Fishery Data Series No. 11-27

Afognak Lake Sockeye Salmon Stock Monitoring, 2010

by

Robert T. Baer

June 2011

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

Symbols and Abbreviations

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

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

FISHERY DATA SERIES NO. 11-27

AFOGNAK LAKE SOCKEYE SALMON STOCK MONITORING, 2010

by

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ABSTRACT

The Afognak Lake sockeye salmon *Oncorhynchus nerka* run severely declined in 2001. Concerns expressed by local subsistence users to the Alaska Department of Fish and Game and the US Fish and Wildlife Service Office of Subsistence Management prompted an investigation of the lake's rearing environment in 2003 followed by subsequent annual studies. This report provides 2010 project results.

Using mark-recapture techniques, an estimated 309,130 sockeye salmon smolt (95% CI 267,874–350,387) emigrated from Afognak Lake in 2010. The emigrating sockeye salmon smolt population was composed of 237,716 age-1. and 71,415 age-2. smolt. Age-1. smolt had a mean weight of 2.6 g, a mean length of 70 mm, and a mean condition factor of 0.76. Age-2. smolt had a mean weight of 3.9 g, a mean length of 82 mm, and a mean condition factor of 0.69. The total sockeye salmon escapement into Afognak Lake was 52,255 of which 80.6% were age 1.3.

Lake limnology data were collected during 5 monthly sampling events from May to September. In 2010, chlorophyll-*a* concentrations increased, seasonal total phosphorus concentrations declined, seasonal zooplankton densities were low, condition factors of emigrating smolts were low compared to historical data, and there was a positive association (R^2=.83, p<0.00017) between temperature and the condition of emigrating smolt.

Further assessment of photosynthetically active radiation, nutrient availability, phytoplankton population, available forage species vs. actual forage species, and the bioenergetic responses of juvenile salmon will occur over the next 3 years (2011–2013) of this project. This additional information, coupled with annual smolt health and abundance estimates, will provide greater insight into Afognak Lake's freshwater environment and factors affecting smolt production.

Key words: Afognak Lake, Litnik, mark-recapture, age, emigration, escapement, Kodiak Island, *Oncorhynchus nerka*, smolt, sockeye salmon, subsistence harvest, trap, zooplankton.

INTRODUCTION

The Afognak Lake watershed is located on the southeast side of Afognak Island, approximately 45 km northwest of the city of Kodiak (Figure 1). Afognak Lake (58°07' N, 152°55' W) lies 21.0 m above sea level, is 8.8 km long, has a maximum width of 0.8 km, and has a surface area of 5.3 km^2 (Schrof et al. 2000; White et al. 1990). The lake has a mean depth of 8.6 m, a maximum depth of 23.0 m, a total volume of 46.0 km^3, and an estimated lake-water residence time of 0.4 years (Figure 2). Due to its shallow depth Afognak Lake is easily influenced and mixed by wind and ice melt (Cole 1983). Afognak Lake drains in an easterly direction into the 3.2 km long Afognak River, which in turn flows into Afognak Bay, which is part of the Alaska Maritime National Wildlife Refuge and where most subsistence salmon fishing occurs. The Afognak Native Corporation owns the land surrounding the Afognak Lake watershed down to tidewater.

In addition to sockeye salmon *Oncorhynchus nerka*, other fish species in the Afognak Lake drainage include pink salmon *O. gorbuscha*, coho salmon *O. kisutch*, rainbow trout (anadromous and potamodromous) *O. mykiss*, Dolly Varden *Salvelinus malma*, three spine stickleback *Gasterosteus aculeatus*, and coastrange sculpin *Cottus aleuticus* (White et al. 1990). Chinook *O. tshawytscha* and chum *O. keta* salmon have been observed in the Afognak River on occasion but have not established discernable spawning populations (White et. al 1990).

Sockeye salmon from Afognak Lake are an important target species for salmon fisheries within the Kodiak region. Residents of Port Lions, Ouzinkie, Afognak Village, and Kodiak have traditionally harvested salmon in Afognak Bay for subsistence uses (Figure 1). Afognak Lake experienced poor runs in 2001 and fisheries closures in 2002. Local subsistence users, represented by the Kodiak-Aleutians Regional Advisory Council, Kodiak Fish and Game Advisory Committee, and Kodiak Tribal Council, contended that continued closures of the Afognak system would make it more difficult for local residents to harvest sockeye salmon and would shift fishing effort to small nearby sockeye salmon runs and the Buskin River, and this would constitute an emergency situation.

In response to this problem, ADF&G received funding through the Office of Subsistence Management's Fishery Resources Monitoring Program to determine the feasibility of estimating sockeye salmon smolt production in Afognak Lake. The initial feasibility study in 2003 showed that sockeye salmon smolt could be effectively trapped in Afognak River and their abundance reliably estimated using mark-recapture techniques (Honnold and Schrof 2004).

Continued analysis of Afognak Lake and annual smolt emigration studies were deemed of high importance for evaluating changes in nutrient food web dynamics (for example, to determine whether the structure of consumer communities has modified nutrient transfer along the food web) and assessing how changes may have affected the growth and production of emigrating juvenile sockeye salmon. Recognizing the importance of continued analysis on Afognak Lake sockeye salmon production, the Office of Subsistence Management approved project funding to ADF&G for an additional four years (2010–2013). This report provides results from the first (2010) of these additional four years.

The caloric content, or energy budget, of a juvenile salmon provides a more robust indicator of condition and health than traditional length and weight data (Finkle 2004). Paired with diet data, and environmental factors this information can be used with proven bioenergetics modeling approaches that provide valuable insight into growth and production trends. Such modeling can also identify how juvenile fish adapt to their rearing conditions and exogenous factors such as climate change and volcanic ash from previous eruptions.

The goal of this project is to obtain reliable estimates of smolt and adult production over time for Afognak Lake. Data collected from this project will enable researchers to better identify what factors are specifically affecting and controlling sockeye salmon production within the freshwater environment which will help refine the optimum escapement goal and help improve pre-season run forecasts. This will allow managers to better manage for optimum sustainable yield and prevent unnecessary restrictions of Federal and State subsistence fisheries.

Additional historical data, harvest, management, and enhancement background information on Afognak Lake sockeye salmon is referenced in Baer (2010).

PROJECT OBJECTIVES

1. Estimate the abundance, age composition, and average size of sockeye salmon smolt emigrating from Afognak Lake and adults escaping to Afognak Lake from 2010 through 2013.

<u>Smolt</u>

2. Estimate the abundance (N) of emigrating sockeye salmon smolt within 25% (relative error) of the true value with 95% confidence.
3. Estimate the age composition of emigrating sockeye salmon smolt within d=0.05 (size of the effect) of the true proportion (for each major age group within each stratum) with 95% confidence.
4. Estimate the average length (mm) and weight (g) by age group and stratum.

<u>Adults</u>

5. Enumerate the escapement of adult sockeye salmon returns through the weir and into Afognak Lake.
6. Estimate the age and sex composition of adult sockeye salmon returns where estimates are within d=0.07 of the true proportion (for each age group within each stratum) with 95% confidence.

7. Estimate the average length (mm) by age and sex.
8. Evaluate the effects of the water chemistry, nutrient status, and plankton production of Afognak Lake on the smolt production and future adult returns from 2010 through 2013.
9. Evaluate the condition of juvenile (lake rearing) sockeye salmon relative to diet and energy density from 2010 through 2013.
10. Assess available historical fisheries and limnological data in relation to climate change effects, upon completion of objectives 1–3.

METHODS

SMOLT ASSESSMENT

Trap Deployment and Assembly

An inclined-plane trap (Ginetz 1977; Todd 1994) was installed on 09 May 2010 approximately 32 m upstream from the adult salmon weir site (Figure 3). The trap was positioned towards the middle of the river, where water velocity was great enough to make it difficult for smolt to avoid capture. A live box (1.2 m x 1.2 m x 0.5 m) was attached to the cod end of the trap, and the entire trapping device was connected to cables attached to hand-powered cable winches ("come-alongs") fixed to each stream bank. The trap was secured to an aluminum pipe frame, which allowed the vertical trap position to be adjusted in response to water level fluctuations. Perforated (3.2 mm) aluminum sheeting (1.2 m x 2.4 m) supported by a Rackmaster®[1] pipe frame was placed at the entrance of the trap in a "V" configuration to divert smolt into the mouth of the inclined plane trap. The inclined-plane trap fished continuously from 09 May to 16 May, 2010 but was removed from the river on 16 May due to high water conditions. On 18 May, a floating inclined-plane trap was installed and was fished continuously through 24 May until river conditions were favorable to reinstall the original incline-plane trap on 25 May and continue to capture emigrating smolt until it was removed for the season on 01 July after the number of captured smolt dropped to less than 100 per day for 3 consecutive days. Detailed methods of trap installation, operation, and maintenance are described in the 2010 Afognak Lake Operational Plan (Foster et al. 2010).

Smolt Capture and Handling

Smolt were captured in the trapping system and held in the attached live box until they were counted. During the night (2200 to 0800 hours), the live box was checked every 1 to 2 hours, depending on smolt abundance. During the day (0801 to 2159 hours), the live box was checked every 3 to 4 hours. All smolt were removed from the live box with a dip net, counted, and either released downstream of the trap or transferred to an in-stream holding box for sampling and marking. Species identification was made by visual examination of external characteristics (Pollard et al. 1997). All data, including mortality counts, were entered on a reporting form each time the trap was checked.

Trap Efficiency and Mark-Recapture Abundance Estimation

Total smolt abundance was estimated using inanimate objects and mark-recapture procedures to first estimate trap efficiency within specific recapture periods, hereafter referred to as 'stratum'. Trap efficiency was then used to estimate the number of smolt emigrating by strata from the watershed.

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

Releases of sockeye salmon smolt marked with Bismarck Brown Y dye were made once per week, as well as when changes were made to the trapping system. Based on prior years of smolt studies at Afognak Lake (Baer 2010), an effort was made to achieve trap efficiencies of 15%. To estimate total smolt abundance each week with a 5% probability of exceeding a relative error (r) of 25%, we would need to mark and release 330 (20% trap efficiency) to 440 (15% trap efficiency) smolt for each experiment (Carlson et al. 1998; Robson and Regier 1964). Therefore, we attempted to dye approximately 500 smolt each dye release event to help ensure sufficient numbers were marked to account for any delayed mortality due to handling and marking.

Once collected, smolt to be marked were placed in a 26-gallon lidded cooler filled with river water and a 0.25% sodium bicarbonate solution to maintain a stable blood pH. Non-ionized salt was added to the transport water to achieve a 0.75% solution to replicate physiological levels and reduce metabolic stress and electrolyte depletion that can cause post-transport mortality. The transport cooler was continuously supplied with supplemental oxygen at a level of 9 mg/l and within an 80–100% saturation range.

Smolt were transported in a trailer pulled by an all-terrain vehicle to the release site approximately 1,240 m upstream. At the release site, smolt were continuously oxygenated and submerged in a solution of Bismarck Brown Y dye (30 mg/L) for 30 minutes. Dyed smolt that displayed unusual behavior (labored respiration, flared gills, side swimming, etc.) were removed from the experiment and released downstream of the trap. Dyed smolt were then transferred to a holding box at the release site. Between 2100 and 2300 hours, about 500 of the dyed smolt were randomly selected from the holding box, counted, and released across the width of the stream. The remaining dyed smolt (about 100) were counted and left in the holding box for 5 days to estimate delayed mortality resulting from the capture and marking process. The proportion of smolt that died during the 5-day holding period was used to estimate the actual number of marked smolt available for recapture in the experiment (M_h).

All dyed smolt recaptured at the trap site were counted and assigned to the stratum corresponding to the time period starting the day of their release until the day before the next release and mark-recapture event.

Trap efficiency E_h for stratum h was calculated as

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

where

m_h = number of marked smolt recaptured in stratum h

A modification of the stratified Petersen estimator (Carlson et al. 1998) was used to estimate the number of unmarked smolt U_h emigrating within each stratum h as

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

where

u_h = number of unmarked smolt recaptured in stratum h.

Variance of the smolt abundance estimate was estimated as

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

Total abundance of U of unmarked smolt over all strata was estimated by

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

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

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

and 95% confidence intervals were estimated using

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

which assumes that $\hat{U}$ is approximately normally distributed.
Within each stratum h, the total population size by age class j was estimated as,

$$\hat{U}_{jh} = \hat{U}_h \hat{\theta}_{jh} \,, \tag{7}$$

where $\hat{\theta}_{jh}$ is the observed proportion of age class j in stratum h. Variance of $\hat{\theta}_{jh}$ was estimated using the standard variance estimate of a population proportion (Thompson 1987). The variance of $\hat{U}_{jh}$ was then estimated by

$$\hat{\text{var}}\left(\hat{U}_{jh}\right) = \hat{U}_h^{\,2} v\left(\hat{\theta}_{jh}\right) + \hat{U}_h v\left(\hat{\theta}_{jh}\right)^2 . \tag{8}$$

The total number of emigrating smolt within each age class was estimated by summing the individual strata estimates, and its variance was likewise estimated by summation over the individual strata estimates.

Inanimate objects were used to generate a surrogate trap efficiency estimate when mark-recaptures tests were not able to be conducted due to insufficient numbers of smolt for dye release tests. A minimum of 50 buoyant (walnuts and whole peanuts with shells), negatively buoyant (almonds), and neutrally buoyant (pecans) objects were released evenly across the river approximately 50 meters upstream of the trap. Three inanimate object recapture trials were conducted during the first 3 strata of the 2010 season.

Life History-Based Abundance Estimation

In addition to mark-recapture abundance estimates, the predicted number of smolt expected to emigrate in 2010 was estimated based on a life history model. The history-based estimates, utilized the sex composition data from parental spawning escapements in 2007 (51% females) and 2008 (42% females), average egg deposition based on the average fecundity assessment of females used in egg-takes by Pillar Creek Hatchery crews in 2007 (2,359 per female) and 2008 (2,529 eggs per female), a 7% egg-to-fry survival (Drucker 1970, Bradford 1995, and Koenings and Kyle 1997), a 21% fry-to-smolt survival (Koenings and Kyle 1997) from rates reported from other clear water systems, and a smolt age composition of 80% age-1. and 20% age-2. based on the average smolt age composition from 2003 through 2009.

Age, Weight, and Length Sampling

To ensure proportional abundance sampling, approximately 2% of the daily sockeye salmon smolt catch was sampled to obtain AWL data. For every 100 sockeye salmon smolt counted out of the trap, the field crew retained two smolt for AWL sampling the following morning. Smolt were collected throughout the night and held in the in-stream live box. The following day, all

smolt from the live box were anesthetized using tricaine methanesulfonate prior to being sampled. After being sampled, all smolt were held in aerated buckets of water until they recovered from the anesthetic, and subsequently released downstream from the trap.

Fork lengths were recorded to the nearest 1 mm and weights to the nearest 0.1 g. Scales were removed from the preferred area (INPFC 1963) and mounted on a microscope slide for age determination. Age was estimated from scales viewed with a microfiche reader at 60X magnification and recorded in European notation (Koo 1962) following the criteria established by Mosher (1968). In addition, the overall health or condition factor of each sampled smolt was assessed by calculating its body condition factor *K* (Bagenal and Tesch 1978) as

$$K = \frac{W}{L^3} 10^5 \quad . \tag{9}$$

ADULT ASSESSMENT

Weir Installation and Adult Enumeration

A 27 m enumeration weir was installed at the terminus of the Afognak River on 16 May and remained in the river and fish tight through 07 September. The weir was constructed perpendicular to the stream flow and consisted of 10 wooden tripods (each tripod consisting of three 4” x 4” x 8’ spruce timbers and 2” x 6” x 6’ horizontal cat walk supports), 33 aluminum pipes (2” x 10’), 44 picketed aluminum panels (1” aluminum pipe with 1” spacing totaling 30” x 6’), and 2 framed panel gates. All materials were secured and lashed together to create a fish tight structure that conformed to the stream substrate (Figure 4).

The two framed panel gates were placed in the two deepest channels of the river enabling fish to be counted as they pass through the weir. Escapements were manually enumerated by field technicians using hand tally enumerators as fish migrated upstream through the gates. A white flash panel was placed on the substrate at the threshold of each gate opening to enhance visibility and aid in speciation. The counting gates remained closed until staff were present to count fish through the weir for escapement enumeration or when fish were being collected into the upstream ‘scott’ live trap for age, sex, length (ASL) sampling (Foster et al. 2010).

Age, Sex, and Length Sampling

An upstream “scott trap” was installed in front of the near shore (east bank) gate, which acted as a sampling trap as well as a downstream steelhead trap. The trap consisted of 6 weir panels placed horizontally in the river in the form of a diamond.

Adult sockeye salmon were sampled at the weir site throughout the adult escapement. Details and procedures for adult sampling are outlined in the Kodiak Management Area sockeye salmon catch and escapement sampling operational plan, 2010 (Foster et al. 2010). All scales, when possible, were collected from the preferred area of each fish following procedures outlined by the International North Pacific Fisheries Commission (INPFC 1963). Scales were mounted on scale “gum” cards and returned to the Kodiak ADF&G office where impressions were made on cellulose acetate (Clutter and Whitesel 1956). Fish ages were assigned by examining scale impressions for annual growth increments using a microfiche reader fitted with a 48X lens following designation criteria established by Mosher (1968). Ages were recorded using European notation (Koo 1962), where a decimal separates the number of winters spent in fresh water (after emergence) from the number of winters spent in salt water (e.g., 2.3). The total age of the fish

included an additional year representing the time between egg deposition and emergence of fry. Length measurements were taken from mid eye to tail fork (METF) to nearest 1 mm and sex was determined from external morphological characteristics.

Age and sex composition of the upstream migrating adult sockeye salmon were estimated daily as a group of proportions *pij* characterizing a multinomial distribution: $\hat{p}_{ij} = n_{ij} / n$, where n = the number in the sample and *nij* = the number in the sample of age *i* and sex *j*. On days where escapement occurred but no samples collected, proportions were estimated by linear interpolation between sampling events. The sample size was selected so that the proportion of each major age group (by stratum) will be estimated within at least d=0.07 of its true value 95% of the time (Thompson 1987). Standard error of the age proportions was calculated as the square root of estimated variance of a proportion (Thompson 1987). Age and sex composition estimates were post stratified due to earlier run timing and a stronger than anticipated run strength. The four sampling strata were: stratum 1 (5/17–6/6), stratum 2 (6/7–6/13), stratum 3 (6/14–6/20), and stratum 4 (6/21–9/5). Average length (unweighted) was calculated by age and sex.

A total of 1,037 sockeye salmon were sampled from 24 May through 08 August, resulting in a total of 954 sockeye salmon where age could be estimated from the scales. Distribution of the samples was as follows: stratum 1 (n=189), stratum 2 (n=287), stratum 3 (n=275), stratum 4 (n=203), achieving the minimal sample size of 200 fish on all but the first stratum.

LIMNOLOGICAL ASSESSMENT

Lake Sampling Protocol

Five limnological surveys of Afognak Lake were conducted at approximately four week intervals from May to September, 2010. Data and water samples were returned to the ADF&G Near Island Laboratory (NIL; Kodiak, AK) and analyzed as described in Thomsen (2008) and Koenings et al. (1987). Two stations, marked with anchored mooring buoys and located with Global Positioning System (GPS) equipment, were sampled from a float plane during each survey (Figure 2). Zooplankton samples were collected at both stations, but water samples were only collected at Station 1.

Temperature, Dissolved Oxygen, Light, Water Clarity and Euphotic Volume

Water temperature (°C) and dissolved oxygen (mg L^{-1}) levels were measured with a YSI® meter. Surface temperature readings were calibrated against a hand-held mercury thermometer. Temperature and dissolved oxygen readings were recorded at half-meter intervals to a depth of 5 m and then at one-meter depth intervals to the lake bottom. Results were categorized into spring (May–June), summer (July–August), and fall (September–October) sampling periods. In addition three Hobo® water temperature data loggers were deployed in Afognak Lake and recorded water temperatures every hour at depths of 1, 5, and 10 m continuously from 8 May to 19 October.

Water transparency was measured at each station using a Secchi disc as described in Thomsen (2008). Measurements of light in the visible spectrum range (400–700 nanometers), known as photosynthetic active radiation (PAR), were obtained with Li-Cor® Spherical Quantum Sensors every hour from depths of 1 m and 10 m and recorded on a Li-Cor® data logger from 08 May through 03 September. PAR measurements were also obtained with a Protomatic® submersible photometer at the lake sampling stations during the monthly sampling schedule. Readings were taken above the water surface, just below the water surface (subsurface), and at half-meter

intervals below the water surface until reaching a depth of 5 m and then at one-meter intervals to the lake bottom or to a depth at which the reading was (no more than) 1% of the subsurface reading. Measurements were adjusted by linear regression to the Beer-Lambert equation to estimate an integrated vertical extinction coefficient (K_d m^{-1}) for PAR within the euphotic zone, the layer of water from the surface down to 1% of subsurface PAR as

$$K_d\ m^{-1} = (1/z)\ \ln\ (I_z / I_o)\ ,$$

where

I_o = light intensity just below the water surface, and

I_z = light intensity at water depth *z* in meters.

Because an integrated vertical extinction coefficient was used, K_d was treated as being constant with depth, and mean euphotic zone depth was then given by $4.6/K_d$ (Kirk 1994). Lake primary production potential for rearing juvenile sockeye salmon was assessed through a euphotic volume calculation as the product of the average euphotic zone depth for the five monthly sampling periods and lake surface area (Koenings and Burkett 1987; Nelson et al. 2005).

Because Afognak Lake water temperature data was only collected on a bimonthly basis and was limited to the ice free season (May–October), water temperature data from Big Kitoi Lake was used as a surrogate data set to simulate water temperatures sockeye salmon would have experienced in Afognak Lake from the time they emerged from eggs as sac fry until they emigrated from the lake as smolt. Big Kitoi Lake and Afognak Lake share similar vegetative habitats of old growth spruce forests. Because they are located 18.3 miles apart they share similar a coastal climate and precipitation. Mean water temperatures about 3 meters below the surface of Big Kitoi Lake were obtained by hatchery staff on a daily basis and averaged for each 14-month sac fry-to-smolt period (April–May) for Afognak Lake age-1. smolt emigration years 2003–2009. The potential effects of thermal conditions on sockeye salmon juvenile rearing and smolt emigration were explored by looking at correlations between water temperature and various sockeye salmon life history parameters, including condition factor of age-1. smolt.

General Water Chemistry, Phytoplankton and Nutrients

During each survey, water samples were collected at a depth of 1 m below the water's surface using a 4.0 L Van Dorn sampler. Each water sample was emptied into a pre-cleaned polyethylene carboy, which was kept cool and dark, until refrigerated at the Kodiak Island laboratory for no more than 3 days before processing or freezing. Lake water from the carboy was transferred into a 500 ml bottle, refrigerated, and analyzed for alkalinity and pH. A 250 ml bottle was filled with water from the carboy, frozen, and later analyzed for total Kjeldahl nitrogen (TKN) and total phosphorus (TP). A total of 2.0 L of water was filtered using the following two different methods. One 1.0 L of water was filtered through a rinsed 4.25 cm diameter Whatman® GF/F cellulose fiber filter under 15 psi vacuum pressure for filtrate collection. The filtrate was then analyzed for total filterable phosphorus (TFP), filterable reactive phosphorus (FRP), nitrate + nitrite (NO_3^- + NO_2^-), and ammonia (NH_4^+). The second 1.0 L of lake water was filtered through another Whatman fiber filter pad with the addition of approximately 5 ml of magnesium carbonate ($MgCO_3$) added to the final 50 ml of water near the end of the filtration process to act as a preservative. The filtrate was discarded and the fiber filter was retained and frozen on a petri dish for chlorophyll-*a* (chl-*a*) and phaeophytin (pheo-*a*) analysis.

TP, TFP and FRP were analyzed using a Spectronic Genesys 5® (SG5) spectrophotometer using the potassium persulfate-sulfuric acid digestion method described in Thomsen (2008) and Koenings et al. (1987). Unfiltered frozen water was sent to South Dakota University for TKN analysis using the EPA 351.3 method (Nesslerization; AWWA 1998). The pH of water samples was measured with a Corning 430® meter, while alkalinity (mg L^{-1} as $CaCO_3$) was determined from 100 ml of unfiltered water titrated with 0.02 N H_2SO^4 to a pH of 4.5 and measured with a pH meter (Mettler Toledo Seven easy).

Samples for NO_3^- + NO_2^- were analyzed using the cadmium reduction method described in Thomsen (2008) and Koenings et al. (1987). NH_4^+ was analyzed with a SG5 using the phenol-sodium hypochlorite method described in Thomsen (2008). Total nitrogen (TN), the sum of TKN and NO_3^- + NO_2^-, and the ratio of TN to TP was calculated for each sample.

Total filterable phosphorus was determined using the same methods as those for TP utilizing filtered water. Filterable reactive phosphorus was determined using the potassium persulfate-sulfuric acid method described in Thomsen (2008) and Koenings et al. (1987).

Chl-*a* is the primary photosynthetic pigment in plants and is commonly used as an index of phytoplankton abundance, Samples of chl-*a* were prepared for analysis by separately grinding each frozen filter containing the filtrate in 90% buffered acetone using a mortar and pestle, and then refrigerating the resulting slurry from each sample in separate 15-ml glass centrifuge tubes for 2–3 hours to ensure maximum pigment extraction. Pigment extracts were centrifuged, decanted, and diluted to 15 ml with 90% acetone. The extracts were analyzed with a SG5 spectrophotometer using methods described in Thomsen (2008) and Koenings et al. (1987). Concentrations of pheo-*a*, a common degradation product of chl-*a*, were simultaneously estimated during the spectrophotometer analysis of chl-*a*. The ratio of chl-*a* to pheo-*a* was calculated to provide an indicator of phytoplankton physiological condition.

Zooplankton

Vertical zooplankton hauls were made at each station using a 0.2 m diameter conical net with 153 μm mesh. The net was pulled manually at a constant speed (~0.5 m sec^{-1}) from approximately 2 m off the lake bottom to the surface. The contents from each tow were emptied into a 125-ml polyethylene bottle and preserved in 10% buffered formalin. Cladocerans and copepods were identified to genus using taxonomic keys in Edmondson (1959), Wetzel (1983), and Thorp and Covich (2001). Zooplankton lengths were measured in triplicate 1 ml subsamples taken with a Hansen-Stempel pipette and placed in a Sedgewick-Rafter counting chamber. Zooplankton were grouped at the genus level and measured to the nearest 0.01 mm. The standard deviation (SD) of the lengths (L) of up to 15 individuals was estimated. This value was then used to estimate the appropriate sample size (N) by applying it to a *t*-test (t) with a 0.05 significance level and relative to 10% variation from the mean measured length calculated as

$$N=[(t \times SD)/(0.1 \times L)]^2.$$

Biomass was estimated from species-specific linear regression equations of length and dry weight derived by Koenings et al. (1987). For each survey, average density and biomass from the two stations were calculated for each species or genus group.

JUVENILE (LAKE REARING) ASSESSMENT

Juvenile Collection

A total of nine shoal and five mid lake locations were selected to obtain representative samples of Afognak Lake rearing sockeye salmon. The 14 sites were sampled on a bi-weekly basis from June through September in an effort to capture representative fry (age-0.) and fingerling (age-1.) juvenile sockeye salmon. A 50 m tapered beach seine with 4 mm stretched mesh was utilized for the collection of fish on the nine shoal sites. A small mesh pelagic trawl and skiff was initially used on the mid water sites but with no success. As a substitute capture method, the beach seine was used with greater success as a purse seine and juvenile sockeye salmon were round hauled from the middle of the lake. All captured fish were identified and enumerated. Juvenile sockeye salmon were separated into two size groups (≤59 mm and ≥60 mm) to ensure proportional representation of each age group. When available, a minimum of seven juvenile sockeye salmon representing each size and age group were retained for stomach content and bioenergetic analysis. The retained juvenile samples were separated by sample location, stored in Whirl-Pak® bags with lake water, and transported to the field lab where individual AWL data was collected as described by Foster et al. (2010). Each sample was individually stored in smaller Whirl-Pak® bags and frozen in the field before being transported via aircraft to the Kodiak laboratory for further analysis.

Diet and Bioenergetic Analysis

Ages were assigned to all of the collected samples using previously described methods. When seven or more samples were available from each sample location, date, and age group two random samples were selected exclusively for stomach content analysis, leaving five samples for further calorimetric assessment. The stomachs of the selected fish were removed and the contents examined. The density and percent 'fullness' (0–100%) was assessed and the percentage of zooplankton and invertebrates within the stomach was determined. When possible the zooplankton and invertebrates were identified by species through the same methods described in the limnological assessment and through additional taxonomic key identification (McCafferty 1983; Pennak 1989).

The remaining five samples per location, time, and age (or as many were available) were stored at or below -20°C prior to shipping samples to the ADF&G laboratory in Soldotna for further bioenergetic processing.

The energy density or calories per gram (cal/g) of each sockeye salmon sample was determined within a precision of 0.1% through the use of a Parr model 1266 Isoperibol microbomb calorimeter as per the manufactures specifications (Parr 1999). Upon completion of three additional years of caloric and stomach analysis, a bioenergetics model such as the Hewitt and Johnson/Wisconsin model (Hanson et al. 1997) will be used to estimate and identify growth limitations associated with sockeye salmon freshwater condition. Physiological parameters for sockeye salmon provided by the model will be paired with the field generated data (diet, temperature, size at age, and energy density).

PRODUCTION AND EFFECTS OF CLIMATE CHANGE

Recent smolt emigration data combined with bioenergetics modeling, paleolimnologcal analysis, nutrient-phytoplankton-zooplankton models, and spawner-recruit models will be used to help identify the impact climate changes may have on fish species. Due to the complications associated with food web dynamics and multiple sibling populations, it is essential to integrate

the various models to look at possible effects (Hartman and Kitchell 2008). Further assessment and modeling will be conducted upon completion of data collection through 2013.

RESULTS

SMOLT ASSESSMENT

Smolt Capture

The inclined-plane trap was fished continuously from 09–15 May, but due to extreme flooding, the trap was removed from the water from 16–17 May and no trapping occurred (Table 1). A floating incline-plane trap was installed on 18 May and continued to fish through 24 May. The original inclined-plane trap was reinstalled and fished continuously for the duration of the emigration (25 May–01 July).

A total of 42,329 smolt were captured from 09 May–01 July. An additional 332 smolt were estimated to have been captured during the two days, when the trap was not fishing, for an estimated trap catch of 42,661 sockeye smolt (Table 1; Figure 5). The estimate for the two-day data gap was constructed using time series analysis from the period leading up to the flood event and the period after the event.

Trap Efficiency and Mark-Recapture Abundance Estimation

Small daily catches of smolt in the beginning of the emigration (09–17 May) were insufficient to perform a mark-recapture test. As a result, inanimate objects were used on 16 May to estimate trap efficiency and to generate the first strata's total emigration estimate. The surrogate trap efficiency testing also coincided with the high water which forced the trap out of the water later that day and resulted in two consecutive days (16–17 May) of no trapping. As a result, the trap efficiency generated from the inanimate object deployment test (7.3%) was applied to the trap catches for the seven days prior to the high water (09–15 May) and the two days in which trap catches were generated from time series analysis (16–17 May), all of which made up the first stratum 1 (09–17 May). The standard mark-recapture trap efficiency methods were used to generate the total emigration for the remaining six strata. In conjunction with standard mark-recapture testing, trap efficiencies were also estimated with inanimate objects twice during stratums 2 and 3 to corroborate the validity of the first inanimate object deployment test (16–17 May). The inanimate object tests resulted in a trap efficiency of 8.6% during stratum 2 while the mark-recapture tests resulted in 7.5% trap efficiency. The inanimate object test conducted during stratum 3 resulted in a trap efficiency of 15.5% while the mark-recapture tests resulted in trap efficiency of 14.6%. The seven trap efficiency tests ranged from 18.5% in stratum 4 (01–07 June) to 6.0% in stratum 6 (15 June–21 June) (Table 2; Figure 6). Peak smolt emigration occurred in stratum 3 (25–31 May). Mean estimated trap efficiency for the total emigration was 11.9%. The total number of sockeye salmon smolt estimated to have emigrated from Afognak Lake in 2010 was 309,130 with 95% CI 267,874–350,387 (Table 2).

Life History-Based Abundance Estimation

Using the life history-based abundance method, the 2007 escapement of 21,070 adults (brood year 2007) was expected to produce 74,526 age-2. smolt, and the 2008 escapement of 26,874 adults (brood year 2008) was expected to produce 335,689 age-1. smolt (Table 3). Combining these two age classes resulted in an expected emigration of 410,216 smolt from Afognak Lake in spring 2010.

For the eight years of the project, annual differences between life history-based and mark-recapture estimates ranged from 17% to 44% (R^2=.45, p<0.066; Figure 7). Life history-based estimates have been greater than mark-recapture estimates in five years (2003, and 2006–2008, and 2010) and less than mark-recapture estimates in three years (2004, 2005, and 2009). The cumulative 2003–2010 smolt production from annual life history-based estimates (3.22 million smolt) was 6% greater than that from the annual mark-recapture estimates (3.04 million smolt).

Age, Weight, and Length Data

AWL data were obtained from a total of 861 smolt collected proportionally throughout the trapping period (Table 1). Summing smolt abundance estimates by age class from all seven mark-recapture strata resulted in a total emigration estimate of 237,716 (76.9%) age-1., and 71,415 (23.1%) age-2., smolt (Table 4; Figure 8). Age-1. smolt only comprised 6.0% of the emigration within the first strata (09–17 May) but progressively increased in proportion throughout the emigration until they made up 100% of the emigration in the last two stratum (06 June–01 July).

Sampled age-1. smolt had a mean weight of 2.6 g, a mean length of 70 mm and a mean condition factor of 0.76. Sampled age-2. smolt had a mean weight of 3.9 g, a mean length of 82 mm, and a mean condition factor of 0.69. (Table 5).

The mean condition factor of age-1. smolt emigrating from Afognak Lake during 2003–2010 strongly correlated to 14 month mean water temperatures obtained about 3 meters below the surface of Big Kitoi Lake (R^2=.83, p<0.00017; Figure 9).

ADULT ASSESSMENT

Enumeration

After installing the weir on 16 May, the first salmon to pass through the counting gates was on 19 May, when six adult sockeye salmon were enumerated. Adult Pacific salmon were enumerated on a daily basis until 07 September when the weir was removed and an end of the season in river estimate was added to the total escapement. A total of 52,255 sockeye salmon escaped into Afognak Lake (Table 6) in addition to 62,237 pink salmon, 10,288 coho salmon, and 59 chum salmon. Additionally, 256 seaward-migrating steelhead were enumerated and passed down stream of the weir. Sockeye salmon escapement peaked from 07 through 12 June when 21,680 fish were enumerated during the 6-day period (Table 7).

Age, Sex, and Length Data

The goal of estimating age composition of the escapement within d=0.07 (95%) confidence was achieved for all ages within strata (Table 7). The majority (80.6%) of the escapement was comprised of age-1.3 fish while a much smaller proportion (15.8%) were age-1.2 sockeye salmon. The majority of the age-1.3 fish escaped during the strata 1 and 2, whereas the majority of age-1.2 fish escaped during strata 3 and 4. The estimated sex composition of the total escapement was 60.6% female and 39.4% male. Roughly 64% of the age-1.3 fish sampled were female while only 52% of the age-1.2 fish sampled were female. Average length was 514 mm for age-1.3 fish and 464 mm for age-1.2 fish (Table 8).

LIMNOLOGICAL ASSESSMENT

Temperature, Dissolved Oxygen, Light, Water Clarity and Euphotic Volume

In 2010, water temperatures ranged from 4.7°C near the lake bottom during the spring (May) sampling period to 15.1°C at the surface of the lake during the summer (July) period (Figure 10).

Dissolved oxygen concentrations ranged from 7.4 mg L^{-1} at the bottom in the summer to 12.2 mg L^{-1} at the surface in the spring. Mean vertical light extinction coefficient was -2.29 m^{-1}, mean euphotic zone depth was 10.0 m, and mean Secchi disk reading was 4.5 meters. Estimated euphotic volume for Afognak Lake was 52.95 10^6 m^3. Using the EV model and 800–900 spawners per EV unit resulted in a spawning capacity estimate of 42,400–47,700 adults (Koenings and Kyle 1997).

General Water Chemistry, Phytoplankton, and Nutrients

Afognak Lake mean pH was 7.15 and ranged from 6.96 in August to 7.30 in September (Table 9). Mean alkalinity level was 9.5 mg L^{-1} and ranged from 9.0 mg L^{-1} in May and June to 10.0 mg L^{-1} in July and September. Mean chl-*a* concentration was 1.12 μg L^{-1} and ranged from 0.96 μg L^{-1} in May and August to 1.28 μg L^{-1} in July and September (Table 9). Mean pheo-*a* concentration was 0.63 μg L^{-1} and ranged from 0.38 μg L^{-1} in May to 0.96 μg L^{-1} in September. Three different measures of seasonal phosphorus were made (Table 10). Mean TP concentration was 4.4 μg L^{-1} and ranged from 3.4 μg L^{-1} in May to 5.4 μg L^{-1} in June (Table 10). Mean TFP concentration was 2.5 μg L^{-1} and ranged from 2.0 μg L^{-1} in July to 3.1 μg L^{-1} in June. Mean FRP concentration was 1.7 μg L^{-1} and ranged from 1.4 μg L^{-1} in August to 2.1 μg L^{-1} in June.

Three different measures of seasonal nitrogen were made (Table 10). Mean TKN concentration was 28.0 μg L^{-1} and ranged from 3.0 μg L^{-1} in August to 50.0 μg L^{-1} in September. Mean NH_{4+} concentration was 4.3 μg L^{-1} and ranged from 3.6 μg L^{-1} in July to 5.3 μg L^{-1} in June. Mean NO_2 + NO_3 concentration was 22.5 μg L^{-1} and ranged from 3.3 μg L^{-1} in August to 77.5 μg L^{-1} in May. Mean TN concentration was 50.5 μg L^{-1} and ranged from 115.5 to 8.4 μg L^{-1}. The overall mean TN to TP ratio, by weight, was 28.9:1 and ranged from 4.0:1 in August to 75.0:1 in May.

Zooplankton

Zooplankton weighted mean density was 99,467 animals m^{-2} in Afognak Lake (Table 11). All zooplankton identified were crustaceans commonly referred to as either cladocerans (*Order* Anomopoda and Ctenopoda) or copepods (*Order* Calanoida, Cyclopoida, and Harpacticoida). Cladocerans were more abundant (72.5% of weighted mean density) than copepods (27.5%). Among the cladocerans, the two most abundant groups were the *Bosmina* (45.5%) and a pooled category we called "other cladocerans" (24.9%), which consisted of various unidentified immature cladocerans. Other observed cladoceran genera were *Daphnia* (0.8%) and *Holopedium* (1.4%). The largest contributor to the copepods was the pooled category of "other copepods" (17.0%) which was made up mostly of the genus *Harpaticus* and various unidentified nauplii (larvae). The other copepod genera included *Epischura* (9.6%), *Cyclops*, usually an important component of the zooplankton community in sockeye salmon rearing lakes, (0.7%), and *Diaptomus* (0.1%).

Mean total zooplankton biomass was 64.0 mg m^{-2}, and was mostly comprised (56.0% of mean total biomass) of cladocerans (Table 11). The cladoceran genus *Bosmina* represented most of the biomass (50.8%), followed by the copepod genus *Epischura* (42.2%). The remaining biomass

was composed of *Holopedium* (3.7%), *Daphnia* (1.5%), *Cyclops* (1.3%), *Diaptomus* (0.4%) and "other copepods and cladocerans", which consisted of larvae too small to weigh.

The copepod *Epischura* was the largest zooplankton member measured, with a mean length of 0.78 mm (Table 11). Mean lengths of the remaining zooplankton measured, in decreasing size, were 0.70 mm for the copepod, *Diaptomus,* 0.62 mm for the cladoceran *Daphnia*, 0.57 mm for the copepod *Cyclops*, 0.45 mm for the cladoceran *Holopedium*, and 0.28 mm for the cladoceran *Bosmina*.

JUVENILE (LAKE REARING) ASSESSMENT

Juvenile Collection

A total of 256 lake rearing juvenile sockeye salmon were captured from Afognak Lake's shoal and mid lake collection sites from June through September. The eight shoal collection sites produced a total of 146 specimens while 110 juvenile sockeye salmon were collected from the five mid lake collection sites. Of the shoal samples, 60 were age-0. and 86 were age-1. Of the mid lake samples, 97 were age-0. and 13 were age-1. The average size of lake rearing fish steadily increased throughout the sampling period (Table 12; Figure 11).

Diet and Bioenergetic Analysis

Of the 88 juveniles captured in August for calorimetric analysis, 55 were age-0. and 33 were age-1. Of the age-0. fish, 12 were from the shoals and 43 were from mid lake; of the age-1. fish, 26 were from shoals and 7 were from mid lake. Of the age-0. fish, those from shoals averaged 5,799 cal/g and those from mid lake averaged 5,869 cal/g. Of the age-1. fish, those from shoals averaged 5,780 cal/g and those from mid lake averaged 5,924 cal/g.

Stomachs were analyzed from 46 age-0. fish and 23 age-1. fish (Table 13). Monthly average stomach fullness decreased throughout the sampling period (Table 13; Figure 12). For both juvenile salmon age groups, the proportion of insects within the diet decreased over time, while the proportion of zooplankton increased over time (Table 13; Figures 13, 14). Energy content (cal/g) was assessed for a total of 99 age-0. fish and 75 age-1. fish. The average cal/g of age-0. samples was greatest in June whereas age-1. fish had the greatest cal/g in September (Table 14 and Figure 15). Age-1. juveniles appeared to show an increasing trend of cal/g from June through September whereas age-0 fish decreased in July before they displayed an increase cal/g trend. This may be a function of higher energy values stored in juvenile sac fry as opposed to summer alevin which have fully absorbed their yolk sac and are just beginning to forage.

DISCUSSION

This was the eighth consecutive year in which the same methods and materials were used to generate the smolt population emigrating from Afognak Lake. The targeted trap efficiency has been 15% for each year and despite different field personnel and variable environmental conditions, mean trap efficiencies have ranged between 11.4% and 19.9% annually (Appendix A1 and A2). A shortage of smolt captured during the first strata in 2010 precluded the prescribed mark-recapture experiment to be conducted, which also coincided with a high water flood event. Trap efficiencies were estimated with inanimate objects during this time, and fell within historical ranges using marked fish. Subsequent concurrent tests of inanimate objects and marked fish supported the conclusion that the inanimate objects provide useful estimates of smolt capture efficiency, and thus can be used to estimate total abundance.

Life history-based estimates of smolt outmigration abundance have been calculated to compare with mark-recapture estimates. Although annual differences between the life history-based and mark-recapture estimates ranged from 17% to 44%, the overall difference between cumulative smolt production for all eight years for the two methods was only 6%. Interannual differences between methods may be due to interannual variability in age composition, which are then modulated when multiple cohort years were considered. Since there also appears to be no consistent directional bias between life history-based and mark-recapture estimates across years, it is believed the life history-based method may provide a reasonable and unbiased estimate of actual smolt abundance, presuming there are no significant changes in fecundity and freshwater survival assumptions.

Age-1. smolt emigrating from Afognak Lake in 2010 were smaller in size and had a lower mean condition factor (0.76) than the overall mean condition factor of age-1. smolt sampled during 2003–2009 (0.79; Appendix A2). The seasonal mean condition factor (0.69) of age-2. smolt emigrating from Afognak Lake in 2010 was the poorest reported from Afognak Lake. Size and condition of age-1. smolt did improve over the emigration period, and by the end of June, age-1. smolt had a condition factor of 0.87. The improved growth and condition observed at the end of the emigration was in contrast to the poor spring condition factor (0.71).

Water temperature is a critical factor in fish development, and lake studies indicate that metabolic rates of age-0. sockeye salmon increase as temperatures increase within threshold levels, as long as food supplies are not limiting (Brett 1971). The rate of egg development and time of alevin emergence is also largely dependent upon the temperature regimes in the redd (Burgner 1991, Groot and Margolis 1991).

Based on Kodiak airport air temperature data, late-winter and early-spring (January–May) air temperatures in 2007 through 2009 were on average 1.5°C colder than the previous 76-year historical average for the same 5-month time period. It is likely these colder temperatures not only resulted in later fry emergence and slowed metabolic processes in juveniles, but may have also affected phytoplankton production (Sommer and Lengfellner 2008; Staeher and Sands-Jensen 2006). Lower phytoplankton biomass may have resulted in later growth and development of zooplankton and could have caused copepods to go into diapauses (Thorp and Covich 2001). This phase would have reduced the forage base for juvenile sockeye salmon, and thus, could have reduced growth and condition of age-1. smolt emigrating out of the system in 2008–2010. As was previously reported the average water temperatures in Big Kitoi Lake at shallow depths (about 3 m) from the time of hatching to smolt emigration (14 months) was strongly correlated (R^2=.83, p<0.00017) with the condition of age-1. smolt from corresponding emigration years (Figure 9).

Despite repeated attempts, all efforts to collect juvenile salmon rearing in mid lake with the mid water trawl were unsuccessful. It was not until 12 August that juvenile samples were collected through alternative methods employing a beach seine that functioned as a purse seine in mid lake. Due to the lack of mid water samples in early summer is it not possible to identify and compare prey preference and caloric condition between fish obtained on shoals and the mid lake portion of rearing habitat. Although the small sample size may not be conclusive as to the disparity in energy content between shoal and mid lake, these samples do suggest more favorable rearing conditions in the mid lake environment during the month of August. The increase in zooplankton production later in the growing season and the reduction of insects identified in the diet suggests that a more caloric rich diet may be obtained in the mid lake habitat. It is unclear why more of the larger age-1. juveniles were captured in the shoal areas as opposed to the calorically richer environment, however one explanation may be due to the small size of the prey

and another explanation could be that the larger juveniles were able to avoid capture during the sampling effort. Further data collection with refined mid water sampling techniques will lend greater insight into possible trends.

Afognak Lake is typically stratified into warmer epilimnion and cooler hypolimnion layers for short periods of time in the middle of the summer, although in 2010 a well-defined thermocline never developed (Figure 10). This may be a result of the shallow morphology of the lake and its high turnover rate. Euphotic zone depth values recorded in 2010 indicated that, on average, the first 10 m of the water column at the sampling stations were photosynthetically active. With an average depth of 8 m, this suggests that the majority of Afognak Lake is capable of primary production.

Seasonal pH and alkalinity levels showed little variation over the sampling season. Variations that did occur may be explained in part by seasonal fluctuations associated with photosynthesis, temperature, and sampling timing. As daylight increases over the summer sampling season, photosynthetic rates may also increase, thereby increasing pH (Wetzel and Likens 2000). Similarly, increasing temperatures may cause pH to decline. Variability among sampling events may also be caused by the variability in photosynthetic rates and changing temperatures relative to the date and time samples were collected.

Nutrient and phytoplankton pigment concentrations also generally showed little variation over the sampling season, with the exception of TKN and NO_3^- + NO_2^- concentrations. The August TKN concentration was roughly 8 times less than the seasonal average. The NO_3^- + NO_2^- concentrations from July through September were less than 5.5 μg L^{-1} and well below the seasonal average of 50.5 μg L^{-1}. Further comparison of the TP to TKN ratio revealed that nitrogen was limiting in August. The variability in TKN and NO_3^- + NO_2^- may be in part explained by primary production (phytoplankton) utilization rates of nitrogen and phosphorous during photosynthesis. Using chl-*a* to phaeo-*a* ratio as an indicator of primary production, the decline in the ratio in August and September indicates that phytoplankton production was occurring, but not being utilized by available zooplankton. If phytoplankton are not being grazed, they can sink in the water column and become unavailable, thereby lowering the available nutrient concentration. This may have occurred since phytoplankton samples from 2010 showed an increase of diatoms from July through September, with the greatest phytoplankton biomass occurring in August. However, it is also possible these differences could also be an artifact of process and measurement error due to the small number of measurements made each year and the inherent variability of evaluating low concentrations of nutrients at a single 1-m depth.

The seasonal mean zooplankton density and biomass estimates were consistently low in Afognak Lake over the sampling season. Lake water residence time in Afognak Lake is estimated to be only 0.4 years, and this rapid lake flushing may physically remove zooplankton more quickly than standing stocks can be replenished through reproduction. This effect may be further compounded during periods of greater than normal precipitation. Since the zooplankton community is the primary forage base for juvenile sockeye salmon, total zooplankton density and biomass are often used as a measure to assess juvenile sockeye salmon production potential (Koenings et al. 1987). However, the high phytoplankton biomass in 2010 in combination with low TN to TP ratio suggested that low zooplankton biomass was probably due, at least in part, to overgrazing by juvenile salmon.

Because juvenile sockeye salmon favor cladocerans rather than copepods as a food source, cladoceran abundance has been used as an indicator of juvenile sockeye salmon grazing pressure

(Koenings et al. 1987; Kyle 1996). In particular, the presence and abundance of *Daphnia* is considered a very important indicator of grazing pressure since it is a preferred prey item for juvenile sockeye salmon, (Honnold and Schrof 2001; Kyle 1996). However, *Daphnia* abundance can be limited in other ways. For example, *Daphnia* require phosphorus-rich diets, and it is possible their phytoplankton forage base in Afognak Lake has been altered in recent years, which has caused reductions in *Daphnia* populations. The concentration of TP during 2010 has also been at low (oligotrophic) levels (Carlson and Simpson 1996). It is thus unclear whether low *Daphnia* abundance was due to grazing pressures, nutrient limitations or a combination of these and other factors.

Data from the two predominate zooplankton taxa, the cladoceran *Bosmina* and the copepod *Epischura*, suggest overgrazing by juvenile sockeye salmon may be occurring. *Bosmina* had the greatest biomass in 2010 and was the most abundant taxon, comprising 45.5% of total average zooplankton density. *Bosmina* were very small, and their mean length of 0.28 mm was below the juvenile sockeye salmon minimum elective feeding threshold of 0.40 mm (Kyle 1992). *Epischura* were much larger, and their mean length of 0.78 mm was well above the juvenile sockeye salmon feeding threshold. The small size and large abundance of *Bosmina* could be a result of grazing juvenile sockeye salmon removing the larger *Bosmina*. That *Epischura* were not as abundant as *Bosmina* may also be a function of salmonid predation and lake conditions. Copepods can enter a state of diapause as an egg or copepdid in response to overcrowding, photoperiod, or predation (Thorpe and Covich 2001). Increases in *Epischura* biomass and abundance coincided with the conclusion of the sockeye salmon smolt emigration from Afognak Lake, which would have resulted in fewer juvenile sockeye salmon remaining in the lake to feed upon zooplankton. Additionally, the warmest temperatures in Afognak Lake occurred in July, when *Epischura* biomass was at its lowest. These temperatures may have been too warm for *Epischura*, causing them to enter diapause and effectively removing them from the zooplankton population.

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TABLES AND FIGURES

Table 1.–Sockeye salmon smolt catch, number of AWL samples collected, mark-recapture releases and recoveries, and trap efficiency estimates from Afognak River by stratum, 2010.

Date	Daily Catch	AWL Samples	Marked releases[a]	Marked recoveries	Carlson Trap efficiency
		Stratum 1			
9-May	11	11	0	0	7.3%
10-May	30	0	0	0	7.3%
11-May	97	5	0	0	7.3%
12-May	79	5	0	0	7.3%
13-May	90	5	0	0	7.3%
14-May	169	5	0	0	7.3%
15-May	218	5	0	0	7.3%
16-May	181	0	150	10	7.3%
17-May	151	0	0	0	7.3%
Total Stratum 1	1,026	36	150	10	7.3%
		Stratum 2			
18-May	47	10	0	0	7.5%
19-May	42	10	0	0	7.5%
20-May	88	10	0	0	7.5%
21-May	120	10	0	0	7.5%
22-May	70	10	0	0	7.5%
23-May	242	10	0	0	7.5%
24-May	179	10	385	28	7.5%
Total Stratum 2	788	70	385	28	7.5%
		Stratum 3			
25-May	2,784	20	0	0	14.6%
26-May	2,226	39	274	29	14.6%
27-May	3,382	65	0	7	14.6%
28-May	2,969	61	0	1	14.6%
29-May	3,999	80	0	2	14.6%
30-May	1,574	30	0	0	14.6%
31-May	686	15	0	0	14.6%
Total Stratum 3	17,620	310	274	39	14.6%
		Stratum 4			
1-Jun	1,277	25	275	44	18.5%
2-Jun	1,215	25	0	4	18.5%
3-Jun	2,073	40	0	2	18.5%
4-Jun	1,773	35	0	0	18.5%
5-Jun	1,284	25	0	0	18.5%
6-Jun	1,618	35	0	0	18.5%
7-Jun	1,447	25	0	0	18.5%
Total Stratum 4	10,687	210	275	50	18.5%

-continued-

Table 1.–Page 2 of 2.

Date	Daily Catch	AWL Samples	Marked releases[a]	Marked recoveries	Carlson Trap efficiency
		Stratum 5			
8-Jun	817	20	228	26	16.2%
9-Jun	2,078	0	0	10	16.2%
10-Jun	1,828	40	414	41	16.2%
11-Jun	1,296	20	0	0	16.2%
12-Jun	1,411	25	0	0	16.2%
13-Jun	795	15	0	0	16.2%
14-Jun	577	15	0	0	16.2%
Total Stratum 5	8,802	135	642	77	16.2%
		Stratum 6			
15-Jun	1,136	15	464	16	6.0%
16-Jun	328	5	0	10	6.0%
17-Jun	190	5	0	1	6.0%
18-Jun	60	5	0	0	6.0%
19-Jun	201	5	0	0	6.0%
20-Jun	332	7	0	0	6.0%
21-Jun	319	7	0	0	6.0%
Total Stratum 6	2,566	49	464	27	6.0%
		Stratum 7			
22-Jun	235	5	488	43	13.5%
23-Jun	235	5	0	18	13.5%
24-Jun	319	6	0	4	13.5%
25-Jun	112	5	0	0	13.5%
26-Jun	71	5	0	0	13.5%
27-Jun	19	5	0	0	13.5%
28-Jun	51	5	0	0	13.5%
29-Jun	56	5	0	0	13.5%
30-Jun	43	5	0	0	13.5%
1-Jul	31	5	0	0	13.5%
Total Stratum 7	1,172	51	488	65	13.5%
Total Strata 1-7	42,661	861	2,677	296	11.9%

[a] Stratum 1 trap efficiency releases consisted of 150 inanimate objects. Strata 2-7 trap efficiency release tests were adjusted using the delayed mortality methods.

Table 2.–Estimated abundance of sockeye salmon smolt emigrating from Afognak Lake, 2010.

Stratum (h)	Starting date	Ending date	Catch (u_h)	Released (M_h)	Recaptured (m_h)	Carlson Trap efficency (%)	Estimate (U_h)	Variance (U_h)	95% Confidence Interval lower	95% Confidence Interval upper
1	5/9	5/17	1,026	150	10	7.3%	14,090	1.55E+07	6,373	21,807
2	5/18	5/24	788	385	28	7.5%	10,489	3.52E+06	6,813	14,164
3	5/25	5/31	17,620	274	39	14.6%	120,961	3.06E+08	86,699	155,224
4	6/1	6/7	10,687	275	50	18.5%	57,852	5.27E+07	43,620	72,084
5	6/8	6/14	8,802	228	36	16.2%	54,477	6.58E+07	38,584	70,371
6	6/15	6/21	2,566	464	27	6.0%	42,585	5.94E+07	27,478	57,691
7	6/22	7/1	1,172	488	65	13.5%	8,677	1.03E+06	6,691	10,663
Total						11.9%	309,130	4.43E+08	267,874	350,387
								SE= 21,049		

Table 3.–Theoretical production of Afognak Lake sockeye salmon eggs, emergent fry, and smolt by age from brood years 2007 and 2008 and predicted smolt emigration for 2010.

Production		Brood Year		Estimate 2010
Parameter	Assumption	2007	2008	Age-1. and -2. smolt
Escapement		21,070	26,874	
Females spawning	51% (2007) 42% (2008)[a]	10,746	11,287	
Deposited Eggs	2,359 (2007) 2,529 (2008)[b]	25,349,106	28,545,025	
Emergent Fry	7% egg-to-fry survival[c]	1,774,437	1,998,152	
Smolt	21% fry-to-smolt survival[d]	372,632	419,612	
2010 Smolt Emigration	80% age-1., 20% age-2.[e]	74,526	335,689	410,216

[a] Female sex composition derived from 2007 and 2008 sex data obtained from adult ALS sampling.
[b] Actual fecundity of Afognak Lake sockeye salmon as reported from Pillar Creek Hatchery (2007 and 2008).
[c] Egg to fry survival assumption from Drucker (1970), Bradford (1995), and Koenings and Kyle (1997).
[d] Fry to smolt survival assumptions from Koenings and Kyle (1997).
[e] Age composition assumptions derived from the average of 2003–2009 smolt age class estimates.

Table 4.–Estimated emigration abundance of Afognak Lake sockeye salmon smolt by time period (stratum) and age class, 2010.

			Age			
Stratum	Date		1.	2.	3.	Total
1	(5/9-5/17)	Number	848	13,242	0	14,090
		Percent	6.0%	94.0%	0.0%	100%
2	(5/18-5/24)	Number	2,200	8,288	0	10,489
		Percent	21.0%	79.0%	0.0%	100%
3	(5/25-5/31)	Number	79,050	41,911	0	120,961
		Percent	65.4%	34.6%	0.0%	100%
4	(6/1-6/7)	Number	51,328	6,524	0	57,852
		Percent	88.7%	11.3%	0.0%	100%
5	(6/8-6/15)	Number	71,881	1,449	0	73,330
		Percent	98.0%	2.0%	0.0%	100%
6	(6/16-6/22)	Number	25,472	0	0	25,472
		Percent	100.0%	0.0%	0.0%	100%
7	(6/23-7/1)	Number	6,937	0	0	6,937
		Percent	100.0%	0.0%	0.0%	100%
Total		Number	237,716	71,415	0	309,130
		Percent	76.9%	23.1%	0.0%	100.0%

Table 5.–Length, weight, and condition of sockeye salmon smolt from the Afognak River, 2010.

Stratum	Dates	Sample Size	Weight (g) Mean	Weight (g) Standard Error	Length (mm) Mean	Length (mm) Standard Error	Condition Mean	Condition Standard Error
				Age 1.				
1	(5/9-5/17)	4	2.0	0.16	66.0	1.78	0.71	0.014
2	(5/18-5/24)	13	2.4	0.10	67.7	1.21	0.77	0.038
3	(5/25-5/31)	167	2.4	0.02	69.2	0.19	0.73	0.004
4	(6/1-6/7)	186	2.4	0.02	68.6	0.18	0.74	0.004
5	(6/8-6/15)	146	2.8	0.03	70.4	0.24	0.79	0.005
6	(6/16-6/22)	39	3.0	0.07	71.7	0.45	0.81	0.007
7	(6/23-7/1)	46	3.8	0.08	75.7	0.44	0.87	0.008
Totals		601	2.6	0.02	69.9	0.13	0.76	0.003
				Age 2.				
1	(5/9-5/17)	32	4.1	0.12	84.0	0.57	0.68	0.008
2	(5/18-5/24)	56	3.9	0.08	81.9	0.67	0.70	0.007
3	(5/25-5/31)	82	3.8	0.07	81.8	0.43	0.69	0.006
4	(6/1-6/7)	24	3.8	0.15	81.6	0.72	0.69	0.013
5	(6/8-6/15)	4	4.2	0.37	80.5	1.32	0.80	0.073
6	(6/16-6/22)	0						
7	(6/23-7/1)	0						
Totals		198	3.9	0.05	82.1	0.29	0.69	0.004

Table 6.–Afognak Lake sockeye salmon escapement, harvest, and total run estimates, 1978–2010.

		Harvest			
Year	Escapement	Commercial[a]	Subsistence[b]	Total[c]	Total Run
1978	52,701	3,414	1,632	5,046	57,747
1979	82,703	2,146	2,069	4,215	86,918
1980	93,861	28	3,352	3,380	97,241
1981	57,267	16,990	3,648	20,638	77,905
1982	123,055	21,622	3,883	25,505	148,560
1983	40,049	4,349	3,425	7,774	47,823
1984	94,463	6,130	3,121	9,251	103,714
1985	53,563	1,980	6,804	8,784	62,347
1986	48,328	2,585	3,450	6,035	54,363
1987	25,994	1,323	2,767	4,090	30,084
1988	39,012	14	2,350	2,364	41,376
1989	88,825	0	3,859	3,859	92,684
1990	90,666	22,149	4,469	26,618	117,284
1991	88,557	47,237	5,899	53,136	141,693
1992	77,260	2,196	4,638	6,834	84,094
1993	71,460	1,848	4,580	6,428	77,888
1994	80,570	17,362	3,329	20,691	101,261
1995	100,131	67,665	4,390	72,055	172,186
1996	101,718	106,141	11,023	117,164	218,882
1997	132,050	10,409	12,412	22,821	154,871
1998	66,869	26,060	4,690	30,750	97,619
1999	95,361	34,420	5,628	40,048	135,409
2000	54,064	14,124	7,572	21,696	75,760
2001	24,271	0	4,720	4,720	28,991
2002	19,520	0	1,279	1,279	20,799
2003	27,766	0	604	604	28,370
2004	15,181	0	567	567	15,748
2005	21,577	356	696	1,052	22,629
2006	22,933	6	451	457	23,390
2007	21,070	0	490	490	21,560
2008	26,874	1,098	594	1,692	28,566
2009	31,358	363	2,085	2,448	33,806
2010	52,255	9,755	2,003	11,758	64,013

[a] Statistical fishing section 252-34 (Southeast Afognak Section).

[b] Data as of 4/04/2011 from ADF&G subsistence catch database 1978–2010.

[c] Sport harvest data does not have enough respondents to provide reliable estimates and was determined to be negligible.

Table 7.–Afognak Lake sockeye salmon escapement by time period (statistical week) and age class, 2010.

Stat Week	Dates	Sample Size		Age 1.1	1.2	1.3	1.4	2.1	2.2	2.3	Total Fish
21	May 17 - May 23	0	Percent	0.0	2.6	97.4	0.0	0.0	0.0	0.0	100.0
			Numbers	0	3	124	0	0	0	0	127
22	May 24 - May 30	76	Percent	0.0	2.9	97.0	0.0	0.0	0.1	0.1	100.0
			Numbers	0	214	5,981	0	0	10	10	6,216
23	May 31 - Jun 06	113	Percent	0.0	6.4	92.4	0.0	0.0	0.6	0.6	100.0
			Numbers	0	425	5,974	0	0	36	36	6,470
24	Jun 07 - Jun 13	287	Percent	0.5	12.6	86.2	0.1	0.2	0.2	0.2	100.0
			Numbers	88	2,577	18,897	15	29	37	37	21,680
25	Jun 14 - Jun 20	275	Percent	3.7	23.6	71.0	0.3	0.5	0.5	0.5	100.0
			Numbers	199	1,326	3,876	15	31	31	31	5,508
26	Jun 21 - Jun 27	39	Percent	8.2	30.3	61.5	0.0	0.0	0.0	0.0	100.0
			Numbers	276	1,037	2,114	0	0	0	0	3,427
27	Jun 28 - Jul 04	0	Percent	3.4	29.1	67.4	0.0	0.0	0.0	0.0	100.0
			Numbers	75	657	1,525	0	0	0	0	2,257
28	Jul 05 - Jul 11	60	Percent	0.1	28.8	71.1	0.0	0.0	0.0	0.0	100.0
			Numbers	1	625	1,555	0	0	0	0	2,181
29	Jul 12 - Jul 18	10	Percent	0.5	31.1	67.6	0.2	0.0	0.7	0.0	100.0
			Numbers	6	408	882	3	0	10	0	1,309
30	Jul 19 - Jul 25	46	Percent	4.8	38.7	49.5	1.7	0.1	5.3	0.0	100.0
			Numbers	24	207	276	9	0	27	0	543
31	Jul 26 - Aug 01	0	Percent	21.7	32.8	38.3	0.9	1.3	5.1	0.0	100.0
			Numbers	367	477	563	10	22	74	0	1,513
32	Aug 02 - Aug 08	48	Percent	33.3	27.1	33.3	0.0	2.1	4.2	0.0	100.0
			Numbers	262	213	262	0	16	33	0	786
33	Aug 09 - Aug 15	0	Percent	33.3	27.1	33.3	0.0	2.1	4.2	0.0	100.0
			Numbers	51	41	51	0	3	6	0	153
34	Aug 16 - Aug 22	0	Percent	33.3	27.1	33.3	0.0	2.1	4.2	0.0	100.0
			Numbers	16	13	16	0	1	2	0	49
35	Aug 23 - Aug 29	0	Percent	33.3	27.1	33.3	0.0	2.1	4.2	0.0	100.0
			Numbers	5	4	5	0	0	1	0	14
36	Aug 30 - Sep 05	0	Percent	33.3	27.1	33.3	0.0	2.1	4.2	0.0	100.0
			Numbers	7	6	7	0	0	1	0	22
Totals		954	Percent	2.6	15.8	80.6	0.1	0.2	0.5	0.2	100.0
			Numbers	1,377	8,234	42,108	52	103	267	114	52,255

Table 8.–Afognak Lake sockeye salmon escapement mean length by sex and age class, 2010.

	Age							
	1.1	1.2	1.3	1.4	2.1	2.2	2.3	Total
				Males				
Mean Length (mm)	353.4	469.2	526.6	561.0	352.5	457.8	0.0	502.7
Standard Error	5.37	3.17	1.46	0.00	23.50	11.66	0.00	0.12
Range	311-398	390-532	436-579	561-561	329-376	425-479		311-579
Sample Size	20	78	252	1	2	4	0	357
				Females				
Mean Length (mm)	333.0	459.8	507.4	509.0	356.0	457.0	515.7	497.5
Standard Error	4.36	2.36	1.01	0.00	0.00	2.12	2.03	0.10
Range	312-344	406-540	352-569	509-509	356-356	452-461	512-519	312-569
Sample Size	8	86	479	1	1	4	3	582
				All[a]				
Mean Length (mm)	347.6	464.2	514.2	535.0	353.7	457.4	515.7	499.7
Standard Error	4.37	1.97	0.89	26.00	13.62	5.49	2.03	1.35
Range	311-398	390-540	352-579	509-561	329-376	425-479	512-519	311-579
Sample Size	28	165	745	2	3	8	3	954

[a] Includes fish not assigned a sex.

Table 9.–General water chemistry and algal pigment concentrations at 1 m water depth, station 1, Afognak Lake 2010.

Date	pH (units)	Alkalinity (mg L^{-1})	Chlorophyll *a* (µg L^{-1})	Pheophytin *a* (µg L^{-1})
4-May	7.09	9.0	0.96	0.38
22-Jun	7.21	9.0	1.12	0.45
22-Jul	7.18	10.0	1.28	0.51
24-Aug	6.96	9.5	0.96	0.83
20-Sep	7.30	10.0	1.28	0.96
Average	7.15	9.5	1.12	0.63
SD	0.13	0.5	0.16	0.25

Table 10.–Seasonal phosphorus and nitrogen concentrations at 1 m water depth, station 1, Afognak Lake, 2010.

Date	Total filterable-P (µg L^{-1})	Filterable reactive-P (µg L^{-1})	Total-P (µg L^{-1})	Ammonia (µg L^{-1})	Total Kjeldahl Nitrogen (µg L^{-1})	Nitrate + Nitrite (µg L^{-1})	Total Nitrogen (µg L^{-1})	TN:TP ratio
18-May	2.7	1.7	3.4	3.7	38.0	77.5	115.5	75.0
15-Jun	3.1	2.1	5.4	5.3	17.0	24.6	41.6	17.2
16-Jul	2.0	1.4	4.8	3.6	32.0	1.9	33.9	15.6
24-Aug	2.3	1.4	4.6	3.7	3.0	5.4	8.4	4.0
22-Sep	2.5	1.8	3.6	5.1	50.0	3.3	53.3	32.8
Average	2.5	1.7	4.4	4.3	28.0	22.5	50.5	28.9
SD	0.4	0.3	0.8	0.8	18.3	32.1	39.9	27.7

Table 11.–Weighted mean zooplankton density, biomass, and size by individual station for all data from Afognak Lake, 2010.

Station	*n*		*Epischura*	*Diaptomus*	*Cyclops*	Other Copepods	*Bosmina*	*Daphnia*	*Holopedium*	Other Cladocerans	Total Copepods	Total Cladocerans	Total all zooplankton
1	5	density (no. m^{-2})	14,841	212	987	19,087	64,830	1,327	1,624	38,599	35,127	106,380	141,507
		%	10.5%	0.1%	0.7%	13.5%	45.8%	0.9%	1.1%	27.3%	24.8%	75.2%	100.0%
		biomass (mg m^{-2})	48.1	0.5	1.1	–[a]	49.5	1.6	3.2	–[a]	49.7	54.2	104.0
		%	46.2%	0.5%	1.1%	–[a]	47.6%	1.5%	3.1%	–[a]	47.8%	52.2%	100.0%
		size (mm)	0.89	0.82	0.59	–[a]	0.29	0.53	0.49	–[a]			
2	5	density (no. m^{-2})	4,273	0	504	14,745	25,653	191	1,205	10,855	19,522	37,904	57,426
		%	7.4%	0.0%	0.9%	25.7%	44.7%	0.3%	2.1%	18.9%	34.0%	66.0%	100.0%
		biomass (mg m^{-2})	6.1	0.0	0.5	–[a]	15.5	0.4	1.6	–[a]	6.6	17.5	24.0
		%	25.2%	0.0%	2.1%	–[a]	64.6%	1.6%	6.5%	–[a]	27.3%	72.7%	100.0%
		size (mm)	0.67	0.00	0.55	–[a]	0.26	0.65	0.41	–[a]			
All Data		density (no. m^{-2})	9,557	106	746	16,916	45,242	759	1,415	24,727	27,325	72,142	99,467
		%	9.6%	0.1%	0.7%	17.0%	45.5%	0.8%	1.4%	24.9%	27.5%	72.5%	100.0%
		biomass (mg m^{-2})	27.1	0.3	0.8	–[a]	32.5	1.0	2.4	–[a]	28.1	35.8	64.0
		%	42.2%	0.4%	1.3%	–[a]	50.8%	1.5%	3.7%	–[a]	44.0%	56.0%	100.0%
		size (mm)	0.78	0.70	0.57	–[a]	0.28	0.59	0.45	–[a]			

[a] Other copepods and cladocerans are composed of immature species that are too small to measure to generate a biomass estimate.

Table 12.–Length, weight, and condition of lake rearing juvenile sockeye salmon from Afognak Lake, 2010.

Sample Dates by Month	Sample Size	Weight (g) Mean	Weight (g) Standard Error	Length (mm) Mean	Length (mm) Standard Error	Condition Mean	Condition Standard Error
Age 0.							
June (6/10 & 6/24)	20	0.4	0.12	34.0	1.90	0.89	0.19
July (7/8, 7/26, & 7/28)	23	0.9	0.39	43.6	6.34	1.03	0.14
August (8/11, 812, 8/13, 8/26, & 8/27)	92	2.1	0.50	54.9	4.67	1.26	0.11
September (9/8)	22	2.3	0.65	55.6	5.47	1.29	0.12
June - September	157	1.7	0.84	50.6	8.98	1.18	0.19
Age 1.							
June (6/10 & 6/24)	20	2.5	0.57	63.8	5.26	0.97	0.11
July (7/8, 7/26, & 7/28)	26	4.0	0.83	71.1	3.71	1.10	0.10
August (8/11, 812, 8/13, 8/26, & 8/27)	49	4.8	0.61	73.7	2.70	1.20	0.09
September (9/8)	4	4.9	0.64	74.0	2.45	1.20	0.05
June - September	99	4.1	1.10	71.0	4.96	1.11	0.15

Table 13.–Stomach fullness and percentage of insects and zooplankton within the stomachs of lake rearing juvenile sockeye salmon from Afognak Lake, 2010.

Sample Dates by Month	Sample Size	Stomach Fullness (%)	Insects (%)	Zooplankton (%)
		Age 0.		
June (6/10 & 6/24)	7	93.6	96.3	3.7
July (7/8, 7/26, & 7/28)	6	69.2	63.2	36.8
August (8/11, 812, 8/13, 8/26, & 8/27)	25	52.4	44.8	55.2
September (9/8)	8	50.6	11.3	88.8
June - September	46	60.5	49.2	50.8
		Age 1.		
June (6/10 & 6/24)	5	90.0	99.2	0.6
July (7/8, 7/26, & 7/28)	6	75.0	78.7	21.3
August (8/11, 812, 8/13, 8/26, & 8/27)	10	51.0	53.9	46.1
September (9/8)	0			
June - September	23	62.6	74.2	25.8

Table 14.–Calories and condition of lake rearing juvenile sockeye salmon from Afognak Lake, 2010.

Sample Dates by Month	Sample Size	Calorimetry (cal/g) Mean	Calorimetry (cal/g) Standard Error	Condition Mean	Condition Standard Error
Age 0.					
June (6/10 & 6/24)	14	6141.5	375.13	0.84	0.15
July (7/8, 7/26, & 7/28)	17	5704.5	117.13	1.03	0.13
August (8/11, 812, 8/13, 8/26, & 8/27)	55	5853.2	146.05	1.26	0.11
September (9/8)	13	5940.9	171.54	1.31	0.14
June - September	99	5880.0	228.62	1.17	0.20
Age 1.					
June (6/10 & 6/24)	14	5183.0	153.95	0.98	153.95
July (7/8, 7/26, & 7/28)	18	5614.5	294.94	1.08	294.94
August (8/11, 812, 8/13, 8/26, & 8/27)	33	5810.2	288.76	1.21	288.76
September (9/8)	3	6044.7	100.58	1.20	100.58
June - September	75	5584.3	360.40	1.11	360.40

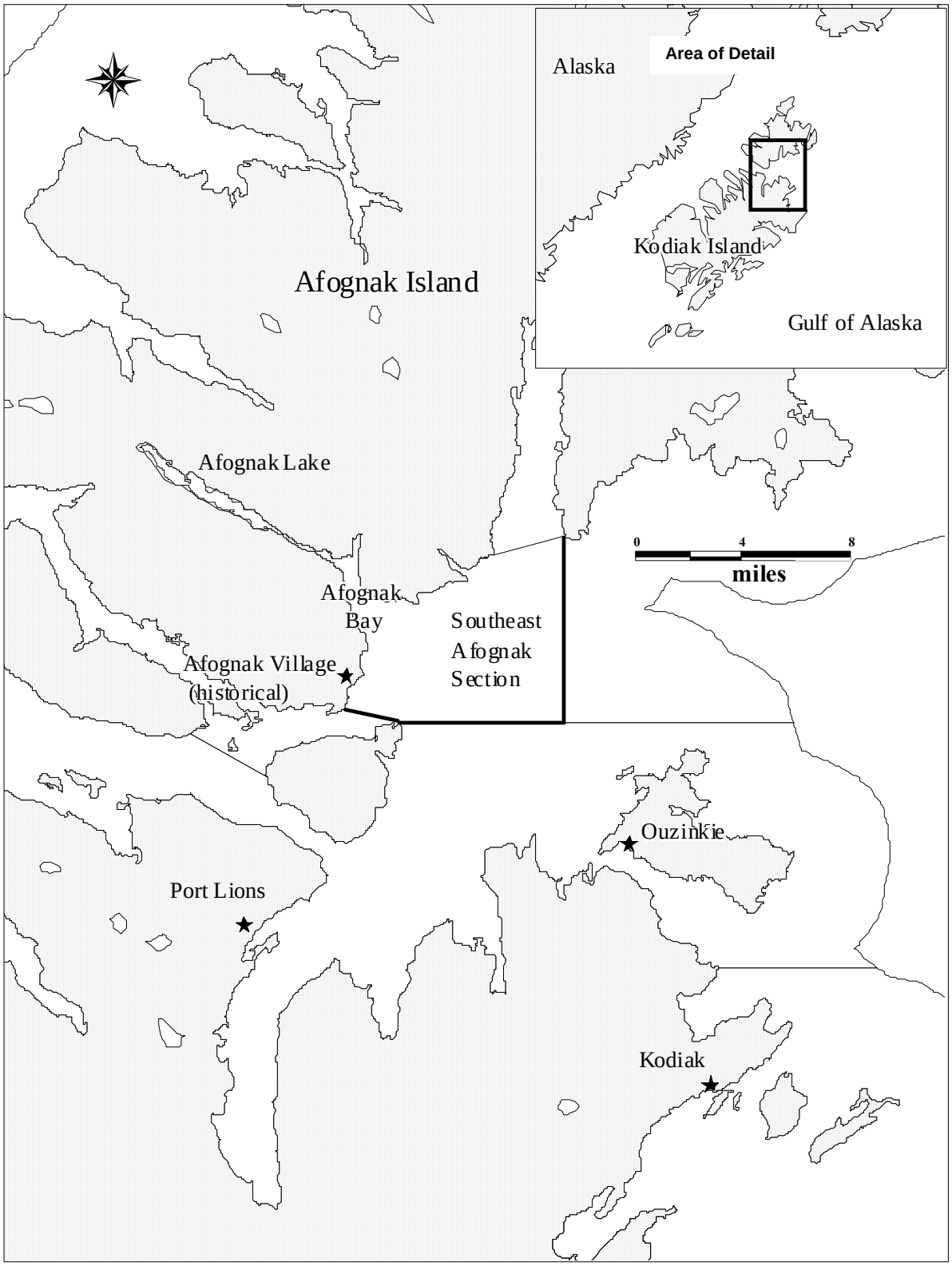

Figure 1.–Map depicting the location of Kodiak City, and the villages of Port Lions, and Ouzinkie and their proximity to the Afognak Lake drainage on Afognak Island.

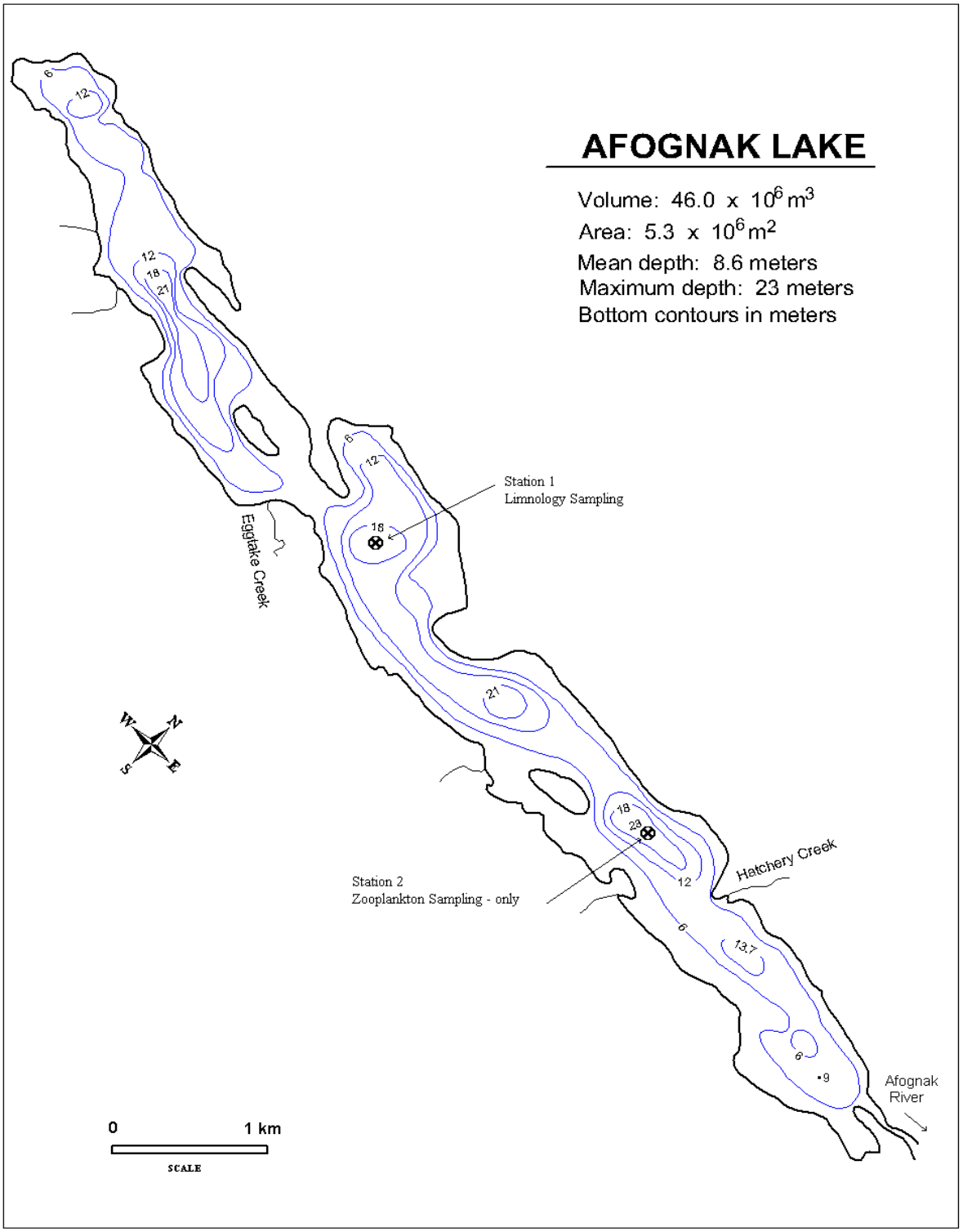

Figure 2.–Bathymetric map showing the limnology and zooplankton sampling stations on Afognak Lake.

Figure 3.–The juvenile trapping system, 2010.

Figure 4.–The adult salmon enumeration weir in Afognak River, 2010.

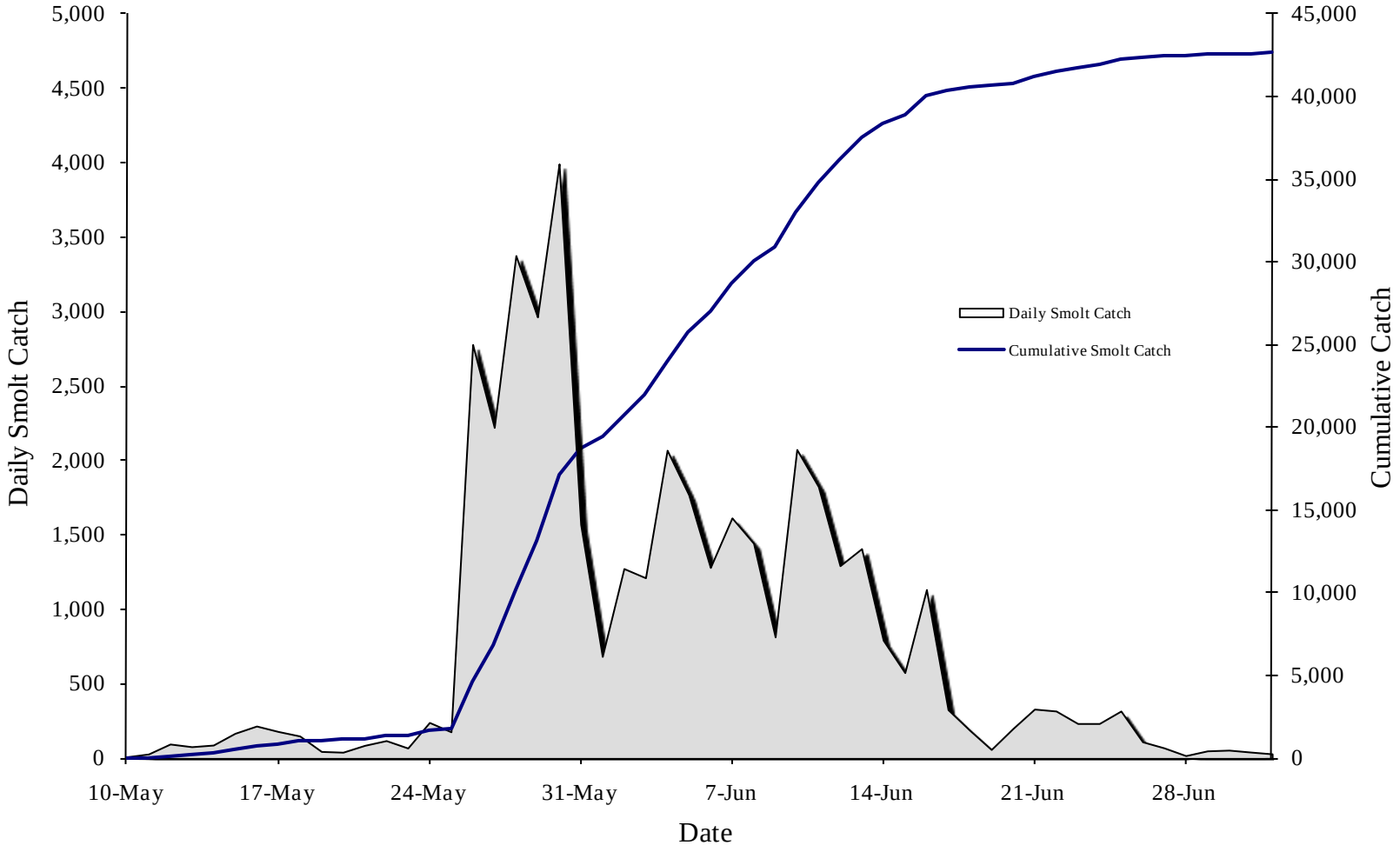

Figure 5.–Daily and cumulative sockeye salmon smolt trap catch from 9 May to 1 July in the Afognak River, 2010.

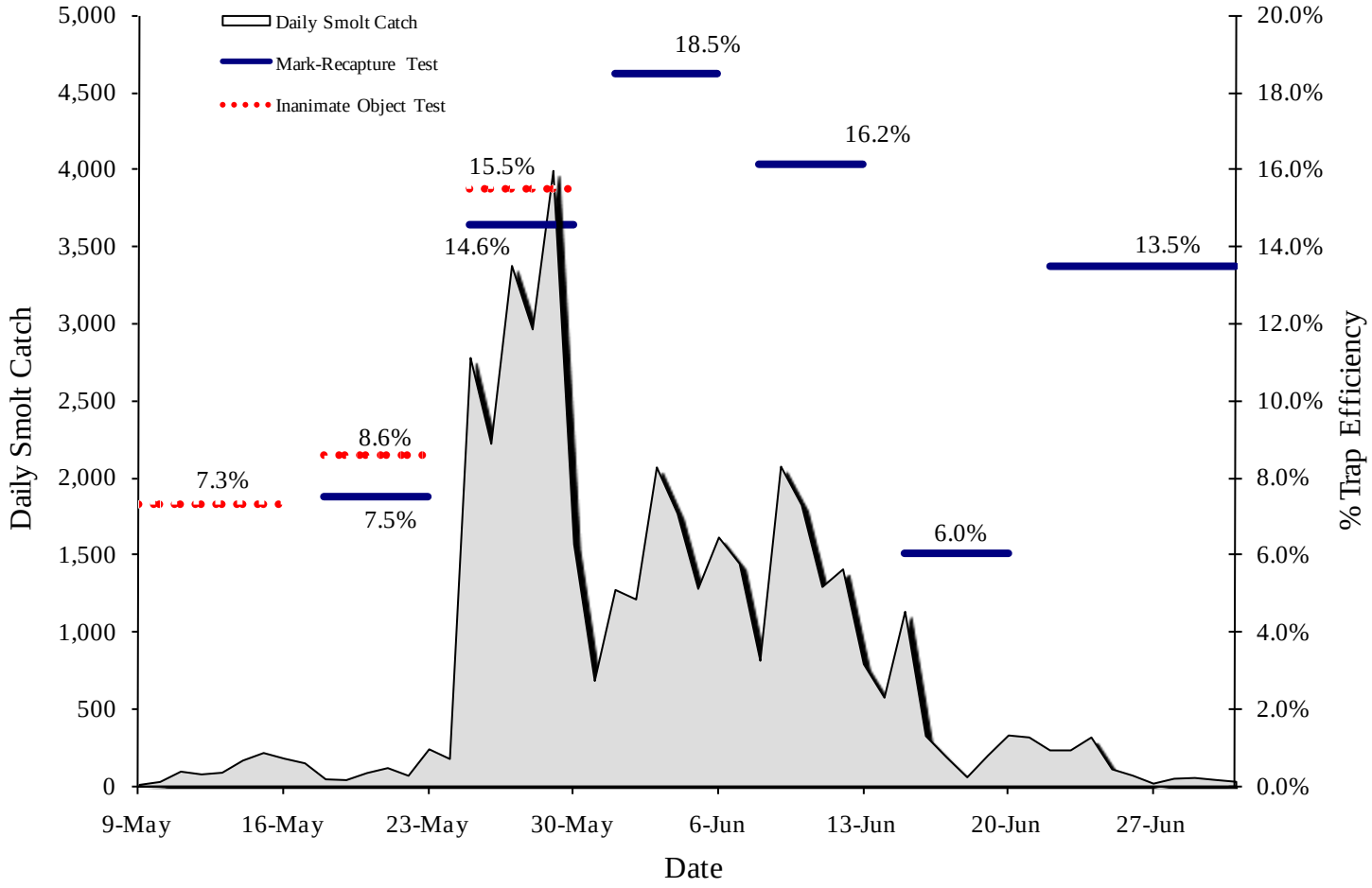

Figure 6.–Daily sockeye salmon smolt trap catch and trap efficiency estimates by strata from 9 May to 1 July in the Afognak River, 2010.

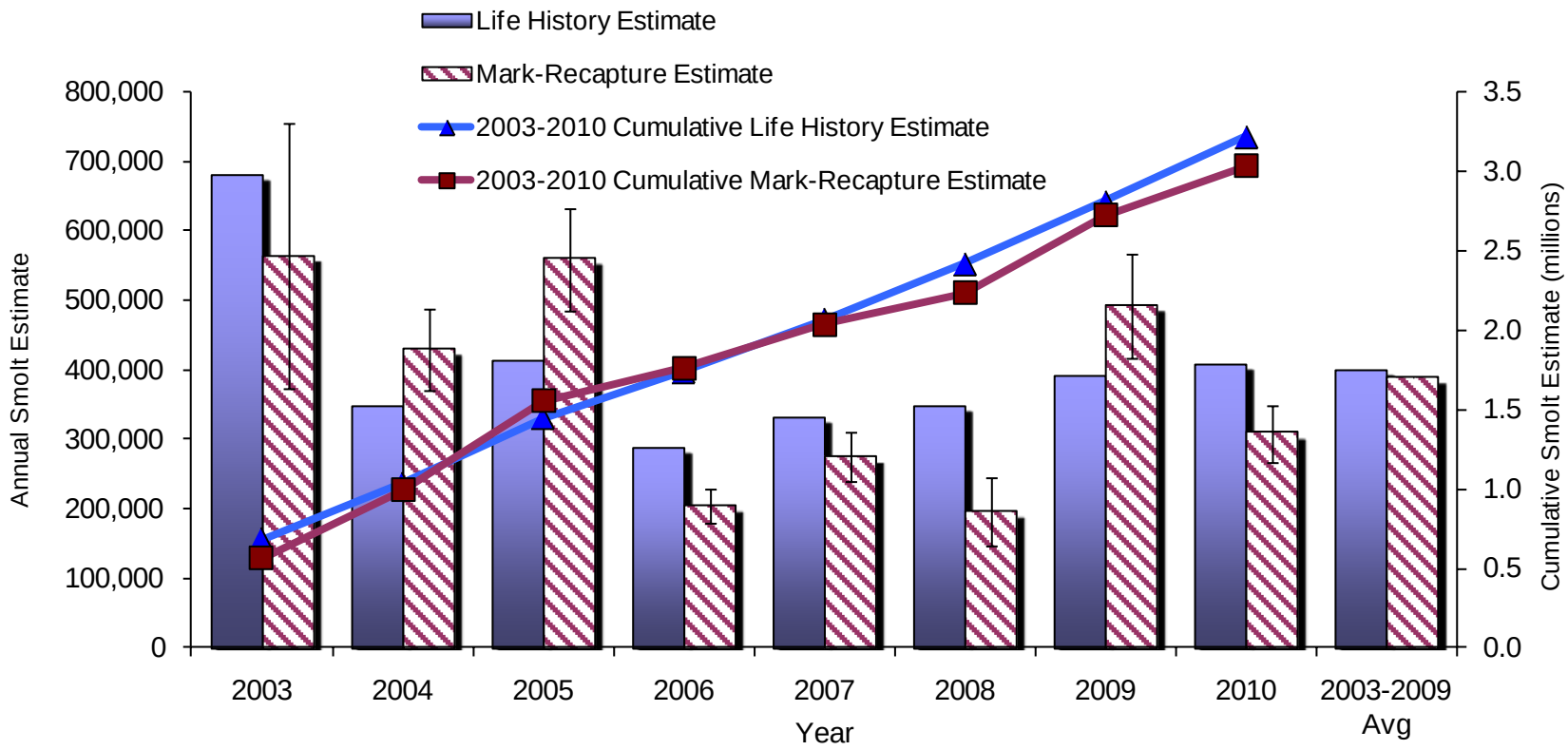

Figure 7.–Comparison of sockeye salmon smolt abundance estimates from life history and mark-recapture models, 2003–2010. For mark-recapture estimates, the 95% CI is shown as a vertical line superimposed on each bar.

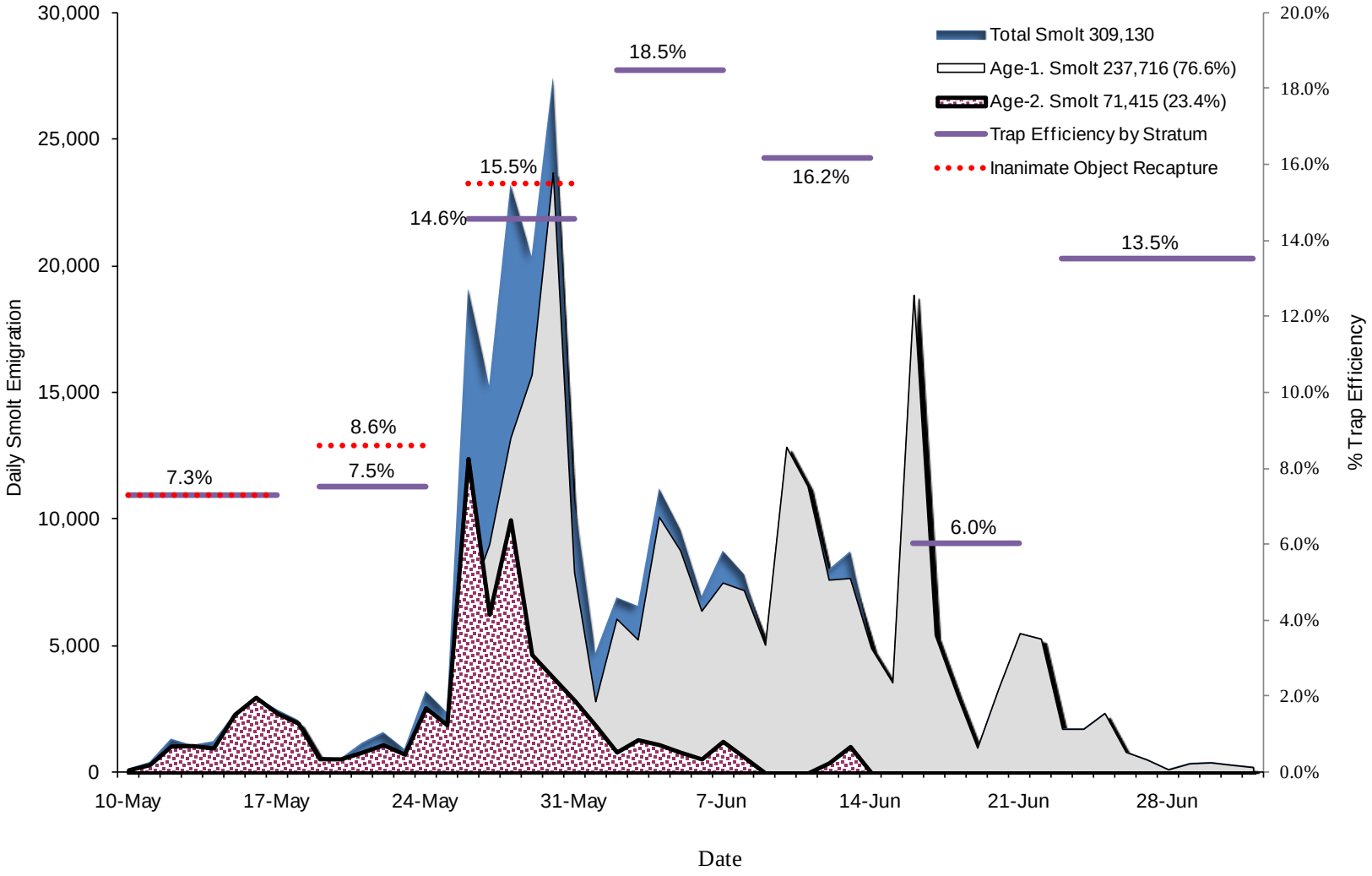

Figure 8.–Afognak Lake sockeye salmon smolt daily emigration estimates by age class, 2010.

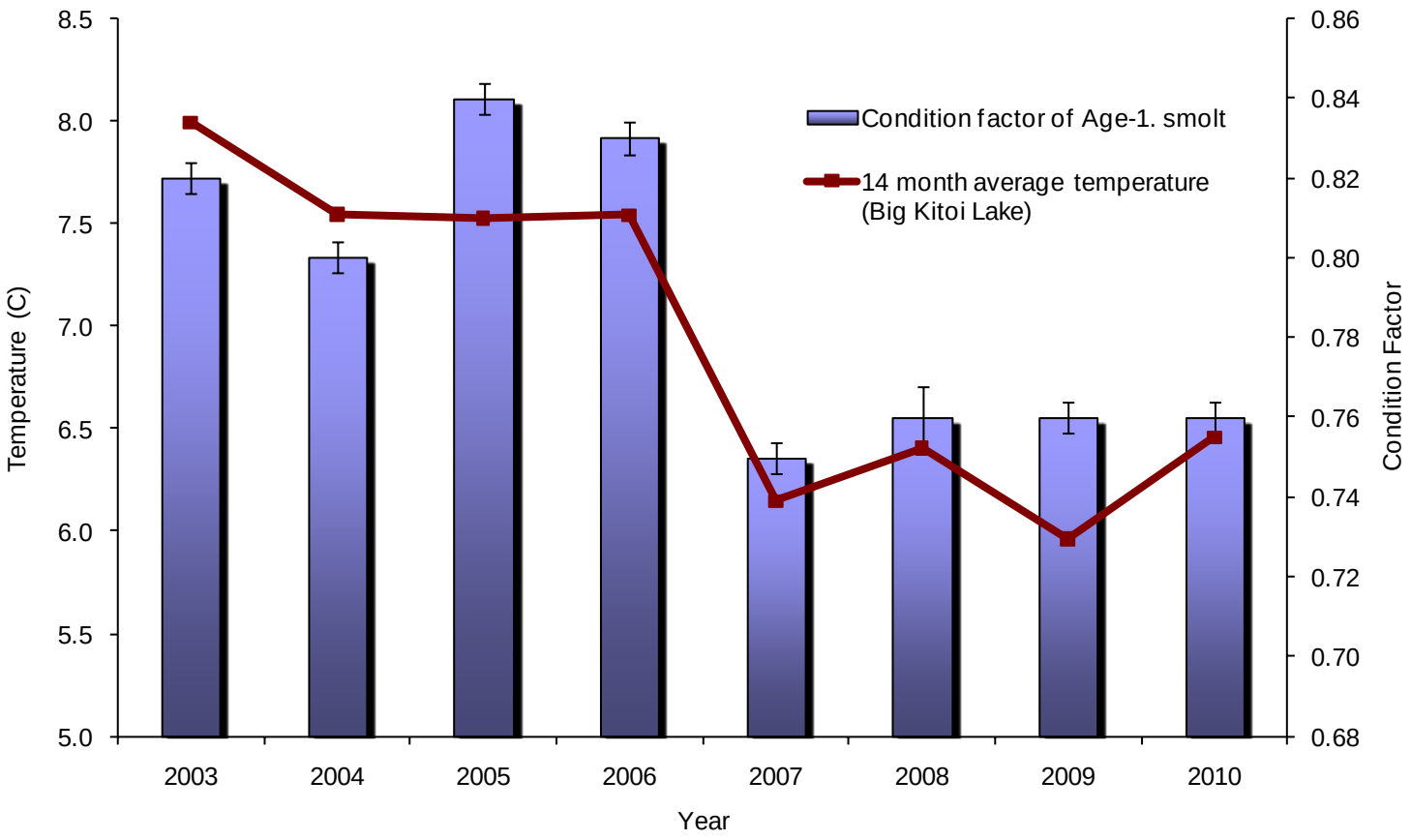

Figure 9.–Seasonal averages of age-1. sockeye salmon smolt body condition (95% CI) and water temperatures recorded from Big Kitoi Lake, which was used as a surrogate for Afognak Lake water temperature, 2003–2010.

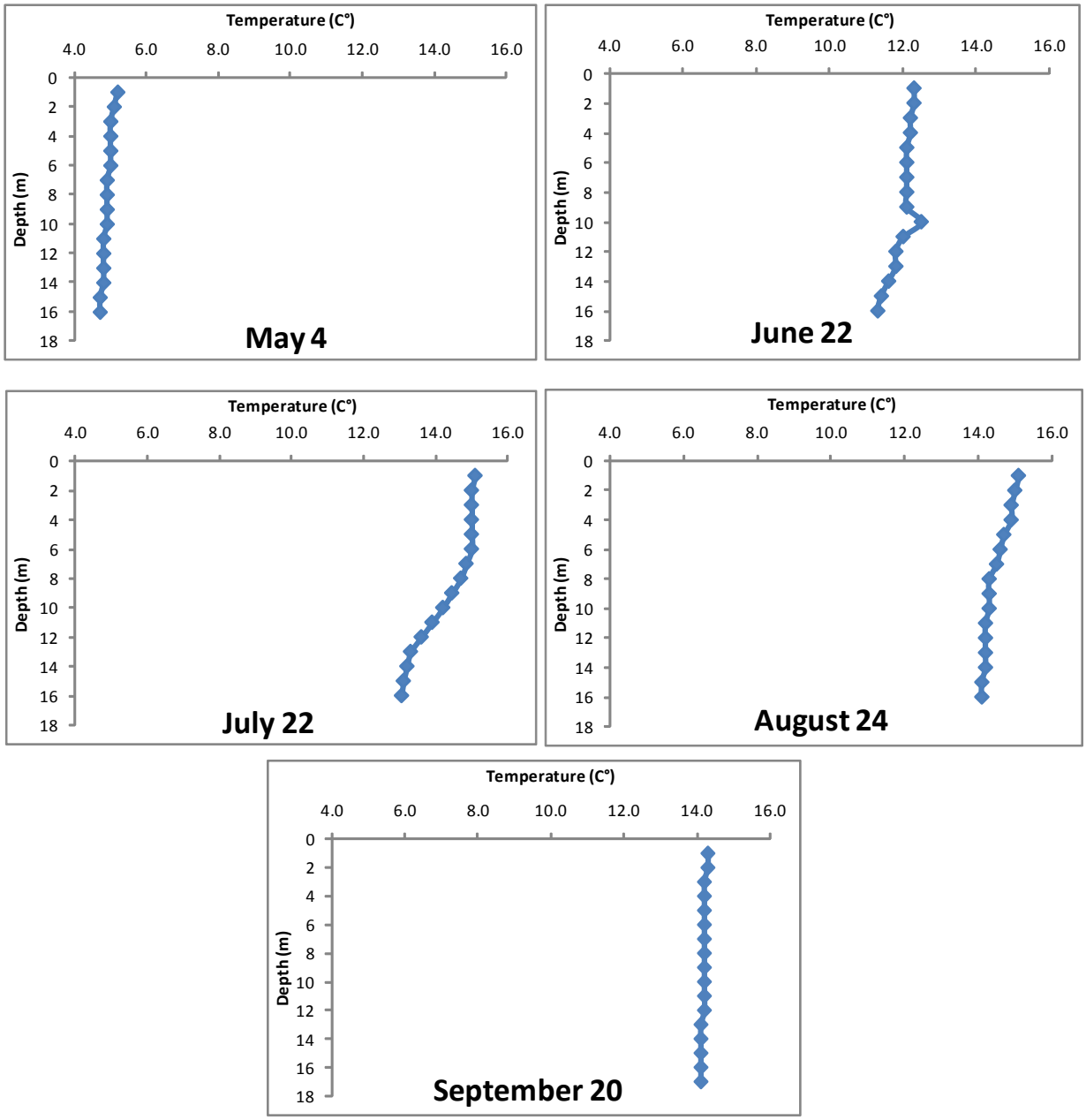

Figure 10.–Temperature profiles by sampling date from Afognak Lake, 2010.

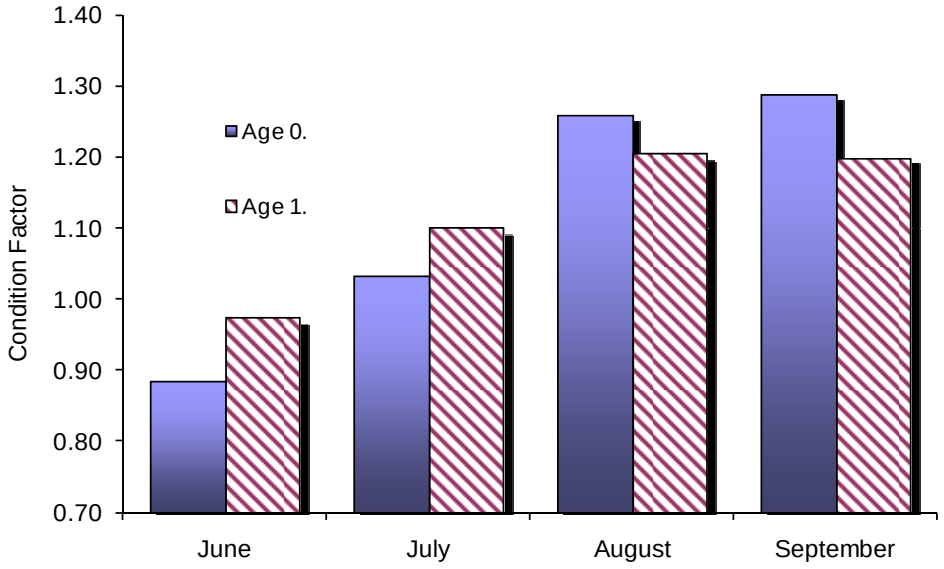

Figure 11.–Condition of lake rearing juvenile sockeye salmon by month from Afognak Lake, 2010.

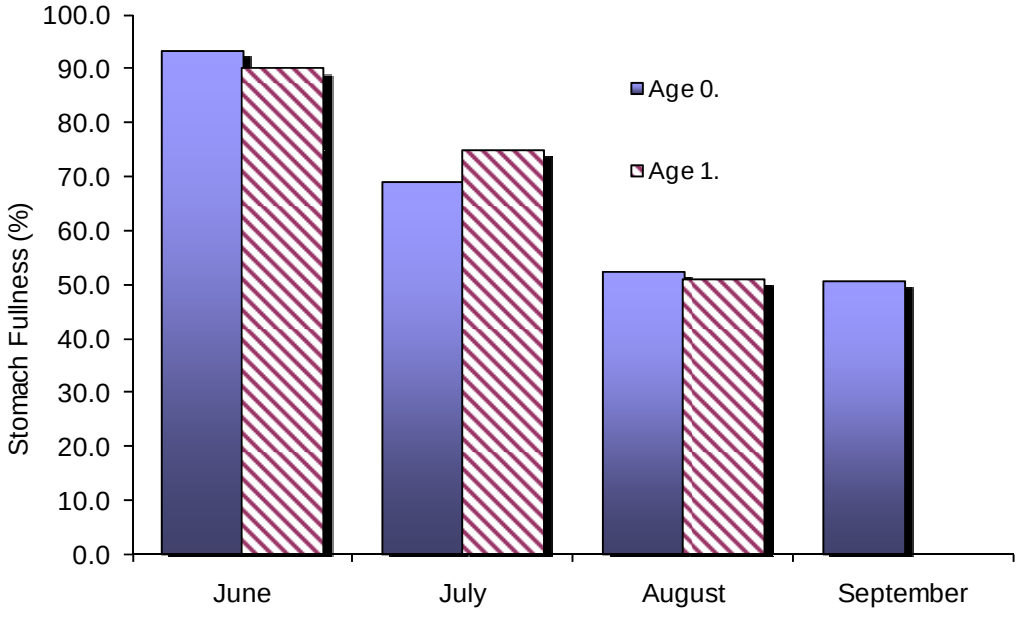

Figure 12.–Stomach fullness of lake rearing juvenile sockeye salmon by month from Afognak Lake, 2010.

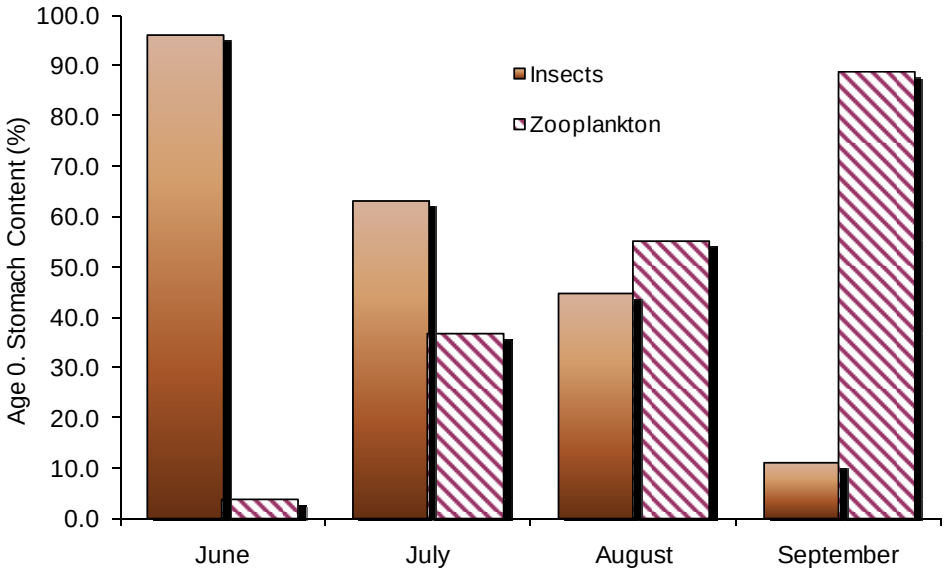

Figure 13.–Percentage of insects and zooplankton within the stomachs of lake rearing Age 0. juvenile sockeye salmon from Afognak Lake, 2010.

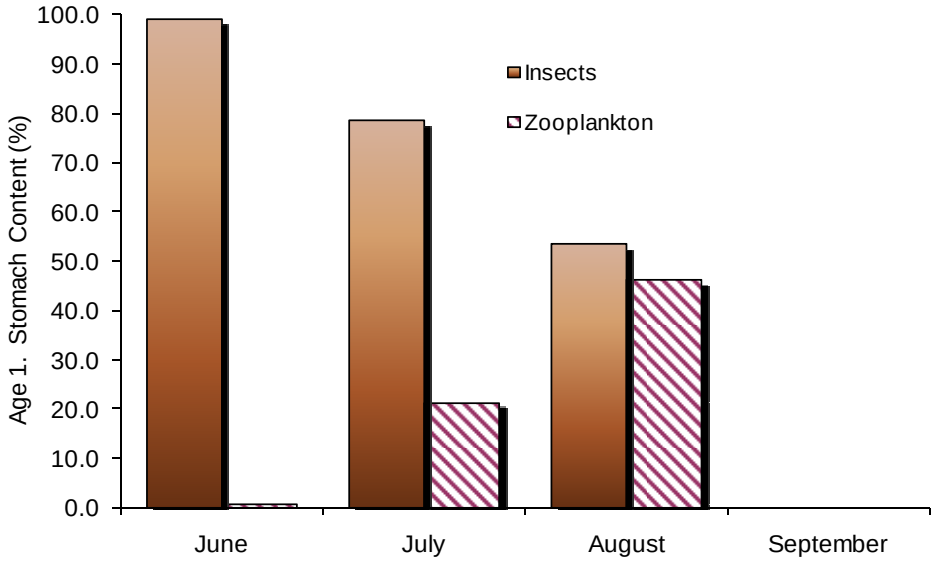

Figure 14.–Percentage of insects and zooplankton within the stomachs of lake rearing Age 1. juvenile sockeye salmon from Afognak Lake, 2010.

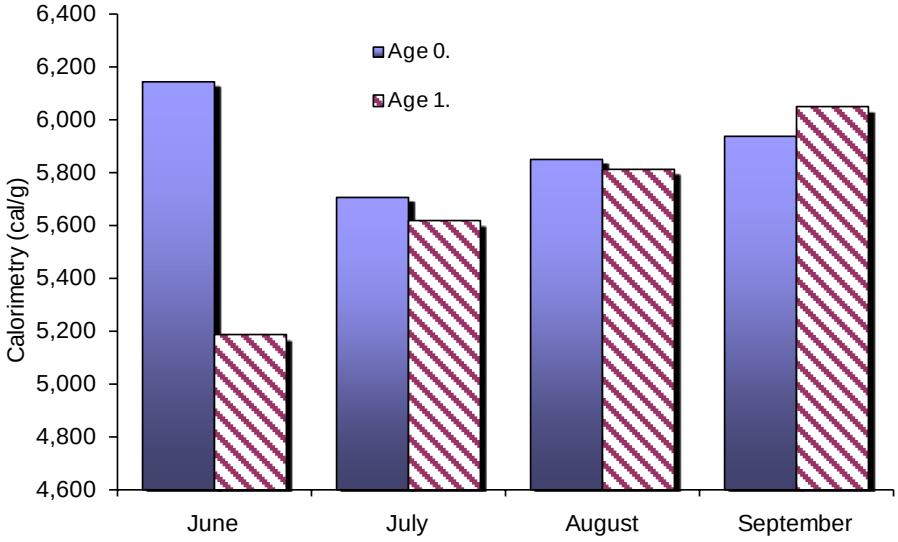

Figure 15.–Calorie content of lake rearing juvenile sockeye salmon by month from Afognak Lake, 2010.

APPENDIX A. SUPPORTING HISTORICAL INFORMATION

Appendix A1.–Population estimates of the sockeye salmon emigrations from Afognak Lake 2003–2010.

Stratum (h)	Starting date	Ending date	Catch (u_h)	Released (M_h)	Recaptured (m_h)	Carlson trap efficency (%)	Estimate (U_h)	Variance (U_h)	95% Confidence Interval lower	95% Confidence Interval upper
						2003				
1	5/12	5/19	1,387	239	5	2.1%	55,480	4.31E+08	14,809	96,151
2	5/20	5/25	2,912	239	5	2.1%	116,480	1.89E+09	31,188	201,772
3	5/26	5/31	11,966	706	161	22.8%	52,222	1.31E+07	45,136	59,308
4	6/1	6/7	31,358	638	133	20.8%	149,536	1.31E+08	127,063	172,008
5	6/8	6/10	11,153	686	257	37.5%	29,698	2.18E+06	26,807	32,589
6	6/11	6/18	18,696	679	103	15.2%	122,243	1.21E+08	100,663	143,823
7	6/19	6/26	4,762	506	79	15.6%	30,179	9.63E+06	24,097	36,261
8	6/27	7/3	736	218	17	7.8%	8,955	3.97E+06	5,050	12,859
Total			82,970	3,911	760	19.9%	564,793	2.61E+09	374,814	754,772
							SE=	5.10E+04		
						2004				
1	5/11	5/26	24,278	525	56	10.7%	224,039	7.73E+08	169,530	278,548
2	5/27	6/3	17,727	547	96	17.6%	100,148	8.47E+07	82,111	118,186
3	6/4	6/11	16,658	700	211	30.1%	55,081	1.01E+07	48,864	61,299
4	6/12	6/19	5,086	613	119	19.4%	26,023	4.61E+06	21,815	30,231
5	6/20	7/3	3,779	581	88	15.1%	24,712	5.88E+06	19,958	29,466
Total			67,528	2,966	570	18.6%	430,004	8.79E+08	371,905	488,104
							SE=	2.96E+04		

Note: SE = standard error

-continued-

Appendix A1.–Page 2 of 3.

Stratum (h)	Starting date	Ending date	Catch (u_h)	Released (M_h)	Recaptured (m_h)	Avg.trap efficency (%)	Estimate (U_h)	Variance (U_h)	95% Confidence Interval lower	95% Confidence Interval upper
						2005				
1	5/10	5/21	27,226	489	70	14.3%	184,879	4.05E+08	145,443	224,314
2	5/22	5/26	13,627	518	43	8.3%	155,259	4.89E+08	111,932	198,587
3	5/27	6/5	15,210	482	44	9.1%	158,499	4.94E+08	114,948	202,050
4	6/6	6/27	17,634	368	103	28.0%	61,593	2.58E+07	51,640	71,546
Total			73,697	1,857	260	14.9%	560,230	1.41E+09	486,554	633,906
							SE=	3.76E+04		
						2006				
1	5/16	6/1	25,983	312	73	23.6%	110,017	1.24E+08	88,224	131,809
2	6/2	6/6	8,199	515	98	19.2%	42,726	1.49E+07	35,153	50,299
3	6/7	6/16	7,108	485	95	19.8%	35,975	1.09E+07	29,519	42,432
4	6/17	6/29	2,534	492	75	15.4%	16,435	3.06E+06	13,009	19,861
Total			43,824	1,804	341	19.5%	205,153	1.52E+08	180,952	229,353
							SE=	1.23E+04		
						2007				
1	5/10	6/5	14,450	415	51	12.5%	115,690	2.22E+08	86,501	144,879
2	6/6	6/12	19,469	202	124	61.5%	31,680	3.09E+06	28,235	35,125
3	6/13	6/20	15,281	510	82	16.2%	94,135	8.88E+07	75,660	112,609
4	6/21	6/27	5,216	541	108	20.1%	25,914	4.98E+06	21,541	30,288
5	6/28	7/4	899	401	44	11.2%	8,031	1.31E+06	5,790	10,272
Total			55,315	2,070	409	19.9%	275,450	3.20E+08	240,388	310,512
							SE=	1.79E+04		

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Appendix A1.–Page 3 of 3.

Stratum (h)	Starting date	Ending date	Catch (u_h)	Released (M_h)	Recaptured (m_h)	Avg.trap efficency (%)	Estimate (U_h)	Variance (U_h)	95% Confidence Interval lower	95% Confidence Interval upper
						2008				
1	5/16	5/31	6,516	202	44	21.2%	29,434	1.48E+07	21,903	36,966
2	6/1	6/11	12,500	394	32	8.4%	149,621	6.05E+08	101,411	197,831
3	6/12	6/19	2,559	244	53	22.0%	11,989	2.08E+06	9,162	14,815
4	6/20	7/3	1,290	306	62	20.5%	5,896	4.54E+05	4,575	7,217
Total			22,865	1,147	191	18.3%	196,941	6.22E+08	148,046	245,835
							SE=	2.49E+04		
						2009				
1	5/10	5/22	14,338	381	65	17.3%	82,891	8.52E+07	64,799	100,983
2	5/23	6/1	37,537	356	50	14.3%	262,568	1.14E+09	196,454	328,681
3	6/2	6/9	5,829	420	43	10.5%	55,727	6.23E+07	40,261	71,192
4	6/10	6/21	5,753	425	35	8.5%	68,080	1.15E+08	47,025	89,136
5	6/22	7/3	1,510	93	5	6.4%	23,732	7.56E+07	6,686	40,778
Total			64,967	1,674	198	11.4%	492,998	1.48E+09	417,689	568,306
							SE=	3.84E+04		
						2010				
1	5/9	5/17	1,026	150	10	7.3%	14,090	1.55E+07	6,373	21,807
2	5/18	5/24	788	385	28	7.5%	10,489	3.52E+06	6,813	14,164
3	5/25	5/31	17,620	274	39	14.6%	120,961	3.06E+08	86,699	155,224
4	6/1	6/7	10,687	275	50	18.5%	57,852	5.27E+07	43,620	72,084
5	6/8	6/14	8,802	228	36	16.2%	54,477	6.58E+07	38,584	70,371
6	6/15	6/21	2,566	464	27	6.0%	42,585	5.94E+07	27,478	57,691
7	6/22	7/1	1,172	488	65	13.5%	8,677	1.03E+06	6,691	10,663
Total						11.9%	309,130	4.43E+08	267,874	350,387
								SE= 21,049		

Appendix A2.–Mean weight, length, and condition factor by age for sockeye salmon smolt sampled at Afognak Lake, 1987–2001, and 2003–2010.

		Age-1				Age-2			
Year	Sampling Period	n	Weight (g)	Length (mm)	Condition (K)	n	Weight (g)	Length (mm)	Condition (K)
1987	8-Jun	36	3.6	74.9	0.85	186	3.6	79.3	0.86
1988	15-Jun	202	4.1	77.9	0.90	0			
1989	15-Jun	208	4.1	76.8	0.91	2	5.2	78.0	1.10
1990	May 23-June 24	544	2.5	68.8	0.76	21	3.4	77.3	0.73
1991	May 13-June 26	1,895	3.1	72.9	0.78	176	3.9	78.3	0.81
1992	June 7-20	268	3.8	77.0	0.82	37	3.8	76.9	0.83
1993	May 24-30	274	3.0	72.7	0.78	21	3.3	74.8	0.79
1994	May 17-23	138	3.0	72.0	0.81	142	4.7	84.3	0.79
1995	May 31-June 13	394	2.8	69.4	0.84	5	3.6	78.8	0.74
1996	June 5-11	54	4.6	80.9	0.87	339	4.8	81.6	0.88
1997	May 24-30	76	4.3	81.7	0.78	122	4.4	82.1	0.79
1998	May 24-30	116	2.6	66.4	0.82	46	6.6	88.0	0.90
1999	May 31-June 6	96	2.8	74.6	0.66	98	2.1	66.6	0.69
2000	May 31-June 13	84	4.9	81.5	0.89	100	5.6	85.3	0.89
2001	June 11-13	44	7.0	90.1	0.93	17	5.8	85.6	0.92
2003	May 12-July 3	1,031	4.2	79.1	0.82	383	4.2	81.4	0.77
2004	May 11-July 3	1,370	3.6	75.7	0.80	81	3.6	78.7	0.74
2005	May 10-June 27	1,248	3.9	76.8	0.84	65	4.2	81.3	0.77
2006	May 16-June 29	765	3.0	70.8	0.83	202	3.8	79.6	0.75
2007	May 21 - July 2	960	2.6	70.4	0.75	129	3.4	76.5	0.74
2008	May 26 - June 28	169	3.4	75.9	0.76	164	4.0	81.7	0.73
2009	May 13 - June 29	1,053	3.5	76.7	0.76	205	5.3	88.8	0.75
2010	May 9 - July 1	601	2.6	69.9	0.76	198	3.9	82.1	0.69
2003-2009		6,596	3.5	75.1	0.79	1,229	4.1	81.1	0.75
2003-2010		7,197	3.4	74.4	0.79	1,427	4.1	81.3	0.74