

The 2015 Chignik River Sockeye Salmon Smolt Outmigration: An Analysis of the Population and Lake Rearing Conditions

by

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and

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Divisions of Sport Fish and Commercial Fisheries



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Weights and measures (metric)		General		Mathematics, statistics		
centimeter	cm	Alaska Administrative Code	AAC	all standard mathematical signs, symbols and abbreviations		
deciliter	dL	all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.	alternate hypothesis	H _A	
gram	g	all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.	base of natural logarithm	e	
hectare	ha			catch per unit effort	CPUE	
kilogram	kg			coefficient of variation	CV	
kilometer	km	at	@	common test statistics	(F, t, χ^2 , etc.)	
liter	L			confidence interval	CI	
meter	m			correlation coefficient		
milliliter	mL	compass directions:		(multiple)	R	
millimeter	mm	east	E	correlation coefficient		
Weights and measures (English)		north	N	(simple)	r	
	cubic feet per second	ft³/s	south	S	covariance	cov
	foot	ft	west	W	degree (angular)	°
	gallon	gal	copyright	©	degrees of freedom	df
	inch	in	corporate suffixes:		expected value	E
	mile	mi	Company	Co.	greater than	>
	nautical mile	nmi	Corporation	Corp.	greater than or equal to	≥
	ounce	oz	Incorporated	Inc.	harvest per unit effort	HPUE
	pound	lb	Limited	Ltd.	less than	<
	quart	qt	District of Columbia	D.C.	less than or equal to	≤
yard	yd	et alii (and others)	et al.	logarithm (natural)	ln	
Time and temperature		et cetera (and so forth)	etc.	logarithm (base 10)	log	
		exempli gratia		logarithm (specify base)	log ₂ , etc.	
	day	d	(for example)	e.g.	minute (angular)	'
	degrees Celsius	°C	Federal Information Code	FIC	not significant	NS
	degrees Fahrenheit	°F	id est (that is)	i.e.	null hypothesis	H ₀
	degrees kelvin	K	latitude or longitude	lat or long	percent	%
	hour	h	monetary symbols		probability	P
	minute	min	(U.S.)	\$, ¢	probability of a type I error	
	second	s	months (tables and figures): first three		(rejection of the null hypothesis when true)	α
	Physics and chemistry		letters	Jan,...,Dec	probability of a type II error	
all atomic symbols		registered trademark	®	(acceptance of the null hypothesis when false)	β	
alternating current	AC	trademark	™	second (angular)	"	
ampere	A	United States		standard deviation	SD	
calorie	cal	(adjective)	U.S.	standard error	SE	
direct current	DC	United States of America (noun)	USA	variance		
hertz	Hz	U.S.C.	United States Code	population sample	Var var	
horsepower	hp					
hydrogen ion activity (negative log of)	pH					
parts per million	ppm	U.S. state	use two-letter abbreviations			
parts per thousand	ppt, ‰		(e.g., AK, WA)			
volts	V					
watts	W					

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**THE 2015 CHIGNIK RIVER SOCKEYE SALMON SMOLT
OUTMIGRATION: AN ANALYSIS OF THE POPULATION AND LAKE
REARING CONDITIONS**

by
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ABSTRACT

This report describes the results of the sockeye salmon *Oncorhynchus nerka* smolt monitoring and enumeration project conducted by the Alaska Department of Fish and Game in the Chignik River system in 2015. The research was designed to estimate population size and age structure of outmigrating smolt, assess fish body condition, describe limnetic habitat conditions and forage base in rearing lakes, collect samples for future genetic stock identification analysis, and provide data for the Chignik River preseason adult sockeye salmon forecast. The abundance of sockeye salmon smolt was estimated using a rotary-screw trap array and mark-recapture techniques. In 2015, a total of 9.4 million (95% CI 6.94 million to 11.87 million) sockeye salmon smolt were estimated to have outmigrated from April 17 to June 15. Of these, 133,103 (1.4%) were freshwater-age-0; 7.15 million (76.0%) were freshwater-age-1; 2.11 million (22.4%) were freshwater-age-2; and approximately 11,860 (<1%) were freshwater-age-3 smolt. Limnology surveys were conducted in Chignik Lake monthly from May through September and in Black Lake in May, June, and July 2015 to describe physical characteristics, nutrient availability, phytoplankton biomass, and zooplankton forage available to rearing juvenile sockeye salmon. Smolt were of below-average body condition and zooplankton biomass was slightly lower in both lakes compared to 2014. The smolt-based forecast predicts a total adult run of 2.9 million sockeye salmon in 2016. Findings from this project are key to understanding effects of escapement abundance and environmental changes on sockeye salmon population dynamics in the Chignik River system.

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

INTRODUCTION

Located on the southern side of the Alaska Peninsula in western Alaska, the Chignik River system produces the vast majority of the sockeye salmon *Oncorhynchus nerka* in the Chignik Management Area (CMA; Wilburn and Stumpf 2016). The salmon resources of this area are important for local residents, and all 5 species of North American Pacific salmon are commercially harvested in the CMA: Chinook *O. tshawytscha*, sockeye *O. nerka*, coho *O. kisutch*, pink *O. gorbuscha*, and chum *O. keta* salmon. The exvessel value for the 2015 salmon harvest in the CMA totaled approximately \$7.88 million. Runs of sockeye salmon are the primary commercial and subsistence resource in the area, while Chinook and coho salmon are targeted in area sport fisheries.

The Chignik watershed consists of a lagoon, two large lakes, and several tributaries that provide rearing habitat for juvenile salmon (Figure 1). Black Lake, at the head of the system, has a surface area of approximately 41.1 km² and is shallow (mean depth 1.5 m), turbid, and surrounded by low relief. Black Lake drains via the Black River into Chignik Lake, which is deeper (maximum depth 64 m), and surrounded by mountains. Chignik Lake then drains via the Chignik River into Chignik Lagoon and into the Gulf of Alaska (Narver 1966; Dahlberg 1968; Chasco et al. 2003). Chignik Lagoon is a semi-enclosed estuary with salinities ranging from full marine seawater at the outer spit to nearly freshwater conditions at the head of the lagoon (Simmons et al. 2013b).

Each lake and associated tributaries maintains its own genetically distinct runs of adult sockeye salmon (Templin et al. 1999; Creelman et al. 2011). Early-run sockeye salmon enter the river from June through July and spawn in Black Lake and its tributaries. Late-run sockeye salmon return from early July through the late fall and spawn in the tributaries and shoals of Chignik Lake. The early run has a biological escapement goal (BEG) range of 350,000–450,000 fish, while the late run has a sustainable escapement goal (SEG) range of 200,000–400,000 fish, with an additional 50,000 fish inriver run goal (IRRG) in August and between September 1 and 15 (Schaberg et al. 2015).

Over the past twenty years, annual runs of sockeye salmon to the Chignik River have shown periods of relatively high productivity in the late 1990s, followed by low productivity from approximately 2001–2008, and higher productivity since 2008 (with the notable exception of 2014; Figure 2). Black Lake (early run) sockeye salmon runs have been more variable over the past twenty years (average run size 1,290,587 fish, minimum run 410,134 fish in 2014, maximum run 2,394,072 fish in 2011) than Chignik Lake (late run) sockeye salmon (average run size of 1,084,575 fish, minimum run 405,402 fish in 2004, maximum run 1,964,900 fish in 1999).

Historically, smolt investigations were conducted throughout Alaska in the 1980s, but due to budget cuts, statistical uncertainty, and apparent usefulness of abundance estimates in large, high-velocity systems, many were discontinued, or methods of enumeration changed. Interest in smolt data renewed in the mid-2000s due to increased discussion of escapement goals after the Alaska Board of Fisheries adopted the Policy for the Statewide Escapement Goals (5 AAC 39.223). In the most recent decade, juvenile salmon projects have increasingly been recognized as priority research programs throughout Alaska and the Pacific Northwest, as scientists and other stakeholder groups identify the need for freshwater investigations (for example, see DeCino 2014, Duesterloh 2007, Gerken 2013, Loewen 2014, Nemeth 2014, Thomsen and Ruhl 2015) and data on salmon early life stages.

Smolt research provides information used in life-history brood tables needed to improve forecasts, evaluate escapement goals, and examine effects of ocean conditions on stock productivity. Alaska salmon fisheries are managed to achieve escapement goals that provide for sustained yields, and production curves and biological reference points are often estimated using spawner and adult return data. However, much of the variability in adult returns results from density-independent marine survival rates that tend to vary over long time scales. Information on spawner abundances can be confounded with ocean productivity. Estimation of production curves using smolt data can help reduce these confounding effects. The Alaska Department of Fish and Game (ADF&G) has monitored the sockeye salmon smolt outmigration in the Chignik River annually since 1994, and collected data has been used to gauge the health of smolt leaving the system, estimate age composition of the outmigrating population and estimate marine survival. The Chignik sockeye salmon smolt project is unique in that it has been conducted annually since 1994, resulting in a nearly unparalleled dataset within Alaska (Skilak and Kenai lakes on Alaska's Kenai Peninsula and certain rivers in Bristol Bay have also had smolt investigations since the mid-1980s, but enumeration methodology has varied within that time frame).

Through long-term monitoring of sockeye salmon smolt, variations in population abundance and characteristics in the Chignik River watershed have been documented. For example, estimates of smolt outmigrations from the Chignik River have ranged from 2 to 40 million fish (Table 1). Additionally, Chignik sockeye salmon historically outmigrate beginning in early May, peaking in late May; however, peak outmigration in 2014 and 2015 shifted earlier in spring, occurring in late April and May. These early outmigrations coincided with warmer-than-average winter and spring air temperatures, a trend observed throughout the state in recent years. Furthermore, the smolt outmigration historically is predominantly composed of freshwater-age-1 and freshwater-age-2 individuals. Between 2005–2008, freshwater-age-0 and freshwater-age-3 smolt were observed in significant numbers, but in recent years the age composition of the outmigrating population has returned to primarily freshwater-age-1 and -2 smolt. Smolt age, weight, and

length (AWL) data are crucial elements of the freshwater production of salmon, and complement annual abundance estimates, helping to understand the overall health of the population leaving fresh water and to make inferences about survival during the early marine stages of the life cycle. Monitoring such population changes showcases the ability of salmon smolt, through shifts in population characteristics such as body size and weight, age structure, and abundance, to serve as sentinels of freshwater habitat change, which ultimately has consequences for adult returns.

Additionally, monitoring of sockeye salmon juveniles is valuable for improving the management of salmon. Analysis of genetic samples collected from 2009–2012 showed the proportions of each run to the outmigrating population varied significantly from year to year, and also acted as an early indicator of a weak early run in 2014. Outmigration data improves preseason forecasts of returning adult salmon and helps to understand the relationship between parent escapements and smolt production, and how this may change over time.

In the Chignik drainage, Black Lake is a highly productive, warm lake, which provides excellent potential rearing habitat. However, numerous studies show Black Lake water levels have decreased since the 1960s. Reported decreases in water surface elevation range from 0.5 to 2.2 meters resulting in volume reductions of 23% to 44% (Dahlberg 1968; CH2MHILL 1994; Elhakeem and Papanicolaou 2008; Griffiths et al. 2011; U.S. Army Corps of Engineers 2012). Black Lake water temperatures are highly influenced by air temperatures (Griffiths et al. 2011) and the most recent three years have recorded the highest summer temperatures since 1990 (2013–2015, as measured at the Cold Bay airport; Figure 3). As water temperatures increase, the metabolic demands on juvenile salmon exceed the benefits provided by Black Lake's productive habitat, and early-run sockeye salmon juveniles migrate to Chignik Lake. Chignik salmon fishery stakeholders have been concerned that the loss of Black Lake volume has led to a reduction in rearing habitat and forage, intensifying competition among stocks rearing in shared habitat in Chignik Lake.

Typically, juvenile sockeye salmon rear in freshwater for 1–3 years and migrate to sea after certain size thresholds are met, during specific seasons, and under certain environmental conditions. Prior to the 1960s, early-run sockeye salmon juveniles would rear and overwinter in Black Lake and its tributaries, migrating through Chignik Lake on their way to the marine environment. With the environmental changes in Black Lake habitat over the last 60 years, several studies indicate Black Lake juveniles move into Chignik Lake to overwinter, with potential deleterious effects on Chignik Lake juveniles (Ruggerone 2003; Westley and Hilborn 2006; Simmons et al. 2013a). Westley (2008) found the timing of downstream migration from Black Lake to Chignik Lake has shifted earlier in the year since the 1970s, from August to June and early July.

Salmon smolt outmigration may be triggered by warming springtime water temperatures ($>4^{\circ}\text{C}$), increased photoperiod (Clarke and Hirano 1995), and smolt size (Rice et al. 1994). Sockeye salmon rearing in Chignik and Black lakes are exposed to different types and levels of environmental stress that may influence their life history strategies, such as outmigration timing. Variables affecting growth in juvenile salmon include temperature, competition, food quality and availability, and water chemistry characteristics (Moyle and Cech 1988, Edmundson and Mazumder 2001, Quinn 2005). Over the course of the Chignik watershed smolt project, changes in outmigration timing and smolt condition have been observed, highlighting the variable nature of the freshwater habitat and the need for separation of freshwater factors and marine conditions in overall salmon productivity (St. Saviour and Shedd 2012; Loewen and Baechler 2014).

Competition for food and habitat can influence growth and survival rates as well as migratory behavior of juvenile sockeye salmon (Rice et al. 1994). Interactions between the early and late sockeye salmon runs and their freshwater habitat use by juveniles are not completely understood in the Chignik watershed, but density-dependent factors have proven to influence smolt migration timing and habitat use (Griffiths et al. 2013). Further, Westley (2008) found unhealthy juveniles moved out of Black Lake into Chignik Lake earlier than healthy fish, and growth rates of Black Lake fish remained slow even when in Chignik Lake (Griffiths et al. 2013). Simmons et al. (2013a) and Walsworth (2014) found some sockeye salmon juveniles reared in Chignik Lagoon in the summer, which is a productive source of food (Finkle and Bouwens 2003), then returned to Chignik River or Chignik Lake to overwinter.

Smolt outmigration data can also serve as an indicator of future run strength and overall stock status, and in recent years, abundance and age data from the enumeration project have been used to generate an adult sockeye salmon forecast for the Chignik River. Genetics samples from sockeye salmon smolt from 2006–2012 showed variable proportions of Black Lake and Chignik Lake stock-of-origin juveniles in the outmigrating population (Creelman 2010, St. Saviour and Shedd 2014, ADF&G *unpublished*). Further analysis shows variable marine survival rates by both age and stock-of-origin (ADF&G *unpublished*).

Information on freshwater rearing conditions is needed to determine what factors may affect sockeye salmon production and life-history traits in the Chignik River system. ADF&G has conducted comprehensive limnology studies of Chignik and Black lakes since 2000. In 2008, limnology was formally incorporated into the smolt enumeration project. To date, limnology and smolt data from the Chignik system have been used to describe top-down pressures on the Chignik Lake aquatic community, such as decreased zooplankton size of *Bosmina* from Chignik and Black lakes (Kyle 1992; Bouwens and Finkle 2003; US Army Corps of Engineers 2012). The limnology portion of this project is used to identify and understand the relationships among juvenile sockeye salmon and zooplankton relative to physical conditions such as temperature, turbidity, dissolved oxygen, and available nutrients. When taken in consideration with changes in outmigration population size and the long-term dataset of the Chignik River smolt project, continued investigation of the influence of changing physical and environmental factors upon the outmigration of juvenile sockeye salmon and subsequent adult production is an important part of understanding the overall health of the Chignik salmon system.

The 2015 field season was the 22nd year of the ADF&G Chignik River sockeye salmon smolt monitoring and enumeration project. This report presents data collected in 2015, compares the results of 2015 to previous years, and provides a 2016 adult sockeye salmon forecast based on smolt data.

OBJECTIVES

The objectives for the 2015 season were as follows:

1. Estimate the total number of Chignik River system outmigrating sockeye salmon smolt by freshwater-age class.
2. Describe outmigration timing and growth characteristics (length, weight, and body condition factor) of sockeye salmon smolt by freshwater-age class for the Chignik River system.
3. Describe the physical characteristics of Black and Chignik lakes, including temperature, dissolved oxygen, and light penetration profiles.

4. Describe the nutrient availability and phytoplankton communities and biomass of Black and Chignik lakes.
5. Quantify the zooplankton forage base available to juvenile sockeye salmon in Black and Chignik lakes.
6. Estimate Chignik sockeye salmon marine survival and build a smolt-based forecast model to estimate future runs.
7. Collect genetic samples from outmigrating sockeye salmon smolt for use in a stock identification study.

METHODS

The methods used by ADF&G in 2015 follow methods used consistently since 2008. For more detailed information on methods, please see Loewen and Baechler 2014, and Baechler and Loewen 2015.

STUDY SITE AND TRAP DESCRIPTION

Two rotary-screw traps were operated side by side to capture smolt outmigrating from the Chignik River system. The trapping site was located 8.6 km upstream from Chignik Lagoon and 1.9 km downstream from the outlet of Chignik Lake (56°15'26" N lat, 158°43'49" W long [North American Datum 1983]; Figure 4). The traps were located near a bend in the river with relatively high current velocity and narrow span.

Each trap consisted of a perforated aluminum cone (5 mm holes) mounted on two aluminum pontoons. The cone mouth diameter of the small trap was 1.5 m, and the cone mouth diameter of the large trap was 2.4 m. The small and large trap sampled an area of 0.73 m², and 2.0 m² of the river's cross-sectional profile, respectively. The river current rotated both cones from 5 to 10 revolutions per minute (RPM).

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

SMOLT ENUMERATION

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

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

Cummings 1984; Pennak 1989) were captured in the traps and were identified, counted and released.

TRAP EFFICIENCY AND SMOLT POPULATION ESTIMATES

To determine trap efficiency, mark–recapture experiments were conducted weekly, or as soon as possible after a shift in trap placement, river level, or observed change in outmigration magnitude, provided a sufficient number of smolt were captured to conduct a marking event. Between 1,200 and 3,030 sockeye salmon smolt were marked with Bismarck Brown-Y dye for each experiment. Marked smolt were transported upstream in aerated containers and released evenly across the breadth of the river approximately 1.3 km upstream of the traps (56°15'15" N lat, 158°44'51" W long; Figure 4). The marking event was performed so that the marked fish were released before midnight. The number of smolt recaptured in the traps was recorded for several days until recoveries ceased. Sockeye salmon smolt recaptured during mark–recapture experiments were recorded separately from unmarked smolt and excluded from daily total catch records to prevent double counting.

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

The trap efficiency E was calculated by

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

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

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

where

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

Variance was estimated by

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

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

$$\hat{U} = \sum_{h=1}^L \hat{U}_h, \quad (4)$$

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

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

and 95% confidence intervals were estimated from

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

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

The estimate of outmigrating smolt by age class (freshwater-age-0, -age-1, -age-2, and age-3) for each stratum h was determined by first calculating the proportion of each age class of smolt in the sample population as

$$\hat{\theta}_{jh} = \frac{A_{jh}}{A_h}, \quad (7)$$

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

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

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

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

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

$$v(\hat{U}_{jh}) = \hat{U}_j^2 v(\hat{\theta}_{jh}) + \hat{U}_{jh} v(\hat{U}_j). \quad (10)$$

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

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

with the variance estimated by

$$v(\hat{U}_j) = \sum_{h=1}^L v(\hat{U}_{jh}) \quad (12)$$

AGE, WEIGHT, LENGTH AND GENETICS SAMPLING

Forty sockeye salmon smolt were randomly collected for AWL sampling from the traps' live boxes 5 days per statistical week. All AWL sampled smolt were anesthetized with either a nonlethal (smolt > 100 mm) or lethal (smolt ≤ 100 mm) amount of tricaine methanesulfonate MS-222, FL was measured to the nearest 1 mm, and smolt weighed to the nearest 0.1 g. Scales were removed from the preferred area (International North Pacific Fisheries Commission 1963) and mounted on a microscope slide for age determination. Age was estimated from scales under 60X magnification and described using the European notation (Koo 1962). Condition factor (K) (Bagenal and Tesch 1978) was determined for each smolt sampled using

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

where K is smolt condition factor, W is weight in g, and L is FL in mm. Fin clips were collected from all AWL-sampled fish for genetic analysis and placed on Whatman filter paper to dry, following ADF&G Gene Conservation Lab protocol. As with samples collected in 2014, fin clips were sent to the ADF&G Gene Conservation Laboratory in Anchorage for storage until future analysis. A lethal dose of MS-222 was administered to 10 of the AWL-sampled fish, which were then preserved in ethanol with their abdominal cavity split for potential future stomach content analysis.

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

MARINE SURVIVAL ESTIMATES AND RUN FORECASTING

The total adult sockeye salmon run to the Chignik River system was calculated by summing Chignik River sockeye salmon escapement and harvest from the CMA. In years when a harvest occurs, 80% of the pre-July 26 sockeye salmon catch from the Southeastern District Mainland (SEDM) of the Alaska Peninsula Management Area (excluding Northwest Stepovak Section July 1–July 25), and 90% of the pre-July 26 catch from the Cape Igvak Section of the Kodiak Management Area are added to estimate the total Chignik run (5 AAC 09.360(g); 5 AAC 18.360(d)). Marine survival by age class and smolt produced per spawner from their respective brood years (BYs) were also calculated.

The total 2016 Chignik sockeye salmon run was forecasted using a simple linear regression model of total outmigrating smolt and ocean-age-2 and -3 adult returns, as well as median returns of other ocean-age classes in the most recent 17 years. Data from 1996 and 2007–2008 were excluded due to unrealistic estimates of marine survival and anomalous adult runs. The model was evaluated using standard regression diagnostics and tested for autocorrelation by examining residual plots and Durbin-Watson statistics. This smolt-based forecast is separate from the formal forecast (Brenner et al. *in prep*) which uses adult age-class sibling relationships and escapement data, and is stock-specific.

LIMNOLOGY

Limnology data were collected at one sampling station on Black Lake and four stations on Chignik Lake (Figure 5). Sampling occurred monthly from May through September when weather allowed. 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); for further details see Loewen and Baechler 2014, and Baechler and Loewen 2015.

Dissolved Oxygen, Light, and Temperature

Water temperature (°C) and dissolved oxygen (mg/L) levels were measured with a YSI Pro ODO meter. Measurements of photosynthetically active radiation ($\mu\text{mol}/\text{m}^2/\text{sec}$) were taken with a Li-Cor LI-250A photometer. The mean euphotic zone depth (EZD) was calculated for each lake (Koenings et al. 1987; Koenings and Kyle 1997). One-meter temperature and dissolved oxygen measurements were compared to assess the physical conditions in the euphotic zones of each lake. Secchi depth readings were collected from each station to measure water transparency.

Water Sampling

A Van Dorn sampler was used to collect approximately 8 liters of water from a depth of 1 m from each lake and from a depth of 29 m at each of two stations in Chignik Lake. Water sampling and processing techniques have been consistent since 2000 and follow protocols outlined in Finkle (2007). Water analyses were performed at the Chignik field laboratory for pH and alkalinity and at the ADF&G Kodiak Island Limnology Laboratory (KILL) for total phosphorus (TP), total ammonia (TA), nitrate + nitrite, total filterable phosphorus (TFP), filterable reactive phosphorus (FRP), chlorophyll *a*, and phaeophytin *a*. Nutrient and photosynthetic pigment analyses were conducted at KILL using a SEAL AutoAnalyser 3 HR; methods followed the equipment protocol. Total Kjeldahl nitrogen (TKN) was analyzed at the University of Georgia, Agricultural and Environmental Service Laboratories, Feed and Environmental Water Laboratory in Athens, GA.

Zooplankton

One vertical zooplankton tow was made at each limnology station with a 0.2 m diameter, 153 micron net from 1 meter above the lake bottom to the surface. Subsamples of zooplankton were keyed to genus or species and counted on a 1mL Sedgewick-Rafter counting slide, with a minimum of 3 replications per 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).

BEACH SEINING IN BLACK LAKE AND CHIGNIK LAGOON

Once per month, 4 sites each in Black Lake and Chignik Lagoon were sampled with a 3 mm mesh, 10 m long, 1 m deep beach seine (Figures 5 and 6). All species caught were identified and enumerated. From each site, 20 sockeye and 20 coho smolts from each site were anesthetized with MS-222 and brought back to the lab for AWL sampling. If possible, up to 20 additional sockeye and 20 coho salmon smolts were measured at each site and released.

RESULTS

SMOLT OUTMIGRATION TIMING AND POPULATION ESTIMATES

In 2015, a total of 9,402,309 sockeye salmon smolt (95% CI 6,935,873 fish to 11,868,745 fish; Table 1, Figure 7) were estimated to have outmigrated from April 17 to June 15. Of these, 133,103 fish (1.4%) were freshwater-age-0; 7,149,366 fish (76.0%) were freshwater-age-1; 2,107,981 fish (22.4%) were freshwater-age-2; and approximately 11,860 fish (<1%) were freshwater-age-3 smolt.

The majority of fish outmigrated from late April to mid-May (Table 2, Figures 8 and 15, Appendix A1 and A2). The largest nightly outmigration was observed April 21, on an evening with very strong overnight winds blowing downriver. By May 6, approximately 50% (4.7 million) of the total smolt had outmigrated. Not including trap catches from April 21, catches through the entirety of the season remained fairly constant (mean daily catch 908 sockeye salmon smolt).

TRAPPING EFFORT AND CATCH

The smolt traps were in place for a total of 60 days, beginning on April 17. During 24 hours in June, the small trap was removed from the water for repairs. The duration of the 2015 trapping season was average (mean season duration since 2000 = 60 days). Trapping was discontinued at noon on June 16, after a period of 10 days near or below 1% of the total season catch each night.

A total of 63,074 sockeye salmon smolt were captured in the traps between smolt days April 17 and June 15. Daily catch of all species is reported in Appendix A1. The small screw trap caught approximately 37% of the total sockeye salmon smolt catch, and the large trap 63% (Appendix A2).

TRAP EFFICIENCY ESTIMATES

Mark-recapture experiments were conducted on 7 occasions: April 21 and 26; May 8, 13, 19, and 25; and June 5 (Table 3; Appendix A1). Over 14,400 smolt were marked and released, and a total of 112 sockeye salmon smolt were recaptured in total. Trap efficiency estimates per stratum ranged from 0.45% to 1.45 (Table 3, Appendix A1). The majority of recaptured marked smolt were caught within the first 24 hours of release.

AGE, WEIGHT, AND LENGTH DATA

A total of 1,716 usable samples were collected from sockeye salmon smolt for AWL data. Freshwater-age-1 and freshwater-age-2 smolt made up the majority of the outmigration (Tables 1 and 2; Figure 9). Sockeye salmon fry (<45 mm FL) were captured throughout the trapping season but were most abundant in April.

The mean length, weight, and condition factor K of sampled smolt is shown in Table 4, and Figures 10 and 11. Condition factor increased throughout the season for sampled fish of all age classes, although it was more variable for freshwater-age-2 smolt than freshwater-age-1 smolt (freshwater-age-3 smolt were such a small proportion of the outmigrating population that trends were not discernible). Length, weight and condition factor K information weighted by sample size and weekly outmigrating population size is presented in Appendix A2.

PHYSICAL DATA

Water depth measured at the trap location ranged from 17 cm to 72 cm. The beginning of the season was dominated by lower water levels, but river height rose quickly during the latter half of May. Water temperature was first observed at 2.4°C on April 20 and reached an observed maximum of 9.8°C on June 16, the final day of the season (Appendix B1 and B2). Unusual south and southeast winds (upriver) and low water levels dominated the 2015 season.

ADULT RUN FORECAST

The smolt-based regression model forecasts a 2016 total adult run of 2.13 million sockeye salmon (80% prediction interval 1.0 to 3.3 million), compared to the formal adult forecast, which predicts a run of 2.91 million sockeye salmon (Brenner et al. *in prep*).

LIMNOLOGY

Poor weather and low water levels prevented sampling in August in Black Lake. Sampling was conducted in Black Lake on May 31, June 22, and July 8 and in Chignik Lake on May 12, June 13, July 10, August 17, and September 13. Comparisons with historical limnological data are in Appendices C1 and C2.

Black Lake

Temperature, Dissolved Oxygen, and Light

The average 1 m temperature in Black Lake was measured at 11.8°C in May, increasing to 15.1°C in June, and 13.7°C in July, whereas dissolved oxygen level at the 1 m depth was highest in May at 11.1 mg/L and lowest in June at 10.2 mg/L (Figure 12). Light penetrated the majority of the water column in Black Lake during the 2015 sampling season. The ESD (3.50 m) of Black Lake was near its maximum depth (4.2 m) throughout the entire sampling season. The mean lake depth (1.9 m) was used to calculate the euphotic volume (EV) of $78.09 \times 10^6 \text{ m}^3$ (Table 5; Figure 14). Mean Secchi depth readings were 0.98 m.

Water Quality Parameters, Nutrient Levels, and Photosynthetic Pigments

Mean monthly and annual pH, alkalinity, TP, TFP, FRP, TKN, ammonia, nitrate + nitrite, Silicon, chlorophyll *a*, and phaeophytin *a* measurements from Black Lake in 2015 are shown in Table 6 and comparisons with previous years in Appendix C1.

Zooplankton

Zooplankton samples were only available from May and July collections. Cladocerans were more abundant in Black Lake than copepods (Table 7), and *Bosmina* was the most abundant by both number and biomass. In the two samples obtained, *Cyclops* was the most prevalent copepod genera. Copepod biomass was greatest in July and was composed mostly of *Cyclops* (10.31 mg/m² weighted average) and *Eurytemora* (11.33 mg/m² weighted average) in both collected samples. The total weighted average copepod biomass was less than cladoceran biomass (Table 8; Appendix C4). However, obtaining only two samples throughout the season prevents a full analysis of the zooplankton community throughout the season. Average weighted lengths of the major non-egg-bearing zooplankton in Black Lake were 0.53 mm for *Cyclops*, 0.62 mm for *Eurytemora*, and 0.28 mm for *Bosmina* (Table 9).

Chignik Lake

Temperature, Dissolved Oxygen, and Light

The average 1 m temperature in Chignik Lake increased from 4.5°C on May 12 to 12.3°C on August 17 and decreased to 11.6°C on September 13 (Figure 13). Dissolved oxygen levels decreased from 14.2 mg/L to 10.6 mg/L and increased to 11.1 mg/L over the same time period. Temperature levels were similar throughout the water column at each sampling date, with no more than 4.3°C difference between surface and 50 m (August 17). Dissolved oxygen levels were similar throughout the water column from May through the end of September.

EZD varied between sampling dates, peaked during the month of August, and averaged 6.67 m. Heavy rains in July made Chignik Lake murky for a period of several weeks. The EV in Chignik Lake averaged $235.46 \times 10^6 \text{ m}^3$ (Table 5; Figure 14). Mean Secchi depth readings were 1.66 m.

Water Quality Parameters, Nutrient Levels, and Photosynthetic Pigments

Mean monthly and annual pH, alkalinity, TP, TFP, FRP, TKN, ammonia, nitrate + nitrite, Silicon, chlorophyll *a*, and phaeophytin *a* measurements from Chignik Lake in 2015 are shown in Table 10, and comparisons with previous years are provided in Appendix C2.

Zooplankton

Copepods were more abundant than cladocerans throughout the entirety of the 2015 sampling season (May through September). The seasonal abundance of copepods was also greater than cladocerans. *Cyclops*, *Eurytemora*, and nauplii were the most abundant genera of copepods. *Daphnia* and *Bosmina* were the most common cladoceran genera in Chignik Lake (Table 11; Appendix C5).

Copepod biomass was composed predominantly of *Cyclops* in May and June. Beginning in July and continuing through September, copepod biomass was composed primarily of *Eurytemora*. Cladoceran biomass was composed primarily of *Daphnia* with greatest biomass in September. The total weighted seasonal average copepod biomass was greater than the cladoceran seasonal average biomass (Table 12; Appendix C6).

Average weighted seasonal lengths of the major non-egg-bearing zooplankton in Chignik Lake are shown in Table 13. Ovigerous zooplankton were, on average, longer than non-egg-bearing individuals.

BEACH SEINING IN BLACK LAKE AND CHIGNIK LAGOON

Black Lake

Four sites were sampled in Black Lake in May (Figure 6), with a total catch of 87 sockeye salmon juveniles, of which 40 were sampled for AWL. Poor weather and lack of staffing prevented sampling in June, and 3 sites were sampled in July with a total catch of 34 sockeye salmon juveniles (Tables 14 and 15). Only one site was sampled in August, and no sockeye salmon juveniles were caught.

Chignik Lagoon

All sites were sampled in each month in Chignik Lagoon, with the exception of site 3 in August, due to rough weather. The majority of sockeye salmon juveniles were caught in May (799 juveniles, Table 14), with fewer fish caught later in the season. Smolt of freshwater-age-0, -1,

and -2 were captured in Chignik Lagoon, whereas the majority of fish caught in Black Lake were freshwater-age-0 (Table 15). Fish length increased for all age classes through the season in Chignik Lagoon (Table 16), with the exception of sampled freshwater-age-1 fish in August. Tables of each seining effort and catches from 2009–2015 are presented in Appendix D.

DISCUSSION

SOCKEYE SALMON SMOLT POPULATION ESTIMATES AND OUTMIGRATION TIMING

The point estimate of the 2015 total sockeye salmon smolt outmigration (9.4 million fish) was below the 20-year average (14.7 million fish; Table 1, Figure 7). Although the total estimated outmigration population is larger than in 2014, the total number of sockeye salmon smolt caught in the traps was lower than most years. Outmigration timing and magnitude in 2015 allowed for 7 mark–recapture events throughout the season with approximately 14,500 smolt marked and released, which is comparable to past years of the project. Therefore, a large percentage of the total outmigrating smolt population underwent the dye and release process. Recapture rates were comparable to past years, and mortality rates of held fish were much lower than those observed in 2014, likely a result of better smolt conditions observed in 2015.

The Chignik smolt enumeration conducts mark–recapture experiments every 5–7 days and applies the trap efficiency, per marking period, to smolt emigration numbers for each day between marking events. Every effort is put forward to conduct a mark–recapture event immediately after any major adjustments are applied to the trap position in the river due to changes in water level or flow, or observed changes in outmigration magnitude. Protocols for mark–recapture experiments in 2015 remained the same as previous years. Historic annual trap efficiencies average ~1–3% annually and individual mark–recapture events often are <1%. Low trap efficiencies are expected considering the size of the Chignik River and small proportion that the traps cover. Studies using up-looking sonar arrays in Bristol Bay, Alaska, have shown that outmigrating smolt use the upper 1 m of the water column, and are often bank-oriented (Nemeth et al. 2014); therefore, trap placement in Chignik River should be appropriate to capture outmigrating sockeye salmon smolt.

Using the mark–recapture model is a common practice in fisheries, especially for estimating the abundance of salmon populations, both smolts and adult. Capture probability can vary over time as a consequence of variable flow conditions that affect trap performance, changes in the composition or characteristics of the population during the migration season, seasonal changes in individual behavior, or changes in trap operation (Schwarz and Dempson 1994; Polos 1997; Plante et al. 1998). In systems where environmental conditions are likely to change more frequently throughout the season, monthly, weekly, and even daily marking events have been employed. As the frequency of marking events increase, the complexity and cost of the project also increase.

Since its inception, the Chignik smolt enumeration project has followed the protocol for mark–recapture estimation of smolt abundance as outlined in Carlson et al. (1998). Carlson et al. modified the basic Peterson mark–recapture estimation method, which uses one mark–recapture estimate and applies it to the entire smolt emigration. The Peterson method does not account for changes in several factors such as streamflow, temporal variation in the age structure and size of smolts, and changes in sampling methods by the researcher (Carlson et al. 1998). Carlson

proposed a modified version of the Peterson method: a 2-sample stratified design called the “simple stratified M-R design”. This model accounts for potential changes in trap efficiency but maintains a modest assumption of stratum consistency.

Concerns by the funding agency regarding the validity of Carlson’s method lead to a literature review of smolt mark–recapture techniques throughout Alaska and the Pacific Northwest. The majority of authors and researchers studying salmon adult and smolt populations using mark–recapture techniques use modifications of the Peterson method and a 1- or 2-sample stratified design. Rawson (1984) described mark–recapture work in the Kasilof River, Upper Thumb River, and Crescent Lake, all located in Alaska, using a technique similar to the 2-sample design, but more simple in that it only uses 1 sampling site and trap efficiency trials discretely paired with capture periods. More recent literature discusses the idea of using Bayesian P-splines to smooth estimates for time-stratified mark–recapture experiments (for example, Bonner and Schwarz 2011), but that is beyond the scope of the Chignik smolt project.

Stratified mark–recapture estimators provide a means of accommodating variability in capture probability and thus reducing the consequences of variability for the accuracy of the abundance estimate. The trap efficiencies from each of the marking events in the Chignik smolt enumeration project can be estimated as a “single release” of marked fish and a “single recovery” or the trap efficiencies can be directly attributed to an individual strata of a determined length (Rawson 1984). Bjorkstedt (2005) discussed the importance of maintaining unique marking and recovery periods by emphasizing the importance of being able to associate marked recaptured fish to the unique tagging period in which they were released. Otherwise, the accuracy of resulting abundance estimates “can be seriously degraded by undetected variation among marked individuals with respect to the interval between their release and subsequent susceptibility to recapture.” Carlson’s method attributes recaptured marks to discrete strata, with the marking event in the mid-point of the strata. Therefore, the trap efficiencies are applied to the outmigration conditions at both capture and release of dyed fish. The Chignik smolt enumeration project has historically applied trap efficiency estimates forward from the release date, which results in trap efficiencies being applied to the outmigrating population into which the dyed fish are released and with which they travel downstream.

At the request of the project funding agency, a population estimate of sockeye salmon outmigrating in 2015 was calculated by applying the trap efficiency of each event forward or backward to the midpoint of the time between the next nearest mark–recapture event. This calculation resulted in 321 fewer fish estimated in the total outmigration, which was not significantly different from the standard estimate calculated using Carlson’s equation. However, the age composition of the population did shift somewhat: 10,964 fewer fish were estimated as freshwater-age-0 fish (122,139 fish or 1.3% of the total population if calculated applying trap efficiencies forward and backward to the midpoint between releases, compared to 133,103 freshwater-age-0 fish or 1.42% of the total population using the standard estimation method). In addition, 166,531 fewer fish were estimated as freshwater-age-1, and 177,063 more fish were estimated as outmigrating freshwater-age-2 (2,285,043 fish versus 2,107,981 freshwater-age-2 in the standard estimate, or 22.4% of the total outmigrating population using the standard estimation method versus 24.3% of the total outmigrating population if calculated applying trap efficiencies forward and backward to the midpoint between releases). Specifically, in the week of May 3, fewer smolt would have been estimated to leave the system, while more freshwater-age-1 and -2 smolt would have been apportioned to the week of May 17 through May 23. Given

the lack of significant difference in total population estimate, and that there is little to no literature suggesting applying mark–recapture rates to the midpoint between events, the standard method of calculating population estimates based on specific strata between marking periods was maintained in 2015. As always, the reasoning behind weekly strata for mark–recapture experiments in the Chignik smolt project is to account for environmental and migratory changes. Mark–recapture events, as per the Chignik Smolt Enumeration Operational Plan, are to take place immediately (or as soon as possible) after any changes or modifications are made to the traps or the placement of traps in the river, or if changes in the outmigration magnitude are noticed by crew.

The outmigration timing of sockeye salmon smolt in 2015 was earlier than average (Figure 15). The largest night of outmigration occurred on April 21, when strong downstream winds may have pushed smolt out of the lake. The age composition of smolt captured this night was not significantly different than the surrounding samples, however, suggesting that these juveniles were actively outmigrating.

Although not designed to select for or against stickleback, questions regarding capture rates of stickleback have arisen during the duration of the sockeye salmon enumeration project. In 2015, 36,268 stickleback were captured, which is more than the 10-year average catch of 27,868 stickleback. However, annual stickleback catches vary wildly, ranging from 131,571 fish caught in the traps in 2006, to 6,715 fish caught in 2013, and the traps are not designed to target outmigrating stickleback, making interannual comparison of stickleback catches tenuous at best.

AGE, WEIGHT, AND CONDITION

The 2015 outmigrating smolt population comprised approximately 1.4% freshwater-age-0, 76% freshwater-age-1, 22% freshwater-age-2, and <1% freshwater-age-3 smolt. The Chignik River typically displays an outmigration pattern of older fish leaving the system sooner than younger fish, but freshwater-age-1 juveniles dominated the outmigration throughout the 2015 season.

In general, by age-class, fish were below average length, weight, and condition factor, although fish were larger, heavier, and of better condition factor than 2014 (Figure 16). Size-at-ocean-entry is generally accepted as a major factor in determining mortality rates for salmon smolts. Therefore, freshwater-age-1 smolt may experience higher mortality rates at sea than older smolt. Run reconstruction of adult returns and genetics composition of outmigrating smolt show that the majority of freshwater-age-2 smolt are of Chignik Lake origin, suggesting these fish take longer to reach an appropriate size and readiness for outmigration. Stock-specific AWL investigations, through use of genetic stock identification, would provide greater insight into the freshwater health and size-at-outmigration, and potential marine survival rates, of each run by age class.

Temperature also has a strong effect on smolt outmigration and condition at outmigration. Griffiths et al. (2011) showed air temperatures and water temperatures are closely coupled in Black Lake due to the shallow depth of the water body. Air temperatures may play a larger role in the condition and success of sockeye salmon juveniles in Black Lake, but during a very warm year such as 2015, overwintering juveniles in either lake would be affected. In warmer years, thermal stress may cause earlier outmigration of Black Lake juveniles into Chignik Lake (Finkle 2006; Westley et al. 2008). In 2015, fewer fry were captured in beach seines in Black Lake compared to 2014. However, the lack of data in July and August prevents full analysis of possible triggers of outmigration timing from Black Lake. Air temperatures in early spring 2015 were warm, following the warmest overwintering temperatures on record in 2014. These warm

winter conditions may be beneficial for recently emerged, overwintering fish in Black Lake, because a lack of ice cover may prevent hypoxic conditions (Ruggerone 1994). However, summer thermal regimes result in early and large outmigrations of fish that historically might have oversummered in the lake to take advantage of its productive habitat.

Unlike other systems where smolt leave the freshwater environment and enter directly into entirely marine nearshore feeding areas, the Chignik system has a large lagoon that acts as a transition zone between the freshwater and saltwater ecosystems. This provides a forage base of amphipods, pericardians, and other small crustaceans, which may alleviate some of the top-down pressure in Chignik Lake (Bouwens and Finkle 2003). Simmons et al. (2013b) found that sockeye salmon fry were abundant in Chignik Lagoon throughout the summer and that residency time was closely related to sockeye salmon length and age, with smaller fish remaining longer to achieve additional growth in body size before their migration to the marine environment. Similar to 2014, beach seine hauls in Chignik lagoon in May captured a large amount (>500) of sockeye smolt and fry, indicating these fish had already moved to the saline environment, possibly as a result of limited resources in the lake, or metabolic stresses as a result of unusually warm early-season temperatures. Under stressful environmental conditions, such as elevated temperatures and poor visibility, underyearling sockeye salmon may migrate to sea (Rice et al. 1994). Smolt and fry catches in the lagoon were low later in the season, and given the early outmigration, it is possible fish observed early in May were able to attain optimal body size and migrate to the marine environment earlier.

ZOOPLANKTON

Because only 2 zooplankton samples were obtained in Black Lake in 2015, comprehensive analysis of the zooplankton community is not possible. However, zooplankton density and biomass was higher than 2014 and continues to increase since low levels from 2006–2008. Historically, zooplankton density in Black Lake is usually dominated by copepods early in the season, decreasing from May to June, then peaking in late July or August (Finkle and Ruhl 2008). Cladocerans become the dominant zooplankton in Black Lake late in the summer when phytoplankton levels have increased (chlorophyll *a* from 1.5 to 10.4 μL , for example). The absence of these late-season samples in 2015 prevents meaningful insight to lake conditions for rearing fish in August and September, and results in a low seasonal average if compared to other years.

In Chignik Lake, the most recent 8 years have shown cyclical patterns of copepod abundance and biomass, with higher densities of copepods in odd years (2009, 2011, 2013, 2015). However, this pattern is not yet clearly linked to total smolt outmigration or annual *K* of outmigrating smolt. Future seasons of limnology, potentially linked with genetic stock identification, may provide more insight into whether this cyclic pattern of zooplankton abundance has a bearing on smolt production, or is simply an indicator of other dynamics in the lake such as changes in phytoplankton communities.

Chignik Lake zooplankton seasonal patterns are usually similar to those in Black Lake, with the exception that copepods remain dominant in Chignik Lake later into the season when overall zooplankton densities are greatest (Tables 9 and 12). Chignik Lake copepod populations historically are composed primarily of *Cyclops*, and the most abundant cladoceran is *Bosmina*. In 2015, *Eurytemora* and *Cyclops* were equally abundant when averaged throughout the entire season, although *Eurytemora* was most abundant in August. *Eurytemora* was identified in

samples in 1991, then again since 2010, and was extremely abundant in 2014. Although a known prey item for juvenile sockeye salmon in Chignik Lake as early as 1972 (Parr 1972 in Groot and Margolis 1991), this species had not historically been present in large numbers in Chignik Lake until 2010. Additionally, cladoceran density throughout the season was composed primarily of *Daphnia L.*, which is an important primary prey item for juvenile sockeye salmon (Kyle 1992; Honnold and Schrof 2001) and may be a more important indicator of lake forage activity. Further, *Daphnia* abundance and density has increased in Chignik Lake in the past three years, which may indicate a more robust rearing environment for juveniles.

Edmundson and Mazumder (2001) suggested that juvenile sockeye salmon starve when zooplankton biomass levels approach about 100 mg/m² and are fully satiated at levels above 1,000 mg/m². Zooplankton biomass had steadily increased from 2003-2007, but dropped again in 2008, probably due to flood effects. Low biomass levels observed in 2012 were likely due to grazing pressure by juveniles from the large early-run escapement in 2011. In the most recent 2 years, the overall zooplankton biomass in Chignik has been stable and the cladoceran biomass increased substantially (Loewen and Baechler 2015). Because cladocerans are a preferred food source for juvenile sockeye salmon, their abundance may be a strong indicator of potential juvenile sockeye salmon production (Koenings et al. 1987; Kyle 1992).

When competition is too great or rearing conditions are poor in the freshwater environment, the lagoon may provide important rearing habitat for juvenile sockeye salmon before continuing to the marine environment (Simmons et al. 2013a; Simmons et al. 2013b). Smolt entering the marine environment in good condition have been shown to have higher survival than those with lower *K* (Foerster 1954; Henderson and Cass 1991; Quinn 2005). Managing spawning levels of adult salmon to balance juvenile salmon populations and zooplankton levels in the lakes should help promote productive adult returns in future years. Although 2015 had a large escapement of adult sockeye salmon in both runs, the low early-run escapement in 2014 is likely to result in fewer-than-average juveniles rearing in Chignik Lake in 2015–2016, relative to recent years, which may offset potential deleterious density-dependent effects on rearing smolts.

LIMNOLOGY

In a separately funded project, ADF&G conducted a bathymetric survey of Black Lake using an autonomously operated vehicle in early August 2015. This survey updated the bathymetry map of the lake, including average and maximum depth of the main basin of the lake. This data is included in Figure 5.

Nutrient data can indicate limitations in aquatic environments. A ratio of total nitrogen (TN) to total phosphorous (TP) is commonly used to indicate nutrient status, and both are necessary for primary production at specific ratios (Wetzel 1983; University of Florida 2000). Nitrogen-phosphorous ratios of less than 10:1 indicate nitrogen limitations, whereas ratios greater than about 25:1 indicate phosphorus limitation (Wetzel 1983). Water quality data from 2015 indicated nutrient levels in both lakes fell into low to medium production (mesotrophic) levels as defined by several trophic state indices (Carlson 1977; Carlson and Simpson 1996) but were comparable to other Alaska lakes in the region (Schorf and Honnold 2003). The seasonally averaged TN:TP ratio for Black Lake was 23.3:1 in 2015, which is higher than 2014 levels and much higher than 2012 and 2011 levels. The seasonal average for Chignik Lake was 38.1:1 and was highest in May and lowest in September. This seasonally averaged ratio is greater than the 10-year average (19.2:1).

The quantity of photosynthetic pigments present in an aquatic system is related to the biomass of primary producers, and in a location such as Chignik, which can receive significant nutrients from terrestrial inputs as well as from marine-derived nutrients in returning adult salmon, may be a better indicator of the potential production level of the system. The ratio of chlorophyll *a* (associated with active cells) to phaeophytin *a* (the byproduct of photosynthesis associated with senescent cells) serves as an indicator of the algal community condition. High chlorophyll *a* to phaeophytin *a* ratios indicate there are adequate nutrients and suitable physical conditions for primary production within the lake. Conversely, low ratios may suggest that primary productivity is taxed. The ratio of chlorophyll *a* was below average in Chignik Lake this season (2015 ratio 2.51:1; 10-year average 5.9:1), but this may reflect the flooding that occurred in Chignik Lake in July, rather than overall strain on lake productivity. Changes in nutrients and forage bases can significantly impact higher trophic levels (Kyle et al. 1988; Milovskaya et al. 1998). Chignik Lake community dynamics are thought to be largely controlled by top-down pressures (Finkle 2006), although stochastic events such as flooding can impact the system, and a rearing population of juvenile salmon between June and August could have significantly impacted primary production levels. The seasonal pH levels in Black and Chignik lakes were slightly higher than historical seasonal averages from the 1960s (1960s Black Lake seasonal average pH = 7.42; 1960s Chignik Lake seasonal average pH = 7.27; Narver 1966), but well within a safe pH range for aquatic organisms.

MARINE SURVIVAL ESTIMATES

All adult sockeye salmon offspring from brood year (BY) 1991 through 2009 and most offspring from BY 2010 have returned to the Chignik River; overall marine survival has ranged from 6.6% for BY 1999 to 67% for BY 1993 (mean survival 28%; Table 17). The estimation of the 1993 and 1994 BY marine survival includes a portion of the outmigration estimate from 1996, which is considered an unrealistically low estimate (Edwards and Bouwens 2002). Additionally, it is likely that outmigration estimates were low in 2006 and 2008. When presented by outmigration year, marine survivals have ranged from 5% for outmigration year 2001 to 84% for outmigration year 2007, with a mean survival rate of 27% (Table 16). The very high marine survival estimate for outmigration year 2007 is a result of good ocean conditions, coupled with an unrealistically low smolt outmigration estimate. Smolt were much larger than average in 2007, so they entered the ocean in good condition and probably had higher survival than average (Figure 9). They also may have been stronger swimmers and been able to avoid the traps, resulting in biased-low smolt population estimates. Efficiency estimates would not necessarily have accounted for trap avoidance because trap catches were low for much of 2007 and did not allow for consistent mark-recapture experiments. A more realistic marine survival estimate came with the return of the 2009 outmigration year, which also had average *K* (Table 17).

BEACH SEINING OF JUVENILES

Black Lake

The majority of juveniles caught in beach seines in Black Lake were freshwater-age-0 fish, although 3 freshwater-age-1 fish were captured near the outlet of the lake in July. Freshwater-age-0 fish captured in July were longer and heavier than freshwater-age-0 fish captured in July in 2009-2013. Causes of downstream migration of Black Lake juveniles have been attributed to low winter oxygen levels (Ruggerone 1994), density dependence (Norver 1966, Parr 1972), and spring or summer temperatures (Finkle 2006). Water temperatures were actually cooler in July

than those measured in June in 2015, which may have allowed juveniles to remain longer in the lake before migrating downstream.

Chignik Lagoon

The freshwater/saltwater transition zone provided by estuary habitat can be important to the success of sockeye salmon smolt. A productive estuary provides necessary food resources and can offer refuge from predators such as fish and bird species. Chignik Lagoon may provide a source of food and habitat to offset competitive or stressful conditions in Chignik Lake.

From 2000 through 2006 (Finkle 2007) and 2009 through 2012 (ADF&G unpublished data), beach seine catches were greatest in late June or early July. However, in 2015 and 2014, largest catches in Chignik Lagoon beach seines occurred in May and June. When considered with changes in annual and winter temperatures, this may signal earlier outmigration timing shifts for sockeye salmon juveniles. The lack of fish in late-season beach seine hauls may indicate these fish have moved into the marine environment, or back into Chignik Lake. Simmons et al. (2013a) and Walsworth (2014) found some sockeye salmon juveniles reared in Chignik Lagoon in the summer, then returned to Chignik Lake to overwinter, although these fish were a small portion of the overall population that returned as adults. Further work involving isotopic analysis or genetic identification of Chignik Lagoon smolt might elucidate whether this rearing pattern is becoming a more important life history strategy, due to shifts in outmigration timing as a result of environmental changes or increased competition in Chignik Lake.

FORECASTS OF ADULT SALMON RETURNS

A smolt-based sockeye salmon forecast has been developed annually since 2002. Since its inception, the smolt-based forecast has overestimated the actual total sockeye salmon adult run to the Chignik system by as much as 107% (2004 forecast) and underestimated it by as much as 53% (2011 forecast). The 2015 forecast point estimate was 11% greater than the actual run. Forecast methods have included simple and multiple linear regressions of smolt outmigrants by age class to ocean-age class adult returns and multiple regressions of outmigrant-age class smolt and temperature to ocean-age class adult returns. The 2016 smolt-based forecast used total smolt outmigration estimates to predict a total adult run of 2.13 million, compared to the formal adult-based forecast total of 2.91 million.

The smolt-based forecasting method does not currently have the resolution to forecast by run because the stock-specific data series is relatively short (seven years of data from 2006–2012 have been analyzed). However, if continued, long-term genetic stock identification will provide a means for Chignik sockeye salmon smolt stock separation, stock-specific smolt-based forecasts, and smolt production estimates of each stock. For example, the genetic samples collected from smolt in 2011 indicated that adult returns of early-run sockeye salmon in 2014 would be weak due to the lack of freshwater-age-1 smolt of Black Lake origin, whereas samples from 2012 correctly pointed to a stronger overall run with relatively even numbers of early and late-run sockeye salmon. Continued analysis of samples collected from the smolt project will add valuable information to this dataset to provide stock-specific smolt-based forecasts and provide insight to freshwater effects on the population long before they become apparent in adult returns.

CONCLUSION

Reductions in Black Lake water volume and rearing habitat, along with increased air and water temperatures, have been occurring since the 1960s. Subsequent competition between Black Lake emigrants and Chignik Lake rearing smolt has been demonstrated (Parr 1972; Ruggerone 2003) and is probably stronger in years when Black Lake is warmer, due to increased and early outmigration of juveniles. High escapement and recruitment also likely have an effect on competition between stocks. Continued monitoring of smolt outmigration and limnology, including analysis of historical phytoplankton data, is the best way to detect changes in early life history strategies that may be deleterious to Chignik sockeye salmon fisheries, especially if winters of warm temperatures and lack of ice persist.

The sockeye salmon smolt enumeration project permits an evaluation of abundance and health associated with the freshwater portion of the sockeye salmon life cycle. When evaluated as part of a long-term monitoring program, the smolt information can be compared with adult spawner indices to describe potential ocean productivity and survival. Continuous, comprehensive long-term datasets of adult and smolt abundance estimates, such as are available from Chignik sockeye salmon, are rare and increasingly valuable as sentinels of change in the freshwater environment.

The smolt population estimate is a useful tool in differentiation of freshwater and marine survival rates, and the AWL data collected by the smolt project is a powerful metric to judge watershed productivity and carrying capacity. Condition factor by age class can provide useful insights to predicting marine survival rates. Size at ocean entry is typically understood as the main factor determining survival to adult; however, Friedland et al. (2014) found that growth shortly after smolt transition was a strong predictor of survival to adulthood in the Keogh River from 1977 to 1999. Furthermore, this growth was strongly correlated to sea-surface temperatures during outmigrating. In addition to AWL and condition factor information collected in season, investigating potential changes in growth patterns in ADF&G's adult ASL database might provide information on when growth bottlenecks or periods of increased mortality are occurring in the Chignik watershed.

Tissue samples were collected from outmigrating smolt from 2006–2012 to investigate stock-of-origin by age and outmigration timing. Analysis of these samples showed variability in timing, age class, and relative abundance, and were indicators of several important outcomes for adult populations, such as the low numbers of early-run sockeye salmon in 2014. Although samples have been collected from smolt since 2013, these have not been analyzed due to funding limitations. Future work to analyze these samples would provide greater insight into changes in stock abundance and health, and potentially allow for more detailed forecasts of adult returns. Similarly, samples from outmigrating smolt for stomach content analysis and from adult returns for isotopic composition have been collected, but a lack of funding has prevented any analysis of these samples.

Arguably the greatest long-term threat to Alaska salmon fisheries is climate warming. Ocean growth and survival of all species of Pacific salmon can be affected by periodic warm water events (such as El Niño) in local waters, and by cyclic changes in ocean conditions. For example, increased mortalities and reduced growth have been noted in Pacific salmon populations off Oregon and Washington after previous El Niño events. In recent years, warm ocean waters in the Gulf of Alaska have been linked to a lack of available food for seabirds and fish, with negative

implications for growth-at-sea and overall survival rates for juvenile salmon. Increased sea-surface temperatures in the summer and fall post-smoltification were also found to be negatively correlated with salmonid returns in BC (Friedlander et al. 2014), and warm waters and decreased food availability in nearshore marine may result in increased marine mortality. As summer thermal maximums increase, Black Lake sockeye salmon juveniles may find rearing habitat increasingly unavailable. However, the Chignik watershed provides a diverse matrix of rearing habitat to offset losses of rearing habitat in Black Lake, especially Chignik Lagoon. Understanding early life history requirements and key rearing habitat areas are critical components to maintain and manage habitat necessary for sustained production. Future work could include tagging juveniles with Passive Integrated Transponder (PIT) or acoustic tags to gain insight to their patterns of movement throughout the watershed as juveniles.

ADF&G has conducted the smolt enumeration project since 1994, formally incorporating the collection of limnology samples from both lakes in 2008, and has collected genetic samples since 2006. Taken together, the data set is a long and comprehensive time series, useful for identifying longer-term environmental changes that are occurring in the system. The smolt project has provided understanding of the mechanisms behind freshwater production and for enhancing management of the system. Data from this project are essential for monitoring the health of sockeye salmon in Chignik system because smolt outmigration information may be the only available means to link changes in run strength to freshwater, marine, or climate influences before they become apparent in adult returns.

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TABLES AND FIGURES

Table 1.—Chignik River outmigrating sockeye salmon smolt population estimates, by freshwater-age class, 1994–2015.

		Number of smolt						95% C.I.		
Year		Freshwater- age-0	Freshwater- age-1	Freshwater- age-2	Freshwater- age--3	Freshwater- age-4	Total	S.E.	Lower	Upper
1994	Numbers	0	7,263,054	4,270,636	0	0	11,533,690	1,332,321	8,922,341	14,145,038
	Percent	0.0	63.0	37.0	0.0	0.0	100.0			
1995	Numbers	735,916	2,843,222	5,178,450	0	0	8,757,588	1,753,022	5,321,664	12,193,512
	Percent	8.4	32.5	59.1	0.0	0.0	100.0			
1996	Numbers	80,245	1,200,793	731,099	5,018	0	2,017,155	318,522	1,392,852	2,641,459
	Percent	4.0	59.5	36.2	0.2	0.0	100.0			
1997	Numbers	528,846	11,172,150	13,738,356	122,289	0	25,561,641	2,962,497	19,755,145	31,368,136
	Percent	2.1	43.7	53.7	0.5	0.0	100.0			
1998	Numbers	75,560	5,790,587	20,374,245	158,056	0	26,398,448	3,834,506	18,882,817	33,914,080
	Percent	0.3	21.9	77.2	0.6	0.0	100.0			
1999	Numbers	73,364	12,705,935	8,221,631	78,798	0	21,079,728	3,070,060	15,062,412	27,097,045
	Percent	0.3	60.3	39.0	0.4	0.0	100.0			
2000	Numbers	1,270,101	8,047,526	4,645,121	160,017	0	14,122,765	1,924,922	10,349,918	17,895,611
	Percent	9.0	57.0	32.9	1.1	0.0	100.0			
2001	Numbers	521,546	18,940,752	5,024,666	516,723	5,671	25,009,358	5,042,604	15,125,854	34,892,862
	Percent	2.1	75.7	20.1	2.1	0.0	100.0			
2002	Numbers	440,947	13,980,423	2,223,996	72,184	0	16,717,551	2,112,220	12,577,007	20,856,909
	Percent	2.6	83.6	13.3	0.4	0.0	100.0			
2003	Numbers	155,047	5,146,278	1,449,494	0	0	6,750,819	527,041	5,717,820	7,783,819
	Percent	2.3	76.2	21.5	0.0	0.0	100.0			
2004	Numbers	244,206	6,172,902	2,239,716	0	0	8,656,824	1,219,278	6,267,039	11,046,609
	Percent	2.8	71.3	25.9	0.0	0.0	100.0			
2005	Numbers	859,211	2,075,681	1,468,208	32,889	0	4,435,988	1,034,892	2,407,600	6,464,376
	Percent	19.4	46.8	33.1	0.7	0.0	100.0			
2006	Numbers	1,744,370	2,849,043	2,847,624	119,614	0	7,560,651	2,280,536	3,090,799	12,030,502
	Percent	23.1	37.7	37.7	1.6	0.0	100.0			
2007	Numbers	9,286	1,926,682	1,028,865	0	0	2,964,833	969,567	1,064,482	4,865,184
	Percent	0.3	65.0	34.7	0.0	0.0	100.0			
2008	Numbers	1,017,498	3,309,894	987,928	41,136	0	5,356,455	605,266	4,170,134	6,542,777
	Percent	19.0	61.8	18.4	0.8	0.0	100.0			

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Table 1.–Page 2 of 2.

		Number of smolt							95% C.I.	
Year		Age-0	Age-1	Age-2	Age-3	Age-4	Total	S.E.	Lower	Upper
2009	Numbers	110,446	3,777,572	4,288,491	0	0	8,176,509	320,013	7,472,166	8,880,852
	Percent	1.4	46.2	52.4	0.0	0.0	100.0			
2010	Numbers	1,039,131	17,684,165	9,347,999	91,509	0	28,162,803	4,433,289	19,473,557	36,852,050
	Percent	3.7	62.8	33.2	0.3	0.0	100.0			
2011	Numbers	203,380	10,684,120	1,371,044	0	0	12,258,543	1,802,506	8,725,631	15,791,456
	Percent	1.7	87.2	11.2	0.0	0.0	100.0			
2012	Numbers	685,707	16,328,172	22,734,743	196,575	0	39,945,197	4,551,145	31,024,952	48,865,441
	Percent	1.7	40.9	56.9	0.5	0.0	100.0			
2013	Numbers	117,435	8,314,053	10,467,154	176,196	0	19,074,838	3,252,943	12,699,069	25,450,606
	Percent	0.6	43.6	54.9	0.9	0.0	100.0			
2014	Numbers	4,250	2,757,054	1,507,021	26,869	0	4,295,195	349,136	3,610,889	4,979,501
	Percent	0.1	64.2	35.1	0.6	0.0	100.0			
2015	Numbers	133,103	7,149,366	2,107,981	11,860	0	9,402,309	1,258,386	6,935,873	11,868,745
	Percent	1.4	76.0	22.4	0.1	0.0	100.0			

Table 2.—Estimated sockeye salmon smolt outmigration from the Chignik River in 2015 by freshwater-age class and statistical week.

Statistical Week	Date	Number of smolt								Total
		Freshwater-age-0	%	Freshwater-age-1	%	Freshwater-age-2	%	Freshwater-age-3	%	
16 ^a	12-Apr	930	1.3%	55,817	75.0%	17,675	23.8%	-	0.0%	74,423
17	19-Apr	15,414	0.4%	3,284,671	89.5%	369,938	10.1%	-	0.0%	3,670,023
18	26-Apr	23,918	3.0%	672,892	84.4%	100,455	12.6%	-	0.0%	797,266
19	3-May	25,210	5.0%	355,460	70.5%	123,529	24.5%	-	0.0%	504,199
20	10-May	11,584	1.0%	573,410	49.5%	567,618	49.0%	5,792	0.5%	1,158,403
21	17-May	-	0.0%	453,127	44.0%	576,707	56.0%	-	0.0%	1,029,834
22	24-May	-	0.0%	946,630	78.0%	260,930	21.5%	6,068	0.5%	1,213,628
23	31-May	2,543	0.5%	421,691	82.9%	84,440	16.6%	-	0.0%	508,674
24	7-Jun	43,686	12.0%	314,901	86.5%	5,461	1.5%	-	0.0%	364,047
25	14-Jun	9,817	12.0%	70,767	86.5%	1,227	1.5%	-	0.0%	81,811
Total		133,103	1.4%	7,149,366	76.0%	2,107,981	22.4%	11,860	0.1%	9,402,309

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

^a Statistical week 16 only includes data from April 17–April 19.

Table 3.—Results from mark–recapture tests performed on sockeye salmon smolt outmigrating from the Chignik River, 2015.

Date	Number released ^a	Total recaptures	Trap efficiency ^b
4/21-4/25	1,987	8	0.45%
4/26-5/7	2,598	12	0.50%
5/8-5/12	1,168	16	1.45%
5/13-5/18	2,996	28	0.97%
5/19-5/24	2,306	21	0.95%
5/25-6/4	1,611	8	0.56%
6/5-6/15	1803	19	1.11%
Total	14,469	112	0.86%

^a The number released accounts for delayed mortality.

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

Table 4.–Mean length, weight, and condition factor of sockeye salmon smolt samples from the Chignik River, by year and freshwater-age, 1994–2015.

Year	Age	Length (mm)			Weight (g)			Condition factor		
		Sample size	Mean	Standard error	Sample size	Mean	Standard error	Sample size	Mean	Standard error
1995	0	272	46	0.18	272	0.7	0.01	272	0.74	0.01
1996	0	125	49	0.45	113	1.0	0.03	113	0.82	0.01
1997	0	195	46	0.22	195	0.8	0.01	195	0.83	0.01
1998	0	15	45	0.96	15	0.7	0.03	15	0.73	0.03
1999	0	40	52	0.79	40	1.3	0.06	40	0.97	0.03
2000	0	223	60	0.52	223	2.1	0.05	223	0.91	0.01
2001	0	96	56	0.51	96	1.5	0.04	96	0.88	0.01
2002	0	217	49	0.27	217	1.2	0.02	217	0.98	0.01
2003	0	149	56	0.53	149	1.5	0.05	149	0.79	0.01
2004	0	347	56	0.44	347	1.7	0.05	347	0.91	0.01
2005	0	652	56	0.28	649	1.5	0.03	649	0.83	0.01
2006	0	427	52	0.24	427	1.0	0.02	427	0.70	0.01
2007	0	6	64	2.47	6	2.5	0.08	6	1.03	0.16
2008	0	568	53	0.17	566	1.1	0.01	566	0.76	0.01
2009	0	198	53	0.39	196	1.4	0.04	196	0.93	0.01
2010	0	128	54	0.48	128	1.2	0.04	128	0.78	0.01
2011	0	100	49	0.41	100	1.0	0.03	100	0.86	0.01
2012	0	129	52	0.35	129	0.9	0.02	129	0.65	0.01
2013	0	32	52	0.69	32	1.2	0.04	32	0.83	0.02
2014	0	115	48	0.28	115	0.9	0.02	115	0.79	0.01
2015	0	45	49	0.28	45	0.7	0.02	45	0.62	0.01
1994	1	1,715	67	0.16	1,706	2.3	0.02	1,706	0.75	0.00
1995	1	1,272	60	0.34	1,272	2.0	0.04	1,272	0.82	0.00
1996	1	1,423	68	0.29	1,356	2.7	0.04	1,356	0.81	0.00
1997	1	1,673	63	0.35	1,673	2.4	0.04	1,673	0.81	0.00
1998	1	785	69	0.38	780	2.7	0.06	780	0.78	0.01
1999	1	1,344	77	0.17	1,344	4.1	0.03	1,344	0.89	0.00
2000	1	1,175	72	0.22	1,175	3.3	0.04	1,175	0.86	0.00
2001	1	1,647	65	0.13	1,647	2.1	0.02	1,647	0.76	0.00
2002	1	1,588	65	0.18	1,588	2.3	0.02	1,588	0.83	0.00
2003	1	1,665	65	0.11	1,665	2.1	0.01	1,665	0.75	0.00
2004	1	1,030	69	0.20	1,030	2.8	0.03	1,030	0.83	0.00
2005	1	892	69	0.25	892	2.7	0.03	892	0.81	0.00
2006	1	662	68	0.28	662	2.4	0.03	662	0.76	0.00
2007	1	809	82	0.16	809	4.9	0.03	809	0.88	0.00
2008	1	844	65	0.17	817	2.1	0.02	817	0.76	0.00
2009	1	588	79	0.45	571	3.8	0.08	571	0.77	0.00
2010	1	1,205	69	0.17	1,205	2.6	0.02	1,205	0.76	0.00
2011	1	1,401	70	0.22	1,400	2.8	0.03	1,400	0.88	0.01
2012	1	733	68	0.25	733	2.2	0.04	733	0.68	0.00
2013	1	793	72	0.25	792	3.1	0.03	792	0.81	0.00
2014	1	1,053	58	0.22	1,053	1.2	0.02	1,053	0.60	0.00
2015	1	1,263	66	0.22	1,263	1.9	0.02	1,263	0.64	0.00

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Table 4.–Page 2 of 2.

Year	Age	Length (mm)			Weight (g)			Condition Factor		
		Sample size	Mean	Standard error	Sample size	Mean	Standard error	Sample size	Mean	Standard error
1994	2	1,091	77	0.22	1,068	3.6	0.04	1,068	0.74	0.00
1995	2	1,008	75	0.23	1,008	3.5	0.04	1,008	0.80	0.00
1996	2	548	80	0.34	533	4.2	0.06	533	0.81	0.00
1997	2	772	83	0.25	772	4.7	0.05	772	0.80	0.00
1998	2	1,925	72	0.13	1,881	3.0	0.03	1,881	0.76	0.00
1999	2	784	81	0.28	784	4.8	0.07	784	0.89	0.00
2000	2	503	76	0.34	503	3.6	0.07	503	0.80	0.00
2001	2	389	75	0.45	387	3.4	0.09	387	0.77	0.01
2002	2	225	80	0.78	225	4.9	0.18	225	0.88	0.01
2003	2	279	76	0.48	279	3.5	0.09	279	0.76	0.01
2004	2	274	77	0.41	274	3.9	0.09	274	0.82	0.00
2005	2	397	76	0.33	397	3.5	0.06	397	0.79	0.00
2006	2	518	78	0.35	518	3.8	0.08	518	0.78	0.00
2007	2	272	90	0.36	272	6.6	0.09	272	0.91	0.00
2008	2	288	79	0.35	287	3.7	0.06	287	0.73	0.01
2009	2	413	80	0.31	411	4.0	0.05	411	0.76	0.00
2010	2	359	81	0.30	359	4.0	0.05	359	0.74	0.00
2011	2	159	78	0.71	158	4.1	0.16	158	0.82	0.01
2012	2	452	78	0.27	452	3.4	0.05	452	0.69	0.00
2013	2	632	80	0.33	630	4.1	0.07	630	0.78	0.00
2014	2	418	80	0.30	418	3.3	0.06	418	0.65	0.00
2015	2	406	77	0.34	406	3.1	0.06	406	0.67	0.00
1997	3	12	87	1.34	12	5.2	0.35	12	0.77	0.02
1998	3	20	84	3.39	19	5.5	0.99	19	0.81	0.02
1999	3	7	90	5.76	7	6.8	1.66	7	0.85	0.03
2000	3	14	86	2.36	14	5.3	0.63	14	0.79	0.01
2001	3	62	90	1.60	61	6.9	0.42	61	0.86	0.01
2002	3	6	110	7.24	6	13.8	2.67	6	1.00	0.03
2005	3	7	108	4.35	7	11.4	1.21	7	0.89	0.02
2006	3	32	99	1.89	32	8.9	0.55	32	0.89	0.02
2008	3	17	91	2.54	17	6.1	0.70	17	0.77	0.02
2010	3	2	92	1.50	2	6.0	0.35	2	0.78	0.01
2012	3	5	87	1.66	5	4.4	0.27	5	0.66	0.02
2013	3	16	92	1.25	16	6.3	0.36	16	0.80	0.01
2014	3	4	98	5.33	4	7.6	1.72	4	0.77	0.06
2015	3	2	94	1.00	2	6.5	0.55	2	0.77	0.04
2001	4	1	125	-	1	18.8	-	1	0.96	-

Table 5.–Euphotic Zone Depth (EZD) and Euphotic Volume (EV) of Chignik and Black lakes, by month, 2015.

Lake		2015					Average ^a
		May	June	July	August	September	
Chignik	EZD	7.73	7.06	4.12	8.11	6.32	6.67
	Mean Ev ^b	186.3	170.1	99.3	195.5	152.3	160.7
Black ^c	EZD ^d	3.40	3.90	3.20			3.90
	Mean Ev ^b	78.09	78.09	78.09			78.09

^a EZD calculated per station then averaged for the month ($\mu\text{mol/s/m}^2$)

^b EV units = $\times 10^6 \text{ m}^3$

^c Black Lake was not sampled in August or September.

^d The mean depth of Black Lake is 1.9 m; this value was used for the EV calculations instead of the EZDs when the EZD exceeded 1.9 m

Table 6.–Water quality parameters, nutrient concentrations, and photosynthetic pigments by sample date for Black Lake, 2015.

	2015 ^a			
	31-May	22-Jun	8-Jul	Average
pH	7.89	7.64	7.86	7.80
Alkalinity (mg/L CaCO_3)	24.00	26.00	27.00	25.67
Total phosphorous ($\mu\text{g/L P}$)	15.00	10.50	23.70	16.40
Total filterable phosphorous ($\mu\text{g/L P}$)	6.20	3.60	3.30	4.37
Filterable reactive phosphorous ($\mu\text{g/L P}$)	3.40	1.70	0.90	2.00
Total Kjeldhal nitrogen ($\mu\text{g/L N}$)	5.00	598.00	291.00	298.00
Ammonia ($\mu\text{g/L N}$)	14.20	1.30	2.90	6.13
Nitrate + Nitrite ($\mu\text{g/L N}$)	0.10	3.00	0.20	1.10
Silicon ($\mu\text{g/L}$)	2923.90	2724.00	2140.20	2596.03
Chlorophyll a ($\mu\text{g/L}$)	7.48	8.01	7.54	7.68
Phaeophytin a ($\mu\text{g/L}$)	0.00	2.83	0.38	1.07

^a Limnology sampling did not occur in August or September 2015.

Table 7.–Number of zooplankton by taxon per m² from Black Lake by sample date, 2015.

Taxon	Sample date	
	31-May	8-Jul
Copepods		
<i>Cyclops</i>	2,123	19,904
<i>Epischura</i>	0	5,573
<i>Eurytemora</i>	1,592	7,962
<i>Nauplii</i>	11,147	22,293
Total copepods	14,862	55,732
Cladocerans		
<i>Bosmina</i>	1,592	58,121
<i>Ovig. Bosmina</i>	1,592	15,127
<i>Chydorinae</i>	1,592	23,885
<i>Ovig. Chydorinae</i>	0	4,777
<i>Immature Cladocera</i>	0	3,981
Total cladocerans	4,777	97,134
Total copepods + cladocerans	19,639	152,866

Table 8.–Biomass estimates (mg dry weight/m²) of the major Black Lake zooplankton taxa by sample date, 2015.

Taxon	Sample date	
	31-May	8-Jul
Copepods		
<i>Cyclops</i>	1.30	19.39
<i>Epischura</i>	0.00	2.53
<i>Eurytemora</i>	3.23	19.75
Total copepods	4.53	41.67
Cladocerans		
<i>Bosmina</i>	1.40	40.89
<i>Ovig. Bosmina</i>	0.91	13.88
<i>Chydorinae</i>	0.74	11.08
<i>Ovig. Chydorinae</i>	0.00	3.75
Total cladocerans	3.05	69.61
Total copepods + cladocerans	7.59	111.27

Table 9.–Length (mm) of zooplankton from Black Lake by sample date, 2015.

Taxon	Sample date	
	31-May	8-Jul
Copepods		
<i>Cyclops</i>	0.44	0.54
<i>Epischura</i>	-	0.45
<i>Eurytemora</i>	1.03	0.59
Cladocerans		
<i>Bosmina</i>	0.31	0.28
<i>Ovig. Bosmina</i>	0.43	0.32
<i>Chydorinae</i>	0.28	0.23
<i>Ovig. Chydorinae</i>	-	0.30

Table 10.–Water quality parameters, nutrient concentrations, and photosynthetic pigments by sample date for Chignik Lake, 2015.

	2015					Average
	12-May	13-Jun	10-Jul	17-Aug	13-Sep	
pH	7.80	7.81	7.73	7.42	7.36	7.62
Alkalinity (mg/L CaCO ₃)	23.17	25.00	21.92	16.67	20.17	21.38
Total phosphorous (µg/L P)	5.95	6.80	5.28	7.80	9.75	7.12
Total filterable phosphorous (µg/L P)	2.32	1.60	2.28	2.65	3.37	2.44
Filterable reactive phosphorous (µg/L P)	3.13	0.87	1.68	3.23	4.73	2.73
Total Kjeldhal nitrogen (µg/L N)	180.83	182.17	194.00	244.75	212.75	202.90
Ammonia (µg/L N)	13.63	2.98	10.68	6.38	4.65	7.67
Nitrate + Nitrite (µg/L N)	161.02	26.40	19.30	54.28	79.02	68.00
Silicon (µg/L)	5,222.90	4,459.42	3,862.55	5,178.75	4,959.28	4,736.58
Chlorophyll a (µg/L) ^b	10.73	13.62	2.35	2.24	3.20	6.43
Phaeophytin a (µg/L) ^b	4.44	3.58	0.90	1.91	1.99	2.56

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

Table 11.—Average number of zooplankton by taxon per m² from Chignik Lake by sample date, 2015.

Taxon	Sample date					Seasonal average
	12-May	13-Jun	10-Jul	17-Aug	13-Sep	
Copepods						
<i>Cyclops</i>	28,264	45,913	88,774	17,051	89,039	53,808
<i>Ovig. Cyclops</i>	0	995	14,530	7,630	2,256	5,082
<i>Eurytemora</i>	3,450	12,473	44,387	158,771	42,065	52,229
<i>Ovig. Eurytemora</i>	0	1,393	2,787	8,957	31,714	8,970
<i>Harpacticus</i>	1,592	0	0	0	796	478
<i>Ovig. Harpacticus</i>	0	199	0	0	0	40
<i>Nauplii</i>	16,587	27,933	96,338	80,215	628,583	169,931
Total copepods	49,894	88,907	246,815	272,625	794,453	290,539
Cladocerans						
<i>Bosmina</i>	2,123	1,592	19,108	35,297	67,542	25,133
<i>Ovig. Bosmina</i>	133	199	3,384	4,976	23,620	6,462
<i>Chydorinae</i>	133	4,777	8,758	4,114	0	3,556
<i>Ovig. Chydorinae</i>	0	0	398	464	0	173
<i>Daphnia L.</i>	1,924	2,123	6,170	63,694	436,837	102,150
<i>Ovig. Daphnia L.</i>	132	199	3,782	17,516	106,688	25,663
<i>Immature Cladocera</i>	16,056	1,990	4,777	22,028	69,135	22,797
Total cladocerans	20,502	10,881	46,377	148,089	703,822	185,934
Total copepods + cladocerans	70,395	99,788	293,193	420,714	1,498,275	476,473

Table 12.–Biomass estimates (mg dry weight/m²) of the major Chignik Lake zooplankton taxa by sample date, 2015.

Taxon	Sample date					Seasonal average	Weighted average
	12-May	13-Jun	10-Jul	17-Aug	13-Sep		
Copepods							
<i>Cyclops</i>	31.63	78.10	146.61	28.96	80.17	73.09	55.13
<i>Ovig. Cyclops</i>	0.00	3.88	81.43	43.07	16.39	28.95	28.95
<i>Eurytemora</i>	13.39	48.33	178.89	829.85	155.19	245.13	161.76
<i>Ovig. Eurytemora</i>	0.00	14.33	28.77	80.21	289.00	82.46	82.46
<i>Harpaticus</i>	1.59	0.00	0.00	0.00	0.36	0.39	0.39
<i>Ovig. Harpaticus</i>	0.00	0.11	0.00	0.00	0.00	0.02	0.02
Total copepods	46.61	144.76	435.70	982.09	541.10	430.05	328.71
Cladocerans							
<i>Bosmina</i>	1.90	1.08	12.57	29.56	46.59	18.34	10.54
<i>Ovig. Bosmina</i>	0.21	0.60	4.70	5.24	26.73	7.49	4.28
<i>Chydorinae</i>	0.08	3.38	5.27	1.81	0.00	2.11	2.11
<i>Ovig. Chydorinae</i>	0.00	0.00	0.35	0.37	0.00	0.14	0.14
<i>Daphnia L.</i>	3.17	2.46	6.61	94.17	502.41	121.76	63.76
<i>Ovig. Daphnia L.</i>	0.30	0.32	8.87	61.99	297.67	73.83	38.98
Total cladocerans	5.65	7.84	38.37	193.14	873.39	223.68	119.81
Total copepods + cladocerans	52.26	152.60	474.08	1175.22	1414.49	653.73	448.52

Table 13.–Weighted average length (mm) of zooplankton from Chignik Lake by sample date, 2015.

Taxon	Sample date					Weighted average
	12-May	13-Jun	10-Jul	17-Aug	13-Sep	
Copepods						
<i>Cyclops</i>	0.58	0.65	0.69	0.70	0.53	0.62
<i>Ovig. Cyclops</i>	-	1.04	1.15	1.22	1.34	1.23
<i>Eurytemora</i>	0.76	0.77	0.81	0.89	0.75	0.87
<i>Ovig. Eurytemora</i>	-	1.42	1.44	1.30	1.34	1.33
<i>Harpaticus</i>	0.55	-	-	-	0.38	0.49
<i>Ovig. Harpaticus</i>	-	0.42	-	-	-	0.42
Cladocerans						
<i>Bosmina</i>	0.31	0.28	0.27	0.28	0.27	0.28
<i>Ovig. Bosmina</i>	0.41	0.56	0.38	0.34	0.35	0.36
<i>Chydorinae</i>	0.26	0.27	0.28	0.23	-	0.26
<i>Ovig. Chydorinae</i>	-	-	0.32	0.30	-	0.31
<i>Daphnia L.</i>	0.59	0.48	0.50	0.57	0.52	0.53
<i>Ovig. Daphnia L.</i>	0.72	0.62	0.72	0.88	0.78	0.80

Table 14.–Sockeye salmon smolt catches from Black Lake and Chignik Lagoon beach seine sampling events, 2015

Site	Location	May	June	July	August
Black Lake					
1	Outlet of lake	0	ND	46	ND
2	South side of spit	0	ND	ND	ND
4	North side spit	80	ND	0	ND
5	Cabin beach	0	ND	19	0
Chignik Lagoon					
1	Upper lagoon	627	64	1	2
2	Lower Chignik Island	14	23	30	3
3	Spit	0	179	25	-
4	Mensis Point	88	13	0	24

Table 15.—Number and percentage of sampled sockeye salmon smolt from beach seine catches in Black Lake and Chignik Lagoon, 2015

Date	Freshwater-age-0		Freshwater-age-1		Freshwater-age-2		Total
Black Lake	Number	%	Number	%	Number	%	
5/31/2015	40	1.00					40
7/8/2015	31	0.91	3	0.09			34
Chignik Lagoon							
5/3/2015	39	0.41	37	0.39	19	0.20	95
6/2/2015	5	0.06	58	0.68	22	0.26	85
7/10/2015	4	0.08	42	0.86	3	0.06	49
8/26/2015			26	0.93	2	0.07	28

Table 16.—Ages of sampled sockeye salmon smolt from beach seine catches in Black Lake and Chignik Lagoon, 2015.

Date	Freshwater-age-0			Freshwater-age-1			Freshwater-age-2		
	Sample size	Length (mm)	Weight (g)	Sample size	Length (mm)	Weight (g)	Sample size	Length (mm)	Weight (g)
Black Lake									
5/31/2015	40	39.4	0.6						
7/8/2015	31	58.4	2.9	3	71.7	4.7			
Chignik Lagoon									
5/3/2015	39	33.3	0.3	37	68.5	2.5	19	83.4	4.6
6/2/2015	5	40.4	0.6	58	66.5	2.3	22	79.4	4.3
7/10/2015	4	52.5	1.6	42	74.3	4.4	3	76	4.7
8/26/2015	0			26	63.8	2.9	2	106.5	12.4

Table 17.—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, 1991–2009.

Brood year	Escapement	Estimated smolt production				Total smolt	Smolt / spawner	Adult Returns					Return/ spawner	Marine survival
		Age-0.	Age-1.	Age-2.	Age-3.			Age-0.	Age-1.	Age-2.	Age-3.	Total		
1991	1,040,098	NA	NA	4,270,636	0	4,270,636	4.11	5,541	1,795,467	737,680	11,621	2,550,309	2.5	NA
1992	764,436	NA	7,263,054	5,178,450	5,018	12,446,522	16.28	151,608	649,920	1,159,871	93,372	2,054,771	2.7	17%
1993	697,377	0	2,843,222	731,099	122,289	3,696,610	5.30	16,007	457,189	1,998,416	7,265	2,478,877	3.6	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	3.4	21%
1995	739,920	80,245	11,172,150	20,374,245	78,798	31,705,447	42.85	36,053	2,391,036	942,680	17,366	3,387,135	4.6	11%
1996 ^a	749,137	528,846	5,790,587	8,221,631	160,017	14,701,081	19.63	144,144	1,999,024	877,189	13,958	3,034,314	4.1	21%
1997	775,618	75,560	12,705,935	4,645,121	516,723	17,943,339	23.13	15,467	770,649	956,007	5,627	1,747,750	2.3	10%
1998	701,128	73,364	8,047,526	5,024,666	72,184	13,217,740	18.85	5,515	1,030,710	353,826	8,451	1,398,502	2.0	11%
1999	715,966	1,270,101	18,940,752	2,223,996	0	22,434,849	31.34	26,176	913,849	403,536	1,663	1,345,224	1.9	6%
2000	805,225	521,546	13,980,423	1,449,494	0	15,951,463	19.81	15,176	1,988,373	699,285	2,729	2,705,564	3.4	17%
2001	1,136,918	440,947	5,146,278	2,239,716	32,889	7,859,830	6.91	78,019	1,031,100	696,415	482	1,806,016	1.6	23%
2002	725,220	155,047	6,172,902	1,468,208	119,614	7,915,771	10.91	17,633	700,976	412,758	2,079	1,133,445	1.6	14%
2003	684,145	244,206	2,075,681	2,847,624	0	5,167,511	7.55	84,284	875,278	736,979	3,227	1,699,768	2.5	33%
2004	578,259	859,211	2,849,043	1,028,865	41,136	4,778,255	8.26	129,303	1,067,014	987,159	10,222	2,193,698	3.8	46%
2005	581,382	1,744,370	1,926,682	987,928	0	4,658,980	8.01	28,613	1,461,254	935,660	94,411	2,519,938	4.3	54%
2006	735,493	9,286	3,309,894	4,288,491	91,509	8,285,029	11.26	33,123	2,865,182	1,866,956	56,981	4,822,242	6.6	58%
2007	654,974	1,017,498	3,777,572	9,347,999	0	13,608,359	20.78	45,736	520,516	1,297,433	1,045	1,864,729	2.8	14%
2008	706,058	110,446	17,684,165	1,371,044	196,575	19,311,090	27.35	17,460	3,028,245	532,617	9,568	3,587,889	5.1	19%
2009	720,062	1,039,131	10,684,120	22,734,743	176,196	34,634,189	48.10	7,884	304,973	1,351,492	6,608	1,670,957	2.3	5%
2010	743,911	203,380	16,328,172	10,467,154	26,869	27,025,574	36.33	391	1,316,748	265,563				
2011	753,817	685,707	8,314,053	1,507,021	11,860	10,518,641	13.95							
2012	712,389	117,435	2,757,054	2,107,981										
2013	756,101	4,250	7,149,366											
2014	651,609	133,103												
2015	1,123,897													
1992-2009 Average, excluding 1993, 2002-2004													3.18	16%

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

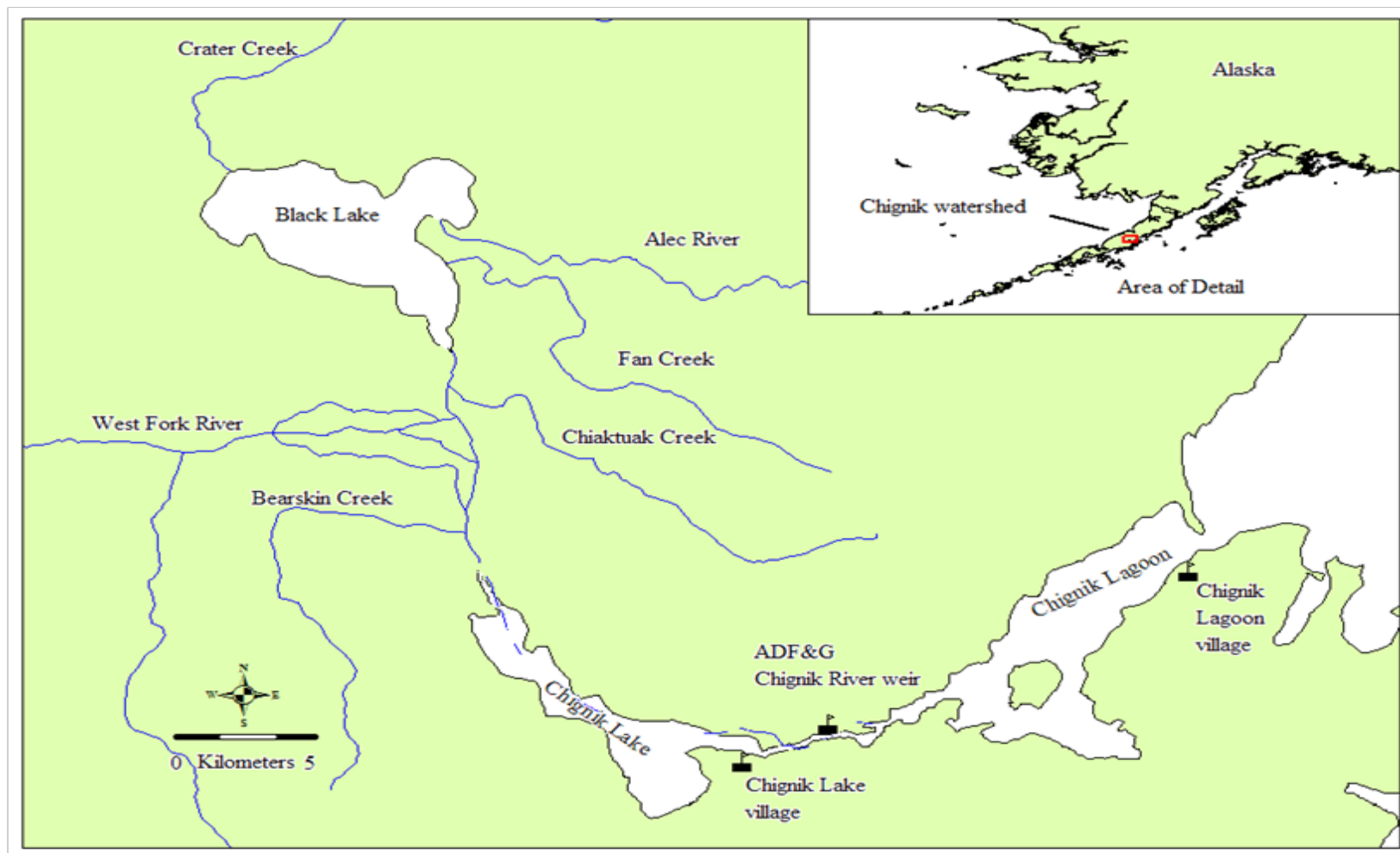


Figure 1.—Map of the Chignik watershed.

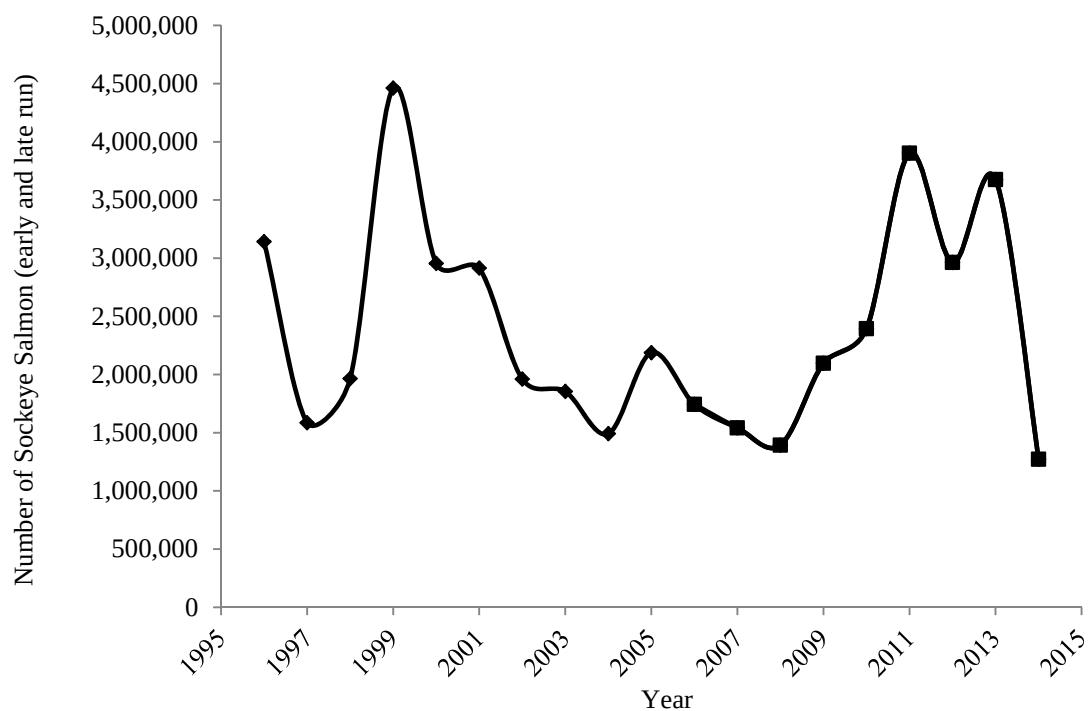


Figure 2.—Total annual run of sockeye salmon to the Chignik watershed.

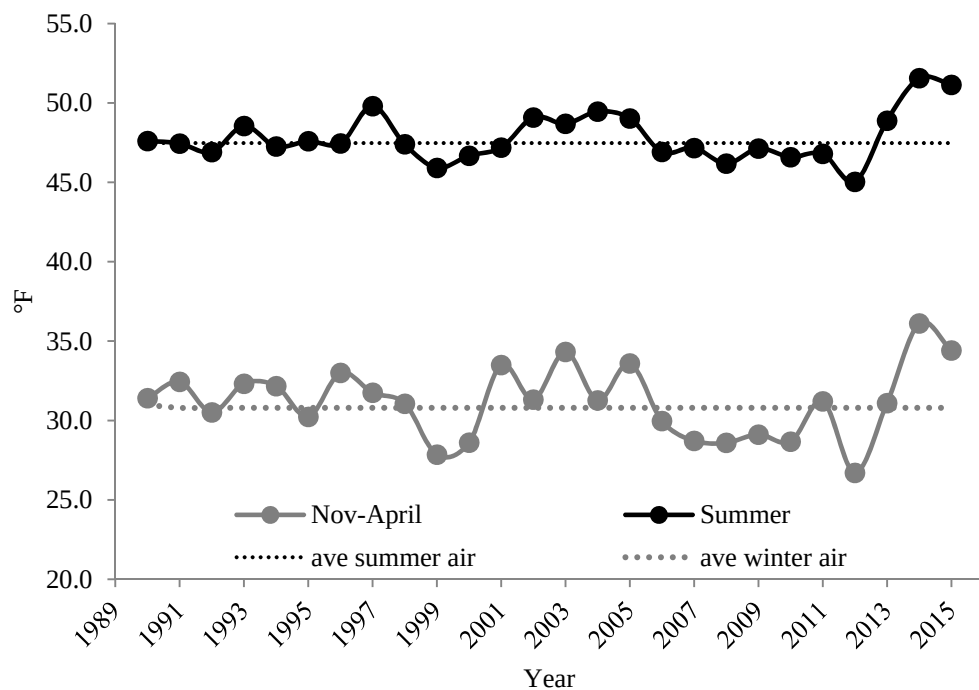


Figure 3.—Summer and winter air temperatures, as measured at the Cold Bay Airport.

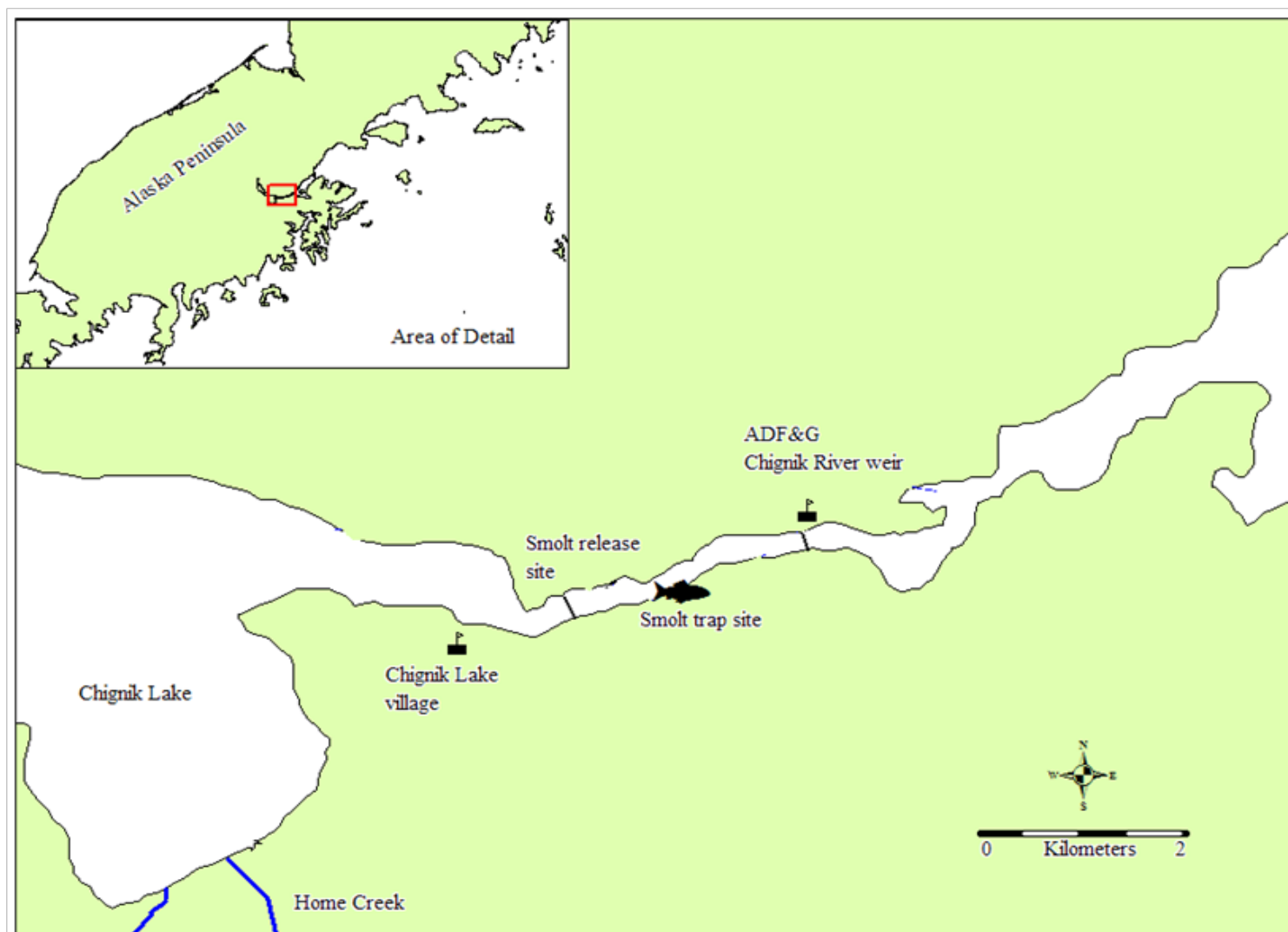


Figure 4.—Location of the smolt traps and the release site of marked smolt in the Chignik River, Alaska, 2015.

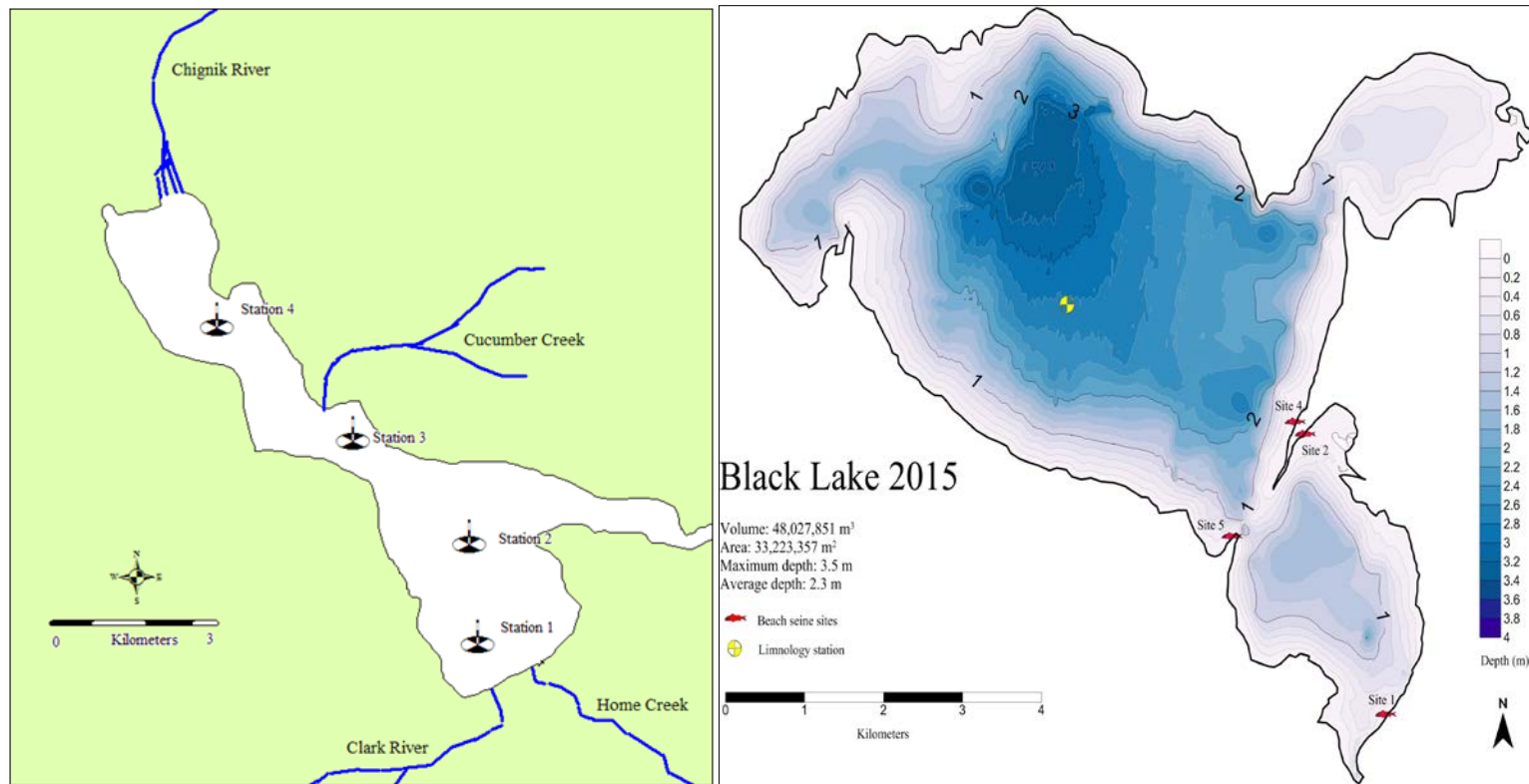


Figure 5.—Location of the Chignik Lake limnology sampling stations and Black Lake limnology and beach seining stations, 2015.

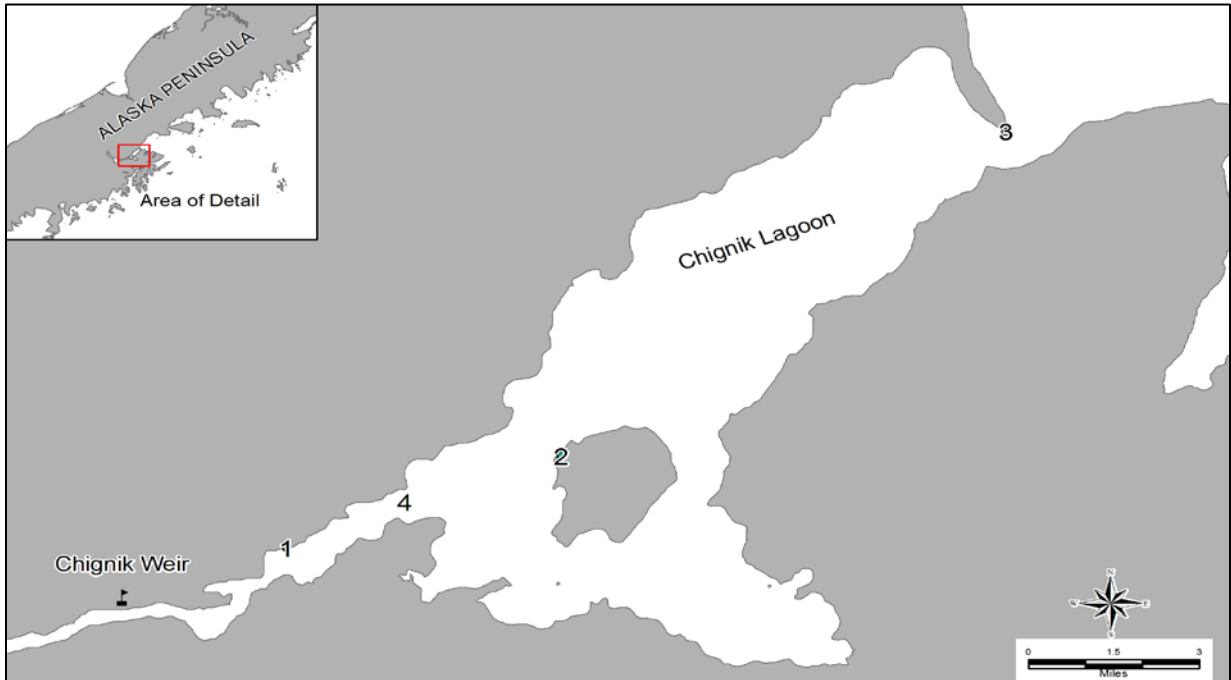


Figure 6.—Location of beach seine sites in Chignik Lagoon, 2015.

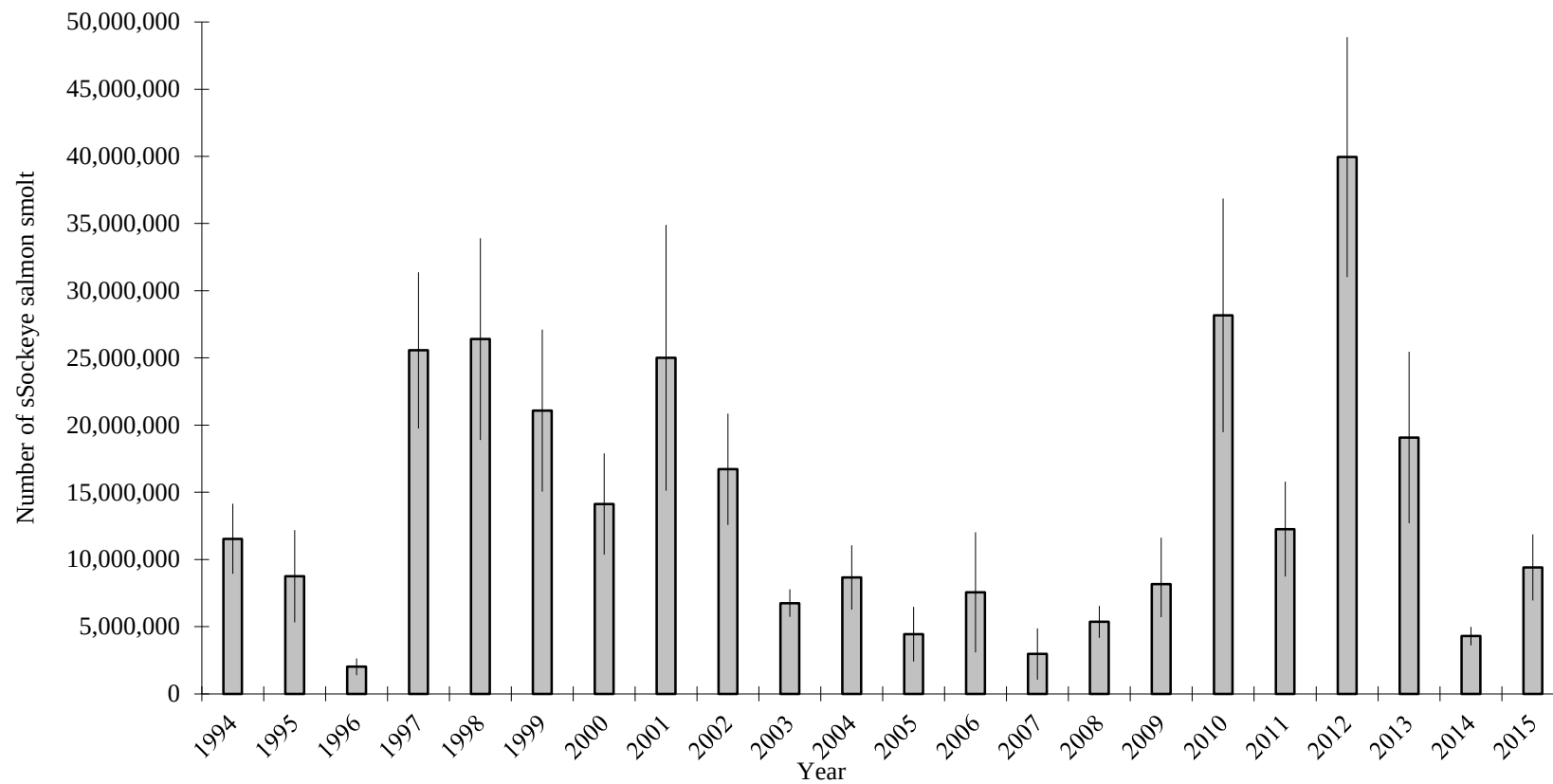


Figure 7.—Annual sockeye salmon smolt outmigration estimates and corresponding 95% confidence intervals, Chignik River, 1994–2015.

Note: Outmigration estimates from 1996 were underestimated and certain age classes of the 2007 and 2008 outmigration underestimated.

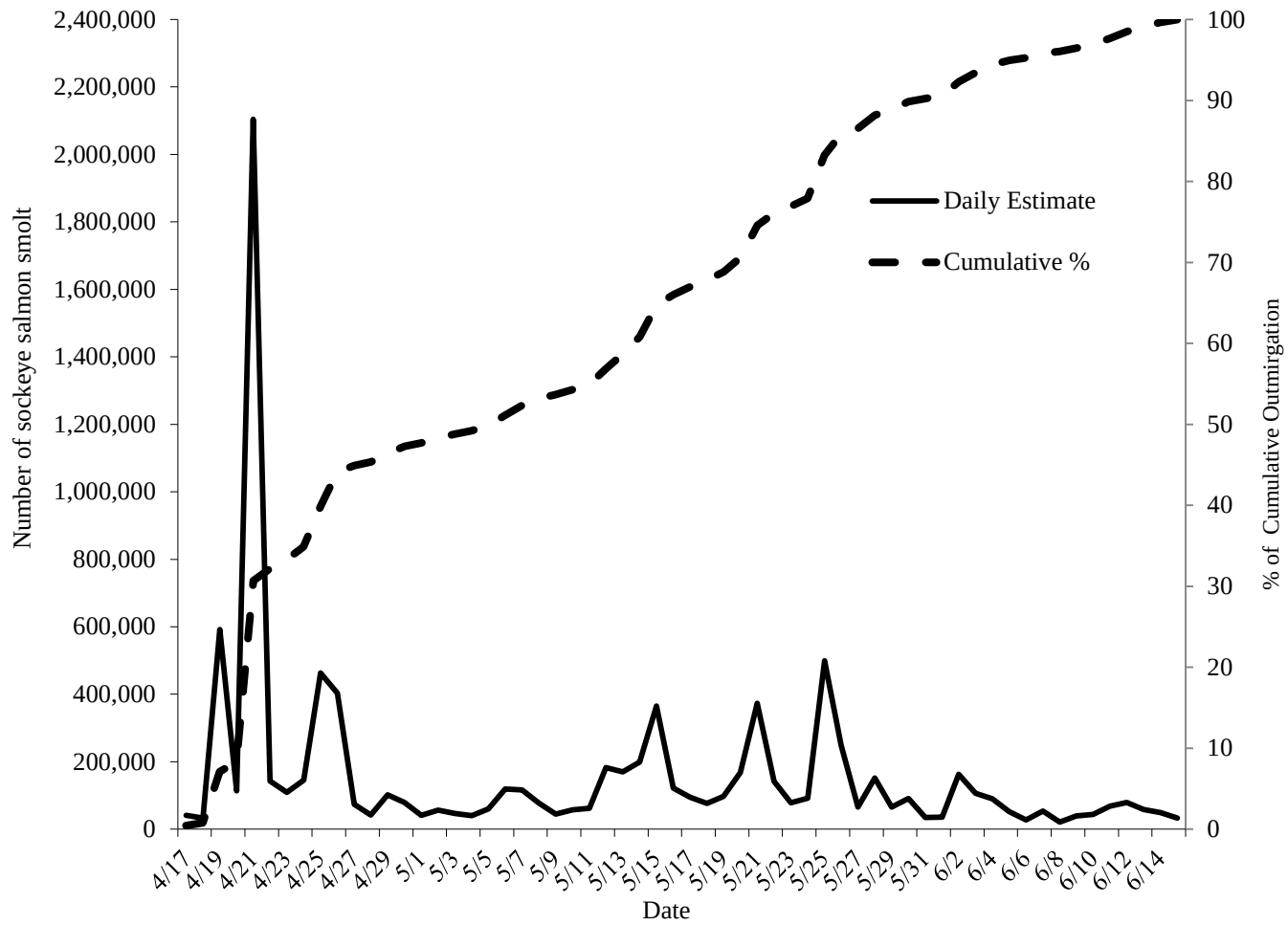


Figure 8.—Daily estimate and cumulative percentage of the sockeye salmon smolt outmigration from the Chignik River, 2015.

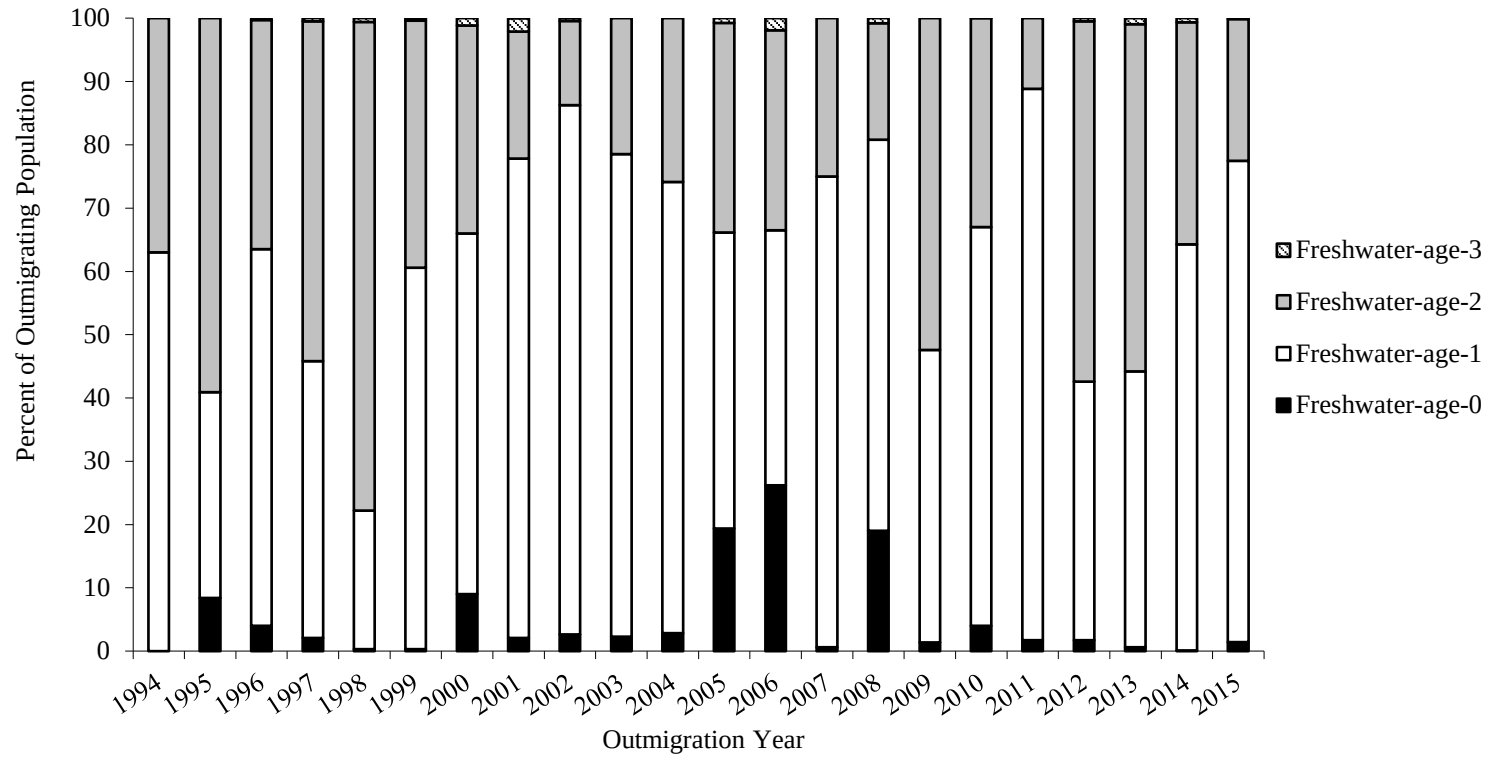


Figure 9.—Comparison of the estimated age structure of freshwater-age-0 to freshwater-age-3 sockeye salmon smolt outmigrations from the Chignik River, Alaska, 1994–2015.

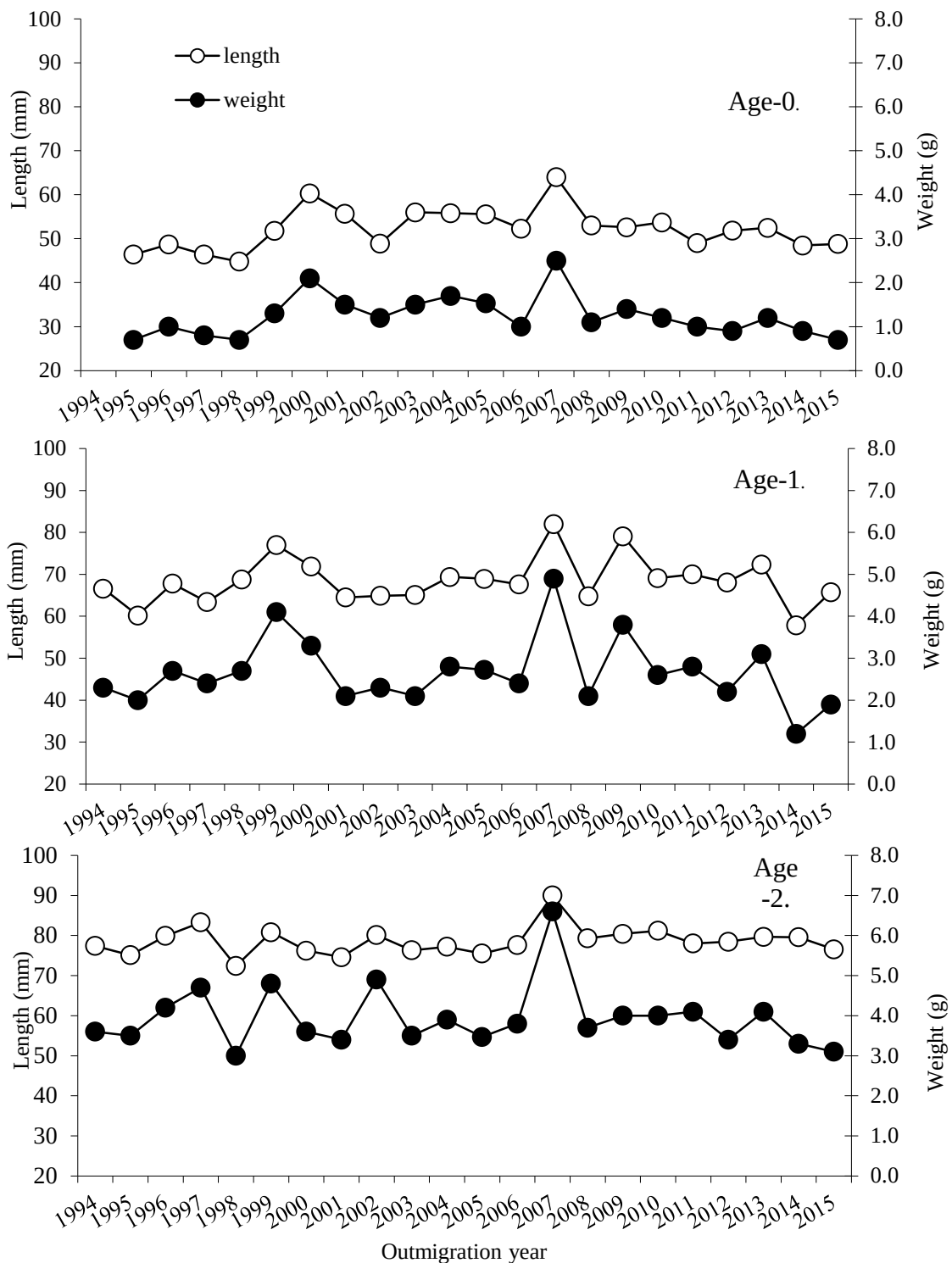


Figure 10.—Average length and weight of sampled freshwater-age-0, freshwater-age-1 and freshwater-age-2 sockeye salmon smolt, by year, 1994–2015.

Note: Freshwater-age-3 smolt make up a negligible percentage of the yearly outmigrating population.

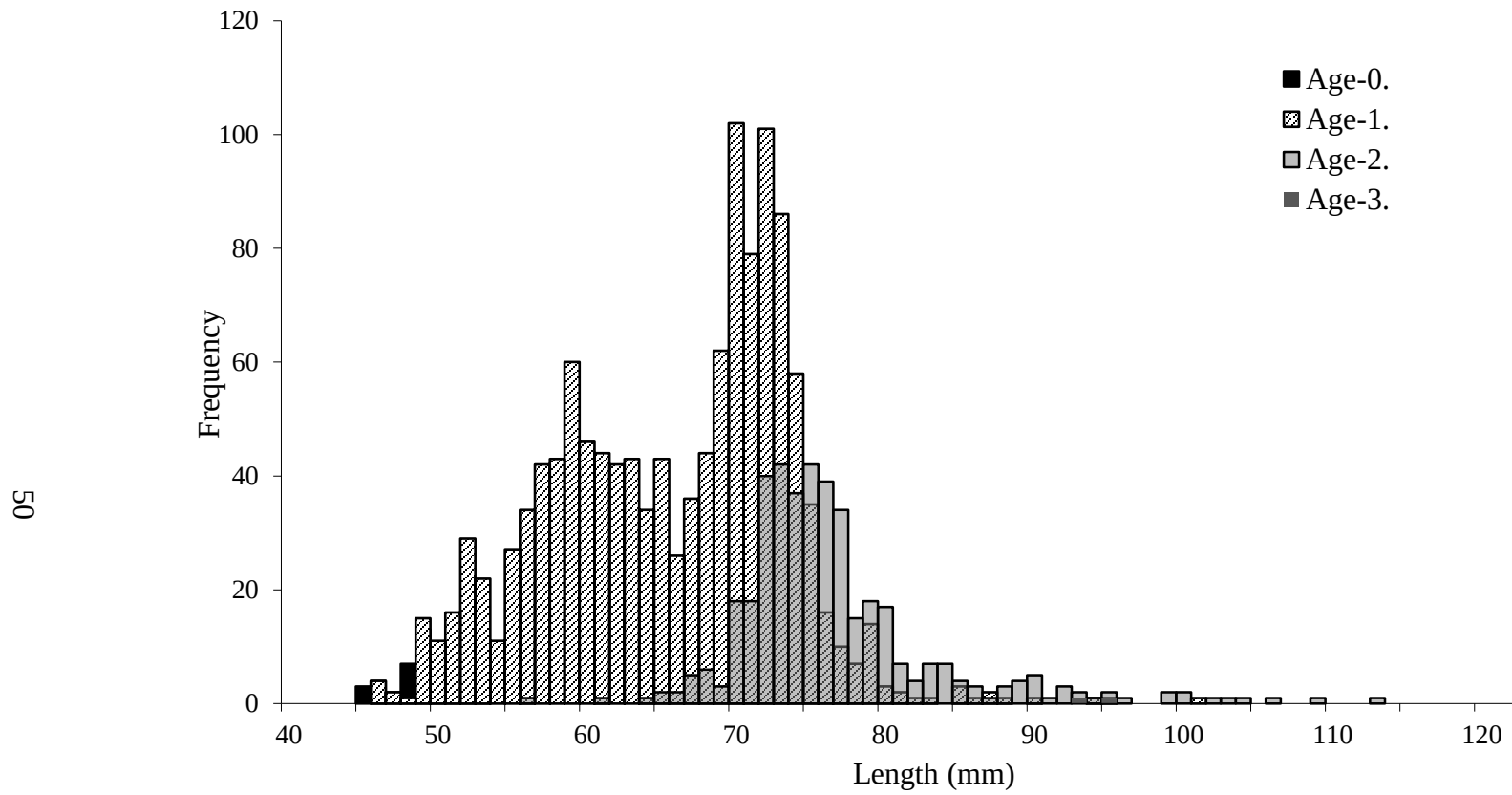


Figure 11.—Length frequency histogram of sockeye salmon smolt from the Chignik River, by freshwater age, 2015.

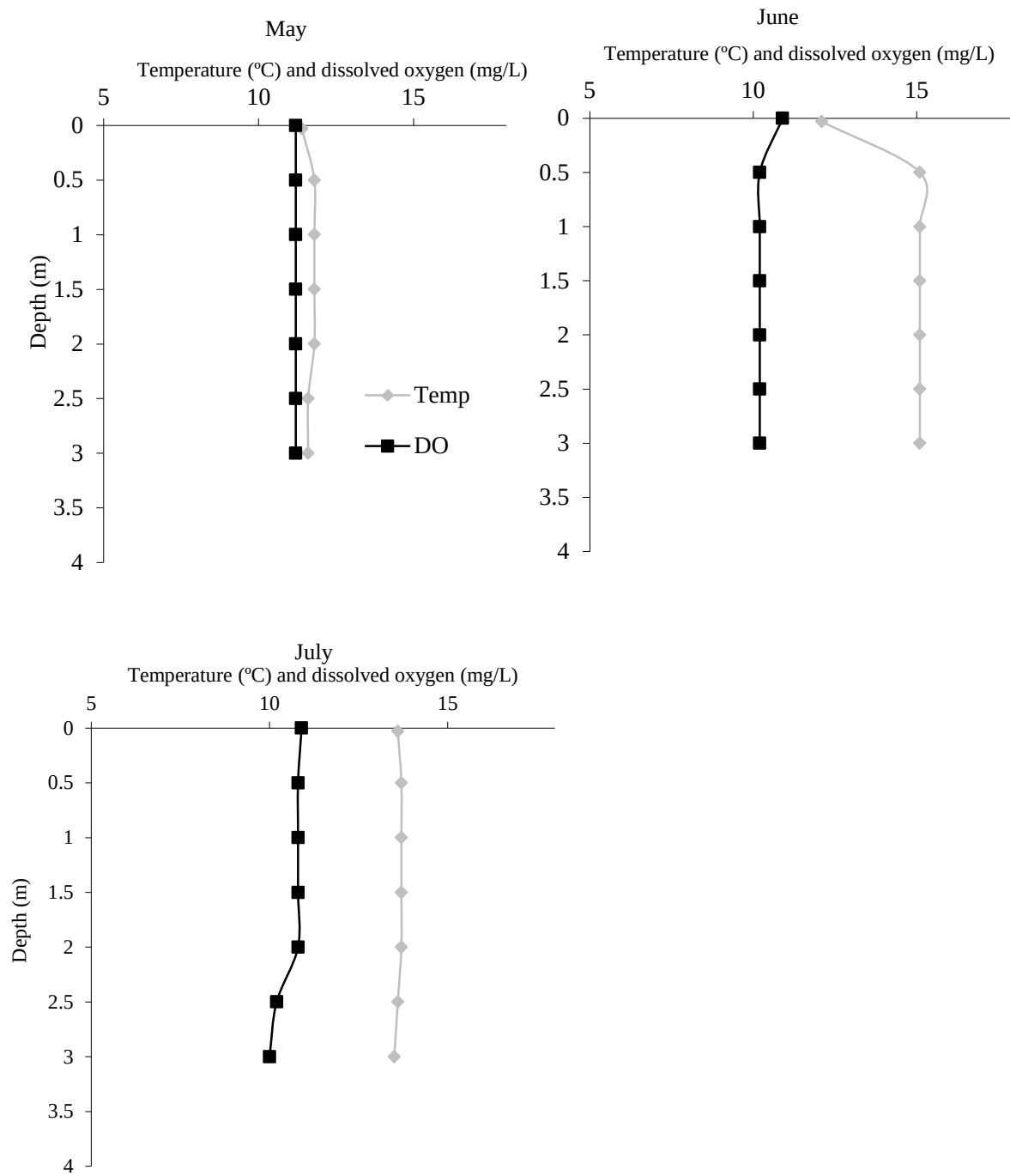


Figure 12.—Mean monthly temperature (°C) and dissolved oxygen (mg/L) profiles in Black Lake, 2015.

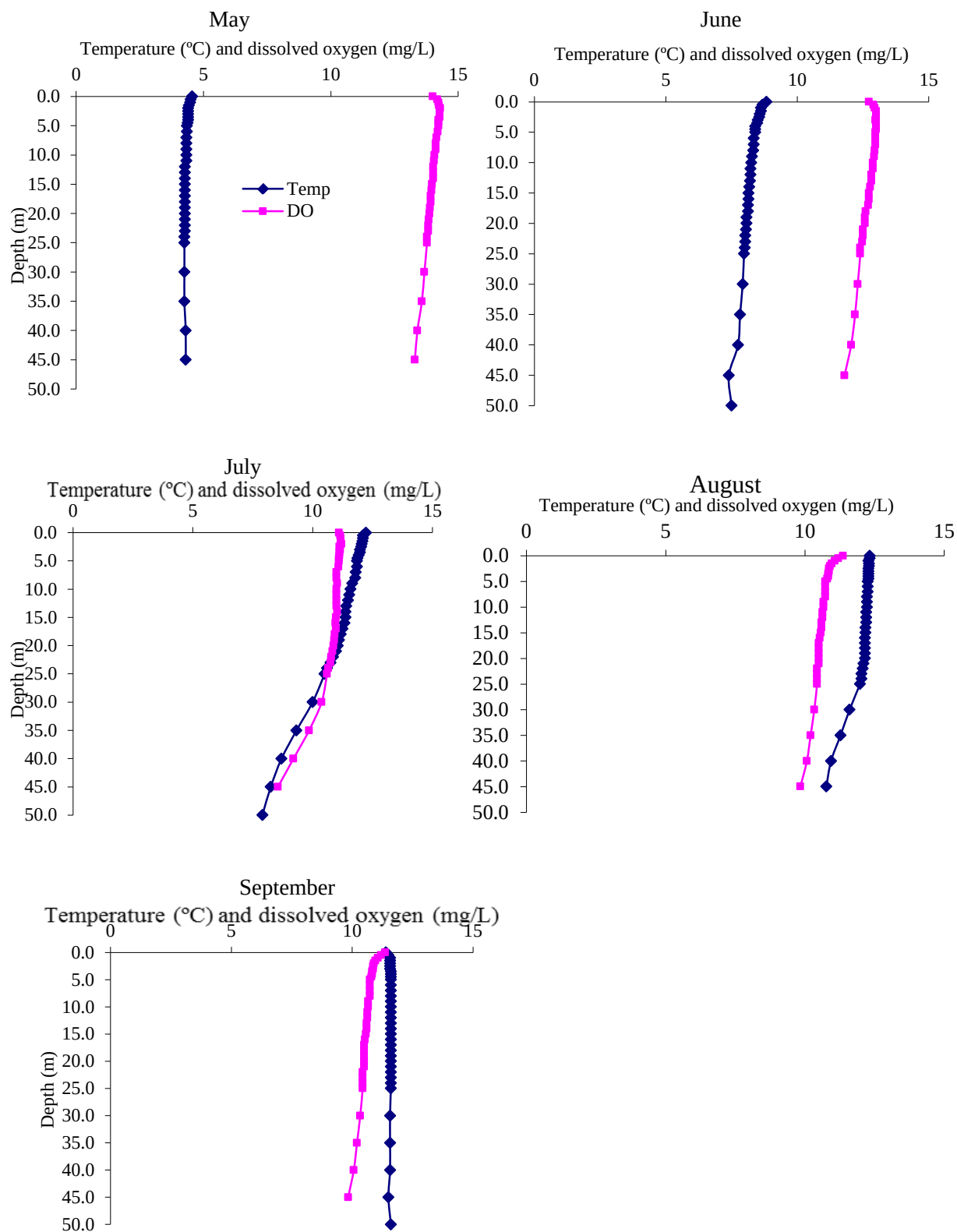


Figure 13.—Mean monthly temperature (°C) and dissolved oxygen (mg/L) profiles in Chignik Lake, 2015.

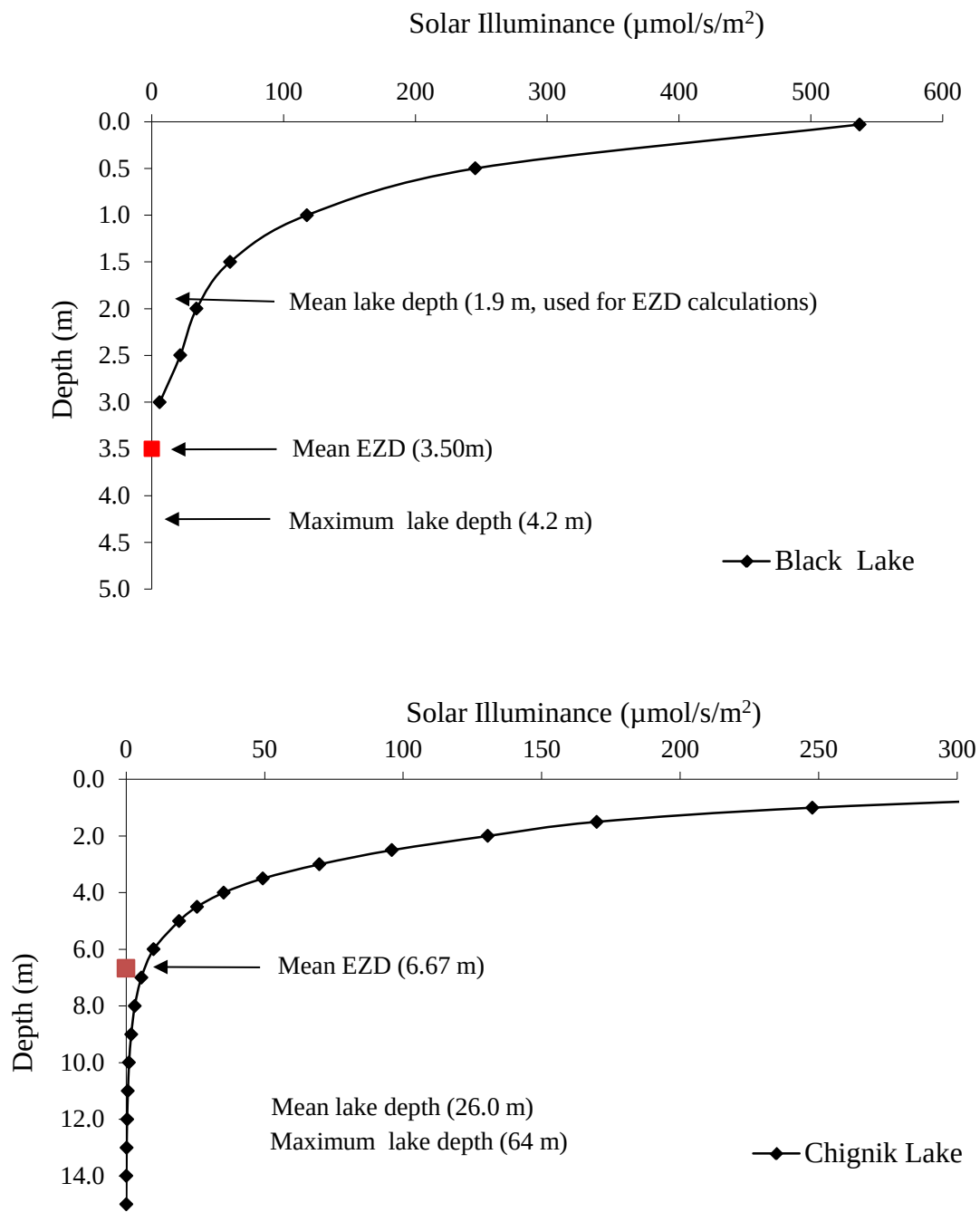


Figure 14.—Light penetration curves relative to mean depth, euphotic zone depth (EZD), and maximum depth in Black and Chignik lakes, 2015.

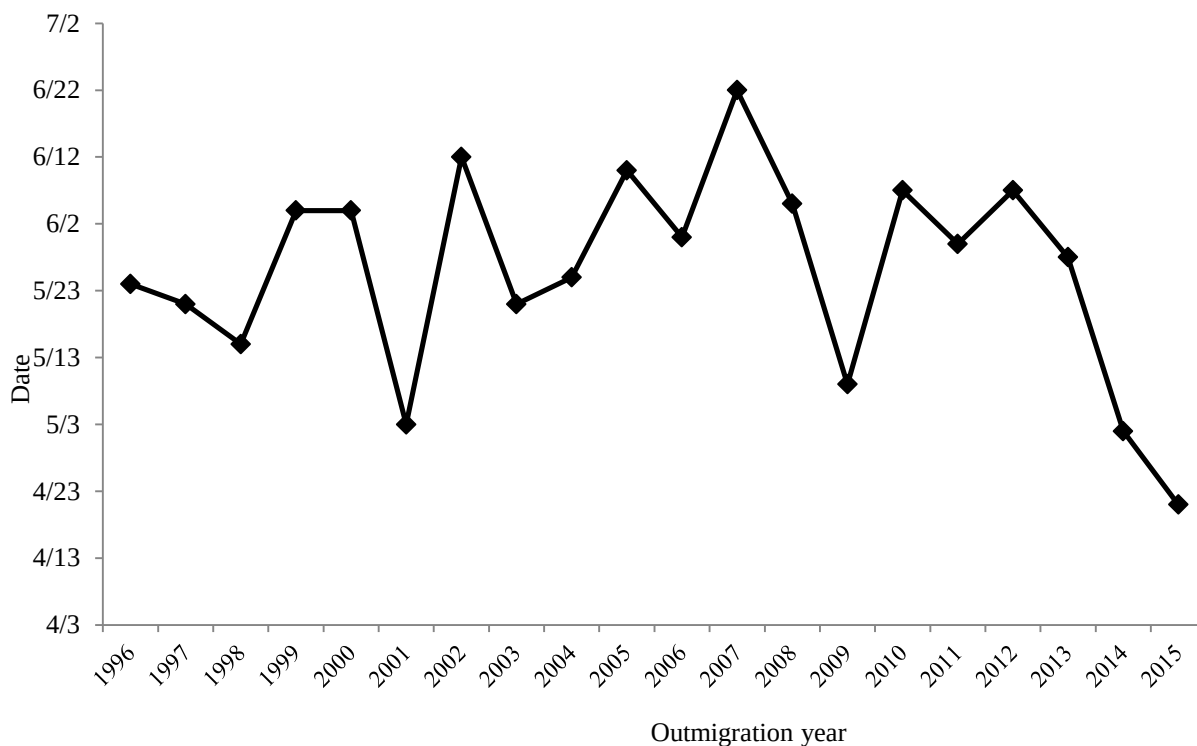


Figure 15.—Peak sockeye salmon smolt outmigration date from Chignik River, by year, 1996–2015.

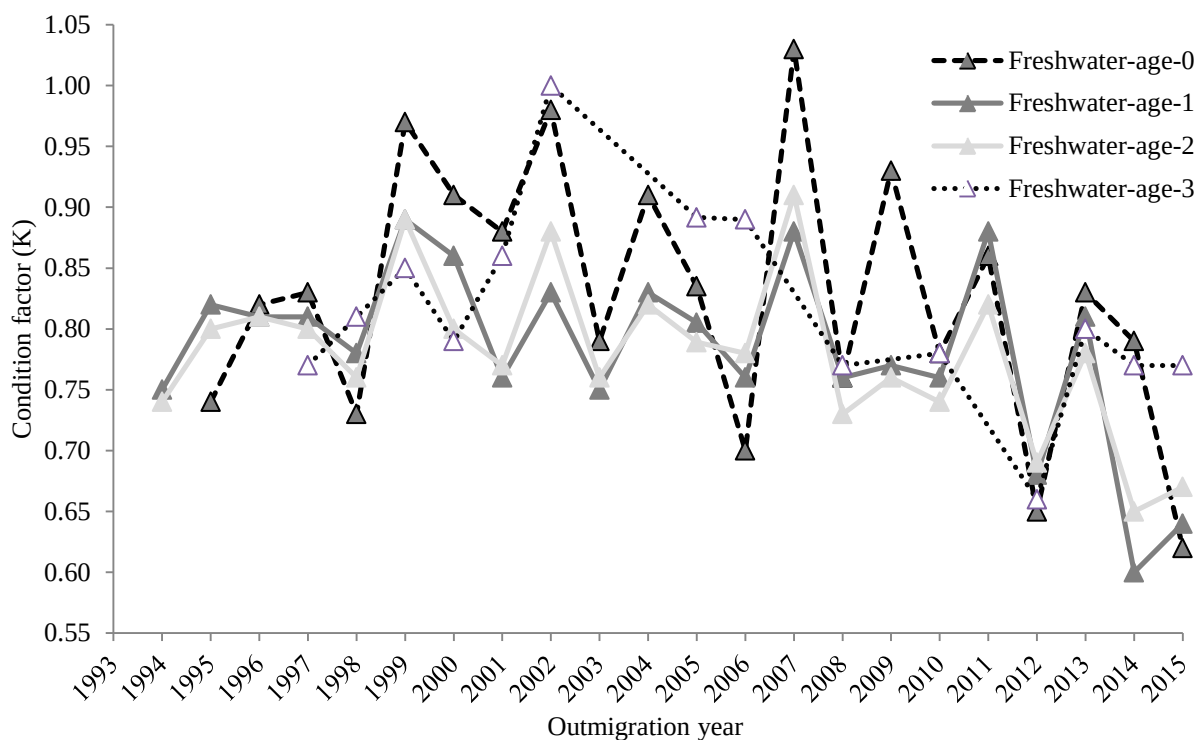


Figure 16.—Average seasonal K by age class of outmigrating sockeye salmon smolt, Chignik.

APPENDIX A. SMOLT TRAP CATCHES

Appendix A1.–Daily trap catch and efficiency from the Chignik River, April 17-June 15, 2015.

	Sockeye Smolt		Trap Efficiency Test					Incidental Catch ^a															
			Actual	Adjusted	Daily	Cum.	Adjusted	Sockeye	Coho														
Date	Daily	Cum.	Released ^b	Released ^c	Recoveries	Recoveries	Efficiency ^d	fry	Coho	fry	Pink	Chnk	Chum	DV	SB	SC	SF	PS	PW	AB	ISO	EU	
4/17 ^e	187	187					0.45%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
4/18	150	337					0.45%	53	3	0	0	0	0	0	263	5	1	2	0	0	2	0	
4/19	2,678	3,015					0.45%	725	26	1	0	0	0	3	1203	25	0	1	0	0	9	0	
4/20	515	3,530					0.45%	294	4	1	0	0	0	3	597	11	1	0	0	0	3	0	
4/21	9,529	13,059	2,048	1,987	8	8	0.45%	152	28	2	0	0	0	3	991	20	4	1	1	0	6	0	
4/22	645	13,704			0	8	0.45%	594	3	0	0	0	0	0	1008	14	2	0	1	0	3	0	
4/23	496	14,200			0	8	0.45%	374	0	0	0	0	0	2	555	11	1	2	0	0	4	0	
4/24	658	14,858			0	8	0.45%	286	5	1	0	0	0	1	350	13	2	4	0	0	1	0	
4/25	2,317	17,175			0	8	0.45%	335	9	0	0	0	0	2	1171	11	2	3	0	0	4	0	
4/26	2,015	19,190	2,919	2,598	9	9	0.50%	527	15	0	0	0	0	6	1031	10	3	2	0	0	1	0	
4/27	371	19,561			3	12	0.50%	420	5	0	0	0	0	10	499	9	3	6	0	0	5	0	
4/28	210	19,771			0	12	0.50%	454	3	0	0	0	0	1	387	3	0	3	0	0	3	0	
4/29	510	20,281			0	12	0.50%	92	1	1	0	0	0	3	301	4	0	3	1	0	5	0	
4/30	395	20,676			0	12	0.50%	274	2	0	0	0	0	4	575	0	0	2	0	0	2	0	
5/1	204	20,880			0	12	0.50%	77	0	0	0	0	0	1	310	1	2	2	0	0	3	0	
5/2	283	21,163			0	12	0.50%	51	1	0	0	0	0	3	498	0	1	0	0	0	1	0	
5/3	232	21,395			0	12	0.50%	159	1	0	0	0	0	0	566	0	0	2	0	0	2	0	
5/4	202	21,597			0	12	0.50%	27	0	0	0	0	0	3	130	4	5	0	0	0	2	0	
5/5	299	21,896			0	12	0.50%	36	2	0	0	0	0	3	149	5	9	0	0	0	1	0	
5/6	597	22,493			0	12	0.50%	31	1	0	0	0	0	9	217	3	9	2	0	0	0	0	
5/7	1,689	24,182			0	12	0.50%	85	9	0	0	0	0	17	347	5	23	3	0	0	2	0	
5/8	1,127	25,309	1,298	1,168	12	12	1.45%	86	8	2	0	0	0	14	543	3	4	6	1	0	3	0	
5/9	649	25,958			3	15	1.45%	52	5	2	0	0	0	8	346	11	12	5	0	0	1	0	
5/10	833	26,791			1	16	1.45%	33	10	1	0	0	0	10	226	17	15	4	0	0	4	0	
5/11	907	27,698			0	16	1.45%	40	8	0	0	0	0	18	289	13	10	13	1	0	2	0	
5/12	1,769	29,467			0	16	1.45%	38	10	0	0	0	0	9	357	18	18	5	1	0	2	0	
5/13	1,645	31,112	3,026	2,996	25	25	0.97%	30	8	0	0	0	0	10	346	10	7	6	1	0	2	0	
5/14	1,922	33,034			1	26	0.97%	15	9	1	0	0	0	6	281	12	17	9	1	0	9	0	
5/15	3,534	36,568			1	27	0.97%	9	12	0	0	0	0	8	304	7	6	9	0	0	3	0	
5/16	1,182	37,750			1	28	0.97%	18	16	0	0	0	0	11	315	16	17	8	1	0	8	0	
5/17	913	38,663			0	28	0.97%	28	19	0	0	0	0	9	226	3	8	1	2	0	1	0	

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Appendix A1.–Page 2 of 3.

Sockeye Smolt			Trap Efficiency Test					Incidental Catch ^a														
			Actual	Adjusted	Daily	Cum.	Adjusted	Sockeye	Coho													
Date	Daily	Cum.	Released ^b	Released ^c	Recoveries	Recoveries	Efficiency ^d	fry	Coho	fry	Pink	Chnk	Chum	DV	SB	SC	SF	PS	PW	AB	ISO	EU
5/18	727	39,390			0	28	0.97%	10	14	0	0	0	0	11	224	0	17	2	4	0	4	0
5/19	927	40,317	2,306	2,306	14	14	0.95%	2	29	0	0	0	0	5	232	5	15	6	6	0	1	0
5/20	1,603	41,920			6	20	0.95%	8	15	0	0	0	0	16	196	9	12	6	4	0	0	2
5/21	3,560	45,480			0	20	0.95%	11	25	0	0	0	0	18	212	5	14	8	1	0	4	0
5/22	1,355	46,835			1	21	0.95%	33	33	0	0	1	0	10	225	4	12	7	2	0	2	0
5/23	749	47,584			0	21	0.95%	32	12	0	0	0	0	7	281	1	10	6	1	0	1	0
5/24	513	48,097			0	21	0.95%	12	6	0	0	0	0	4	276	0	8	4	1	0	1	0
5/25	2,788	50,885	2,014	1,611	6	6	0.56%	36	21	0	0	0	0	13	218	6	8	15	11	1	1	0
5/26	1,387	52,272			2	8	0.56%	18	14	0	0	0	0	3	321	6	7	10	2	0	2	1
5/27	366	52,638			0	8	0.56%	37	18	0	0	0	0	4	215	2	5	2	1	0	0	1
5/28	846	53,484			0	8	0.56%	43	12	0	0	1	0	29	456	23	22	5	4	0	40	2
5/29	365	53,849			0	8	0.56%	63	24	0	0	0	0	15	409	16	19	20	11	0	60	0
5/30	510	54,359			0	8	0.56%	33	27	0	0	1	0	8	348	13	5	16	2	0	10	0
5/31	192	54,551			0	8	0.56%	22	17	0	0	0	0	14	490	2	1	11	3	0	7	0
6/1	200	54,751			0	8	0.56%	78	8	0	0	3	0	8	551	8	0	7	5	0	12	0
6/2	907	55,658			0	8	0.56%	35	25	0	0	2	0	12	846	21	6	11	8	0	4	0
6/3 ^f	595	56,253			0	8	0.56%	7	32	0	0	2	0	10	833	14	4	12	9	0	9	0
6/4	996	57,249			0	8	0.56%	12	39	0	0	1	0	13	1,305	18	0	63	2	0	10	0
6/5	573	57,822	1,803	1803	11	11	1.11%	10	108	0	0	2	0	26	2,637	7	4	33	12	0	5	0
6/6	309	58,131			2	13	1.11%	364	61	0	0	2	0	12	2,099	20	0	28	8	0	9	0
6/7	593	58,724			1	14	1.11%	138	65	0	0	2	0	16	1,650	28	6	26	5	0	11	0
6/8	230	58,954			3	17	1.11%	98	18	0	0	0	0	2	831	10	0	17	5	0	5	1
6/9	438	59,392			1	18	1.11%	44	68	0	0	0	0	7	524	23	5	38	6	0	9	0
6/10	486	59,878			1	19	1.11%	208	39	0	0	2	0	32	462	17	1	59	41	0	10	0
6/11	761	60,639			0	19	1.11%	12	149	0	0	0	0	9	1,680	21	2	93	11	0	8	0
6/12	880	61,519			0	19	1.11%	11	140	0	0	6	0	11	2,033	20	0	77	5	0	9	0
6/13	648	62,167			0	19	1.11%	6	133	0	0	0	0	7	996	16	4	74	4	0	13	0
6/14	542	62,709			0	19	1.11%	16	83	0	0	0	0	6	837	4	0	55	0	0	4	0
6/15	365	63,074			0	19	1.11%	7	112	0	0	0	0	8	500	7	0	68	0	0	4	0
Total		63,074	15,414	14,469	112		0.86%	6,801	1,570	12	0	25	0	513	36,268	590	369	883	185	1	349	7

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- ^a Coho = juvenile coho salmon, Pink = juvenile pink salmon, Chnk = juvenile Chinook salmon, Chum = juvenile chum salmon, DV = Dolly Varden, SB = stickleback, SC = sculpin, SF = starry flounder, PS = pond smelt, PW = pygmy whitefish, and AB = Alaskan blackfish, ISO = isopods, and EU = eulachon.
- ^b Actual number of smolt released, not adjusted for delayed mortality.
- ^c Number of smolt released adjusted for delayed mortality.
- ^d Calculated by: $= \{(R+1)/(M+1)\} * 100$ where: R = number of marked fish recaptured and M = number of marked fish (Carlson et al. 1998) after adjusting for delayed mortality.
- ^e Small and large traps fishing for the season at 20:00 on April 17. Partial smolt day; counts only for sockeye.

Appendix A2.–Number of sockeye salmon smolt caught by trap, by day from the Chignik River, April 17–June 15, 2015.

Date ^a	Small Trap		Large Trap		Combined		Daily Proportion	
	Daily	Cumulative	Daily	Cumulative	Daily	Cumulative ^b	Small	Large
4/17	-	-	-	-	187	187	-	-
4/18	43	43	107	107	150	337	28.67%	71.33%
4/19	1,490	1,533	1,188	1,295	2,678	3,015	55.64%	44.36%
4/20	237	1,770	278	1,573	515	3,343	46.02%	53.98%
4/21	4,198	5,968	5,331	6,904	9,529	12,872	44.05%	55.95%
4/22	237	6,205	408	7,312	645	13,517	36.74%	63.26%
4/23	252	6,457	244	7,556	496	14,013	50.81%	49.19%
4/24	237	6,694	421	7,977	658	14,671	36.02%	63.98%
4/25	756	7,450	1,561	9,538	2,317	16,988	32.63%	67.37%
4/26	611	8,061	1,404	10,942	2,015	20,003	30.32%	69.68%
4/27	123	8,184	248	11,190	371	19,374	33.15%	66.85%
4/28	79	8,263	131	11,321	210	19,584	37.62%	62.38%
4/29	174	8,437	336	11,657	510	20,094	34.12%	65.88%
4/30	110	8,547	285	11,942	395	20,489	27.85%	72.15%
5/1	91	8,638	113	12,055	204	20,693	44.61%	55.39%
5/2	129	8,767	154	12,209	283	20,976	45.58%	54.42%
5/3	82	8,849	150	12,359	232	21,208	35.34%	64.66%
5/4	97	8,946	105	12,464	202	21,410	48.02%	51.98%
5/5	152	9,098	147	12,611	299	21,709	50.84%	49.16%
5/6	258	9,356	339	12,950	597	22,306	43.22%	56.78%
5/7	899	10,255	790	13,740	1,689	23,995	53.23%	46.77%
5/8	527	10,782	600	14,340	1,127	25,122	46.76%	53.24%
5/9	132	10,794	517	14,857	649	25,651	20.34%	79.66%
5/10	295	11,089	538	15,395	833	26,484	35.41%	64.59%
5/11	308	11,397	599	15,994	907	27,391	33.96%	66.04%
5/12	372	11,769	1,397	17,391	1,769	29,160	21.03%	78.97%
5/13	499	12,268	1,146	18,537	1,645	30,805	30.33%	69.67%
5/14	392	12,660	1,530	20,067	1,922	32,727	20.40%	79.60%
5/15	618	13,278	2,916	22,983	3,534	36,261	17.49%	82.51%
5/16	221	13,499	961	23,944	1,182	37,443	18.70%	81.30%
5/17	376	13,875	537	24,481	913	38,356	41.18%	58.82%
5/18	641	14,516	86	24,567	727	39,083	88.17%	11.83%
5/19	218	14,734	709	25,276	927	40,010	23.52%	76.48%
5/20	515	15,249	1,088	26,364	1,603	41,613	32.13%	67.87%
5/21	1,439	16,688	2,121	28,485	3,560	45,173	40.42%	59.58%
5/22	568	17,256	787	29,272	1,355	46,528	41.92%	58.08%
5/23	190	17,446	559	29,831	749	47,277	25.37%	74.63%
5/24	135	17,581	378	30,209	513	47,790	26.32%	73.68%
5/25	872	18,453	1,916	32,125	2,788	50,578	31.28%	68.72%
5/26	484	18,937	903	33,028	1,387	51,965	34.90%	65.10%
5/27	268	19,205	98	33,126	366	52,331	73.22%	26.78%
5/28	355	19,560	491	33,617	846	53,177	41.96%	58.04%
5/29	155	19,715	210	33,827	365	53,542	42.47%	57.53%

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Appendix A2.–Page 2 of 2.

Date ^a	Small Trap		Large Trap		Combined		Daily Proportion	
	Daily	Cumulative	Daily	Cumulative	Daily	Cumulative	Small	Large
5/30	161	19,876	349	34,176	510	54,052	31.57%	68.43%
5/31	75	19,961	117	34,293	192	54,254	39.06%	60.94%
6/1	108	20,059	92	34,385	200	54,444	54.00%	46.00%
6/2	127	20,186	780	35,165	907	55,351	14.00%	86.00%
6/3	245	20,431	350	35,515	595	55,946	41.18%	58.82%
6/4	161	20,592	835	36,350	996	56,942	16.16%	83.84%
6/5	279	20,871	294	36,644	573	57,515	48.69%	51.31%
6/6	105	20,976	204	36,848	309	57,824	33.98%	66.02%
6/7	178	21,154	415	37,263	593	58,417	30.02%	69.98%
6/8	157	21,311	73	37,336	230	58,647	68.26%	31.74%
6/9	169	21,480	269	37,605	438	59,085	38.58%	61.42%
6/10	264	21,844	222	37,827	486	59,671	54.32%	45.68%
6/11	219	22,063	542	38,369	761	60,432	28.78%	71.22%
6/12	422	22,485	458	38,827	880	61,312	47.95%	52.05%
6/13	279	22,764	369	39,196	648	61,960	43.06%	56.94%
6/14	238	23,002	304	39,500	542	62,502	43.91%	56.09%
6/15	174	23,176	191	39,691	365	62,867	47.67%	52.33%
Total		23,176		39,691		62,867	36.87%	63.13%

^a Small and large traps were raised at 8:00 and 12:00, respectively on June 15 for the season.

^b Combined cumulative total includes the partial day, 4/17.

Appendix A3.–Weighted mean length, weight, and condition factor (K) of sampled smolt, 2015.

Age	Stat Week	Starting Date	Sample Size	Length (mm)		Weight (g)		Condition factor	
				Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
0	16	4/12	1	47	0.0	0.4	0.0	0.39	0.0
0	17	4/19	1	51	0.0	0.8	0.0	0.60	0.0
0	18	4/26	6	48	0.5	0.7	0.0	0.58	0.0
0	19	5/3	10	48	0.5	0.7	0.0	0.59	0.0
0	20	5/10	2	49	0.0	0.7	0.0	0.59	0.0
0	23	5/31	1	50	0.0	0.8	0.0	0.64	0.0
0	24	6/7	24	49	0.4	0.8	0.0	0.65	0.0
Total	Weighted by SS		45	49	0.6	0.8	0.1	0.62	0.0
	Weighted by OM			49		0.7		0.61	
1	16	4/12	60	68	0.8	2.1	0.1	0.65	0.0
1	17	4/19	213	68	0.5	2.1	0.0	0.64	0.0
1	18	4/26	168	64	0.7	1.7	0.1	0.63	0.0
1	19	5/3	141	67	0.7	2.0	0.1	0.65	0.0
1	20	5/10	99	70	0.6	2.3	0.1	0.64	0.0
1	21	5/17	88	70	0.7	2.3	0.1	0.64	0.0
1	22	5/24	156	66	0.5	1.9	0.1	0.63	0.0
1	23	5/31	165	63	0.5	1.7	0.1	0.65	0.0
1	24	6/7	173	61	0.6	1.6	0.1	0.66	0.0
Total	Weighted by SS		1,263	67	11.1	2.0	1.0	0.64	0.1
	Weighted by OM			66		2.0		0.64	
2	16	4/12	19	76	1.5	3.0	0.2	0.66	0.0
2	17	4/19	24	78	1.2	3.2	0.2	0.66	0.0
2	18	4/26	25	75	1.6	3.0	0.2	0.68	0.0
2	19	5/3	49	79	1.0	3.3	0.2	0.67	0.0
2	20	5/10	98	76	0.6	3.0	0.1	0.66	0.0
2	21	5/17	112	76	0.4	2.9	0.1	0.67	0.0
2	22	5/24	43	75	1.3	3.0	0.3	0.66	0.0
2	23	5/31	33	80	2.1	4.1	0.5	0.73	0.0
2	24	6/7	3	68	1.5	2.1	0.2	0.68	0.0
Total	Weighted by SS		406	77	3.7	3.1	0.8	0.67	0.0
	Weighted by OM			77		3.1		0.67	
3	20	5/10	1	95	0.0	7.0	0.0	0.82	0.0
3	22	5/24	1	93	0.0	5.9	0.0	0.73	0.0

APPENDIX B. WEATHER AND PHYSICAL OBSERVATIONS, 2015

Appendix B1.–Daily observations at the Chignik River smolt traps in 2015.

Date ^a	Time	Air (°C)	Water (°C)	Cloud ^b Cover (%)	Wind ^b Dir	Vel. ^b (mph)	Trap Revolutions (rpm)		Stream Gauge (cm)	Comments
							Small	Large		
4/17	-	-	-	-	-	-	-	-	-	no data
4/18	-	-	-	-	-	-	-	-	-	no data
4/19	-	-	-	-	-	-	-	-	-	no data
4/20	12:05	-	2.4	100	W	8	4.25	4.00	-	mixed rain/snow
4/21	12:05	3.0	2.3	100	Variable	3	4.00	4.00	-	mixed rain/snow
4/22	12:15	4.0	3.1	5	W	12	4.00	4.00	0	sunny, partly cloudy, breezy
4/23	11:50	7.8	3.4	100	S	5	3.50	3.75	0	low water, moved traps out 2 ft
4/24	12:15	6.4	3.4	70	S	3	4.00	4.00	17	calm winds, partly sunny
4/25	12:25	5.7	3.3	100	Variable	3	4.75	4.50	17	calm, light rain
4/26	12:25	7.8	3.8	30	NW	12	4.00	3.75	18	windy downstream, sunny
4/27	12:15	3.6	3.5	0	NW	8	4.00	4.00	17	sunny
4/28	11:50	6.7	3.9	20	SE	5	3.75	3.75	17	sunny
4/29	12:10	5.6	3.7	100	No wind	0	3.50	3.75	17	calm
4/30	12:15	8.1	4.0	95	W	5	3.75	3.75	17	calm
5/1	11:50	7.2	4.4	15	W	5	3.75	3.75	17	mostly sunny
5/2	11:55	3.9	3.7	100	NW	8	3.75	4.75	18	moved traps out 3 ft
5/3	11:50	5.7	3.9	100	NW	8	4.00	4.00	18	overcast
5/4	12:25	8.5	4.5	75	SE	5	3.50	4.50	17	partly sunny, calm
5/5	12:06	7.8	4.3	100	SE	5	3.60	4.80	17	calm
5/6	12:12	8.1	4.2	100	E	3	3.75	4.00	18	calm
5/7	12:00	7.3	4.5	100	E	3	3.80	4.00	21	calm
5/8	12:00	3.7	4.3	100	NW	20	4.50	4.50	22	rain
5/9	11:45	4.6	4.4	10	W	15	4.75	4.50	26	sunny
5/10	12:00	6.6	4.6	100	E	8	4.50	4.25	25	overcast
5/11	11:55	7.8	4.6	100	W	8	4.75	4.50	26	overcast, light rain
5/12	12:25	9.8	5.3	20	E	8	4.70	4.50	27	mostly sunny
5/13	12:10	10.9	4.7	100	SE	5	4.50	4.50	28	overcast
5/14	12:00	8.8	4.9	100	SE	5	5.00	5.00	30	
5/15	12:10	8.9	5.1	80	SE	5	5.50	5.15	34	
5/16	12:10	6.4	4.9	100	SE	23	5.30	5.00	34	rain
5/17	11:50	7.5	4.9	100	SE	15	6.00	5.50	42	moved traps in 8 inches

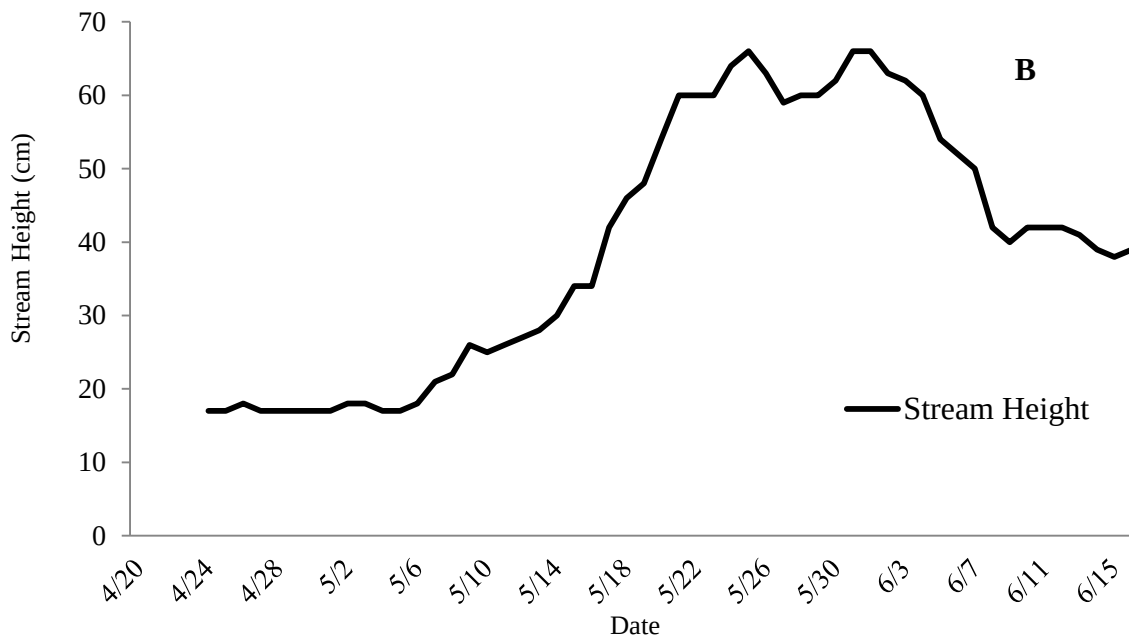
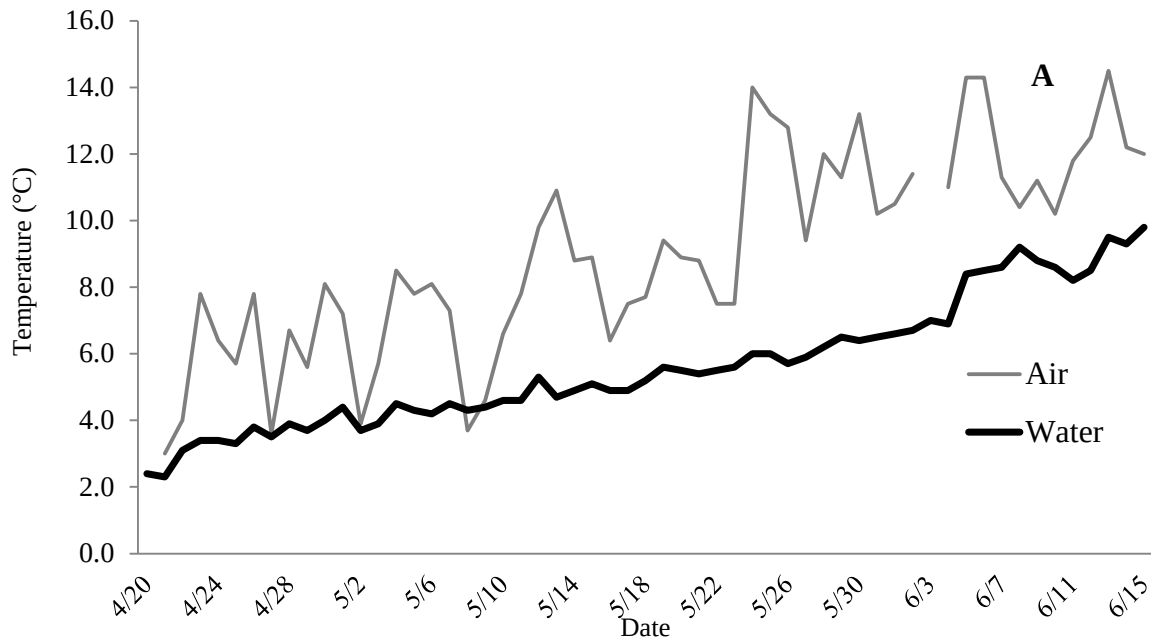
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Appendix B1.–Page 2 of 2.

Date ^a	Time	Air (°C)	Water (°C)	Cloud ^b Cover (%)	Wind ^b Dir	Vel. ^b (mph)	Trap Revolutions (rpm)		Stream Gauge (cm)	Comments
							Small	Large		
5/18	12:00	7.7	5.2	95	S	5	6.50	6.00	46	moved traps in 1 foot
5/19	12:10	9.4	5.6	100	S	13	6.50	6.00	48	
5/20	12:15	8.9	5.5	100	SE	5	-	6.25	54	small trap raised at 8:00AM
5/21	12:15	8.8	5.4	100	E	3	7.50	6.75	60	moved legs in, water very swift
5/22	12:00	7.5	5.5	100	E	13	8.00	6.75	60	rain
5/23	12:15	7.5	5.6	100	E	20	8.00	6.75	60	rain
5/24	12:30	14.0	6.0	50	E	8	8.25	6.80	64	
5/25	12:15	13.2	6.0	50	E	3	8.75	7.25	66	mostly sunny
5/26	12:00	12.8	6	90	S	8	8.50	7.00	63	
5/27	12:05	9.4	6	100	S	5	8.00	6.90	59	rainy
5/28	11:55	12	6	98	SE	8	8.25	7.000	60	
5/29	12:04	11.3	6.5	100	SE	10	8.00	7.20	60	
5/30	12:17	13.2	6.4	100	No wind	0	8.25	7.25	62	
5/31	12:00	10.2	6.5	100	SE	5	8.80	7.25	66	
6/1	12:10	10.5	6.6	100	Variable	3	8.00	7.75	66	
6/2	12:10	11.4	6.7	90	Variable	3	8.00	7.50	63	
6/3	12:15	-	7.0	100	NW	5	8.00	7.25	62	
6/4	11:55	11.0	6.9	100	No wind	0	8.75	7.00	60	light rain
6/5	12:07	14.3	8.4	90	No wind	0	6.75	7.75	54	
6/6	12:03	14.3	8.5	85	NW	3	7.25	6.5	52	
6/7	12:00	11.3	8.6	99	NW	3	6.90	6.00	50	
6/8	12:05	10.4	9.2	100	SE	10	6.50	6.00	42	rain, water level dropping quickly
6/9	12:00	11.2	8.8	100	S	5	6.25	5.75	40	
6/10	12:07	10.2	8.6	90	W	15	6.00	5.50	42	breezy; gusts to 20-25 mph
6/11	12:00	11.8	8.2	60	W	3	6.30	6.00	42	partly sunny
6/12	12:00	12.5	8.5	5	NW	10	6.25	6.00	42	sunny
6/13	12:15	14.5	9.5	0	W	5	6.25	6.00	41	foggy/sunny
6/14	12:00	12.2	9.3	0	NW	15	6.25	5.50	39	sunny
6/15	12:10	12.0	9.8	0	NW	15	6.25	5.50	38	sunny, breezy
6/16	11:48	14.7	9.8	0	NW	10	-	5.50	39	sunny; traps raised for season

^a Corresponding to actual calendar day, and beginning of smolt day^b Based on observer estimates.

Appendix B2.—Air and water temperature (A), and stream height measured at the Chignik River smolt traps (B), 2015.



APPENDIX C. HISTORICAL LIMNOLOGY DATA

Appendix C1.–Seasonal averages of water quality parameters, nutrient concentrations, and photosynthetic pigments by year for Black Lake, 2000–2015.

	2000 ^a	2001 ^b	2002	2003	2004	2005	2006 ^{b,c}	2007 ^b	2008 ^b	2009	2010	2011	2012 ^c	2013 ^{b,c,d}	2014 ^{c,e}	2015 ^b
pH	7.43	7.53	7.45	7.45	7.81	7.57	8.01	7.64	7.64	7.67	7.78	7.69	7.69	7.89	8.23	7.80
Alkalinity (mg/L CaCO ₃)	13.3	32.5	32.3	32.3	30.2	24.3	20.5	19.7	19.0	29.4	22.0	26.6	26.7	29.5	34.8	25.7
Total phosphorous (µg/L P)	56.8	35.2	37.1	41.6	22.2	27.9	20.4	24.4	22.2	41.1	29.8	34.3	11.0	31.9	13.9	16.4
Total filterable phosphorous (µg/L P)	10.7	9.8	98.0	10.1	5.1	8.6	11.0	ND	ND	6.9	8.0	4.3	3.2	4.9	3.3	4.4
Filterable reactive phosphorous (µg/L P)	4.0	7.4	24.7	5.4	2.6	7.2	9.1	ND	ND	ND	3.3	3.2	1.5	1.3	3.3	2.0
Total kjedhal nitrogen (µg/L N)	ND	320.6	323.5	256.8	188.8	324.5	216.0	124.3	263.7	233.5	210.8	426.5	ND	979.7	277.0	298.0
Ammonia (µg/L N)	36.6	3.3	4.1	4.5	9.7	3.9	11.0	130.1	3.7	2.6	6.4	3.3	6.0	4.4	5.3	6.1
Nitrate + Nitrite (µg/L N)	38.9	15.5	8.3	25.2	3.7	1.9	0.9	1.6	0.6	1.9	1.0	1.1	2.4	2.9	5.7	1.1
Silicon (µg/L)	ND	ND	ND	ND	3382.8	ND	ND	ND	ND	ND	ND	2925.7	1618.6	1541.2	2752.0	2596.0
Chlorophyll a (µg/L)	18.1	4.3	2.6	5.1	3.6	5.0	4.4	3.3	6.6	3.0	2.8	4.6	5.8	5.0	4.1	7.7
Phaeophytin a (µg/L)	10.0	11.9	1.4	1.8	0.2	1.0	0.8	0.9	1.4	1.4	1.5	0.5	0.8	1.7	1.3	1.1

^a Seasonal average includes a surface water sample in August.

^b Limnology samples were not collected in August.

^c Limnology samples were not collected in May.

^d Limnology samples were collected in September.

^e Limnology samples were not collected in July.

Appendix C2.–Seasonal averages of water quality parameters, nutrient concentrations, and photosynthetic pigments for Chignik Lake, 2000–2015.

	2000	2001	2002	2003	2004	2005	2006 ^a	2007 ^a	2008 ^a	2009	2010	2011 ^{a,b}	2012 ^c	2013 ^{a,b}	2014 ^{a,b,e}	2015 ^b
pH	7.81	7.47	7.45	7.38	7.62	7.57	7.70	7.46	7.48	7.50	7.22	7.52	7.36	7.71	7.75	7.62
Alkalinity (mg/L CaCO ₃)	15.0	24.8	24.6	23.5	22.4	23.8	24.8	18.2	21.0	23.8	20.1	22.9	24.1	26.2	26.2	21.4
Total phosphorous (µg/L P)	14.5	27.6	19.7	16.7	18.6	15.8	20.1	14.2	15.6	22.3	13.6	12.4	10.2	14.5	8.1	7.1
Total filterable phosphorous (µg/L P)	5.9	12.3	8.5	7.5	6.5	6.5	8.3	ND	ND	ND	5.4	3.3	3.5	3.0	2.3	2.4
Filterable reactive phosphorous (µg/L P)	5.2	8.3	4.6	5.6	4.1	5.7	8.9	ND	ND	ND	4.5	5.1	2.4	1.9	3.9	2.7
Total kjedhal nitrogen (µg/L N) ^d	230.0	101.8	119.7	99.0	146.5	199.5	86.0	148.3	96.3	79.8	44.5	151.0	ND	344.5	71.1	202.9
Ammonia (µg/L N)	28.2	10.3	10.5	9.8	9.1	6.4	10.7	7.9	5.9	5.8	6.7	8.3	11.0	5.8	4.3	7.7
Nitrate + Nitrite (µg/L N)	162.6	191.6	117.4	166.7	128.0	103.3	129.9	194.0	192.5	152.3	154.4	187.1	171.7	133.3	149.1	68.0
Silicon (µg/L)	ND	ND	ND	ND	4128.8	ND	ND	ND	ND	ND	5986.1	2966.0	5289.8	4445.1	5396.3	4736.6
Chlorophyll a (µg/L)	9.1	4.7	2.3	2.3	4.0	3.0	6.6	2.2	2.2	2.3	1.5	2.2	2.9	2.9	1.9	6.4
Phaeophytin a (µg/L)	1.6	1.3	1.3	0.5	0.3	0.6	0.9	0.4	0.6	0.6	0.8	0.5	0.3	0.7	0.8	2.6

^a Limnological samples were not collected in August.

^b Limnological samples were collected in September.

^c Limnological samples were not collected in May.

^d TKN only processed on 1m samples.

^e Limnological samples were collected on July 1 and July 31.

Appendix C3.–Seasonal average number of zooplankton per m² from Black Lake by year, 2000–2015.

	2000	2001 ^a	2002 ^b	2003	2004	2005	2006 ^{a,c}	2007 ^a	2008 ^a	2009	2010	2011	2012 ^c	2013 ^{a,b,c}	2014 ^{c,d}	2015 ^{a,e}
Taxon																
Copepods																
<i>Cyclops</i>	39,819	3,668	50,573	19,042	46,198	46,842	31,582	5,131	13,093	24,031	18,312	8,519	15,906	48,461	36,385	11,014
<i>Ovig. Cyclops</i>	-	-	-	265	-	-	-	-	-	-	66	1,354	-	-	-	-
<i>Diaptomus</i>	3,747	1,533	3,153	11,080	23,010	3,716	796	1,062	-	2,489	2,787	-	-	-	-	-
<i>Ovig. Diaptomus</i>	-	-	-	1,327	-	265	-	-	-	-	149	-	-	-	-	-
<i>Epischura</i>	9,166	1,946	6,805	6,303	37,649	18,113	-	5,750	-	3,729	4,263	2,389	5,166	10,899	-	5,573
<i>Ovig. Epischura</i>	159	-	-	-	-	-	-	-	-	-	-	318	-	584	-	-
<i>Eurytemora</i>	-	-	-	-	-	-	-	-	-	-	199	2,309	3,769	5,547	-	4,777
<i>Ovig. Eurytemora</i>	-	-	-	-	-	-	-	-	-	-	-	2,866	-	2,707	-	-
<i>Harpacticus</i>	-	1,062	-	531	531	-	265	-	-	-	149	-	177	-	-	-
<i>Nauplii</i>	24,298	3,716	24,023	24,350	40,509	38,150	8,758	9,996	16,189	28,938	12,971	18,869	10,209	41,012	19,719	16,720
Total copepods	77,189	11,925	84,554	62,898	147,897	107,086	41,401	21,939	29,282	59,188	38,897	36,624	35,226	109,209	56,104	38,084
Cladocerans																
<i>Bosmina</i>	46,900	38,417	86,316	285,496	398,855	203,755	2,322	619	1,681	49,209	28,646	3,424	27,955	25,088	20,541	29,857
<i>Ovig. Bosmina</i>	13,008	9,802	35,159	39,809	90,147	29,989	796	-	1,681	11,545	7,431	52,787	2,300	584	3,556	8,360
<i>Chydorinae</i>	14,441	369,840	30,127	3,516	78,716	12,407	3,052	2,919	-	-	-	318	1,203	26,787	690	12,739
<i>Ovig. Chydorinae</i>	-	-	446	-	398	-	-	-	-	-	-	8,121	-	1,645	-	4,777
<i>Daphnia L.</i>	861	248	-	1,526	199	-	-	-	-	66	-	80	531	1,062	-	-
<i>Holopedium</i>	-	-	-	-	-	-	-	-	-	-	66	-	531	584	-	-
<i>Immature Cladocera</i>	1,115	-	-	21,895	7,083	17,914	2,588	-	-	8,824	4,943	16,162	7,006	36,837	-	3,981
Total cladocerans	76,324	418,306	152,049	352,243	575,398	264,066	8,758	3,539	3,362	69,644	41,086	80,892	39,526	92,587	24,788	59,713
Total copepods + cladocerans	153,513	430,231	236,603	415,141	723,295	371,152	50,159	25,478	32,643	128,832	79,983	117,516	74,752	201,796	80,892	97,797

^a Zooplankton samples were not collected in August.

^b Zooplankton samples were collected in September.

^c Zooplankton samples were not collected in May.

^d Zooplankton samples were not collected in July.

^e Zooplankton samples were not collected in June.

Appendix C4.–Average weighted biomass estimates (mg dry weight/m²) of the major Black Lake zooplankton taxon by year, 2000–2015.

Taxon	2000	2001 ^a	2002 ^b	2003	2004	2005	2006 ^{a,c}	2007 ^a	2008 ^a	2009	2010	2011	2012 ^c	2013 ^{a,b,c}	2014 ^{c,d}	2015 ^{a,e}
Copepods																
<i>Cyclops</i>	45.36	4.36	35.79	18.34	35.15	44.39	22.04	4.47	14.02	23.90	12.46	8.26	15.05	42.55	65.52	10.31
<i>Ovig. Cyclops</i>	-	-	-	0.80	-	-	-	-	-	-	0.38	3.36	-	-	-	-
<i>Diaptomus</i>	13.70	3.29	15.71	42.68	29.55	8.20	1.11	2.89	-	5.58	7.05	-	-	-	-	-
<i>Ovig. Diaptomus</i>	-	-	-	8.88	-	2.24	-	-	-	-	1.16	-	-	-	-	-
<i>Epischura</i>	10.40	9.16	3.58	3.57	65.64	14.02	-	10.04	-	3.19	2.89	1.64	4.52	8.18	-	1.26
<i>Ovig. Epischura</i>	1.68	-	-	-	-	-	-	-	-	-	-	0.60	-	6.42	-	-
<i>Eurytemora</i>	-	-	-	-	-	-	-	-	-	-	1.26	9.52	20.36	25.04	-	11.33
<i>Ovig. Eurytemora</i>	-	-	-	-	-	-	-	-	-	-	-	24.04	-	26.64	-	-
<i>Harpacticus</i>	-	1.78	-	0.35	-	-	0.17	-	-	-	0.09	-	0.18	-	-	-
Total copepods	71.14	18.59	55.08	74.62	130.34	68.85	23.32	17.40	14.02	32.67	25.29	47.42	40.11	108.83	65.52	22.90
Cladocerans																
<i>Bosmina</i>	43.23	40.64	66.42	294.29	372.52	180.80	2.07	0.34	1.45	49.59	25.02	2.31	22.47	25.73	13.73	21.14
<i>Ovig. Bosmina</i>	17.10	10.48	44.36	78.67	128.39	43.31	0.81	-	2.58	18.07	12.28	70.25	2.99	0.88	7.20	7.37
<i>Chydorinae</i>	8.16	1685.43	15.52	2.35	38.91	8.58	1.84	2.08	-	-	-	-	0.45	15.91	0.54	5.90
<i>Ovig. Chydorinae</i>	-	-	0.41	-	0.42	-	-	-	-	-	-	4.53	-	1.77	-	1.88
<i>Daphnia L.</i>	0.73	0.07	-	2.31	0.05	-	-	-	-	0.16	-	0.17	0.55	-	-	-
<i>Holopedium</i>	-	-	-	-	-	-	-	-	-	-	0.77	-	0.40	1.29	-	-
Total cladocerans	69.22	1736.62	126.71	377.62	540.29	232.69	4.72	2.42	4.03	67.82	38.07	77.26	26.86	45.58	21.47	36.29
Total biomass	140.36	1755.21	181.79	452.24	670.63	301.54	28.04	19.82	18.05	100.49	63.36	124.68	66.97	154.41	86.99	59.19

^a Zooplankton samples were not collected in August.

^b Zooplankton samples were collected in September.

^c Zooplankton samples were not collected in May.

^d Zooplankton samples were not collected in July.

^e Zooplankton samples were not collected in June.

Appendix C5.–Seasonal average number of zooplankton per m² from Chignik Lake by year, 2000–2015.

Taxon	2000	2001	2002	2003 ^a	2004	2005	2006	2007	2008	2009	2010	2011	2012 ^{a,b,c}	2013 ^{a,c}	2014 ^{a,c,d}	2015 ^a
Copepods																
<i>Cyclops</i>	193,005	43,363	170,001	37,726	140,995	120,322	175,889	292,645	82,109	130,339	92,755	142,259	72,426	152,987	46,554	53,808
<i>Ovig. Cyclops</i>	2,119	3,507	14,580	916	4,547	10,388	24,648	10,898	2,637	3,767	3,679	6,844	1,920	12,435	244	5,082
<i>Diaptomus</i>	11,072	12,869	35,347	62,274	44,994	49,367	17,350	8,741	14,099	34,562	32,866	-	-	-	-	-
<i>Ovig. Diaptomus</i>	765	48	4,777	1,393	2,704	2,816	1,169	1,443	1,858	1,368	1,302	-	-	-	-	-
<i>Epischura</i>	33,615	13,400	49,645	70,621	66,980	51,946	6,842	3,168	10,350	5,180	10,039	17,411	15,822	9,081	66	-
<i>Ovig. Epischura</i>	149	48	-	-	-	-	-	-	-	-	-	265	-	100	-	-
<i>Eurytemora</i>	-	-	-	-	-	-	-	-	-	-	2,223	18,063	8,740	13,008	45,746	52,229
<i>Ovig. Eurytemora</i>	-	-	-	-	-	-	-	-	-	-	-	12,029	164	896	1,181	8,970
<i>Harpacticus</i>	178	528	1,244	398	979	348	1,335	265	100	604	559	-	332	149	-	478
<i>Ovig. Harpacticus</i>	-	-	-	-	-	-	-	133	-	-	66	-	62	-	-	40
<i>Nauplii</i>	41,723	14,969	92,473	55,573	73,434	115,371	87,024	47,605	36,148	48,066	35,065	63,923	47,607	92,054	68,183	169,931
Total copepods	282,626	88,733	368,067	228,901	334,632	350,559	314,258	364,898	147,301	223,885	178,554	260,795	147,072	280,708	161,974	290,539
Cladocerans																
<i>Bosmina</i>	46,646	30,213	70,113	73,447	59,531	88,990	37,553	13,021	38,112	22,030	39,442	10,735	50,495	25,832	77,854	25,133
<i>Ovig. Bosmina</i>	12,137	4,622	19,622	14,358	8,919	24,968	8,393	2,604	9,372	1,592	3,581	20,674	1,132	1,612	2,988	6,462
<i>Chydorinae</i>	4,000	1,516,382	11,462	1,115	8,207	6,179	13,311	6,137	531	43,676	7,844	2,057	2,066	9,587	166	3,556
<i>Ovig. Chydorinae</i>	-	-	133	-	166	-	-	-	-	13,854	1,555	3,299	88	100	-	173
<i>Daphnia L.</i>	8,251	1,462	20,750	68,073	30,072	15,787	8,053	38,681	11,901	-	-	10,707	1,407	87,279	100,292	102,150
<i>Ovig. Daphnia L.</i>	909	33	10,516	7,086	7,501	6,336	1,120	16,073	2,189	-	-	7,912	212	12,011	17,030	25,663
<i>Holopedium</i>	40	-	-	-	-	-	-	-	-	-	-	-	102	-	-	-
<i>Immature Cladocera</i>	1,411	5,862	5,955	5,679	4,082	12,415	9,554	-	-	6,251	7,593	10,646	5,281	22,310	17,825	22,797
Total cladocerans	73,393	1,558,574	138,552	169,759	118,478	154,674	77,984	76,516	62,105	87,402	60,015	66,030	60,784	158,730	216,155	185,934
Total copepods + cladocerans	356,019	1,647,307	506,618	398,660	453,110	505,233	392,242	441,415	209,407	311,287	238,570	326,825	207,856	439,438	378,130	476,473

^a Zooplankton samples were collected in September.

^b Zooplankton samples were not collected in May.

^c Zooplankton samples were not collected in August.

^d Zooplankton samples were collected on July 1 and July 31.

Appendix C6.—Average weighted biomass estimates (mg dry weight/m²) of the major Chignik Lake zooplankton taxon by year, 2000–2015.

Taxon	2000	2001	2002	2003 ^a	2004	2005	2006	2007	2008	2009	2010	2011	2012 ^{a,b,c}	2013 ^{a,c}	2014 ^{a,c,d}	2015 ^a
Copepods																
<i>Cyclops</i>	356.85	333.52	200.10	36.40	137.55	138.37	376.50	467.14	131.58	220.36	112.79	171.18	91.04	165.90	59.75	55.13
<i>Ovig. Cyclops</i>	15.31	135.69	58.16	3.71	20.39	40.33	153.67	58.86	13.40	25.27	15.51	32.21	9.58	57.04	1.25	28.95
<i>Diaptomus</i>	252.75	423.33	129.24	136.41	97.45	125.38	37.81	40.58	76.05	72.87	100.40	-	-	-	-	-
<i>Ovig. Diaptomus</i>	18.42	0.07	28.74	7.18	16.54	23.24	12.34	13.43	6.40	13.19	12.13	-	-	-	-	-
<i>Epischura</i>	146.70	405.59	34.33	37.86	50.36	43.47	4.90	4.17	13.16	4.21	7.98	16.17	15.38	6.45	0.09	0.00
<i>Ovig. Epischura</i>	1.03	0.08	-	-	-	-	-	-	-	-	-	0.29	-	1.07	-	-
<i>Eurytemora</i>	-	-	-	-	-	-	-	-	-	-	11.76	95.90	48.65	84.60	177.44	161.76
<i>Ovig. Eurytemora</i>	-	-	-	-	-	-	-	-	-	-	-	95.53	1.58	7.84	10.31	82.46
<i>Harpacticus</i>	0.12	1.45	0.76	0.26	0.60	0.27	1.09	0.39	0.05	0.43	0.34	-	0.21	0.27	-	0.39
<i>Ovig. Harpacticus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02
Total copepods	791.18	1299.73	451.33	221.82	322.89	371.06	586.31	584.57	240.64	336.33	260.91	411.28	166.44	323.17	248.84	328.71
Cladocerans																
<i>Bosmina</i>	182.98	141.13	57.52	77.57	47.50	77.73	30.74	12.37	35.48	23.33	35.80	9.01	45.93	27.70	56.15	10.54
<i>Ovig. Bosmina</i>	66.93	29.81	27.30	24.83	11.32	31.43	9.86	5.66	11.87	2.60	5.72	27.26	1.48	2.39	3.15	4.28
<i>Chydorinae</i>	5.16	15.48	7.47	0.75	5.80	3.90	9.25	3.52	0.15	-	-	1.20	1.32	5.62	0.24	2.11
<i>Ovig. Chydorinae</i>	-	-	0.09	-	0.23	-	-	-	-	-	-	2.28	0.09	0.08	-	0.14
<i>Daphnia L.</i>	23.20	15.17	23.94	77.20	34.64	19.22	8.90	47.63	13.33	52.15	9.19	8.09	1.44	90.89	121.98	63.76
<i>Ovig. Daphnia L.</i>	6.03	0.09	33.57	19.31	24.07	19.21	2.66	45.04	8.05	34.75	5.69	18.01	0.60	29.42	46.35	38.98
<i>Holopedium</i>	0.22	-	-	-	-	-	-	-	-	-	-	-	0.04	-	-	-
Total cladocerans	284.52	201.68	149.89	199.66	123.56	151.49	61.41	114.22	68.88	112.83	56.40	65.85	50.90	156.10	227.87	119.81
Total biomass	1075.70	1501.41	601.22	421.48	446.45	522.55	647.72	698.79	309.52	449.16	317.31	477.13	217.34	479.27	476.71	448.52

^a Zooplankton samples were collected in September.

^b Zooplankton samples were not collected in May.

^c Zooplankton samples were not collected in August.

^d Zooplankton samples were collected on July 1 and July 31.

APPENDIX D. BEACH SEINE DATA

Appendix D1.–Sampling events in Black Lake, 2009–2015.

	May	June	July	August	September
2009		X	X		
2010	X	X	X		
2011	X	X	X		
2012		X	X		
2013		X	X		X
2014	X	X			
2015	X		X	X ^a	

^a Only 1 site was sampled in Black Lake in August 2015.

Appendix D2.–Black Lake beach seine catches, 2010–2015.

Year	Month	Sockeye juveniles	Sockeye fry	Total Sockeye	Coho juveniles	Coho fry	Chinook smolt	Stickleback	Pond Smelt	Dolly Varden	Sculpin
2010	May	0	46	46	3	ND	0	5	0	0	ND
	June	750	772	1522	1	ND	17	209	554	0	ND
	July	23	67	90	3	ND	1	50	0	0	ND
2011	May	0	132	132	319	ND	1	853	1	0	ND
	June	3	914	917	2	ND	5	10	11	3	ND
	July	157	34	191	79	ND	0	13	186	2	ND
2012	June	0	7928	7928	5	0	0	15	0	2	0
	July	108	1246	1354	12	7	0	147	162	1	0
2013	June	5	765	770	9	0	0	597	0	1	17
	July	0	381	381	0	0	0	81	0	0	17
	September	20	0	20	19	0	0	68	67	0	16
2014	May	0	1416	1416	7	29	0	36	2	0	8
	June	434	70	504	6	6	0	230	107	0	5
2015	May	80	7	87	157	2	0	133	0	0	1
	July	65	0	65	15	0	0	410	5	1	0
	August ^a	0	0	0	24	0	0	40	0	0	0

^a Only 1 set at outlet of Black Lake sampled in August 2015.

Appendix D3.–Sampling events in Chignik Lagoon, 2009–2015.

Year	May	June	July	August
2009	X	X	X	
2010		X	X	
2011	X	X ^a	X	
2012		X	X	
2013	X	X	X	X
2014	X	X	X	X
2015	X	X	X	X

^a Only 1 site sampled in June 2011.

Appendix D4.–Chignik Lagoon beach seine catches, 2010-2015.

Year	Month	Sockeye smolt	Sockeye fry	Total Sockeye	Coho smolt	Coho fry	Chinook smolt	Stickleback	Pond Smelt	Dolly Varden	Sculpin
2010	June	65	27	92	5	ND	3	21	0	12	1
	July	83	319	402	2	ND	70	39	0	69	1
2011	May	77	803	880	3	ND	22	11	0	109	5
	June ^a	90	61	151	3	ND	23	7	0	87	3
	July	113	0	113	9	ND	62	14	0	99	4
2012	June	0	0	0	0	0	0	0	0	4	0
	July	305	32	337	27	32	0	9	0	225	2
2013	May	85	3	88	9	0	0	13	0	17	0
	June	140	6	146	6	0	2	2	0	189	7
	July	380	1	381	21	0	0	3	0	59	6
	August	27	11	38	15	3	0	5	2	11	9
2014	May	768	134	902	12	0	0	366	66	93	8
	June	102	7	109	35	0	0	52	0	40	1
	July	90	4	94	2	0	0	3	0	192	22
	August	8	0	8	17	0	0	13	0	40	15
2015	May	729	70	799	2	1	0	5,020	0	78	6
	June	278	3	281	41	0	0	505	0	364	2
	July	56	1	57	1	0	0	25,619	1,050	4	0
	August	29	0	29	30	0	0	4	3	22	10

^a Only 1 site sampled in June 2011.

Appendix D5.—Mean length and weight of juvenile sockeye salmon, by age class, captured in beach seines, 2009–2015, in Black Lake and Chignik Lagoon

Year	Location	Date	Freshwater-age-0			Freshwater-age-1			Freshwater-age-2		
			Sample size	Length (mm)	Weight (g)	Sample size	Length (mm)	Weight (g)	Sample size	Length (mm)	Weight (g)
2009	Black Lake	6/15/2009	37	48.3	1.4	0					
		7/9/2009	63	50.4	1.4	3	54.3	1.7			
	Chignik Lagoon	5/24/2009	10	53.6	1.5	20	75.6	3.9	4	76.5	4.2
		6/24/2009	53	61.4	2.8	19	83.4	6.2	1	83.0	5.6
		7/5/2009				25	76.0	5.1	2	77.0	5.2
2010	Black Lake	6/28/2010	41	48.8	1.5						
		7/10/2010	20	47.3	1.3						
	Chignik Lagoon	6/23/2010	16	62.3	2.4	33	73.5	4.1	11	84.5	6.2
		7/7/2010	7	54.6	1.6	34	68.6	3.3	7	81.6	5.9
2011	Black Lake	6/20/2011	6	47.2	1.3						
		7/14/2011	37	49.2	1.4						
	Chignik Lagoon	5/29/2011	2	64.5	2.6	39	71.0	4.4			
		6/22/2011	2	48.0	1.5	39	76.5	4.9	4	80.8	5.7
		7/13/2011				68	86.6	6.5	6	92.7	7.9
2012	Chignik Lagoon	6/12/2012				30	67.5	2.8	20	69.6	3.3
		7/2/2012	10	62.0	2.33	55	70.0	3.7	15	81.1	5.9
2013	Black Lake	6/13/2013	74	38.8	0.6						
		7/5/2013	74	44.6	1.1						
		9/9/2013	8	63.9	2.9	11	69.8	3.8			
	Chignik Lagoon	5/7/2013	3	32.7	0.2	30	71.5	2.9	27	79.4	4.2
		6/12/2013	1	40.0	0.9	46	71.9	3.5	18	78.3	4.9
		7/7/2013	2	45.5	0.9	80	81.0	5.1	18	81.9	5.5
		8/31/2013	24	52.8	1.5	2	61.5	2.5	1	108.0	15.2
2014	Black Lake	5/27/2014	49	38.3	0.6						
		6/24/2014	11	49.3	1.5	13	60.2	2.8			
	Chignik Lagoon	5/6/2014	18	33.3	0.2	47	54.7	1.1	11	73.5	2.9
		6/11/2014	7	36.3	0.5	20	63.7	2.3	45	77.3	4.7
		7/3/2014	24	48.8	1.2	16	63.3	2.6	23	93.3	9.3
		8/4/2014				1	72.0	3.8	6	88.3	7.2
2015	Black Lake	5/31/2015	40	39.4	0.6						
		7/8/2015	31	58.7	2.9	3	65.3	3.7			
	Chignik Lagoon	5/3/2015	39	33.3	0.3	37	68.5	2.5	19	83.4	4.6
		6/2/2015	5	40.4	0.6	58	66.5	2.3	22	79.4	4.3
		7/10/2015	4	52.5	1.6	42	74.3	4.4	3	76.0	4.7
		8/26/2015				26	63.8	2.9	2	106.5	12.4