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Sockeye Salmon Smolt Investigations on the Chignik River, 2010

by

Mary Loewen

and

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June 2011

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

FISHERY DATA SERIES NO. 11-26

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ABSTRACT

This report describes the results of the sockeye salmon *Oncorhynchus nerka* smolt monitoring and enumeration project conducted by the Alaska Department of Fish and Game (ADF&G) in the Chignik River watershed in 2010. The research was designed to estimate smolt population size and age structure, describe limnotic habitat conditions and forage base, assess fish body condition, collect samples for genetic stock identification, and provide data for the Chignik River sockeye salmon forecast. The abundance of sockeye salmon smolt was estimated using a rotary-screw trap array and mark-recapture techniques. In 2010, a total of 28,162,803 sockeye salmon smolt were estimated to pass downstream of the traps from May 12 to July 9. Of these, 1,309,131 (3.7%) were age-0.; 17,684,165 (62.8%) were age-1.; 9,347,999 (33.2%) were age-2.; and 91,509 (0.3%) were age-3. smolt. Limnological surveys were conducted in Chignik and Black lakes each month from May to August 2010, to describe the physical characteristics, nutrient availability, primary production, and zooplankton forage available to rearing juvenile sockeye salmon. Low zooplankton biomass and small size suggested top-down grazing pressure existed from May through July in Black Lake, and from May through June in Chignik Lake.

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

INTRODUCTION

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

The Chignik River basin produces the vast majority of the sockeye salmon in the Chignik Management Area (CMA) (Bouwens 2004). It consists of a large shallow lagoon, two large lakes, and several tributaries that provide spawning and rearing habitat for sockeye salmon (Figure 1). Black Lake, at the head of the system, has a surface area of approximately 35.7 km^2 and is shallow (maximum depth 4.2 m) and turbid. In contrast, Chignik Lake is smaller (22 km^2), deeper (maximum depth 64 m), and is surrounded by mountains. Black Lake drains via the Black River into Chignik Lake, which flows through Chignik River into Chignik Lagoon, and then into the Gulf of Alaska (Narver 1966; Dahlberg 1968). Chignik Lagoon is a semi-enclosed estuary with salinities ranging from full marine seawater at the outer spit to nearly freshwater conditions at the head of the lagoon (Simmons 2009).

Both lakes are considered oligotrophic (Kyle 1992) and each maintains its own genetically distinct, though temporally overlapping, runs of adult sockeye salmon (Templin et al. 1999). Early-run sockeye salmon enter the watershed from June through mid-July and spawn in Black Lake and its tributaries. Late-run sockeye salmon return from late June through the late fall and spawn in the tributaries and shoals of Chignik Lake. The early run has a sustainable escapement goal (SEG) range of 350,000 to 400,000 fish through July 4, while the late run has an SEG range of 200,000 to 400,000 fish beginning on July 5 and an additional 50,000 fish inriver run goal (IRRG) apportioned between August and September (Witteveen et al. 2007) and added to the bottom range of the escapement goal.

Juvenile salmon are known to migrate to sea after certain size thresholds are met, during specific seasons, and under certain environmental conditions (Clarke and Hirano 1995). Salmon smolt emigration may be triggered by warming springtime water temperatures (>4°C) and increased photoperiod (Clarke and Hirano 1995). Variables affecting growth in juvenile salmon include temperature, competition, food quality and availability, and water chemistry characteristics (Moyle and Cech 1988). Because of these dynamic factors, annual growth and survival from egg to smolt of sockeye salmon often varies among lakes, years, and within individual populations (Bumgarner 1993).

Smolt emigration studies can provide information on life history strategies and annual changes in emigration timing. Combined with limnological investigations, this type of study can provide insight as to how environmental factors may influence food availability, juvenile emigration timing, and overwintering habitat selection. Sockeye salmon rearing in Chignik and Black lakes are exposed to varying levels and types of environmental stresses which may influence their life history strategies. For example, if growth rates are not sufficient to achieve the threshold size necessary to emigrate in the spring, juvenile fish may stay in a lake to feed for another year (Burgner 1991), possibly increasing competition among younger age classes in the same rearing area. Conversely, stressed smolt may emigrate early in order to take advantage of better rearing conditions in the marine environment (Rice et al. 1994). Over the past several decades, mean annual temperature and precipitation (as measured at Cold Bay, Alaska; Alaska Climate Research Center, 2010) has increased, while Black Lake water levels have decreased to two-thirds of the 1968 mean depth of 3.0 m (Dahlberg 1968; Ruggerone et al. 1993). Changes in temperature regimes and the loss of Black Lake rearing habitat may create thermally stressful environments for juvenile sockeye salmon and stress the available forage base intensifying competition and top-down pressures on zooplankton by juvenile salmon.

In addition to growth and survival rates of juvenile salmon, competition for food and habitat can influence migratory behavior of sockeye salmon smolt (Rice et al. 1994). Recent work in the watershed (Finkle 2004; Westley and Hilborn 2006; Simmons 2009) indicates Black Lake juveniles move into Chignik Lake to overwinter, with possible deleterious effects on Chignik Lake juveniles. Top-down pressures are often indicated by decreased zooplankton size, which has been observed in *Bosmina* from Chignik and Black lakes (Kerfoot 1987; Kyle 1992; Bouwens and Finkle 2003). The usage of available rearing habitat specific to each stock, and the interactions between the Black Lake (early run) and Chignik Lake (late run) stocks are not completely understood but have been the focus of numerous studies (Bumgarner 1993; Ruggerone 2003; Westley et al. 2008; Simmons 2009; Westley et al. 2009). In particular, the influence of changing physical and environmental factors upon the emigration of juvenile sockeye salmon merits continued investigations. 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 offset or avoid overtaxed Chignik Lake rearing conditions and subsequently return to Chignik Lake in the fall of the same year (Roos 1957, 1959; Iverson 1966; Phinney 1968). Competition for space and food between populations of juvenile sockeye salmon in Chignik Lake may cause seasonal migrations of either subpopulation into areas of lower smolt density and possibly migration into Chignik Lagoon. Information derived from smolt and watershed monitoring is crucial for understanding changes in the production capacity of the salmon habitat of both Black and Chignik lakes.

Since the inception of the sockeye salmon smolt enumeration project in 1994, estimates of sockeye smolt emigrations from the Chignik River watershed have ranged from 2 to 26 million sockeye salmon. Chignik sockeye salmon smolt generally have been observed to emigrate beginning in early May, peaking in mid-to-late May and are predominantly composed of age-1. and -2. fish (Loewen and Bradbury 2010). Differences in emigration timing by stocks is theorized, and genetic analysis is underway to determine whether this occurs consistently (Creelman 2010).

Smolt emigration data can serve as an indicator of future run strength and overall stock status. In recent years, abundance and age data from the enumeration project have been used to generate an adult sockeye salmon forecast for the Chignik watershed (Eggers et al. 2010). Forecasts enable harvesters and fish processors to estimate their potential supply and production needs. Historical forecast methods use historic age class relationships and smolt emigration estimates to predict the adult runs to the Chignik watershed (Eggers and Carroll 2011). Additionally, genetic identification of emigrating Chignik sockeye smolt began with an M.S. study in 2006 to provide insight to annual fluctuations in the population size and juvenile-to-adult survivorship of each emigrating stock. Genetic studies, now funded by a grant from Alaska Sustainable Salmon Fund, will also elucidate potential differences in emigration timing between stocks and provide further detail for stock-specific return predictions.

In addition to smolt abundance data, genetic stock identification, biological characteristics of the smolt collected at the smolt trap, and information on rearing conditions are needed to determine what other factors may affect sockeye salmon production in the Chignik River system. Comprehensive limnological investigations in the Chignik watershed have occurred annually since 2000. In 2008 limnological studies were formally incorporated into the smolt enumeration project. To date, limnology and smolt data from the Chignik watershed have been used to describe top-down limitations to rearing sockeye salmon and trends in the life history strategies of juvenile sockeye salmon relative to recent physical changes to the watershed (Buffington 2001; Bouwens and Finkle 2003; Finkle 2004). The limnology portion of this study seeks to identify and understand the relationships among juvenile sockeye salmon and zooplankton relative to physical conditions such as temperature, turbidity, dissolved oxygen saturation of the water, and available nutrients such as nitrogen and phosphorous.

The 2010 field season was the seventeenth year of the ADF&G Chignik River sockeye salmon smolt monitoring and enumeration project which has been funded by the Chignik Regional Aquaculture Association (CRAA) since inception. The sampling protocol has been consistent for these 17 years. This report presents data collected in 2010, compares the results of 2010 to previous years, and provides the 2011 adult sockeye salmon forecast based on smolt data.

OBJECTIVES

The objectives for the 2010 season were to

1. estimate the total number of emigrating sockeye salmon smolt, by age, from the Chignik River watershed;
2. describe emigration timing and growth characteristics (length, weight, and condition factor) of sockeye salmon smolt by age for the Chignik River watershed;
3. present a stewardship-building sockeye salmon smolt presentation to students at CMA schools;
4. describe the physical characteristics of Black and Chignik lakes including: temperature, dissolved oxygen, and light penetration profiles;
5. describe the nutrient availability and primary productivity of Black and Chignik lakes;
6. describe the zooplankton forage base available to juvenile sockeye salmon in Black and Chignik lakes;
7. continue to build a smolt-based forecast model in an effort to estimate marine survival and future runs; and
8. collect genetic samples from emigrating sockeye salmon smolt for use in a future stock separation study.

METHODS

Study Site and Trap Description

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

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

Each trap consisted of a cone constructed of aluminum perforated plate (5 mm holes) mounted on two aluminum pontoons, with the large open end of the cone pointed upstream. The cone mouth diameter was 1.5 m on the small trap (placed nearshore), and 2.4 m on the large trap (placed offshore). The small trap sampled an area of approximately 0.73 m^2, and the large trap sampled an area of approximately 2.0 m^2 of the river's profile because only the bottom half of the cone was submerged. The river current upon an internal screw welded to the inside of each cone rotated the cones at approximately 3–9 revolutions per minute (RPM) during average water flow conditions. Ideal trap RPM is between 6 and 7, and adjustments to the traps were made in order to obtain this speed. Fish were funneled through the cones into live boxes, each approximately 0.7 m^3 in volume. The live boxes sat on the downstream end of each trap. A pair of adjustable aluminum support legs was utilized to maintain and adjust the traps' positions from the shore and their orientation to the current.

A floating platform supporting a 3 m x 4 m weatherport was tied directly behind the live box work station, to provide shelter for the crew when processing samples taken from the traps.

During the 2010 field season, both of the traps were operated continuously from 1600 hours on May 12 to 1035 hours on July 9. Periods of inoperation of the large trap due to maintenance needs were limited to periods of 4 hours or less on three separate afternoons. At the completion of the project, both traps were disassembled and stored.

Smolt Enumeration

Because smolt primarily emigrate at night, sampling days extended for a 24-hour period from noon to noon and were identified by the date of the first noon-to-midnight period. The traps were checked a minimum of three times each day beginning at noon, between 1900 and 2200 hours, and no later than 0800 hours the next morning. Traps were checked more frequently during periods of increased smolt emigration.

Juvenile sockeye salmon greater than 45 mm fork length (FL; measured from tip of snout to fork of tail) were considered smolt (Thedinga et al. 1994). All fish were netted out of the traps' live boxes, identified (McConnell and Snyder 1972; Pollard et al. 1997), enumerated and released, except for those sockeye salmon retained for age-weight-length (AWL) samples and smolt to be used for mark-recapture tests. Sockeye salmon fry (<45 mm FL), coho salmon *O. kisutch* juveniles, chinook salmon *O. tshawytscha* juveniles, Dolly Varden *Salvelinus malma*, stickleback of the family Gasterosteidae, pond smelt *Hypomesus olidus*, pygmy whitefish *Prosopium coulteri*, starry flounder *Platichthys stellatus*, coastrange sculpin *Cottus aleutus*, and the isopod *Mesidotea entomon* (Merrit and Cummings 1984; Pennak 1989) were also identified and counted.

TRAP EFFICIENCY AND SMOLT POPULATION ESTIMATES

Mark-recapture experiments were conducted on May 12 and every 5–6 days from May 25–June 26 to determine trap efficiency when a sufficient number of smolt were captured to conduct a marking event. Between approximately 800 and 3,000 sockeye salmon smolt for each experiment were collected from the traps and transferred to the live box. Smolt were retained in the live box for no more than three nights if sufficient numbers were not initially captured to perform a mark-recapture experiment. Past mark retention and delayed mortality experiments indicated that most of the captured smolt mortalities occurred within the first three days of capture (Bouwens and Newland 2003). Thus, after three nights, all captured live smolt were released if the minimum sample size was not met.

Sockeye salmon smolt were netted from the live box, counted, and transferred into an aerated repository containing a Bismarck Brown-Y dye solution (4.6 g of dye to 92.4 L of water) for 15 minutes. Fresh water was then pumped into the container to slowly flush out the dye (90 min). The smolt were allowed to recover in the circulating water. At the end of the marking process, any dead or stressed smolt were removed, counted, and disposed of downstream of the traps.

The remaining marked smolt were taken to the upriver release site (56°15'15" N lat, 158°44'51" W long), approximately 1.3 km upstream of the traps (Figure 2). The smolt were transported upstream in aerated containers and released evenly across the breadth of the river from the south bank to the north bank. The marking event was performed so that the marked fish were released before midnight. The number of smolt recaptured in the traps was recorded for several days until recoveries ceased. Sockeye salmon smolt recaptured during mark-recapture experiments were recorded separately from unmarked smolt and excluded from daily total catch to prevent double counting.

Additionally, 100 marked smolt and 100 unmarked smolt were held at the traps in instream live boxes to ensure assumptions of the mark-recapture experiments were validated. Any mortality observed in the held smolt was incorporated into daily population estimates.

The trap efficiency E was calculated by

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

where

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

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

and

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

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

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

where

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

Variance was estimated by

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

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

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

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

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

and 95% confidence intervals were estimated from

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

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

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

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

where

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

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

with the variance estimated as

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

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

$$\hat{U}_{jh} = \hat{U}_j \hat{\theta}_{jh} , \qquad (9)$$

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

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

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

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

with the variance estimated by

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

AGE, WEIGHT, AND LENGTH SAMPLING

Smolt were collected throughout the night's migration and held in an instream live box. On each of five days per statistical week, 40 sockeye salmon smolt were randomly collected from the accumulated fish in the live box, anesthetized with Tricaine methanesulfonate (MS-222), and sampled for age, weight, and length (AWL) data. All smolt sampling data reflected the smolt day in which the fish were captured, and samples were not mixed between days.

Fork length (FL) was measured to the nearest 1 mm, and each smolt weighed to the nearest 0.1 g. Scales were removed from the preferred area (INPFC 1963) and mounted on a microscope slide for age determination. Fin clips were collected from all AWL-sampled fish for genetic analysis and stored in ethanol following ADF&G protocol (Anderson and Loewen 2010).

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

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

$$K = \frac{W}{L^3} 10^5 , \qquad (13)$$

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

CLIMATE AND HYDROLOGY

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

MARINE SURVIVAL ESTIMATES AND FUTURE RUN FORECASTING

The total return to the Chignik River watershed was calculated by adding the total Chignik River sockeye salmon escapement, the total harvest from the CMA, and a portion of the sockeye salmon catch from the Southeastern District Mainland (SEDM) of the Alaska Peninsula Management Area and the Cape Igvak Section of the Kodiak Management Area (5 AAC 09.360(g); 5 AAC 18.360(d)). Marine survival, by age, and the number of smolt produced per spawner from their respective brood years (BYs) were also calculated.

Returns of 3-ocean sockeye salmon were predicted by regressing the estimated 1.- and 2.- smolt from the same emigration year to create a late-run forecast. Additionally, a statistically significant simple regression relationship was used to forecast the saltwater-age-3 (3-ocean) component (historically, about 85% of the entire run) of the 2010 adult sockeye salmon run from the age-2. smolt emigration data, using data from 1994 through 2005 (excluding 1996). The adult return estimates for the 3-ocean age class were expanded to account for the total run from their historical proportion of the total run.

LIMNOLOGY

One limnology sampling station was set on Black Lake (Figure 3), and four sampling stations were established on Chignik Lake (Figure 3). Sampling occurred monthly from May through August. Each station's location was logged with a global positioning system (GPS, using NAD 1983 datum) and Chignik Lake stations marked with a buoy. The station on Black Lake was not marked with a buoy, instead the station was plotted on a GPS to ensure accurate resampling at the same site each time. 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 ProODO™ [1] meter. Readings were recorded at half-meter intervals from 0–5 m, and then intervals increased to one meter. Upon reaching a depth of 25 m, the intervals increased to every five meters up to 50 m (the depth limit of the equipment). A mercury thermometer was used to ensure the meter's calibration. Measurements of photosynthetically active wavelengths (kLux) were taken with a Li-Cor LI-250A photometer. Readings began above the surface, at the surface, and proceeded at half-meter intervals until reaching a depth of 5 m. Readings were then recorded at one-meter intervals until the lake bottom or light penetration reaches 1% of the surface reading was reached. The mean euphotic zone depth (EZD) was calculated for each lake (Koenings et al. 1987; Koenings and Kyle 1997). One-meter temperature and dissolved oxygen measurements were compared to assess the physical conditions in the euphotic zones of each lake. Secchi disc readings were collected from each station to measure water transparency. The depths at which the Secchi disc disappeared when lowered into the water column and reappeared when raised in the water column were recorded and averaged.

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

Water Sampling

Seven to eight liters of water were collected with a Van Dorn bottle from the epilimnion (depth of 1 m) of both lakes and from the hypolimnion (depth of 29 m) of Chignik Lake. Water sampling and processing techniques have been consistent since 2000 and follow protocols outlined in Finkle (2007). Water analyses were performed at the Chignik field laboratory for pH and alkalinity and at the ADF&G Near Island laboratory for total phosphorous (TP), total ammonia (TA), nitrate + nitrite, total filterable phosphorous (TFP), filterable reactive phosphorous (FRP), chlorophyll *a*, and phaeophytin *a*. All laboratory analyses adhered to the methods of Koenings et al. (1987) and Thomsen et al. (2002). Total Kjeldahl nitrogen (TKN) was processed by the Olsen Biochemistry Lab at South Dakota State University.

Zooplankton

One vertical zooplankton tow was made at each limnology station with a 0.2 m diameter, 153-micron net from one meter above the lake bottom to the surface. One sample was placed in a 125 ml poly bottle containing 12.5 ml of concentrated formalin to yield a 10% buffered formalin solution. Samples were stored for analysis at the ADF&G Near Island laboratory. Subsamples of zooplankton were keyed to genus or species and counted on a Sedgewick-Rafter counting slide. This process was replicated three times per sample, then counts were averaged and extrapolated over 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

Both traps were in place for a total of 59 days beginning on May 12 and ending on July 9 (Appendix A1 and B1). The duration of the 2010 trapping season was 4 days shorter than the 2009 season. Bad weather and presence of lake ice precluded the installation of the traps prior to May 12.

A total of 116,792 sockeye salmon smolt were captured in the traps in 2010 (Appendix A1 and B1). In addition to sockeye salmon smolt, 15,078 sockeye salmon fry, 424 juvenile coho salmon, 1,690 juvenile Chinook salmon, 429 Dolly Varden char, 11,679 stickleback, 119 sculpin, 72 starry flounders, 261 pond smelt, 254 pygmy whitefish, and 73 isopods were captured (Appendix A1). The small screw trap caught 15.1% of the trapped sockeye salmon smolt (Appendix B1).

SMOLT EMIGRATION TIMING AND POPULATION ESTIMATES

An estimated 28,162,803 (95% CI 19,473,557-36,852,050) sockeye salmon smolt emigrated in 2010 (Table 1; Figure 4) based upon mark-recapture estimates and trap counts (Table 3). The majority of these fish emigrated from late May to mid-June (Table 2; Figure 5). The 2010 emigration estimate consisted of 1,039,131 age-0., 17,684,165 age-1., 9,347,999 age-2 and 91,509 age-3. sockeye salmon smolt (Tables 1 and 2; Figure 6). Age-1. and age-2. fish comprised the vast majority (96%) of the smolt emigration.

TRAP EFFICIENCY ESTIMATES

Mark-recapture experiments were conducted on eight occasions beginning on May 16 and ending on June 26 (Table 3; Appendix A1). A total of 16,968 smolt, approximately 14.5% of the total catch, were marked and released. Fifty-three smolt were recaptured, and trap efficiency estimates per stratum ranged from 0.28% to 1.02% (Table 3; Appendix A1). The majority of marked smolt were recaptured within two days of being released. Tests were not conducted after June 26 because trap catches were below the minimum sample size needed. Therefore, the efficiencies from the June 26 test were applied to all smolt emigrating through July 9 (2.9% of the total emigration).

AGE, WEIGHT, AND LENGTH DATA

A total of 1,694 legible samples were collected from sockeye salmon smolt for AWL data. Over the entire season 7.6% of smolt sampled were age-0. (BY 09), 71.1% were age-1. (BY 08), 21.2% were age-2. (BY 07), and 0.1% were age-3 (BY 06). The highest proportion by age class was in early July for age-0. smolt (21.5% of samples), mid-June for age-1. smolt (95% of samples) and late May for age-2. smolt (55.0% of samples). Peak emigration was the second week of June for age-1., late May for age-2., and late May for age-3. Age-0. smolt emigration timing had a bimodal peak, in early June and again in late June (Table 2).

The mean length, weight and condition factor of age-0. smolt were 54 mm, 1.2 g, and 0.78. The mean length, weight and condition factor of age-1. smolt were 69 mm, 2.6 g, and 0.76. The mean length, weight, and condition factor of age-2. smolt were 81 mm, 4.0 g, and 0.74. The mean length, weight and condition factor of age-3. smolt were 92 mm, 6.0 g, and 0.78 (Table 4, Figure 7). Length frequency histograms indicated that larger smolt (> 65 mm) composed the majority of the catch throughout the season (Figures 8, 9). Sockeye salmon fry <45 mm FL were captured throughout the trapping season, but were most abundant in the first month of the study (Appendix A1).

PHYSICAL DATA

The absolute water depth at the trap location varied from 85 to 167 cm during the season. Water temperatures averaged near 3.2°C during the first few days the traps were installed (May 12 through May 13) and increased steadily throughout the season to a maximum of 9.5°C (Appendix C1 and C2). The season began with exceptionally low water levels that increased with snowpack melt before stabilizing in mid-June. Cool temperatures, light winds and overcast skies dominated the 2010 season.

ADULT RETURN FORECAST

The smolt regression model in 2010 forecasted a 2010 total adult run of 1.54 million sockeye salmon, while the formal adult forecast predicted a run of 2.19 million sockeye salmon (Eggers et al. 2010). The total actual 2010 run was approximately 2.39 million sockeye salmon.

LIMNOLOGY

Sampling was conducted each month in both Black Lake (May 31, June 28, July 10, and August 20) and Chignik Lake (May 21, June 19, July 1, and August 19). Comparisons with historical limnological data can be found in Appendices E1 and E2.

Temperature and Dissolved Oxygen

Black Lake

The 1-m temperature in Black Lake in 2010 increased from 9.4°C on May 31, to 12.6° on July 10, and was 12.3° on August 20. (Table 8; Figure 10). Dissolved oxygen levels at the 1 m depth fluctuated over the same dates, though August levels were greater than either June or July (Table 8; Figure 10).

Chignik Lake

The average 1-m temperature in Chignik Lake increased from 3.4°C on May 21, to 11.2°C on August 19 (Table 9; Figure 11). Dissolved oxygen levels increased from 10.1 mg/L to 12.2 mg/L in June, then decreased to 10.4 mg/L by August (Table 9; Figure 11). Within the water column temperature and dissolved oxygen levels each remained similar throughout June, July, and August, with no more than 1.3°C variation in temperature between surface and deeper water at any point. The greatest variation of DO within the water column occurred in May (6.7 mg/L).

Light Penetration and Water Transparency

Black Lake

Light penetrated the entire water column in Black Lake, as averaged across the 2010 sampling season (Table 10; Figure 12). The EZD of Black Lake exceeded its maximum depth throughout the entire sampling season. The mean lake depth (1.9 m) was used to calculate the euphotic volume (EV) of 143.2 x 10^6 m^3 (Table 10; Figure 12). During the 2010 sampling season average Secchi disc were at a mean depth of 0.8 m.

Chignik Lake

Light penetration reached 1% of surface levels at a depth of 11.0 m in May, 11.5 m in June, 10.0 m in July, and at 4.5 m in August (Table 11; Figure 12). The EZD was 10.6 m in May, 10.4 m in June, 9.6 m in July, and 3.7 m in August (Table 10). The EV in Chignik Lake averaged 257.7 x 10^6 m^3 (Table 10). Average Secchi disc readings were at a mean depth of 2.6 m.

Water Quality Parameters, Nutrient Levels, and Photosynthetic Pigments

Black Lake

In 2010, the pH in Black Lake averaged 7.8 and alkalinity averaged 22.0 mg/L $CaCO_3$ (Table 12) across stations and depth. Total phosphorous (TP) averaged 29.8 μg/L P and TKN averaged 210.8 μg/L N. Ammonia averaged 6.4 μg/L N and nitrate + nitrite averaged 1.0 μg/L N in 2010. Chlorophyll *a* averaged 2.8 μg/L and phaeophytin *a* had a seasonal mean of 1.5 μg/L. Though pH decreased throughout the season from May to August, TKN and ammonia levels fluctuated, with TKN values greatest in June and August and ammonia levels greatest in May and July. Phaeophytin *a* levels were highest in May and July (Table 12).

Chignik Lake

In 2010, seasonally averaged pH measured 7.2 and alkalinity averaged 20.0 mg/L $CaCO_3$ across stations and depth. Average TP measured 13.6 μg/L P and TKN averaged 44.5 μg/L N, though it should be noted that levels of TKN were so low in July and August they were undetectable (<20 μg/L N). Averaged ammonia measured 6.8 μg/L N and nitrate + nitrite averaged 154.4

μg/L N. Measurements of chlorophyll *a* remained constant through the season and averaged 1.5 μg/L and phaeophytin *a* had a seasonal mean of 0.8 μg/L and levels decreased from May to July and then increased in August (Table 13).

ZOOPLANKTON

Black Lake

Copepod abundance (season average of 38,963 individuals/m^2) was comparable to cladoceran abundance (season average of 36,077 individuals/m^2) when averaged over the sampling season in Black Lake. On average, the most prevalent identifiable stage of copepods in Black Lake were *Cyclops* (18,312/m^2). Nauplii (juvenile) copepod were also abundant with a seasonal mean of 12,971/m^2 (Table 14; Appendix E3). *Bosmina* were the only cladoceran observed in Black Lake (season average of 28,646 individuals/m^2) and abundance peaked in July (Table 14).

Copepod biomass was greatest in July and was composed predominantly of *Cyclops* (24.0 mg/m^2 in July, 12.5 mg/m^2 weighted season average) and *Diaptomus* (23.7 mg/m^2 in July, 7.1 mg/m^2 weighted season average; Table 15). Cladoceran biomass, including ovigerous individuals, was predominantly composed of *Bosmina* throughout the sampling season with a weighted seasonal average biomass of 25.0 mg/m^2, with greatest biomass observed in August (49.7 mg/m^2; Table 15; Appendix E4). Copepod biomass was slightly less than cladoceran biomass throughout the sampling season (Table 15).

Average seasonal lengths of the major zooplankton in Black Lake were 0.48 mm for C*yclops*, and 0.30 mm for *Bosmina* (Table 16).

Chignik Lake

Copepod abundance (season average of 179,612 individuals/m^2) was greater than the average weighted seasonal cladoceran abundance (53,815 individuals/m^2; Table 17; Appendix E5). Not including ovigerous zooplankton, *Cyclops* (92,755/m^2), nauplii (35,065 individuals m^2) and *Diaptomus* (32,733 individuals/m^2), were the most abundant genera of copepods during the season (Table 17; Appendix E5). *Bosmina* (39,697 individuals/m^2) and *Daphnia* (8,631 individuals/m^2) were the most common cladocerans in Chignik Lake (Table 17; Appendix E5).

Copepod biomass was composed predominantly of *Cyclops* in May through July, with the greatest biomass occurring in July (329.7 mg/m^2; weighted seasonal average 123.4 mg/m^2; Table 18). In August *Diaptomus* and *Cyclops* made up the majority of the biomass (305.8 mg/m^2 and 223.7 mg/m^2 respectively). Biomass estimates of *Cyclops* were substantially greater than estimates of other copepods and cladocerans from May through July, however *Diaptomus* were dominant in August (305.8 mg/m^2; Table 18) followed by *Cyclops* (223.7 mg/m^2; Table 20). Cladoceran biomass was composed primarily of *Daphnia* and *Bosmina*. *Bosmina* increased from May to August, while *Daphnia* biomass was high in May (Table 18). The weighted seasonal average copepod biomass (271.2 mg/m^2) was greater than weighted seasonal average cladoceran biomass (55.2 mg/m^2) resulting in a total weighted average of 326.4 mg/m^2 of all Chignik Lake zooplankton (Table 18; Appendix E6).

Average seasonal lengths of the major non-egg bearing zooplankton in Chignik Lake were 0.93 mm for *Diaptomu*s, 0.61 mm for C*yclops*, 0.57 mm for *Epischura*, 0.33 mm for *Bosmina*, and 0.48 mm for *Daphnia* (Table 19). Ovigerous zooplankton were generally longer than non-egg bearing individuals (Table 19).

DISCUSSION

SMOLT EMIGRATION TIMING, POPULATION ESTIMATES AND AGE STRUCTURE

The traps were installed on May 12, as ice had prevented installation prior to this date. The point estimate of the 2010 total smolt emigration was the largest on record. The 2010 emigration occurred mid to late season and showed similar timing to 1997. The emigration estimate was comparable to estimates from 1997, 1998, and 2001 (Figure 4). Early emigration timing occurred in 2009, but trap installation occurred after the start of the emigration and the overall population estimate was low. Given the timing and magnitude of the 2010 emigration, it is possible that the peak of the 2009 emigration occurred even earlier than previously reported and the actual 2009 emigration population was higher than reported.

Emigration timing and magnitude in 2010 allowed for eight mark-recapture events throughout the season with approximately 17,000 smolt marked and released. Trap efficiency estimates in 2010 were consistent with previous years. Trap efficiencies usually average <2% annually and individual mark-recapture events often are <1%. These efficiencies are consistent throughout the season and have never been more than 3% in the history of the project (Loewen and Bradbury 2010). Although these trap efficiency estimates result in wide confidence intervals around the population point estimate, the interannual trap efficiency consistency provides confidence that the yearly population estimates are robust and comparable among years.

The 2010 emigration population, as determined from scale samples, was comprised of 70% age-1, 22% age-2, and 7.7% age-0 smolt. Age-1 smolt generally make up the greatest proportion of the emigration, with age-2 smolt comprising approximately 37% of the historical emigration. A general pattern of condition-at-time-of-migration has been observed in the Chignik watershed; in years when emigrations occur evenly throughout the season, competition for feeding opportunities in freshwater was probably high, and the smolt that remained until June were in poorer condition relative to those that left earlier. In 2010, however, condition factor increased throughout the season among all age classes. Juveniles remaining in the lake after the majority of smolt have left the system likely had decreased competition for zooplankton, and therefore were in better condition later in the season.

In addition to sockeye salmon smolt, approximately 15,000 sockeye fry were captured in the traps. Unlike other systems where smolt leave the lakes and enter directly into the coastal waters and feeding grounds, Chignik has a lagoon which acts as a buffer between the freshwater and saltwater ecosystems. This provides a forage base of amphipods, pericardians, and other small crustacean taxa which may alleviate some of the top-down pressure in Chignik Lake (Bouwens and Finkle 2003). Simmons (2009) found that sockeye salmon fry were abundant in Chignik Lagoon throughout the summer and that residency time was closely related to sockeye salmon length and age, with smaller fish remaining longer to achieve additional growth in body size before their migration to the marine environment. Phinney (1968) found smaller smolt occupied the littoral areas while larger smolt occupied the pelagic zone within the lagoon. Under stressful environmental conditions, such as elevated temperatures and poor visibility, underyearling sockeye salmon may successfully migrate to sea (Rice et al. 1994). In 2005, 2006, and 2007 a greater proportion of age-0 smolt were observed outmigrating, possibly due to stressful lake conditions as a result of decreased available zooplankton forage base. The low proportion of age-0. fish and sockeye fry emigrating in 2010 may suggest that freshwater rearing conditions were improved in recent years, allowing fish to remain in the watershed to overwinter.

Since 2003, managers have attempted to target the lower bounds of the escapement goal for both runs, in order to reduce competition for resources and allow the available zooplankton forage base to increase under reduced top-down grazing pressure from rearing sockeye salmon (Finkle 2007). Decreased competition among juveniles for food may be allowing juveniles to successfully grow, rear and overwinter in the lakes rather than migrate to the marine environment early. Although the rearing and migratory behavior of juvenile sockeye salmon in Chignik Lagoon is not completely understood, in a system with variable and limiting freshwater conditions such as those seen in the Chignik watershed, Chignik Lagoon may provide the best opportunity for additional growth for emigrating juvenile sockeye (Simmons 2009). These data do suggest that as rearing habitat in Black Lake continues to decrease, the lagoon may provide an important rearing habitat for juvenile sockeye salmon before continuing to the marine environment.

Survival by age class and marine survival of Chignik sockeye salmon smolt, when assessed by fully recruited emigration year (excluding 1996), are well within the ranges observed in other Alaskan sockeye systems (Burgner 1991; Bradford 1995). This variability in marine survival implies that given constant freshwater production, adult returns would still fluctuate because of annual differences in productivity of the marine environment.

ZOOPLANKTON ABUNDANCE AND SPECIES COMPOSITION

Though not as great as densities observed in 2009, zooplankton densities in both Black and Chignik lakes were high compared to recent years and followed historical patterns of seasonal population abundance. Zooplankton density in Black Lake is historically predominated by copepods early in the season, decreasing from May to June, then peaking in late July or August (Finkle and Ruhl 2008; Loewen and Bradbury 2010). Cladoceran densities become the predominant zooplankton in Black Lake late in the summer, after increasing steadily throughout the season with population densities peaking in August when phytoplankton levels increased and many of the zooplanktivorous fish have left the lake. Recorded densities for 2009 and 2010 were high when compared to recent years, but it should be noted that August samples were not collected in 2006–2008. Zooplankton abundance in 2009 was the greatest observed in several years and this availability of prey likely allowed for the large emigrations in 2009 and 2010. In 2010, cladoceran biomass peaked early in July. Since cladocerans are a preferred food source for juvenile sockeye salmon, their abundance may be a better indicator of potential juvenile sockeye salmon production (Koenings et al. 1987; Kyle 1992).

Chignik Lake zooplankton populations historically follow a pattern similar to Black Lake zooplankton populations, but copepods dominate the zooplankton population even in late season when overall zooplankton densities are greatest. Chignik Lake copepod populations historically are comprised primarily of *Cyclops*, while the most abundant cladoceran is *Bosmina*. In 2010, overall densities were very similar to 2009, but most of the biomass was comprised of copepods, with fewer cladocerans in Chignik Lake. Again, the collection of zooplankton samples in August are important for accurate seasonal average comparisons because cladoceran abundance may not peak until late July or mid-August, and therefore would not be represented in samples collected earlier in the season.

Evidence of overgrazed zooplankton populations can be reflected by reductions in zooplankton length and shifts in species composition (Kyle 1992; Schindler 1992). The continued observed trend of inseason zooplankton composition changes and density fluctuations are indicative of top-down grazing pressure on zooplankton (Kyle 1992; Stockner and MacIsaac 1996), as the emigration of sockeye salmon juveniles from Black Lake in July and August corresponded to the greatest overall zooplankton densities, and greatest number of *Bosmina* in zooplankton samples. This *Bosmina* spike coincides with the migration of Black Lake juvenile sockeye salmon to Chignik Lake, which suggests that the impact and magnitude of top-down pressures are greater than bottom-up pressures in Black Lake as biomass increases with a reduction in grazing pressure. In 2010, greatest observed biomass occurred in Black Lake in July, consistent with an early outmigrating timing. Mean cladoceran length increased through the season in Black Lake, but remained constant or decreased in Chignik Lake, suggesting a population of planktivores continued to exert grazing pressure on the zooplankton stock even in August. Whether these were sockeye salmon juveniles preparing to overwinter in the lakes or other planktivores is uncertain. *Bosmina* average lengths were consistently below the minimum elective feeding threshold of 0.40 mm for juvenile sockeye salmon (Kyle 1992), indicating that top-down grazing pressures were removing larger *Bosmina* from the system. Finally, the observed inseason composition changes suggest top-down limitations occurred because the nutrients that drove primary production, chlorophyll *a* and phaeophytin *a*, fluctuated minimally over the 2010 sampling season.

Juveniles rearing in the watershed from 2004 to 2006 may have been stressed by resource limitation including competition for zooplankton, increased temperatures, and turbidity. These fish left the system at age-0. as observed in smolt trap catches from 2005, 2006, and 2008 (Loewen and Bradbury 2010). Targeting the lower end of the escapement goals since 2003 may have successfully reduced foraging competition among juveniles, allowing for more efficient feeding as zooplankton levels recovered from years of over-grazing. In 2010, few age-0. fish or fry were observed in the traps, suggesting these fish may be remaining in the watershed to overwinter before emigrating as age-1. smolt. Similar proportions of age classes in the 2011 emigration will be a positive indicator that rearing conditions in the Chignik watershed are improving from those observed from 2003 to 2007.

LIMNOLOGY

The Alaska Peninsula, as indicated by annual monthly air temperatures at Cold Bay from 1961 to 2010 (Alaska Climate Research Center 2010), has generally been experiencing warmer temperatures. Griffiths (2011) showed air temperatures and water temperatures are closely coupled in Black Lake due to the shallow depth of the water body. Air temperatures may play a larger role in the condition and success of sockeye salmon juveniles in Black Lake, as thermal stress may cause earlier emigration timing of Black Lake juveniles into Chignik Lake. In 2010, air temperature as measured at the smolt trap was cooler than recent years, and water temperatures in both Chignik and Black lakes were also cooler than in most recent years. Monthly 1-m and 29-m temperatures in 2010 in both Chignik and Black lakes were as cool as or cooler than all years since 2000 and the water column less stratified. A late spring, heavy snowpack, and cool summer conditions contributed to the overall cold freshwater conditions seen throughout the season. Although both lakes were more turbid in 2009 than in the previous 5 seasons, both lakes have shown a general pattern of decreasing turbidity since 1991, which should provide better feeding conditions for both juvenile fishes and zooplankton. Light penetration depths in both lakes were deeper in 2010 than in 2009. Cooler temperatures and increased water clarity would provide less metabolically taxing conditions for juveniles and allow young-of-the-year sockeye salmon to successfully remain in the watershed for overwintering rather than emigrate as age-0. fish.

Nutrient data can indicate limitations in aquatic environments. A comparison of total nitrogen (TN) to total phosphorous (TP) is a simple indicator of aquatic ecosystem health because both are necessary for primary production (Wetzel 1983; UF 2000). Nitrogen-phosphorous ratios of less than 10:1 indicate nitrogen limitations (USEPA 2000). Based on the 2010 water quality data, nutrient levels in both lakes fell into low production (oligotrophic) levels as defined by several trophic state indices (Carlson 1977; Forsberg and Ryding 1980, Carlson and Simpson 1996) but were comparable to other Alaskan lakes (Honnold et al. 1996; Schrof and Honnold 2003). Seasonally averaged TN:TP ratios for Black Lake were 7.3:1, and oscillated throughout the summer season, with high ratios in June and August (9.2:1). Similarly, the seasonal Chignik Lake average was 15.1:1, although TKN levels were so low in July and August they were undetectable. This average ratio is comparable to 2003, 2004, 2006. Black Lake TN:TP ratios were slightly low when compared to the 2002–2009 average (9.2:1), but higher than average ratios observed in 2009 (3.5:1). Low TN:TP ratios also occurred in 2003 (6.1:1) and 2007 (5.1:1).

The quantity of photopigments present in an aquatic system is related to the biomass of primary producers and the potential production level of the system. The ratio of chlorophyll *a* (associated with active cells) to phaeophytin a (the byproduct of photosynthesis associated with senescent cells) serves as an indicator of the algal community condition. High chlorophyll-*a* to phaeophytin-*a* ratios indicate there are adequate nutrients and suitable physical conditions for primary production within the lake. Conversely, low ratios may suggest that primary productivity is taxed. A comparison of the photosynthetic pigment, chlorophyll *a*, to its byproduct, phaeophytin *a*, showed that chlorophyll *a* concentrations were low in both lakes compared to recent years (seasonal mean of 1.8 chlorophyll *a* to 1 phaeophytin *a* in Chignik Lake and 1.9 chlorophyll *a* to 1 phaeophytin *a* in Black Lake). These ratios are similar to conditions observed from 2000 to 2002 and in contrast to recent trends in the watershed (2003–2009 average: 4.1 chlorophyll *a* to 1 phaeophytin *a*). A high percentage of cloud cover throughout the season, as well as heavy rains which caused increased turbidity in Chignik Lake in August may have contributed to these conditions. Changes in nutrients and forage bases can significantly impact higher trophic levels such as secondary or tertiary consumers (Kyle et al. 1988; Milovskaya et al. 1998). For the Chignik watershed, these negative changes could cause migratory behavior or decreased juvenile sockeye salmon freshwater survival (Parr 1972; Ruggerone 1994; Bouwens and Finkle 2003). Thus, it is important to know and understand patterns of resource abundance and habitat usage in the watershed if the carrying capacities for each lake are to be estimated.

The seasonal pH levels in Black Lake remained consistent with observations from recent years; slightly higher than seasonal averages from the 1960s (1960s Black Lake seasonal average pH = 7.42) while pH levels in Chignik Lake were the lowest recorded since 2000, and similar to historic values (1960s Chignik Lake seasonal average pH = 7.27; Narver 1966). The current levels are well within a safe pH range of roughly 4.5 to 9.5 (Wetzel 1983). Higher pH in 2004–2006 may have been the result of predation on zooplankton from increased densities of juvenile fish, which in turn resulted in increased phytoplankton production. The decreased grazing pressure by zooplankton allows phytoplankton biomass to increase and remove greater quantities of carbon dioxide from the water through photosynthesis, increasing the overall level of pH in each lake. In contrast, the apparent low phytoplankton biomass in Chignik Lake as a result of cool temperatures and increased turbidity may have contributed to the low pH levels there.

MARINE SURVIVAL ESTIMATES AND RUN FORECASTING

All adult sockeye salmon offspring from BYs 1991 through 2002 and most offspring from BY 2003 have returned to the Chignik River watershed, and the overall marine survival of smolt ranged from 6% for BY 1999 to 67% for BY 1993 (mean survival 19%, Table 6). The estimation of the 1993 and 1994 BY marine survival includes a portion of the emigration estimate from 1996, which is considered erroneous (Edwards and Bouwens 2002). When the data were presented by emigration year, however, marine survivals ranged from 5% for emigration year 2001 to 32% for emigration year 2005, with a mean survival rate of 17% (Table 7).

FORECASTS OF ADULT SALMON RETURNS

A formal forecast for the early and late 2011 adult runs was estimated by age class based on sibling ocean age-class relationships, smolt emigration estimates, and median values when sibling relationships did not exist. Using these methods, the 2011 Chignik sockeye salmon forecast is 2.32 million (Eggers and Carroll 2011).

Ocean-age-class relationships and smolt emigration estimates were analyzed for the late-run forecast and added to median return estimates of other age classes for a late run forecast of 1.02 million sockeye salmon.

Additionally, in keeping with past years of forecasting, a simple regression model was developed to forecast the 2011 total adult run using smolt emigration data. The regression relationship using outmigrant age-2. smolt and 3-ocean adult returns was statistically significant ($P = 0.007$) and accounted for 82% of the total return. The 2011 smolt-based forecast of 1.86 million sockeye salmon is approximately 465,000 fewer fish than was forecasted in the formal forecast.

A smolt-based forecast has been developed annually since 2002. Since its inception, the smolt-based forecast has overestimated the actual total sockeye salmon adult return to the Chignik watershed by as much as 107% (2004 forecast) and underestimated it by as little as 9% (2003 forecast). 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 against ocean-age class adult returns. Forecast accuracy varies annually with no clear pattern of under- or over-forecasting by either sibling temperature relationships or smolt linear regression techniques.

The smolt forecasting method does not have the resolution to forecast by run because we have not yet determined the stock-of-origin of the smolt. However, current genetic analyses may provide a basis for Chignik sockeye salmon smolt stock separation. Genetic samples collected in 2006–2008 were analyzed by a graduate student. A grant from Alaska Sustainable Salmon Fund has allowed analysis of samples from 2009 to 2010, with the study to continue through 2012. Genetic analyses of the Chignik sockeye salmon smolt emigration lend themselves to stock-based smolt forecasts in addition to providing information on stock-specific life history traits of rearing and emigrating juveniles.

Additionally, a presentation describing the sockeye salmon life cycle and the Chignik Sockeye Salmon Smolt Enumeration project was given to students in Perryville, Chignik Bay, and

Chignik Lake. The goal of the presentation was to relay the value of the smolt project and foster stewardship in students for their resource and to help them learn about resource sustainability, as well as encourage participation in a student internship. A student internship involving a Chignik Lake high school student took place in June and July 2010. By actively promoting community youth involvement, it is hoped the smolt project can foster a sense of inclusion in the many research and management projects the department oversees in the Chignik watershed.

CONCLUSION

The continued collection of smolt emigration data aids with investigations of changes in life history strategies in the Chignik watershed caused by changes in environmental conditions, such as those seen in Black Lake. Reductions in Black Lake water volume and rearing habitat have occurred simultaneously with warmer water temperatures since the 1970s. Timing of Black Lake emigration has shifted earlier in the summer relative to 1970s timing (Westley et al. 2008). Chignik Lake species composition has shifted since the 1960s (Westley et al. 2009) to encompass a greater diversity and more even proportions of non-sockeye species. Competition between Black Lake emigrants and Chignik Lake smolt has been demonstrated (Parr 1972; Ruggerone 2003). Top-down pressures on the Chignik Lake zooplankton community may be caused by over-grazing from rearing sockeye salmon, and likely due to the downstream migration of Black Lake juveniles and increased use of Chignik Lake resources.

ADF&G has conducted the smolt enumeration project since 1994 and in 2008 formally incorporated the collection of valuable limnological samples from both lakes. When smolt enumeration and limnological data are combined, they provide a means to investigate life history changes in emigrating juvenile sockeye salmon, levels of primary and secondary production, and watershed health as an indicator of habitat available for rearing salmon. These data have proven instrumental for enhancing management of the system, such as targeting the lower ends of the escapement goals in light of overescapement and decreased rearing habitat in Black Lake. Genetic samples collected from emigrating sockeye salmon smolt will also provide a better understanding of ecological events in the watershed. Data from this project are essential for monitoring the health of sockeye salmon in Chignik River watershed because smolt emigration information may be the only available means to link changes in run strength to freshwater or marine influences or climate change.

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TABLES AND FIGURES

Table 1.–Chignik River sockeye salmon smolt population estimates, by age class, 1994 to 2010.

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

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Table 1.–Page 2 of 2.

Year		Number of Smolt							95% C.I.	
		Age-0.	Age-1.	Age-2.	Age-3.	Age-4.	Total	S.E.	Lower	Upper
2005	Numbers	859,211	2,075,681	1,468,208	32,889	0	4,435,988	1,034,892	2,407,600	6,464,376
	Percent	19.4	46.8	33.1	0.7	0.0	100.0			
2006	Numbers	1,744,370	2,849,043	2,847,624	119,614	0	7,560,651	2,280,536	3,090,799	12,030,502
	Percent	23.1	37.7	37.7	1.6	0.0	100.0			
2007	Numbers	9,286	1,926,682	1,028,865	0	0	2,964,833	969,567	1,064,482	4,865,184
	Percent	0.6	74.4	25.0	0.0	0.0	100.0			
2008	Numbers	1,017,498	3,309,894	987,928	41,136	0	5,356,455	605,266	4,170,134	6,542,777
	Percent	19.0	61.8	18.4	0.8	0.0	100.0			
2009	Numbers	110,446	3,777,572	4,288,491	0	0	8,176,509	320,013	7,472,166	8,880,852
	Percent	1.4	46.2	52.4	0.0	0.0	100.0			
2010	Numbers	1,039,131	17,684,165	9,347,999	91,509	0	28,162,803	4,433,289	19,473,557	36,852,050
	Percent	7.7	69.9	22.3	0.1	0.0	100.0			

Table 2.–Estimated sockeye salmon smolt emigration from the Chignik River in 2010 by age class and statistical week.

Statistical Week	Week	Number of Smolt age-0.	%	age-1.	%	age-2.	%	age -3.	%	Total
20	5/16	28,206	5%	246,836	44%	283,074	51%	0	-	558,117
21	5/23	81,959	1%	2,756,527	43%	3,520,699	55%	42,023	1%	6,401,208
22	5/30	507,599	7%	2,983,572	44%	3,262,844	48%	49,486	1%	6,803,501
23	5/31- 6/6	70,957	1%	3,790,696	73%	1,296,040	25%	0	-	5,157,692
24	6/7- 6/13	131,397	2%	4,380,036	81%	868,301	16%	0	-	5,379,734
25	6/14- 6/20	24,986	1%	1,926,728	95%	71,504	4%	0	-	2,023,218
26	6/21- 6/27	117,508	12%	857,732	87%	10,251	1%	0	-	985,491
27	6/28- 7/4	55,054	7%	659,662	88%	34,575	5%	0	-	749,291
28	7/5- 7/9	21,465	21%	82,376	79%	711	1%	0	-	104,552
Total		1,039,131	4%	17,684,165	63%	9,347,999	33%	91,509	0.3%	28,162,803

Table 3.–Results from mark-recapture tests performed on sockeye salmon smolt migrating through the Chignik River, 2010.

Date	No. Marked	Total Recaptures	Trap Efficiency[a]
5/16-5/24	2,220	5	0.30%
5/25-5/29	2,332	6	0.32%
5/30- 6/3	2,556	5	0.36%
6/4- 6/8	2,175	15	1.02%
6/9- 6/13	2,395	8	0.48%
6/14- 6/19	2,347	8	0.51%
6/20- 6/26	2,171	5	0.29%
6/26- 7/9	772	1	0.28%
Total	16,968	53	0.45%

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

Table 4.–Length, weight, and condition factor of Chignik River sockeye salmon smolt samples in 2010, by age and statistical week.

				Length (mm)		Weight (g)		Condition Factor	
Age	Stat Week	Starting Date	Sample Size	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
0	20	5/10	8	51	1.52	0.8	0.05	0.64	0.02
0	21	5/17	6	60	4.03	1.7	0.40	0.69	0.04
0	22	5/24	17	49	0.59	0.8	0.03	0.63	0.01
0	23	5/31	4	56	5.65	1.3	0.51	0.66	0.10
0	24	6/7	6	49	1.10	0.8	0.07	0.63	0.04
0	25	6/14	2	65	1.00	2.0	0.05	0.75	0.05
0	26	6/21	30	53	0.88	1.3	0.06	0.83	0.02
0	27	6/28	17	55	1.41	1.4	0.12	0.82	0.03
0	28	7/5	38	55	0.43	1.4	0.04	0.85	0.02
Total			128	54	0.48	1.2	0.04	0.78	0.01
1	20	5/10	50	74	1.09	2.9	0.13	0.69	0.01
1	21	5/17	103	74	0.45	3.0	0.06	0.74	0.01
1	22	5/24	84	72	0.67	2.7	0.08	0.72	0.01
1	23	5/31	137	70	0.35	2.5	0.04	0.73	0.01
1	24	6/7	163	69	0.44	2.4	0.05	0.71	0.01
1	25	6/14	190	70	0.36	2.7	0.05	0.77	0.00
1	26	6/21	168	67	0.44	2.4	0.05	0.78	0.01
1	27	6/28	172	69	0.37	2.7	0.04	0.82	0.01
1	28	7/5	138	64	0.48	2.1	0.05	0.80	0.01
Total			1205	69	0.17	2.6	0.02	0.76	0.00
2	20	5/10	62	85	0.66	4.4	0.11	0.71	0.01
2	21	5/17	89	83	0.48	4.3	0.08	0.75	0.00
2	22	5/24	96	81	0.44	4.1	0.07	0.75	0.00
2	23	5/31	59	77	0.66	3.4	0.09	0.73	0.01
2	24	6/7	31	78	0.92	3.6	0.16	0.74	0.01
2	25	6/14	8	79	3.56	4.1	0.87	0.78	0.03
2	26	6/21	2	78	2.50	3.9	0.05	0.83	0.07
2	27	6/28	11	76	1.45	3.7	0.24	0.82	0.02
2	28	7/5	1	76	0.00	3.7	0.00	0.84	0.00
Total			359	81	0.30	4.0	0.05	0.74	0.00
3	21	5/17	1	90	0	5.6	0	0.77	0
3	22	5/24	1	93	0	6.3	0	0.78	0
Total			2	92	0	6.0	0.35	0.78	0.008

Table 5.–Mean length, weight, and condition factor of sockeye salmon smolt samples from the Chignik River, year and age, 1994–2010.

		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	1.20	0.04	128	0.78	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
1994	2	1,091	77	0.22	1,068	3.6	0.04	1,068	0.74	0.00
1995	2	1,008	75	0.23	1,008	3.5	0.04	1,008	0.80	0.00
1996	2	548	80	0.34	533	4.2	0.06	533	0.81	0.00
1997	2	772	83	0.25	772	4.7	0.05	772	0.80	0.00
1998	2	1,925	72	0.13	1,881	3.0	0.03	1,881	0.76	0.00
1999	2	784	81	0.28	784	4.8	0.07	784	0.89	0.00
2000	2	503	76	0.34	503	3.6	0.07	503	0.80	0.00
2001	2	389	75	0.45	387	3.4	0.09	387	0.77	0.01
2002	2	225	80	0.78	225	4.9	0.18	225	0.88	0.01
2003	2	279	76	0.48	279	3.5	0.09	279	0.76	0.01
2004	2	274	77	0.41	274	3.9	0.09	274	0.82	0.00
2005	2	397	76	0.33	397	3.5	0.06	397	0.79	0.00
2006	2	518	78	0.35	518	3.8	0.08	518	0.78	0.00
2007	2	272	90	0.36	272	6.6	0.09	272	0.91	0.00
2008	2	288	79	0.35	287	3.7	0.06	287	0.73	0.01
2009	2	413	80	0.31	411	4.0	0.05	411	0.76	0.00
2010	2	359	81	0.3	359	4.0	0.05	359	0.74	0.00

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Table 5.–Page 2 of 2.

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

Table 6.–Chignik River sockeye salmon escapement, estimated number of smolt by freshwater age, smolt per spawner, adult return by freshwater age, return per spawner, and marine survival, by brood year, from 1991 to 2010.

Brood Year	Escapement	Smolt Produced Age-0.	Age-1.	Age-2.	Age-3.	Total Smolt	Smolt / Spawner	Adult Returns Age-0.	Age-1.	Age-2.	Age-3.	Total	Return / Spawner	Marine Survival
1991	1,040,098	NA	NA	4,270,636	0	4,270,636	4.11	6,868	1,795,467	737,680	11,621	2,551,636	2.45	NA
1992	764,436	NA	7,263,054	5,178,450	5,018	12,446,522	16.28	152,005	649,920	1,159,871	93,372	2,055,168	2.69	17%
1993	697,377	0	2,843,222	731,099	122,289	3,696,610	5.30	16,270	457,189	1,998,416	7,265	2,479,140	3.55	67%
1994	966,909	735,916	1,200,793	13,738,356	158,056	15,833,121	16.37	251	1,818,410	1,483,548	2,467	3,304,676	3.42	21%
1995	739,920	80,254	11,172,150	20,374,245	78,798	31,705,447	42.85	36,053	2,391,218	942,680	17,366	3,387,317	4.58	11%
1996[a]	749,137	528,846	5,790,587	8,221,631	160,017	14,701,081	19.63	145,189	1,998,842	877,180	13,958	3,035,168	4.05	21%
1997	775,618	75,560	12,705,935	4,645,121	516,723	17,943,339	23.13	15,852	770,645	956,005	5,627	1,748,129	2.25	10%
1998	701,128	73,364	8,047,526	5,024,666	72,184	13,217,740	18.85	5,515	1,030,709	350,167	1,052	1,387,443	1.98	10%
1999	715,966	1,270,101	18,940,752	2,223,996	0	22,434,849	31.34	26,176	913,849	403,536	1,663	1,345,224	1.88	6%
2000	805,225	521,546	13,980,423	1,449,494	0	15,951,463	19.81	15,176	1,988,373	699,285	2,729	2,705,565	3.36	17%
2001	1,136,918	440,947	5,146,278	2,239,716	32,889	7,859,830	6.91	78,019	1,031,100	696,415	482	1,807,624	1.59	23%
2002	725,220	155,047	6,172,902	1,468,208	119,614	7,915,771	10.91	17,633	700,976	412,758	2,079	1,136,292	1.57	14%
2003	684,145	244,206	2,075,681	2,847,624	0	5,167,511	7.55	84,284	875,278	736,979	3,227	691,350	1.01	13%
2004	578,259	859,211	2,849,043	1,028,865	41,136	4,778,255	8.26							
2005	581,382	1,744,370	1,926,682	987,928	0	4,658,980	8.01							
2006	735,493	9,286	3,309,894	4,874,340	91,509	8,285,029	11.3							
2007	654,974	1,017,498	3,242,862	9,347,999		13,608,359								
2008	706,058	59,306	17,684,165											
2009	720,062	1,039,131												
2010	743,911													
1994-2003 Average, excluding 1996														19%

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

Table 7.–Estimated marine survival of sockeye salmon smolt from the Chignik River by emigration year and ocean age adult returns for each emigration year from 1994 to 2010.

Emigration	Smolt estimates					Adult returns					Marine
Year	Age-0.	Age-1.	Age-2.	Age-3.	Total	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*	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	1,419,540	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			
2008	1,017,498	3,309,894	987,928	41,136	5,356,455	1,734	337,732				
2009	59,306	3,242,862	4,874,340	0	8,176,508	6,022					
2010	1,039,131	17,684,165	9,347,999	91,509	28,162,804						
1994-2006 Average, Excluding 1996											17%

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

Table 8.–Black Lake water temperature (°C) and DO (mg/L) by depth and date, 2010.

Depth	Temperature (°C)				Dissolved oxygen (mg/L)			
(m)	31-May	28-Jun	10-Jul	20-Aug	31-May	28-Jun	10-Jul	20-Aug
0.0	9.4	11.7	12.6	13.2	11.7	10.4	9.8	10.7
0.5	9.5	11.7	12.6	13.0	12.0	10.4	9.8	10.9
1.0	9.4	11.6	12.6	12.3	11.5	10.4	9.8	10.9
1.5	9.3	11.6	12.6	12.2	11.5	10.3	9.8	10.7
2.0	9.1	11.6	12.6	12.2	11.5	10.2	9.8	10.5
2.5	9.0	11.5	12.5	12.1	11.4	10.2	9.8	10.4
3.0	8.5		12.5		11.5		9.8	
3.5							9.6	
4.0								

Table 9.–Chignik Lake water temperature (°C) and DO (mg/L) averaged over all stations by depth and date in 2010.

Depth	Temperature (°C)				Dissolved oxygen (mg/L)			
(m)	21-May	19-Jun	1-Jul	19-Aug	21-May	19-Jun	1-Jul	19-Aug
0.0	3.6	7.3	8.9	11.2	10.9	12.9	11.1	10.5
0.5	3.4	7.2	8.7	11.2	12.4	12.4	11.2	10.4
1.0	3.4	7.2	8.5	11.2	10.1	12.2	11.2	10.4
1.5	3.3	7.2	8.4	11.2	8.8	12.1	11.2	10.4
2.0	3.3	7.1	8.3	11.2	8.0	12.1	11.2	10.4
2.5	3.3	7.0	8.3	11.2	7.5	12.0	11.2	10.4
3.0	3.3	7.0	8.3	11.2	7.1	11.9	11.2	10.4
3.5	3.3	6.9	8.2	11.2	7.0	12.0	11.2	10.4
4.0	3.3	6.9	8.2	11.2	7.5	12.0	11.2	10.4
4.5	3.3	6.8	8.2	11.2	7.7	11.9	11.2	10.4
5.0	3.3	6.8	8.2	11.2	7.4	11.8	11.2	10.4
6.0	3.3	6.8	8.2	11.2	8.0	11.9	11.2	10.3
7.0	3.3	6.7	8.2	11.2	8.1	37.9	11.1	10.3
8.0	3.3	6.7	8.2	11.2	7.5	11.8	11.1	10.3
9.0	3.3	6.7	8.1	11.2	7.1	11.8	11.1	10.3
10.0	3.3	6.7	8.1	11.2	6.8	11.7	11.1	10.3
11.0	3.3	6.7	8.1	11.2	6.3	11.8	11.1	10.3
12.0	3.3	6.7	8.1	11.2	7.4	11.8	11.1	10.3
13.0	3.3	6.7	8.1	11.2	7.1	11.8	11.0	10.3
14.0	3.3	6.7	8.1	11.2	7.0	11.7	11.0	10.3
15.0	3.3	6.7	8.0	11.2	6.9	11.8	11.0	10.3
16.0	3.3	6.7	8.0	11.2	6.7	11.8	11.0	10.3
17.0	3.3	6.7	8.0	11.2	6.5	11.8	11.0	10.3
18.0	3.3	6.7	8.0	11.2	6.3	11.8	11.0	10.3
19.0	3.3	6.7	8.0	11.2	6.1	11.7	10.9	10.2
20.0	3.3	6.7	8.0	11.2	5.6	11.8	10.9	10.2
21.0	3.3	6.7	8.0	11.2	5.3	11.7	10.9	10.2
22.0	3.3	6.7	8.0	11.2	5.2	11.7	10.9	10.2
23.0	3.3	6.7	8.0	11.2	4.9	11.7	10.9	10.2
24.0	3.3	6.7	8.0	11.2	4.8	11.7	10.9	10.2
25.0	3.3	6.7	8.0	11.2	4.5	11.7	10.8	10.2
30.0	3.3	6.6	8.0	11.2	4.2	11.6	10.8	10.1
35.0		6.6	8.0	11.2		11.7	10.7	10.1
40.0		6.6	7.9	11.2		11.4	10.5	10.0
45.0		6.6	7.7	11.1		11.4	10.3	10.0
50.0		6.5	7.6	11.2		11.2	9.2	9.9

Table 10.–Euphotic Zone Depth (EZD) and Euphotic Volume (EV) of Black and Chignik lakes, by month, 2010.

		2010				
Lake		May	June	July	August	Average[a]
Black[b]	EZD	3.82	3.98	4.34	3.05	3.48
	Mean EV[c]	157.1	163.7	178.5	125.4	143.2
Chignik	EZD	4.41	11.72	10.28	4.41	10.69
	Mean EV[c]	106.3	282.4	247.8	106.2	257.7

[a] Averages calculated from mean light reading (kLux) data.

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

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

Table 11.–Average monthly solar illuminance readings by depth and month for Chignik Lake, 2010.

	Solar illuminance (kLux)				
Depth	May	June	July	August	Average
0.0	2,919	3,144	5,060	1,904	3,707
0.5	2,251	2,463	3,251	1,059	2,655
1.0	1,651	3,025	2,734	560	2,470
1.5	1,299	2,112	1,809	318	1,740
2.0	1,008	1,545	1,470	180	1,341
2.5	836	1,370	1,292	99	1,166
3.0	660	1,072	1,054	62	929
3.5	532	922	877	38	777
4.0	408	777	680	22	622
4.5	332	651	535	13	506
5.0	265	573	430	8	423
6.0	172	376	275	4	274
7.0	112	235	182	1	176
8.0	76	109	115	1	100
9.0	50	71	75	0	65
10.0	33	97	47	-	59
11.0	29	49	31	-	36
12.0	19	29	20	-	23
13.0	-	21	16	-	18
14.0	-	20	13	-	17
15.0	-	9	9	-	9
16.0	-	9	7	-	8
17.0	-	6	-	-	6

Table 12.–Water quality parameters, nutrient concentrations, and photosynthetic pigments by sample date for Black Lake, 2010.

	2010				
	31-May	28-Jun	10-Jul	20-Aug	Average[a]
pH	8.0	7.8	7.7	7.6	7.8
Alkalinity (mg/L)	18.0	22.0	24.0	24.0	22.0
Total P (µg/L P)	37.3	23.0	29.5	29.5	29.8
TKN (µg/L N)	185.0	212.0	174.0	272.0	210.8
Ammonia (µg/L N)	8.7	5.6	7.6	3.5	6.4
Nitrate + Nitrite (µg/L N)	0.9	0.3	2.3	0.3	1.0
Chlorophyll *a* (µg/L)	3.9	2.5	2.3	2.6	2.8
Phaeophytin *a* (µg/L)	1.6	1.5	1.6	1.3	1.5

[a] Averaged values do not always exactly match the values reported in Appendix F due to rounding.

Table 13.–Water-quality parameters, nutrient concentrations, and photosynthetic pigments by sample date for Chignik Lake, 2010. All stations and depths are averaged for each sample date.

	2010				
	21-May	19-Jun	1-Jul	19-Aug	Average[a]
pH	7.4	7.3	7.3	6.9	7.2
Alkalinity (mg/L)	21.8	19.6	19.6	19.1	20.0
Total P (µg/L P)	10.7	14.5	9.7	19.4	13.6
TKN (µg/L N)[b]	40.0	49.0	<20	<20	44.5
Ammonia (µg/L N)[b]	5.4	6.6	5.3	9.7	6.8
Nitrate + Nitrite (µg/L N)	209.5	162.5	133.4	112.2	154.4
Chlorophyll *a* (µg/L)	1.8	1.4	1.3	1.4	1.5
Phaeophytin *a* (µg/L)	1.0	1.0	0.5	0.8	0.8

[a] Averaged values do not always exactly match the values reported in Appendix F due to rounding.

Table 14.–Average number of zooplankton by taxon per m^2 from Black Lake by sample date, 2010.

Taxon	Sample date				Seasonal
	31-May	28-Jun	10-Jul	20-Aug	average
Copepods					
Epischura	796	6,635	6,170	3,715	4,329
Diaptomus	-	1,327	9,554	265	3,715
Ovig. Diaptomus	-	-	597	-	597
Eurytemora	-	-	-	796	796
Cyclops	1,327	12,473	26,274	33,174	18,312
Ovig. Cyclops	-	-	-	265	265
Harpaticus	-	-	597	-	597
Nauplii	2,654	22,824	13,137	13,270	12,971
Total copepods	4,777	43,259	56,330	51,486	38,963
Cladocerans					
Bosmina	265	5,839	59,912	48,567	28,646
Ovig. Bosmina	-	1,327	25,478	2,919	9,908
Total cladocerans	265	7,166	85,390	51,486	36,077
Total copepods + cladocerans	5,042	50,425	141,720	102,972	75,040

Table 15.–Biomass estimates (mg dry weight/m^2) of the major Black Lake zooplankton taxa by sample date, 2010.

Taxon	Sample date				Seasonal average	Weighted average
	31-May	28-Jun	10-Jul	20-Aug		
Copepods						
Epischura	1.9	4.4	3.3	2.8	3.1	3.0
Diaptomus	-	4.1	23.7	0.4	9.4	7.1
Ovig. Diaptomus	-	-	4.6	-	4.6	1.2
Eurytemora	-	-	-	5.0	5.0	1.0
Cyclops	1.0	10.3	24.0	15.7	12.8	12.5
Ovig. Cyclops	-	-	-	1.5	1.5	0.4
Harpaticus	-	-	0.4	-	0.4	0.1
Total copepods	2.9	18.8	56.1	25.5	25.8	25.1
Cladocerans						
Bosmina	0.2	4.1	46.6	49.7	25.1	25.0
Ovig. *Bosmina*	-	2.7	41.9	4.5	16.4	12.3
Holopedium	3.1	-	-	-	3.1	0.8
Total cladocerans	3.3	6.8	88.6	54.2	38.2	38.1
Total Biomass	6.2	25.6	144.7	79.6	64.0	63.1

Table 16.–Average length (mm) of zooplankton in Black Lake by sample date, 2010.

Taxon	Sample date				Seasonal average
	31-May	28-Jun	10-Jul	20-Aug	
Copepods					
Epischura	0.80	0.51	0.47	0.53	0.58
Diaptomus	-	0.89	0.82	0.70	0.81
Ovig. Diaptomus	-	-	1.23	-	1.23
Eurytemora	-	-	-	1.05	1.05
Cyclops	0.49	0.50	0.53	0.39	0.48
Ovig. Cyclops	-	-	-	1.24	1.24
Harpaticus	-	-	0.44	-	0.44
Cladocerans					
Bosmina	0.27	0.28	0.30	0.34	0.30
Ovig. *Bosmina*	-	0.47	0.42	0.41	0.43
Ovig. *Holopedium*	1.01	-	-	-	1.01

Table 17.–Average number of zooplankton by taxon per m^2 from Chignik Lake, by sample date, 2010.

Taxon	Sample date 21-May	19-Jun	1-Jul	19-Aug	Seasonal average
Copepods					
Epischura	531	3,938	9,282	26,805	10,139
Diaptomus	-	14,139	16,010	100,783	32,733
Ovig. *Diaptomus*	-	1,146	2,654	3,981	1,945
Eurytemora	-	-	-	8,891	2,223
Cyclops	85,191	72,058	101,310	112,460	92,755
Ovig. *Cyclops*	-	-	1,964	13,071	3,759
Harpaticus	663	629	557	2,123	993
Nauplii	20,170	21,890	38,489	59,713	35,065
Total copepods	106,555	113,800	170,266	327,826	179,612
Cladocerans					
Bosmina	708	3,369	5,295	149,416	39,697
Ovig. *Bosmina*	-	987	1,755	11,744	3,621
Daphnia l.	5,573	722	1,357	26,871	8,631
Ovig. *Daphnia l.*	663	1,030	531	5,242	1,866
Total cladocerans	6,944	6,108	8,937	193,272	53,815
Total Copepods + Cladocerans	113,500	119,908	179,203	521,099	233,427

Table 18.–Biomass estimates (mg dry weight/m^2) of the major zooplankton species in Chignik Lake by sample date, 2010.

Taxon	Sample date 21-May	19-Jun	1-Jul	19-Aug	Seasonal average	Weighted average
Copepods						
Epischura	0.6	8.5	15.8	39.5	16.1	8.1
Diaptomus	-	58.0	60.7	305.8	106.1	101.1
Ovig. *Diaptomus*	-	15.5	13.3	25.8	13.7	9.4
Eurytemora	-	-	-	15.3	3.8	8.2
Cyclops	138.8	187.4	329.7	223.7	219.9	123.4
Ovig. *Cyclops*	-	-	7.1	80.2	21.8	20.6
Harpaticus	0.6	0.5	0.5	1.3	0.7	0.4
Total Copepods	140.0	269.9	427.2	691.6	382.2	271.2
Cladocerans						
Bosmina	0.7	3.2	4.8	139.2	37.0	32.1
Ovig. *Bosmina*	-	1.9	1.8	13.6	4.3	5.5
Daphnia l.	9.0	0.8	1.3	32.3	10.9	12.0
Ovig. *Daphnia l.*	1.1	2.8	0.8	15.5	5.1	5.6
Total Cladocerans	10.8	8.7	8.7	200.7	57.2	55.2
Total Biomass	150.8	278.6	435.9	892.3	439.4	326.4

Table 19.–Average length (mm) of zooplankton from Chignik Lake by sample date, 2010.

Taxon	Sample date 21-May	19-Jun	1-Jul	19-Aug	Seasonal average
Copepods					
Epischura	0.63	0.61	0.57	0.52	0.57
Diaptomus	-	0.96	0.96	0.87	0.93
Ovig. *Diaptomus*	-	1.50	1.45	1.28	1.34
Eurytemora	-	-	-	0.94	1.00
Cyclops	0.52	0.67	0.67	0.56	0.61
Ovig. *Cyclops*	-	1.03	0.96	1.09	1.03
Harpaticus	-	-	-	0.42	0.45
Cladocerans					
Bosmina	0.34	0.32	0.33	0.32	0.33
Ovig. *Bosmina*	-	0.47	0.43	0.41	0.44
Daphnia l.	0.60	0.43	0.48	0.53	0.48
Ovig. *Daphnia l.*	0.96	0.84	0.85	0.90	0.86

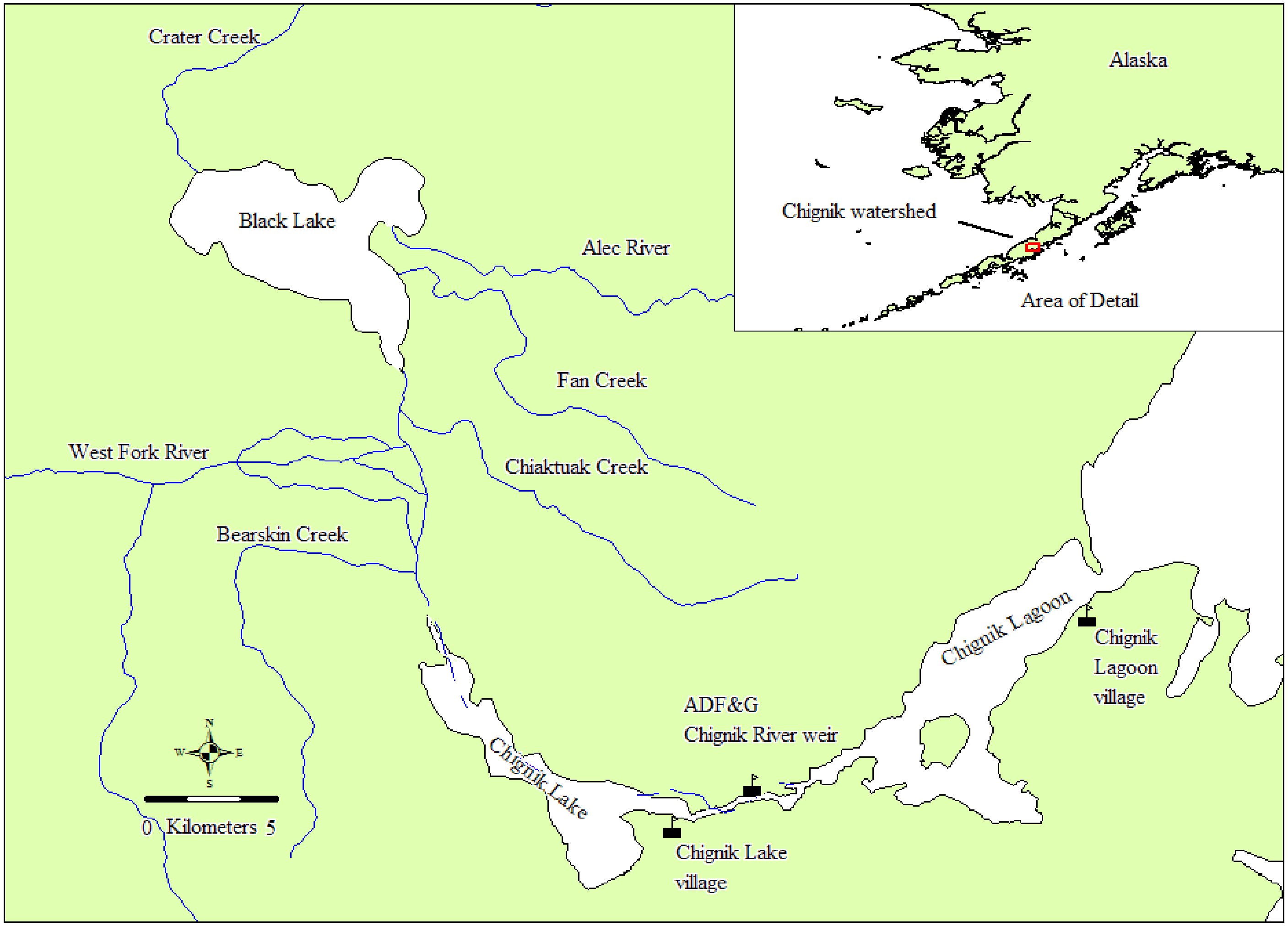

Figure 1.–Map of the Chignik River watershed.

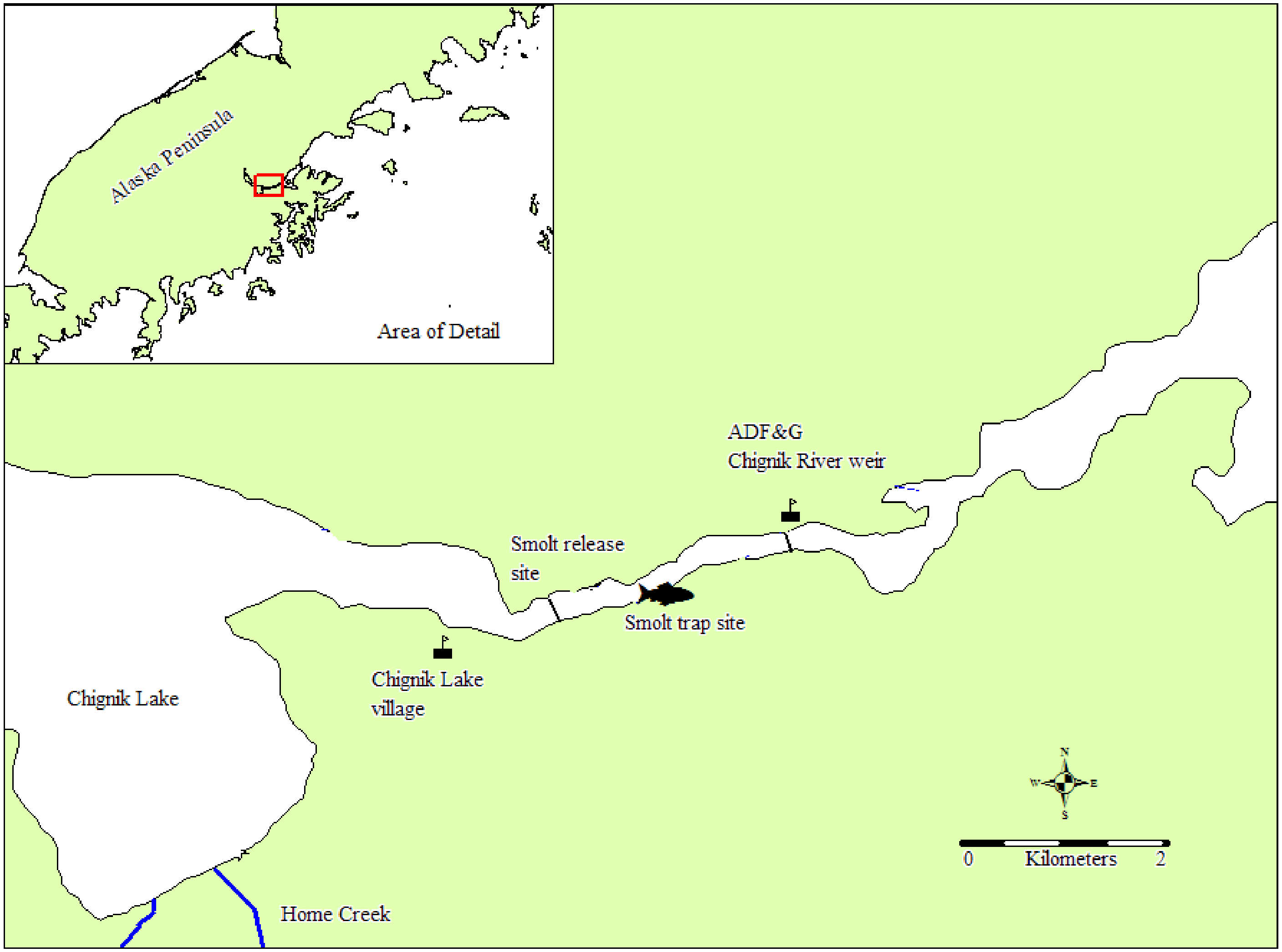

Figure 2.–Location of the traps and the release site of marked smolt in the Chignik River, Alaska, 2010.

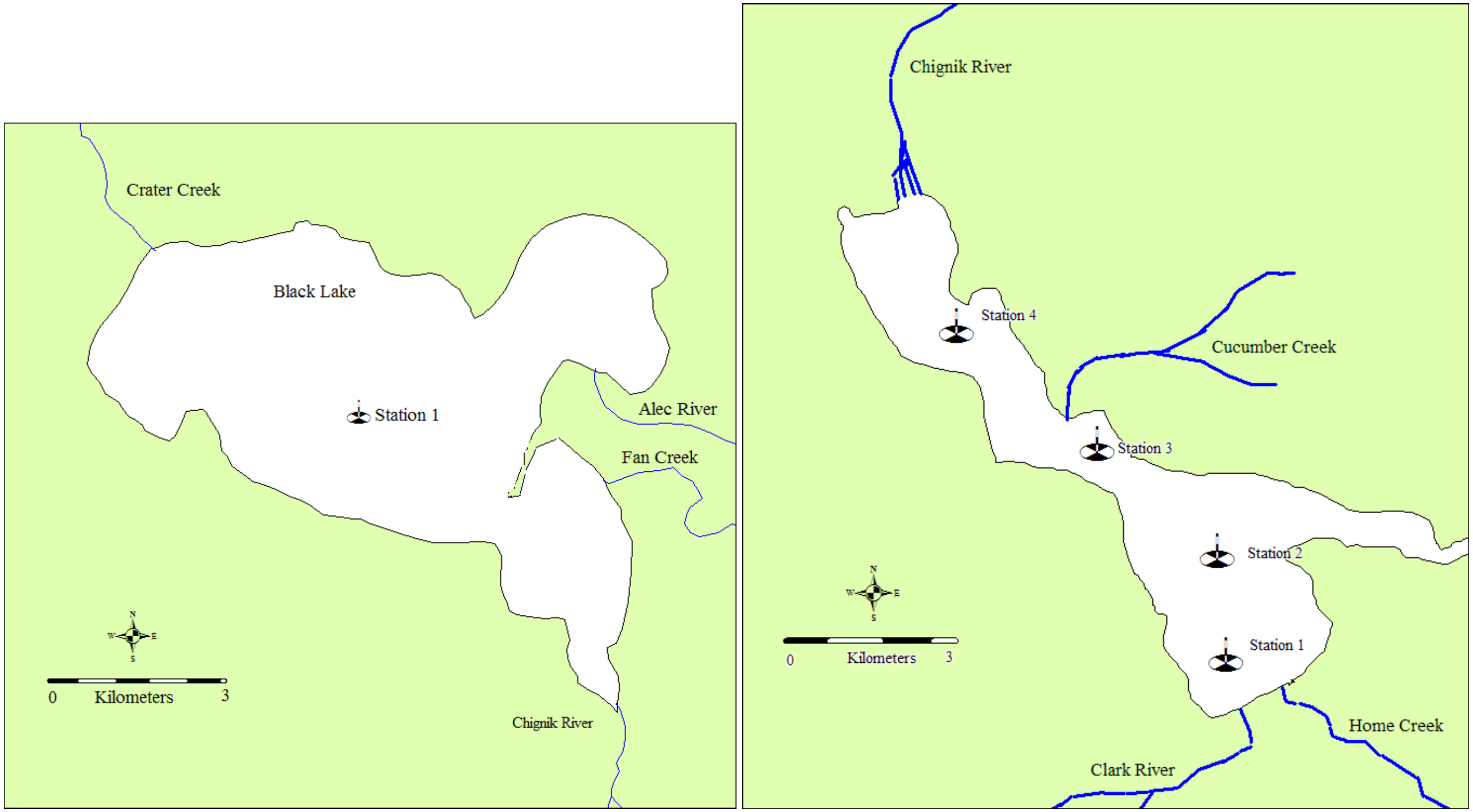

Figure 3.–Location of the Black Lake and Chignik Lake limnology sampling stations, 2010.

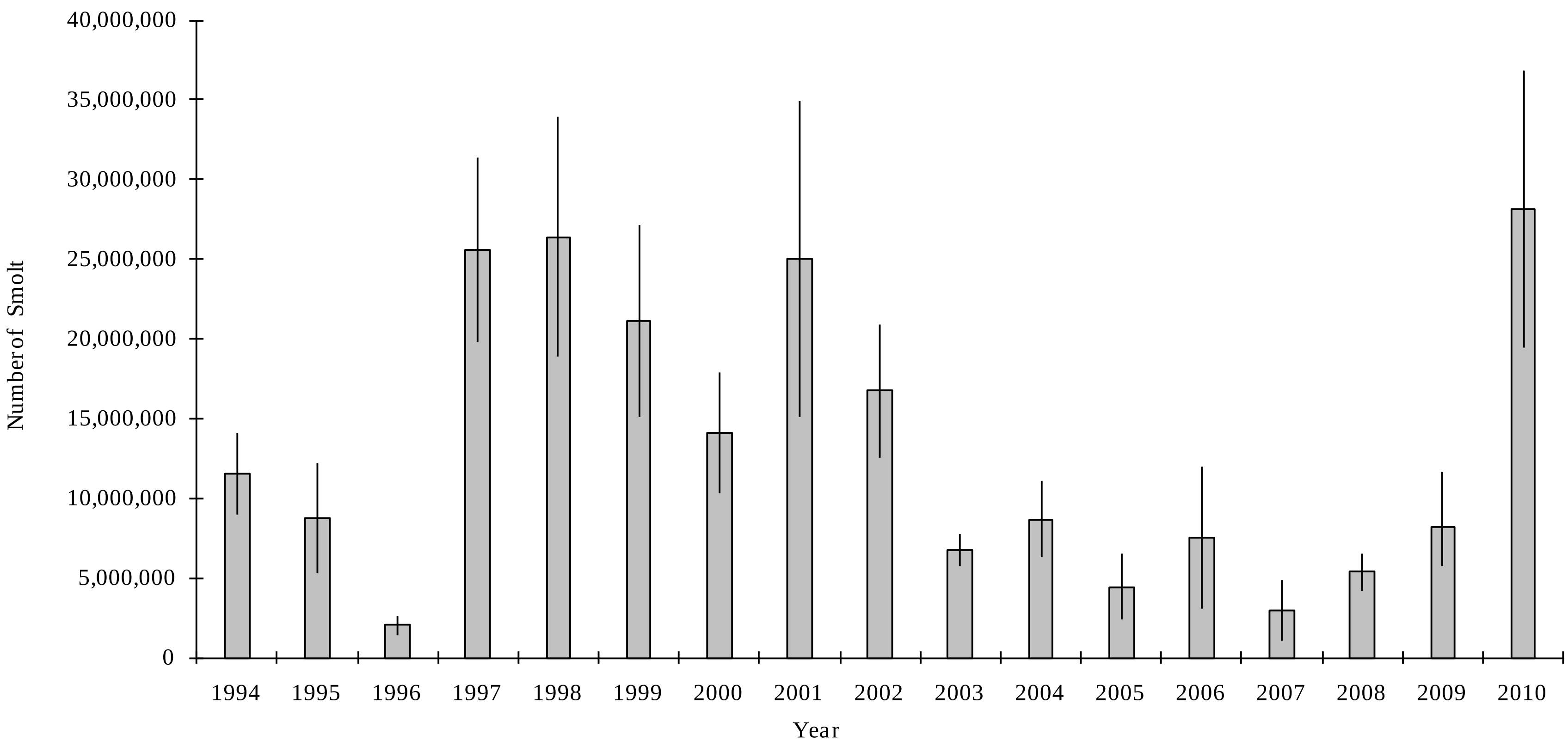

Figure 4.–Annual sockeye salmon smolt emigration estimates and corresponding 95% confidence intervals, Chignik River, 1994–2010. Emigration estimates from 1996 were underestimated.

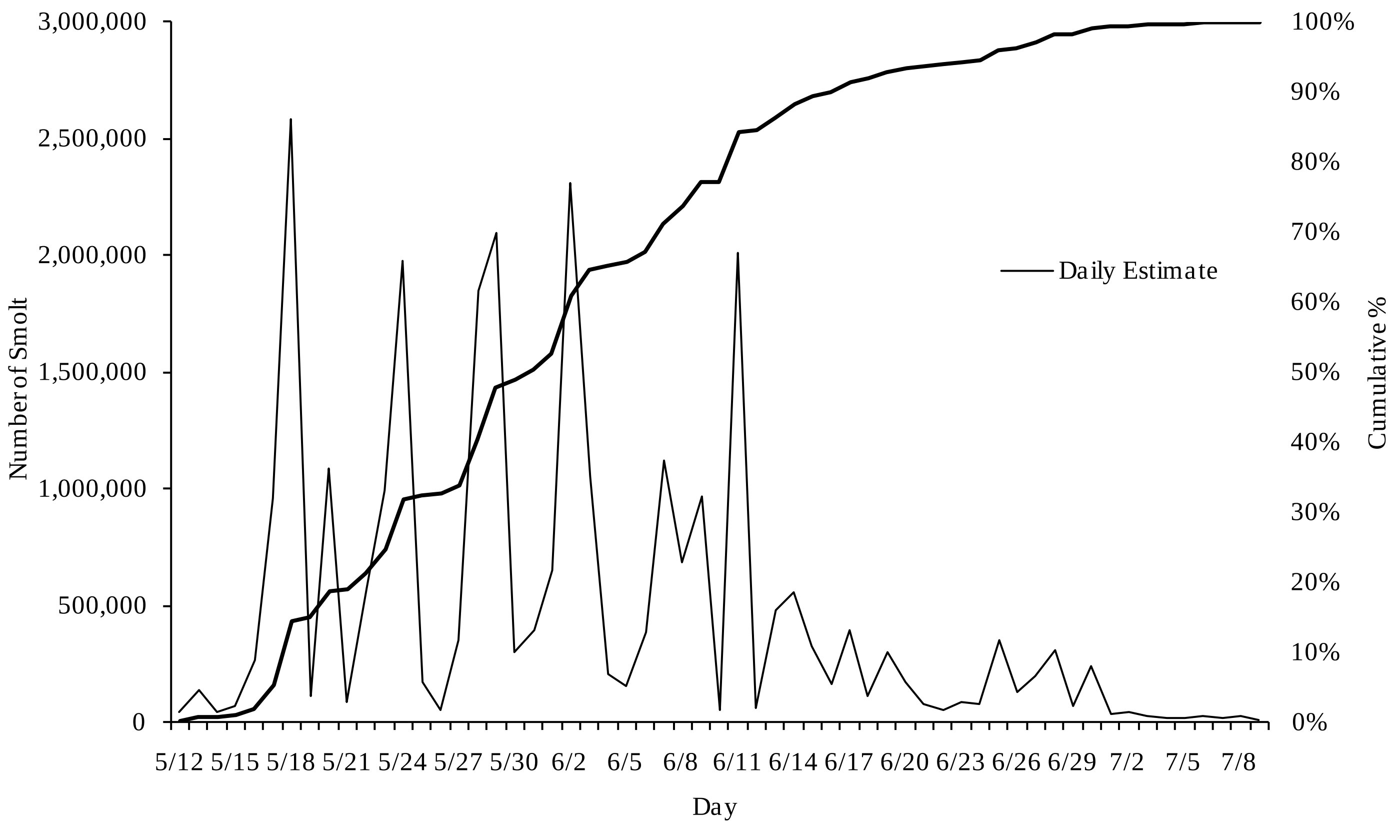

Figure 5.–Daily counts and cumulative percentage of the sockeye salmon smolt emigration from the Chignik River in 2010.

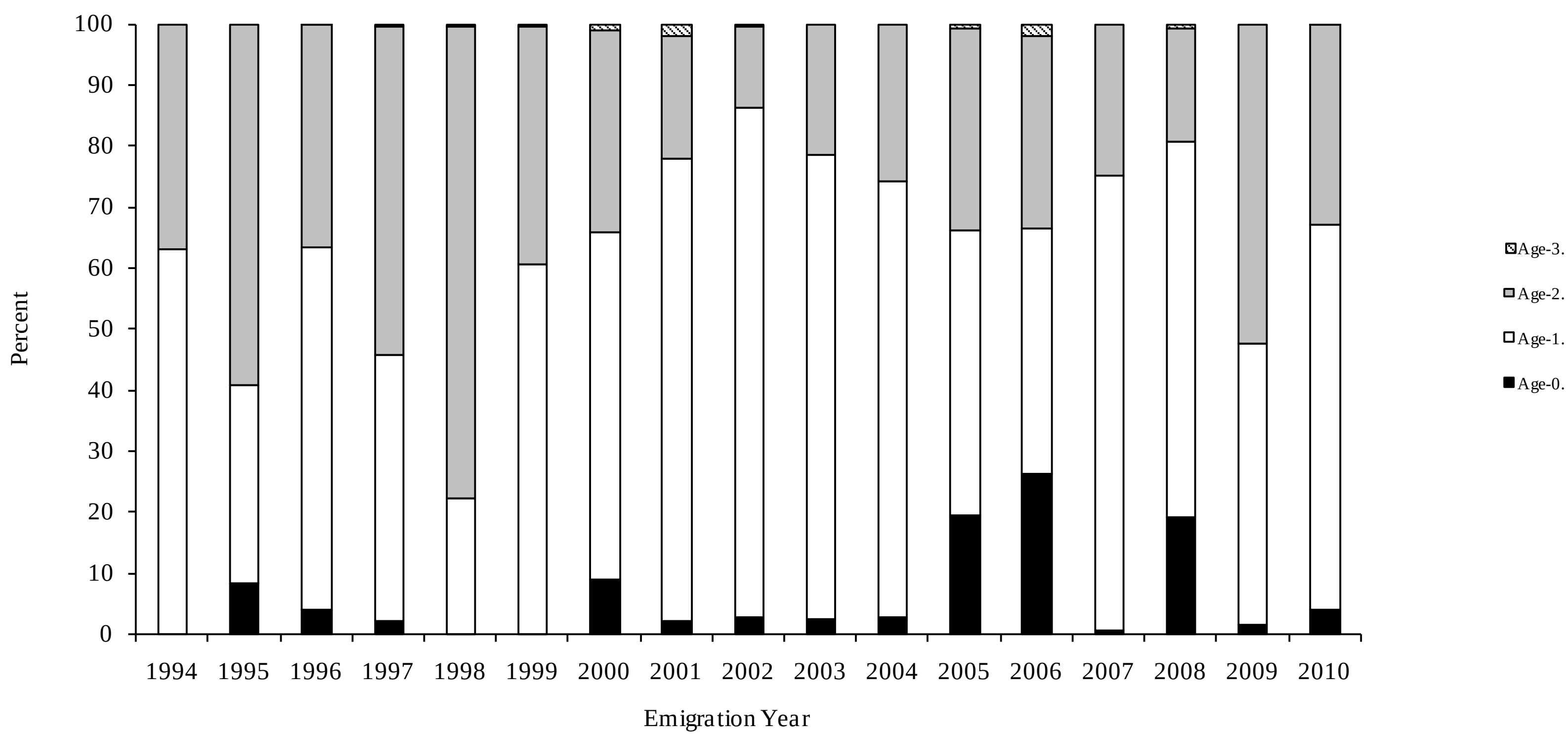

Figure 6.–A comparison of the estimated age structure of age-0. to age-3. sockeye salmon smolt emigrations from the Chignik River, 1994–2010.

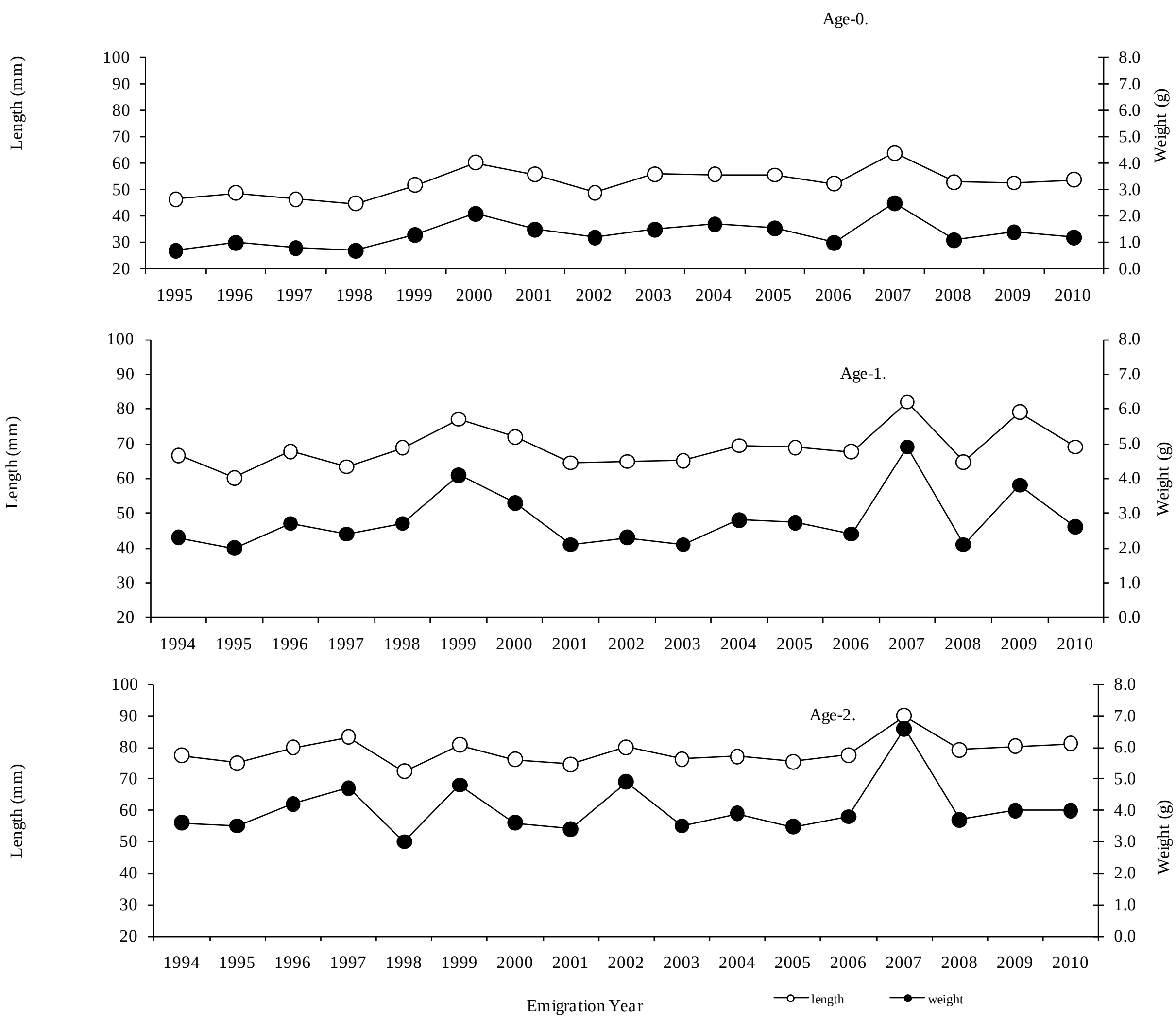

Figure 7.–Average length and weight of sampled age-0., age-1. and age-2. sockeye salmon smolt, by year from 1994 to 2010. Age-3. smolt comprise such a small percentage of the yearly population as to be negligible.

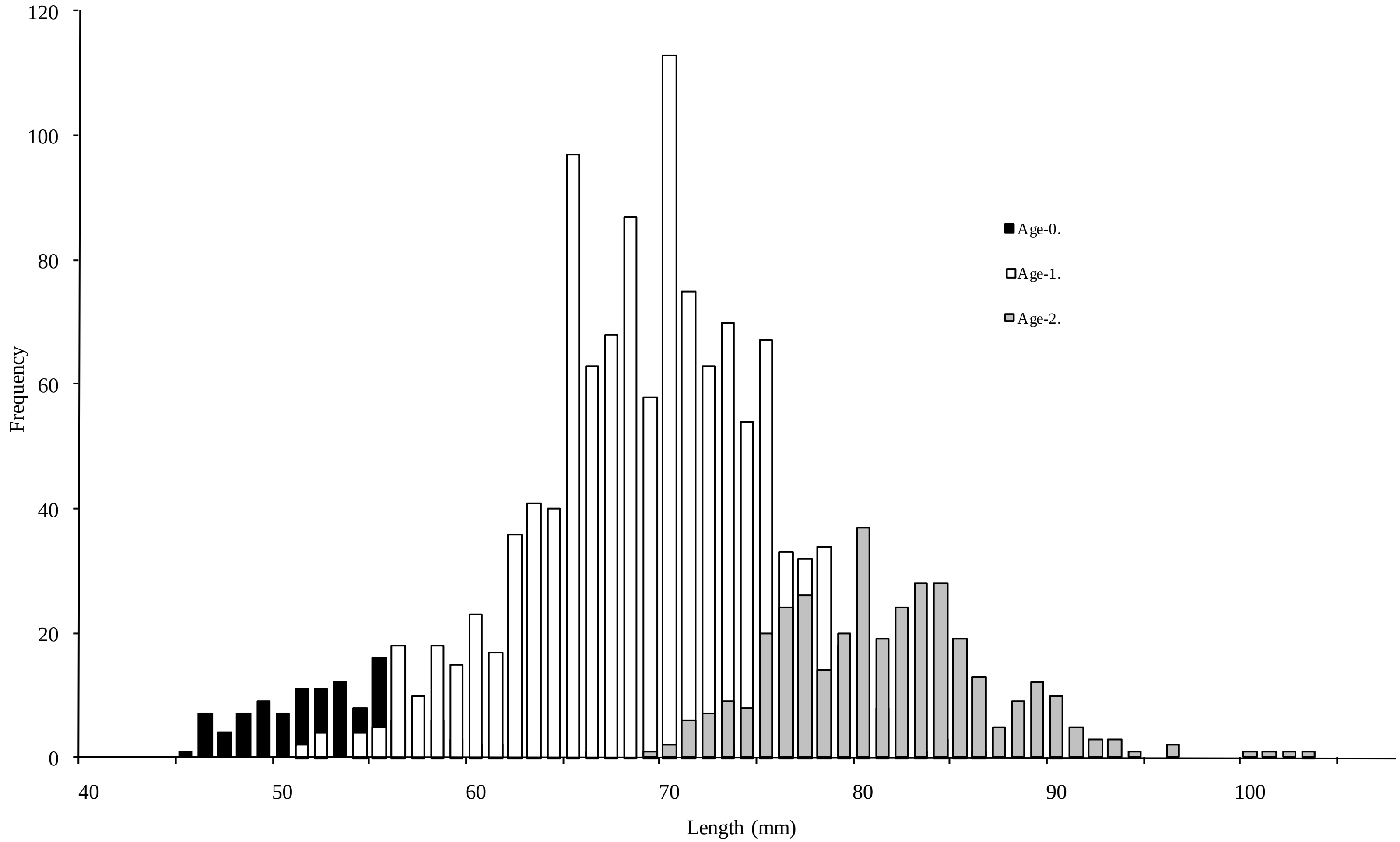

Figure 8.–Length frequency histogram of sockeye salmon smolt from the Chignik River in 2010 by age.

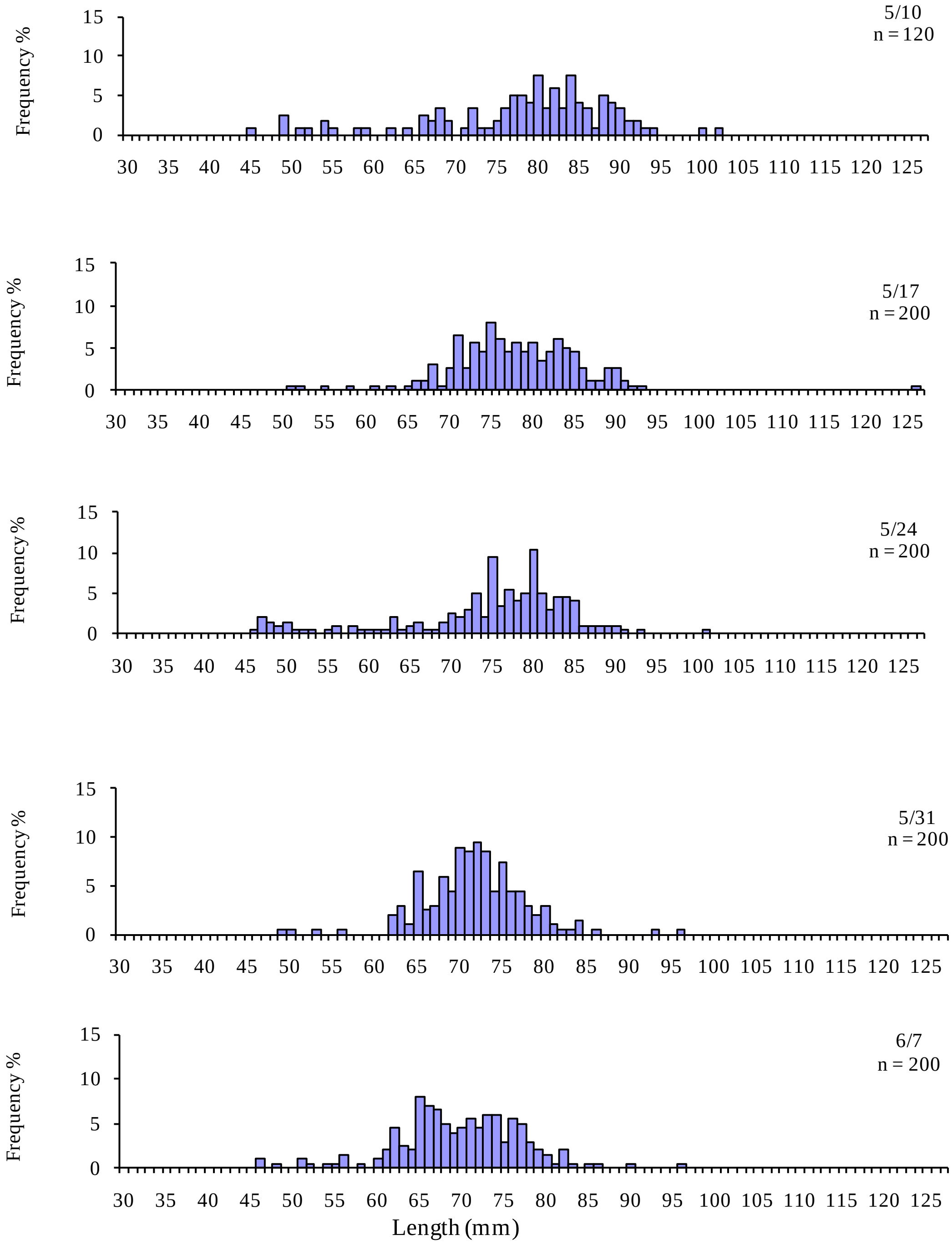

Figure 9.–Length frequency histograms of weekly total sockeye salmon catch samples in the screw traps in 2010.

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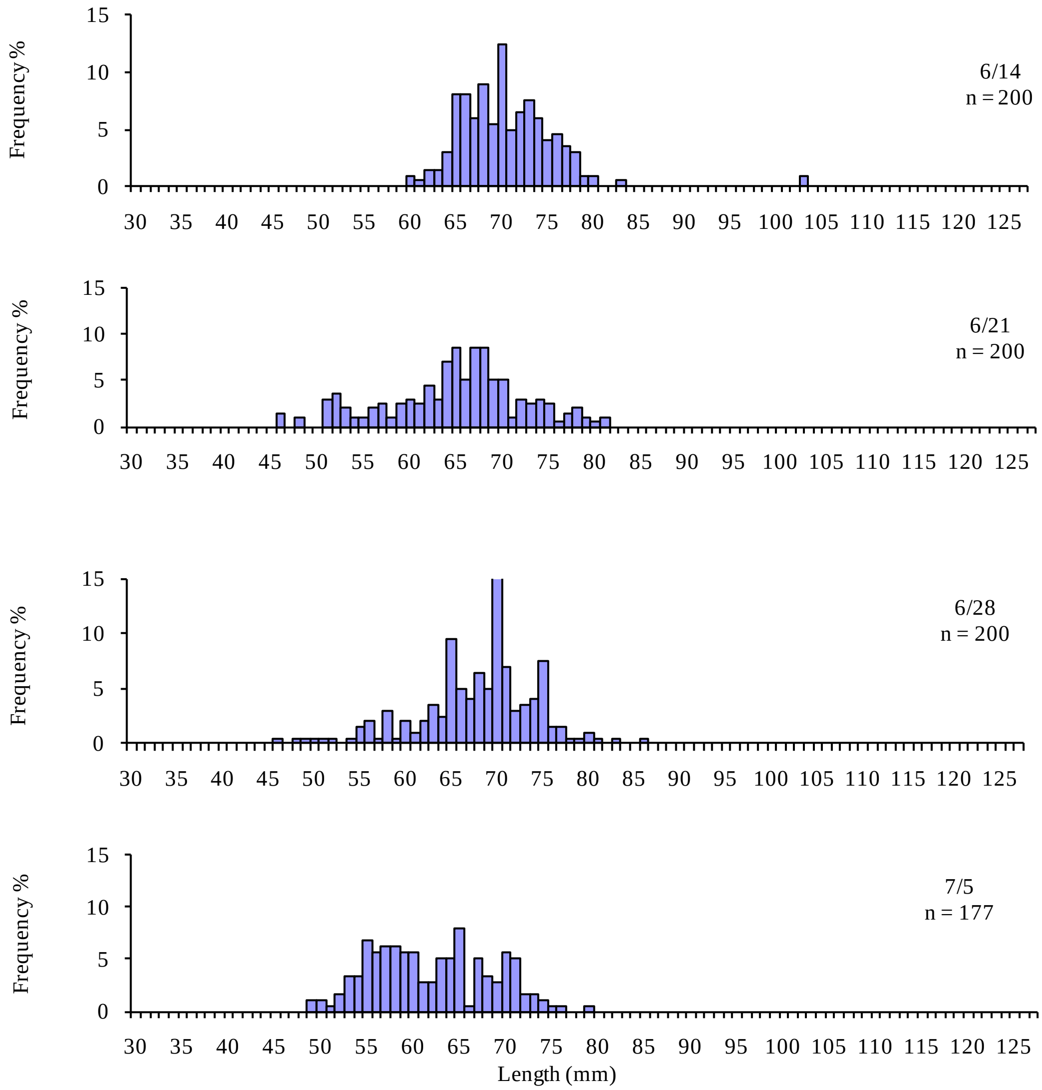

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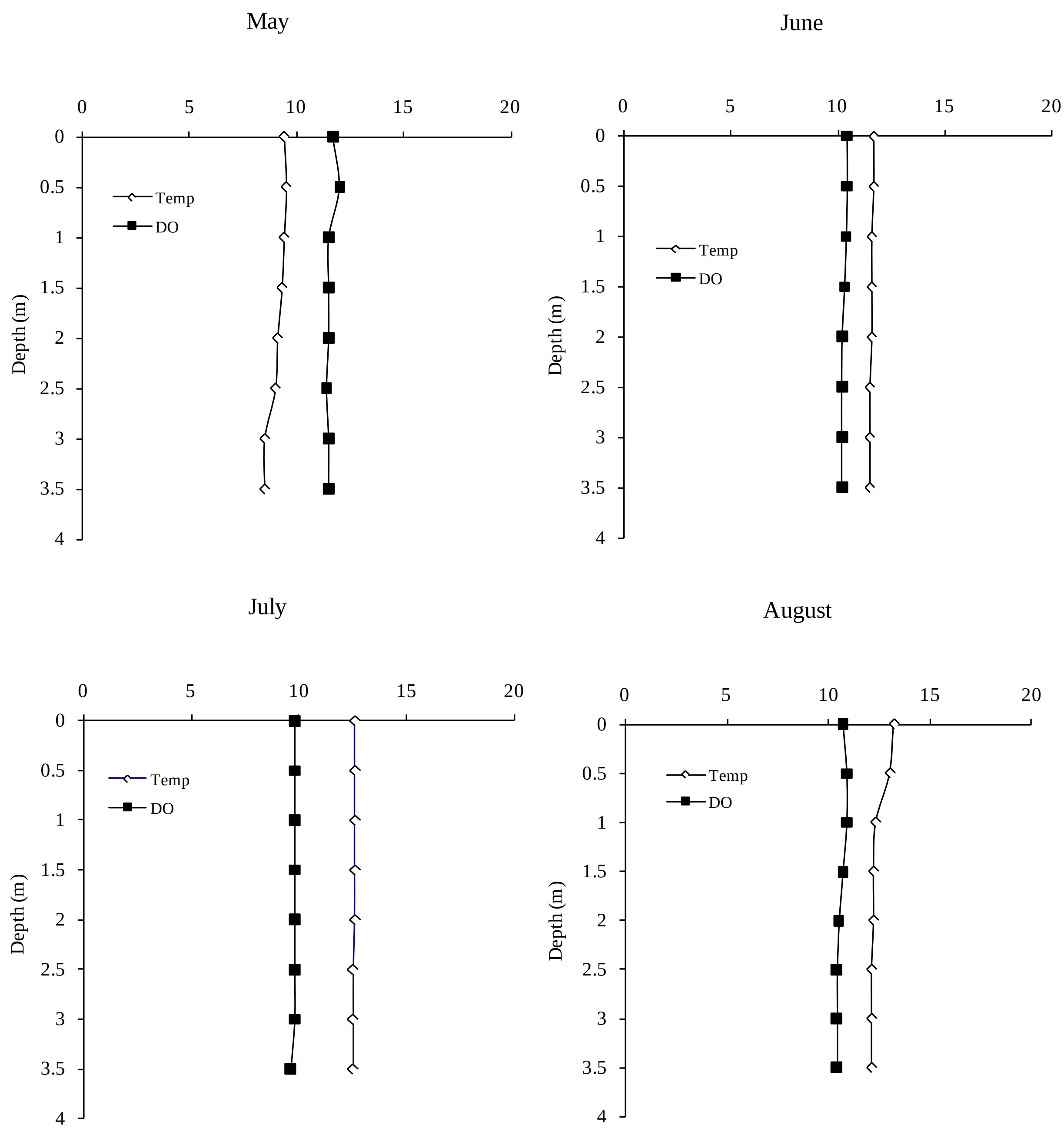


Figure 10.–Mean monthly temperature (°C; Y-axis) and dissolved oxygen (DO; X-axis) profiles in Black Lake in 2010.

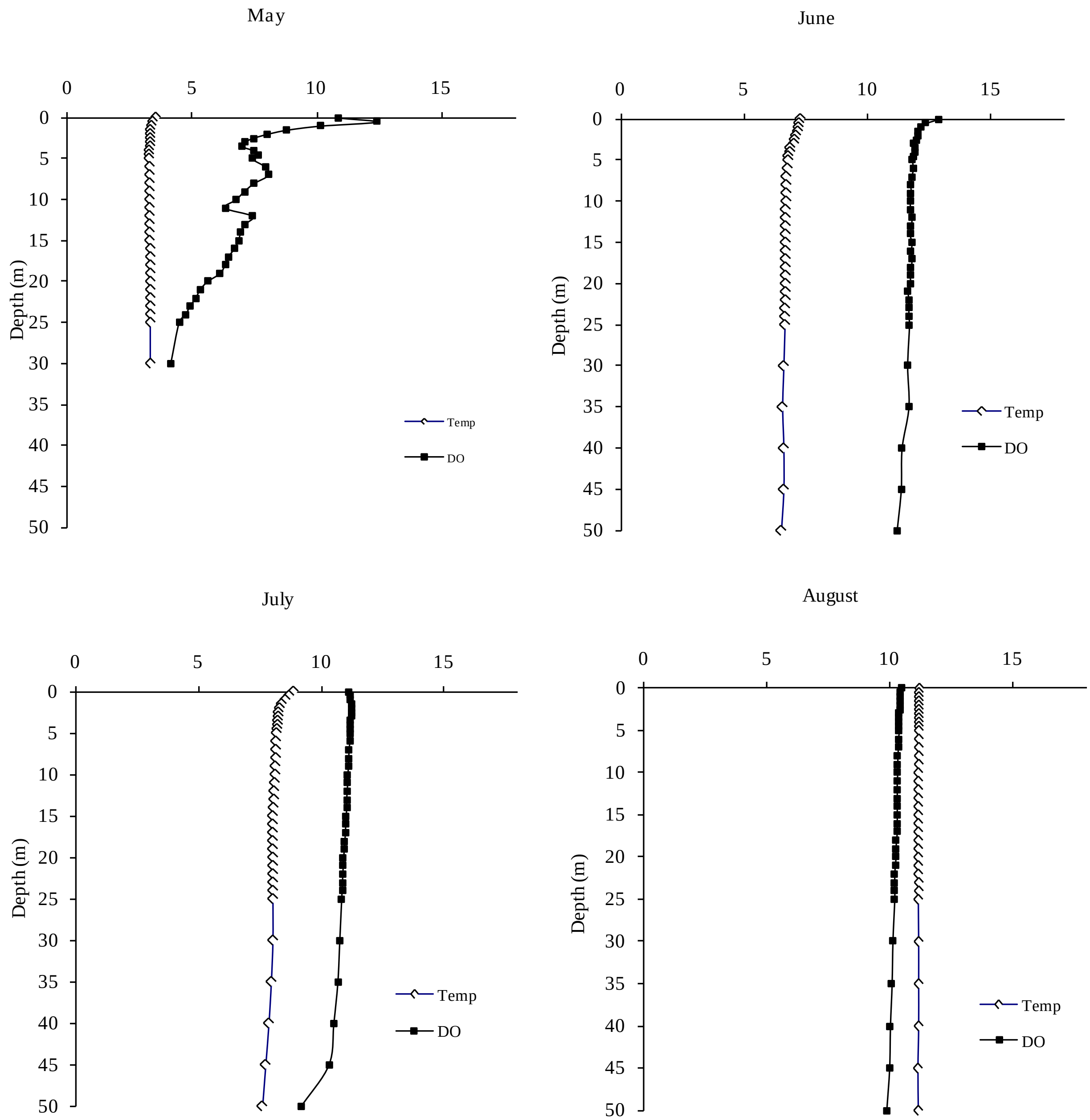
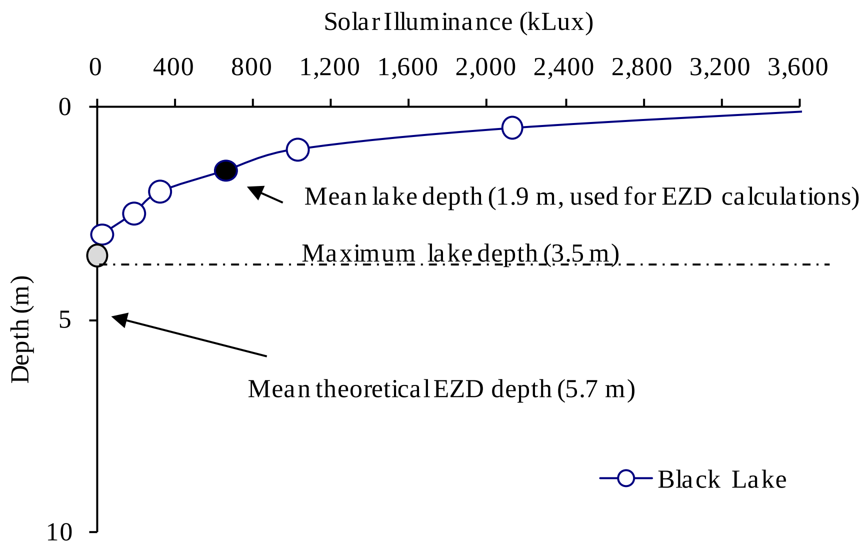


Figure 11.–Mean monthly temperature (°C; Y-axis) and dissolved oxygen (DO; X-axis) profiles in Chignik Lake in 2010.



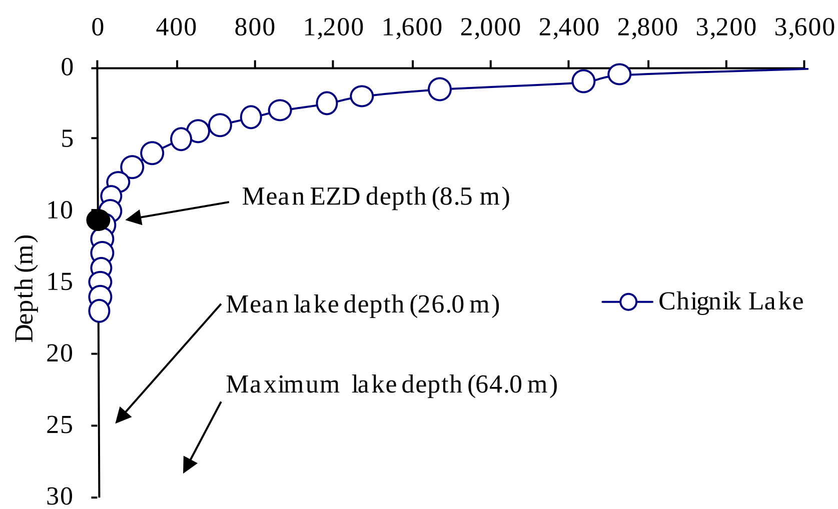


Figure 12.–Light penetration curves relative to mean depth, euphotic zone depth (EZD), and maximum depth in Chignik and Black lakes in 2010.

APPENDIX A. SMOLT TRAP CATCHES BY DAY

Appendix A1.–Actual daily counts and trap efficiency data of the Chignik River sockeye salmon smolt project, 2010.

	Actual Sockeye Smolt		Trap Efficiency Test				Incidental Catch[a]										
Date	Daily	Cum.	Marked	Daily Recoveries	Cum. Recoveries	Efficiency[b]	Soc Fry	Coho	Pink	Chnk	DV	SB	SC	SF	PS	PW	ISO
12-May	131	131	0	0	0	0.30%	111	0	0	0	2	57	3	0	1	0	0
13-May	413	544	0	0	0	0.30%	1,246	2	0	3	4	173	1	3	9	0	0
14-May	135	679	0	0	0	0.30%	303	3	0	0	1	228	5		7	0	0
15-May	201	880	0	0	0	0.30%	157	0	21	0	0	115	7	0	2	0	0
16-May	814	1,694	2220	4	4	0.30%	559	3	37	0	0	166	2	0	12	0	0
17-May	2,910	4,604	0	0	4	0.30%	195	7	0	7	6	100	0	4	14	1	0
18-May	7,851	12,455	0	0	4	0.30%	100	5	0	9	5	147	0	2	8	0	0
19-May	344	12,799	0	0	4	0.30%	695	5	0	1	3	176	2	11	16	0	2
20-May	3,290	16,089	0	0	4	0.30%	228	3	0	2	3	106	3	1	8	1	0
21-May	267	16,356	0	0	4	0.30%	415	3	0	1	2	168	2	0	1	0	0
22-May	1,744	18,100	0	1	5	0.30%	124	3	0	0	2	164	2	2	9	0	2
23-May	3,023	21,123	2332	4	4	0.32%	196	2	0	0	0	160	5	0	8	1	1
24-May	6,008	27,131	0	1	5	0.32%	1,099	12	0	6	3	326	1	6	6	0	0
25-May	563	27,694	0	0	5	0.32%	1,307	4	0	1	0	402	1	1	5	0	0
26-May	162	27,856	0	0	5	0.32%	898	3	0	2	0	136	0	0	6	0	0
27-May	1,135	28,991	0	1	6	0.32%	389	6	0	8	2	96	0	1	3	0	0
28-May	5,892	34,883	2556	2	2	0.36%	80	9	0	3	8	35	0	0	6	0	0
29-May	6,693	41,576	0	0	2	0.36%	152	4	0	8	3	71	1	2	1	0	1
30-May	1,061	42,637	0	1	3	0.36%	221	0	0	4	5	106	1	4	6	1	0
31-May	1,415	44,052	0	0	3	0.36%	204	2	0	6	5	150	0	1	0	0	0
1-Jun	2,323	46,375	0	1	4	0.36%	218	2	0	3	3	92	0	0	0	0	1
2-Jun	8,198	54,573	2175	8	8	1.02%	417	20	0	19	30	171	1	1	2	1	0
3-Jun	3751	58,324	0	5	13	1.02%	766	10	0	5	10	245	2	4	2	2	2
4-Jun	2,118	60,442	0	1	14	1.02%	1,156	18	0	7	35	238	0	2	5	5	0
5-Jun	1,549	61,991	0	1	15	1.02%	554	7	0	13	23	133	3	0	5	3	0
6-Jun	3,935	65,926	0	1	14	1.02%	511	9	0	14	22	183	1	0	8	2	5
7-Jun	11,426	77,352	0	1	15	1.02%	171	9	0	41	19	124	5	2	7	1	6

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	Actual Sockeye Smolt		Trap Efficiency Test				Incidental Catch[a]										
Date	Daily	Cum.	Marked	Daily Recoveries	Cum. Recoveries	Efficiency[b]	Soc Fry	Coho	Pink	Chnk	DV	SB	SC	SF	PS	PW	ISO
8-Jun	7,006	84,358	0	0	15	1.02%	165	13	0	20	10	158	2	1	6	2	1
9-Jun	4,675	89,033	2395	6	6	0.48%	136	12	0	7	21	269	1	0	5	4	4
10-Jun	256	89,289	0	0	6	0.48%	316	10	0	51	14	286	3	1	8	2	1
11-Jun	9,671	98,960	0	2	8	0.48%	154	55	0	491	20	352	1	1	6	3	1
12-Jun	308	99,268	0	0	8	0.48%	284	18	0	86	11	498	4	0	18	1	3
13-Jun	2,302	101,570	0	0	8	0.48%	92	4	0	13	17	464	1	2	5	0	6
14-Jun	2,855	104,425	2347	5	5	0.51%	100	13	0	55	2	413	2	1	8	8	2
15-Jun	1,683	106,108	0	2	7	0.51%	71	7	0	22	7	184	3	2	1	1	3
16-Jun	827	106,935	0	2	9	0.51%	83	8	0	13	18	244	2	1	4	3	1
17-Jun	2,018	108,953	0	1	10	0.51%	38	2	0	22	11	383	1	0	4	2	4
18-Jun	555	109,508	0	0	10	0.51%	46	3	0	25	8	265	0	2	1	5	3
19-Jun	1,526	111,034	0	0	10	0.51%	45	5	0	14	5	316	1	0	0	10	1
20-Jun	503	111,537	2171	4	4	0.29%	33	1	0	16	5	161	0	0	2	8	0
21-Jun	228	111,765	0	0	4	0.29%	26	13	0	33	12	109	2	2	6	7	1
22-Jun	165	111,930	0	0	4	0.29%	51	6	0	29	5	110	1	1	0	9	8
23-Jun	254	112,184	0	0	4	0.29%	341	0	0	8	2	214	2	1	2	5	1
24-Jun	236	112,420	0	1	5	0.29%	43	8	0	57	6	181	3	0	3	8	0
25-Jun	1,038	113,458	0	0	5	0.29%	117	24	0	26	6	305	0	2	0	13	0
26-Jun	375	113,833	772	1	1	0.28%	173	8	0	82	11	557	3	2	7	13	1
27-Jun	558	114,391	0	0	1	0.28%	152	18	0	28	7	631	6	4	8	10	2
28-Jun	870	115,261	0	0	1	0.28%	58	2	0	25	5	143	7	2	4	9	1
29-Jun	206	115,467	0	0	1	0.28%	17	5	0	55	3	116	3	0	0	4	0
30-Jun	665	116,132	0	0	1	0.28%	26	3	0	56	2	79	3	0	3	12	1
1-Jul	109	116,241	0	0	1	0.28%	18	6	0	56	5	90	1	0	0	14	4
2-Jul	136	116,377	0	0	1	0.28%	2	4	0	89	2	131	3	0	0	14	1
3-Jul	69	116,446	0	0	1	0.28%	4	5	0	23	1	154	0	0	0	7	0
4-Jul	52	116,498	0	0	1	0.28%	1	3	0	19	0	113	1	0	0	14	0
5-Jul	55	116,553	0	0	1	0.28%	2	2	0	28	0	105	2	0	1	10	1
6-Jul	75	116,628	0	0	1	0.28%	5	1	0	22	4	125	3	0	0	6	2
7-Jul	55	116,683	0	0	1	0.28%	2	2	0	24	1	93	3	0	0	18	0

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	Actual Sockeye Smolt		Trap Efficiency Test				Incidental Catch[a]										
Date	Daily	Cum.	Marked	Daily Recoveries	Cum. Recoveries	Efficiency[b]	Soc Fry	Coho	Pink	Chnk	DV	SB	SC	SF	PS	PW	ISO
8-Jul	80	116,763	0	0	1	0.28%	4	9	0	16	11	94	4	0	1	10	0
9-Jul	29	116,792	0	0	1	0.28%	1	3	0	16	1	68	3	0	1	4	0
Total		116,792	16,968	53	53	0.36%	15,078	424	58	1,690	429	11,679	119	72	261	254	73

[a] Soc Fry = sockeye salmon fry, Coho = juvenile coho salmon, Pink = juvenile pink salmon, Chnk = juvenile chinook salmon, DV = Dolly Varden, SB = stickleback, SC = sculpin, SF = starry flounder, PS = pond smelt, PW = pygmy whitefish, ISO = isopods.

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

APPENDIX B. SMOLT CATCHES BY TRAP

Appendix B1.–Number of sockeye salmon smolt caught by trap, by day, from the Chignik River, May 12 through July 9, 2010.

	Small Trap		Large Trap		Combined		Daily Proportion	
Date	Daily	Cumulative	Daily	Cumulative	Daily	Cumulative	Small	Large
5/12	30	30	101	101	131	131	22.9%	77.1%
5/13	93	123	320	421	413	544	22.5%	77.5%
5/14	41	164	94	515	135	679	30.4%	69.6%
5/15	34	198	167	682	201	880	16.9%	83.1%
5/16	44	242	770	1,452	814	1,694	5.4%	94.6%
5/17	183	425	2,727	4,179	2,910	4,604	6.3%	93.7%
5/18	1,062	1,487	6,789	10,968	7,851	12,455	13.5%	86.5%
5/19	60	1,547	284	11,252	344	12,799	17.4%	82.6%
5/20	224	1,771	3,066	14,318	3,290	16,089	6.8%	93.2%
5/21	51	1,822	216	14,534	267	16,356	19.1%	80.9%
5/22	134	1,956	1,610	16,144	1,744	18,100	7.7%	92.3%
5/23	335	2,291	2,688	18,832	3,023	21,123	11.1%	88.9%
5/24	447	2,738	5,561	24,393	6,008	27,131	7.4%	92.6%
5/25	112	2,850	451	24,844	563	27,694	19.9%	80.1%
5/26	70	2,920	92	24,936	162	27,856	43.2%	56.8%
5/27	95	3,015	1,040	25,976	1,135	28,991	8.4%	91.6%
5/28	1,033	4,048	4,859	30,835	5,892	34,883	17.5%	82.5%
5/29	607	4,655	6,086	36,921	6,693	41,576	9.1%	90.9%
5/30	27	4,682	1,034	37,955	1,061	42,637	2.5%	97.5%
5/31	1,036	5,718	379	38,334	1,415	44,052	73.2%	26.8%
6/1	1,136	6,854	1,187	39,521	2,323	46,375	48.9%	51.1%
6/2	3,441	10,295	4,757	44,278	8,198	54,573	42.0%	58.0%
6/3	470	10,765	3,281	47,559	3,751	58,324	12.5%	87.5%
6/4	316	11,081	1,802	49,361	2,118	60,442	14.9%	85.1%
6/5	152	11,233	1,397	50,758	1,549	61,991	9.8%	90.2%
6/6	371	11,604	3,564	54,322	3,935	65,926	9.4%	90.6%
6/7	1,611	13,215	9,815	64,137	11,426	77,352	14.1%	85.9%
6/8	393	13,608	6,613	70,750	7,006	84,358	5.6%	94.4%
6/9	106	13,714	4,569	75,319	4,675	89,033	2.3%	97.7%
6/10	61	13,775	195	75,514	256	89,289	23.8%	76.2%
6/11	337	14,112	9,334	84,848	9,671	98,960	3.5%	96.5%
6/12	47	14,159	261	85,109	308	99,268	15.3%	84.7%
6/13	68	14,227	2,234	87,343	2,302	101,570	3.0%	97.0%
6/14	124	14,351	2,731	90,074	2,855	104,425	4.3%	95.7%
6/15	75	14,426	1,608	91,682	1,683	106,108	4.5%	95.5%
6/16	58	14,484	769	92,451	827	106,935	7.0%	93.0%
6/17	87	14,571	1,931	94,382	2,018	108,953	4.3%	95.7%
6/18	28	14,599	527	94,909	555	109,508	5.0%	95.0%
6/19	57	14,656	1,469	96,378	1,526	111,034	3.7%	96.3%
6/20	61	14,717	442	96,820	503	111,537	12.1%	87.9%
6/21	24	14,741	204	97,024	228	111,765	10.5%	89.5%

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	Small Trap		Large Trap		Combined		Daily Proportion	
Date	Daily	Cumulative	Daily	Cumulative	Daily	Cumulative	Small	Large
6/22	40	14,781	125	97,149	165	111,930	24.2%	75.8%
6/23	60	14,841	194	97,343	254	112,184	23.6%	76.4%
6/24	17	14,858	219	97,562	236	112,420	7.2%	92.8%
6/25	58	14,916	980	98,542	1,038	113,458	5.6%	94.4%
6/26	63	14,979	312	98,854	375	113,833	16.8%	83.2%
6/27	34	15,013	524	99,378	558	114,391	6.1%	93.9%
6/28	33	15,046	837	100,215	870	115,261	3.8%	96.2%
6/29	20	15,066	186	100,401	206	115,467	9.7%	90.3%
6/30	16	15,082	649	101,050	665	116,132	2.4%	97.6%
7/1	29	15,111	80	101,130	109	116,241	26.6%	73.4%
7/2	10	15,121	126	101,256	136	116,377	7.4%	92.6%
7/3	12	15,133	57	101,313	69	116,446	17.4%	82.6%
7/4	3	15,136	49	101,362	52	116,498	5.8%	94.2%
7/5	19	15,155	36	101,398	55	116,553	34.5%	65.5%
7/6	16	15,171	59	101,457	75	116,628	21.3%	78.7%
7/7	14	15,185	41	101,498	55	116,683	25.5%	74.5%
7/8	13	15,198	67	101,565	80	116,763	16.3%	83.8%
7/9	5	15,203	24	101,589	29	116,792	17.2%	82.8%
Total		15,203		101,589		116,792	15.1%	84.9%

APPENDIX C. CLIMATOLOGICAL OBSERVATIONS

Appendix C1.–Daily climatological observations for the Chignik River sockeye salmon smolt project, 2010.

				Cloud[b]			Trap Revolutions (rpm)		Stream	
		Air	Water	Cover	Wind[b]	Vel.[b]			Gauge	
Date[a]	Time	(°C)	(°C)	%	Dir	(mph)	Small	Large	(cm)	Comments
5/13	12:02	6.5	3.5	80%		0	3.25	3.50	85	
5/14	12:19	6.0	3.0	30%	NW	15-20	3.50	3.75	86	
5/15	12:04	5.5	3.5	100%		0	3.25	3.75	85	
5/16	12:05	4.0	3.5	100%	SE	15-20	4.00	4.00	92	rain
5/17	12:05	5.0	3.0	80%	SE	15-20	6.50	6.00	104	
5/18	12:10	5.0	3.3	99%	SE	10-15	7.50	6.50	115	
5/19	12:04	7.0	3.5	30%	NW	5-10	7.50	6.75	120	
5/20	12:06	1.0	2.5	100%		0	7.75	6.75	121	snow!
5/21	12:02	3.5	3.0	100%	NW	5-10	8.00	6.75	124	
5/22	12:09	6.0	3.5	100%	SE	10-15	7.50	6.50	121	
5/23	12:03	5.0	3.5	100%	NW	0-5	7.50	6.50	122	
5/24	12:04	4.0	3.5	60%	NW	10-15	7.50	6.50	122	
5/25	11:58	8.0	4.0	0%	NW	0-5	7.50	6.75	121	
5/26	12:04	8.0	4.0	100%	SE	5-10	7.00	6.50	115	
5/27	12:00	7.5	4.0	100%	SE	15-20	7.00	6.25	113	
5/28	12:05	6.5	4.0	100%	SE	10-15	8.00	7.00	122	
5/29	12:02	6.5	4.0	100%	SE	0-5	8.50	7.50	134	drizzle
5/30	11:53	6.5	4.5	100%	SE	10-15	9.25	8.00	145	
5/31	12:23	6.0	4.0	100%	NW	0-5	9.50	8.00	154	
6/1	12:03	8.0	4.5	100%	SE	0-5	8.75	7.50	162	
6/2	12:10	8.0	5.0	50%	NW	15-25	9.50	8.25	167	
6/3	12:10	4.5	4.5	80%	NW	15-20	9.75	8.25	154	depth sandbag moved. Legs adjusted
6/4	11:58	5.5	5.0	90%	NW	10-15	9.00	7.75	156	
6/5	11:57	7.0	5.0	100%	NW	10-15	8.50	7.75	149	
6/6	11:50	5.5	5.0	100%	SE	0-5	8.75	7.50	142	rain
6/7	12:00	6.0	5.0	100%	NW	0-5	8.75	7.50	152	intermittent rain
6/8	12:05	7.0	5.0	100%	SE	10	8.50	7.50	140	little rain on and off
6/9	12:05	8.0	5.5	100%	SE	10	8.50	7.75	135	
6/10	12:06	9.0	6.0	90%	SE	0-5	7.75	7.75	143	

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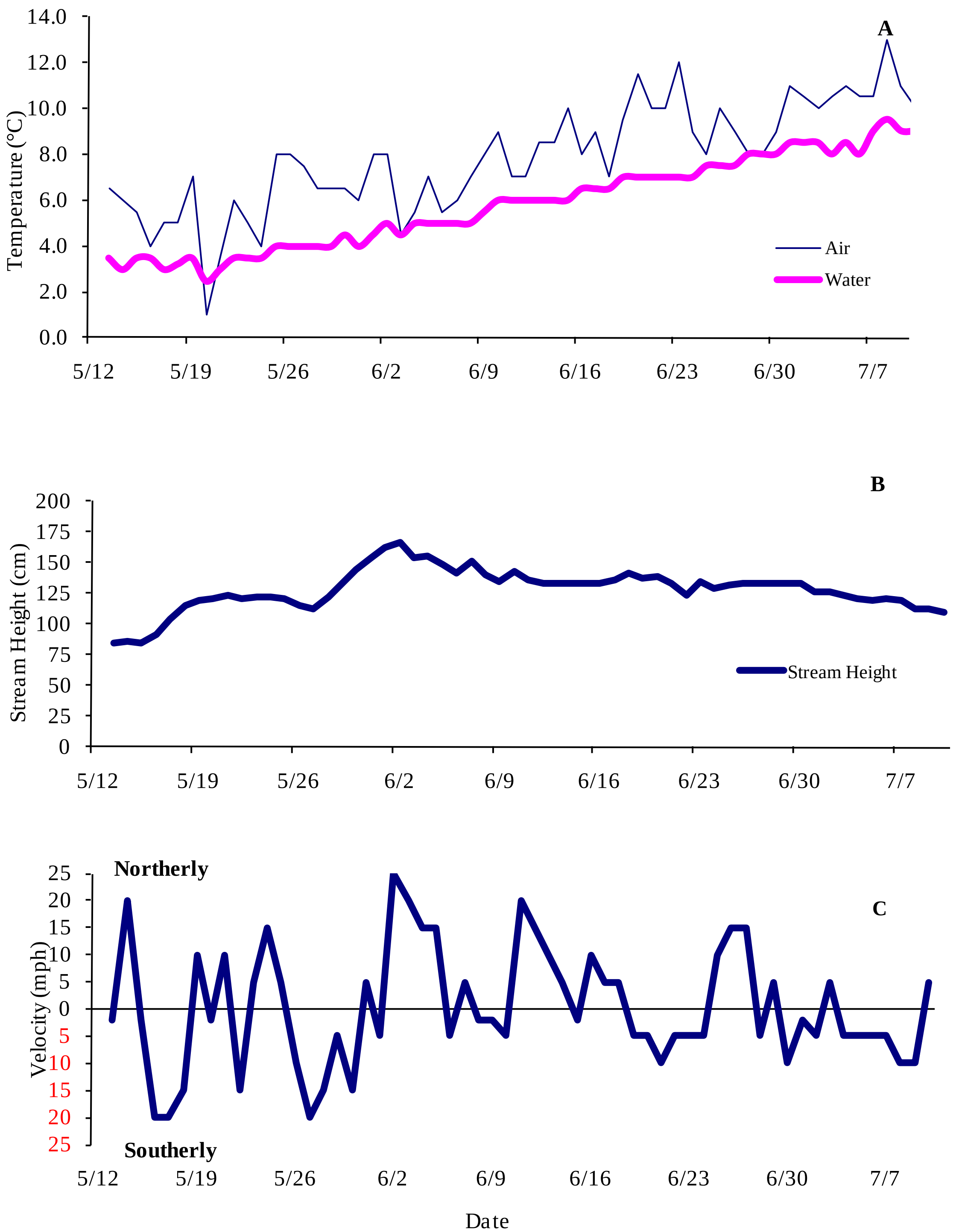
Date[a]	Time	Air (°C)	Water (°C)	Cloud[b] Cover (%)	Wind[b] Dir	Vel.[b] (mph)	Trap Revolutions (rpm) Small	Trap Revolutions (rpm) Large	Stream Gauge (cm)	Comments
6/11	12:02	7.0	6.0	100%	NW	15-20	8.25	8.00	136	
6/12	12:20	7.0	6.0	50%	N	10-15	8.00	7.25	134	
6/13	12:12	8.5	6.0	95%	NW	5-10	8.50	7.50	133	
6/14	11:38	8.5	6.0	100%	variable	0-5	9.00	7.25	134	
6/15	12:06	10.0	6.0	99%		0	8.25	7.25	134	
6/16	12:00	8.0	6.5	100%	nw	5-10	9.25		134	Large trap not fishing at noon due to repairs
6/17	12:14	9.0	6.5	70%	NW	0-5	8.75	8.00	136	
6/18	11:52	7	6.5	95%	NW	0-5	8.5	8	142	
6/19	12:05	9.5	7.0	60%	SE	0-5	8.00	7.50	137	
6/20	11:56	11.5	7.0	70%	SE	0-5	8.00	7.50	139	
6/21	12:00	10.0	7.0	100%	SE	5-10	7.75	7.5	133	
6/22	12:27	10.0	7.0	100%	SE	0-5	7.25	7.00	124	
6/23	12:05	12.0	7.0	95%	SE	0-5	7.50	7.25	135	
6/24	12:00	9.0	7.0	100%	SE	0-5	7.50	7.25	129	
6/25	11:56	8.0	7.5	100%	NW	5-10	8.00	7.50	132	
6/26	12:04	10.0	7.5	40%	NW	10-15	8.00	7.50	134	
6/27	12:00	9.0	7.5	60%	NW	10-15	7.75	7.50	133	
6/28	12:30	8.0	8.0	85%	SE	0-5	8.00	7.50	133	high hazy clouds
6/29	12:02	8.0	8.0	100%	NW	0-5	8.00	7.50	133	
6/30	12:06	9.0	8.0	100%	SE	5-10	8.00	7.25	133	rain
7/1	12:24	11.0	8.5	100%		0	7.75	7.00	127	up at Chignik lake sampling for noon check
7/2	12:15	10.5	8.5	100%	SE	0-5	7.25	7.00	126	
7/3	12:02	10.0	8.5	95%	NW	0-5	7.25	7.00	123	
7/4	11:57	10.5	8.0	100%	SE	0-5	7.00	6.75	121	
7/5	12:09	11.0	8.5	100%	SE	0-5	7.00	6.75	120	
7/6	11:54	10.5	8.0	100%	SE	0-5	6.50	6.50	121	
7/7	12:01	10.5	9.0	95%	SE	0-5	7.25	7.75	120	
7/8	12:14	13.0	9.5	20%	SE	5-10	6.25	6.25	113	
7/9	12:04	11.0	9.0	100%	SE	5-10	6.00	6.25	112	

[a] Actual calendar dates.

[b] Based on observer estimates.

Appendix C2.–Air and water temperature (A), stream gauge height (B), and wind velocity and direction data gathered at the Chignik River smolt traps, 2010.



APPENDIX D. HISTORICAL AGE COMPOSITION DATA

Appendix D1.–Estimated age composition of Chignik River sockeye salmon smolt samples, 1994–2010.

Year	Dates	Sample Size		Number of Smolt Age-0.	Age-1.	Age-2.	Age-3.	Age-4.	Total
1994	5/6-6/30	2,806	Percent	0.0	61.1	38.9	0.0	0.0	100.0
			Numbers	0	1,715	1,091	0	0	2,806
1995	5/6-6/29	2,557	Percent	10.7	49.8	39.5	0.0	0.0	100.0
			Numbers	273	1,274	1,010	0	0	2,557
1996	5/6-7/28	2,099	Percent	6.0	67.8	26.1	0.1	0.0	100.0
			Numbers	125	1,423	548	3	0	2,099
1997	5/4-7/22	2,657	Percent	7.3	63.1	29.1	0.5	0.0	100.0
			Numbers	195	1,676	774	12	0	2,657
1998	5/2-7/30	2,745	Percent	0.5	28.6	70.1	0.7	0.0	100.0
			Numbers	15	785	1,925	20	0	2,745
1999	5/10-7/3	2,180	Percent	1.8	61.7	36.1	0.3	0.0	100.0
			Numbers	40	1,345	788	7	0	2,180
2000	4/22-7/20	1,915	Percent	11.6	61.4	26.3	0.7	0.0	100.0
			Numbers	223	1,175	503	14	0	1,915
2001	4/29-7/12	2,195	Percent	4.4	75.0	17.7	2.8	0.0	100.0
			Numbers	96	1,647	389	62	1	2,195
2002	5/01-7/8	2,038	Percent	10.6	77.9	11.1	0.3	0.0	100.0
			Numbers	217	1,588	227	6	0	2,038
2003	4/25-7/8	2,098	Percent	7.1	79.6	13.3	0.0	0.0	100.0
			Numbers	149	1,670	279	0	0	2,098
2004	5/6-7/1	1,651	Percent	21.0	62.4	16.6	0.0	0.0	100.0
			Numbers	347	1,030	274	0	0	1,651
2005	4/26-7/8	1,950	Percent	33.5	45.7	20.4	0.4	0.0	100.0
			Numbers	654	892	397	7	0	1,950
2006	4/27-7/9	1,644	Percent	26.2	40.3	31.6	1.9	0.0	100.0
			Numbers	430	663	519	32	0.0	1,644
2007	5/9-7/8	1,087	Percent	0.6	74.4	25.0	0.0	0.0	100.0
			Numbers	6	809	272	0	0	1,087
2008	5/9-7/9	1,717	Percent	33.1	49.2	16.8	1.0	0.0	100.0
			Numbers	568	844	288	17	0	1,717
2009	5/6-7/7	1,201	Percent	16.6	49.0	34.4	0.0	0.0	100.0
			Numbers	199	589	413	0	0	1,201
2010	5/12-7/9	1,694	Percent	7.7	69.9	22.3	0.1	0.0	100.0
			Numbers	128	1205	359	2	0	1,694

APPENDIX E. HISTORICAL LIMNOLOGY DATA

Appendix E1.–Seasonal averages of water quality parameters, nutrient concentrations, and photosynthetic pigments by year for Black Lake, 2000–2010.

	2000	2001	2002	2003	2004	2005	2006[b]	2007[b]	2008[b]	2009	2010
	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average
pH	7.43	7.53	7.45	7.46	7.81	7.62	8.01	7.64	7.64	7.7	7.8
Alkalinity (mg/L)	13.0	32.5	32.3	32.3	30.2	25.00	20.5	19.7	19.0	23.5	22.0
Total P (mg/L P)	57.0	35.0	22.0	41.7	22.2	27.93	20.4	24.43	22.23	41.1	29.8
TFP (mg/L P)	11.0	10.0	10.0	9.8	5.1	8.58	ND	ND	ND	ND	8.0
FRP (μg/L P)	4.0	7.0	5.0	5.8	2.6	7.20	9.1	ND	ND	ND	3.3
TKN (μg/L N)	ND	ND	323.5	256.8	188.8	324.5	216.0	124.3	263.7	233.5	210.8
Ammonia (μg/L N)	37.0	3.3	4.4	3.7	9.7	3.9	11.0	130.1	3.7	2.6	6.4
Nitrate + Nitrite (μg/L N)	64.0	4.5	8.3	25.2	3.7	1.93	0.9	1.57	0.6	1.3	1.0
Chlorophyll *a* (μg/L)	18.06	4.26	2.64	5.12	3.60	4.97	4.44	3.28	6.56	3	2.8
Phaeophytin *a* (μg/L)	9.98	11.94	1.44	1.78	0.15	0.98	0.76	0.93	1.42	1.4	1.5

[b] No limnological sampling occurred in August

Appendix E2.–Seasonal averages of water quality parameters, nutrient concentrations, and photosynthetic pigments for Chignik Lake, 2000–2010.

	2000	2001	2002	2003	2004	2005	2006[b]	2007[b]	2008[b]	2009	2010
	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average
pH	7.8	7.5	7.5	7.4	7.6	7.6	7.7	7.5	7.5	7.5	7.3
Alkalinity (mg/L)	15.1	24.8	24.6	23.6	22.4	23.8	24.8	18.2	21.0	22.9	20.1
Total P (mg/L P)	13.2	27.6	19.7	16.7	18.5	15.8	16.0	14.2	15.6	22.3	13.6
TFP (mg/L P)	5.3	12.2	8.5	7.5	6.5	6.6	ND	ND	ND	ND	5.40
FRP (mg/L P)	4.8	8.4	4.6	5.8	4.1	6.0	8.90	ND	ND	ND	4.50
TKN (mg/L N)[b]	230.0	99.5	119.7	99.0	146.5	199.5	86.0	148.3	96.3	79.8	44.5
Ammonia (mg/L N)	29.8	10.3	10.5	10.1	9.1	6.2	14.1	7.9	4.7	5.8	6.8
Nitrate + Nitrite (mg/L N)	102.6	132.9	117.4	166.6	128.0	110.9	129.9	194.0	192.5	151.8	154.4
Chlorophyll *a* (mg/L)	9.47	4.69	2.34	2.30	4.02	3.27	6.60	2.19	2.15	2.3	1.5
Phaeophytin *a* (mg/L)	1.69	1.31	1.34	0.51	0.32	0.65	0.90	0.37	0.56	0.6	0.8

[b] No limnological sampling occurred in August

Appendix E3.–Seasonal average number of zooplankton per m^2 from Black Lake, 2000–2010.

	2000	2001	2002	2003	2004	2005	2006[a]	2007[a]	2008[a]	2009	2010
Taxon	Seasonal average	Seasonal average	Seasonal average	Seasonal average	Seasonal average	Seasonal average	Seasonal average	Seasonal average	Seasonal average	Seasonal average	Seasonal average
Copepods											
Epischura	7,850	2,654	2,605	6,303	37,649	18,113	-	5,750	-	3,729	4,329
Ovig. *Epischura*	127	-	-	-	-	-	-	-	-	-	-
Diaptomus	3,575	1,239	5,893	11,080	25,000	3,716	796	3,185	-	2,490	3,715
Ovig. *Diaptomus*	-	-	-	1,327	149	266	-	-	-	-	597
Eurytemora							-	-	-	-	796
Cyclops	35,398	7,307	25,622	19,042	46,198	46,842	31,582	5,662	13,093	24,031	18,312
Ovig. *Cyclops*	-	-	-	266	-	-	-	-	-	-	256
Harpaticus	-	531	-	531	531	-	266	-	-	-	579
Napulii	21,967	6,458	13,385	24,350	40,509	38,150	7,564	9,996	16,189	28,938	12,971
Total copepods	68,917	18,188	47,505	62,898	150,036	107,086	40,207	24,593	29,282	59,188	41,584
Cladocerans											
Bosmina	38,455	25,779	32,379	285,496	398,855	203,755	2,323	1,858	1,681	49,209	28,646
Ovig. *Bosmina*	10,446	4,883	13,384	39,809	90,147	29,990	796	-	1,681	12,142	9,908
Daphnia l.	868	372	-	1,526	199	-	-	-	-	66	-
Ovig. *Daphnia l.*	-	-	-	-	-	-	-	-	-	-	-
Chydorinae	11,632	526,097	11,697	3,517	78,954	12,407	3,052	2,919	-	-	-
Total cladocerans	61,401	557,130	57,460	330,348	568,156	246,152	6,171	4,777	3,362	61,417	38,554
Total copepods + cladocerans	130,318	575,318	104,965	393,246	718,192	353,238	46,378	29,370	32,643	120,605	80,138

[a] No limnological sampling occurred in August

Appendix E4.–Average weighted biomass estimates (mg dry weight/m^2) of the major Black Lake zooplankton taxa, 2000–2010.

	2000	2001	2002	2003	2004	2005	2006[a]	2007[a]	2008[a]	2009	2010
Taxon	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average
Copepods:											
Epischura	7.29	1.57	3.55	3.59	21.24	14.29	-	28.30	-	3.20	2.96
Diaptomus	8.86	3.85	46.95	42.19	31.52	8.26	1.11	8.70	-	5.40	7.05
Ovig. Diaptomu	-	-	-	-	-	-	-		-	-	1.16
Eurytemora	-	-	-	-	-	-	-		-	-	0.99
Cyclops	32.09	9.12	36.04	18.30	35.75	44.28	22.11	10.40	13.79	24.00	12.46
Ovig. Cyclops	-	-	-	-	-	-	-		-	-	0.38
Harpaticus	-	0.89	-	0.35	-	-	0.17		-	-	0.09
Total copepods	48.24	15.43	86.54	64.43	88.51	66.83	23.39	47.40	13.79	32.60	25.0
Cladocerans:											
Bosmina	32.86	15.80	65.10	290.05	365.58	180.73	2.14	1.00	1.45	49.50	25.00
Ovigerous *Bosm*	13.49	5.18	45.07	77.61	125.78	43.00	0.83		2.58	19.80	12.28
Daphnia longi	0.46	0.10	-	2.29	0.05	-	-		-	-	-
Holopedium	-	-	-	-	-	-	-		-	-	0.77
Chydorinae	6.59	5.05	16.15	2.38	40.46	8.66	1.8	6.20	-	-	-
Total cladocerans	53.40	26.13	125.64	186.16	531.87	232.39	4.77	7.20	4.03	69.30	38.10
Total Biomass	101.64	41.56	162.42	218.38	620.38	299.22	28.16	54.60	17.82	101.9	63.00

[a] No limnological sampling occurred in August

Appendix E5.–Seasonal average number of zooplankton per m^2 from Chignik Lake, by year, 2000–2010.

Taxon	2000 Seasonal average	2001 Seasonal average	2002 Seasonal average	2003 Seasonal average	2004 Seasonal average	2005 Seasonal average	2006[a] Seasonal average	2007[a] Seasonal average	2008[a] Seasonal average	2009 Seasonal average	2010 Seasonal average
Copepods:											
Epischura	38,354	9,249	34,939	70,621	67,163	51,946	6,842	3,981	10,350	5,139	10,139
Ovigerous *Epischura*	398	53	-	-	-	-	-	-	-	-	-
Diaptomus	12,988	15,552	25,557	62,275	45,467	49,367	17,350	4,305	14,265	46,038	32,733
Ovigerous *Diaptomus*	780	106	2,760	1,742	3,605	2,816	1,393	619	1,592	2,303	1,945
Eurytemora											2,223
Cyclops	172,192	38,767	151,287	37,726	140,871	120,322	175,889	327,406	87,331	130,339	92,755
Ovigerous *Cyclops*	1,975	4,399	9,713	1,393	4,532	10,388	24,648	1,150	2,720	9,946	3,759
Harpaticus	355	292	703	531	1,078	348	1,335	1,062	100	672	993
Napulii	46,439	12,812	75,588	55,971	73,733	115,371	87,024	23,664	37,097	48,066	35,065
Total copepods:	273,481	81,230	300,549	230,258	336,447	350,559	314,482	362,187	153,455	225,277	179,612
Cladocerans:											
Bosmina	58,978	31,356	56,091	73,448	59,929	88,990	74,459	4,453	38,125	21,939	39,697
Ovigerous *Bosmina*	14,394	4,386	15,698	14,358	8,944	24,968	16,956	575	9,372	1,989	3,621
Daphnia longiremis	9,157	1,858	17,003	68,073	29,824	15,787	22,805	8,139	11,968	43,643	8,631
Ovigerous *Daphnia longirem*	1,312	53	8,373	7,086	7,501	6,336	6,919	2,861	2,189	13,854	1,866
Chydorinae	3,989	24,728	9,129	1,115	8,373	6,179	-	3,340	1,062	-	-
Total cladocerans:	87,830	62,381	106,294	164,079	114,570	142,259	121,139	19,367	62,716	80,928	53,815
Total Copepods + Cladocerans	361,311	143,611	406,843	394,337	451,017	492,818	435,621	381,554	216,171	306,205	233,427

[a] No limnological sampling occurred in August

Appendix E6.–Average weighted biomass estimates (mg dry weight/m^2) of the major Chignik Lake zooplankton taxa by year, 2000–2010.

	2000	2001	2002	2003	2004	2005	2006[a]	2007[a]	2008[a]	2009	2010
Taxon	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average	Weighted average
Copepods											
Epischura	43.4	18.0	32.6	42.1	49.5	43.4	5.5	8.1	11.3	3.0	8.1
Ovigerous *Epischura*	3.0	0.3	-	-	-	-	-	-	-	-	-
Diaptomus	82.2	44.5	114.1	148.9	92.1	121.3	37.7	53.2	109.6	56.5	101.1
Ovigerous *Diaptomus*	9.4	0.3	27.3	8.6	22.2	23.1	28.4	89.0	-	10.0	9.4
Eurytemora	-	-	-	-	-	-	-	-	-		8.2
Ovigerous *Eurytemora*	-	-	-	-	-	-	-	-	-		-
Cyclops	250.1	128.1	179.0	46.1	155.5	153.9	300.7	557.8	147.2	191.6	123.4
Ovigerous *Cyclops*	10.4	33.5	58.8	5.7	20.4	49.3	138.7	69.0	10.1	28.3	20.6
Harpaticus	0.3	0.6	0.9	0.4	0.6	0.2	1.0	4.3	0.1	0.2	0.4
Total Copepods:	398.8	225.3	412.7	251.9	340.2	391.2	463.1	781.5	278.3	289.5	271.2
Cladocerans											
Bosmina	76.1	27.4	55.7	85.5	49.5	79.4	36.8	11.2	18.9	15.5	32.1
Ovigerous *Bosmina*	27.9	6.0	25.1	26.4	11.4	31.0	12.2	12.0	12.0	1.9	5.5
Daphnia longiremis	12.6	5.2	22.2	42.7	37.2	19.2	10.2	31.0	6.9	34.3	12.0
Ovigerous *Daphnia lon*	3.4	0.4	29.6	23.2	23.6	19.2	2.8	32.5	6.4	28.8	5.6
Chydorinae	3.6	2.2	6.9	0.7	6.0	4.0	6.6	4.6	0.3		-
Total Cladocerans:	123.5	41.2	139.6	178.5	127.7	152.8	68.6	91.3	44.6	80.5	55.2
Total Biomass	522.3	266.6	552.3	430.4	467.9	544.0	586.1	872.8	322.8	370.0	326.4

[a] No limnological sampling occurred in August

APPENDIX F. DISTRIBUTION LIST

Appendix F1.–Distribution List

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