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The 2014 Chignik River Sockeye Salmon Smolt Outmigration: An Analysis of the Population and Lake Rearing Conditions

by

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and

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January 2015

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

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

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

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ABSTRACT

This report describes the results of the sockeye salmon *Oncorhynchus nerka* smolt monitoring and enumeration project conducted by the Alaska Department of Fish and Game in the Chignik River system in 2014. The research was designed to estimate population size and age structure of outmigrating smolt, assess fish body condition, describe limnetic habitat conditions and forage base in rearing lakes, collect samples for genetic stock identification, and provide data for the Chignik River preseason adult sockeye salmon forecast. The abundance of sockeye salmon smolt was estimated using a rotary-screw trap array and mark-recapture techniques. In 2014, a total of 4.3 million (95% CI 3.61 million to 5.0 million) sockeye salmon smolt were estimated to have outmigrated from April 25 to July 4. Of these, 4,250 (<1%) were freshwater-age-0; 2.76 million (64.2%) were freshwater-age-1; 1.51 million (35.1%) were freshwater-age-2; and approximately 26,900 (<1%) were freshwater-age-3 smolt. Limnology surveys were conducted in Chignik Lake monthly in May, June, July (twice), and September and in Black Lake in June and August 2014 to describe physical characteristics, nutrient availability, phytoplankton biomass, and zooplankton forage available to rearing juvenile sockeye salmon. Smolt were of below-average body condition and zooplankton levels were lower than the previous year. The smolt-based forecast predicts a total adult run of 3.03 million sockeye salmon in 2015. Findings from this project are key to understanding effects of escapement abundance and environmental changes on sockeye salmon population dynamics in the Chignik River system.

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

INTRODUCTION

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

The Chignik River system produces the vast majority of the sockeye salmon in the Chignik Management Area (CMA; Bouwens 2004). It consists of a 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 and is shallow (maximum depth 4.2 m), turbid, and surrounded by low relief. In contrast, Chignik Lake is smaller (22.0 km^2), deeper (maximum depth 64 m), and surrounded by mountains. Black Lake drains via the Black River into Chignik Lake, which drains via the Chignik River into Chignik Lagoon and then into the Gulf of Alaska (Narver 1966; Dahlberg 1968; Chasco et al. 2003). Chignik Lagoon is a semi-enclosed estuary with salinities ranging from full marine seawater at the outer spit to nearly freshwater conditions at the head of the lagoon (Simmons et al. 2013b).

Both lakes are considered oligotrophic (Kyle 1992), and each maintains its own genetically distinct runs of adult sockeye salmon (Templin et al. 1999; Creelman et al. 2011). Early-run sockeye salmon enter the river from June through 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 biological escapement goal (BEG) range of 350,000–450,000 fish through approximately July 4. The late run has a sustainable escapement goal (SEG) range of 200,000– 400,000 fish beginning on approximately July 5 with an additional 50,000 fish in-river run goal (IRRG) in August and September (Sagalkin et al. 2013).

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

Hirano 1995), and smolt size (Rice et al. 1994). Variables affecting growth in juvenile salmon include temperature, competition, food quality and availability, and water chemistry characteristics (Moyle and Cech 1988). Because of these dynamic factors, annual growth and survival from egg to smolt of sockeye salmon often varies among lakes, years, and within individual populations (Bumgarner 1993).

Smolt outmigration studies provide information on life history strategies and annual changes in outmigration timing. Combined with limnological investigations, this type of study can provide insight as to how environmental and anthropogenic factors may influence food availability, juvenile outmigration timing, and overwintering habitat selection. Sockeye salmon rearing in Chignik and Black lakes are exposed to different types and levels of environmental stress which may influence their life history strategies. For example, if growth rates are not sufficient to achieve the threshold size necessary to outmigrate in the spring, juvenile fish may stay in a lake to feed for another year (Burgner 1991), possibly increasing competition among age classes. Conversely, stressed smolt may use an entirely different strategy and outmigrate early in order to take advantage of better rearing conditions in the marine environment (Rice et al. 1994). Numerous studies show Black Lake water levels have decreased since the 1960s. Reported decreases in water surface elevation range from 0.5 to 2.2 meters resulting in volume reductions of 23% to 44%. There is some uncertainty in the measurements due to differences in datums used, but it is widely accepted that a decrease has occurred (Dahlberg 1968; CH2MHILL 1994; Elhakeem and Papanicolaou 2008; Griffiths et al. 2011; U.S. Army Corps of Engineers 2012). Chignik stakeholders have been concerned that the loss of Black Lake volume has led to a reduction in rearing habitat and forage, intensifying competition among stocks.

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 potential deleterious effects on Chignik Lake juveniles (Ruggerone 2003; Finkle 2004; Westley and Hilborn 2006; Simmons et al. 2013a). Top-down pressures have been indicated by decreased zooplankton size of *Bosmina* from Chignik and Black lakes (Kyle 1992; Bouwens and Finkle 2003). Interactions between the early and late sockeye salmon runs 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; Westley et al. 2010; Simmons et al. 2013a; Simmons et al. 2013b; Walsworth et al. 2014). In particular, the influence of changing physical and environmental factors upon the outmigration of juvenile sockeye salmon merits continued investigation. Other past studies have also suggested that a component of juvenile sockeye salmon rear in the Chignik River and Chignik Lagoon during the summer to avoid overtaxed Chignik Lake rearing habitat and subsequently return to Chignik Lake in the fall of the same year (Roos 1957, 1959; Iverson 1966; Phinney 1968; Griffiths et al. 2013; Walsworth et al. 2014). Information derived from smolt and lake-assessment monitoring is necessary for understanding changes in the production capacity of the salmon habitat of both Black and Chignik lakes.

Since the inception of the sockeye salmon smolt enumeration project in 1994, estimates of sockeye salmon smolt outmigrations from the Chignik River have ranged from 2 to 40 million sockeye salmon. Chignik sockeye salmon smolt generally have been observed to outmigrate beginning in early May, peak in late May, and are predominantly composed of freshwater-age-1 and freshwater-age-2 individuals. Smolt outmigration data can serve as an indicator of future run strength and overall stock status, and 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. Forecast methods use historical age class relationships and smolt outmigration estimates to predict adult runs.

The Chignik smolt enumeration project has also supplied samples for genetic analysis since 2006, and these samples have been processed through the 2012 sample year. Genetic analyses have provided valuable information about stock-specific run timing and age composition, including that stock-specific outmigration timing varies from year to year (Creelman 2010). Additionally, analysis of age and stock-of-origin revealed that smolt age was not a consistent indicator of stock origin as previously thought (Narver 1966; Witteveen and Botz 2004). In 2008 and 2009, smolt age compositions were similar to those of returning adults, where the vast majority of Black Lake stock were freshwater-age-1 and Chignik Lake stock were freshwater age-2. However, in other years, the proportions of freshwater-age-1 and freshwater-age-2 sockeye salmon smolt were more evenly distributed among stocks (mean 44 to 57%; Creelman 2010). In 2011, the outmigrating smolt were predominantly Chignik Lake stock regardless of age class, which was seen in the low returns of Black Lake fish in early 2014. In 2012, the majority of freshwater-age-1 smolt were Black Lake stock, and the majority of freshwater-age-2 smolt were Chignik Lake stock, suggesting the 2015 adult run may be similar in proportion to 2008 and 2009.

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

The 2014 field season was the 21st year of the ADF&G Chignik River sockeye salmon smolt monitoring and enumeration project. The sampling protocol has been consistent for these 21 years. This report presents data collected in 2014, compares the results of 2014 to previous years, and provides a 2015 adult sockeye salmon forecast based on smolt data.

OBJECTIVES

The objectives for the 2014 season were as follows:

1. Estimate the total number of Chignik River system outmigrating sockeye salmon smolt by freshwater-age class.
2. Describe outmigration timing and growth characteristics (length, weight, and body condition factor) of sockeye salmon smolt by freshwater-age class 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 phytoplankton communities and biomass of Black and Chignik lakes.
5. Quantify the zooplankton forage base available to juvenile sockeye salmon in Black and Chignik lakes.

6. Estimate Chignik sockeye salmon marine survival and build a smolt-based forecast model to estimate future runs.
7. Collect genetic samples from outmigrating sockeye salmon smolt for use in a stock identification study.

METHODS

STUDY SITE AND TRAP DESCRIPTION

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

Each trap was secured to shore with highly visible polypropylene line. The line and a red photosensitive strobe light attached to the safety railing of the offshore trap were employed to facilitate safe navigation of local boat traffic around the traps and anchor lines. 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 the cone mouth diameter of the large trap was 2.4 m. The small trap sampled an area of 0.73 m^2, and the large trap sampled an area of 2.0 m^2 of the river's cross-sectional profile because only the bottom half of the cone was submerged. The river current rotated both cones from 5 to 10 revolutions per minute (RPM) during average discharge. Ideal trap RPM is between 6 and 7 RPM; trap distance from shore was adjusted to maintain 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 was used to maintain and adjust the traps' positions from the shore and their orientation to the current. A floating platform supporting a 3 m by 4 m Weatherport was tied directly behind the live box work station to provide a sheltered work station while sampling and maintaining the traps.

Both screw traps began fishing on May 1, the large trap at 1210 hours and the small trap at 1515 hours. Minor periods of fishing interruption occurred throughout the season to clear debris and for trap maintenance. Both traps were removed and disassembled for storage on July 4.

SMOLT ENUMERATION

Since smolt primarily outmigrate at night, sampling days occurred for a 24-hour period from noon to noon and were identified by the date of the first noon-to-midnight period. The traps were checked a minimum of 3 times each day beginning at noon, between 2000 and 2200 hours and no later than 0900 hours the next morning. Traps were checked more frequently throughout the evening during periods of increased smolt outmigration.

Juvenile sockeye salmon greater than 45 mm fork length (FL; measured from tip of snout to fork of tail) were considered smolt (Thedinga et al. 1994). All fish were netted out of the traps' live boxes, identified (McConnell and Snyder 1972; Pollard et al. 1997), enumerated, and released, except for those retained for age-weight-length (AWL), genetic samples, and mark-recapture estimates. In addition to sockeye salmon smolt, sockeye salmon fry (<45 mm FL), coho salmon *O. kisutch* juveniles, Chinook salmon *O. tshawytscha* juveniles, pink salmon *O. gorbuscha* juveniles, chum salmon *O. keta* juveniles, Dolly Varden *Salvelinus malma*, stickleback of the family *Gasterosteidae*, pond smelt *Hypomesus olidus*, pygmy whitefish *Prosopium coulteri*, starry flounder *Platichthys stellatus*, Coast Range sculpin *Cottus aleutus*, Alaska blackfish *Dallia pectoralis,* eulachon *Thaleichthys pacificus,* and isopod *Mesidotea entomon* (Merrit and Cummings 1984; Pennak 1989) are captured by the traps and were identified, counted and released.

The number of smolts emigrating during any time period when the traps were not operating was estimated from known counts during adjacent time periods using time series analysis in SYSTAT (SYSTAT Software, Inc.). Autocorrelation diagnostic tests (plots of autocorrelation function and partial autocorrelation function) were run to assess and correct for autocorrelation. Such time periods without gear operation could occur early in the season before traps are installed, during the season from trap malfunction or breakdown, or at the end of the season after the traps are removed from the river. If the period of missed counts occurred at the beginning or end of the season, the SYSTAT function estimated the number of smolts by extrapolating from known counts after the trap was installed or before it was removed for the season. If the period of missed counts occurred during the season, the SYSTAT function estimated the number of smolts by interpolating from the known counts on the days before and after.

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 850 and 4,000 sockeye salmon smolt for each experiment were collected from the traps, counted, and transferred to the live box. If sufficient numbers of smolt were not initially captured to perform a mark-recapture experiment, they were cumulatively retained in the live box for a maximum of 3 nights. After 3 nights, all captured live smolt were released downstream of the traps if the minimum sample size was not met. Mortalities that occurred during the holding time were removed and subtracted from the total released.

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

Additionally, 100 marked smolt and 100 unmarked smolt were held in instream live boxes for the duration of each mark-recapture stratum to ensure the assumptions of the mark-recapture experiments were validated. Delayed mortality of smolt held for this purpose was incorporated into daily population estimates.

The trap efficiency E was calculated by

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

where

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

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

and

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

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

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

where

u_h = the number of unmarked smolt captured in stratum h.

Variance was estimated by

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

The population estimate $\hat{U}$ 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 and normally distributed.

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

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

where

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

A_h = the number of smolt sampled in stratum h

with the variance estimated as

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

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, LENGTH AND GENETICS SAMPLING

Forty sockeye salmon smolt were randomly collected for AWL sampling from the traps' live boxes 5 days per statistical week, while the remaining smolt were released downstream. All AWL sampled smolt were anesthetized with either a non-lethal (smolt > 100 mm) or lethal (smolt ≤ 100 mm) amount of tricaine methanesulfonate MS-222. For all AWL sampled smolt, FL was measured to the nearest 1 mm, and each smolt weighed to the nearest 0.1 g. Scales were removed from the preferred area (International North Pacific Fisheries Commission 1963) and mounted on a microscope slide for age determination. Fin clips were collected from all AWL-sampled fish for genetic analysis and stored in ethanol following ADF&G protocol. As with samples collected in 2013, fin clips were sent to the ADF&G Gene Conservation Laboratory in Anchorage for storage until future analysis. Age was estimated from scales under 60X magnification and described using the European notation (Koo 1962). Condition factor (*K*)

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

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

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

After sampling, live fish were held in aerated water until they completely recovered from the anesthetic and released downstream from the traps.

CLIMATE AND HYDROLOGY

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

MARINE SURVIVAL ESTIMATES AND RUN FORECASTING

The total sockeye salmon adult run to the Chignik River system was calculated by adding total Chignik River sockeye salmon escapement and total harvest from the CMA. In years when a harvest occurs, 80% of the pre-July 26 sockeye salmon catch from the Southeastern District Mainland (SEDM) of the Alaska Peninsula Management Area (excluding Northwest Stepovak Section July 1–July 26), and 90% of the pre-July 26 catch from the Cape Igvak Section of the Kodiak Management Area are added to calculate the total Chignik run (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 2015 Chignik early and late adult sockeye salmon run was forecasted using a simple linear regression model of total outmigrating smolt and ocean-age-3 adult returns, as well as median returns of other ocean-age classes in the most recent 30 years. Data from 1996 and 2008 were excluded due to unrealistic estimates of marine survival and anomalous adult runs. The model was evaluated using standard regression diagnostics and tested for autocorrelation by examining residual plots and Durbin-Watson statistics. This smolt-based forecast is separate from the formal forecast (Munro et al. 2014) which uses adult age-class sibling relationships and escapement data and is stock-specific.

LIMNOLOGY

Limnology data were collected at one sampling station on Black Lake and at four sampling stations on Chignik Lake (Figure 3). Sampling occurred monthly from May through September when logistically possible. 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 5 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 radiation (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 1-meter intervals until the lake bottom or light penetration reached zero. The mean euphotic zone depth (EZD) was calculated for each lake (Koenings et al. 1987; Koenings and Kyle 1997). One-meter temperature and dissolved oxygen measurements were compared to assess the physical conditions in the euphotic zones of each lake. Secchi depth 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

A Van Dorn sampler was used to collect approximately 8 liters of water from a depth of 1 m from each lake and from a depth of 29 m at each of two stations in 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 Kodiak Island Laboratory (KIL) for total phosphorus (TP), total ammonia (TA), nitrate + nitrite, total filterable phosphorus (TFP), filterable reactive phosphorus (FRP), chlorophyll *a*, and phaeophytin *a*. Nutrient and photosynthetic pigment analyses were conducted at KIL using a SEAL AutoAnalyser 3 HR; methods followed the equipment protocol. Total Kjeldahl nitrogen (TKN) was analyzed at the University of Georgia, Agricultural and Environmental Service Laboratories, Feed and Environmental Water Laboratory in Athens, GA.

Zooplankton

One vertical zooplankton tow was made at each limnology station with a 0.2 m diameter, 153 micron net from 1 meter above the lake bottom to the surface. Each sample was placed in a 125 mL poly bottle containing 12.5 mL of concentrated formalin and subsequently filled with deionized water to yield a 10% buffered formalin solution. Samples were stored for analysis at the ADF&G KIL. 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 3 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 smolt traps were in place for a total of 65 days, beginning on May 1. During three days in June, the large trap was removed from the water for repairs. The duration of the 2014 trapping season was slightly longer than average.

A total of 110,085 sockeye salmon smolt were captured in the traps between May 1 and July 4. (Appendices A1 and B1). In addition to sockeye salmon smolt, 5,074 sockeye salmon fry, 877 coho salmon smolt, 9 coho salmon fry, 52 juvenile Chinook salmon, 238 Dolly Varden char, 17,449 stickleback, 389 sculpin, 7 starry flounder, 7,788 pond smelt, 150 pygmy whitefish, 10 Alaska blackfish, 271 isopods, and 18 eulachon were captured (Appendix A1). The small screw trap caught 34.0% of the observed trapped sockeye salmon smolt, and the large trap 66.0% (Appendix B1).

TRAP EFFICIENCY ESTIMATES

Mark-recapture experiments were conducted on four occasions: May 2, 8, 15, and 23 (Table 1; Appendix A1). Appendix A shows unadjusted release numbers for each mark-recapture experiment. When adjusted for delayed mortality, 5,798 sockeye salmon smolt (4.3% of the total catch) were released (Table 1). One hundred ninety-six sockeye salmon smolt were recaptured and trap efficiency estimates per stratum ranged from 2.31% to 6.70% (Table 1; Appendix A1). The majority of recaptured marked smolt were caught within the first 24 hours of being released.

SMOLT OUTMIGRATION TIMING AND POPULATION ESTIMATES

The majority of these fish outmigrated from early to late May (Figure 5, Appendix A1 and B1). The largest nightly outmigration was observed immediately after the traps were operational, indicating the smolt outmigration had begun before trap installation; therefore, daily outmigration for the 6 days prior to trap operation were estimated using time series analysis based on counts from May 1–May 9. It is assumed the peak of the migration was captured by the smolt traps, and time series analysis using the first 9 days of smolt counts provided an estimate of the smolt population that may have emigrated downstream before the traps were installed. Other time periods considered for time series included daily counts through May 13 or May 6. An additional 923,998 fish were included in the 2014 total season outmigration estimates (Table 3; Figure 5). An estimated 4.3 million smolt (95% CI 3.61 million to 5.0 million) sockeye salmon smolt outmigrated in 2014 (Table 2; Figure 4). This estimate should be viewed with less confidence than estimates from years when all emigrating smolts were encompassed by the dates of the smolt enumeration project. Freshwater-age-1 (64.2%) and freshwater-age-2 (35.1%; Tables 2 and 3; Figure 6) smolt comprised the majority of the outmigration. Sockeye salmon fry (<45 mm FL) were captured throughout the trapping season but were most abundant in May (Appendix A1).

AGE, WEIGHT, AND LENGTH DATA

A total of 1,593 usable samples were collected from sockeye salmon smolt for AWL data. The mean length, weight, and *K* of sampled freshwater-age-0 smolt was 48 mm, 0.9 g, and 0.79 respectively. The mean length, weight, and *K* of sampled freshwater-age-1 smolt was 58 mm, 1.2 g, and 0.60 respectively. The mean length, weight, and *K* of sampled freshwater-age-2 smolt was 80 mm, 3.3 g, and 0.65 respectively. The mean length, weight, and *K* of sampled freshwater-age-3 smolt was 109 mm, 11.5 g, and 0.82 respectively (Tables 4 and 5; Figures 7 and 8). Condition factor increased throughout the season for all age classes, although it was more variable for freshwater-age-2 smolt than freshwater-age-1 smolt (freshwater-age-3 smolt were such a small proportion of the outmigrating population that this trend is not discernible).

PHYSICAL DATA

The absolute water depth measured against the shore at the trap location ranged from 24 cm to 48 cm. Water levels were lower than average throughout the entirety of the season. Water temperature was first observed at 4.5°C on May 3 and reached an observed maximum of 11.5°C on July 4, the final day of the season (Appendix C1 and C2). Unusually warm temperatures, moderate winds, and clear skies dominated the 2014 season.

ADULT RUN FORECAST

The smolt-based regression model forecasts a 2015 total adult run of 3.03 million sockeye salmon (80% prediction interval 1.88 to 4.17 million), compared to the formal adult forecast, which predicts a run of 2.54 million sockeye salmon (Munro et al. 2014).

LIMNOLOGY

Sampling was conducted each month when logistically possible in both Black Lake (June 24, and August 2) and Chignik Lake (May 5, June 2, July 1, July 31, and September 2). Comparisons with historical limnology data are in Appendices D1 and D2.

Temperature and Dissolved Oxygen

Black Lake

The meter used to measure temperature and dissolved oxygen did not function during the June sample, and no samples were taken in July due to logistical problems. On August 2 the 1 m temperature in Black Lake was measured at 16.9°C, and dissolved oxygen level at the 1 m depth was 9.6 mg/L.

Chignik Lake

The average 1 m temperature in Chignik Lake increased from 4.7°C on May 5 to 13.4°C on September 2 (Figure 9). Dissolved oxygen levels decreased from 13.3 mg/L to 10.4 mg/L over the same time period (Figure 9). Temperature levels were similar throughout the water column at each sampling date, with no more than 2.3°C difference between surface and deeper water (July 31). Dissolved oxygen levels were similar throughout the water column from May through the end of July, with a difference between surface and deeper water of no more than 1.7 mg/L, and only slightly more variable on September 2, with a difference of 3.5 mg/L between surface and 50 m depth.

Light Penetration and Water Transparency

Black Lake

Light penetrated the entire water column in Black Lake during the 2014 sampling season. The EZD (4.06 m) of Black Lake was nearly the same as its maximum depth (4.2 m) throughout the entire sampling season. The mean lake depth (1.9 m) was used to calculate the euphotic volume (EV) of 78.09 x 10^6 m^3 (Table 6; Figure 10). Mean Secchi depth readings were 1.2 m.

Chignik Lake

EZD varied between sampling dates, peaked during the month of July, and averaged 9.77 m. The EV in Chignik Lake averaged 235.46 x 10^6 m^3 (Table 6; Figure 10). Mean Secchi depth readings were 2.98 m.

Water Quality Parameters, Nutrient Levels, and Photosynthetic Pigments

Black Lake

In 2014, the pH at the Black Lake station averaged 8.2 and alkalinity averaged 34.8 mg/L $CaCO_3$. TP averaged 13.9 µg/L, TFP averaged 3.3 µg/L, and FRP averaged 3.3 µg/L. TKN averaged 277.0 µg/L, ammonia averaged 5.3 µg/L, and nitrate + nitrite averaged 5.7 µg/L. Silicon averaged 2,752.0 µg/L, chlorophyll *a* averaged 4.1 µg/L, and phaeophytin *a* averaged 1.3 µg/L (Table 7, Appendix D1).

Chignik Lake

In 2014, the pH in Chignik Lake averaged 7.8 and alkalinity averaged 26.2 mg/L $CaCO_3$ across stations and depths. TP averaged 8.1 µg/L, TFP averaged 2.3 µg/L, and FRP averaged 3.9 µg/L. TKN averaged 71.1 µg/L, ammonia averaged 4.3 µg/L, and nitrate + nitrite averaged 149.1 µg/L. Silicon averaged 5,396.3 µg/L, chlorophyll *a* averaged 1.9 µg/L, and phaeophytin *a* averaged 0.8 µg/L. (Table 8, Appendix D2).

ZOOPLANKTON

Black Lake

Copepods were the most abundant zooplankton in Black Lake (seasonal average 56.11×10^3 individuals/m^2) followed by cladocerans (seasonal average 24.81×10^3 individuals/m^2). In the two samples obtained, the most prevalent copepod genera in Black Lake was *Cyclops* (36.41×10^3 individuals/m^2) (Table 9; Appendix D3). *Bosmina* were the most abundant cladoceran genera with a seasonal average of 24.1×10^3 individuals/m^2 (including *Ovig. Bosmina*) followed by *Chydorinae* (seasonal average 690 individuals/m^2). Total zooplankton abundance was higher in August than in June (Table 9).

Copepod biomass was greatest in June and was composed completely of *Cyclops* (65.5 mg/m^2 weighted season average) in both collected samples. Cladoceran biomass was predominantly composed of *Bosmina* throughout the sampling season with a weighted seasonal average of 20.9 mg/m^2 (including *Ovig. Bosmina*) and greatest biomass observed in the August sample. The total weighted seasonal average copepod biomass (65.5 mg/m^2) was greater than cladoceran biomass (21.5 mg/m^2) and resulted in a total weighted seasonal average of 86.99 mg/m^2 for all the Black Lake zooplankton (Table 10; Appendix D4). However, the lack of samples in May, July, and September prevent full analysis of the zooplankton community throughout the season.

Average weighted seasonal lengths of the major non-egg bearing zooplankton in Black Lake were 0.72 mm for *Cyclops*, 0.27 mm for *Bosmina*, and 0.29 mm for *Chydorinae* (Table 11).

Chignik Lake

Copepods were more abundant than cladocerans in May, June, and in early July, while Cladocerans were more abundant in late July and September samples. The seasonal abundance of cladocerans was greater (216.2×10^3 individuals/m^2) than copepods (161.9×10^3 individuals/m^2) due to the high abundance of cladocerans in late July and September samples. *Cyclops* (46.6×10^3 individuals/m^2) *Eurytemora* (45.8×10^3 individuals/m^2), and nauplii (68.2×10^3 individuals/m^2) were the most abundant genera of copepods. *Daphnia* (100.3×10^3 individuals/m^2) and *Bosmina* (77.9×10^3 individuals/m^2) were the most common cladocerans in Chignik Lake (Table 12; Appendix D5).

Copepod biomass was composed predominantly of *Cyclops* in May (36.8 mg/m^2.) Beginning in June and continuing through September, copepod biomass was composed primarily of *Eurytemora* (177.4 mg/m^2 weighted seasonal average, greatest in late July at 416.2 mg/m^2). Cladoceran biomass was composed primarily of *Daphnia* (121.98 mg/m^2 weighted season average) with greatest biomass in September (499.1 mg/m^2). The total weighted seasonal average copepod biomass (248.8 mg/m^2) was slightly greater than the cladoceran seasonal average biomass (227.9 mg/m^2), with a weighted seasonal average of 476.7 mg/m^2 for all Chignik Lake zooplankton (Table 13; Appendix D6).

Average weighted seasonal lengths of the major non-egg bearing zooplankton in Chignik Lake were 0.62 mm for *Cyclops*, 0.78 mm for *Eurytemora*, 0.38 mm for Bosmina, and 0.54 mm for *Daphnia*. Ovigerous zooplankton were, on average, longer than non-egg bearing individuals (Table 14). On average, *Cyclops* and *Daphnia* were slightly larger than the most-recent 5-year size average, while *Bosmina* were slightly smaller than average and *Eurytemora* significantly smaller than average.

DISCUSSION

SOCKEYE SALMON SMOLT POPULATION ESTIMATES AND OUTMIGRATION TIMING

The point estimate of the 2014 total sockeye salmon smolt outmigration (4.3 million) was well below the 20-year average (14.7 million). This estimate, however, should be viewed with less confidence than estimates from years when all emigrating smolts were encompassed by the dates of the smolt enumeration project. A daily outmigration for the period of April 25 through April 30 was calculated using time series analysis to back-cast the beginning of the smolt outmigration; the estimate of 923,998 outmigrating sockeye salmon smolt between April 25 and April 30 is a large portion of the overall population estimate but is considered conservative. The poor condition of the outmigrating smolt could be due to density-dependent factors, suggesting a large number of smolt before trap installation, but the anticipated low marine survival rate of smolt observed outmigrating in 2014 warrants a cautious population estimate.

Outmigration timing and magnitude in 2014 allowed for 4 mark-recapture events throughout the season with approximately 6,000 smolt marked and released. Protocols for mark-recapture experiments remained the same as previous years, and the absolute number of smolt captured and released for each dye test was average, but mortality rates were high among smolt held for delayed-mortality estimates, which, when applied to the total population, resulted in trap efficiency estimates greater than any in previous years. Historic efficiencies have generally averaged ~1% annually and individual mark-recapture events often were <1%. Low trap efficiencies are expected considering the size of the Chignik River and small proportion that the traps cover. Higher trap efficiencies translate to lower daily and cumulative population estimates.

It is possible that the low water levels through the duration of the 2014 trapping season caused smolt to traveled in unusual paths or different areas of the river and avoid the traps, resulting in low population estimates. However, the overall number of smolt caught in the traps was not unusual (and was similar to total trap catches in 2001–2003, and 2010, 2011 and 2013), and the number of recaptures was similar to previous years, suggesting that avoidance due to water levels was not an issue. However, the trap efficiency estimates as a result of high mortality rates resulted in a much lower total population estimate than if trap efficiencies had been 2% or less, which is typical for the Chignik smolt project. Additionally, low capture rates after May 22 precluded frequent, multiple mark-recapture tests throughout the second half of the season. This lack of frequent mark-recapture events reduces the ability to characterize fluctuations in population outmigration throughout the season. Mark-recapture events early in May had lower trap efficiency estimates–more in line with historical Chignik trap efficiencies–than the 2 mark-recapture events later in the season.

Mortality rates were similar among held marked and un-marked fish, suggesting that the dye process itself was not responsible for increased mortality. However, although protocols for mark-recapture experiments remained the same as previous years, which should have prevented undue handling mortality, the overall low condition of outmigrating smolt likely made them particularly vulnerable to any handling effects. Additionally, although fish were held instream, water temperatures were 0.5 to 1 degree warmer in the holding pens than in the river, which may have further stressed the smolt and led to high mortality.

Outmigration timing was earlier than average, with the greatest single night of observed outmigration occurring on May 2, the second night of trap operation. Similar outmigration timing was observed in 2001, which also was a mild winter. In 2014, 90% of the total smolt captured in the traps had been enumerated by May 19. In comparison, the average date at which 90% of outmigrating smolt have been caught in the traps is around June 10 (average since 2002; Figure 11). Although the beginning of May is typically the time when traps are installed, a mild winter resulted in unusually warm water and air temperatures at the start of the 2014 season. Logistic and budgetary constraints prevented the installation of traps before May 1, and some portion of the 2014 sockeye salmon smolt population had already left the river before traps were installed.

The outmigration estimate for 2014 is not the smallest outmigration on record, but in contrast to other years of low population estimates (for example 1996, 2005, and 2007), outmigrating fish in 2014 were small. In other years of low outmigration estimates, it is thought that large, healthy smolt have been able to avoid the traps, thereby precluding mark-recapture experiments and leading to a low population estimate. In contrast, in 2014, condition factor among all age classes was very low, and for freshwater-age-1 and freshwater-age-2 smolt was the lowest on record. It is unknown whether smolt outmigrating before the traps were installed would have displayed this low condition factor, or if they would have been more robust. It would be expected that large fish with high condition factor would outmigrate sooner, and that with warmer water temperatures, many fish would outmigrate earlier than average. It is possible that many fish survived the winter and the low condition factor observed among outmigrating smolt was a result of density-dependant competition. Although the population estimate of 4.25 million includes a conservative estimate of how many fish may have left the system before traps were installed, the low condition factor of the observed outmigrating smolt and anticipated subsequent low marine survival rates justifies a cautious population estimate.

AGE STRUCTURE

The 2014 outmigrating smolt population comprised approximately <1% freshwater-age-0, 64% freshwater-age-1, 35% freshwater-age-2, and <1% freshwater-age-3 smolt. The Chignik River typically displays an outmigration pattern of older fish leaving the system sooner than younger fish. Scale samples were collected beginning on May 4, and age class compositions from these date were applied to smolt outmigration estimates before May 4. Since scale samples were not available until May 4th, when freshwater-age-1 smolt already made up 66% of the population, and these age compositions were applied to estimates of outmigration before trap installation, the number of freshwater-age-1 smolt outmigrating in April and early May may be overestimated, while the number of freshwater-age-2 smolt outmigrating in April and early May may be underestimated. However, patterns of age composition in the outmigration are variable from year to year, and freshwater-age-2 fish do not always dominate the early portion of the outmigration. Attempts to estimate the number of outmigrating smolt before traps were installed in 2014 based on patterns of age composition and outmigration timing were unsuccessful due to these annual variations in outmigration timing by age class.

Some years have displayed varying compositions of age classes (such as 2011, when 87% of the outmigrating smolt were freshwater-age-1, or 2012 and 2013 which had higher-than-average proportions of freshwater-age-2 smolt), but the 2014 age composition structure from sampled smolt is similar to the historical seasonal average age composition for the Chignik River system (57.4% freshwater-age-1 and 36.6% freshwater-age-2 since 1994). The large freshwater-age-1 component in the outmigration may have occurred in 2014 due to higher over-winter juvenile survival, as a result of mild winter conditions, or the application of age compositions from later in the season to early outmigrants. Juveniles that would have normally died over the winter may have survived because of the early spring, resulting in more freshwater-age-1 fish outmigrating in 2014. However, freshwater-age-1 smolt in 2014 were small and of low condition factor, suggesting they had entered the winter in poor condition. Warmer water combined with a lack of available food would have metabolically taxed these fish, and many juveniles may have just barely survived to the spring. Alternatively, many freshwater-age-1 juveniles may have died overwinter, and the application of late-season (first and second weeks of May) age compositions misrepresents the proportion of freshwater-age-1 fish in the outmigration. The above-average mortality rates observed in delayed mortality experiments further suggests a high mortality among outmigrating smolt.

Two consecutive years of a higher-than-average proportion of freshwater-age-2 smolt observed in 2012 and 2013 suggested that Chignik sockeye salmon smolt exhibited the life history strategy where they do not outmigrate until a threshold size is met (Burgner 1991). It would take longer to meet this threshold with more intraspecific competition and less food resources available. More fish staying for an extra year in Chignik Lake could perpetuate the problem of high competition and low food resources. The proportion of freshwater-age-1 fish outmigrating in 2014 would seem to suggest the opposite, but the unknown age composition of early migrants prevents total dismissal of this theory. Additionally, the proportion of freshwater-age-2 salmon in late-run adult returns has steadily increased since 2009. Freshwater-age-1 smolt may experience higher mortality rates at sea than older smolt, but genetics composition show that the majority of freshwater-age-2 smolt are of Chignik Lake origin, suggesting these fish take longer to reach an appropriate size and readiness for outmigration.

Temperature also has a strong effect on smolt outmigration and condition at outmigration. Griffiths et al. (2011) showed air temperatures and water temperatures are closely coupled in Black Lake due to the shallow depth of the water body. Air temperatures may play a larger role in the condition and success of sockeye salmon juveniles in Black Lake, but during a very warm year such as 2014, overwintering juveniles in either lake would be affected. In warmer years, thermal stress may cause earlier outmigration of Black Lake juveniles into Chignik Lake (Finkle 2004; Westley et al. 2008). In May 2014, many fry were captured in beach seines in Black Lake, but very few in June. However, the lack of data in July and August prevents full analysis of possible triggers of outmigration timing from Black Lake. The annual temperature in 2014 was the warmest since 1970, and also the warmest over-winter air temperatures recorded during this time period (Figure 12), and outmigrating smolt condition factor was very low. As of December 2014, air temperatures remained above average, suggesting smolt in 2015 may also outmigrate early or in poor condition.

Unlike other systems where smolt leave the freshwater environment and enter directly into entirely marine near-shore feeding areas, the Chignik system has a large lagoon which acts as a transition zone between the freshwater and saltwater ecosystems. This provides a forage base of amphipods, pericardians, and other small crustaceans which may alleviate some of the top-down pressure in Chignik Lake (Bouwens and Finkle 2003). Simmons et al. (2013b) 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). Beach seine hauls in Chignik lagoon on May 6 captured a large amount (>500) sockeye smolt and fry, indicating these fish had already moved to the saline environment, possibly as a result of limited resources in the lake, or metabolic stresses as a result of unusually warm early-season temperatures. Smolt and fry catches in the lagoon were low later in the season, and given the early outmigration, it is possible fish observed early in May were able to attain optimal body size and migrate to the marine environment earlier than usual.

An estimated 4,250 freshwater-age-0 sockeye salmon, greater than 45 mm in length, outmigrated in 2014 (Table 3). Fry less than 45 mm are not considered smolt (Thedinga et al. 1994), as they are very difficult to remove scales from and age due to their small size. On average, approximately 5.2% of the outmigrating population is considered freshwater-age-0, but this average is driven by large percentages in 2005, 2006, and 2008. The proportion of freshwater-age-0 smolt in 2014 was below the recent average. Whether that is because these fish experienced high mortality rates before reaching the traps, outmigrated before the traps were installed, or remained in the lake to grow is unknown. Some of these freshwater-age-0 fish return as adults, as evidenced by adult scales (Sagalkin et al. 2013). Some rear in the lagoon or river for the summer (Simmons et al. 2013a; Simmons et al. 2013b) before outmigrating, and others may return to Chignik Lake as juveniles to overwinter. Ongoing otolith microchemistry work should shed light on the frequency of these different life-history strategies (Walsworth et al. 2014).

GENETIC ANALYSIS

While samples collected in 2014 are not scheduled for analysis, the time series of genetic information from outmigrating smolt is becoming a useful and informative dataset. Including analysis done as part of Creelman (2010), 7 years of stock-of-origin data have been analyzed. These have shown that outmigrating patterns vary each year, that age proportions can vary between stocks, and have provided valuable insight to future adult returns. For example, genetics collected in 2011 showed a low proportion of smolt belonged to the early-run stock, which was verified by poor early-run returns in 2014. Analysis of data from genetics collected in 2012 suggest that the proportion of adults returning in 2015 will be much more even, although there will be few freshwater-age-2 adults in the early run. Further, when combined with the outmigration estimate of 2012, that the 2015 adult returns should be stronger than in 2014.

Analysis of the age compositions from smolt samples collected in 2006–2012 shows that freshwater-age-0 juveniles are most often of Chignik Lake origin. This may suggest that the emigration of higher-condition Black Lake juveniles into Chignik Lake essentially "push out" small Chignik Lake juveniles to Chignik Lagoon. Some portion of these fish return to Chignik Lake to overwinter (Walsworth 2014), and the lagoon is known to serve as an important rearing area. Additionally, outmigrating freshwater-age-2 fish are more often from Chignik Lake origin than from Black Lake. If Chignik watershed fish follow a "threshold" strategy of reaching a certain size before outmigrating, and outmigrating juveniles from Black Lake to Chignik Lake are generally of better condition (Westley 2006), Black Lake juveniles would be able to outmigrate to the sea at a younger age than Chignik Lake fish.

Further analysis of genetic samples should be undertaken to ensure this valuable dataset is used effectively. For example, the proportion of each stock in annual smolt outmigrations can be compared to adult returns for better estimates of marine survival by stock. Additionally, genetic identification of outmigrating smolt can provide insight to future adult returns, as was seen in 2014, and help separate freshwater limitations from marine conditions that may affect survival. It is hoped that the most recent 3 years of genetic samples (2013–2015) will be analyzed after the 2015 season to further elucidate population dynamics and age compositions of each stock.

ZOOPLANKTON AND PHYTOPLANKTON

Black Lake zooplankton density and biomass was lower than 2013, but continues to increase since record low levels from 2006–2008, although total Cladoceran biomass was the lowest since 2008. However, samples were only collected in June and August in 2014, which prevents a comprehensive analysis of the zooplankton community throughout the season. Seasonal patterns of zooplankton density and biomass were similar to what has been observed historically; zooplankton density in Black Lake is usually dominated by copepods early in the season, decreasing from May to June, then peaking in late July or August (Finkle and Ruhl 2008). Cladocerans become the dominant zooplankton in Black Lake late in the summer when phytoplankton levels have increased (chlorophyll *a* from 1.5 to 10.4 μ/L) and many of the zooplanktivorous fish have left the lake. Chignik Lake total zooplankton density and biomass were average in 2014 (average biomass since 2002 is 356 mg/m^2), although it should be noted that copepod density was below average (349 mg/m^2) while cladoceran abundance was over twice the average density (109 mg/m^2) since 2002.

Of particular note, cladoceran density has continued to increase since historic lows from 2010–2012 (Appendices D5 and D6). Cladoceran biomass levels in 2014 seem to indicate a recovery from the strong top-down pressure on this aquatic community seen in 2012. The most recent 8 years have shown cyclical patterns of copepod abundance and biomass in Chignik Lake, with odd-years (2009, 2011, and 2013) having higher densities of copepods than even years. However, this pattern is not clearly linked to total smolt outmigration or annual K of outmigrating smolt. Future seasons of limnology, potentially linked with genetic stock identification, may provide more insight into whether this cyclic pattern of zooplankton abundance has a bearing on smolt production, or is simply an indicator of other dynamics in the lake such as changes in phytoplankton communities.

Chignik Lake zooplankton seasonal patterns are usually similar to those found in Black Lake, with the exception that copepods remain dominant later into the season when overall zooplankton densities are greatest (Tables 9 and 12). Chignik Lake copepod populations historically are composed primarily of *Cyclops*, while the most abundant cladoceran is *Bosmina*. However, in 2014, *Eurytemora* was the most prevalent copepod, which is unusual. *Eurytemora* was identified in samples in 1991, then again since 2010, and was extremely abundant in 2014. *Bosmina* were small, which can indicate nutrient deficiencies, and additionally, cladoceran density throughout the season was composed primarily of *Daphnia.* These shifts in species composition and size may indicate top-down pressures.

Phytoplankton has been collected from Black and Chignik lakes since 2000 but has not been analyzed until recently. Data from 2013 and 2014 are not complete, but initial analysis shows the Chignik Lake biovolume of phytoplankton in 2013 (>5 billion um3/L) was an order of magnitude greater than in 2010 (383 million um3/L). The 2013 biovolumes were driven by one genera of diatom (*Stephanodiscus*), which can survive in sediment conditions. *Stephanidiscus* is often considered an indicator of mesotrophic conditions in lakes, and additionally, some phytoplankton species such as *stephanodiscus* act as energy "sinks" because they are not available to zooplankton as food, either because of size (both too large or too small) or because structural composition of diatoms (silica content) means that the heavy phytoplankton sink in the water column, out of the feeding area of juvenile fish.

In 2012, zooplankton biomasses were relatively depressed throughout the season. Zooplankton biomasses were greater in 2013, until September, when phytoplankton samples indicate there was a sediment event. The sediment load may have prevented phytoplankton production in the fall, which is turn could have limited zooplankton. Eurytemora may have been able to thrive in this situation, and begin to dominate the zooplankton community. With fewer predatory copepods such as *Cyclops*, Daphnia may have been able to be more successful, though still limited. With changes in environmental conditions such as increased sediment load in the early fall or changes in light levels, the zooplankton community may have gone into diapause early, and were unavailable as forage for juvenile sockeye salmon. Subsequently, juvenile sockeye salmon may have had a poor condition factor as they entered the winter, further exacerbated by warm overwintering temperatures but a lack of available food, which could have resulted in the low condition factor observed in outmigrating smolt in 2014. Complete analysis of historical phytoplankton species composition and abundance will add greatly to the limnology dataset and allow for further investigation of whole-lake trophic webs.

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 et al. 2013a; Simmons et al. 2013b). Smolt entering the marine environment in good condition (high *K*) have been shown to have higher survival than those with lower *K* (Foerster 1954; Henderson and Cass 1991). Keeping the sockeye salmon smolt population and zooplankton levels, particularly Chignik Lake cladocerans, in balance will help promote productive adult returns in future years. This may be achieved by using zooplankton and smolt *K* data to inform managers of where to aim within the escapement goal range (Sagalkin et al. 2013).

LIMNOLOGY

Nutrient data can indicate limitations in aquatic environments. A ratio of total nitrogen (TN) to total phosphorous (TP) is commonly used to indicate nutrient status, and both are necessary for primary production at specific ratios (Wetzel 1983; University of Florida 2000). Nitrogen-phosphorous ratios of less than 10:1 indicate nitrogen limitations, whereas ratios greater than about 25:1 indicate phosphorus limitation (Wetzel 1983; U.S. Environmental Protection Agency 2000). Water quality data from 2014 indicated nutrient levels in both lakes fell into low to medium production (mesotrophic) levels as defined by several trophic state indices (Carlson 1977; Carlson and Simpson 1996) but were comparable to other Alaskan lakes in the region (Honnold et al. 1996; Schrof and Honnold 2003). The seasonally averaged TN:TP ratio for Black Lake was 20.4:1 this season, which is lower than 2013 levels but much higher than 2012 and 2011 levels. Of the two, phosphorus was likely the limiting nutrient in Black Lake during the 2014 season. The seasonal average for Chignik Lake was 27.3:1 and was stable throughout the season. This seasonally averaged ratio is greater than the 10-year average (19.2:1).

The quantity of photosynthetic pigments present in an aquatic system is related to the biomass of primary producers, and in a location such as Chignik, which can receive significant nutrients from terrestrial inputs, may be a better indicator of 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. The ratio of chlorophyll *a* was below average in Chignik Lake this season (2014 ratio 3.16:1; 10-year average 5.9:1) and may indicate primary productivity is being strained in Chignik Lake. Chlorophyll *a* levels were higher in May and September samples. Changes in nutrients and forage bases can significantly impact higher trophic levels (Kyle et al. 1988; Milovskaya et al. 1998). Chignik Lake community dynamics are thought to be largely controlled by top-down pressures (Finkle 2004), and a rearing population of juvenile salmon between June and August could have significantly impacted primary production levels. Parent escapements have not been overly large in recent years, and conditions in summer of 2013 suggested that lake productivity was not taxed and carrying capacity had not been exceeded (St. Saviour and Shedd, 2014). However, the warm winter conditions in 2013/2014 may have placed an extreme thermal stress on the number of juveniles overwintering in the lake. Continued collection of limnology data is important to understand mechanisms driving resource abundance and to assess feedbacks from sockeye fry predation to the zooplankton forage base.

The seasonal pH levels in Black and Chignik lakes were slightly higher than historical seasonal averages from the 1960s (1960s Black Lake seasonal average pH = 7.42; 1960s Chignik Lake seasonal average pH = 7.27; Narver 1966), but well within a safe pH range for aquatic organisms of 4.5 to 9.5.

MARINE SURVIVAL ESTIMATES

All adult sockeye salmon offspring from BYs 1991 through 2006 and most offspring from BY 2007 have returned to the Chignik River; overall marine survival has ranged from 6% for BY 1999 to 67% for BY 1993 (mean survival 28%; Table 15). The estimation of the 1993 and 1994 BY marine survival includes a portion of the outmigration estimate from 1996, which is considered erroneous (Edwards and Bouwens 2002). When presented by outmigration year, marine survivals ranged from 5% for outmigration year 2001 to 84% for outmigration year 2007, with a mean survival rate of 27% (Table 16). The very high marine survival estimate for outmigration year 2007 may be due to truly high survival and a biased low smolt outmigration estimate. Smolt were much larger than average, so they entered the ocean in good condition and likely had higher survival than average (Figure 7). They also may have been stronger swimmers and been able to avoid the traps resulting in biased-low smolt population estimates. Efficiency estimates would not necessarily have accounted for trap avoidance because trap catches were low for much of 2007 and did not allow for consistent mark-recapture experiments. A more realistic marine survival estimate came with the return of the 2009 outmigration year which also had average *K* (Tables 5 and 16). Outmigrating smolt in 2010 had a fairly low condition factor, which may have influenced their marine survival rate of 16%. Given the high mortality observed during the outmigration in 2014, as well as the low condition factor of smolt, it is anticipated that marine survival of smolt from the 2014 outmigration year will be low.

FORECASTS OF ADULT SALMON RETURNS

A smolt-based sockeye salmon forecast has been developed annually since 2002. Since its inception, the smolt-based forecast has overestimated the actual total sockeye salmon adult run to the Chignik system by as much as 107% (2004 forecast) and underestimated it by as much as 53% (2011 forecast). The 2014 forecast point estimate was 60% greater than the actual run. Forecast methods have included simple and multiple linear regressions of smolt outmigrants by age class to ocean-age class adult returns and multiple regressions of outmigrant-age class smolt and temperature to ocean-age class adult returns. The 2015 smolt-based forecast used total smolt outmigration estimates to predict a total adult run of 3.03 million. It is 19% higher than the formal adult-based forecast total of 2.54 million.

The smolt-based forecasting method does not currently have the resolution to forecast by run because the stock-specific data series is relatively short (seven years of data from 2006–2012 have been analyzed). However, if continued, long term genetic stock identification will provide a means for Chignik sockeye salmon smolt stock separation, stock-specific smolt-based forecasts, and smolt production estimates of each stock. For example, the genetic samples collected from smolt in 2011 indicated that adult returns of early-run sockeye salmon in 2014 would be weak due to the lack of freshwater-age-1 smolt of Black Lake origin. The early run was still composed primarily of age 1.x adult fish, but the majority of these adults were age 1.2 from the 2012 smolt outmigration. Samples collected in 2012 have been analyzed and show that the majority of outmigrating freshwater-age-1 smolt were of Black Lake origin, while the majority of outmigrating freshwater-age-2 smolt were of Chignik Lake origin. While some of these Black Lake origin fish returned as age 1.2 adults in 2014, given the large smolt outmigration in 2012, it is anticipated that the 2015 early-run will have a large component of 1.3 adults. Continued analysis of samples collected from the smolt project will add valuable information to this dataset to provide stock-specific smolt-based forecasts and provide insight to freshwater effects on the population long before they become apparent in adult returns.

CONCLUSION

The continued collection of smolt outmigration data allows ADF&G to monitor changes in life history strategies of sockeye salmon in the Chignik River system caused by changes in environmental conditions. Reductions in Black Lake water volume and rearing habitat have occurred along with shifts in water temperatures since the 1960s. Competition between Black

Lake emigrants and Chignik Lake smolt has been demonstrated (Parr 1972; Ruggerone 2003) and is likely stronger in years when Black Lake is warmer. High escapement and recruitment also likely have an effect on competition between stocks as evidenced by top-down pressures on the Chignik Lake zooplankton community. Continued monitoring of smolt outmigration and limnology, including analysis of historical phytoplankton data, is the best way to detect changes in early life history strategies that may be deleterious to Chignik sockeye salmon fisheries, especially if winters of warm temperatures and lack of ice persist. The temperatures during 2013 and 2014 were the warmest on record since 1970, and the observed condition factor of outmigrating smolt may have deleterious impacts on marine survival. The outmigrating smolt population estimate of 2014 is considered conservative and very likely an underestimate of total smolt population, as well as potentially underestimating freshwater-age-2 outmigrants.

ADF&G has conducted the smolt enumeration project since 1994, formally incorporating the collection of limnology samples from both lakes in 2008, and has collected genetic samples since 2006. Taken together, the data set is becoming a long and comprehensive time series, useful for identifying longer-term changes that may be occurring in the system, as well as quantifying long-term natural variation. The future inclusion of phytoplankton data from 2000–2014 (anticipated in the 2015 report) will be a valuable addition. The smolt project has provided understanding of the mechanisms behind freshwater production and for enhancing management of the system. For example, information collected in 2011 showed that in addition to a fairly small outmigration, most smolt were of Chignik Lake origin, which was substantiated by poor early-run returns in 2014. Analysis of data collected in 2012 suggest that in addition to a much larger smolt outmigration than 2011, the stock composition of adults returning in 2015 will be much more even, although there will be few freshwater-age-2 adults returning in the early run. In 2012, freshwater-age-2 fish were primarily of Chignik Lake origin, and some of these fish were seen in the high percentage of 2.2 adults returning in 2014. The 2015 late-run run should also be dominated by freshwater-age-2 adults, perhaps similar to adult age compositions observed in 2012 and 2014. Data from this project are essential for monitoring the health of sockeye salmon in Chignik system because smolt outmigration information may be the only available means to link changes in run strength to freshwater, marine, or climate influences before they become apparent in adult returns.

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TABLES AND FIGURES

Table 1.–Results from mark-recapture tests performed on sockeye salmon smolt outmigrating from the Chignik River, 2014.

Date	No. Released [a]	Total Recaptures	Trap Efficiency [b]
4/25-5/7 [c]	3,206	80	2.53%
5/8-5/14	1,168	26	2.31%
5/15-5/22	843	52	6.28%
5/23-7/4	581	38	6.70%
Total	5,798	196	4.46%

[a] The number released accounts for delayed mortality.

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

[c] These data are based on a recapture event that took place on May 2.

Table 2.–Chignik River sockeye salmon smolt population estimates, by freshwater-age class, 1994–2014, and adult returns.

		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			
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			

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Table 2.–Page 2 of 2.

		Number of Smolt							95% C.I.	
Year		Age-0	Age-1	Age-2	Age-3	Age-4	Total	S.E.	Lower	Upper
2009	Numbers	110,446	3,777,572	4,288,491	0	0	8,176,509	320,013	7,472,166	8,880,852
	Percent	1.4	46.2	52.4	0.0	0.0	100.0			
2010	Numbers	1,039,131	17,684,165	9,347,999	91,509	0	28,162,803	4,433,289	19,473,557	36,852,050
	Percent	3.7	62.8	33.2	0.3	0.0	100.0			
2011	Numbers	203,380	10,684,120	1,371,044	0	0	12,258,543	1,802,506	8,725,631	15,791,456
	Percent	1.7	87.2	11.2	0.0	0.0	100.0			
2012	Numbers	685,707	16,328,172	22,734,743	196,575	0	39,945,197	4,551,145	31,024,952	48,865,441
	Percent	1.7	40.9	56.9	0.5	0.0	100.0			
2013	Numbers	117,435	8,314,053	10,467,154	176,196	0	19,074,838	3,252,943	12,699,069	25,450,606
	Percent	0.6	43.6	54.9	0.9	0.0	100.0			
2014	Numbers	4,250	2,757,054	1,507,021	26,869	0	4,295,195	349,136	3,610,889	4,979,501
	Percent	0.1	64.2	35.1	0.6	0.0	100.0			

Table 3.–Estimated sockeye salmon smolt outmigration from the Chignik River in 2014 by freshwater-age class and statistical week.

Statistical Week	Date	Number of Smolt								
		age-0	%	age-1	%	age-2	%	age-3	%	Total
17 [a,b]	4/19–4/25	-	0.0%	72,171	65.5%	37,463	34.0%	551	0.5%	110,184
18 [b]	4/26–5/2	-	0.0%	977,431	65.5%	507,369	34.0%	7,461	0.5%	1,492,261
19	5/3–5/9	-	0.0%	816,811	65.5%	423,993	34.0%	6,235	0.5%	1,247,039
20	5/10–5/16	-	0.0%	644,648	65.5%	334,626	34.0%	4,921	0.5%	984,196
21	5/17–5/23	-	0.0%	190,313	51.3%	173,530	46.7%	7,463	2.0%	371,306
22	5/24–5/30	-	0.0%	21,869	46.2%	25,194	53.3%	237	0.5%	47,300
23	5/31–6/6	-	0.0%	10,946	89.1%	1,341	10.9%	-	0.0%	12,288
24	6/7–6/13	-	0.0%	12,065	85.4%	2,059	14.6%	-	0.0%	14,124
25	6/14–6/20	1,333	17.1%	5,618	72.0%	857	11.0%	-	0.0%	7,808
26	6/21–6/27	1,268	30.0%	2,465	58.3%	493	11.7%	-	0.0%	4,225
27	6/28–7/4	1,650	37.0%	2,717	60.9%	97	2.2%	-	0.0%	4,464
Total		4,250	0.1%	2,757,054	64.2%	1,507,021	35.1%	26,869	0.6%	4,295,195

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

[a] Statistical week 17 only includes data from April 25.

[b] Data from April 25–April 30 are based on outmigration estimates before traps were installed.

Table 4.–Length, weight, and condition factor of Chignik River sockeye salmon smolt samples in 2014, by freshwater-age and statistical week. Totals weighted by sample size (SS) and by outmigration magnitude (OM).

				Length (mm)		Weight (g)		Condition Factor (K)	
Age	Stat Week	Starting Date	Sample Size	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
0	25	6/14	28	49	0.48	0.9	0.04	0.76	0.02
0	26	6/21	36	49	0.52	0.9	0.03	0.79	0.01
0	27	6/28	51	48	0.45	0.9	0.03	0.79	0.01
Total	Weighted by SS		115	48.5	0.48	0.9	0.03	0.79	0.02
	Weighted by OM			49		0.9		0.78	
1	19	5/3	131	56	0.56	1.0	0.04	0.57	0.01
1	20	5/10	131	58	0.68	1.2	0.05	0.56	0.01
1	21	5/17	102	57	0.72	1.1	0.05	0.54	0.01
1	22	5/24	92	65	0.91	1.8	0.08	0.60	0.01
1	23	5/31	155	57	0.51	1.1	0.04	0.56	0.01
1	24	6/7	170	59	0.54	1.3	0.04	0.60	0.01
1	25	6/14	118	56	0.46	1.2	0.04	0.64	0.01
1	26	6/21	70	58	0.65	1.4	0.06	0.72	0.02
1	27	6/28	84	56	0.50	1.3	0.05	0.74	0.02
Total	Weighted by SS		1,053	58	0.61	1.2	0.05	0.60	0.01
	Weighted by OM			57		1.1		0.56	
2	19	5/3	68	81	0.64	3.5	0.12	0.64	0.01
2	20	5/10	68	80	0.68	3.5	0.12	0.65	0.01
2	21	5/17	93	80	0.48	3.3	0.08	0.64	0.01
2	22	5/24	106	79	0.47	3.2	0.07	0.64	0.01
2	23	5/31	19	79	2.15	3.5	0.49	0.64	0.03
2	24	6/7	29	80	1.01	3.3	0.26	0.65	0.03
2	25	6/14	18	76	2.00	3.0	0.26	0.67	0.03
2	26	6/21	14	80	3.63	3.9	0.87	0.67	0.04
2	27	6/28	3	70	4.26	2.5	0.58	0.72	0.12
Total	Weighted by SS		418	80	1.70	3.3	0.32	0.65	0.03
	Weighted by OM			81		3.5		0.64	
3	19	5/3	1	84	0.00	3.8	0.00	0.64	0.00
3	20	5/10	1	97	0.00	6.8	0.00	0.75	0.00
3	21	5/17	1	110	0.00	12.1	0.00	0.91	0.00
3	22	5/24	1	99	0.00	7.7	0.00	0.79	0.00
Total	Weighted by SS		4	109	0.00	11.5	0.00	0.82	0.00
	Weighted by OM			97		7.0		0.76	

Table 5.–Mean length, weight, and condition factor of sockeye salmon smolt samples from the Chignik River, by year and freshwater-age, 1994–2014.

		Length (mm)			Weight (g)			Condition Factor		
Year	Age	Sample Size	Mean	Standard Error	Sample Size	Mean	Standard Error	Sample Size	Mean	Standard Error
1995	0	272	46	0.18	272	0.7	0.01	272	0.74	0.01
1996	0	125	49	0.45	113	1.0	0.03	113	0.82	0.01
1997	0	195	46	0.22	195	0.8	0.01	195	0.83	0.01
1998	0	15	45	0.96	15	0.7	0.03	15	0.73	0.03
1999	0	40	52	0.79	40	1.3	0.06	40	0.97	0.03
2000	0	223	60	0.52	223	2.1	0.05	223	0.91	0.01
2001	0	96	56	0.51	96	1.5	0.04	96	0.88	0.01
2002	0	217	49	0.27	217	1.2	0.02	217	0.98	0.01
2003	0	149	56	0.53	149	1.5	0.05	149	0.79	0.01
2004	0	347	56	0.44	347	1.7	0.05	347	0.91	0.01
2005	0	652	56	0.28	649	1.5	0.03	649	0.83	0.01
2006	0	427	52	0.24	427	1.0	0.02	427	0.70	0.01
2007	0	6	64	2.47	6	2.5	0.08	6	1.03	0.16
2008	0	568	53	0.17	566	1.1	0.01	566	0.76	0.01
2009	0	198	53	0.39	196	1.4	0.04	196	0.93	0.01
2010	0	128	54	0.48	128	1.2	0.04	128	0.78	0.01
2011	0	100	49	0.41	100	1.0	0.03	100	0.86	0.01
2012	0	129	52	0.35	129	0.9	0.02	129	0.65	0.01
2013	0	32	52	0.69	32	1.2	0.04	32	0.83	0.02
2014	0	115	48	0.28	115	0.9	0.02	115	0.79	0.01
1994	1	1,715	67	0.16	1,706	2.3	0.02	1,706	0.75	0.00
1995	1	1,272	60	0.34	1,272	2.0	0.04	1,272	0.82	0.00
1996	1	1,423	68	0.29	1,356	2.7	0.04	1,356	0.81	0.00
1997	1	1,673	63	0.35	1,673	2.4	0.04	1,673	0.81	0.00
1998	1	785	69	0.38	780	2.7	0.06	780	0.78	0.01
1999	1	1,344	77	0.17	1,344	4.1	0.03	1,344	0.89	0.00
2000	1	1,175	72	0.22	1,175	3.3	0.04	1,175	0.86	0.00
2001	1	1,647	65	0.13	1,647	2.1	0.02	1,647	0.76	0.00
2002	1	1,588	65	0.18	1,588	2.3	0.02	1,588	0.83	0.00
2003	1	1,665	65	0.11	1,665	2.1	0.01	1,665	0.75	0.00
2004	1	1,030	69	0.20	1,030	2.8	0.03	1,030	0.83	0.00
2005	1	892	69	0.25	892	2.7	0.03	892	0.81	0.00
2006	1	662	68	0.28	662	2.4	0.03	662	0.76	0.00
2007	1	809	82	0.16	809	4.9	0.03	809	0.88	0.00
2008	1	844	65	0.17	817	2.1	0.02	817	0.76	0.00
2009	1	588	79	0.45	571	3.8	0.08	571	0.77	0.00
2010	1	1,205	69	0.17	1,205	2.6	0.02	1,205	0.76	0.00
2011	1	1,401	70	0.22	1,400	2.8	0.03	1,400	0.88	0.01
2012	1	733	68	0.25	733	2.2	0.04	733	0.68	0.00
2013	1	793	72	0.25	792	3.1	0.03	792	0.81	0.00
2014	1	1,053	58	0.22	1,053	1.2	0.02	1,053	0.60	0.00

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Table 5.–Page 2 of 2.

		Length (mm)			Weight (g)			Condition Factor		
Year	Age	Sample Size	Mean	Standard Error	Sample Size	Mean	Standard Error	Sample Size	Mean	Standard Error
1994	2	1,091	77	0.22	1,068	3.6	0.04	1,068	0.74	0.00
1995	2	1,008	75	0.23	1,008	3.5	0.04	1,008	0.80	0.00
1996	2	548	80	0.34	533	4.2	0.06	533	0.81	0.00
1997	2	772	83	0.25	772	4.7	0.05	772	0.80	0.00
1998	2	1,925	72	0.13	1,881	3.0	0.03	1,881	0.76	0.00
1999	2	784	81	0.28	784	4.8	0.07	784	0.89	0.00
2000	2	503	76	0.34	503	3.6	0.07	503	0.80	0.00
2001	2	389	75	0.45	387	3.4	0.09	387	0.77	0.01
2002	2	225	80	0.78	225	4.9	0.18	225	0.88	0.01
2003	2	279	76	0.48	279	3.5	0.09	279	0.76	0.01
2004	2	274	77	0.41	274	3.9	0.09	274	0.82	0.00
2005	2	397	76	0.33	397	3.5	0.06	397	0.79	0.00
2006	2	518	78	0.35	518	3.8	0.08	518	0.78	0.00
2007	2	272	90	0.36	272	6.6	0.09	272	0.91	0.00
2008	2	288	79	0.35	287	3.7	0.06	287	0.73	0.01
2009	2	413	80	0.31	411	4.0	0.05	411	0.76	0.00
2010	2	359	81	0.30	359	4.0	0.05	359	0.74	0.00
2011	2	159	78	0.71	158	4.1	0.16	158	0.82	0.01
2012	2	452	78	0.27	452	3.4	0.05	452	0.69	0.00
2013	2	632	80	0.33	630	4.1	0.07	630	0.78	0.00
2014	2	418	80	0.30	418	3.3	0.06	418	0.65	0.00
1997	3	12	87	1.34	12	5.2	0.35	12	0.77	0.02
1998	3	20	84	3.39	19	5.5	0.99	19	0.81	0.02
1999	3	7	90	5.76	7	6.8	1.66	7	0.85	0.03
2000	3	14	86	2.36	14	5.3	0.63	14	0.79	0.01
2001	3	62	90	1.60	61	6.9	0.42	61	0.86	0.01
2002	3	6	110	7.24	6	13.8	2.67	6	1.00	0.03
2005	3	7	108	4.35	7	11.4	1.21	7	0.89	0.02
2006	3	32	99	1.89	32	8.9	0.55	32	0.89	0.02
2008	3	17	91	2.54	17	6.1	0.70	17	0.77	0.02
2010	3	2	92	1.50	2	6.0	0.35	2	0.78	0.01
2012	3	5	87	1.66	5	4.4	0.27	5	0.66	0.02
2013	3	16	92	1.25	16	6.3	0.36	16	0.80	0.01
2014	3	4	98	5.33	4	7.6	1.72	4	0.77	0.06

Table 6.–Euphotic Zone Depth (EZD) and Euphotic Volume (EV) of Chignik and Black lakes, by month, 2014.

		2014					
Lake		May [a]	June	July	August[b]	September	Average[c]
Chignik	EZD	9.63	10.04	11.42	10.21	7.55	9.77
	Mean EV [e]	232.1	242.0	275.2	246.1	182.0	235.46
Black [d]	EZD		5.29		2.82		4.06
	Mean EV [e]		78.09		78.09		78.09

[a] Black Lake was not sampled in May, July, or September

[b] Chignik Lake August sample conducted on July 31

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

[d] 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

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

Table 7.–Water quality parameters, nutrient concentrations, and photosynthetic pigments by sample date for Black Lake, 2014.

	6/24	8/2	Average[a]
pH	8.3	8.2	8.2
Alkalinity (mg/L $CaCO_3$)	33.5	36.0	34.8
Total phosphorous (µg/L P)	15.5	12.2	13.9
Total filterable phosphorous (µg/L P)	3.1	3.4	3.3
Filterable reactive phosphorous (µg/L P)	3.5	3.0	3.3
Total Kjeldhal nitrogen (µg/L N)	213.0	341.0	277.0
Ammonia (µg/L N)	3.1	7.4	5.3
Nitrate + Nitrite (µg/L N)	5.5	5.9	5.7
Silicon (µg/L)	2,689.2	2,814.7	2,752.0
Chlorophyll *a* (µg/L) [b]	4.1	ND	4.1
Phaeophytin *a* (µg/L) [b]	1.3	ND	1.3

[a] Limnology sampling did not occur in May or July 2014.

[b] Chlorophyll *a* and Phaeophytin *a* were not measured in August 2014.

Table 8.–Water quality parameters, nutrient concentrations, and photosynthetic pigments by sample date for Chignik Lake, 2014.

	5/5	6/2	7/1	7/31	9/2	Average[a]
pH	7.7	7.6	7.8	7.8	7.9	7.8
Alkalinity (mg/L $CaCO_3$)	24.4	25.5	27.1	24.5	29.0	26.1
Total phosphorous (µg/L P)	9.4	7.8	7.1	5.8	8.9	7.8
Total filterable phosphorous (µg/L P)	2.6	2.3	1.9	2.3	2.1	2.2
Filterable reactive phosphorous (µg/L P)	4.0	3.6	3.9	4.2	4.0	3.9
Total Kjeldhal nitrogen (µg/L N) [b]	79.5	43.5	50.0	25.0	157.5	71.1
Ammonia (µg/L N)	2.4	3.6	7.4	7.2	3.9	4.9
Nitrate + Nitrite (µg/L N)	199.5	191.9	120.9	96.1	96.6	141.0
Silicon (µg/L)	5,113.2	5,787.1	5,366.3	5,185.6	5,408.8	5,372.2
Chlorophyll *a* (µg/L) [c]	2.4	1.6	1.4	ND	2.3	1.9
Phaeophytin *a* (µg/L) [c]	0.7	1.1	0.8	ND	0.7	0.8

[a] Limnology sampling did not occur in August 2014, but did occur on July 1 and July 31.

[b] TKN values came from 1 m samples only.

[c] Chlorophyll *a* and Phaeophytin *a* were not measured on July 31, 2014.

Note: All stations and depths are averaged for each sample date.

Table 9.–Average number of zooplankton by taxon per m^2 from Black Lake by sample date, 2014.

		Sample date[a]		Seasonal
	Taxon	6/24	8/2	average
Copepods				
	Cyclops	54,140	18,631	36,385
	Nauplii	15,287	24,151	19,719
Total copepods		69,427	42,781	56,104
Cladocerans				
	Bosmina	3,822	37,261	20,541
	Ovig. *Bosmina*	5,732	1,380	3,556
	Chydorinae	–	1,380	690
Total cladocerans		9,554	40,021	24,788
Total copepods + cladocerans		78,981	82,803	80,892

[a] Zooplankton samples were not collected in May or July 2014.

Table 10.–Biomass estimates (mg dry weight/m^2) of the major Black Lake zooplankton taxa by sample date, 2014.

	Taxon	Sample date[a] 6/24	8/2	Seasonal average	Weighted average
Copepods					
	Cyclops	122.78	14.21	68.49	65.52
Total copepods		122.78	14.21	68.49	65.52
Cladocerans					
	Bosmina	4.97	22.94	13.96	13.73
	Ovig. *Bosmina*	13.80	1.11	7.45	7.20
	Chydorinae	–	1.07	0.54	0.54
Total cladocerans		18.77	25.12	21.95	21.47
Total biomass		141.55	39.33	90.44	86.99

[a] Zooplankton samples were not collected in May or August 2014.

Table 11.–Weighted average length (mm) of zooplankton from Black Lake by sample date, 2014.

	Taxon	Sample date[a] 6/24	8/2	Seasonal average
Copepods				
	Cyclops	0.81	0.48	0.72
Cladocerans				
	Bosmina	0.38	0.26	0.27
	Ovig. *Bosmina*	0.50	0.30	0.46
	Chydorinae	–	0.29	0.29

[a] Zooplankton samples were not collected in May or July 2014.

Table 12.–Average number of zooplankton by taxon per m^2 from Chignik Lake by sample date, 2014.

Taxon	Sample date[a] 5/5	6/2	7/1	7/31	9/2	Seasonal Average
Copepods						
Cyclops	31,684	15,924	46,364	89,437	49,363	46,554
Ovig. *Cyclops*	133	133	358	199	398	244
Epischura	332	0	0	0	0	66
Eurytemora	929	8,824	29,087	109,475	80,414	45,746
Ovig. *Eurytemora*	0	597	1,062	2,189	2,057	1,181
Nauplii	7,248	11,677	41,866	169,785	110,337	68,183
Total copepods	40,325	37,155	118,737	371,085	242,569	161,974
Cladocerans						
Bosmina	350	863	9,806	197,519	180,733	77,854
Ovig. *Bosmina*	0	133	2,999	3,649	8,161	2,988
Chydorinae	166	0	0	663	0	166
Daphnia L.	464	1,261	5,905	92,821	401,009	100,292
Ovig. Daphnia L.	0	332	2,680	12,805	69,334	17,030
Immature *Cladocera*	100	0	4,167	23,156	61,704	17,825
Total cladocerans	1,080	2,588	25,557	330,613	720,940	216,155
Total copepods + cladocerans	41,405	39,743	144,294	701,698	963,509	378,130

[a] Limnology sampling did not occur in August 2014, but did occur on July 1 and July 31.

Table 13.–Biomass estimates (mg dry weight/m^2) of the major Chignik Lake zooplankton taxa by sample date, 2014.

Taxon	Sample date[a] 5/5	6/2	7/1	7/31	9/2	Seasonal average	Weighted average
Copepods							
Cyclops	36.81	28.61	70.48	109.48	61.44	61.36	59.75
Ovig. *Cyclops*	0.50	0.50	2.02	1.24	1.46	1.14	1.25
Epischura	0.43	–	–	–	–	0.09	0.09
Eurytemora	2.93	42.63	113.52	416.17	319.23	178.89	177.44
Ovig. *Eurytemora*	–	5.40	10.58	18.97	16.64	10.32	10.31
Total copepods	40.67	77.14	196.60	545.86	398.77	251.80	248.84
Cladocerans							
Bosmina	0.25	0.98	8.67	129.84	141.54	56.26	56.15
Ovig. *Bosmina*	0.00	0.22	4.33	3.88	7.81	3.25	3.15
Chydorinae	0.10	–	–	1.14	–	0.25	0.24
Daphnia L.	0.19	0.82	7.25	90.30	499.11	119.54	121.98
Ovig. *Daphnia L.*	–	0.75	9.03	33.91	190.35	46.81	46.35
Total cladocerans	0.54	2.77	29.28	259.07	838.81	226.11	227.87
Total biomass	41.21	79.91	225.88	804.93	1237.58	477.91	476.71

[a] Limnology sampling did not occur in August 2014, but did occur on July 1 and July 31.

Table 14.–Weighted average length (mm) of zooplankton from Chignik Lake by sample date, 2014.

Taxon	Sample date[a] 5/5	6/2	7/1	7/31	9/2	Seasonal average
Copepods						
Cyclops	0.58	0.70	0.66	0.60	0.60	0.62
Ovig. *Cyclops*	1.02	1.02	1.42	1.29	1.01	1.18
Epischura	0.65	–	–	–	–	0.65
Eurytemora	0.77	0.87	0.79	0.77	0.77	0.78
Ovig. *Eurytemora*	–	1.31	1.40	1.30	1.22	1.29
Cladocerans						
Bosmina	0.28	0.34	0.31	0.27	0.30	0.28
Ovig. *Bosmina*	–	0.41	0.41	0.34	0.31	0.34
Chydorinae	0.27	–	–	0.43	–	0.40
Daphnia L.	0.35	0.41	0.56	0.50	0.55	0.54
Ovig. *Daphnia L.*	–	0.71	0.78	0.76	0.79	0.79

[a] Limnology sampling did not occur in August 2014, but did occur on July 1 and July 31.

Table 15.–Chignik River sockeye salmon escapement, estimated number of smolt by freshwater age, smolt per spawner, adult return by freshwater age, return per spawner, marine survival, by brood year, 1991–2007.

		Smolt Produced						Adult Returns						
Brood Year	Escapement	Age-0	Age-1	Age-2	Age-3	Total Smolt	Smolt / Spawner	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	5,541	1,795,467	737,680	11,621	2,550,309	2.45	NA
1992	764,436	NA	7,263,054	5,178,450	5,018	12,446,522	16.28	151,608	649,920	1,159,871	93,372	2,054,771	2.69	17%
1993 [a]	697,377	0	2,843,222	731,099	122,289	3,696,610	5.30	16,007	457,189	1,998,416	7,265	2,478,877	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	2,391,036	942,680	17,366	3,387,135	4.58	11%
1996	749,137	528,846	5,790,587	8,221,631	160,017	14,701,081	19.63	144,144	1,999,024	877,189	13,958	3,034,314	4.05	21%
1997	775,618	75,560	12,705,935	4,645,121	516,723	17,943,339	23.13	15,467	770,649	956,007	5,627	1,747,750	2.25	10%
1998	701,128	73,364	8,047,526	5,024,666	72,184	13,217,740	18.85	5,515	1,030,710	353,826	8,451	1,398,502	1.99	11%
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	2,705,564	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	1,806,016	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	1,133,445	1.56	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	129,303	1,067,014	987,159	10,222	2,193,698	3.79	46%
2005	581,382	1,744,370	1,926,682	987,928	0	4,658,980	8.01	28,613	1,461,254	935,660	94,411	2,519,938	4.33	54%
2006	735,493	9,286	3,309,894	4,874,340	91,509	8,285,029	11.26	33,123	2,865,182	1,866,956	56,981	4,822,242	6.56	58%
2007	654,974	1,017,498	3,242,862	9,347,999	0	13,608,359	20.78	45,736	520,516	1,297,433	1,045	1,864,729	2.85	14%
2008	706,058	59,306	17,684,165	1,371,044	196,575	19,311,090	27.35	17,460	3,028,245					
2009	720,062	1,039,131	10,684,120	22,734,743	176,196	34,634,189	48.10	4,891						
2010	743,911	203,380	16,328,172	10,467,154	26,869	27,025,575	36.33							
2011	753,817	685,707	8,314,053	1,507,021										
2012	712,389	117,435	2,757,054											
2013	756,101	4,250												
2014	651,609													
1992–2007 Average[a]													3.12	24%

[a] Portions of the smolt produced from the 1993 brood year were enumerated in the 1994, 1995, and primarily 1996 outmigration estimate, which underestimated the number of smolt leaving Chignik River. The marine survival rate of the 1993 brood year is therefore excluded from analysis.

Table 16.–Chignik River sockeye salmon smolt estimates, ocean-age-class returns, and marine survival by outmigration years, 1994–2010.

Outmigration	Smolt estimates					Adult returns					Marine
Year	Age-0.	Age-1.	Age-2.	Age-3.	Total Smolt	Age-.1	Age-.2	Age-.3	Age-.4	Total	Survival
1994	0	7,263,054	4,270,636	0	11,533,690	4,063	208,548	1,207,343	9,782	1,429,736	12%
1995	735,916	2,843,222	5,178,450	0	8,757,588	14,186	343,315	1,267,456	3,975	1,628,932	19%
1996 [a]	80,245	1,200,793	731,099	5,018	2,017,155	28,209	675,848	3,225,337	16,857	3,946,250	196%
1997	528,846	11,172,150	13,738,356	122,289	25,561,641	11,814	1,232,238	2,767,364	15,622	4,027,038	16%
1998	75,560	5,790,587	20,374,245	158,056	26,398,448	601	170,545	2,756,954	31,741	2,959,840	11%
1999	73,364	12,705,935	8,221,631	78,798	21,079,728	446	136,822	1,524,022	9,416	1,670,706	8%
2000	1,270,101	8,047,526	4,645,121	160,017	14,122,765	5,460	404,961	1,611,191	5,237	2,026,848	14%
2001	521,546	18,940,752	5,024,666	516,723	25,003,687	324	229,693	1,051,600	3,203	1,284,819	5%
2002	440,947	13,980,423	2,223,996	72,184	16,717,551	4,164	432,476	2,013,710	22,238	2,472,588	15%
2003	155,047	5,146,278	1,449,494	0	6,750,819	2,282	158,558	1,540,591	51,097	1,752,528	26%
2004	244,206	6,172,902	2,239,716	0	8,656,824	1,316	178,412	1,285,999	17,447	1,483,173	17%
2005	859,211	2,075,681	1,468,208	32,889	4,435,988	804	204,180	1,205,391	9,166	1,419,541	32%
2006	1,744,370	2,849,043	2,847,624	119,614	7,560,651	771	169,698	1,655,282	8,933	1,834,684	24%
2007	9,286	1,926,682	1,028,865	0	2,964,833	793	429,607	2,041,386	12,977	2,484,763	84%
2008	1,017,498	3,309,894	987,928	41,136	5,356,455	1,734	337,732	3,457,883	61,180	3,858,529	72%
2009	110,446	3,777,572	4,288,491	0	8,176,509	6,022	425,225	2,043,248	24,848	2,499,343	31%
2010	1,039,131	17,684,165	9,347,999	91,509	28,162,803	6,097	856,890	3,511,683	15,875	4,390,545	16%
2011	203,380	10,684,120	1,371,044	0	12,258,543	2,423	134,426	700,712			
2012	685,707	16,328,172	22,734,743	196,575	39,945,197	5,237	524,004				
2013	117,435	8,314,053	10,467,154	176,196	19,074,838	31,729					
2014	4,250	2,757,054	1,507,021	26,869	4,295,194						
Average [a]	491,812	8,088,463	6,170,769	89,643	14,840,688						25%

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

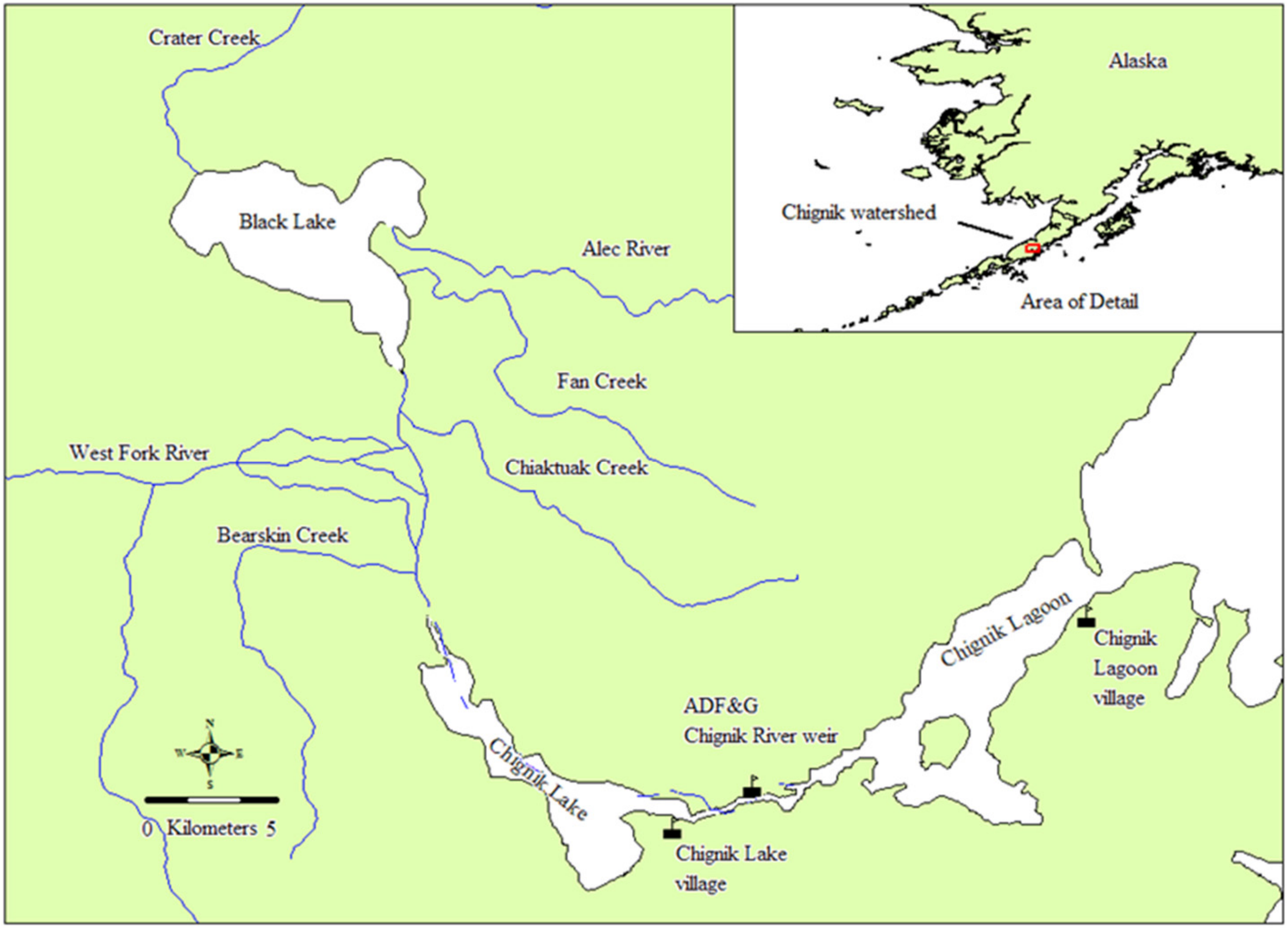

Figure 1.–Map of the Chignik River Watershed.

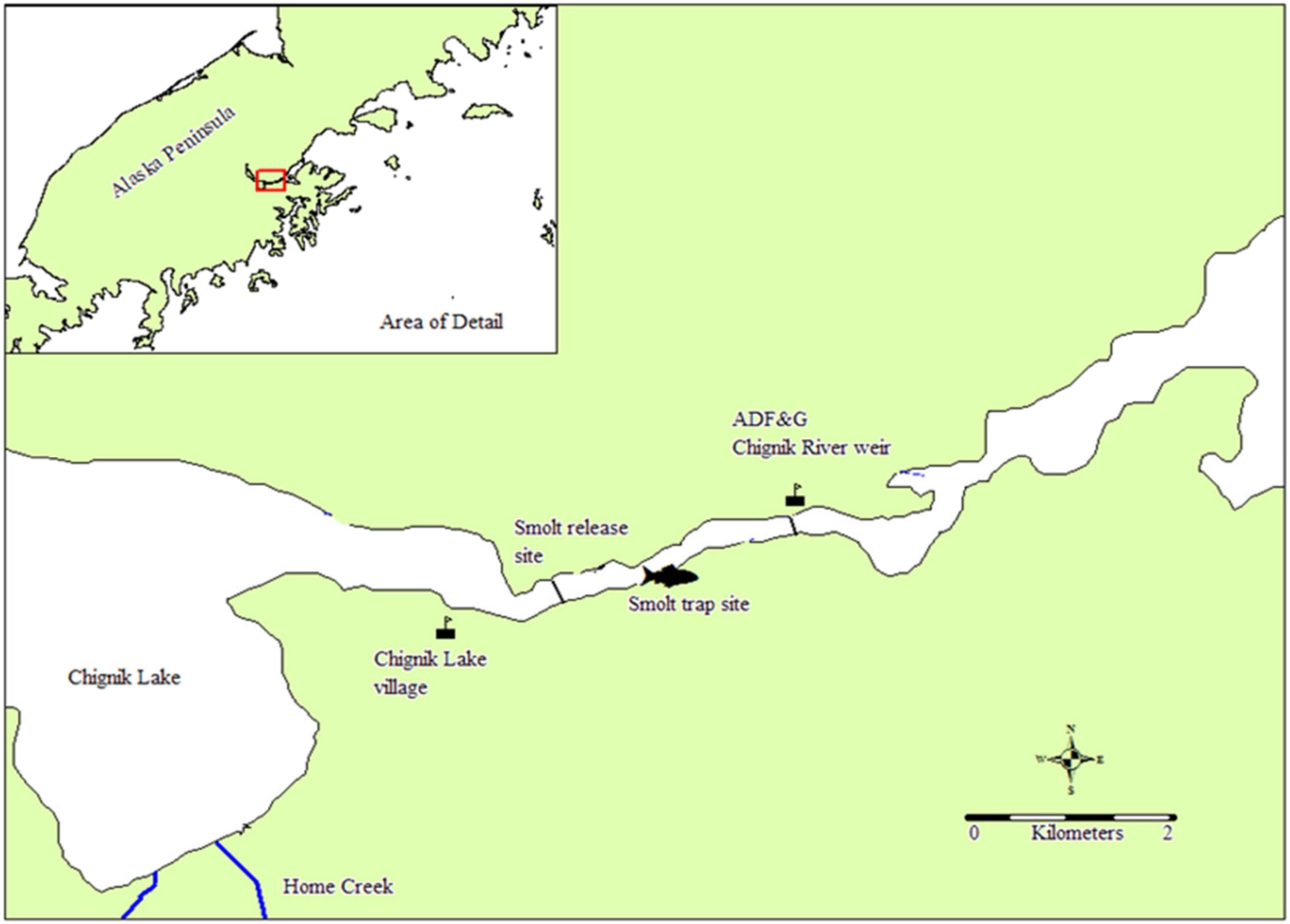

Figure 2.–Location of the smolt traps and the release site of marked smolt in the Chignik River, Alaska, 2014.

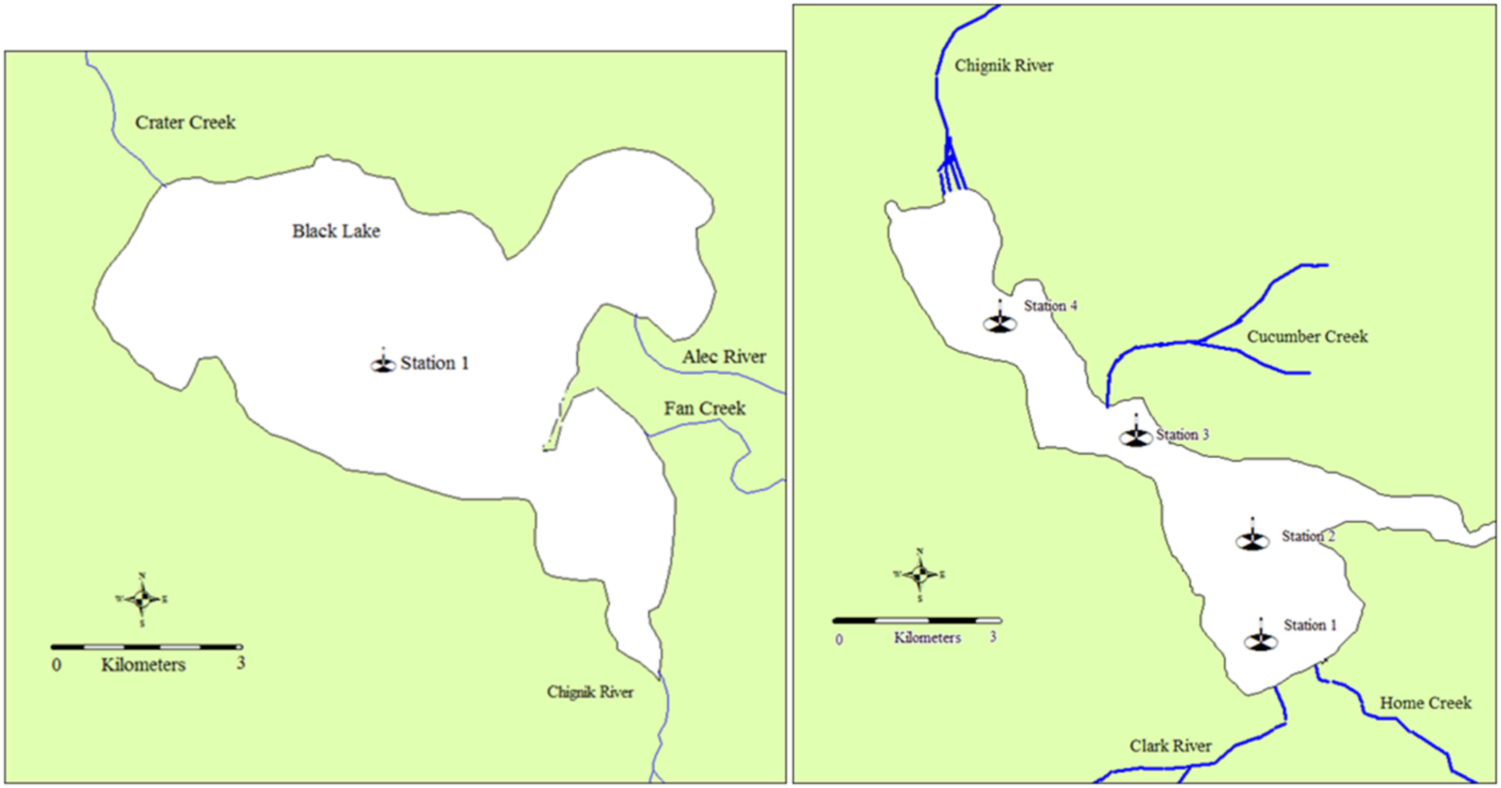

Figure 3.–Location of the Black Lake and Chignik Lake limnology sampling stations, 2014.

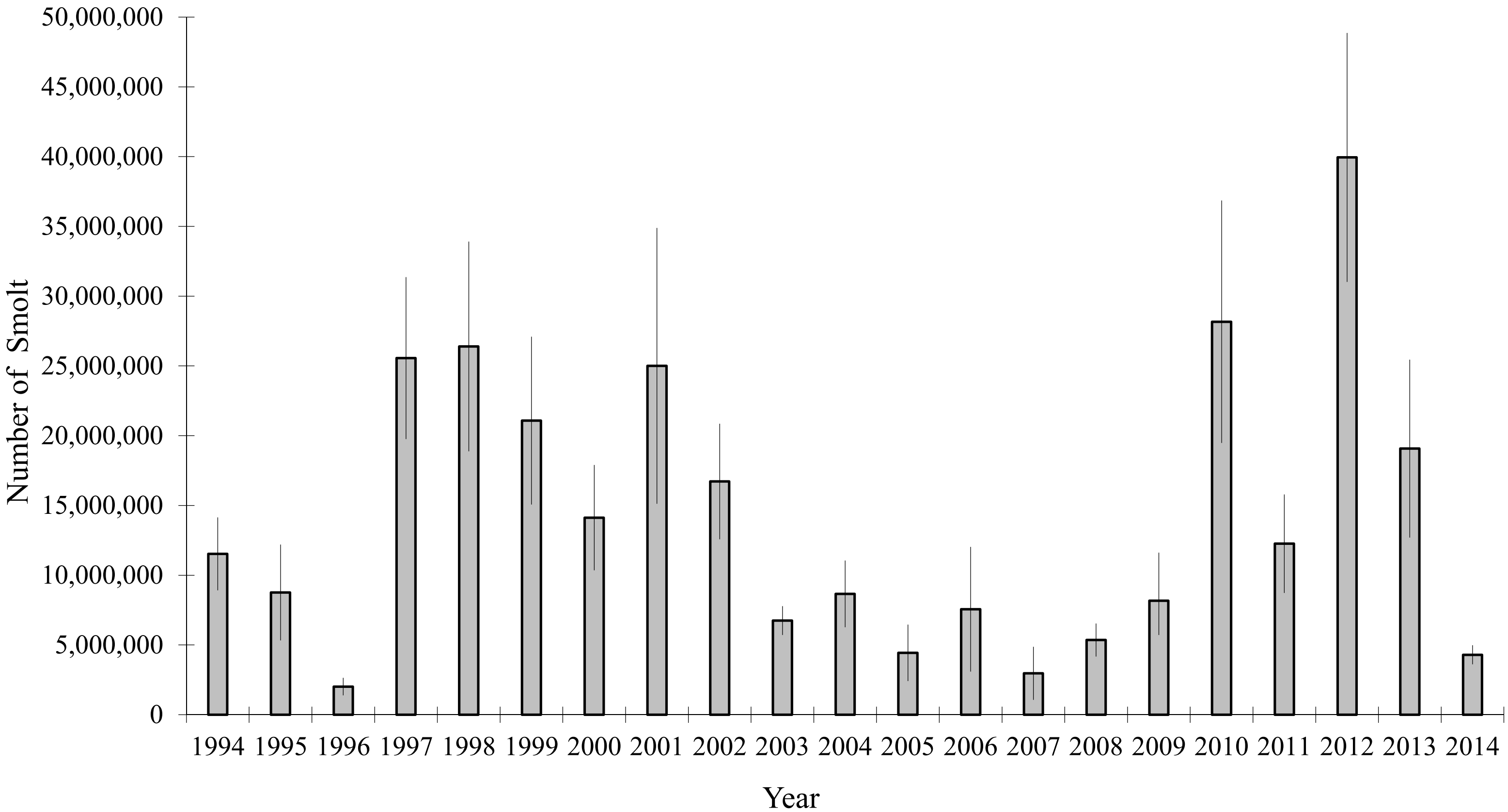

Figure 4.–Annual sockeye salmon smolt outmigration estimates and corresponding 95% confidence intervals, Chignik River, 1994–2014.

Note: Outmigration estimates from 1996 were underestimated.

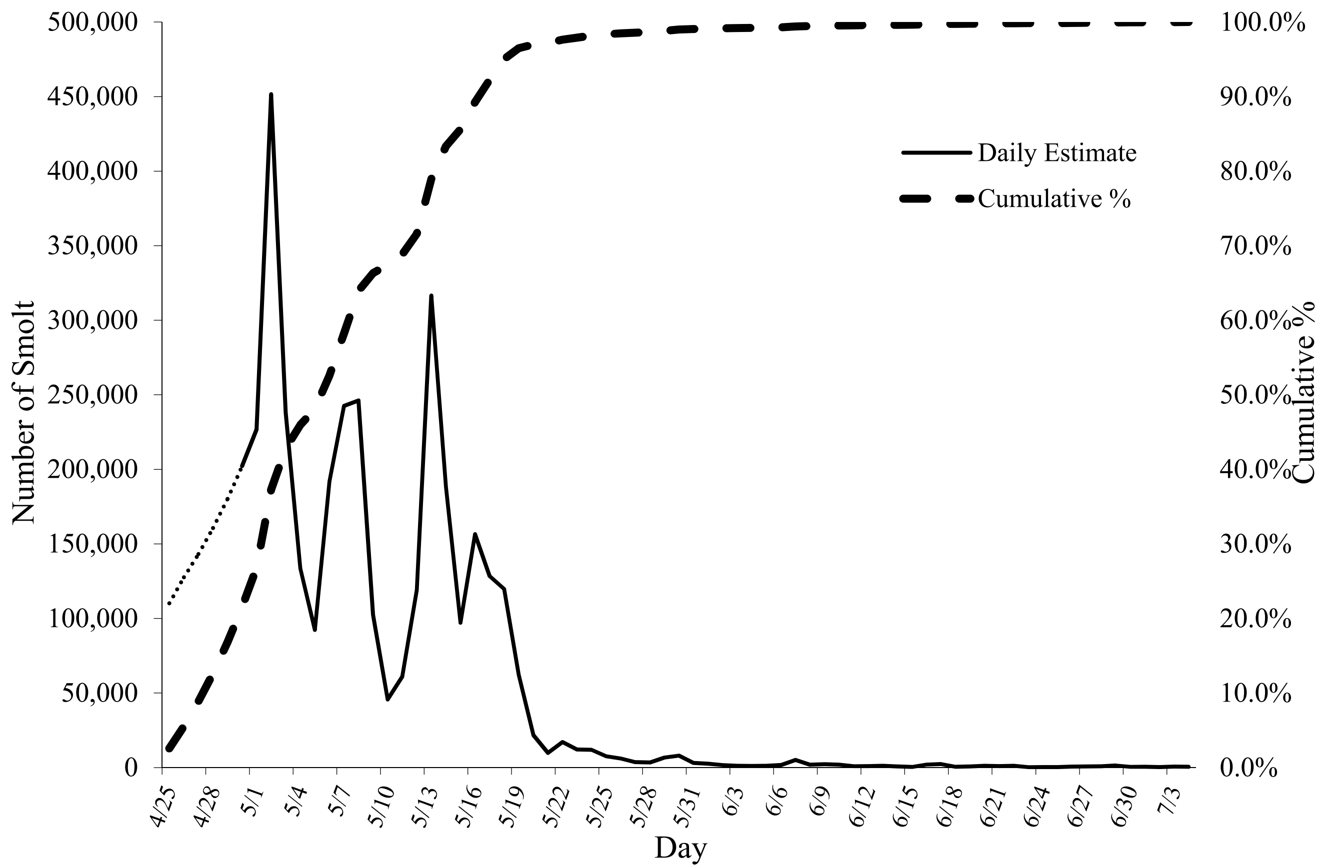

Figure 5.–Daily estimate and cumulative percentage of the sockeye salmon smolt outmigration from the Chignik River, 2014.

Note: Daily outmigration from April 25–April 31 is estimated.

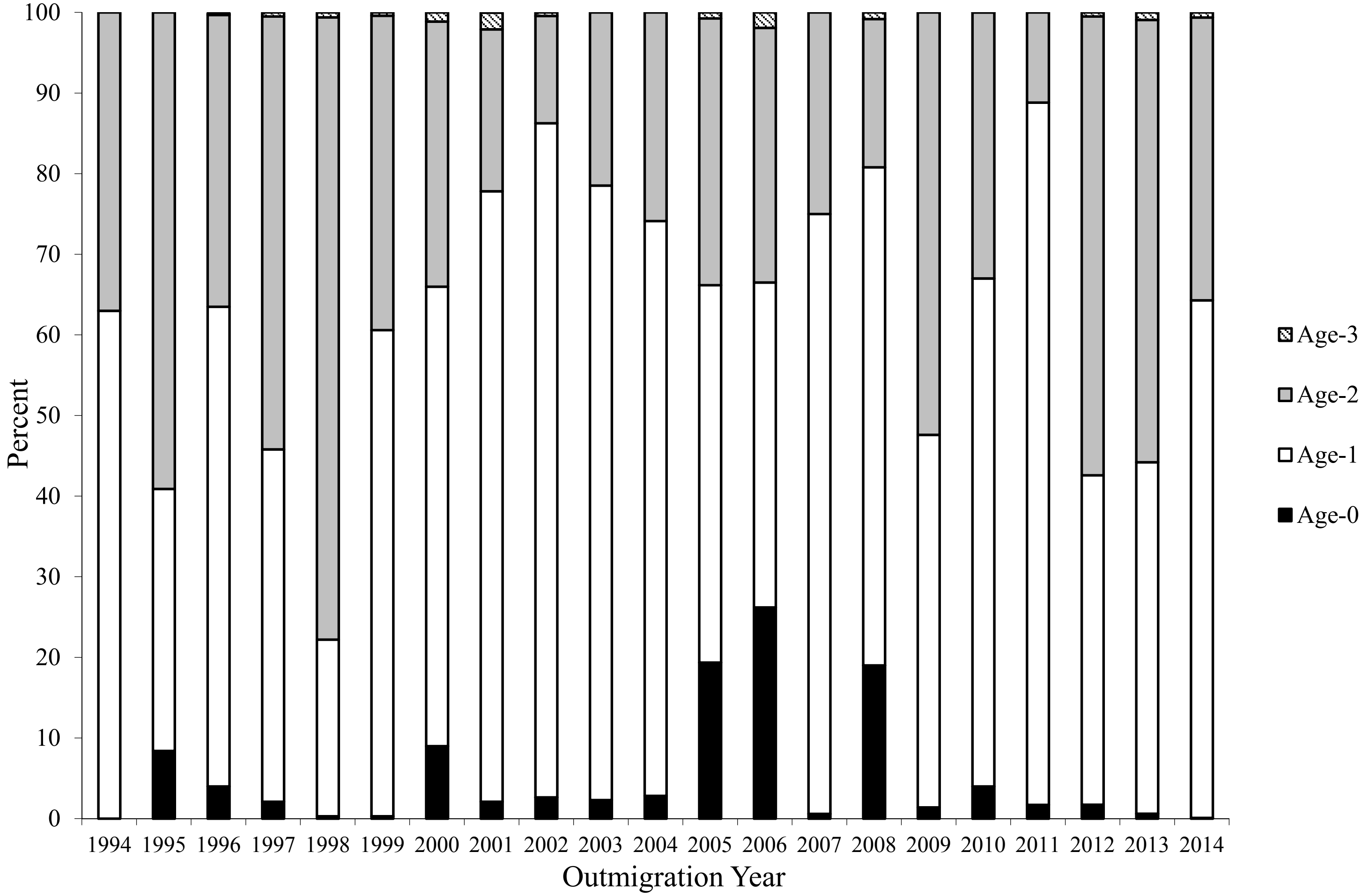

Figure 6.–A comparison of the estimated age structure of freshwater-age-0 to freshwater-age-3 sockeye salmon smolt outmigrations from the Chignik River, Alaska, 1994–2014.

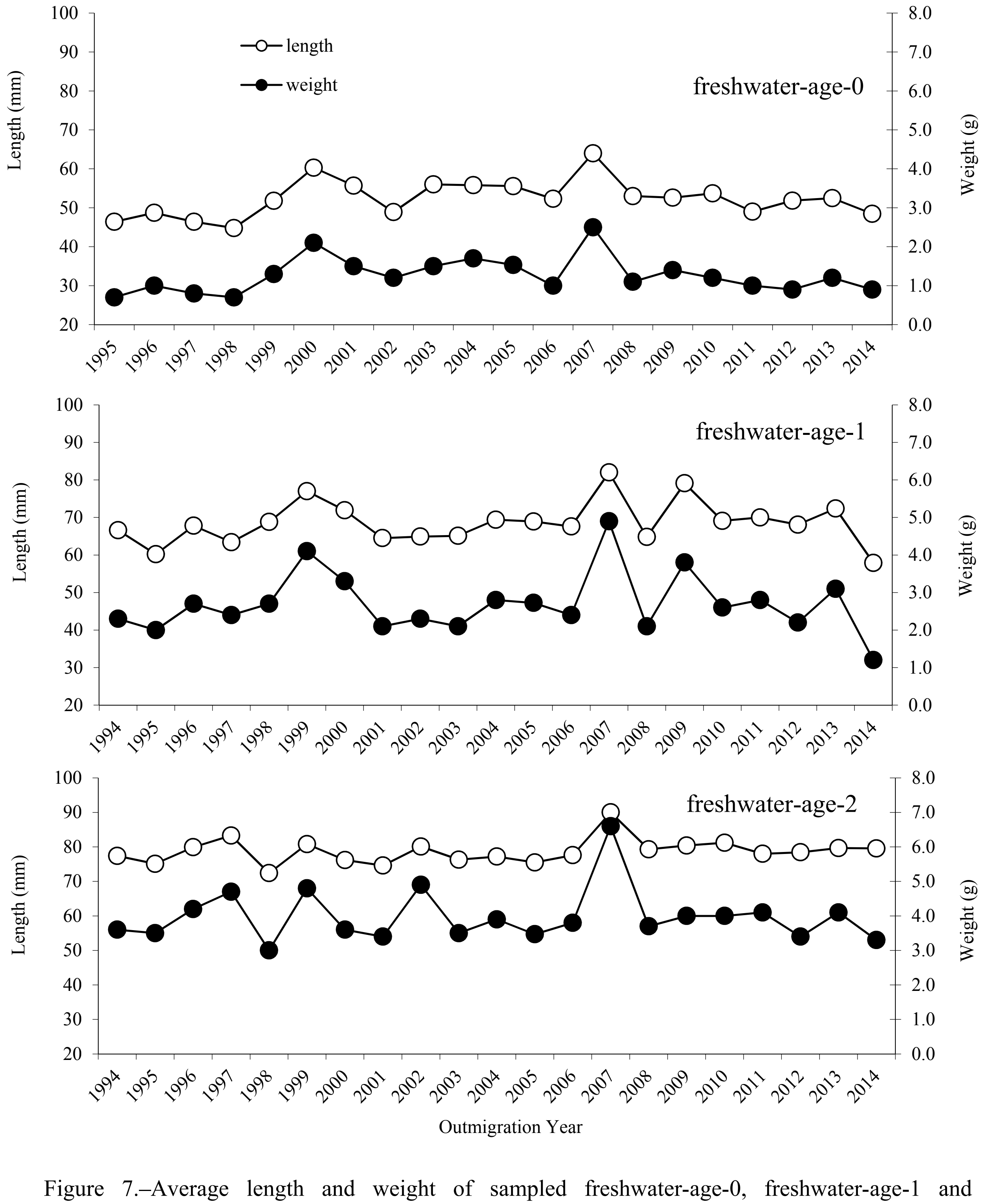

Figure 7.–Average length and weight of sampled freshwater-age-0, freshwater-age-1 and freshwater-age-2 sockeye salmon smolt, by year, 1994–2014.

Note: Freshwater-age-3 smolt comprise a neglible percentage of the yearly outmigrating population.

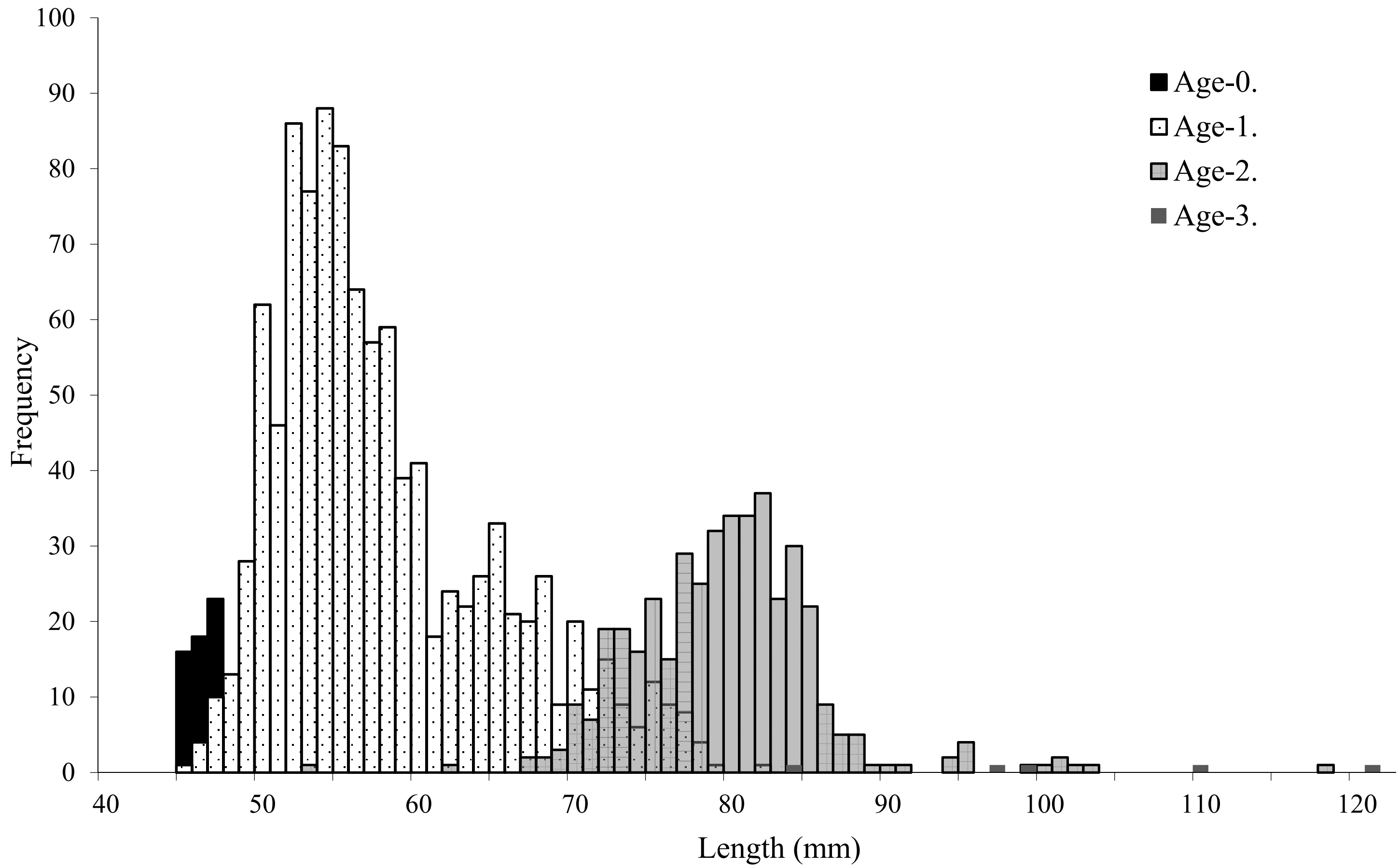

Figure 8.–Length frequency histogram of sockeye salmon smolt from the Chignik River, by freshwater age, 2014.

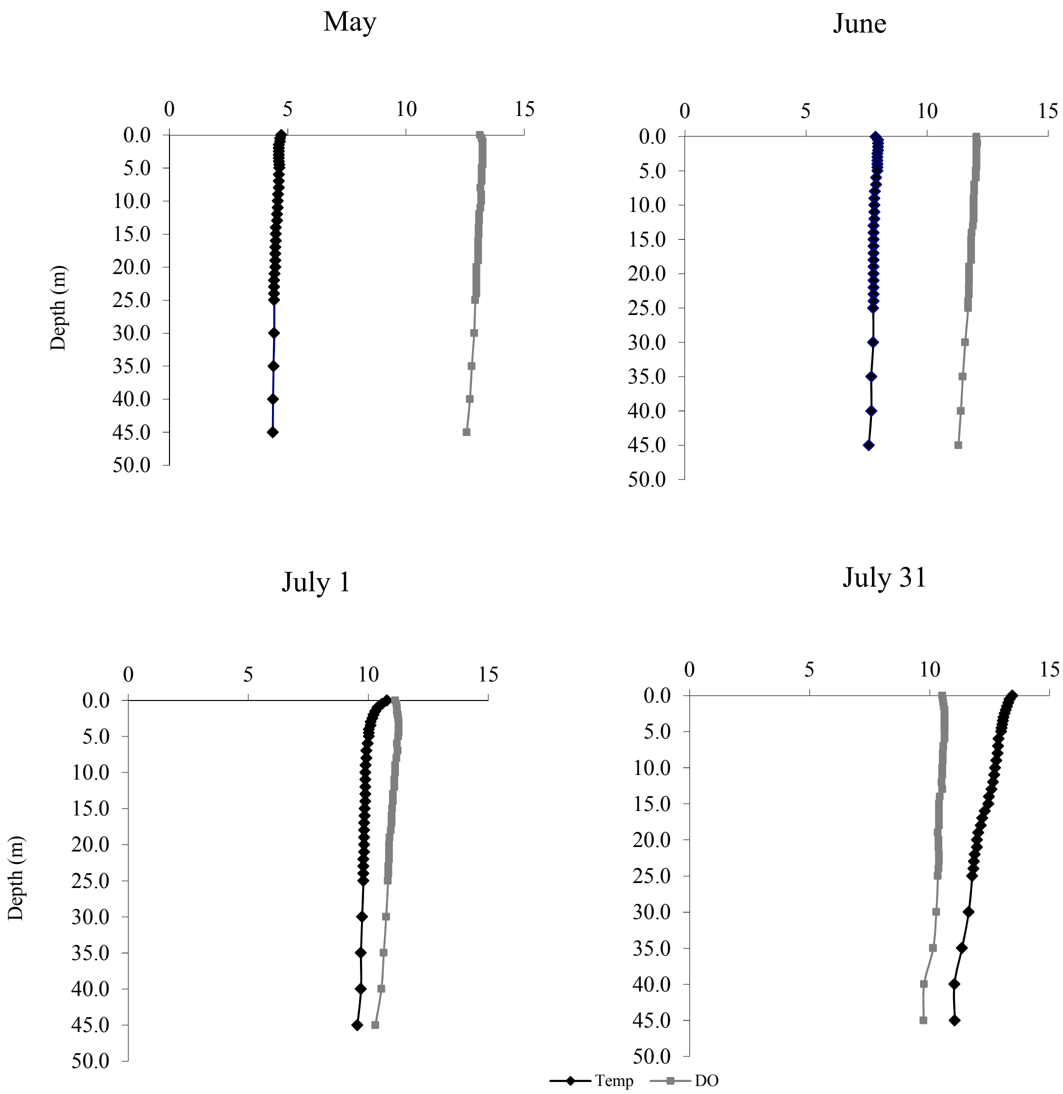

Figure 9.–Mean monthly temperature and dissolved oxygen profiles in Chignik Lake, 2014.

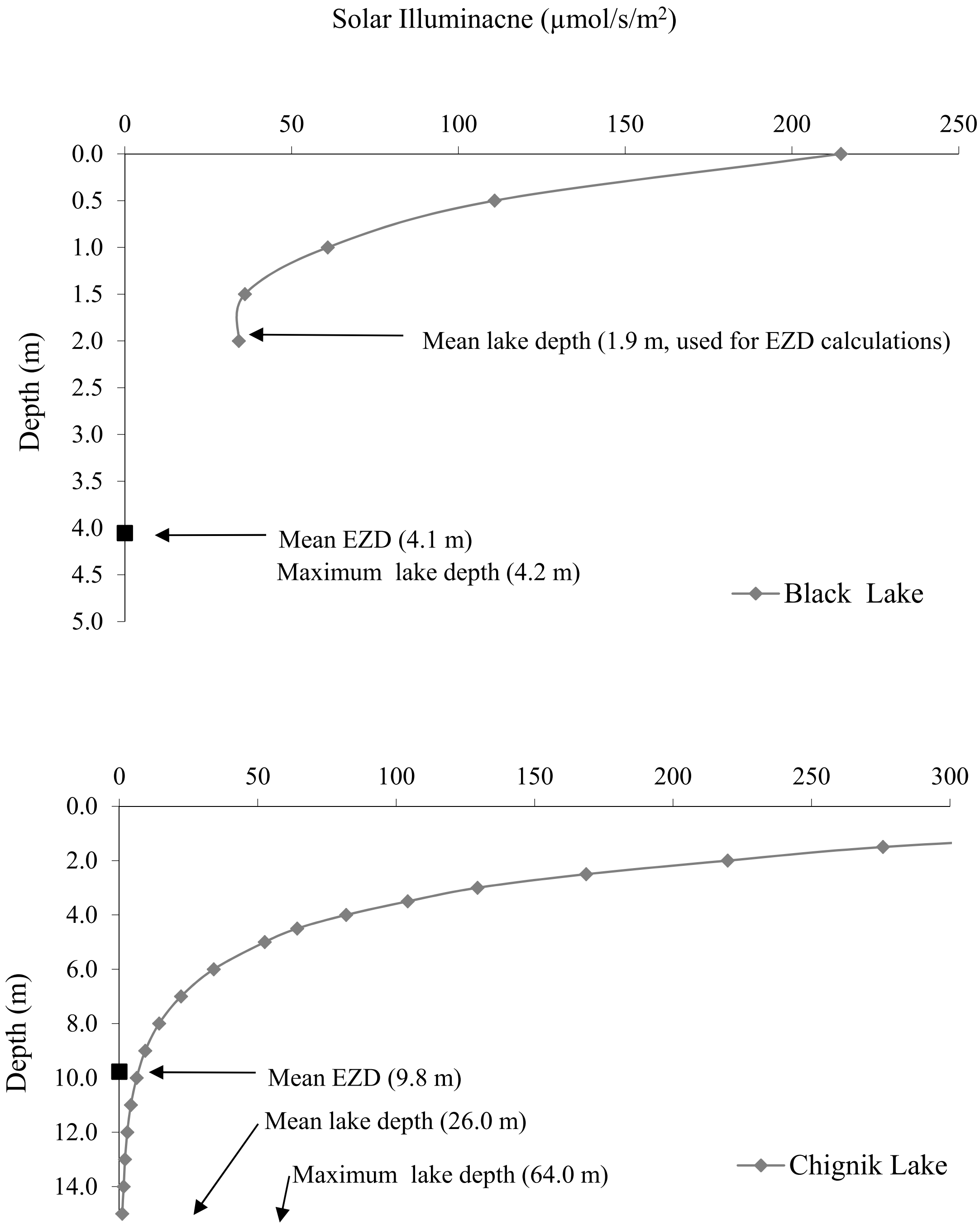

Figure 10.–Light penetration curves relative to mean depth, euphotic zone depth (EZD), and maximum depth in Black and Chignik lakes, 2014.

Note: Range of vertical axes differ between charts.

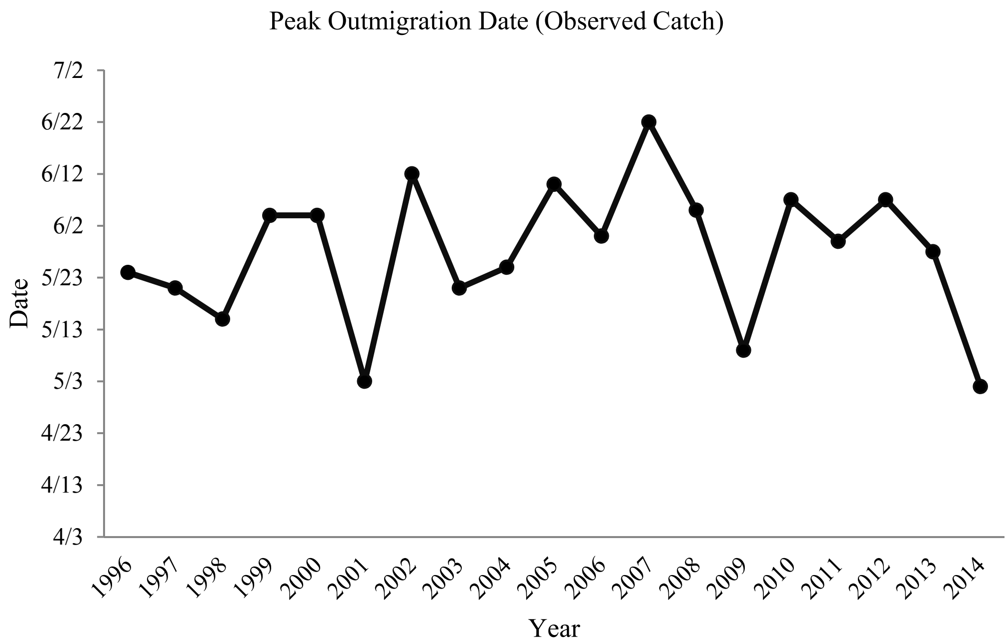

Figure 11.–Peak sockeye salmon smolt outmigration date from Chignik River, by year, 1996–2014.

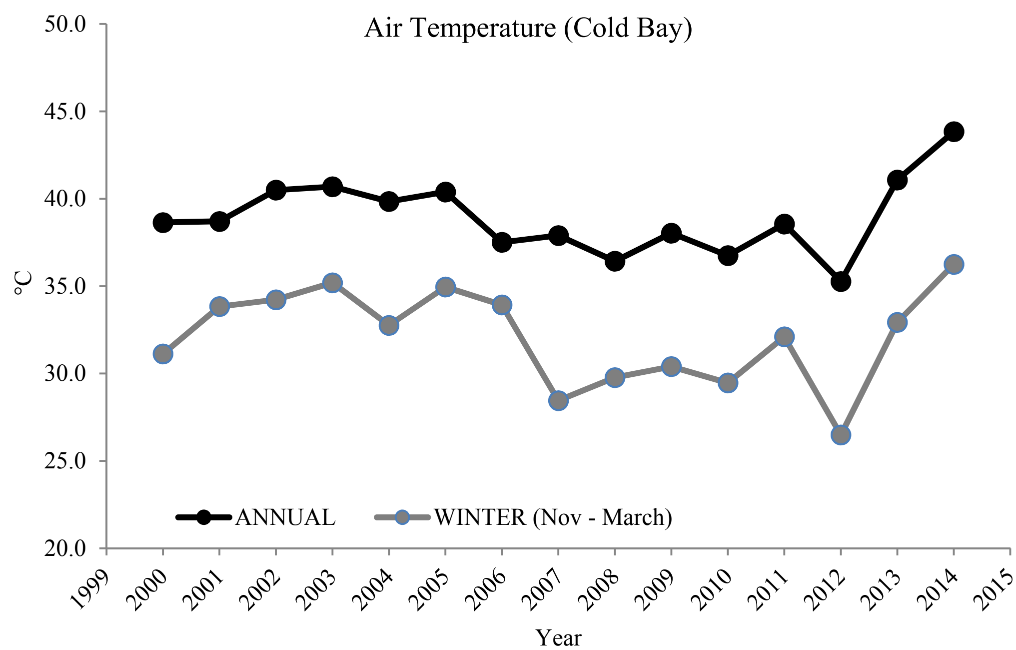

Figure 12.–Air Temperatures as measured at Cold Bay Airport, Alaska, 2000–2014.

APPENDIX A. SMOLT TRAP CATCHES BY DAY

Appendix A1.–Daily trap catch and efficiency from the Chignik River, April 25–July 4, 2014.

	Sockeye Smolt		Trap Efficiency Test					Incidental Catch[a]														
Date	Daily	Cum.	Marked[b]	Marked[c]	Daily Recoveries	Cum. Recoveries	Efficiency[d]	Sockeye fry	Coho	Coho fry	Pink	Chnk	Chum	DV	SB	SC	SF	PS	PW	AB	ISO	EU
4/25[e]	2,783	2,783					2.53%															
4/26[e]	3,223	6,006					2.53%															
4/27[e]	3,616	9,622					2.53%															
4/28[e]	4,057	13,679					2.53%															
4/29[e]	4,552	18,231					2.53%															
4/30[e]	5,107	23,338					2.53%															
5/1	5,730	29,068					2.53%	416	2	0	0	0	0	11	1253	6	0	213	2	1	4	3
5/2	11,406	40,474	3,685	3,206	73	73	2.53%	792	7	0	0	0	0	6	1879	7	2	748	1	0	1	0
5/3	6,014	46,488			6	79	2.53%	452	7	0	0	2	0	3	899	3	0	433	1	0	1	0
5/4	3,374	49,862			1	80	2.53%	336	4	1	0	0	0	7	335	9	0	257	2	0	1	0
5/5	2,331	52,193			0	80	2.53%	277	2	0	0	0	0	2	226	0	0	161	0	0	2	0
5/6	4,846	57,039			0	80	2.53%	259	5	0	0	0	0	10	495	2	0	172	2	0	4	1
5/7	6,126	63,165			0	80	2.53%	418	5	0	0	0	0	7	571	1	0	316	0	0	3	0
5/8	5,685	68,850	1,537	1,168	25	25	2.31%	445	4	0	0	0	0	5	546	9	0	305	0	1	2	0
5/9	2,367	71,217			1	26	2.31%	312	6	0	0	0	0	3	213	4	0	117	0	0	4	0
5/10	1,053	72,270			0	26	2.31%	425		0	0	0	0	6	209	3	0	98	0	2	1	0
5/11	1,407	73,677			0	26	2.31%	114	2	0	0	0	0	4	199	1	0	83	0	0	1	0
5/12	2,751	76,428			0	26	2.31%	93	3	1	0	0	0	3	378	7	0	234	0	0	2	0
5/13	7,310	83,738			0	26	2.31%	59	12	0	0	0	0	11	673	10	2	247	0	0	5	0
5/14	4,352	88,090			0	26	2.31%	21		0	0	0	0	1	695	2	0	94	1	0	2	0
5/15	6,097	94,187	1,686	843	50	50	6.28%	51	5	0	0	0	0	10	802	5	0	139	0	1	9	0
5/16	9,827	104,014			2	52	6.28%	42	13	0	0	0	0	12	1,238	21	0	250	1	0	4	1
5/17	8,064	112,078			0	52	6.28%	116	10	0	0	0	0	4	1,227	6	0	320	2	0	13	0
5/18	7,520	119,598			0	52	6.28%	106	52	0	0	0	0	14	610	17	0	206	5	0	8	1
5/19	3,913	123,511			0	52	6.28%	50	8	0	0	0	0	7	436	17	0	154	2	0	11	0
5/20	1,368	124,879			0	52	6.28%	21	7	0	0	0	0	8	373	7	0	72	1	0	3	1
5/21	618	125,497			0	52	6.28%	8	5	0	0	0	0	9	366	4	0	34	1	0	4	0
5/22	1,077	126,574			0	52	6.28%	4	2	0	0	0	0	3	399	7	0	41	3	0	5	0
5/23	807	127,381	1,211	581	30	30	6.70%	3	5	0	0	2	0	1	232	7	0	37	2	1	2	0
5/24	793	128,174			6	36	6.70%	5	6	0	0	0	0	3	176	1	0	19	1	1	4	0
5/25	504	128,678			0	36	6.70%	0	6	0	0	0	0	5	69	11	1	19	4	0	5	0
5/26	410	129,088			1	37	6.70%	2	8	0	0	2	0	4	79	7	0	19	6	0	5	0
5/27	242	129,330			0	37	6.70%	2	3	0	0	0	0	8	137	14	0	36	5	1	4	0
5/28	231	129,561			1	38	6.70%	0	5	2	0	1	0	1	59	18	0	24	4	0	6	0
5/29	450	130,011			0	38	6.70%	1	30	0	0	1	0	5	111	14	0	31	7	0	12	2
5/30	538	130,549			0	38	6.70%	8	14	0	0	1	0	3	327	3	0	91	12	0	0	0
5/31	207	130,756			0	38	6.70%	3	6	0	0	3	0	1	267	2	1	35	2	0	1	0
6/1	171	130,927			0	38	6.70%	1	20	1	0	0	0	0	248	2	0	17	7	0	3	0
6/2	116	131,043			0	38	6.70%	0	7	0	0	0	0	1	132	4	0	10	1	0	1	0

- continued -

Appendix A1.–Page 2 of 2.

	Sockeye Smolt		Trap Efficiency Test					Incidental Catch[a]														
Date	Daily	Cum.	Marked[b]	Marked[c]	Daily Recoveries	Cum. Recoveries	Efficiency[d]	Sockeye fry	Coho	Coho fry	Pink	Chnk	Chum	DV	SB	SC	SF	PS	PW	AB	ISO	EU
6/3[f]	79	131,122			0	38	6.70%	2	1	0	0	0	0	1	64	2	0	14	2	0	0	0
6/4[f]	67	131,189			0	38	6.70%	1	2	0	0	1	0	0	27	0	0	5	0	0	2	1
6/5[f]	74	131,263			0	38	6.70%	7	8	3	0	1	0	0	14	3	0	2	0	0	1	0
6/6[f]	109	131,372			0	38	6.70%	4	32	0	0	8	0	6	47	10	0	11	3	0	4	1
6/7	340	131,712			0	38	6.70%	3	98	0	0	21	0	5	125	20	0	17	5	0	11	2
6/8	128	131,840			0	38	6.70%	4	67	0	0	2	0	1	140	2	0	18	8	0	3	1
6/9	149	131,989			0	38	6.70%	6	31	0	0	2	0	0	82	1	0	24	5	0	3	0
6/10	124	132,113			0	38	6.70%	5	18	0	0	0	0	1	98	1	0	17	4	0	5	1
6/11	64	132,177			0	38	6.70%	10	25	0	0	0	0	2	74	4	0	11	4	0	3	0
6/12	64	132,241			0	38	6.70%	5	20	0	0	1	0	0	79	6	0	7	4	0	4	0
6/13	77	132,318			0	38	6.70%	3	27	0	0	3	0	1	89	1	0	5	2	0	5	0
6/14	45	132,363			0	38	6.70%	8	19	0	0	0	0	0	47	7	0	5	3	0	4	0
6/15	26	132,389			0	38	6.70%	2	19	1	0	0	0	0	44	2	0	6	3	0	7	0
6/16	136	132,525			0	38	6.70%	10	43	0	0	0	0	6	62	5	0	6	2	0	5	2
6/17	156	132,681			0	38	6.70%	55	24	0	0	0	0	1	105	8	1	48	5	0	2	0
6/18	32	132,713			0	38	6.70%	36	18	0	0	0	0	1	40	16	0	43	9	1	8	0
6/19	51	132,764			0	38	6.70%	34	10	0	0	0	0	0	28	9	0	34	2	0	11	0
6/20	77	132,841			0	38	6.70%	13	10	0	0	0	0	0	37	5	0	30	1	0	2	0
6/21	59	132,900			0	38	6.70%	8	9	0	0	0	0	4	34	9	0	25	1	0	4	0
6/22	75	132,975			0	38	6.70%	1	13	0	0	0	0	3	66	3	0	34	0	0	5	0
6/23	22	132,997			0	38	6.70%	5	4	0	0	0	0	1	24	3	0	55	2	0	4	0
6/24	20	133,017			0	38	6.70%	0	17	0	0	0	0	5	18	9	0	38	0	0	3	0
6/25	17	133,034			0	38	6.70%	0	5	0	0	0	0	2	10	0	0	19	0	0	4	0
6/26	44	133,078			0	38	6.70%	0	18	0	0	1	0	4	14	4	0	13	3	0	0	0
6/27	46	133,124			0	38	6.70%	0	15	0	0	0	0	0	15	3	0	21	3	1	3	0
6/28	53	133,177			0	38	6.70%	1	17	0	0	0	0	3	22	0	0	26	0	0	3	0
6/29	89	133,266			0	38	6.70%	1	7	0	0	0	0	1	25	4	0	84	0	0	3	0
6/30	32	133,298			0	38	6.70%	2	2	0	0	0	0	0	13	3	0	19	0	0	4	0
7/1	33	133,331			0	38	6.70%	2	6	0	0	0	0	4	32	4	0	92	2	0	8	0
7/2	22	133,353			0	38	6.70%	1	7	0	0	0	0	0	24	2	0	271	2	0	3	0
7/3	39	133,392			0	38	6.70%	3	4	0	0	0	0	5	20	5	0	794	0	0	8	0
7/4	31	133,423			0	38	6.70%	0	10	0	0	0	0	3	71	7	0	962	0	0	6	1
Total		133,423	8,119	5,798	196		4.45%	0	5,074	877	9	0	52	0	238	17,449	389	7	7,788	150	10	271

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

[b] "Actual" number released, not adjusted for delayed mortality.

[c] Released number adjusted for delayed mortality.

[d] Calculated by: = {(R+1)/(M+1)}*100 where: R = number of marked fish recaptured and M = number of marked fish (Carlson et al. 1998) after adjusting for delayed mortality.

[e] Actual Sockeye Smolt values (Daily and Cumulative) include estimates from 4/25-4/30.

[f] Large trap was removed from the water for repairs from 21:00 6/3/2014 - 19:00 6/6/2014.

APPENDIX B. SMOLT CATCHES BY TRAP

Appendix B1.–Number of sockeye salmon smolt caught by trap, by day from the Chignik River, May 9–July 4, 2014.

	Small Trap		Large Trap		Combined		Daily Proportion	
Date	Daily	Cumulative	Daily	Cumulative	Daily	Cumulative [a]	Small	Large
4/25					2,783	2,783		
4/26					3,223	6,006		
4/27					3,616	9,622		
4/28					4,057	13,679		
4/29					4,552	18,231		
4/30					5,107	23,338		
5/1	1,186	1,186	4,544	4,544	5,730	29,068	20.7%	79.3%
5/2	2,800	3,986	8,606	13,150	11,406	40,474	24.5%	75.5%
5/3	1,863	5,849	4,151	17,301	6,014	46,488	31.0%	69.0%
5/4	1,208	7,057	2,166	19,467	3,374	49,862	35.8%	64.2%
5/5	1,016	8,073	1,315	20,782	2,331	52,193	43.6%	56.4%
5/6	1,925	9,998	2,921	23,703	4,846	57,039	39.7%	60.3%
5/7	1,691	11,689	4,435	28,138	6,126	63,165	27.6%	72.4%
5/8	1,371	13,060	4,314	32,452	5,685	68,850	24.1%	75.9%
5/9	662	13,722	1,705	34,157	2,367	71,217	28.0%	72.0%
5/10	383	14,105	670	34,827	1,053	72,270	36.4%	63.6%
5/11	410	14,515	997	35,824	1,407	73,677	29.1%	70.9%
5/12	700	15,215	2,051	37,875	2,751	76,428	25.4%	74.6%
5/13	1,506	16,721	5,804	43,679	7,310	83,738	20.6%	79.4%
5/14	1,927	18,648	2,425	46,104	4,352	88,090	44.3%	55.7%
5/15	2,588	21,236	3,509	49,613	6,097	94,187	42.4%	57.6%
5/16	3,846	25,082	5,981	55,594	9,827	104,014	39.1%	60.9%
5/17	4,421	29,503	3,643	59,237	8,064	112,078	54.8%	45.2%
5/18	2,677	32,180	4,843	64,080	7,520	119,598	35.6%	64.4%
5/19	1,291	33,471	2,622	66,702	3,913	123,511	33.0%	67.0%
5/20	524	33,995	844	67,546	1,368	124,879	38.3%	61.7%
5/21	248	34,243	370	67,916	618	125,497	40.1%	59.9%
5/22	482	34,725	595	68,511	1,077	126,574	44.8%	55.2%
5/23	311	35,036	496	69,007	807	127,381	38.5%	61.5%
5/24	335	35,371	458	69,465	793	128,174	42.2%	57.8%
5/25	110	35,481	394	69,859	504	128,678	21.8%	78.2%
5/26	93	35,574	317	70,176	410	129,088	22.7%	77.3%
5/27	77	35,651	165	70,341	242	129,330	31.8%	68.2%
5/28	57	35,708	174	70,515	231	129,561	24.7%	75.3%
5/29	119	35,827	331	70,846	450	130,011	26.4%	73.6%
5/30	257	36,084	281	71,127	538	130,549	47.8%	52.2%
5/31	90	36,174	117	71,244	207	130,756	43.5%	56.5%
6/1	78	36,252	93	71,337	171	130,927	45.6%	54.4%
6/2	45	36,297	71	71,408	116	131,043	38.8%	61.2%
6/3 [b]	51	36,348	28	71,436	79	131,122	64.6%	35.4%
6/4 [b]	67	36,415	-	71,436	67	131,189	100.0%	0.0%
6/5 [b]	74	36,489	-	71,436	74	131,263	100.0%	0.0%
6/6 [b]	54	36,543	55	71,491	109	131,372	49.5%	74.3%
6/7	108	36,651	232	71,723	340	131,712	31.8%	68.2%
6/8	77	36,728	51	71,774	128	131,840	60.2%	39.8%
6/9	53	36,781	96	71,870	149	131,989	35.6%	64.4%
6/10	56	36,837	68	71,938	124	132,113	45.2%	54.8%
6/11	40	36,877	24	71,962	64	132,177	62.5%	37.5%

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Appendix B1.–Page 2 of 2.

	Small Trap		Large Trap		Combined		Daily Proportion	
Date	Daily	Cumulative	Daily	Cumulative	Daily	Cumulative	Small	Large
6/12	40	36,917	24	71,986	64	132,241	62.5%	37.5%
6/13	47	36,964	30	72,016	77	132,318	61.0%	39.0%
6/14	26	36,990	19	72,035	45	132,363	57.8%	42.2%
6/15	17	37,007	9	72,044	26	132,389	65.4%	34.6%
6/16	105	37,112	31	72,075	136	132,525	77.2%	22.8%
6/17	75	37,187	81	72,156	156	132,681	48.1%	51.9%
6/18	8	37,195	24	72,180	32	132,713	25.0%	75.0%
6/19	8	37,203	43	72,223	51	132,764	15.7%	84.3%
6/20	12	37,215	65	72,288	77	132,841	15.6%	84.4%
6/21	18	37,233	41	72,329	59	132,900	30.5%	69.5%
6/22	24	37,257	51	72,380	75	132,975	32.0%	68.0%
6/23	6	37,263	16	72,396	22	132,997	27.3%	72.7%
6/24	13	37,276	7	72,403	20	133,017	65.0%	35.0%
6/25	9	37,285	8	72,411	17	133,034	52.9%	47.1%
6/26	23	37,308	21	72,432	44	133,078	52.3%	47.7%
6/27	15	37,323	31	72,463	46	133,124	32.6%	67.4%
6/28	36	37,359	17	72,480	53	133,177	67.9%	32.1%
6/29	32	37,391	57	72,537	89	133,266	36.0%	64.0%
6/30	7	37,398	25	72,562	32	133,298	21.9%	78.1%
7/1	13	37,411	20	72,582	33	133,331	39.4%	60.6%
7/2	5	37,416	17	72,599	22	133,353	22.7%	77.3%
7/3	8	37,424	31	72,630	39	133,392	20.5%	79.5%
7/4	16	37,440	15	72,645	31	133,423	51.6%	48.4%
Total		37,440		72,645		133,423	34.0%	66.0%

[a] Combined cumulative total includes daily estimates from 4/25–4/30 before traps were operational.

[b] Large trap was removed from the water for repairs from 2100 hours 6/3/2014 - 1900 hours 6/6/2014.

APPENDIX C. CLIMATE OBSERVATION

Appendix C1.– Daily climate observations at the Chignik River smolt traps in 2014.

Date [a]	Time [a]	Air (°C)	Water (°C)	Cloud [b] Cover (%)	Wind [b] Dir.	Wind Vel.[b] (mph)	Trap Revolutions (rpm) Small	Large	Stream Gauge (cm)	Comments
5/3	11:30	ND	4.5	0	W	8	6.00	5.50	33	sunny; placed depth gauge
5/4	12:00	ND	4.5	0	W	10	6.00	5.50	34	
5/5	9:00	ND	4.0	100	W	5	6.00	5.50	32	
5/6	9:00	ND	3.0	100	W	3	ND	ND	33	
5/7	12:00	7.5	4.0	50	W	25	6.00	5.50	34	
5/8	11:35	9.0	4.5	40	W	18	6.00	5.50	32	
5/9	12:00	7.5	5.0	0	W	28	6.00	5.50	30	
5/10	12:00	9.5	5.5	0	W	13	6.00	5.25	28	very sunny
5/11	11:45	15.0	5.5	0	calm	calm	5.75	5.25	28	sunny, warm, calm
5/12	11:50	15.5	6.0	0	calm	calm	6.00	5.25	28	sunny, warm, calm
5/13	11:45	8.5	5.5	0	W	18	6.00	5.75	30	
5/14	12:00	13.0	6.0	0	W	8	6.00	5.75	32	hot
5/15	12:00	17.0	7.0	0	calm	calm	6.00	5.75	35	hot
5/16	11:45	8.5	7.5	0	W	28	7.50	6.25	38	windy
5/17	12:00	8.0	7.5	25	W	20	7.50	6.25	36	very windy
5/18	12:00	7.5	7.0	70	NW	20	7.50	6.25	40	
5/19	11:45	6.5	6.0	10	NW	25	7.50	6.00	43	very windy; strong wind gusts
5/20	12:00	9.0	7.0	0	W	5	6.25	5.50	38	
5/21	12:00	9.8	8.0	100	W	3	6.25	5.50	36	
5/22	12:00	8.0	8.0	30	W	3	6.00	5.25	37	
5/23	11:45	10.0	8.0	0	W	3	5.75	5.25	33	light wind; pleasant
5/24	11:45	8.5	8.0	0	W	15	6.00	5.75	32	breezy
5/25	11:45	12.0	8.5	0	W	3	5.75	5.25	32	light wind, sunshine
5/26	11:50	6.5	8.8	95	variable	5	6.00	5.25	31	calm, quiet
5/27	11:45	13.0	8.8	90	SW	2	5.50	5.25	31	calm
5/28	13:00	10.0	9.0	100	calm	0	ND	ND	33	no trap RPM data
5/29	11:45	12.5	8.5	100	W	5	6.25	6.00	38	
5/30	11:45	7.0	8.5	100	W	3	7.00	6.25	44	
5/31	11:50	13.0	8.0	45	W	3	7.00	6.25	45	
6/1	11:45	12.5	8.0	100	W	3	6.50	6.00	39	
6/2	11:45	11.0	8.5	100	NW	3	6.00	5.50	36	
6/3	11:30	9.5	8.5	10	E	3	5.50	5.25	31	large trap pulled; cone damage

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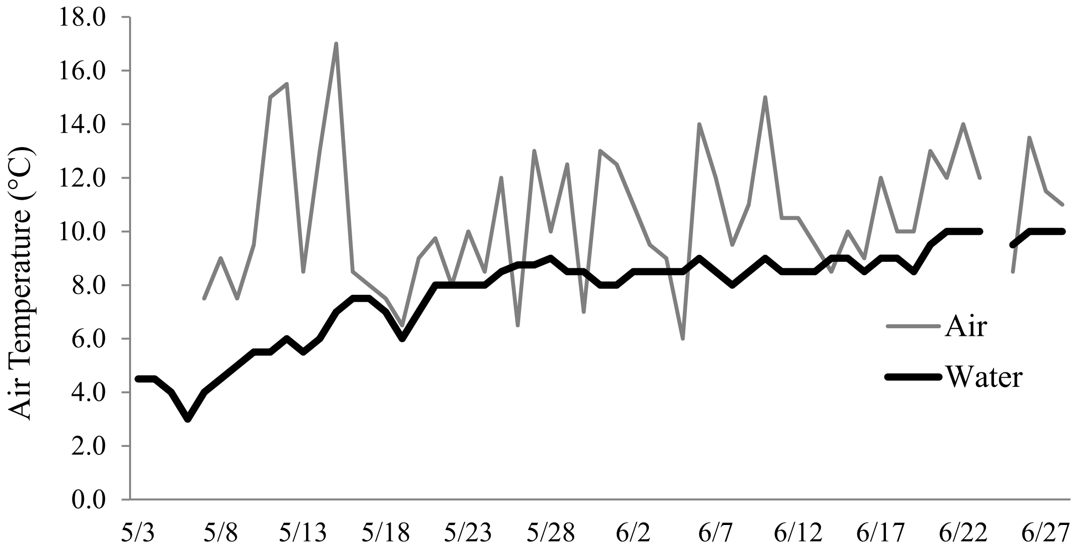
Appendix C1.–Page 2 of 2.

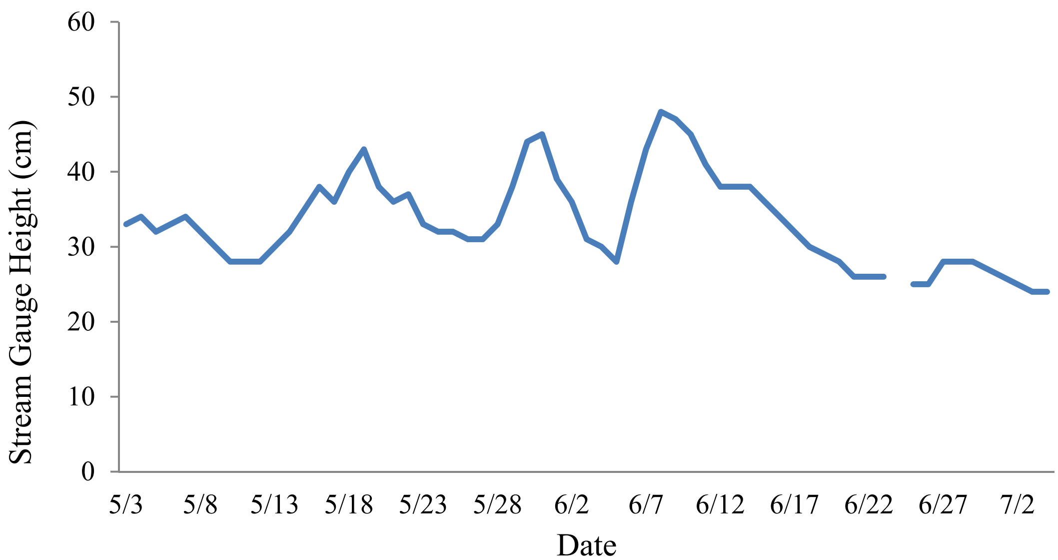
Date [a]	Time [a]	Air (°C)	Water (°C)	Cloud [b] Cover (%)	Wind [b] Dir.	Wind Vel.[b] (mph)	Trap Revolutions (rpm) Small	Large	Stream Gauge (cm)	Comments
6/4	11:45	9.0	8.5	100	E	2	5.75	ND	30	only small trap fishing
6/5	12:30	6.0	8.5	100	E	13	6.25	ND	28	only small trap fishing
6/6	11:45	14.0	9.0	100	variable	2	7.00	ND	36	large trap placed; both traps fishing
6/7	12:15	12.0	8.5	100	NW	8	7.50	6.50	43	
6/8	12:00	9.5	8.0	95	NW	8	7.75	7.75	48	depth gauge repositioned @ 08:50
6/9	11:45	11.0	8.5	95	NW	3	7.25	6.50	47	calm at traps, breezy elsewhere
6/10	11:45	15.0	9.0	75	W	2	7.50	6.75	45	calm; sunny
6/11	11:40	10.5	9	100	W	8	7.25	6.50	41	overcast
6/12	11:40	10.5	9	100	W	2	7.25	6.50	38	
6/13	11:40	9.5	9	100	NW	10	7.50	6.50	38	breezy, overcast, chilly
6/14	11:50	8.5	9.0	100	NW	5	7.00	6.00	38	breezy in afternoon
6/15	11:45	10.0	9.0	70	NW	2	7.25	6.50	36	calm
6/16	11:40	9.0	8.5	100	NW	2	7.25	6.50	34	overcast, light wind
6/17	11:40	12.0	9.0	20	NW	32	6.00	5.75	32	very windy; gusts 40–45 kts
6/18	11:45	10.0	9.0	100	calm	0	6.00	5.00	30	calm
6/19	11:50	10.0	8.5	100	NW	5	6.00	5.00	29	
6/20	12:15	13.0	9.5	100	W	2	6.00	5.00	28	light breeze
6/21	12:00	12.0	10.0	0	NW	10	5.25	5.00	26	water dropping
6/22	11:55	14.0	10.0	0	W	5	5.25	5	26	sunny; low water
6/23	11:45	12.0	10.0	10	NW	5	5.25	5.00	26	sunny
6/24	ND	ND	ND	ND	ND	ND	ND	ND	ND	SE wind; partly cloudy
6/25	11:45	8.5	9.5	100	SE	13	4.75	4.75	25	drizzle; overcast; gusts to 10 kts
6/26	11:45	13.5	10.0	70	N/NW	5	5.00	5.00	25	mostly cloudy
6/27	11:40	11.5	10.0	40	W/NW	13	5.25	5.25	28	gusts to 25 kts; sunny
6/28	11:45	11.0	10.0	5	NW	10	5.50	5.25	28	gusts 15-20 kts
6/29	11:45	9.5	10.0	100	NW	8	5.25	5.25	28	overcast
6/30	11:50	10.0	10.0	100	W	3	5.25	5.25	27	overcast; occasional drizzle
7/1	12:15	15.5	11.0	0	E	3	5.50	5.25	26	sunny; little wind
7/2	12:45	13.0	10.5	100	E	3	5.50	5.25	25	relatively calm
7/3	11:45	12.0	11.0	98	SW	3	5.00	4.75	24	water level low and slow flow
7/4	12:20	9.0	11.5	10	calm	3	5.50	4.25	24	calm

[a] Actual calendar dates and times.

[b] Based on observer estimates.

Appendix C2.–Air and water temperature, and stream gauge height measured at the Chignik River smolt traps, 2014.





APPENDIX D. HISTORICAL LIMNOLOGY DATA

Appendix D1.–Seasonal averages of water quality parameters, nutrient concentrations, and photosynthetic pigments by year for Black Lake, 2000–2014.

	2000 [a]	2001 [b]	2002	2003	2004	2005	2006 [b,c]	2007 [b]	2008 [b]	2009	2010	2011	2012 [c]	2013 [b,c,d]	2014 [c,e]
pH	7.43	7.53	7.45	7.45	7.81	7.57	8.01	7.64	7.64	7.67	7.78	7.69	7.69	7.89	8.23
Alkalinity (mg/L $CaCO_3$)	13.3	32.5	32.3	32.3	30.2	24.3	20.5	19.7	19.0	29.4	22.0	26.6	26.7	29.5	34.8
Total phosphorous (µg/L P)	56.8	35.2	37.1	41.6	22.2	27.9	20.4	24.4	22.2	41.1	29.8	34.3	11.0	31.9	13.9
Total filterable phosphorous (µg/L P)	10.7	9.8	98.0	10.1	5.1	8.6	11.0	ND	ND	6.9	8.0	4.3	3.2	4.9	3.3
								ND	ND						
Filterable reactive phosphorous (µg/L P)	4.0	7.4	24.7	5.4	2.6	7.2	9.1	ND	ND	ND	3.3	3.2	1.5	1.3	3.3
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	ND	979.7	277.0
Ammonia (µg/L N)	36.6	3.3	4.1	4.5	9.7	3.9	11.0	130.1	3.7	2.6	6.4	3.3	6.0	4.4	5.3
Nitrate + Nitrite (µg/L N)	38.9	15.5	8.3	25.2	3.7	1.9	0.9	1.6	0.6	1.9	1.0	1.1	2.4	2.9	5.7
Silicon (µg/L)	ND	ND	ND	ND	3382.8	ND	ND	ND	ND	ND	ND	2925.7	1618.6	1541.2	2752.0
Chlorophyll a (µg/L)	18.1	4.3	2.6	5.1	3.6	5.0	4.4	3.3	6.6	3.0	2.8	4.6	5.8	5.0	4.1
Phaeophytin a (µg/L)	10.0	11.9	1.4	1.8	0.2	1.0	0.8	0.9	1.4	1.4	1.5	0.5	0.8	1.7	1.3

[a] Seasonal average includes a surface water sample in August.
[b] Limnology samples were not collected in August.
[c] Limnology samples were not collected in May.
[d] Season average includes limnology samples collected in September.
[e] Limnology samples were not collected in July.

Appendix D2.–Seasonal averages of water quality parameters, nutrient concentrations, and photosynthetic pigments for Chignik Lake, 2000–2014.

	2000	2001	2002	2003	2004	2005	2006 [a]	2007 [a]	2008 [a]	2009	2010	2011 [a,b]	2012 [c]	2013 [a,b]	2014 [a,b,d]
pH	7.81	7.47	7.45	7.38	7.62	7.57	7.70	7.46	7.48	7.50	7.22	7.52	7.36	7.71	7.75
Alkalinity (mg/L $CaCO_3$)	15.0	24.8	24.6	23.5	22.4	23.8	24.8	18.2	21.0	23.8	20.1	22.9	24.1	26.2	26.2
Total phosphorous (µg/L P)	14.5	27.6	19.7	16.7	18.6	15.8	20.1	14.2	15.6	22.3	13.6	12.4	10.2	14.5	8.1
Total filterable phosphorous (µg/L P)	5.9	12.3	8.5	7.5	6.5	6.5	8.3	ND	ND	ND	5.4	3.3	3.5	3.0	2.3
Filterable reactive phosphorous (µg/L P)	5.2	8.3	4.6	5.6	4.1	5.7	8.9	ND	ND	ND	4.5	5.1	2.4	1.9	3.9
Total kjedhal nitrogen (µg/L N)[d]	230.0	101.8	119.7	99.0	146.5	199.5	86.0	148.3	96.3	79.8	44.5	151.0	ND	344.5	71.1
Ammonia (µg/L N)	28.2	10.3	10.5	9.8	9.1	6.4	10.7	7.9	5.9	5.8	6.7	8.3	11.0	5.8	4.3
Nitrate + Nitrite (µg/L N)	162.6	191.6	117.4	166.7	128.0	103.3	129.9	194.0	192.5	152.3	154.4	187.1	171.7	133.3	149.1
Silicon (µg/L)	ND	ND	ND	ND	4128.8	ND	ND	ND	ND	ND	5986.1	2966.0	5289.8	4445.1	5396.3
Chlorophyll a (µg/L)	9.1	4.7	2.3	2.3	4.0	3.0	6.6	2.2	2.2	2.3	1.5	2.2	2.9	2.9	1.9
Phaeophytin a (µg/L)	1.6	1.3	1.3	0.5	0.3	0.6	0.9	0.4	0.6	0.6	0.8	0.5	0.3	0.7	0.8

[a] Limnology samples were not collected in August

[b] Season average includes limnology samples collected in September.

[c] Limnology samples were not collected in May

[d] Limnology samples were not collected in July.

Appendix D3.–Seasonal average number of zooplankton per m^2 from Black Lake by year, 2000–2014.

Taxon	2000	200 1[a]	2002 [b]	2003	2004	2005	2006 [a,c]	2007 [a]	2008 [a]	2009	2010	2011	2012[c]	201 3[a,b,c]	2014 [c,d]
Copepods															
Cyclops	39,819	3,668	50,573	19,042	46,198	46,842	31,582	5,131	13,093	24,031	18,312	8,519	15,906	48,461	36,385
Ovig. *Cyclops*	-	-	-	265	-	-	-	-	-	-	66	1,354	-	-	-
Diaptomus	3,747	1,533	3,153	11,080	23,010	3,716	796	1,062	-	2,489	2,787	-	-	-	-
Ovig. *Diaptomus*	-	-	-	1,327	-	265	-	-	-	-	149	-	-	-	-
Epischura	9,166	1,946	6,805	6,303	37,649	18,113	-	5,750	-	3,729	4,263	2,389	5,166	10,899	-
Ovig. *Epischura*	159	-	-	-	-	-	-	-	-	-	-	318	-	584	-
Eurytemora	-	-	-	-	-	-	-	-	-	-	199	2,309	3,769	5,547	-
Ovig. *Eurytemora*	-	-	-	-	-	-	-	-	-	-	-	2,866	-	2,707	-
Harpacticus	-	1,062	-	531	531	-	265	-	-	-	149	-	177	-	-
Nauplii	24,298	3,716	24,023	24,350	40,509	38,150	8,758	9,996	16,189	28,938	12,971	18,869	10,209	41,012	19,719
Total copepods	77,189	11,925	84,554	62,898	147,897	107,086	41,401	21,939	29,282	59,188	38,897	36,624	35,226	109,209	56,104
Cladocerans															
Bosmina	46,900	38,417	86,316	285,496	398,855	203,755	2,322	619	1,681	49,209	28,646	3,424	27,955	25,088	20,541
Ovig. *Bosmina*	13,008	9,802	35,159	39,809	90,147	29,989	796	-	1,681	11,545	7,431	52,787	2,300	584	3,556
Chydorinae	14,441	369,840	30,127	3,516	78,716	12,407	3,052	2,919	-	-	-	318	1,203	26,787	690
Ovig. *Chydorinae*	-	-	446	-	398	-	-	-	-	-	-	8,121	-	1,645	-
Daphnia L.	861	248	-	1,526	199	-	-	-	-	66	-	80	531	1,062	-
Holopedium	-	-	-	-	-	-	-	-	-	-	66	-	531	584	-
Immature *Cladocera*	1,115	-	-	21,895	7,083	17,914	2,588	-	-	8,824	4,943	16,162	7,006	36,837	-
Total cladocerans	76,324	418,306	152,049	352,243	575,398	264,066	8,758	3,539	3,362	69,644	41,086	80,892	39,526	92,587	24,788
Total copepods + cladocerans	153,513	430,231	236,603	415,141	723,295	371,152	50,159	25,478	32,643	128,832	79,983	117,516	74,752	201,796	80,892

[a] Zooplankton samples were not collected in August.

[b] Season average includes zooplankton samples collected in September.

[c] Zooplankton samples were not collected in May.

[d] Zooplankton samples were not collected in July.

Appendix D4.–Average weighted biomass estimates (mg dry weight/m^2) of the major Black Lake zooplankton taxon by year, 2000–2014.

Taxon	2000	2001 [a]	2002 [b]	2003	2004	2005	2006[a,c]	2007[a]	2008[a]	2009	2010	2011	2012 [c]	2013 [a,b,c]	2014 [c,d]
Copepods															
Cyclops	45.36	4.36	35.79	18.34	35.15	44.39	22.04	4.47	14.02	23.90	12.46	8.26	15.05	42.55	65.52
Ovig. *Cyclops*	-	-	-	0.80	-	-	-	-	-	-	0.38	3.36	-	-	-
Diaptomus	13.70	3.29	15.71	42.68	29.55	8.20	1.11	2.89	-	5.58	7.05	-	-	-	-
Ovig. *Diaptomus*	-	-	-	8.88	-	2.24	-	-	-	-	1.16	-	-	-	-
Epischura	10.40	9.16	3.58	3.57	65.64	14.02	-	10.04	-	3.19	2.89	1.64	4.52	8.18	-
Ovig. *Epischura*	1.68	-	-	-	-	-	-	-	-	-	-	0.60	-	6.42	-
Eurytemora	-	-	-	-	-	-	-	-	-	-	1.26	9.52	20.36	25.04	-
Ovig. *Eurytemora*	-	-	-	-	-	-	-	-	-	-	-	24.04	-	26.64	-
Harpacticus	-	1.78	-	0.35	-	-	0.17	-	-	-	0.09	-	0.18	-	-
Total copepods	71.14	18.59	55.08	74.62	130.34	68.85	23.32	17.40	14.02	32.67	25.29	47.42	40.11	108.83	65.52
Cladocerans															
Bosmina	43.23	40.64	66.42	294.29	372.52	180.80	2.07	0.34	1.45	49.59	25.02	2.31	22.47	25.73	13.73
Ovig. *Bosmina*	17.10	10.48	44.36	78.67	128.39	43.31	0.81	-	2.58	18.07	12.28	70.25	2.99	0.88	7.20
Chydorinae	8.16	1685.43	15.52	2.35	38.91	8.58	1.84	2.08	-	-	-	-	0.45	15.91	0.54
Ovig. *Chydorinae*	-	-	0.41	-	0.42	-	-	-	-	-	-	4.53	-	1.77	-
Daphnia L.	0.73	0.07	-	2.31	0.05	-	-	-	-	0.16	-	0.17	0.55	-	-
Holopedium	-	-	-	-	-	-	-	-	-	-	0.77	-	0.40	1.29	-
Total cladocerans	69.22	1736.62	126.71	377.62	540.29	232.69	4.72	2.42	4.03	67.82	38.07	77.26	26.86	45.58	21.47
Total biomass	140.36	1755.21	181.79	452.24	670.63	301.54	28.04	19.82	18.05	100.49	63.36	124.68	66.97	154.41	86.99

[a] Zooplankton samples were not collected in August.

[b] Season average includes zooplankton samples collected in September.

[c] Zooplankton samples were not collected in May.

[d] Zooplankton samples were not collected in July.

Appendix D5.–Seasonal average number of zooplankton per m^2 from Chignik Lake by year, 2000–2014.

Taxon	2000	2001	2002	2003 [a]	2004	2005	2006	2007	2008	2009	2010	2011	2012 [b]	2013 [a,c]	2014 [a,c,d]
Copepods															
Cyclops	193,005	43,363	170,001	37,726	140,995	120,322	175,889	292,645	82,109	130,339	92,755	142,259	72,426	152,987	46,554
Ovig. *Cyclops*	2,119	3,507	14,580	916	4,547	10,388	24,648	10,898	2,637	3,767	3,679	6,844	1,920	12,435	244
Diaptomus	11,072	12,869	35,347	62,274	44,994	49,367	17,350	8,741	14,099	34,562	32,866	-	-	-	-
Ovig. *Diaptomus*	765	48	4,777	1,393	2,704	2,816	1,169	1,443	1,858	1,368	1,302	-	-	-	-
Epischura	33,615	13,400	49,645	70,621	66,980	51,946	6,842	3,168	10,350	5,180	10,039	17,411	15,822	9,081	66
Ovig. *Epischura*	149	48	-	-	-	-	-	-	-	-	-	265	-	100	-
Eurytemora	-	-	-	-	-	-	-	-	-	-	2,223	18,063	8,740	13,008	45,746
Ovig. *Eurytemora*	-	-	-	-	-	-	-	-	-	-	-	12,029	164	896	1,181
Harpacticus	178	528	1,244	398	979	348	1,335	265	100	604	559	-	332	149	-
Ovig. *Harpaticus*	-	-	-	-	-	-	-	133	-	-	66	-	62	-	-
Nauplii	41,723	14,969	92,473	55,573	73,434	115,371	87,024	47,605	36,148	48,066	35,065	63,923	47,607	92,054	68,183
Total copepods	282,626	88,733	368,067	228,901	334,632	350,559	314,258	364,898	147,301	223,885	178,554	260,795	147,072	280,708	161,974
Cladocerans															
Bosmina	46,646	30,213	70,113	73,447	59,531	88,990	37,553	13,021	38,112	22,030	39,442	10,735	50,495	25,832	77,854
Ovig. *Bosmina*	12,137	4,622	19,622	14,358	8,919	24,968	8,393	2,604	9,372	1,592	3,581	20,674	1,132	1,612	2,988
Chydorinae	4,000	1,516,382	11,462	1,115	8,207	6,179	13,311	6,137	531	43,676	7,844	2,057	2,066	9,587	166
Ovig. *Chydorinae*	-	-	133	-	166	-	-	-	-	13,854	1,555	3,299	88	100	-
Daphnia L.	8,251	1,462	20,750	68,073	30,072	15,787	8,053	38,681	11,901	-	-	10,707	1,407	87,279	100,292
Ovig. *Daphnia L.*	909	33	10,516	7,086	7,501	6,336	1,120	16,073	2,189	-	-	7,912	212	12,011	17,030
Holopedium	40	-	-	-	-	-	-	-	-	-	-	-	102	-	-
Immature *Cladocera*	1,411	5,862	5,955	5,679	4,082	12,415	9,554	-	-	6,251	7,593	10,646	5,281	22,310	17,825
Total cladocerans	73,393	1,558,574	138,552	169,759	118,478	154,674	77,984	76,516	62,105	87,402	60,015	66,030	60,784	158,730	216,155
Total copepods + cladocerans	356,019	1,647,307	506,618	398,660	453,110	505,233	392,242	441,415	209,407	311,287	238,570	326,825	207,856	439,438	378,130

[a] Season average includes zooplankton samples collected in September.

[b] Zooplankton samples were not collected in May.

[c] Zooplankton samples were not collected in August.

[d] Zooplankton samples were collected on July 1 and July 31.

Appendix D6.–Average weighted biomass estimates (mg dry weight/m^2) of the major Chignik Lake zooplankton taxon by year, 2000–2014.

Taxon	2000	2001	2002	2003 [a]	2004	2005	2006	2007	2008	2009	2010	2011	2012 [b]	2013 [a,c]	2014 [a,c,d]
Copepods															
Cyclops	356.85	333.52	200.10	36.40	137.55	138.37	376.50	467.14	131.58	220.36	112.79	171.18	91.04	165.90	59.75
Ovig. *Cyclops*	15.31	135.69	58.16	3.71	20.39	40.33	153.67	58.86	13.40	25.27	15.51	32.21	9.58	57.04	1.25
Diaptomus	252.75	423.33	129.24	136.41	97.45	125.38	37.81	40.58	76.05	72.87	100.40	-	-	-	-
Ovig. *Diaptomus*	18.42	0.07	28.74	7.18	16.54	23.24	12.34	13.43	6.40	13.19	12.13	-	-	-	-
Epischura	146.70	405.59	34.33	37.86	50.36	43.47	4.90	4.17	13.16	4.21	7.98	16.17	15.38	6.45	0.09
Ovig. *Epischura*	1.03	0.08	-	-	-	-	-	-	-	-	-	0.29	-	1.07	-
Eurytemora	-	-	-	-	-	-	-	-	-	-	11.76	95.90	48.65	84.60	177.44
Ovig. *Eurytemora*	-	-	-	-	-	-	-	-	-	-	-	95.53	1.58	7.84	10.31
Harpacticus	0.12	1.45	0.76	0.26	0.60	0.27	1.09	0.39	0.05	0.43	0.34	-	0.21	0.27	-
Total copepods	791.18	1299.73	451.33	221.82	322.89	371.06	586.31	584.57	240.64	336.33	260.91	411.28	166.44	323.17	248.84
Cladocerans															
Bosmina	182.98	141.13	57.52	77.57	47.50	77.73	30.74	12.37	35.48	23.33	35.80	9.01	45.93	27.70	56.15
Ovig. *Bosmina*	66.93	29.81	27.30	24.83	11.32	31.43	9.86	5.66	11.87	2.60	5.72	27.26	1.48	2.39	3.15
Chydorinae	5.16	15.48	7.47	0.75	5.80	3.90	9.25	3.52	0.15	-	-	1.20	1.32	5.62	0.24
Ovig. *Chydorinae*	-	-	0.09	-	0.23	-	-	-	-	-	-	2.28	0.09	0.08	-
Daphnia L.	23.20	15.17	23.94	77.20	34.64	19.22	8.90	47.63	13.33	52.15	9.19	8.09	1.44	90.89	121.98
Ovig. *Daphnia L.*	6.03	0.09	33.57	19.31	24.07	19.21	2.66	45.04	8.05	34.75	5.69	18.01	0.60	29.42	46.35
Holopedium	0.22	-	-	-	-	-	-	-	-	-	-	-	0.04	-	-
Total cladocerans	284.52	201.68	149.89	199.66	123.56	151.49	61.41	114.22	68.88	112.83	56.40	65.85	50.90	156.10	227.87
Total biomass	1075.70	1501.41	601.22	421.48	446.45	522.55	647.72	698.79	309.52	449.16	317.31	477.13	217.34	479.27	476.71

[a] Season average includes zooplankton samples collected in September.

[b] Zooplankton samples were not collected in May.

[c] Zooplankton samples were not collected in August.

[d] Zooplankton samples were collected on July 1 and July 31.