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Sockeye Salmon Smolt Investigations on the Chignik River, 2011

by

Adam StSaviour

and

Dawn Hunt

April 2012

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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by
Adam StSaviour
Alaska Department of Fish and Game, Division of Commercial Fisheries, Kodiak

and

Dawn Hunt
Alaska Department of Fish and Game, Division of Commercial Fisheries, Kodiak

Alaska Department of Fish and Game
Division of Sport Fish, Research and Technical Services
333 Raspberry Road, Anchorage, Alaska, 99518-1565

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Adam StSaviour
Alaska Department of Fish and Game, Division of Commercial Fisheries
211 Mission Road, Kodiak, AK 99615, USA

and

Dawn Hunt
Alaska Department of Fish and Game, Division of Commercial Fisheries
211 Mission Road, Kodiak, AK 99615, USA

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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 2011. 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 sockeye salmon forecast. The abundance of sockeye salmon smolt was estimated using a rotary-screw trap array and mark-recapture techniques. In 2011, a total of 12,258,543 sockeye salmon smolt were estimated to pass downstream of the traps from May 2 to July 7. Of these, 203,380 (1.7%) were age-0., 10,684,120 (87.2%) were age-1., and 1,371,044 (11.2%) were age-2. smolt. Limnology surveys were conducted in Chignik and Black lakes each month from May to August 2011 to describe physical characteristics, nutrient availability, primary production, and zooplankton forage available to rearing juvenile sockeye salmon. Zooplankton levels were normal and relatively few age-0. smolt emigrated this year suggesting that rearing conditions were adequate. The smolt-based forecast predicts a total adult run of 1.92 million sockeye salmon for 2012. Findings from this project are vital for understanding effects of 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 emigration 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 emigrating 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 is 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 (SEG) range of 350,000 to 400,000 fish through July 4. The late run has an SEG range of 200,000 to 400,000 fish beginning on July 5 with an additional 50,000 fish in-river run goal (IRRG) 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 emigration 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 emigration studies provide information on life history strategies and annual changes in emigration timing. Combined with limnological investigations, this type of study can provide insight as to how environmental factors may influence food availability, juvenile emigration 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 emigrate 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 emigrate 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 (as measured at Cold Bay, Alaska; Alaska Climate Research Center, 2011) has increased, while Black Lake water levels have decreased to two-thirds of the 1968 mean depth of 3.0 m (Dahlberg 1968; Ruggerone et al. 1993). Also, changes in temperature regimes may create thermally stressful environments for juvenile sockeye salmon. Loss of Black Lake volume might also 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 emigration 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 conditions and subsequently return to Chignik Lake in the fall of the same year (Roos 1957, 1959; Iverson 1966; Phinney 1968). Competition for space and food between populations of juvenile sockeye salmon in Chignik Lake may cause seasonal migrations of either subpopulation into areas of lower smolt density and possibly migration into Chignik Lagoon. 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 emigrations from the Chignik River watershed have ranged from 2 to 26 million sockeye salmon. Chignik sockeye salmon smolt generally have been observed to emigrate beginning in early May, peak in mid to late May, and are predominantly composed of age-1. and -2. fish (Loewen and Bradbury 2011). Smolt emigration 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. Forecasts enable harvesters and fish processors to estimate their potential supply and production needs. Forecast methods use historic age class relationships and smolt emigration estimates to predict adult runs (Eggers and Carroll 2011).

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 indicates migration timing of each stock is variable by year. In 2006 and 2008, Black Lake juveniles emigrated 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 (Creelman 2010). In 2008, smolt ages were similar to those of returning adults, where the vast majority of Black Lake stock were age-1.x and Chignik Lake stock were age-2.x (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. Comprehensive limnological investigations of Chignik and Black lakes has occurred annually since 2000. In 2008 limnological studies were formally incorporated into the smolt enumeration project. To date, limnology and smolt data from the Chignik watershed 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 to the Chignik River system (Buffington 2001; Bouwens and Finkle 2003; Finkle 2004). The limnology portion of this study seeks 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 2011 field season was the eighteenth year of the ADF&G Chignik River sockeye salmon smolt monitoring and enumeration project. The sampling protocol has been consistent for these 18 years. This report presents data collected in 2011, compares the results of 2011 to previous years, and provides the 2012 adult sockeye salmon forecast based on smolt data.

OBJECTIVES

The objectives for the 2011 season were to

1. estimate the total number of emigrating sockeye salmon smolt, by age, from the Chignik River system;
2. describe emigration 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. describe 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 emigrating sockeye salmon smolt for use in a stock identification study;
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 emigrating 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 the highest current velocity and narrowest span.

Each trap was secured to shore with highly visible polypropylene line. The line and a 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 2.00 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 three to nine revolutions per minute (RPM) during average discharge. Ideal trap RPM is between six and seven; adjustments to the traps were made in order 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.

For the 2011 field season, both traps were fishing as of 1530 hours on May 2. The small trap was raised for the season at 0930 hours on July 5 because the spindle bushing was worn out while the large trap continued fishing until 1015 hours on July 7. Periods of fishing interruption occurred throughout the season to clear debris, trap maintenance, and repositioning. These periods were limited to 1 hour or less except for one occasion on May 10 which necessitated both traps be raised from 2245 to 1645 hours on the following day due to extreme weather and safety concerns. At the completion of the project, both traps were disassembled and stored.

SMOLT ENUMERATION

Since smolt primarily emigrate at night, sampling days extended for a 24-hour period from noon to noon and were identified by the date of the first noon-to-midnight period. The traps were checked a minimum of three times each day beginning at noon, between 1900 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 emigration.

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*, and Alaska blackfish *Dallia pectoralis* were also identified and counted. The isopod *Mesidotea entomon* (Merrit and Cummings 1984; Pennak 1989) was observed.

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 600 and 3,500 sockeye salmon smolt for each experiment were collected from the traps 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. Past mark retention and delayed mortality experiments indicated that most of the captured smolt mortalities occurred within the first three days of capture (Bouwens and Newland 2003). Thus, after three nights, all captured live smolt were released downstream of the traps if the minimum sample size was not met.

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 added and the containers aerated for 15 min. Fresh water was then pumped into the container 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. Any mortality observed in the held smolt was incorporated into daily population estimates.

The trap efficiency E was calculated by

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

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 emigrating 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

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 age, weight, and length (AWL); the remaining smolt were released downstream. All smolt sampling data reflected the day in which the fish were captured; samples were not mixed between days.

Fork length (FL) was measured to the nearest 1 mm, and each smolt weighed to the nearest 0.1 g. Scales were removed from the preferred area (INPFC 1963) and mounted on a microscope slide for age determination. Fin clips were collected from all AWL-sampled fish for genetic analysis and stored in ethanol following ADF&G protocol (Anderson and Loewen 2011).

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

Condition factor (Bagenal and Tesch 1978), which is a quantitative measure of the isometric growth of a fish, 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 1200 hours.

Marine Survival Estimates and Future 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 (SEDM) 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 2012 Chignik early and late adult sockeye salmon run was forecast using a multiple regression model of total outmigrating smolt and multivariate ENSO index (MEI) of the outmigration year. MEI is a multivariate index that uses six environmental variables to monitor the El Niño/Southern Oscillation, an ocean-atmosphere phenomenon known to drive global climate variability on interannual time scales. The environmental variables used are sea-level pressure, zonal and meridional surface wind, surface water temperature, surface air temperature, and cloud cover (NOAA Earth System Research Laboratory 2011). Data from 1996 and 2007 were excluded due to unrealistic estimates of marine survival. 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 and Carroll 2012) which uses age-class relationships and escapement data and is stock-specific.

Limnology

Limnology data was collected at one sampling station on Black Lake (Figure 3) and at four sampling stations on Chignik Lake (Figure 3). Sampling occurred monthly from May 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 1% of the surface reading. 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 phosphorous (TP), total ammonia (TA), nitrate + nitrite, total filterable phosphorous (TFP), filterable reactive phosphorous (FRP), chlorophyll *a*, and phaeophytin *a*. All laboratory analyses adhered to the methods of Koenings et al. (1987) and Thomsen et al. (2002). Total Kjeldahl nitrogen (TKN) was processed by the University of Georgia Feed and Environmental Water Laboratory.

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. One 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 66 and 64 days respectively. The traps began fishing on May 2. The duration of the 2011 trapping season was 7 days longer than the 2010 season due to an earlier ice break up on Chignik Lake.

A total of 112,072 sockeye salmon smolt were captured in the traps during the 2011 season (Appendix A1 and B1). In addition to sockeye salmon smolt, 11,949 sockeye salmon fry, 618 juvenile coho salmon, 505 juvenile Chinook salmon, 63 juvenile pink salmon, 2 juvenile chum salmon, 399 Dolly Varden char, 15,441 stickleback, 303 sculpin, 55 starry flounders, 97 pond smelt, 119 pygmy whitefish, and 5 Alaskan blackfish were captured (Appendix A1). The small screw trap caught 16.4% of the trapped sockeye salmon smolt (Appendix B1).

SMOLT EMIGRATION TIMING AND POPULATION ESTIMATES

An estimated 12,258,543 (95% CI 8,725,631 to 15,791,456) sockeye salmon smolt emigrated in 2011 (Table 1; Figure 4) based upon mark-recapture estimates and trap counts (Table 3). The majority of these fish emigrated from the early May to early June (Table 2; Figure 5). The 2011 emigration estimate consisted of 203,380 age-0., 10,684,120 age-1., and 1,371,044 age-2.

sockeye salmon smolt (Tables 1 and 2; Figure 6). Age-1. fish comprised the vast majority (87%) of the smolt emigration. Peak emigration was the week of May 24 for age-1. and age-2. smolt. Age-0. smolt peak emigration occurred the week of May 31 (Table 2).

TRAP EFFICIENCY ESTIMATES

Mark-recapture experiments were conducted on six occasions beginning on May 12 and ending on June 17 (Table 3; Appendix A1). A total of 13,998 smolt, 8% of the total catch, were marked and released. One hundred fifty six smolt were recaptured and trap efficiency estimates per stratum ranged from 0.34% to 2.10% (Table 3; Appendix A1). The majority of marked smolt were recaptured within two days of being released. Tests were not conducted after June 17 because trap catches were below the minimum sample size needed to avoid biased estimates. Therefore, the efficiencies from the June 17 test were applied to all smolt emigrating through July 6 (1.2% of the total catch).

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 49 mm, 1.0 g, and 0.86 respectively. The mean length, weight, and condition factor of sampled age-1. smolt was 70 mm, 2.8 g, and 0.88 respectively. The mean length, weight, and condition factor of sampled age-2. smolt was 78 mm, 4.1 g, and 0.82 respectively (Table 4). Sockeye salmon fry (<45 mm FL) were captured throughout the trapping season, but were most abundant in late May and early June (Table 2; Figure 8).

PHYSICAL DATA

The absolute water depth at the trap location ranged from 87 to 192 cm during the season. Water temperatures remained at 3.0°C during the first few days the traps were installed (May 3 through May 5) and increased steadily throughout the season to a maximum of 9.0°C (Appendix C1 and C2). The season began with relatively low water levels that increased with snowpack melt and steady rain before reaching the maximum in the first week of June then declining to 142 cm by the end of the trapping season. Cool temperatures, light winds, and overcast skies dominated the 2011 season.

ADULT RUN FORECAST

The smolt-based regression model forecasted a 2012 total adult run of 1.92 million sockeye salmon (80% prediction interval 981,112 to 2.85 million; significance F 0.06), compared to the formal adult forecast, which predicted a run of 2.29 million sockeye salmon (Eggers and Carroll 2012).

LIMNOLOGY

Sampling was conducted each month in both Black Lake (May 23, June 20, July 14, and August 31) and Chignik Lake (May 19, June 6, July 2, and September 1). Comparisons with historical limnological data can be found in Appendices D1 and D2.

Temperature and Dissolved Oxygen

Black Lake

The 1-m temperature in Black Lake in 2011 increased from 9.1°C on May 23, to 11.7°C on July 14; 11.7°C was recorded again on August 31 (Figure 9). Dissolved oxygen levels at the 1-m depth declined from 11.6 to 11.1 mg/L over the same dates (Figure 9).

Chignik Lake

The average 1-m temperature in Chignik Lake increased from 3.8°C on May 19, to 11.2°C on September 1 (Figure 10). Dissolved oxygen levels decreased from 13.5 mg/L to 11.0 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 0.4°C and 1.0 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 2011 sampling season. The EZD of Black Lake exceeded its maximum depth 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. During the 2011 sampling season average Secchi disc readings were at a depth of 0.83 m (Table 8; Figure 11).

Chignik Lake

Light penetration reached, on average, 1% of surface levels at a depth of 12.0 m in May, 10.0 m in June and July, and at 6.0 m in August. The EZD was 10.96 m in May, 7.05 m in June, 9.49 m in July, and 6.12 m in August. The EV in Chignik Lake averaged 202.7 x 10^6 m^3. Mean Secchi disc readings were at a depth of 2.26 m (Table 8; Figure 11).

Water Quality Parameters, Nutrient Levels, and Photosynthetic Pigments

Black Lake

In 2011, the pH in Black Lake averaged 7.69 and alkalinity averaged 26.6 mg/L $CaCO_3$ across stations and depth. TP averaged 34.3 µg/L P, TFP averaged 4.3 µg/L P, and FRP averaged 3.2 µg/L P. TKN averaged 426.5 µg/L N and ammonia averaged 3.3 µg/L. Nitrate + nitrite averaged 1.1 µg/L and silicon averaged 2925.7 µg/L. Chlorophyll *a* averaged 4.6 µg/L and phaeophytin *a* had a seasonal mean of 0.5 µg/L. TKN and Nitrate + nitrite levels were at their highest levels in May then dropped in June remaining relatively constant for the remainder of the season. Peak ammonia levels occurred in July. Chlorophyll *a* and phaeophytin *a* were greatest in August (4.6 and 0.5 µg/L respectively; Table 9), although seasonally averaged phaeophytin *a* was low compared to other years (Appendix D1).

Chignik Lake

During the 2011 season, the pH in Chignik Lake averaged 7.52 and alkalinity averaged 22.9 mg/L $CaCO_3$ across stations and depth. TP averaged 12.4 µg/L, TFP averaged 3.3 µg/L, and FRP averaged 5.1 µg/L. TKN averaged 151.0 µg/L and ammonia averaged 8.3 µg/L. Nitrate + nitrite averaged 187.1 µg/L N and silicon averaged 2966.0 µg/L. Chlorophyll a averaged 2.2 µg/L and phaeophytin a averaged 0.4 µg/L. TKN fluctuated little throughout the season, ammonia peaked in September (17.0 µg/L), and nitrate + nitrite was at the highest levels in May (241.0 µg/L). Chlorophyll *a* and phaeophytin *a* fluctuated little throughout the season (Table 10) and were comparable to other years (Appendix D2).

ZOOPLANKTON

Black Lake

Cladocerans were the most abundant measured zooplankton in Black Lake (season average of 70,462 individuals/m^2) followed by Copepods (season average of 44,639 individuals/m^2). On average, the most prevalent copepod genera in Black Lake was *Cyclops* (11,332/m^2). Nauplii (juvenile copepods) were the most abundant life stage with a seasonal mean of 21,736/m^2 (Table 10; Appendix D3). Ovigerous *Bosmina* were the most abundant cladoceran genera with a seasonal average of 57,617/m^2; abundance peaked in August (Table 10).

Copepod biomass was greatest in June and was composed predominantly of ovigerous *Eurytemora* (28.98 mg/m^2 weighted season average) and *Cyclops* (10.93 mg/m^2 weighted season average). Cladoceran biomass was predominantly composed of ovigerous *Bosmina* throughout the sampling season with a weighted seasonal average of 76.98 mg/m^2 and greatest biomass observed in August. The total weighted seasonal average copepod biomass (53.73 mg/m^2) was less than cladoceran biomass (84.55 mg/m^2) and resulted in a total weighted average of 138.28 mg/m^2 for all the Black lake zooplankton (Table 11; Appendix D4).

Average seasonal lengths of the major non-egg bearing zooplankton in Black Lake were 0.80 mm for *Eurytemora*, 0.54 mm for *Cyclops*, and 0.28 mm for *Bosmina.* Ovigerous zooplankton were generally longer than non-egg bearing individuals (Table 12).

Chignik Lake

Copepod abundance (season average of 264,202 individuals/m^2) was greater than the average seasonal cladoceran abundance (54,721 individuals/m^2). *Cyclops* (142,259/m^2) and nauplii (63,674/m^2) were the most abundant genera of copepods during the 2011 season. Ovigerous *Bosmina* (20,740 individuals/m^2), *Bosmina* (10,005 individuals/m^2), and *Daphnia l.* (10,707 individuals/m^2) were the most common cladocerans in Chignik Lake (Table 13; Appendix D5).

Copepod biomass was composed predominantly of *Cyclops* in May and June (172.55 mg/m^2 weighted season average), with the greatest biomass occurring in June. In July, *Cyclops*, *Eurytemora*, and ovigerous *Cyclops* made up the majority of the biomass (193.75 mg/m^2, 123.21 mg/m^2, and 163.81 mg/m^2 respectively). Biomass estimates of *Cyclops* were substantially greater than estimates of other copepods and cladocerans from May through July, however ovigerous *Eurytemora* were predominant in August (438.32 mg/m^2; 86.58 mg/m^2 weighted season average) followed by non-ovigerous *Eurytemora* (92.71 mg/m^2; 64.66 mg/m^2 weighted season). Cladoceran biomass was composed primarily of ovigerous *Bosmina* (27.36 mg/m^2 weighted season average) and ovigerous *Daphnia l.* (18.62 mg/m^2 weighted season average), with both reaching their highest biomass in August (62.57 mg/m^2 and 67.66 mg/m^2 respectively). The total weighted seasonal average copepod biomass (384.71 mg/m^2) was greater than the cladoceran biomass (65.97 mg/m^2) resulting in a weighted average of 450.67 mg/m^2 for all Chignik Lake zooplankton (Table 14; Appendix D6).

Average seasonal lengths of the major non-egg bearing zooplankton in Chignik Lake were 0.96 mm for *Eurytemora*, 0.59 mm for *Epishura* and C*yclops*, and 0.48 mm for *Daphnia l*. Ovigerous zooplankton were generally longer than non-egg bearing individuals (Table 15).

DISCUSSION

SMOLT POPULATION ESTIMATES AND AGE STRUCTURE

Traps were installed on May 2, the first day that the river was ice-free. Test fishing was conducted with a fyke net to ensure the run did not begin before the traps were installed. Trap catch histograms indicate that the trapping season encompassed the entire 2011 emigration. The point estimate of the 2011 total smolt emigration (12.3 million) was near the 18 year average (13.1 million). Emigration timing was typical of the last 10 years with the majority occurring at the end of May. There were three peaks in the 2011 emigration on May 10, May 25, and June 4 (Figure 5).

Emigration timing and magnitude in 2011 allowed for six mark-recapture events throughout the season with approximately 14,000 smolt marked and released. Trap efficiency estimates in 2011 were consistent with previous years. Historic efficiencies have generally averaged <2% annually and individual mark-recapture events often were <1%. These efficiencies are consistent throughout the season and have never been more than 3% in the history of the project (Loewen and Bradbury 2011). These low trapping efficiencies are to be expected considering the size of the Chignik River and small proportion that our traps cover. Although these 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 robust and comparable among years.

The 2011 smolt population, as determined from scale samples, was comprised of 87% age-1., 11% age-2., and 2% age-0. smolt. Age-1. smolt generally make up the greatest proportion of the emigration; the proportion of age-.1. to age-2. Smolt tends to fluctuate on a four to five year cycle (Figure 6). The 2011 proportion of age-1.s was much higher than average (59%). In the 2010 and 2011 seasons, condition factor increased throughout the season among all age classes (Table 4). Juveniles remaining in the lake after the majority of smolt have left the system likely had decreased competition for zooplankton. Historically, condition factor or age-1. and age-2. smolt has remained between 0.73 and 0.91. 2011 mean condition factor was considerably greater for age-1. and age-2. smolt than the previous three years (Table 5). These data suggest that current smolt population levels are adequate and not exceeding the carry capacity of the system.

Although age-0. smolt make up a small proportion of the population, fry have not been included in our estimate of age-0.'s. Fry less than 45 mm are not considered smolt (Thedinga et al. 1994), and 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 0. age 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 for the summer (Simmons 2009) before outmigrating and others may return to Chignik Lake as juveniles to overwinter. Upcoming otolith microchemistry work should shed light on the frequency of these different life-history strategies (Walsworth and Schindler *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. Both are necessary for primary production and at specific ratios (Wetzel 1983; UF 2000). Nitrogen-phosphorous ratios of less than 10:1 indicate nitrogen limitations (USEPA 2000). Based on the 2011 water quality data, 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 12.6:1, and oscillated throughout the summer season, with the highest ratio in May (26.9:1). The seasonal average for Chignik Lake was 27.9:1 and was less variable. The highest ratio there also occurred in May (33.5:1). This seasonally averaged ratio is greater than the 10-year average (10.3:1).

The quantity of photopigments 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 were high in Black Lake (8.6:1) compared to the 10-year average (5.3:1). 2011 photosynthetic pigment ratio was near average in Chignik Lake (2011 ratio 4.9:1; 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). For the Chignik River system, these changes could cause altered juvenile sockeye salmon migratory behavior or freshwater survival (Parr 1972; Ruggerone 1994; Bouwens and Finkle 2003). Thus, it is important to understand patterns of resource abundance and habitat use.

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).

Zooplankton

Black Lake zooplankton density was slightly lower in 2011 than in 2009 and 2010 but similar to the five year average. Black Lake zooplankton densities during the recent five years have been more stable and lower than the previous five years. It should be noted that August samples were not collected in 2006-2008. Seasonal patterns of zooplankton density were similar to what has been observed historically. Zooplankton density in Black Lake has been historically predominated by copepods early in the season, decreasing from May to June, then peaking in late July or August (Finkle and Ruhl 2008; Loewen and Bradbury 2011). 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 2011, 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 (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 density in 2011 was higher than in 2010 and also comparable to the five year average. Chignik Lake zooplankton populations historically follow a pattern similar to Black Lake zooplankton populations, however copepods remain predominate late into the season when overall zooplankton densities are greatest. Chignik Lake copepod populations historically are composed primarily of *Cyclops*, while the most abundant cladoceran is *Bosmina*. Collection of zooplankton samples in August are important for accurate seasonal average comparisons because cladoceran abundance may not peak until late July or mid August, and therefore would not be represented in samples collected earlier in the season. Although zooplankton density and biomass are greater in Chignik Lake than in Black Lake, Black Lake is a highly productive rearing environment for juvenile sockeye salmon due to an abundance of chironomids that are not quantified (Finkle 2004).

Evidence of overgrazed zooplankton populations can be reflected by reductions in zooplankton length and shifts in species composition (Kyle 1992; Schindler 1992). Continued observed trends of inseason zooplankton composition changes and density fluctuations are indicative of top-down grazing pressure on zooplankton (Kyle 1992; Stockner and MacIsaac 1996). For example, a spike in *Bosmina* biomass, a preferred zooplankton food source of juvenile sockeye salmon, typically occurs in Black Lake shortly after the juvenile sockeye salmon migration to Chignik Lake. Mean cladoceran length remained the same through the season in Black Lake but decreased in Chignik Lake, suggesting a population of planktivores continued to exert grazing pressure on the zooplankton community into August. Whether these were sockeye salmon juveniles preparing to overwinter in the lakes or other planktivores is uncertain. *Bosmina* average lengths were consistently below the minimum elective feeding threshold of 0.40 mm for juvenile sockeye salmon (Kyle 1992), indicating that top-down grazing pressures were removing larger *Bosmina* from the system.

EMIGRATION TIMING

In addition to sockeye salmon smolt, an estimated 200,000 sockeye salmon fry emigrated. Unlike other systems where smolt leave the freshwater environment and enter directly into the 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 (Rice et al. 1994). In 2005, 2006, and 2008 a greater proportion of age-0 smolt were observed outmigrating, possibly due to stressful lake conditions as a result of elevated competition for zooplankton forage. The low proportion of age-0. sockeye salmon that emigrated in 2011 may suggest that freshwater rearing conditions were improved in recent years, allowing fish to remain in freshwater to overwinter.

Temperature also has a strong effect on smolt emigration. The Alaska Peninsula has generally been experiencing warmer temperatures, as indicated by average annual air temperatures at Cold Bay since 1961, although there have been some colder years recently (1°C increase; Alaska Climate Research Center 2011). 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, as thermal stress may cause earlier emigration of Black Lake juveniles into Chignik Lake (Finkle 2004). In 2011, air temperatures at the smolt traps were cooler than recent years. 2011 monthly temperatures in both Chignik and Black lakes were as cool as or cooler than all years since 2000 and the water column less stratified. Black Lake was slightly clearer in 2011 than in 2010, whereas Chignik Lake was unchanged. 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.

Since 2003, managers have attempted to target the lower bounds of the escapement goal for both runs, in order to reduce competition for resources and allow the available zooplankton forage base to increase under reduced top-down grazing pressure from rearing sockeye salmon (Finkle 2007; Loewen and Bradbury 2011). Decreased competition among juveniles for food may allow juveniles 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). Escapements at the lower end of the goals from 2003 to 2007 may have successfully reduced foraging competition among juveniles, allowing for more efficient feeding as zooplankton levels recovered from years of over-grazing. This also may have translated into larger adult runs Chignik experienced from 2009 through 2011. Escapements were higher in 2010 and 2011, as a result of these very strong runs (Anderson and Nichols *In prep*). If there is an effect on rearing conditions of the recent high escapements it should be evident in smolt and limnology data during the next few years

MARINE SURVIVAL ESTIMATES

All adult sockeye salmon offspring from BYs 1991 through 2003 and most offspring from BY 2004 have returned to the Chignik River; overall marine survival has ranged from 6% for BY 1999 to 67% for BY 1993 (mean survival 19%; Table 6). The estimation of the 1993 and 1994 BY marine survival includes a portion of the emigration estimate from 1996, which is considered erroneous (Edwards and Bouwens 2002). When the data were presented by emigration year, marine survivals ranged from 5% for emigration year 2001 to 84% for emigration year 2007, with a mean survival rate of 22% (Table 7). The unrealistic marine survival estimate for emigration year 2007 is likely due to truly high survival and a biased low smolt emigration estimate (Fig. 7). Smolt were much larger than average that year so they entered the ocean in good condition and likely had higher survival than normal. 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 accounted for trap avoidance because trap catches were low for much of 2007 and did not allow 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 average is very close to the true value, 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. Forecast accuracy varies annually with no clear pattern of under- or over-forecasting by either sibling temperature relationships or smolt linear regression techniques.

The 2012 smolt-based forecast uses total smolt emigration and climate data to predict a total adult run of 1.9 million. This model reflects more of the general trend in smolt to adult returns and does not rely on just a few data points to make the relationship like some previous methods. Similar to the last few years, the point estimate is lower than that of the formal forecast which is 2.2 million for the combined 2012 run.

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 emigration 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. 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 emigrating juveniles.

Stewardship and CMA Schools

To involve the public with this study, a presentation describing the sockeye salmon life cycle and the Chignik Sockeye Salmon Smolt Enumeration project was given to students in Chignik Lake. The goal of the presentation 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, as well as encourage participation in a student internship. By actively promoting community youth involvement, it is hoped the smolt project can foster a sense of inclusion and in the many research and management projects the department oversees in the Chignik River Basin.

CONCLUSION

The continued collection of smolt emigration 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 simultaneously with warmer water temperatures since the 1960s. Timing of Black Lake smolt emigration to Chignik Lake has shifted earlier in the summer relative to 1970s timing (Westley et al. 2008). Chignik Lake species composition has shifted since the 1960s (Westley et al. 2009) to encompass increased proportions of non-sockeye species. 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. Top-down pressures on the Chignik Lake zooplankton community may be caused by over-grazing from rearing sockeye salmon, and likely influenced by migration of Black Lake juveniles and increased use of Chignik Lake resources. Continued monitoring of smolt outmigration and limnology in the system is the best way to detect changes in the early life history strategies that may be deleterious to this vital fishery.

ADF&G has conducted the smolt enumeration project since 1994 and in 2008 formally incorporated the collection of valuable limnological 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 for enhancing management of the system, such as targeting the lower ends of the escapement goals in light of overescapement and decreased rearing habitat in Black Lake. Genetic samples collected from emigrating sockeye salmon smolt will also provide a better understanding of ecological events in the watershed. Data from this project are essential for monitoring the health of sockeye salmon in Chignik system because smolt emigration information may be the only available means to link changes in run strength to freshwater or marine influences or climate change.

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TABLES AND FIGURES

Table 1.–Chignik River sockeye salmon smolt population estimates, by age class, 1994 to 2011.

		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			

Table 2.–Estimated sockeye salmon smolt emigration from the Chignik River in 2011 by age class and statistical week.

Statistical Week	Date	Number of Smolt age-0.	%	age-1.	%	age-2.	%	Total
18	4/26	279	4.2%	5,578	83.3%	837	13%	6,694
19	5/3	4,655	1.9%	231,209	94.3%	9,310	4%	245,174
20	5/10	10,069	1.0%	911,259	90.5%	85,588	9%	1,006,916
21	5/17	0	0.0%	2,641,881	90.0%	293,542	10%	2,935,424
22	5/24	27,058	0.5%	4,572,845	84.5%	811,748	15%	5,411,651
23	5/31	91,003	4.5%	1,820,056	90.0%	111,226	6%	2,022,285
24	6/7	54,535	10.5%	420,698	81.0%	44,147	9%	519,380
25	6/14	11,191	17.0%	43,119	65.5%	11,520	18%	65,831
26	6/21	3,072	9.2%	28,372	84.9%	1,988	6%	33,432
27	6/28	1,493	12.9%	8,959	77.4%	1,120	10%	11,573
28	7/5	24	12.9%	142	77.4%	18	10%	184
Total		203,380	1.7%	10,684,120	87.2%	1,371,044	11%	12,258,543

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

Table 3.–Results from mark-recapture tests performed on sockeye salmon smolt emigrating from the Chignik River, 2011.

Date	No. Marked	Total Recaptures	Trap Efficiency[a]
5/12-5/19	2,788	9	0.36%
5/20-5/25	2,675	8	0.34%
5/26- 6/1	2,520	52	2.10%
6/2- 6/8	2,642	28	1.10%
6/9- 6/16	2,822	51	1.84%
6/17- 7/6	550	8	1.63%
Total	13,998	156	1.23%

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

Table 4.–Length, weight, and condition factor of Chignik River sockeye salmon smolt samples in 2011, by age and statistical week. Totals weighted by sample size (SS) and by outmigration magnitude (OM).

				Length (mm)		Weight (g)		Condition Factor	
Age	Stat Week	Starting Date	Sample Size	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
0	18	4/26	1	46	0.00	0.7	0.00	0.72	0.00
0	19	5/3	3	55	6.36	1.3	0.55	0.68	0.04
0	20	5/10	2	56	6.00	1.1	0.40	0.59	0.04
0	22	5/24	1	49	0.00	0.8	0.00	0.68	0.00
0	23	5/31	9	50	0.85	1.0	0.07	0.82	0.02
0	24	6/7	21	49	1.14	1.0	0.08	0.88	0.01
0	25	6/14	34	48	0.39	1.0	0.03	0.86	0.01
0	26	6/21	17	50	0.75	1.1	0.06	0.91	0.02
0	27	6/28	12	48	1.13	1.0	0.08	0.87	0.02
Total	Weighted by SS		100	49	0.41	1.0	0.03	0.86	0.01
	Weighted by OM			50		1.0		0.81	
1	18	4/26	20	78	1.42	3.6	0.22	0.74	0.02
1	19	5/3	149	74	0.56	3.2	0.08	0.74	0.01
1	20	5/10	181	74	0.36	3.0	0.05	0.72	0.01
1	21	5/17	180	74	0.29	3.1	0.04	0.75	0.00
1	22	5/24	169	72	0.43	3.1	0.07	0.80	0.00
1	23	5/31	180	68	0.46	2.7	0.09	0.82	0.00
1	24	6/7	162	70	0.63	3.0	0.11	0.86	0.01
1	25	6/14	131	64	0.84	2.5	0.12	0.87	0.01
1	26	6/21	157	62	0.67	2.2	0.07	0.89	0.01
1	27	6/28	72	64	1.31	2.6	0.17	0.88	0.01
Total	Weighted by SS		1401	70	0.22	2.8	0.03	0.88	0.01
	Weighted by OM			72		3.0		0.79	
2	18	4/26	3	83	6.01	4.2	0.91	0.72	0.01
2	19	5/3	6	90	5.23	5.9	0.89	0.78	0.01
2	20	5/10	17	77	1.18	3.4	0.21	0.74	0.02
2	21	5/17	20	80	1.42	3.8	0.25	0.71	0.01
2	22	5/24	30	78	1.29	4.0	0.23	0.81	0.01
2	23	5/31	11	76	2.62	3.9	0.58	0.84	0.03
2	24	6/7	17	76	2.41	4.0	0.61	0.85	0.01
2	25	6/14	35	76	1.76	4.2	0.45	0.89	0.01
2	26	6/21	11	80	3.85	4.8	0.99	0.88	0.02
2	27	6/28	9	78	1.22	4.4	0.2	0.94	0.015
Total	Weighted by SS		159	78	0.71	4.1	0.16	0.82	0.01
	Weighted by OM			78		3.9		0.79	

Table 5.–Mean length, weight, and condition factor of sockeye salmon smolt samples from the Chignik River, by year and age, 1994 to 2011.

		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
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
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	0.3	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

- 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
2001	4	1	125	-	1	18.8	-	1	0.96	-

Table 6.–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 2004.

Brood Year	Escapement	Smolt Produced Age-0.	Age-1.	Age-2.	Age-3.	Total Smolt	Smolt / Spawner	Adult Returns Age-0.	Age-1.	Age-2.	Age-3.	Total	Return / Spawner	Marine 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				
2006	735,493	9,286	3,309,894	4,874,340	91,509	8,285,029	11.3	33,123	2,808,615					
2007	654,974	1,017,498	3,242,862	9,347,999	0	13,608,359	20.78	45,736						
2008	706,058	59,306	17,684,165	1,371,044										
2009	720,062	1,039,131	10,684,120											
2010	743,911	203,380												
2011	753,817													
1994-2004 Average, excluding 1996														19%

[a] 1993 data are presented, but considered erroneous due to unrealistic survival estimates and thus not used in subsequent calculations.

Table 6.–Chignik River sockeye salmon smolt estimates, ocean-age-class returns , and marine survival by emigration years 1994 through 2007.

Emigration	Smolt estimates					Adult returns					Marine Survival
Year	Age-0.	Age-1.	Age-2.	Age-3.	Total	Age-.1	Age-.2	Age-.3	Age-.4	Total	
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			
2009	110,446	3,777,572	4,288,491	0	8,176,509	6,022	425,225				
2010	1,039,131	17,684,165	9,347,999	91,509	28,162,803	6,097					
2011	203,380	10,684,120	1,371,044	0	12,258,543						
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.

Table 7.–Euphotic Zone Depth (EZD) and Euphotic Volume (EV) of Chignik and Black lakes, by month, 2011.

		2011					
Lake		May	June	July	August	September	Average[a]
Chignik	EZD	10.96	7.05	9.49		6.12	8.41
	Mean EV[c]	264.1	169.9	228.7		147.5	202.7
Black[b]	EZD	5.35	3.63	3.50	2.28		3.69
	Mean EV[c]	78.09	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 8.–Water quality parameters, nutrient concentrations, and photosynthetic pigments by sample date for Black Lake, 2011.

	2011				
	23-May	20-Jun	14-Jul	31-Aug	Average
pH	7.82	7.55	7.45	7.94	7.69
Alkalinity (mg/L $CaCO_3$)	30.0	21.0	25.0	30.5	26.6
Total phosphorous (µg/L P)	26.5	43.1	36.4	31.3	34.3
Total filterable phosphorous (µg/L P)	6.4	3.3	3.2	4.3	4.3
Filterable reactive phosphorous (µg/L P)	4.0	4.2	1.8	2.6	3.2
Total kjedhal nitrogen (µg/L N)	706.0	344.0	316.0	340.0	426.5
Ammonia (µg/L N)	3.4	2.1	5.0	2.6	3.3
Nitrate + Nitrite (µg/L N)	3.4	0.2	0.6	0.2	1.1
Silicon (µg/L)	1610.5	1513.8	4094.0	4484.4	2925.7
Chlorophyll a (µg/L)	1.5	3.4	3.2	10.4	4.6
Phaeophytin a (µg/L)	0.1	0.1	1.0	1.1	0.5

Table 9.–Water-quality parameters, nutrient concentrations, and photosynthetic pigments by sample date for Chignik Lake, 2011. All stations and depths are averaged for each sample date.

	2011				
	19-May	6-Jun	2-Jul	1-Sep	Average
pH	7.64	7.42	7.60	7.41	7.52
Alkalinity (mg/L $CaCO_3$)	23.5	23.1	22.9	22.3	22.9
Total phosphorous (µg/L P)	11.9	16.3	10.2	11.2	12.4
Total filterable phosphorous (µg/L P)	3.4	3.6	2.6	3.5	3.3
Filterable reactive phosphorous (µg/L P)	1.8	5.5	6.3	6.7	5.1
Total kjedhal nitrogen (µg/L N)	155.0	171.0	135.0	143.0	151.0
Ammonia (µg/L N)	3.2	7.5	5.4	17.0	8.3
Nitrate + Nitrite (µg/L N)	241.0	218.4	162.9	126.2	187.1
Silicon (µg/L)	2840.2	2623.4	2970.1	3430.5	2966.0
Chlorophyll a (µg/L)	2.1	1.7	2.4	2.6	2.2
Phaeophytin a (µg/L)	0.3	0.5	0.5	0.5	0.4

Table 10.–Average number of zooplankton by taxon per m^2 from Black Lake by sample date, 2011.

Taxon		Sample date				Seasonal
		23-May	20-Jun	14-Jul	31-Aug	average
Copepods						
	Epischura	1,274	5,308	3,822	1,274	2,919
	Ovig. Epischura	0	2,123	0	0	531
	Eurytemora	637	2,654	3,822	3,185	2,574
	Ovig. Eurytemora	0	7,431	4,459	2,548	3,609
	Cyclops	1,911	28,132	8,280	7,006	11,332
	Ovig. Cyclops	0	5,839	1,274	637	1,937
	Nauplii	2,548	36,624	31,847	15,924	21,736
Total copepods		6,369	88,110	53,503	30,573	44,639
Cladocerans						
	Bosmina	955	1,062	7,643	4,459	3,530
	Ovig. Bosmina	0	48,301	73,885	108,280	57,617
	Daphnia l.	318	0	0	0	80
	Chydorinae	0	9,554	15,287	12,102	9,236
Total cladocerans		1,274	58,917	96,815	124,841	70,462
Total copepods + cladocerans		7,643	147,028	150,318	155,414	115,101

Table 11.–Biomass estimates (mg dry weight/m^2) of the major Black Lake zooplankton taxa by sample date, 2011.

Taxon		Sample date				Seasonal	Weighted
		23-May	20-Jun	14-Jul	31-Aug	average	average
Copepods							
	Epischura	0.82	3.92	2.09	1.00	1.96	1.94
	Ovig. Epischura	-	3.99	-	-	1.00	1.00
	Eurytemora	1.06	8.04	9.07	7.04	6.31	6.26
	Ovig. Eurytemora	-	54.80	38.70	22.71	29.05	28.98
	Cyclops	1.71	26.73	8.64	6.66	10.94	10.93
	Ovig. Cyclops	-	12.73	4.44	1.50	4.67	4.62
Total copepods		3.60	110.20	62.95	38.91	53.91	53.73
Cladocerans							
	Bosmina	0.75	0.66	5.48	2.65	2.39	2.38
	Ovig. Bosmina	-	67.39	103.35	137.38	77.03	76.98
	Daphnia l.	0.68	-	-	-	0.17	0.17
	Chydorinae	-	5.13	8.40	6.55	5.02	5.02
Total cladocerans		1.43	73.17	117.23	146.58	84.60	84.55
Total Biomass		5.02	183.37	180.17	185.49	138.51	138.28

Table 12.–Average length (mm) of zooplankton in Black Lake by sample date, 2011.

Taxon		Sample date				Seasonal
		23-May	20-Jun	14-Jul	31-Aug	average
Copepods						
	Epischura	0.51	0.53	0.48	0.54	0.51
	Ovig. Epischura		0.74			0.74
	Eurytemora	0.72	0.88	0.81	0.79	0.80
	Ovig. Eurytemora		1.21	1.28	1.30	1.26
	Cyclops	0.52	0.54	0.56	0.54	0.54
	Ovig. Cyclops		0.79	0.99	0.82	0.87
Cladocerans						
	Bosmina	0.30	0.27	0.28	0.26	0.28
	Ovig. Bosmina		0.39	0.39	0.37	0.38
	Daphnia l.	0.70				0.70
	Chydorinae		0.25	0.25	0.25	0.25

Table 13.–Average number of zooplankton by taxon per m^2 from Chignik Lake, by sample date, 2011.

Taxon		Sample date				Seasonal
		19-May	6-Jun	2-Jul	30-Aug	Average
Copepods						
	Epischura	3,298	6,170	17,516	42,662	17,411
	Ovig. Epischura	0	0	531	531	265
	Eurytemora	1,898	10,576	21,497	38,283	18,063
	Ovig. Eurytemora	0	212	1,592	44,984	11,697
	Cyclops	235,105	155,255	127,919	50,756	142,259
	Ovig. Cyclops	0	836	24,947	1,592	6,844
	Nauplii	29,910	27,601	109,076	88,110	63,674
Total copepods		270,210	200,650	303,079	266,919	260,214
Cladocerans						
	Bosmina	717	5,069	24,947	9,289	10,005
	Ovig. Bosmina	133	292	27,601	54,936	20,740
	Daphnia l.	4,505	1,566	3,715	33,041	10,707
	Daphnia l. ovig	863	199	1,858	28,729	7,912
	Chydorinae	458	3,450	12,208	5,308	5,356
Total cladocerans		6,675	10,576	70,329	131,303	54,721
Total copepods + cladocerans		276,884	211,226	373,408	398,222	314,935

Table 14.–Biomass estimates (mg dry weight/m^2) of the major zooplankton species in Chignik Lake by sample date, 2011.

Taxon		Sample date				Seasonal	Weighted
		19-May	6-Jun	2-Jul	30-Aug	Average	average
Copepods							
	Epischura	4.55	7.23	19.28	35.55	16.65	16.26
	Ovig. Epischura	-	-	1.37	3.54	1.23	0.62
	Eurytemora	6.23	51.49	123.21	92.71	68.41	64.66
	Ovig. Eurytemora	-	9.62	20.74	438.32	117.17	86.58
	Cyclops	216.12	251.79	193.75	43.79	176.36	172.55
	Ovig. Cyclops	-	4.41	163.81	12.81	45.26	44.04
Total copepods		226.90	324.54	522.16	626.72	422.68	384.71
Cladocerans							
	Bosmina	4.99	7.65	22.10	5.68	10.10	8.57
	Ovig. Bosmina	0.83	2.21	47.65	62.57	28.32	27.36
	Daphnia l.	7.54	5.13	4.97	21.82	9.86	7.98
	Daphnia l. ovig	2.12	1.91	6.51	67.66	19.55	18.62
	Chydorinae	0.83	2.19	8.82	2.98	3.70	3.43
Total cladocerans		16.30	19.08	90.04	160.71	71.53	65.97
Total copepods + cladocerans		243.21	343.63	612.20	787.43	494.21	450.67

Table 15.–Average length (mm) of zooplankton from Chignik Lake by sample date, 2011.

Taxon		Sample date				Seasonal
		19-May	6-Jun	2-Jul	30-Aug	Average
Copepods						
	Epischura	0.60	0.62	0.60	0.55	0.59
	Ovig. Epischura			0.51	0.71	0.61
	Eurytemora	0.80	1.03	1.13	0.83	0.96
	Ovig. Eurytemora		1.41	1.36	1.21	1.29
	Cyclops	0.53	0.68	0.67	0.48	0.59
	Ovig. Cyclops		0.84	1.13	1.28	1.09
Cladocerans						
	Bosmina	0.43	0.37	0.31	0.25	0.31
	Ovig. Bosmina	0.41	0.45	0.43	0.36	0.40
	Daphnia l.	0.57	0.57	0.48	0.41	0.48
	Daphnia l. ovig	0.64	0.74	0.71	0.73	0.70
	Chydorinae	0.33	0.23	0.28	0.25	0.27

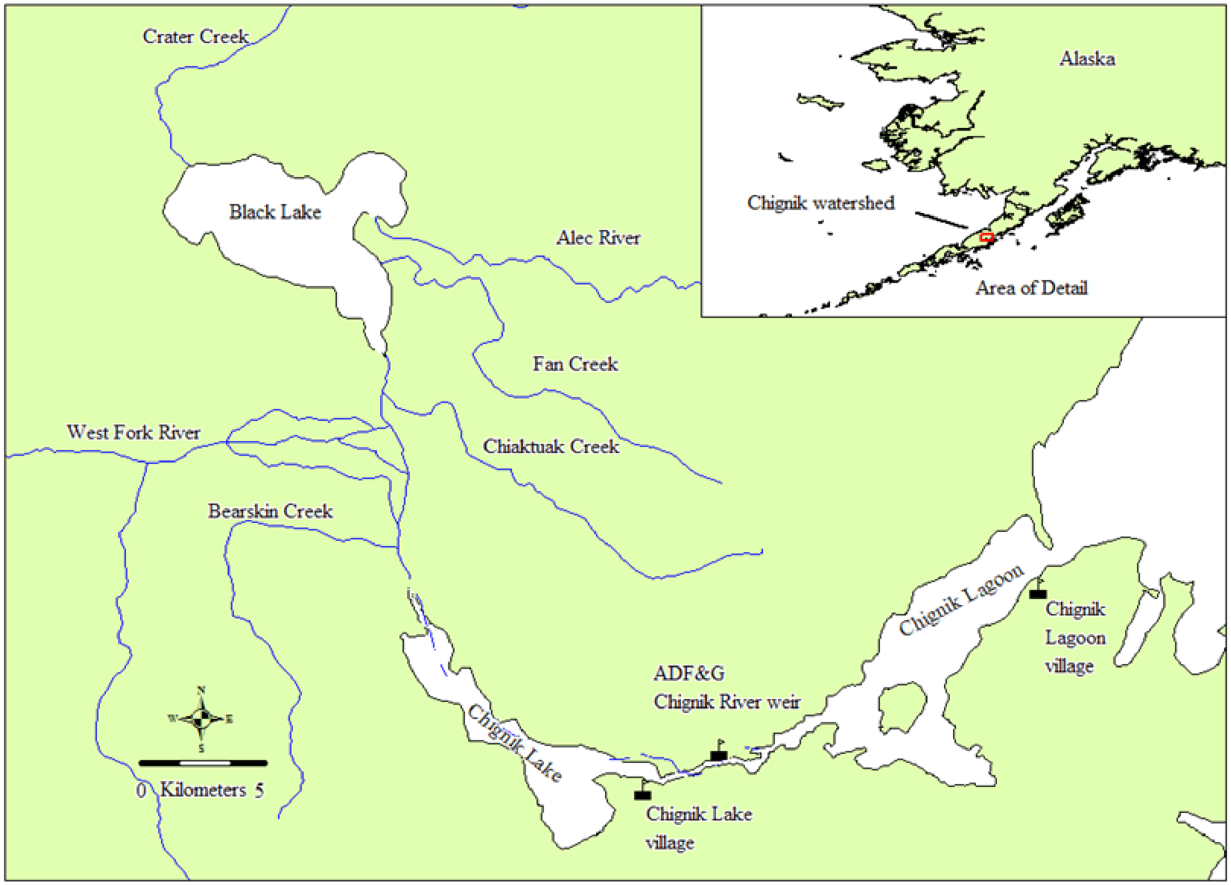


Figure 1.–Map of the Chignik River Basin.

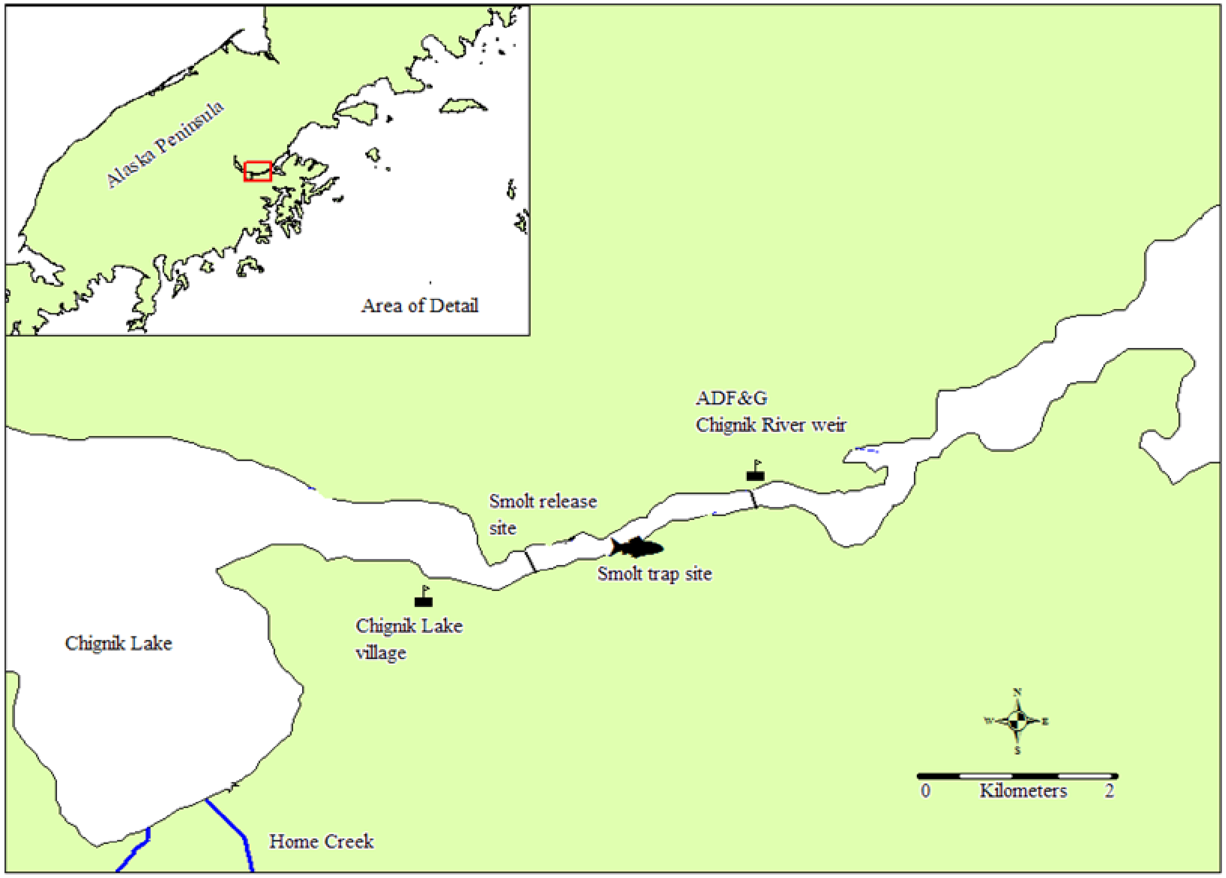


Figure 2.–Location of the traps and the release site of marked smolt in the Chignik River, Alaska, 2011.

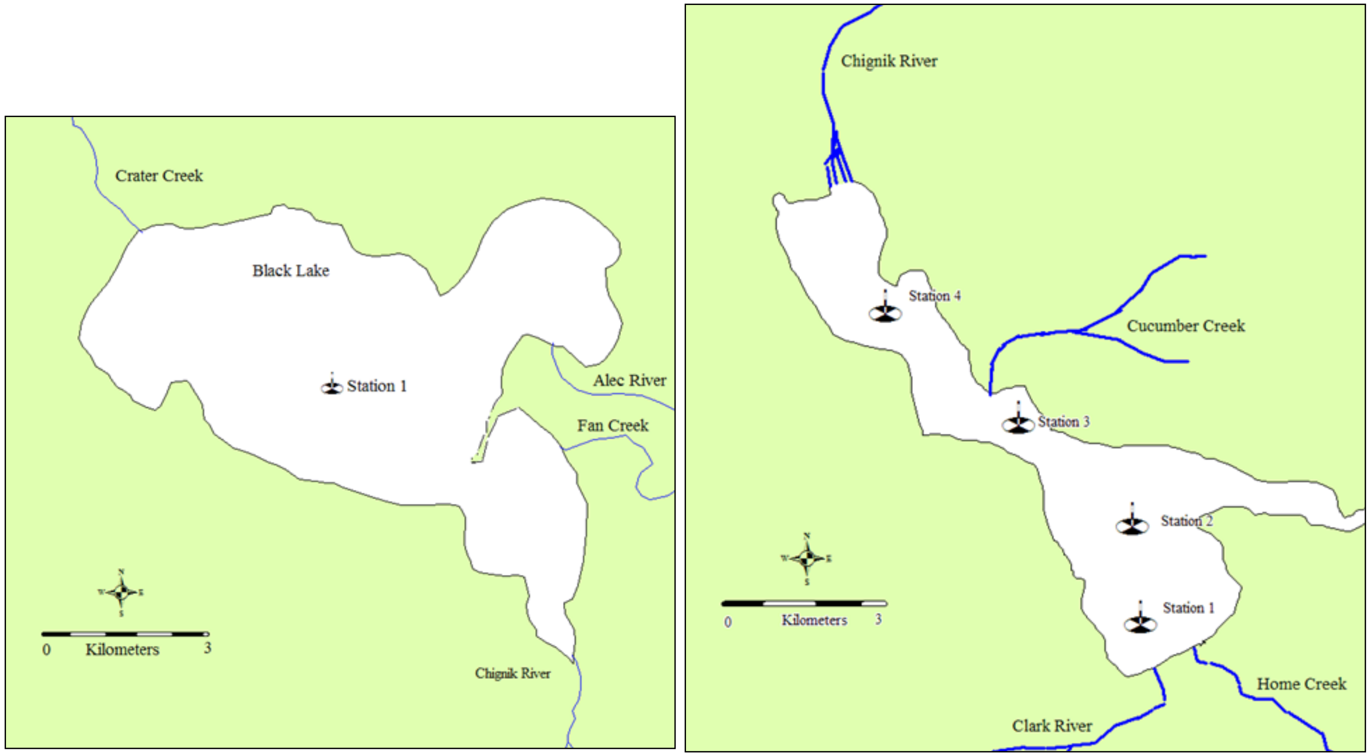


Figure 3.–Location of the Black Lake and Chignik Lake limnology sampling stations, 2011.

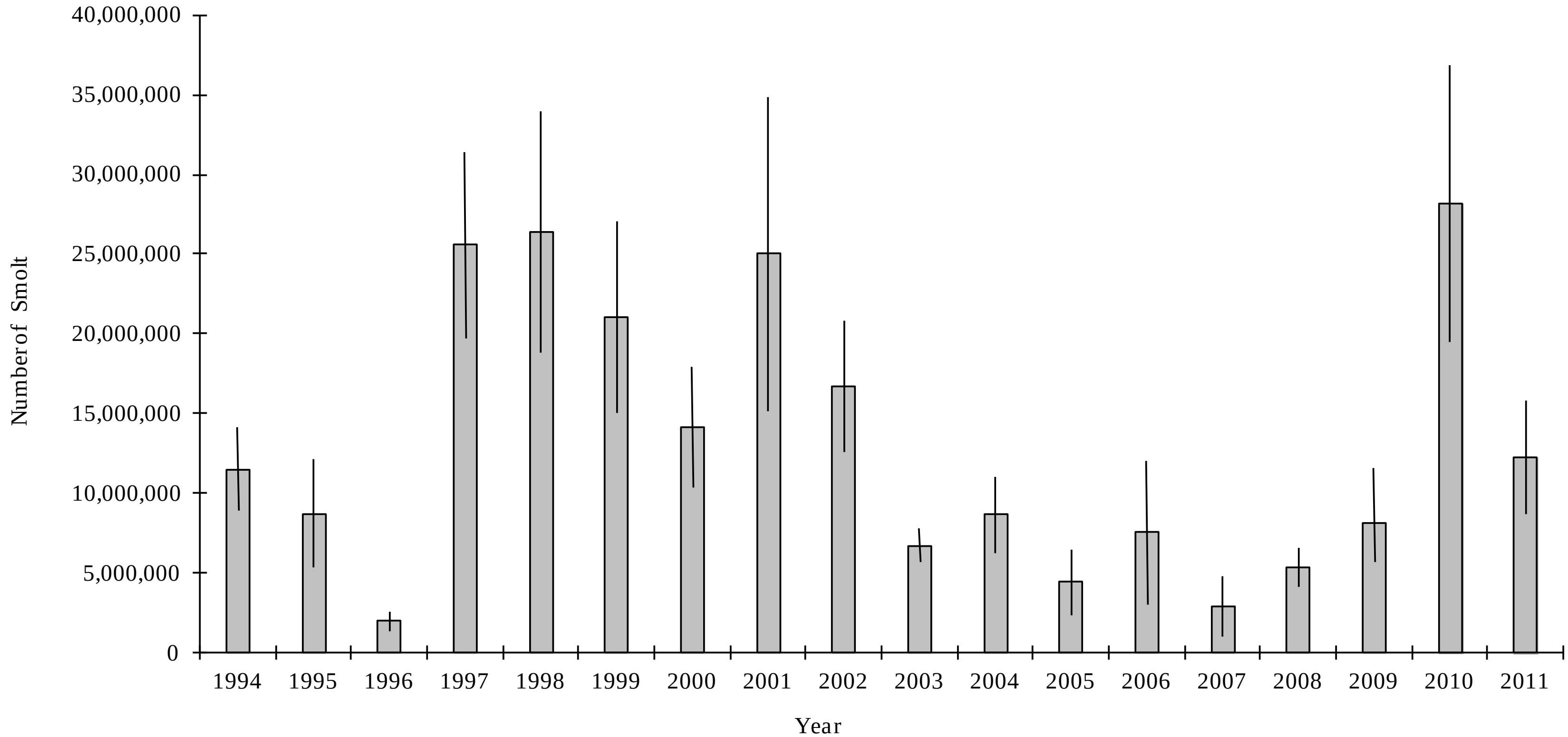


Figure 4.–Annual sockeye salmon smolt emigration estimates and corresponding 95% confidence intervals, Chignik River, 1994–2011. Emigration estimates from 1996 were underestimated.

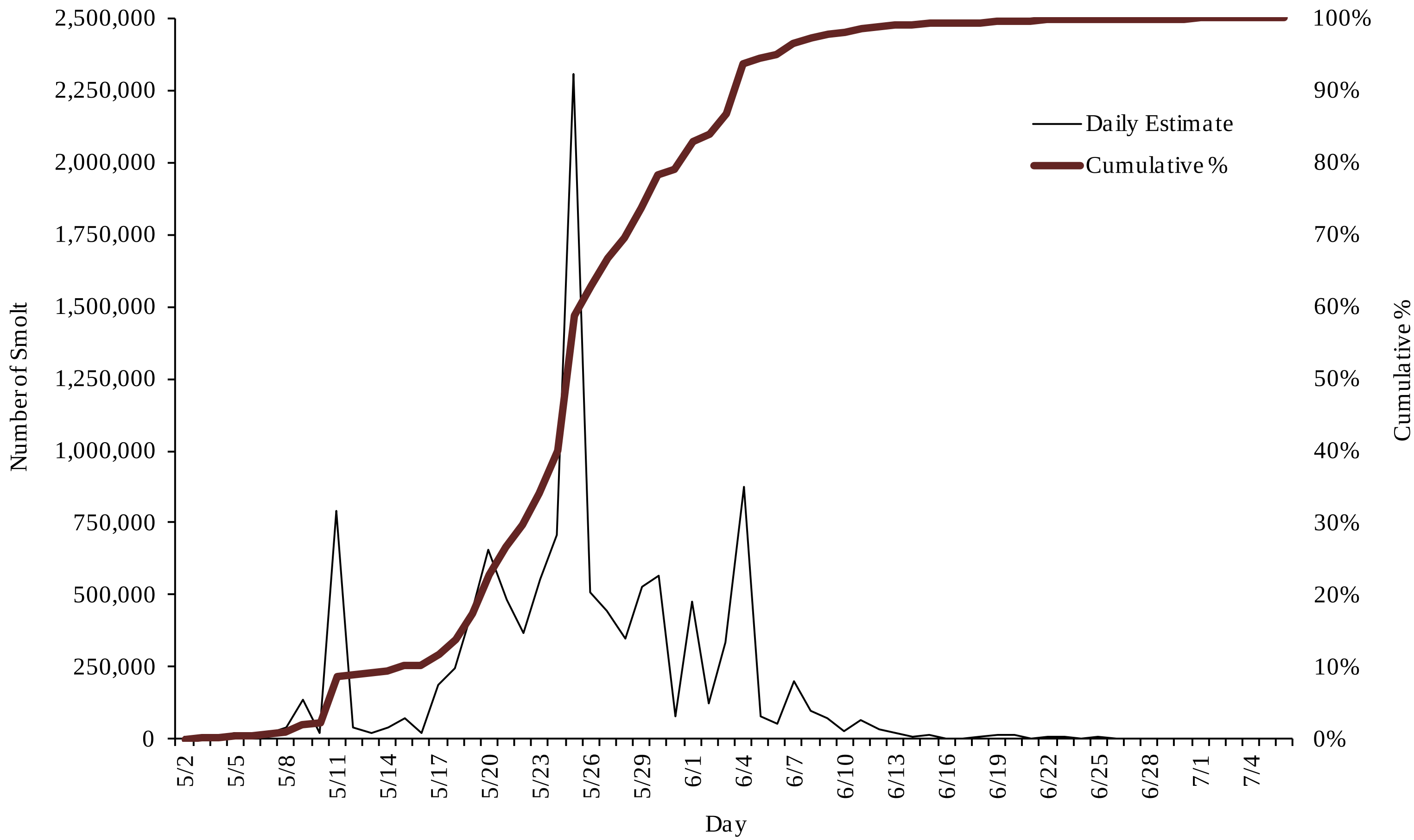


Figure 5.–Daily estimate and cumulative percentage of the sockeye salmon smolt emigration from the Chignik River in 2011.

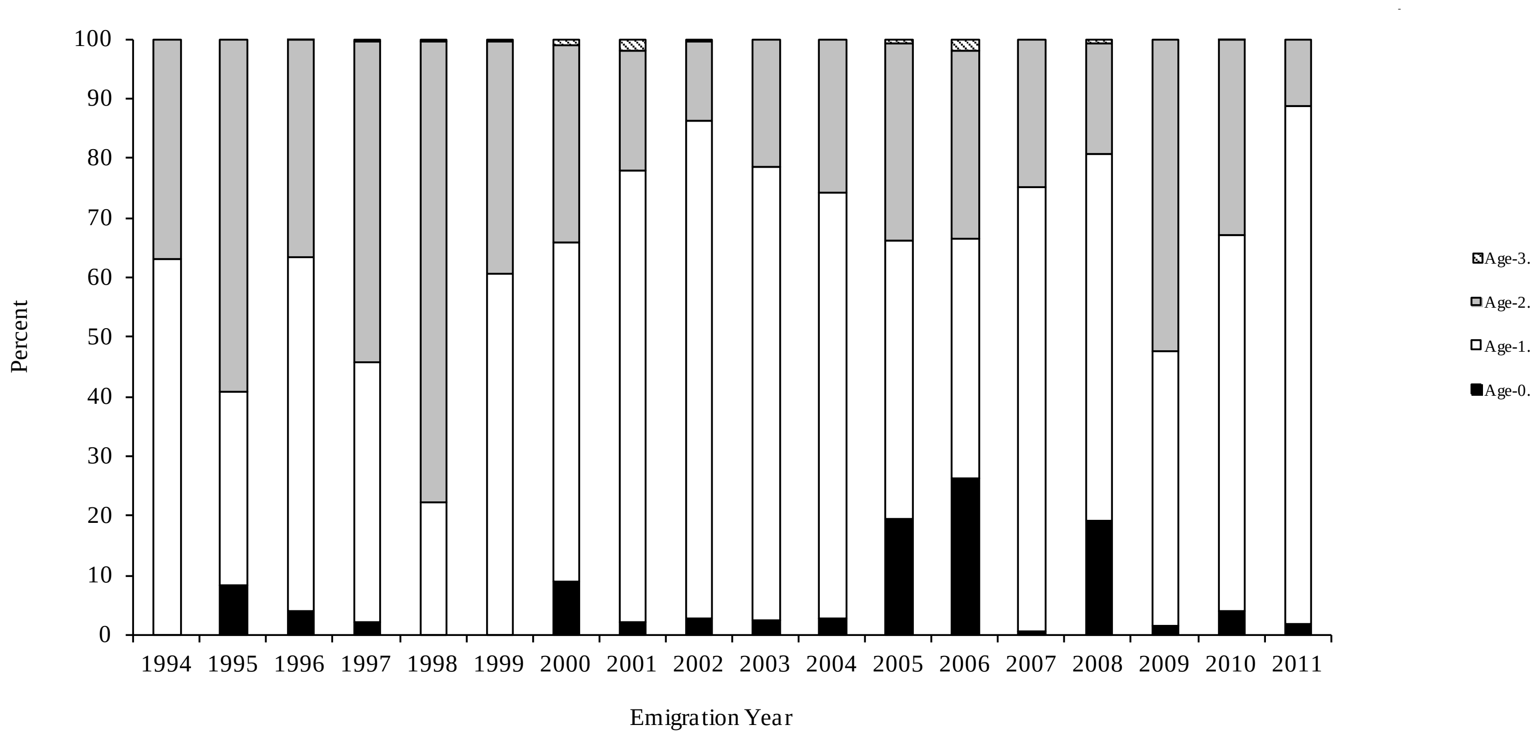


Figure 6.–A comparison of the estimated age structure of age-0. to age-3. sockeye salmon smolt emigrations from the Chignik River, 1994–2011.

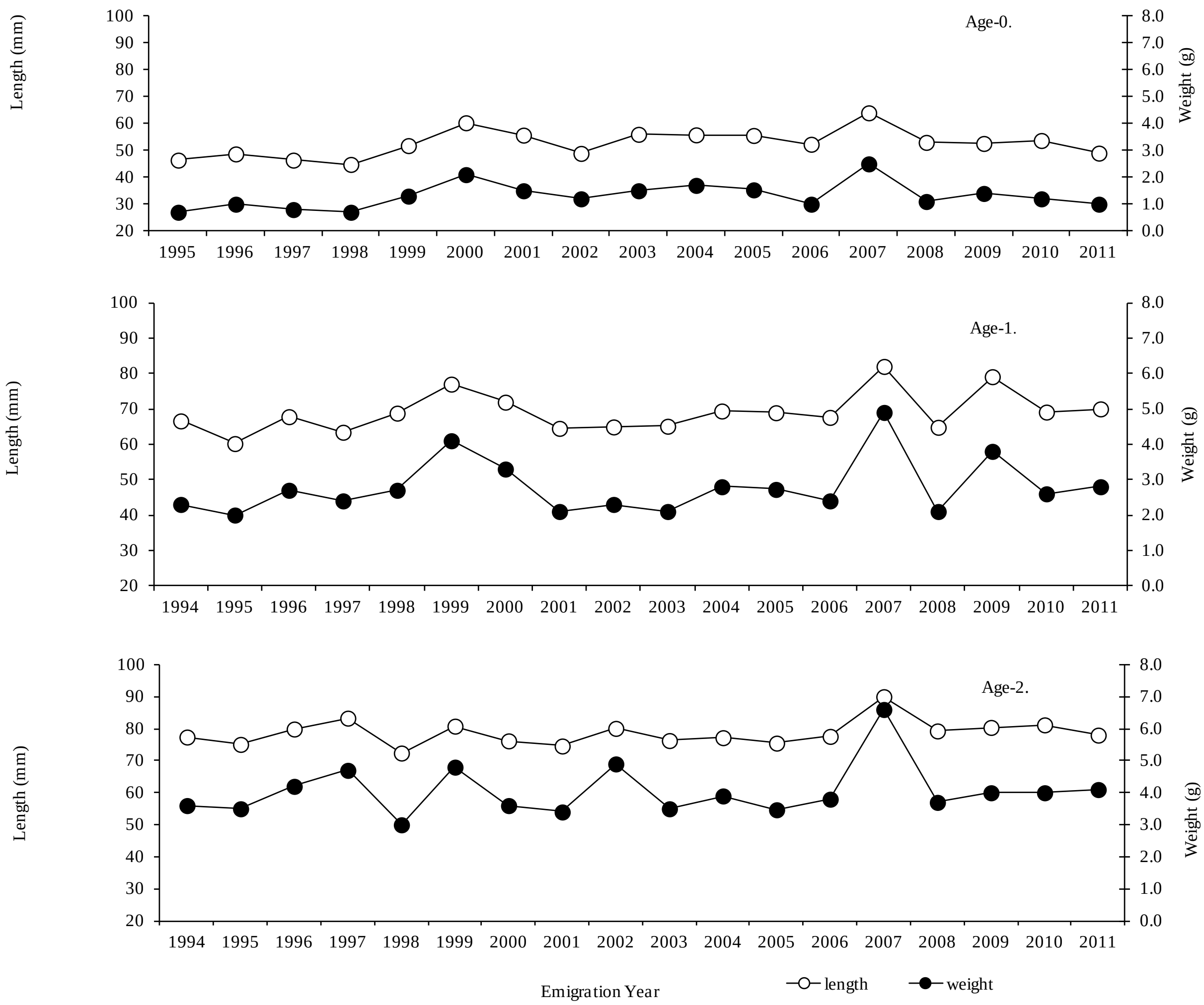


Figure 7.–Average length and weight of sampled age-0., age-1. and age-2. sockeye salmon smolt, by year from 1994 to 2011. Age-3. smolt comprise such a small percentage of the yearly population as to be negligible.

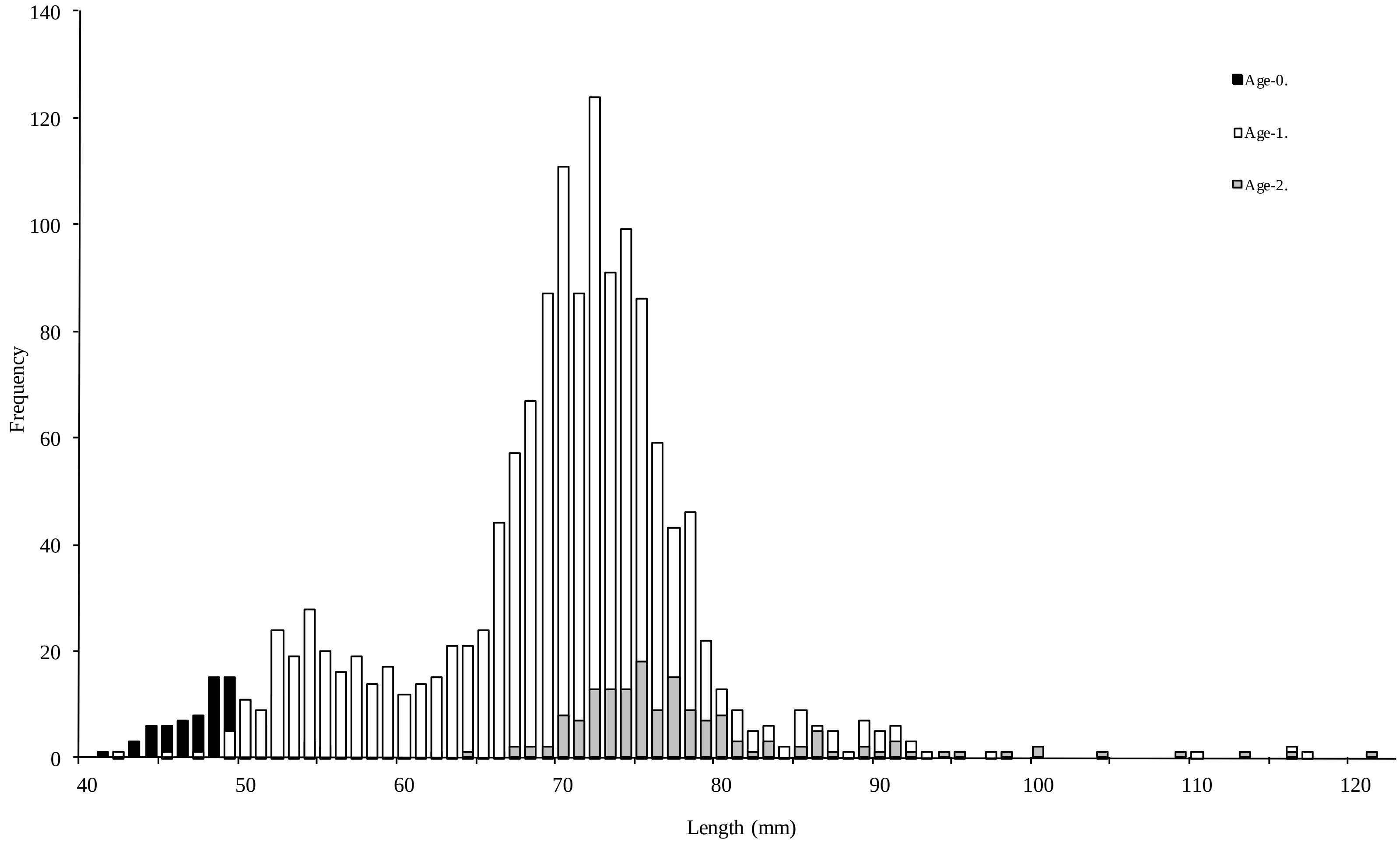


Figure 8.–Length frequency histogram of sockeye salmon smolt from the Chignik River in 2011 by age.

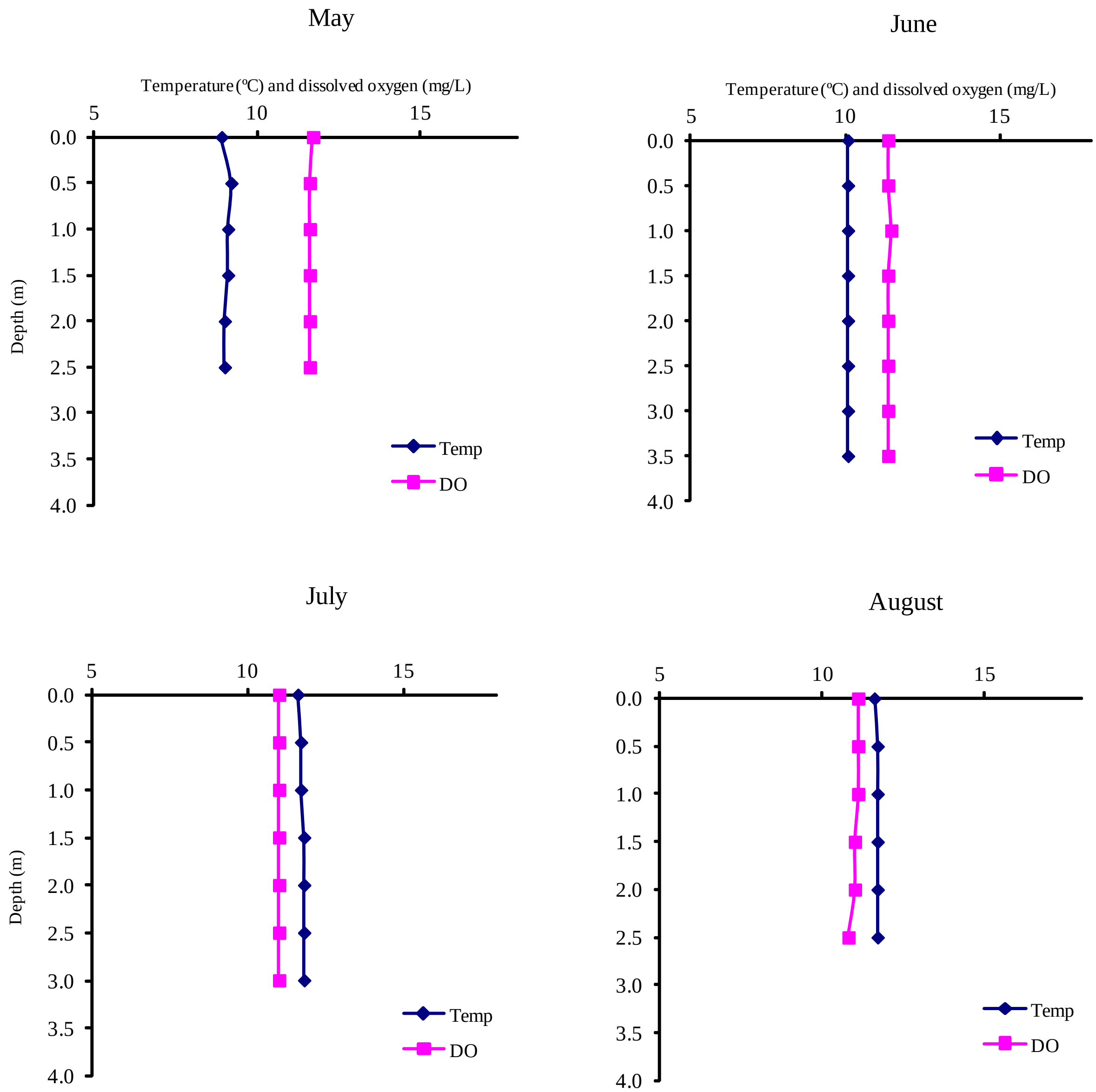


Figure 9.–Mean monthly temperature and dissolved oxygen profiles in Black Lake in 2011.

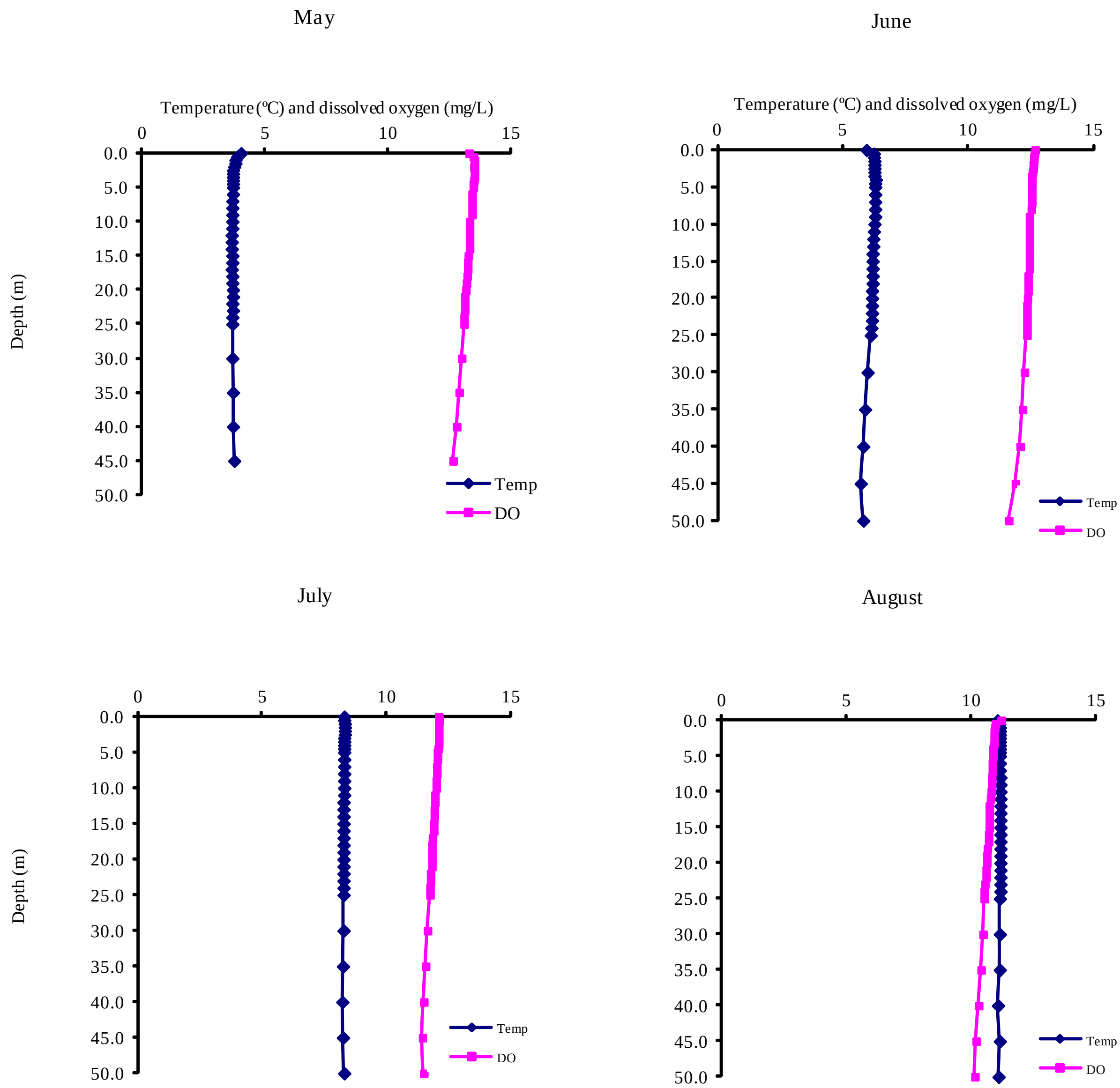
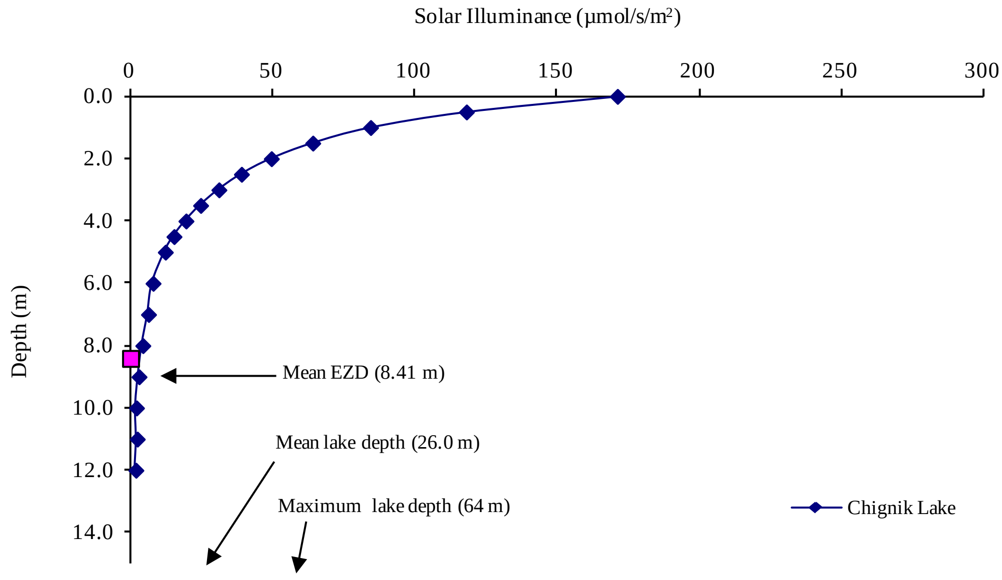


Figure 10.–Mean monthly temperature and dissolved oxygen profiles in Chignik Lake in 2011.



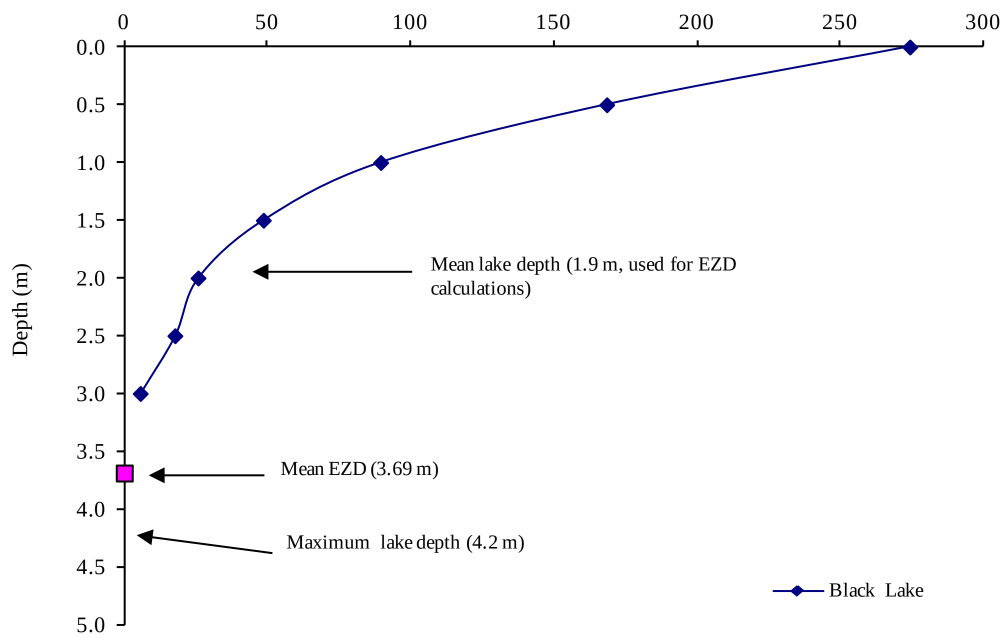


Figure 11.–Light penetration curves relative to mean depth, euphotic zone depth (EZD), and maximum depth in Chignik and Black lakes in 2011.

APPENDIX A. SMOLT TRAP CATCHES BY DAY

Appendix A1.–2011 Daily trap catch and efficiency.

	Actual Sockeye Smolt		Trap Efficiency Test				Incidental Catch[a]											
Date	Daily	Cum.	Marked	Daily Recoveries	Cum. Recoveries	Efficiency[b]	Soc Fry	Coho	Pink	Chnk	Chum	DV	SB	SC	SF	PS	PW	AB
2-May	24	24	0	0	0	0.36%	40	0	0	0	0	0	20	17	1	1	0	0
3-May	20	44	0	0	0	0.36%	42	0	0	0	0	2	65	11	0	2	0	0
4-May	37	81	0	0	0	0.36%	46	0	0	1	0	2	51	12	3	1	0	0
5-May	79	160	0	0	0	0.36%	34	1	0	1	0	2	66	9	0	0	0	0
6-May	38	198	0	0	0	0.36%	39	2	0	1	0	1	60	7	0	0	0	2
7-May	66	264	0	0	0	0.36%	67	0	0	1	0	0	72	6	0	1	1	0
8-May	138	402	0	0	0	0.36%	111	4	0	0	0	5	95	5	0	1	1	0
9-May	501	903	0	0	0	0.36%	398	5	2	0	0	3	202	7	4	1	1	0
10-May	76	979	0	0	0	0.36%	576	0	0	3	0	1	95	0	0	0	0	0
11-May	2,842	3,821	0	0	0	0.36%	347	3	0	0	0	1	332	1	0	1	1	1
12-May	136	3,957	2,788	9	9	0.36%	899	1	0	0	0	0	323	0	0	0	0	0
13-May	71	4,028	0	0	9	0.36%	356	1	0	1	0	1	230	3	0	0	0	0
14-May	149	4,177	0	0	9	0.36%	385	0	0	0	0	0	160	0	0	1	0	0
15-May	268	4,445	0	0	9	0.36%	540	2	20	1	0	0	223	0	0	0	0	0
16-May	69	4,514	0	0	9	0.36%	393	1	4	0	0	0	160	1	0	0	0	0
17-May	667	5,181	0	0	9	0.36%	167	0	1	1	0	0	132	0	0	0	0	0
18-May	874	6,055	0	0	9	0.36%	140	1	0	1	0	1	174	0	0	0	1	0
19-May	1,579	7,634	0	0	9	0.36%	175	1	0	1	0	0	226	0	1	0	1	0
20-May	2,213	9,847	2,675	5	5	0.34%	214	3	0	3	0	0	203	3	2	1	0	0
21-May	1,635	11,482	0	2	7	0.34%	110	3	0	1	0	0	200	5	1	0	1	1
22-May	1,235	12,717	0	1	8	0.34%	135	1	0	0	0	0	201	0	0	0	0	0
23-May	1,862	14,579	0	0	8	0.34%	218	0	0	0	0	1	208	3	1	0	0	0
24-May	2380	16,959	0	0	8	0.34%	181	30	0	21	0	9	65	2	1	0	2	0
25-May	7,765	24,724	0	0	8	0.34%	291	10	0	5	0	3	193	1	0	0	0	0
26-May	10,682	35,406	2,520	51	51	2.10%	227	4	0	11	0	0	68	8	0	1	1	0
27-May	9,365	44,771	0	1	52	2.10%	456	11	0	9	0	5	333	6	2	1	3	0
28-May	7,307	52,078	0	0	52	2.10%	503	6	0	4	0	13	376	9	2	2	5	0
29-May	11,107	63,185	0	0	52	2.10%	445	1	0	15	0	16	322	10	1	0	6	0
30-May	11,884	75,069	0	0	52	2.10%	528	4	0	12	0	10	232	28	4	7	7	0
31-May	1,623	76,692	0	0	52	2.10%	461	9	0	29	0	27	297	10	3	4	5	0

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	Actual Sockeye Smolt		Trap Efficiency Test				Incidental Catch[a]											
Date	Daily	Cum.	Marked	Daily Recoveries	Cum. Recoveries	Efficiency[b]	Soc Fry	Coho	Pink	Chnk	Chum	DV	SB	SC	SF	PS	PW	AB
1-Jun	10,069	86,761	0	0	52	2.10%	388	19	2	26	0	63	390	10	0	1	7	0
2-Jun	1,337	88,098	2,642	19	19	1.10%	351	18	0	18	0	39	236	9	5	7	2	0
3-Jun	3,667	91,765	0	8	27	1.10%	190	5	1	12	0	37	289	9	2	1	6	1
4-Jun	9,625	101,390	0	1	28	1.10%	201	3	0	20	0	50	266	17	1	0	3	0
5-Jun	875	102,265	0	0	28	1.10%	120	7	2	13	0	14	377	5	2	4	2	0
6-Jun	585	102,850	0	0	28	1.10%	119	5	2	11	0	9	279	6	0	1	0	0
7-Jun	2,227	105,077	0	0	28	1.10%	87	11	3	22	0	12	266	5	1	3	4	0
8-Jun	1,047	106,124	0	0	28	1.10%	47	7	1	26	0	15	314	7	0	4	1	0
9-Jun	1,343	107,467	2,822	46	46	1.84%	43	9	1	18	0	6	611	1	2	5	5	0
10-Jun	494	107,961	0	2	48	1.84%	51	4	0	21	0	2	640	0	1	6	1	0
11-Jun	1,183	109,144	0	2	50	1.84%	56	2	1	11	0	1	324	0	2	2	1	0
12-Jun	626	109,770	0	0	50	1.84%	39	0	2	8	0	0	284	0	1	4	0	0
13-Jun	425	110,195	0	1	51	1.84%	153	0	0	0	0	0	326	2	0	3	0	0
14-Jun	154	110,349	0	0	51	1.84%	36	0	3	13	0	2	272	0	0	3	0	0
15-Jun	325	110,674	0	0	51	1.84%	61	0	1	8	0	0	215	0	1	2	0	0
16-Jun	85	110,759	0	0	51	1.84%	67	0	0	8	0	0	198	2	0	4	0	0
17-Jun	65	110,824	550	6	6	1.63%	78	0	0	13	0	3	178	2	0	1	0	0
18-Jun	88	110,912	0	0	6	1.63%	36	0	2	12	0	1	237	3	0	0	4	0
19-Jun	196	111,108	0	1	7	1.63%	86	0	6	7	0	1	304	1	2	5	0	0
20-Jun	226	111,334	0	1	8	1.63%	229	2	3	21	0	0	612	1	1	1	0	0
21-Jun	78	111,412	0	0	8	1.63%	58	1	2	7	0	1	475	2	2	2	0	0
22-Jun	126	111,538	0	0	8	1.63%	322	1	0	8	0	0	218	1	1	0	0	0
23-Jun	103	111,641	0	0	8	1.63%	85	3	0	24	1	0	192	3	0	0	4	0
24-Jun	62	111,703	0	0	8	1.63%	102	1	0	7	1	1	75	0	0	1	0	0
25-Jun	89	111,792	0	0	8	1.63%	24	1	1	19	0	0	94	0	1	0	2	0
26-Jun	36	111,828	0	0	8	1.63%	13	0	0	19	0	0	105	1	1	2	1	0
27-Jun	52	111,880	0	0	8	1.63%	51	31	0	0	0	0	128	3	0	1	2	0
28-Jun	66	111,946	0	0	8	1.63%	216	82	0	0	0	13	745	18	1	3	6	0
29-Jun	19	111,965	0	0	8	1.63%	59	49	0	0	0	4	362	2	0	2	2	0
30-Jun	22	111,987	0	0	8	1.63%	16	52	1	2	0	5	298	10	0	1	6	0

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	Actual Sockeye Smolt		Trap Efficiency Test				Incidental Catch[a]											
Date	Daily	Cum.	Marked	Daily Recoveries	Cum. Recoveries	Efficiency[b]	Soc Fry	Coho	Pink	Chnk	Chum	DV	SB	SC	SF	PS	PW	AB
1-Jul	19	112,006	0	0	8	1.63%	7	39	2	3	0	4	228	3	2	3	4	0
2-Jul	10	112,016	0	0	8	1.63%	10	62	0	3	0	5	139	0	0	0	6	0
3-Jul	26	112,042	0	0	8	1.63%	10	56	0	2	0	4	165	6	0	0	6	0
4-Jul	27	112,069	0	0	8	1.63%	13	24	0	0	0	3	130	4	0	0	4	0
5-Jul	3	112,072	0	0	8	1.63%	1	9	0	0	0	1	62	3	0	0	2	0
6-Jul	0	112,072	0	0	8	1.63%	0	11	0	1	0	0	23	3	0	0	2	0
Total		112,072	13,998	156	1,218	1.19%	11,949	618	63	505	2	399	15,441	303	55	97	119	5

[a] 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.

[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).

APPENDIX B. SMOLT CATCHES BY TRAP

Appendix B1.–Number of sockeye salmon smolt caught by trap, by day, from the Chignik River, May 2 through July 6, 2011.

	Small Trap		Large Trap		Combined		Daily Proportion	
Date	Daily	Cumulative	Daily	Cumulative	Daily	Cumulative	Small	Large
5/2	4	4	20	20	24	24	16.7%	83.3%
5/3	11	15	9	29	20	44	55.0%	45.0%
5/4	11	26	26	55	37	81	29.7%	70.3%
5/5	39	65	40	95	79	160	49.4%	50.6%
5/6	9	74	29	124	38	198	23.7%	76.3%
5/7	15	89	51	175	66	264	22.7%	77.3%
5/8	36	125	102	277	138	402	26.1%	73.9%
5/9	100	225	401	678	501	903	20.0%	80.0%
5/10	3	228	73	751	76	979	3.9%	96.1%
5/11	394	622	2,448	3,199	2,842	3,821	13.9%	86.1%
5/12	27	649	109	3,308	136	3,957	19.9%	80.1%
5/13	22	671	49	3,357	71	4,028	31.0%	69.0%
5/14	35	706	114	3,471	149	4,177	23.5%	76.5%
5/15	62	768	206	3,677	268	4,445	23.1%	76.9%
5/16	16	784	53	3,730	69	4,514	23.2%	76.8%
5/17	69	853	598	4,328	667	5,181	10.3%	89.7%
5/18	75	928	799	5,127	874	6,055	8.6%	91.4%
5/19	255	1,183	1,324	6,451	1,579	7,634	16.1%	83.9%
5/20	307	1,490	1,906	8,357	2,213	9,847	13.9%	86.1%
5/21	257	1,747	1,378	9,735	1,635	11,482	15.7%	84.3%
5/22	208	1,955	1,027	10,762	1,235	12,717	16.8%	83.2%
5/23	283	2,238	1,579	12,341	1,862	14,579	15.2%	84.8%
5/24	17	2,255	2,363	14,704	2,380	16,959	0.7%	99.3%
5/25	1,754	4,009	6,011	20,715	7,765	24,724	22.6%	77.4%
5/26	1,179	5,188	9,503	30,218	10,682	35,406	11.0%	89.0%
5/27	1,491	6,679	7,874	38,092	9,365	44,771	15.9%	84.1%
5/28	957	7,636	6,350	44,442	7,307	52,078	13.1%	86.9%
5/29	615	8,251	10,492	54,934	11,107	63,185	5.5%	94.5%
5/30	1,525	9,776	10,359	65,293	11,884	75,069	12.8%	87.2%
5/31	151	9,927	1,472	66,765	1,623	76,692	9.3%	90.7%
6/1	413	10,340	9,656	76,421	10,069	86,761	4.1%	95.9%
6/2	185	10,525	1,152	77,573	1,337	88,098	13.8%	86.2%
6/3	191	10,716	3,476	81,049	3,667	91,765	5.2%	94.8%
6/4	493	11,209	9,132	90,181	9,625	101,390	5.1%	94.9%
6/5	101	11,310	774	90,955	875	102,265	11.5%	88.5%
6/6	113	11,423	472	91,427	585	102,850	19.3%	80.7%
6/7	119	11,542	2,108	93,535	2,227	105,077	5.3%	94.7%
6/8	68	11,610	979	94,514	1,047	106,124	6.5%	93.5%
6/9	128	11,738	1,215	95,729	1,343	107,467	9.5%	90.5%
6/10	49	11,787	445	96,174	494	107,961	9.9%	90.1%
6/11	61	11,848	1,122	97,296	1,183	109,144	5.2%	94.8%

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	Small Trap		Large Trap		Combined		Daily Proportion	
Date	Daily	Cumulative	Daily	Cumulative	Daily	Cumulative	Small	Large
6/12	67	11,915	559	97,855	626	109,770	10.7%	89.3%
6/13	68	11,983	357	98,212	425	110,195	16.0%	84.0%
6/14	25	12,008	129	98,341	154	110,349	16.2%	83.8%
6/15	17	12,025	308	98,649	325	110,674	5.2%	94.8%
6/16	19	12,044	66	98,715	85	110,759	22.4%	77.6%
6/17	16	12,060	49	98,764	65	110,824	24.6%	75.4%
6/18	15	12,075	73	98,837	88	110,912	17.0%	83.0%
6/19	23	12,098	173	99,010	196	111,108	11.7%	88.3%
6/20	18	12,116	208	99,218	226	111,334	8.0%	92.0%
6/21	23	12,139	55	99,273	78	111,412	29.5%	70.5%
6/22	22	12,161	104	99,377	126	111,538	17.5%	82.5%
6/23	22	12,183	81	99,458	103	111,641	21.4%	78.6%
6/24	7	12,190	55	99,513	62	111,703	11.3%	88.7%
6/25	13	12,203	76	99,589	89	111,792	14.6%	85.4%
6/26	3	12,206	33	99,622	36	111,828	8.3%	91.7%
6/27	7	12,213	45	99,667	52	111,880	13.5%	86.5%
6/28	15	12,228	51	99,718	66	111,946	22.7%	77.3%
6/29	3	12,231	16	99,734	19	111,965	15.8%	84.2%
6/30	3	12,234	19	99,753	22	111,987	13.6%	86.4%
7/1	6	12,240	13	99,766	19	112,006	31.6%	68.4%
7/2	4	12,244	6	99,772	10	112,016	40.0%	60.0%
7/3	4	12,248	22	99,794	26	112,042	15.4%	84.6%
7/4	8	12,256	19	99,813	27	112,069	29.6%	70.4%
7/5		12,256	3	99,816	3	112,072	0.0%	100.0%
7/6		12,256	0	99,816	0	112,072	0.0%	0.0%
Total		12,256		99,816		112,072	11%	89%

APPENDIX C. CLIMATE OBSERVATIONS

Appendix C1.–Daily climatological observations for the Chignik River sockeye salmon smolt project, 2011.

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
5/3	11:45	5.5	3.0	95%		0	4.5	4.0	89	no precipitation
5/4	11:45	6.5	3.0	100%		0	4.0	4.0	87	no precipitation
5/5	11:35	4.0	3.0	100%	SE	0-5	4.0	4.0	90	
5/6	12:00	9.5	3.5	20%		0	4.0	4.0	92	
5/7	11:50	7.0	3.5	90%	NW	1-3	4.0	4.0	91	
5/8	12:00	5.5	3.5	100%	NW	0-5	4.0	4.0	91	drizzle
5/9	11:55	2.0	3.0	100%	SE	10-15	4.5	5.0	97	drizzle, gusty
5/10	11:50	5.0	3.0	30%	NW	20-30	6.0	6.0	105	strong wind gusts
5/11	16:50	4.5	4.0	20%	NW	15	5.5	5.5	100	sunny
5/12	12:00	5.5	3.0	0%		0	5.0	5.0	104	
5/13	11:58	9.0	3.5	100%		0	5.0	5.0	99	high clouds, bright, no sun
5/14	11:50	7.5	4.0	90%	NW	0-5	5.0	5.3	97	
5/15	11:56	3.5	3.5	100%	SE	0-5	5.0	5.5	100	
5/16	12:05	4.5	3.5	100%	SE	10-20	6.0	6.0	105	
5/17	12:00	6.0	4.0	100%		0	6.5	6.0	111	
5/18	11:40	5.0	4.0	100%	SE	0-5	6.5	6.5	111	
5/19	12:30	5.5	4.0	100%	SE	10	6.5	6.5	111	
5/20	11:55	6.0	4.0	100%	SE	5	6.0	6.0	111	
5/21	12:05	5.5	4.0	100%	SE	10	7.0	6.5	113	
5/22	11:50	5.0	4.0	100%	SE	5	7.0	7.0	116	light precipitation.
5/23	13:05	6.0	4.0	100%		0	7.3	7.0	119	light precipitation.
5/24	12:15	5.0	4.0	100%	SE	25	8.0	7.5	123	steady, heavy rain
5/25	12:40	5.0	4.0	100%	SE	15	9.5	8.5	145	light precipitation.
5/26	11:40	6.0	4.0	100%	SE	10-15	8.0	8.0	178	rain; *gauge change, depth values adjusted (+13cm)
5/27	12:05	8.0	4.5	75%	SE	0-5	9.0	8.5	182	
5/28	12:05	5.5	4.5	100%	SE	5	10.0	8.0	191	high clouds, drizzle
5/29	12:05	12.0	5.5	10%	NW	15	9.5	8.0	183	sunny (depth taken at 2135hr)
5/30	12:20	8.5	5.0	100%	E	5	9.0	8.5	183	overcast
5/31	11:50	8.0	5.0	50%	NW	5-10	9.5	9.0	182	low clouds, no precipitation.
6/1	12:00	10.5	5.5	30%	NW	20	9.5	9.0	186	
6/2	12:30	7.5	5.5	100%	SE	10	9.0	8.5	189	
6/3	11:55	6.5	5.5	95%	NW	5	9.5	8.7	192	light precipitation.
6/4	12:10	7.5	5.5	100%	NW	10	9.5	9.0	192	

-continued-

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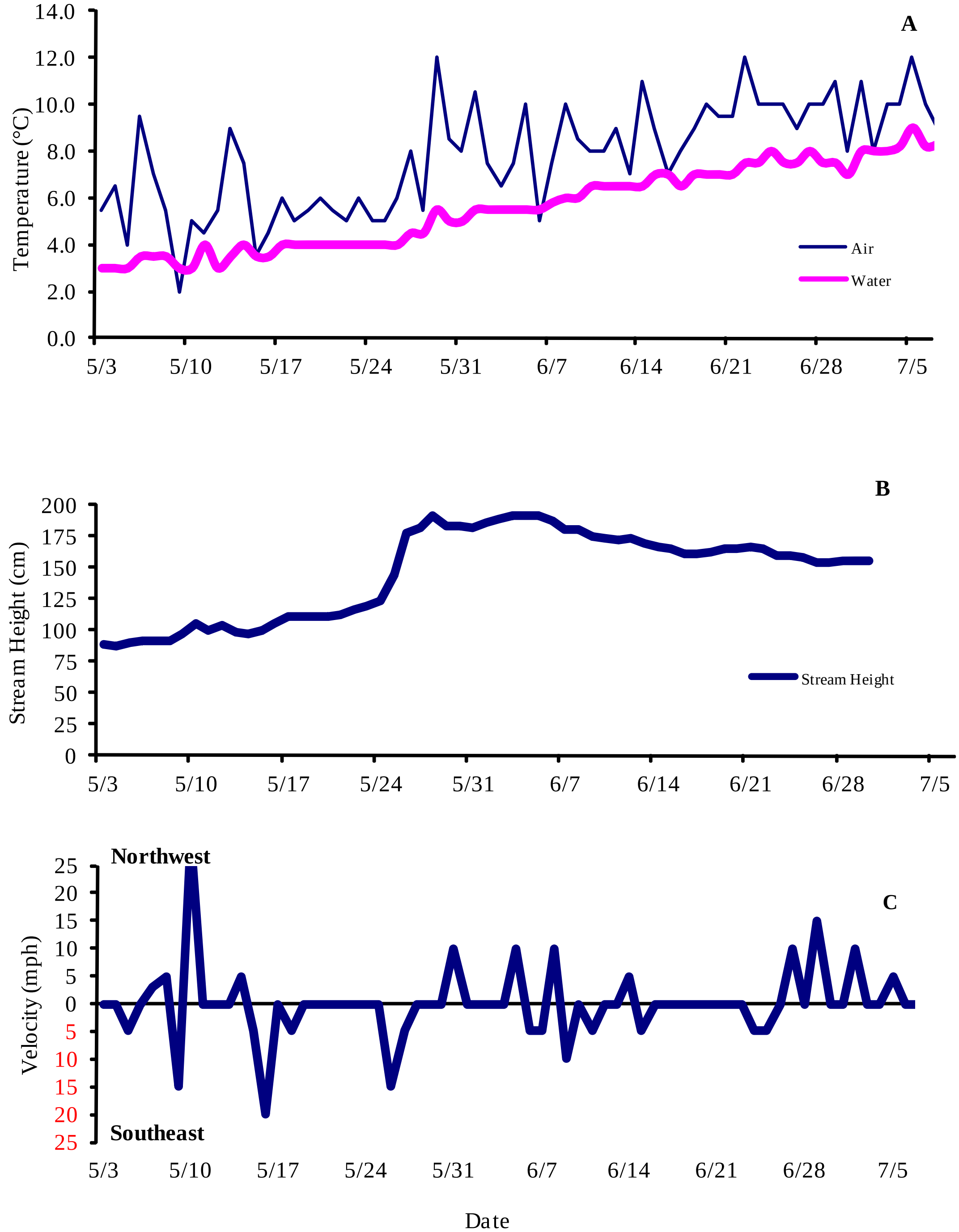
Date[a]	Time	Air (°C)	Water (°C)	Cloud[b] Cover (%)	Wind[b] Dir	Vel.[b] (mph)	Trap Revolutions (rpm) Small	Large	Stream Gauge (cm)	Comments
6/5	12:30	10.0	5.5	50%	NW	5-10	9.0	8.5	192	
6/6	10:00	5.0	5.5	100%	SE	0-5	9.0	8.5	187	heavy rain
6/7	12:05	7.5	5.8	100%	SE	0-5	8.5	8.0	180	light precipitation.
6/8	12:20	10.0	6.0	75%	NW	5-10	8.5	8.5	181	
6/9	12:20	8.5	6.0	100%	SE	5-10	8.5	8.5	175	light precipitation.
6/10	11:50	8.0	6.5	100%	SE	10	8.0	7.0	174	scattered showers
6/11	11:45	8.0	6.5	100%	SE	0-5	8.0	7.5	172	overcast
6/12	12:05	9	6.5	100%	SE	2	8.0	7.5	173	overcast
6/13	12:25	7.0	6.5	100%	NW	8	8.0	7.5	169	high clouds, bright
6/14	12:35	11.0	6.5	75%	NW	0-5	7.8	7.5	167	partly sunny
6/15	11:55	9.0	7.0	70%	SE	0-5	7.5	7.0	165	high clouds, occasional sunshine
6/16	12:45	7.0	7.0	100%	SE	10	7.0	7.0	161	steady rain
6/17	11:50	8.0	6.5	100%	SE	5	7.3	7.0	161	overcast
6/18	12:25	9.0	7.0	100%		0	7.0	7.0	163	overcast, calm
6/19	12:15	10.0	7.0	100%	NW	5	7.0	7.0	165	
6/20	13:15	9.5	7.0	70%	NW	10	7.0	7.0	165	
6/21	12:20	9.5	7.0	60%	NW	5	7.5	7.0	166	high clouds, bright
6/22	12:18	12.0	7.5	95%		0	7.3	7.0	165	high clouds, bright
6/23	12:25	10.0	7.5	100%		0	7.0	7.0	160	
6/24	12:00	10.0	8.0	100%	SE	0-5	6.8	6.8	160	light sprinkle, low clouds
6/25	12:15	10.0	7.5	100%	SE	0-5	6.3	6.5	158	low clouds, no precipitation.
6/26	12:05	9.0	7.5	100%	SE	5	6.3	6.5	154	rain
6/27	12:00	10.0	8.0	75%	NW	5-10	6.0	6.5	154	scattered showers, occasional sunshine
6/28	12:00	10.0	7.5	100%		0	6.0	6.3	156	
6/29	12:20	11.0	7.5	25%	NW	10-15	6.5	7.0	156	gusty, mostly sunny
6/30	12:12	8.0	7.0	60%	NW	5	6.5	6.5	155	
7/1	12:30	11.0	8.0	40%	NW	10	6.0	6.5	154	mostly sunny
7/2	12:30	8.0	8.0	100%	NW	5-10	6.0	6.5	154	
7/3	12:20	10.0	8.0	80%	NW	10	6.0	6.3	152	
7/4	12:25	10.0	8.2	15%	NW	10	5.8	6.0	149	sunny
7/5	12:15	12.0	9.0	30%	NW	0-5	NA	5.8	147	sunny
7/6	12:30	10.0	8.2	100%		0	NA	5.3	142	calm and overcast
7/7	10:10	9.0	8.3	100%		0	NA	5.0	142	calm and overcast

[a] Actual calendar dates.
[b] Based on observer estimates.

Appendix C2.–Air and water temperature (A), stream gauge height (B), and wind velocity and direction data gathered at the Chignik River smolt traps, 2011.



APPENDIX D. HISTORICAL LIMNOLOGY DATA

Appendix D1.–Seasonal averages of water quality parameters, nutrient concentrations, and photosynthetic pigments by year for Black Lake, 2000–2011.

	2000	2001	2002	2003	2004	2005	2006[a]	2007[a]	2008[a]	2009	2010	2011
	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
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
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
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
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
Silicon (µg/L)	ND	ND	ND	ND	3382.8	ND	ND	ND	ND	ND	ND	2925.7
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
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

[a] No limnological sampling occurred in August.

Appendix D2.–Seasonal averages of water quality parameters, nutrient concentrations, and photosynthetic pigments for Chignik Lake, 2000–2011.

	2000	2001	2002	2003	2004	2005	2006[a]	2007[a]	2008[a]	2009	2010	2011
	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
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
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
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
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
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
Silicon (µg/L)	ND	ND	ND	ND	4128.8	ND	ND	ND	ND	ND	5993.7	2966.0
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
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

[a] No limnological sampling occurred in August.

Appendix D3.–Seasonal average number of zooplankton per m^2 from Black Lake, 2000–2011.

Taxon	2000 Seasonal average	2001 Seasonal average	2002 Seasonal average	2003 Seasonal average	2004 Seasonal average	2005 Seasonal average	2006[a] Seasonal average	2007[a] Seasonal average	2008[a] Seasonal average	2009 Seasonal average	2010 Seasonal average	2011 Seasonal average
Copepods												
Epischura	7,850	2,654	2,605	6,303	37,649	18,113	-	5,750	-	3,707	4,329	2,919
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
Ovig. *Cyclops*	-	-	-	266	-	-	-	-	-	-	265	1,937
Harpaticus	-	531	-	531	531	-	266	-	-	-	597	-
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
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
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
Ovig. *Bosmina*	10,446	4,883	13,384	39,809	90,147	29,990	796	-	1,681	12,142	9,908	57,617
Daphnia l.	868	372	-	1,526	199	-	-	-	-	66	-	80
Ovig. *Daphnia l.*	-	-	-	-	-	-	-	-	-	-	-	-
Chydorinae	11,632	526,097	11,697	3,517	78,954	12,407	3,052	2,919	-	-	-	9,236
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
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	70,462

[a] No limnological sampling occurred in August.

Appendix D4.–Average weighted biomass estimates (mg dry weight/m^2) of the major Black Lake zooplankton taxon, 2000–2011.

Taxon	2000 Weighted average	2001 Weighted average	2002 Weighted average	2003 Weighted average	2004 Weighted average	2005 Weighted average	2006[a] Weighted average	2007[a] Weighted average	2008[a] Weighted average	2009 Weighted average	2010 Weighted average	2011 Weighted average
Copepods:												
Epischura	7.29	1.57	3.55	3.59	21.24	14.29	-	28.30	-	3.20	2.96	1.94
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
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
Ovigerous *Cyclops*	-	-	-	-	-	-	-	-	-	-	0.38	4.62
Harpaticus	-	0.89	-	0.35	-	-	0.17	-	-	-	0.09	-
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
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
Ovigerous *Bosmina*	13.49	5.18	45.07	77.61	125.78	43.00	0.83	-	2.58	19.80	12.28	76.98
Daphnia l.	0.46	0.10	-	2.29	0.05	-	-	-	-	-	-	0.17
Holopedium	-	-	-	-	-	-	-	-	-	-	0.77	-
Chydorinae	6.59	5.05	16.15	2.38	40.46	8.66	1.80	6.20	-	-	-	5.02
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
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

[a] No limnological sampling occurred in August.

Appendix D5.–Seasonal average number of zooplankton per m^2 from Chignik Lake, by year, 2000–2011.

Taxon	2000 Seasonal average	2001 Seasonal average	2002 Seasonal average	2003 Seasonal average	2004 Seasonal average	2005 Seasonal average	2006[a] Seasonal average	2007[a] Seasonal average	2008[a] Seasonal average	2009 Seasonal average	2010 Seasonal average	2011 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
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
Ovigerous Eurytemora	-	-	-	-	-	-	-	-	-	-	-	15,596
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
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
Harpaticus	355	292	703	531	1,078	348	1,335	1,062	100	672	993	-
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
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
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
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
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
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
Chydorinae	3,989	24,728	9,129	1,115	8,373	6,179	-	3,340	1,062	-	-	5,356
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
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

[a] No limnological sampling occurred in August.

Appendix D6.–Average weighted biomass estimates (mg dry weight/m^2) of the major Chignik Lake zooplankton taxon by year, 2000–2011.

Taxon	2000 Weighted average	2001 Weighted average	2002 Weighted average	2003 Weighted average	2004 Weighted average	2005 Weighted average	2006[a] Weighted average	2007[a] Weighted average	2008[a] Weighted average	2009 Weighted average	2010 Weighted average	2011 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
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
Ovig. Eurytemora	-	-	-	-	-	-	-	-	-	-	-	86.58
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
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
Harpaticus	0.29	0.62	0.91	0.45	0.55	0.21	0.96	4.31	0.14	0.18	0.37	-
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
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
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
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
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
Chydorinae	3.56	2.20	6.95	0.73	6.03	3.97	6.60	4.64	0.29	-	-	3.43
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
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

[a] No limnological sampling occurred in August