps and fyke net (5/23 – 5/26). Stream gauge height (B) gathered at the Chignik River smolt traps, 2012.



APPENDIX D. HISTORICAL LIMNOLOGY DATA

Appendix D1.–Seasonal averages of water quality parameters, nutrient concentrations, and photosynthetic pigments by year for Black Lake, 2000–2012.

	2000	2001	2002	2003	2004	2005	2006[a]	2007[a]	2008[a]	2009	2010	2011	2012[b]
	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average
pH	7.43	7.53	7.45	7.46	7.81	7.62	8.01	7.64	7.64	7.67	7.78	7.69	7.69
Alkalinity (mg/L $CaCO_3$)	13.3	32.5	32.3	32.3	30.2	25.0	20.5	19.7	19.0	23.5	22.0	26.6	26.7
Total phosphorous (µg/L P)	56.8	35.2	36.3	41.7	22.2	27.9	20.4	24.4	22.2	41.1	29.8	34.3	11.0
Total filterable phosphorous (µg/L P)	10.7	9.8	98.7	9.8	5.1	8.6	11.0	ND	ND	6.9	8.0	4.3	
Filterable reactive phosphorous (µg/L P)	4.0	7.4	16.4	5.8	2.6	7.2	9.1	ND	ND	ND	3.3	3.2	
Total kjedhal nitrogen (µg/L N)	ND	320.6	323.5	256.8	188.8	324.5	216.0	124.3	263.7	233.5	210.8	426.5	
Ammonia (µg/L N)	36.6	3.3	7.4	3.7	9.7	3.9	11.0	130.1	3.7	2.6	6.4	3.3	6.0
Nitrate + Nitrite (µg/L N)	38.9	10.9	7.3	25.2	3.7	1.9	0.9	1.6	0.6	1.3	1.0	1.1	2.4
Silicon (µg/L)	ND	ND	ND	ND	3382.8	ND	ND	ND	ND	ND	ND	2925.7	1618.6
Chlorophyll a (µg/L)	18.1	4.3	2.6	5.1	3.6	5.0	4.4	3.3	6.6	3.0	2.8	4.6	5.8
Phaeophytin a (µg/L)	10.0	11.9	1.4	1.8	0.2	1.0	0.8	0.9	1.4	1.4	1.5	0.5	0.8

[a] No sampling occurred in August
[b] No sampling occurred in May

Appendix D2.–Seasonal averages of water quality parameters, nutrient concentrations, and photosynthetic pigments for Chignik Lake, 2000–2012.

	2000	2001	2002	2003	2004	2005	2006[a]	2007[a]	2008[a]	2009	2010	2011	2012[b]
	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average
pH	7.84	7.50	7.45	7.38	7.62	7.57	7.70	7.46	7.47	7.50	7.22	7.52	7.36
Alkalinity (mg/L $CaCO_3$)	15.1	24.8	24.6	23.5	22.4	23.7	24.8	18.2	21.0	22.9	20.1	22.9	20.3
Total phosphorous (µg/L P)	13.1	27.6	19.7	16.7	18.5	15.8	20.1	14.2	15.6	22.3	13.6	12.4	10.0
Total filterable phosphorous (µg/L P)	5.3	12.2	8.5	7.5	6.5	6.5	8.3	ND	ND	ND	5.4	3.3	
Filterable reactive phosphorous (µg/L P)	4.8	8.4	4.6	5.8	4.1	5.8	8.9	ND	ND	ND	4.5	5.1	2.1
Total kjedhal nitrogen (µg/L N)	230.0	99.5	119.7	99.0	146.5	199.5	86.0	148.3	96.3	79.8	44.5	151.0	
Ammonia (µg/L N)	29.8	10.3	10.5	10.1	9.1	6.3	10.7	7.9	5.9	5.8	6.7	8.3	11.0
Nitrate + Nitrite (µg/L N)	102.6	132.9	117.4	166.6	128.0	105.1	129.9	194.0	192.5	151.8	154.4	187.1	171.7
Silicon (µg/L)	ND	ND	ND	ND	4128.8	ND	ND	ND	ND	ND	5993.7	2966.0	5289.8
Chlorophyll a (µg/L)	9.5	4.7	2.3	2.3	4.0	3.0	6.6	2.2	2.2	2.3	1.5	2.2	2.9
Phaeophytin a (µg/L)	1.7	1.3	1.3	0.5	0.3	0.6	0.9	0.4	0.6	0.5	0.8	0.4	0.3

[a] No sampling occurred in August
[b] No sampling occurred in May

Appendix D3.–Seasonal average number of zooplankton per m^2 from Black Lake, 2000–2012.

	2000	2001	2002	2003	2004	2005	2006[a]	2007[a]	2008[a]	2009	2010	2011	2012[b]
Taxon	Seasonal average	Seasonal average	Seasonal average	Seasonal average	Seasonal average	Seasonal average	Seasonal average	Seasonal average	Seasonal average	Seasonal average	Seasonal average	Seasonal average	Seasonal average
Copepods													
Epischura	7,850	2,654	2,605	6,303	37,649	18,113	-	5,750	-	3,707	4,329	2,919	5,166
Ovig. *Epischura*	127	-	-	-	-	-	-	-	-	-	-	531	-
Diaptomus	3,575	1,239	5,893	11,080	25,000	3,716	796	3,185	-	2,490	3,715	-	-
Ovig. *Diaptomus*	-	-	-	1,327	149	266	-	-	-	-	597	-	-
Eurytemora	-	-	-	-	-	-	-	-	-	-	-	2,574	-
Ovig. Eurytemora	-	-	-	-	-	-	-	-	-	-	-	3,609	-
Cyclops	35,398	7,307	25,622	19,042	46,198	46,842	31,582	5,662	13,093	24,031	18,312	11,332	15,906
Ovig. *Cyclops*	-	-	-	266	-	-	-	-	-	-	265	1,937	-
Harpacticus	-	531	-	531	531	-	266	-	-	-	597	-	177
Nauplii	21,967	6,458	13,385	24,350	40,509	38,150	7,564	9,996	16,189	28,938	12,971	21,736	10,209
Total copepods	68,917	18,188	47,505	62,898	150,036	107,086	40,207	24,593	29,282	59,166	41,584	44,639	35,403
Cladocerans													
Bosmina	38,455	25,779	32,379	285,496	398,855	203,755	2,323	1,858	1,681	49,209	28,646	3,530	27,955
Ovig. *Bosmina*	10,446	4,883	13,384	39,809	90,147	29,990	796	-	1,681	12,142	9,908	57,617	2,300
Daphnia l.	868	372	-	1,526	199	-	-	-	-	66	-	80	531
Ovig. *Daphnia l.*	-	-	-	-	-	-	-	-	-	-	-	-	-
Chydorinae	11,632	526,097	11,697	3,517	78,954	12,407	3,052	2,919	-	-	-	9,236	1,203
Total cladocerans	61,401	557,130	57,460	330,348	568,156	246,152	6,171	4,777	3,362	61,417	38,554	70,462	39,526
Total copepods + cladocerans	130,318	575,318	104,965	393,246	718,192	353,238	46,378	29,370	32,643	120,582	80,138	115,101	74,929

[a] No sampling occurred in August

[b] No sampling occurred in May

Appendix D4.–Average weighted biomass estimates (mg dry weight/m^2) of the major Black Lake zooplankton taxon, 2000–2012.

	2000	2001	2002	2003	2004	2005	2006[a]	2007[a]	2008[a]	2009	2010	2011	2012[b]
Taxon	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average
Copepods:													
Epischura	7.29	1.57	3.55	3.59	21.24	14.29	-	28.30	-	3.20	2.96	1.94	4.52
Ovigerous Epischura	-	-	-	-	-	-	-	-	-	-	-	1.00	-
Diaptomus	8.86	3.85	46.95	42.19	31.52	8.26	1.11	8.70	-	5.40	7.05	-	-
Ovigerous Diaptomus	-	-	-	-	-	-	-	-	-	-	1.16	-	-
Eurytemora	-	-	-	-	-	-	-	-	-	-	0.99	6.26	20.36
Ovigerous Eurytemora	-	-	-	-	-	-	-	-	-	-	-	28.98	-
Cyclops	32.09	9.12	36.04	18.30	35.75	44.28	22.11	10.40	13.79	24.00	12.46	10.93	15.05
Ovigerous Cyclops	-	-	-	-	-	-	-	-	-	-	0.38	4.62	-
Harpaticus	-	0.89	-	0.35	-	-	0.17	-	-	-	0.09	-	0.18
Total copepods	48.24	15.43	86.54	64.43	88.51	66.83	23.39	47.40	13.79	32.60	25.09	53.73	40.11
Cladocerans:													
Bosmina	32.86	15.80	65.10	290.05	365.58	180.73	2.14	1.00	1.45	49.50	25.00	2.38	22.47
Ovigerous *Bosmina*	13.49	5.18	45.07	77.61	125.78	43.00	0.83	-	2.58	19.80	12.28	76.98	2.99
Daphnia l.	0.46	0.10	-	2.29	0.05	-	-	-	-	-	-	0.17	0.55
Holopedium	-	-	-	-	-	-	-	-	-	-	0.77	-	-
Chydorinae	6.59	5.05	16.15	2.38	40.46	8.66	1.80	6.20	-	-	-	5.02	0.45
Total cladocerans	53.40	26.13	125.64	186.16	531.87	232.39	4.77	7.20	4.03	69.30	38.10	84.55	26.46
Total Biomass	101.64	41.56	162.42	218.38	620.38	299.22	28.16	54.60	17.82	101.90	63.00	138.28	66.57

[a] No sampling occurred in August

[b] No sampling occurred in May

Appendix D5.–Seasonal average number of zooplankton per m^2 from Chignik Lake, by year, 2000–2012.

	2000	2001	2002	2003	2004	2005	2006[a]	2007[a]	2008[a]	2009	2010	2011	2012[b]
Taxon	Seasonal average	Seasonal average	Seasonal average	Seasonal average	Seasonal average	Seasonal average	Seasonal average	Seasonal average	Seasonal average	Seasonal average	Seasonal average	Seasonal average	Seasonal average
Copepods													
Epischura	38,354	9,249	34,939	70,621	67,163	51,946	6,842	3,981	10,350	5,139	10,139	17,411	15,822
Ovigerous Epischura	398	53	-	-	-	-	-	-	-	-	-	354	-
Diaptomus	12,988	15,552	25,557	62,275	45,467	49,367	17,350	4,305	14,265	46,038	32,733	-	-
Ovigerous Diaptomus	780	106	2,760	1,742	3,605	2,816	1,393	619	1,592	2,303	1,945	-	-
Eurytemora	-	-	-	-	-	-	-	-	-	-	2,223	18,063	8,740
Ovigerous Eurytemora	-	-	-	-	-	-	-	-	-	-	-	15,596	164
Cyclops	172,192	38,767	151,287	37,726	140,871	120,322	175,889	327,406	87,331	130,339	92,755	142,259	72,426
Ovigerous Cyclops	1,975	4,399	9,713	1,393	4,532	10,388	24,648	1,150	2,720	9,946	3,759	6,844	1,920
Harpaticus	355	292	703	531	1,078	348	1,335	1,062	100	672	993	-	332
Nauplii	46,439	12,812	75,588	55,971	73,733	115,371	87,024	23,664	37,097	48,066	35,065	63,674	50,495
Total copepods	273,481	81,230	300,549	230,258	336,447	350,559	314,482	362,187	153,455	225,277	179,612	264,202	158,700
Cladocerans													
Bosmina	58,978	31,356	56,091	73,448	59,929	88,990	74,459	4,453	38,125	21,939	39,697	10,005	1,132
Ovigerous Bosmina	14,394	4,386	15,698	14,358	8,944	24,968	16,956	575	9,372	1,989	3,621	20,740	1,407
Daphnia l.	9,157	1,858	17,003	68,073	29,824	15,787	22,805	8,139	11,968	43,643	8,631	10,707	212
Ovigerous Daphnia l.	1,312	53	8,373	7,086	7,501	6,336	6,919	2,861	2,189	13,854	1,866	7,912	102
Chydorinae	3,989	24,728	9,129	1,115	8,373	6,179	-	3,340	1,062	-	-	5,356	88
Total cladocerans	87,830	62,381	106,294	164,079	114,570	142,259	121,139	19,367	62,716	81,425	53,815	54,721	3,132
Total copepods + cladocerans	361,311	143,611	406,843	394,337	451,017	492,818	435,621	381,554	216,171	306,702	233,427	318,923	161,832

[a] No sampling occurred in August

[b] No sampling occurred in May

Appendix D6.–Average weighted biomass estimates (mg dry weight/m^2) of the major Chignik Lake zooplankton taxon by year, 2000–2012.

Taxon	2000	2001	2002	2003	2004	2005	2006[a]	2007[a]	2008[a]	2009	2010	2011	2012[b]
	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average
Copepods													
Epischura	43.38	17.98	32.58	42.13	49.46	43.39	5.47	8.15	11.26	3.54	8.09	16.26	15.38
Ovigerous *Epischura*	3.03	0.31	-	-	-	-	-	-	-	-	0.00	0.62	-
Diaptomus	82.20	44.54	114.05	148.91	92.14	121.30	37.70	53.23	109.56	56.47	101.13	-	-
Ovigerous *Diaptomus*	9.43	0.30	27.33	8.63	22.20	23.08	28.39	88.95	-	10.04	9.43	-	-
Eurytemora	-	-	-	-	-	-	-	-	-	-	8.15	64.66	48.65
Ovig. Eurytemora	-	-	-	-	-	-	-	-	-	-	-	86.58	1.58
Cyclops	250.07	128.12	178.97	46.08	155.46	153.87	300.73	557.80	147.23	191.56	123.43	172.55	91.04
Ovigerous *Cyclops*	10.43	33.46	58.85	5.66	20.43	49.32	138.65	69.02	10.08	28.31	20.56	44.04	9.58
Harpaticus	0.29	0.62	0.91	0.45	0.55	0.21	0.96	4.31	0.14	0.18	0.37	-	0.21
Total copepods	398.84	225.33	412.69	251.85	340.23	391.17	463.05	781.46	278.27	290.09	271.16	384.71	166.44
Cladocerans													
Bosmina	76.08	27.44	55.74	85.55	49.46	79.44	36.75	11.19	18.86	15.49	32.10	8.57	45.93
Ovigerous *Bosmina*	27.89	5.98	25.08	26.37	11.40	31.01	12.21	12.00	12.04	1.87	5.49	27.36	1.48
Daphnia l.	12.56	5.18	22.20	42.73	37.16	19.18	10.21	31.01	6.93	34.32	12.05	7.98	1.44
Ovigerous *Daphnia l.*	3.38	0.44	29.61	23.17	23.62	19.24	2.80	32.47	6.43	28.80	5.60	18.62	0.60
Chydorinae	3.56	2.20	6.95	0.73	6.03	3.97	6.60	4.64	0.29	-	-	3.43	1.32
Total cladocerans	123.48	41.23	139.59	178.55	127.67	152.84	68.57	91.30	44.55	80.47	55.24	65.97	50.90
Total Biomass	522.32	266.57	552.28	430.40	467.90	544.02	586.15	872.76	322.83	370.56	326.40	450.67	217.34

[a] No sampling occurred in August

[b] No sampling occurred in May