Fishery Data Series No. 12-25

Afognak Lake Sockeye Salmon Stock Monitoring, 2011

by

Steven E. Thomsen

June 2012

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

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AFOGNAK LAKE SOCKEYE SALMON STOCK MONITORING, 2011

by

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June 2012

This project was granted $141,617 in funding support through the Fisheries Resource Monitoring Program, under agreement number 70181AJ034, as study FIS 10-401.

ADF&G Fishery Data Series was established in 1987 for the publication of Division of Sport Fish technically oriented results for a single project or group of closely related projects, and in 2004 became a joint divisional series with the Division of Commercial Fisheries. Fishery Data Series reports are intended for fishery and other technical professionals and are available through the Alaska State Library and on the Internet: http://www.adfg.alaska.gov/sf/publications/. This publication has undergone editorial and peer review.

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This document should be cited as:
Thomsen, S. E. 2012. Afognak Lake sockeye salmon stock monitoring, 2011. Alaska Department of Fish and Game, Fishery Data Series No. 12-25, Anchorage.

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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 2011 project results.

An estimated 329,948 sockeye salmon smolt (95% CI 288,393–371,502) emigrated from Afognak Lake in 2011, based on the same mark-recapture techniques used in prior years. The emigrating sockeye salmon smolt population was composed of 250,741 age-1. and 79,207 age-2. smolt. Age-1. smolt had a mean weight of 3.1g, a mean length of 72 mm, and a mean condition factor of 0.81. Age-2. smolt had a mean weight of 3.8 g, a mean length of 78 mm, and a mean condition factor of 0.77. The total sockeye salmon escapement into Afognak Lake was 49,193, of which 40.2% were age 1.2 and 28.5% were 1.3.

Lake limnology data was collected during five monthly sampling events from May to September. In 2011, seasonal total phosphorus concentrations and seasonal zooplankton densities remained low, chlorophyll-*a* concentrations remained moderate, the seasonal nitrogen concentrations rose, and the body condition of emigrating smolt remained at healthy levels.

Two years of diet and bioenergetic analysis of juvenile sockeye salmon have revealed that juveniles of all ages primarily consumed insects in the spring, gradually shifting to zooplankton as their primary prey. Additionally, juveniles of all ages consumed the greatest volume of food in June, with their stomach fullness decreasing as prey shifted to zooplankton.

Further assessment of photosynthetically active radiation, nutrient availability, phytoplankton population, and available forage species versus actual forage species will occur over the next two years (2012–2013) 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, bioenergetics, 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 (Figures 2 and 3). Due to its shallow depth, Afognak Lake is easily influenced 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. Afognak Bay is part of the Alaska Maritime National Wildlife Refuge and is 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 discernible 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 fishery 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, constituting an emergency situation. In response to this situation, 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. An 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 the Afognak Lake sockeye salmon 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 second year (2011) of the four year study.

In addition to the ongoing research, we expanded our efforts by investigating the caloric content, or energy budget, of juvenile sockeye salmon as 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 enables researchers to better identify what factors are specifically affecting and controlling sockeye salmon production within the freshwater environment which will help refine the ideal escapement goal and improve pre-season run forecasts. This information allows managers to better manage for maximum 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

<u>Smolt</u>

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.
2. Estimate the abundance (N) of emigrating sockeye salmon smolt within 25% (relative error) of the true value with 95% confidence.
3. Estimate the abundance of emigrating sockeye salmon smolt using a life-history based model for comparison with the mark-recapture estimate.

4. 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.
5. Estimate the average length (mm) and weight (g) by smolt age group and stratum.

Adult salmon

6. Enumerate the escapement of adult sockeye salmon returns through the weir and into Afognak Lake.
7. 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.
8. Estimate the average length (mm) by age and sex.

Lake Studies and Climate Change

9. Evaluate the condition of juvenile (lake rearing) sockeye salmon relative to diet and energy density from 2010 through 2013.
10. 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.
11. 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

Two inclined-plane traps (Ginetz 1977; Todd 1994) were installed in 2011. The downstream trap was installed approximately 32 m upstream from the adult salmon weir site and was utilized for smolt enumeration and the recapture of marked fish (Figure 4). The upstream trap was installed, for the first time in project history, approximately 1.2 km upstream from the adult salmon weir site and was utilized solely to capture smolt for dye release testing. Capturing smolt at the release site (upstream trap) was intended to reduce the high mortality rate encountered during transportation from the capture site (downstream trap).

Both traps were positioned towards the middle of the river at each location, 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 outlet of each trap, and both trapping devices were connected to cables attached to hand-powered cable winches ("come-alongs") fixed to each stream bank. Both traps were secured to an aluminum pipe frame, which allowed the vertical trap position to be adjusted in response to water level fluctuations.

The downstream inclined-plane trap was installed on 09 May and fished continuously through 16 May, but was removed from the river on 17 May due to high water conditions. On 28 May, river conditions were favorable to reinstall the downstream trap and continue to capture emigrating smolt. The trap was removed for the season on 06 July, after the number of captured smolt dropped to less than 100 smolt per day for 3 consecutive days. Detailed methods of trap installation, operation, and maintenance are described in the 2011 Afognak Lake Operational Plan (Foster et al. 2011a).

The upstream inclined-plane trap was installed on 29 May and was fished during four of the five mark-recapture trials. The upstream trap captured a sufficient number of smolt during the first three mark-recapture trials to eliminate the need to transport smolt from the downstream trap for dye release tests. The upstream trap captured fewer smolt for the last two mark-recapture trials, requiring the use of both traps to attain sufficient release numbers.

Smolt Capture and Handling

Smolts captured in both trapping systems were held in their respective live box until they were counted. During the night (2200 to 0800 hours), the live boxes were 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 boxes with a dip net, counted, and either released downstream of the trap or transferred to an in-stream holding box for sampling and marking. The upper trap was only fished until the required number of smolt were captured for the dye release tests and was not fished until the next dye test trial. The smolt were held in the live box until release. 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 mark-recapture procedures to first estimate trap efficiency within specific recapture periods (strata). Trap efficiency was then used to estimate the number of smolt emigrating during each stratum from the watershed.

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%, 330 (20% trap efficiency) to 440 (15% trap efficiency) smolt would need to be marked and released for each experiment (Carlson et al. 1998; Robson and Regier 1964). To estimate any mortality associated with the marking process 100 marked fish were retained and monitored for four days. Therefore, a sample size of 650 was set as the goal for each experiment to account for any handling or marking mortality and mortality testing. Actual numbers of fish marked, released, and retained for mortality testing varied by release event (Table 1). All fish captured and retained were dyed.

Smolt captured for dye release testing at the downstream trap required treatment prior to transportation at the release site (steps 1-5). Smolt were transported in a trailer pulled by an all-terrain vehicle to the release site approximately 1.2 km upstream. Smolt captured at the upstream trap required no transportation and followed steps 3-5.

1. Collected smolt 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 to maintain conditions similar to ambient river water from which the smolt were collected.

2. Dyed smolt were then transferred to a holding box at the release site to rest before the dying process.
3. Collected smolt were placed in a 26-gallon lidded cooler, filled with river water and a 0.25% sodium bicarbonate and Bismarck Brown Y dye (30mg/L) solution. The smolt were continuously oxygenated and submerged in the solution 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 recapture site.
4. Dyed smolt were then transferred to a holding box at the release site. Between 2100 and 2300 hours, roughly 550 of the dyed smolt were randomly selected from the holding box, counted, and released across the width of the stream.
5. The remaining dyed smolt (roughly 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 strata 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

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

which assumes that $\hat{U}$ is approximately normally distributed.

Within each stratum *h*, the total population size by age class *j* was estimated as,

$$\hat{U}_{jh} = \hat{U}_h \hat{\theta}_{jh}, \qquad (7)$$

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

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

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.

Where the following assumptions were not violated (Carlson et al. 1998):

- The population was unchanging (i.e., a closed population with no immigration or emigration),
- all smolt had the same probability of being marked. (i.e., trap is not selective and strata are consistent),
- all smolt had the same probability of capture. (i.e., marking fish does not affect their behavior or ability to be captured),
- all marked smolt released can be recovered. (i.e., marking mortality was accurate),
- all marked smolt were identifiable. (i.e., crew well trained and strata are discrete),
- and marks were not lost after marking. (i.e., effectively stained).

Life History-Based Abundance Estimation

In addition to mark-recapture abundance estimates, the predicted number of smolt expected to emigrate in 2011 was estimated based on a life history model. The history-based estimates utilized the sex composition data from parental spawning escapements in 2008 (42% females) and 2009 (51% females), average egg deposition based on the average fecundity assessment of females used in egg-takes by Pillar Creek Hatchery crews in 2008 (2,529 per female) and 2009 (2,591 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 76% age-1. and 24% age-2. based on the smolt age composition from 2011. Annual differences between life-history based and mark-recapture estimates were regressed for comparison.

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 (MS-222) 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 of each fish following procedures outlined by the International North Pacific Fisheries Commission (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

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

ADULT SALMON ASSESSMENT

Weir Installation and Adult Salmon Enumeration

A 27 m weir was installed at the terminus of the Afognak River on 13 May. The weir remained fish tight from 13 May through 21 May, but was removed on 22 May due to high water conditions. On 28 May, river conditions were favorable to reinstall the weir, fishing continuously until it was removed on 20 August. 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 (Figure 5). All materials were secured with sand bags and lashed together to create a fish tight structure that conformed to the stream substrate.

Two framed panel gates were placed between panels in the two deepest channels of the river enabling fish to be counted as they pass through the weir. A white flash panel was placed on the substrate at the threshold of each gate opening to enhance visibility and aid in speciation. Fish were counted by field technicians using hand tally enumerators as fish migrated upstream through the gates. 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. 2011b).

Age, Sex, and Length Sampling

An upstream “Scott live trap” (local name for a modified trap capable of capturing steelhead) 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, 2011 (Foster et al. 2011b). All scales, when possible, were collected from the preferred area of each fish (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 determined 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 (17 May–6 June), stratum 2 (7 June–13 June), stratum 3 (14 June–20 June), and stratum 4 (21 June–6 July). Average length (unweighted) was calculated by age and sex.

LIMNOLOGICAL ASSESSMENT

Lake Sampling Protocol

Five limnological surveys of Afognak Lake were conducted at approximately four week intervals from May to September, 2011. 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, 10, and 13 m continuously from 7 May to 6 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 17 May to 25 August. PAR measurements were also obtained with a Li-Cor® (Li250) 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.

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).

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 for assessing different water quality parameters. 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 University of Georgia for TKN analysis using the 4500-Norg C Semi-Micro-Kjeldahl method (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).

Chlorophyll *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 1 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 genera.

Phytoplankton

For phytoplankton analysis, 4.0 ml of Lugol's acetate was added to 200 ml of water withdrawn from the contents of the 1 m water sample carboy. Methods were adapted from those described in Koenings (1987) and Thomsen (2008). Samples were sent to the Canadian Museum of Nature (Ottawa, Ontario) for analysis.

JUVENILE (LAKE REARING) ASSESSMENT

Juvenile Collection

A total of five shoal and five mid lake locations were selected to obtain representative samples of Afognak Lake rearing sockeye salmon (Figure 3). The ten sites were sampled on a bi-weekly basis from June through October 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 five shoal sites. A small mesh pelagic trawl or a beach seine were used on the mid water sites. All captured fish were identified and enumerated.

Juvenile sockeye salmon were separated into three size groups (<45 mm, 46 to 65 mm, and ≥ 65 mm) to ensure proportional representation of each age group. When available, a minimum of five 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. (2011a). Each sample was individually stored in 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 five or more samples were available from each sample location, date, and age group, two random samples were selected exclusively for stomach content analysis leaving three 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 genera through the same methods as described in the limnological assessment and through additional taxonomic key identification (McCafferty 1983; Pennak 1989).

The remaining three 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 downstream inclined-plane trap was fished continuously from 09 to 16 May, but due to extreme flooding, the trap was removed from the water on 17 May. The downstream trap was reinstalled and fished continuously for the duration of the emigration (28 May to 06 July; Table 2).

A total of 42,261 smolt were captured from 09 May to 06 July. An additional 12,407 smolt were estimated by time series as captured during the eleven days (17 to 28 May) when the trap was not fishing, for a total estimated trap catch of 54,409 sockeye smolt (Table 2; Figures 6 and 7).

Trap Efficiency and Mark-Recapture Abundance Estimation

Small daily catches of smolt and excessive water levels in the beginning of the emigration (09 to 28 May) prevented completion of a mark-recapture test. As a result, the trap efficiency generated from 30 May, when the water had receded, was used to generate the first strata's total emigration estimate. The standard mark-recapture trap efficiency methods were used to generate the total emigration for the remaining four strata. The five trap efficiency tests ranged from 17.9% in stratum 2 (06 to 13 June) to 12.3% in stratum 5 (28 June to 06 July; Table 1; Figure 7). Mean estimated trap efficiency for the total emigration was 15.7%. Peak smolt emigration occurred in stratum 1 (09 May to 05 June) with the outmigration tapering off in stratum 4. Using the time series estimates and mark-recapture abundance estimation, the total number of sockeye salmon smolt estimated to have emigrated from Afognak Lake in 2011 was 329,949 with 95% CI 288,393–371,502 (Table 1).

Life History-Based Abundance Estimation

Using the life history-based abundance method, the 2008 escapement of 26,874 adults (brood year 2008) was expected to produce 103,176 age-2. smolt. The 2009 escapement of 31,358 adults (brood year 2009) was expected to produce 451,854 age-1. smolt (Table 3). Combining these two age classes resulted in an expected emigration of 555,030 smolt from Afognak Lake in spring 2011.

For the nine years of the project, annual differences between life history-based and mark-recapture estimates ranged from 17% to 44% (R^2=.32, p<0.114; Figure 8). Life history-based estimates have been greater than mark-recapture estimates in six years (2003, 2006 to 2008, and 2010 to 2011) and less than mark-recapture estimates in three years (2004, 2005, and 2009). The cumulative 2003 to 2011 smolt production estimated from annual life history-based estimates (3.78 million smolt) exceeded the estimate from the annual mark-recapture estimates by 11% (3.36 million smolt).

Age, Weight, and Length Data

AWL data were obtained from a total of 898 smolt collected proportionally throughout the trapping period (Table 2). Age-1. smolt comprised 63.2% of the emigration within the first strata (09 May to 05 June) and approximately 90% in the remaining four stratum (06 June to 06 July). Summing smolt abundance estimates by age class from all five mark-recapture strata resulted in a total emigration estimate of 250,741 (76.0%) age-1., and 79,207 (24.0%) age-2. smolt (Table 4; Figure 9).

Sampled age-1. smolt had a mean weight of 3.1 g, a mean length of 72 mm and a mean condition factor of 0.81. Sampled age-2. smolt had a mean weight of 3.8 g, a mean length of 78 mm, and a mean condition factor of 0.77. (Table 5).

ADULT ASSESSMENT

Enumeration

The adult weir was installed on 13 May, with the first salmon passing through the counting gates on 17 May. The weir was removed on 22 May and reinstalled on 28 May, due to extreme flooding. A total of 800 sockeye salmon were added to the escapement to account for estimated daily passage during the flooding. After 28 May, adult Pacific salmon were enumerated on a daily basis until 20 August when the weir was removed. A total of 200 sockeye, 800 pink, and 800 coho salmon in the river below the weir were added to the escapement to account for uncounted salmon passage. In 2011, a total of 49,193 sockeye, 4,241 pink, 2,700 coho, and 4 chum salmon escaped into the Afognak system from 13 May to 20 August (Table 6; Figure 10; Tiernan 2011). Additionally, 128 seaward-migrating steelhead were enumerated and passed down stream of the weir. Sockeye salmon escapement peaked from 31 May through 06 June when 14,378 fish were enumerated during the 23rd statistical week (Table 7).

Age, Sex, and Length Data

A total of 830 sockeye salmon were sampled from 03 June through 03 July, resulting in a total of 750 sockeye salmon where age could be estimated from the scales. Distribution of the samples was as follows: stratum 1 (n=141), stratum 2 (n=291), stratum 3 (n=136), stratum 4 (n=182). 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 (40.2%) of the escapement was comprised of age-1.2 fish while 28.5% were age-1.3 sockeye salmon. The majority of the age-1.2 and age-1.3 fish escaped during early June. A large increase in escapement was observed in mid August when an extended dry period was followed by heavy rain (Figure 10). The estimated sex composition of the total escapement was 63% female and 37% male. Roughly 61% of the age-1.2 fish sampled were female and 69% of the age-1.3 fish sampled were female. Overall average length was 490 mm for age-1.2 fish and 540 mm for age-1.3 fish (Table 8; Appendix A2).

LIMNOLOGICAL ASSESSMENT

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

Water temperatures during the monthly limnology sampling at station 1 ranged from 5.2°C near the lake bottom on 4 May to 15.3°C at 2 m on 8 August (Figure 11). Seasonal mean water temperatures at 1 m and near the bottom were below the historical average (1989-2011; Appendix A3).

In 2011, the data logger at 1 m (Station 2) was operated continuously from 17 May to 6 October, logging temperature every hour. For comparison with monthly limnology sampling averages, mean surface (1 m) temperatures were 9.1°C in the spring, 15.4°C in the summer, and 11.4°C in the fall (Table 9; Appendix A3). The temperature logger recorded a maximum of 17.6°C in August, a minimum of 6.6°C in May, a mean daily variation of 0.5°C, a maximum daily variation of 1.6°C, and a overall mean of 12.8°C.

Dissolved oxygen concentrations ranged from 12.2 mg L^{-1} at the surface in the spring to 8.4 mg L^{-1} at the bottom in the summer (Appendix A4). Mean vertical light extinction coefficient was -0.55 m^{-1}, mean euphotic zone depth was 8.20 m, and mean Secchi disk reading was 4.25 meters

(Appendix A5). Estimated euphotic volume for Afognak Lake was 43.46 10^6 m^3 (Appendix A5). Using the EV model and 800-900 spawners per EV unit resulted in a spawning capacity estimate of 34,800-39,100 adults (Koenings and Kyle 1997).

Euphotic zone depth (EZD) values recorded in 2011 indicated that, on average, the first 8 m of the water column at the sampling stations were photosynthetically active (Appendix A5). Historic mean EZD values were greater, with 9 m of the water column being photosynthetically active (1987-2010; Appendix A5).

General Water Chemistry and Nutrients

Afognak Lake mean pH was 7.35 and ranged from 7.25 in September to 7.49 in August (Table 10;). Mean alkalinity level was 11.6 mg L^{-1} and ranged from 10.3 mg L^{-1} in June to 13.0 mg L^{-1} in May. Mean chl-*a* concentration was 1.19 μg L^{-1} and ranged from 0.96 μg L^{-1} in June, July, and August to 2.29 μg L^{-1} in May (Table 10; Appendix A6). Mean pheo-*a* concentration was 0.62 μg L^{-1} and ranged from 0.27 μg L^{-1} in May to 0.83 μg L^{-1} in June and July. Three different measures of seasonal phosphorus were made (Table 11; Appendix A7). Mean TP concentration was 5.8 μg L^{-1} and ranged from 5.2 μg L^{-1} in September to 6.7 μg L^{-1} in June (Table 11). Mean TFP concentration was 2.5 μg L^{-1} and ranged from 2.1 μg L^{-1} in June to 3.1 μg L^{-1} in May. Mean FRP concentration was 4.7 μg L^{-1} and ranged from 2.3 μg L^{-1} in June to 6.9 μg L^{-1} in May.

Three different measures of seasonal nitrogen were made (Table 11; Appendix A7). Mean TKN concentration was 208.8 μg L^{-1} and ranged from 187.0 μg L^{-1} in May to 235.0 μg L^{-1} in September. Mean NH_{4+} concentration was 17.7 μg L^{-1} and ranged from 9.9 μg L^{-1} in August to 25.9 μg L^{-1} in June. Mean NO_2 + NO_3 concentration was 41.7 μg L^{-1} and ranged from 6.2 μg L^{-1} in August to 72.8 μg L^{-1} in June. Mean TN concentration was 250.5 μg L^{-1} and ranged from 204.2 to 268.9 μg L^{-1}. The overall mean TN to TP ratio, by weight, was 96.1:1 and ranged from 79.3:1 in August to 114.5:1 in September.

Zooplankton

Zooplankton weighted mean density was 91,972 animals m^{-2} in Afognak Lake (Table 12). 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 (62.5% of weighted mean density) than copepods (37.5%). Among the cladocerans, the two most abundant groups were the *Bosmina* (53.3%) and a pooled category called "other cladocerans" (5.9%), which consisted of various unidentified immature cladocerans. Other observed cladoceran genera were *Daphnia* (0.8%) and *Holopedium* (2.5%). Among the copepods, the two most abundant groups were the *Epischura* (15.7%) and the pooled category of "other copepods" (15.4%) which was made up mostly of the genus *Harpaticus* and various unidentified nauplii (larvae) or immature copepods. The other copepod genera included *Cyclops*, usually an important component of the zooplankton community in sockeye salmon rearing lakes (4.2%), and *Diaptomus* (2.1%).

Mean total zooplankton biomass was 86.5 mg m^{-2}, and was mostly comprised (55.0% of mean total biomass) of copepods (Table 12; Appendices 8 and 9). The copepod genus *Epischura* (45.4%) represented most of the biomass, followed by the cladoceran genus *Bosmina* (38.6%). The remaining biomass was composed of *Holopedium* (5.1%), *Daphnia* (1.3%), *Cyclops* (6.5%), *Diaptomus* (3.1%), 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 0.82 mm (Table 12; Appendices A8 and A9). Mean lengths of the remaining zooplankton measured, in decreasing size, were 0.66 mm for the copepods *Diaptomus* and *Cyclops*, 0.58 mm for the cladoceran *Daphnia*, 0.48 mm for the cladoceran *Holopedium*, and 0.28 mm for the cladoceran *Bosmina*.

Phytoplankton

Phytoplankton species composition for 2011 has not been analyzed and will be reported in next year’s report. Phytoplankton species composition for 2010 was not analyzed in time for reporting in last year’s report and therefore is included in this year’s report. In 2010, phytoplankton species composition was predominately composed of Pyrrhophyta, Bacillariophyta, and Chrysophyta (Table 13).

JUVENILE (LAKE REARING) ASSESSMENT

Juvenile Collection

A total of 90 lake rearing juvenile sockeye salmon were captured in Afognak Lake from May to October, 2011. The five shoal collection sites (Figure 3; stations 1–5) provided a total of 38 specimens while 42 juvenile sockeye salmon were collected from the five mid lake collection sites (Figure 3; stations 6–10) and ten juvenile sockeye salmon were captured from unassigned locations. Of the shoal samples, 19 were age-0. and 19 were age-1. Of the mid lake samples, 18 were age-0., 23 were age-1., and one was unreadable. Of the unassigned rearing juvenile sockeye salmon captured, three were age-0. and seven were age-1.

Diet and Bioenergetic Analysis

Fourteen lake rearing juveniles were analyzed for stomach content; of those, eight were age-0. and six were age-1. fish (Table 14). Average monthly stomach fullness increased from May to June for both age groups (Table 14; Figure 13). For age-0. fish, the proportion of insects within the diet decreased over time, while the proportion of zooplankton increased (Table 14; Figure 14). For age-1. fish, the portion of insects and zooplankton remained constant from May to June (Figure 15).

Eighty-one lake rearing juveniles were examined for calorimetric analysis; of those, 37 were age-0., 44 were age-1., and 1 was unreadable. Of the age-0. fish, 19 were from the shoals and 18 were from mid lake. Of the age-1. fish, 19 were from shoals, 23 were from mid lake, and 2 were not assigned a location. Age-0. juveniles from the shoals averaged 5,398 cal/g and those from mid lake averaged 5,163 cal/g. Age-1. juveniles from the shoals averaged 5,133 cal/g and those from mid lake averaged 4,909 cal/g (Table 15).

The average energy content (cal/g) increased over time for both age groups. The average cal/g of age-0. juveniles was greatest in October and age-1. juveniles had the greatest cal/g in July (Table 15 and Figure 16). In all months where data were available age-0. juveniles exhibited a higher average cal/g than age-1. juveniles.

DISCUSSION

SMOLT ASSESSMENT

This was the ninth consecutive year in which the same methods and materials were used to estimate the smolt population emigrating from Afognak Lake (Bear 2011 and 2010). Despite different field personnel, project biologists, and varying environmental conditions, the mean trap efficiency (2003 to 2011; 16.7%) has been greater than the project's target of 15% and ranged between 11.4% to 19.9% annually (Appendices A1 and A2).

Life history-based estimates of smolt emigration abundance are also calculated to compare with mark-recapture estimates. Life history-based estimates have ranged from 44% more (2008) to 35% less (2005) than the mark-recapture estimate (Figure 8). On average, differences between the life history-based and mark-recapture estimates have varied by 11%. In 2011, the life history-based estimate was 41% greater than the mark-recapture estimate.

A time series model was chosen to estimate smolt emigration abundance when the trap was not fished due to high water level. A time series model was employed under similar circumstances in 2005. The time series model generated an estimate close to the life history-based emigration estimate and better fit conventional expectations. Specifically, the time series estimate estimated a larger proportion of age-2. smolt at the start of the migration and estimated a larger number of smolt migrating during the flooding. Typically, smolt (and adults) tend to move in larger numbers during flooding events.

Age-1. smolt emigrating from Afognak Lake in 2011 were under the average weight and length, (2003 to 2010) but had a greater mean condition factor (0.81K; 0.79K; Table 5; Appendix A2). Age-2. smolt were also shorter and weighed less than average (2003 to 2010) and had a greater mean condition factor (0.77K; 0.74K). The number of smolt emigrating from Afognak Lake was correlated with the length of emigrating age-1. smolt (R^2 = 0.53; p = 0.026). This relationship suggests that when age-1. smolt were larger, more smolt tended to emigrate from the lake. This relationship did hold true with age-2. smolt length (R^2 = 0.15; p = 0.31).

JUVENILE ASSESSMENT

Despite repeated attempts, all efforts to collect juvenile sockeye salmon after July 9th were unsuccessful until a single fish was captured on October 6th. Various methods of capture, sampling locations, water depths, tow speeds, and sampling times were attempted during this time. Other species were consistently captured (i.e. coho salmon and stickleback).

Due to the lack of summer and fall samples and the capture of only mid lake samples in May, comparison with last year's samples was limited to the month of June. The average energy content of all juveniles captured, of all ages, was greater in June of 2010 than those from June of 2011. This difference in caloric content between years (2010 and 2011) is corroborated by average juvenile body condition. Further comparison between years reveals that age-1. juveniles captured in 2010 were longer and weighed more than those captured in 2011 (Table 16; Appendix A12). Age-0. juveniles revealed the opposite, with juveniles in 2011 tending to be longer and heavier than those in 2010. This may be an artifact of sampling, but it may indicate that juveniles in 2010 hatched at a later date than those in 2011.

Thus far, juvenile sockeye salmon in Afognak Lake have revealed several trends. Juveniles predominately feed on insects in the spring, steadily increasing their consumption of zooplankton until zooplankton dominates their diet. The condition of juvenile sockeye salmon in Afognak Lake steadily increases over the course of the spring and summer (Figure 12). Stomach fullness of juvenile sockeye salmon increased through the spring of 2011. In contrast, stomach fullness of juvenile sockeye salmon decreased from June through September in 2010 (Table 14 and Appendix A13).

Differences in energy content by age group and sampling location were documented in Chignik and Black Lakes (Finkle 2004). Similar differences in energy content of juvenile sockeye salmon in Afognak Lake are emerging. In Afognak Lake, juvenile fish, regardless of age, captured from the shoals had greater energy content than those captured from the mid lake. In Afognak Lake, age-0. juveniles had a greater energy content than age-1. juveniles, regardless of capture location. Seasonal trends within age classes differ between years, likely a result of differences between sample site locations. Further data collection will lend greater insight into these and other possible trends (Table 14 and Appendix A11).

LIMNOLOGICAL ASSESSMENT

Afognak Lake stratified into a warmer epilimnion and cooler hypolimnion layer during July and August (Figure 11). The stratification of Station 2 was more defined than station 1 and remained stratified into later into the season. Euphotic zone depth (EZD) values recorded in 2011 indicated that, on average, the first 8.2 m of the water column at the sampling stations were photosynthetically active. With an average depth of 8.6 m, this suggests that the majority of Afognak Lake was capable of primary production. Historic mean EZD values were greater than those in 2011, with over 9 m of the water column being photosynthetically active (1987–2010; Appendix A5).

Because historical temperature data for Afognak Lake is limited to those taken on five monthly sampling events, Baer (2011 and 2010) used Big Kitoi Lake temperature data as a surrogate for Afognak Lake temperature. The collection of temperatures every hour with data loggers at station 2 in 2010 and 2011 seems to indicate that temperature regimes in both lakes may be similar. Average monthly temperature data collected in 2011 resulted in slightly lower temperatures in Afognak Lake (Tables 8 and 9; Kitoi, June 11.9°C, July 14.0°C, Aug 14.0°C, and Sept 14.2°C). Average monthly temperatures collected in 2010 also resulted in slightly lower temperatures in Afognak Lake (Kitoi, 11.9°C, 14.0°C, 14.0°C, and 14.2°C; Appendix A14). Temperature data collected from Afognak in May and October were incomplete. Substituting average Afognak Lake temperature data for June through September resulted in no change in the 14 month average in 2010 and a drop of 0.1°C in 2011. In 2011, average water temperatures from Big Kitoi Lake during the 14 months from the time of hatching to smolt emigration was correlated from 2003 to 2011 (R^2 =.57; p = 0.007; Figure 17). Further data logger temperature collection and analysis will be used to replace surrogate temperatures where appropriate.

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 ammonia and NO_3^- + NO_2^- concentrations. The August ammonia concentration was roughly half the seasonal average. The August NO_3^- + NO_2^- concentration was roughly $1/7^{th}$ the season average. Although the phosphorus concentration in 2011 was average, the nitrogen concentration was well above the seasonal average with TKN and ammonia roughly twice the historical average (Appendix A7). The abundance of nitrogen and stable phosphorus concentration coupled with low *chl-a* (primary production) suggests modest rates of photosynthesis, thus reduced uptake of nitrogen and phosphorous.

Typically, ecosystems are dominated by either diatoms or flagellates (Officer and Ryther 1980). In 2010, Afognak Lake was dominated by flagellates with 51% of the biomass consisting of Pyrrhophyta (Phylum; Table 13). Several of the larger lakes in Kodiak, such as Spiridon Lake, are dominated by diatoms (Thomsen 2011). Diatoms are the preferred phytoplankton prey for zooplankton in northern lakes and tend to dominate in oligotrophic systems with sufficient silicon concentration (Officer and Ryther 1980). The mean silicon concentration in Afognak Lake in 2010 reveals that silicon was not limiting. Diatoms are sensitive to temperature and may be inhibited by temperature rather than limited by silicon concentration in Afognak Lake. Phytoplankton species composition for 2011 has not been analyzed yet and will be reported in next year's report. Further collection and assessment of phytoplankton species composition is scheduled through 2013 and should shed more light on factors affecting phytoplankton production in Afognak Lake.

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 (and nutrients) more quickly than standing stocks can be replenished through reproduction. This effect may be further compounded during periods of greater than normal precipitation. The exclusion of large, highly buoyant *Holopedium* in Afognak Lake samples supports this supposition (Appendices A8 and A9).

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* are 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 2011 was at low (oligotrophic) levels. 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 density in 2011, comprising 53.3% of total average zooplankton density. *Bosmina* were very small, and their mean length of 0.28 mm was the lowest recorded (0.31 mm average 1987 to 2011) and below the juvenile sockeye salmon minimum elective feeding threshold of 0.40 mm (Kyle 1992). *Epischura* were much larger, and their mean length of 0.82 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. 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.

ACKNOWLEDGEMENTS

We acknowledge and thank ADF&G personnel Heather Finkle, Dawn Hunt, Matt Foster, Steve Schrof, and Matt Nemeth for their thorough review of this document and Lindsay Gann for publications formatting and assistance. We also acknowledge and thank Rob Baer for allowing us use of content used in his previous versions of this document (Baer 2011 and 2010). Great appreciation is given to the field crew, Natura Richardson, Michael Bach, and Sarah Short for their attention to detail in achieving the project objectives. The U.S. Fish and Wildlife Service, Office of Subsistence Management, provided the final review and evaluation of this report and granted funding support for this project through the Fisheries Resource Monitoring Program, under agreement number 70181AJ034, as study FIS 10-401.

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TABLES AND FIGURES

Table 1.–Estimated abundance of sockeye salmon smolt emigrating from Afognak Lake, 2011.

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	6/5	29,701	511	84	16.6%	178,755	3.11E+08	144,206	213,303
2	6/6	6/13	10,539	200	35	17.9%	58,843	7.71E+07	41,635	76,051
3	6/14	6/20	9,567	462	70	15.3%	62,442	4.62E+07	49,120	75,763
4	6/21	6/27	3,628	169	27	16.5%	21,979	1.40E+07	14,641	29,317
5	6/28	7/6	974	300	36	12.3%	7,930	1.51E+06	5,524	10,336
Total						15.7%	329,949	4.50E+08	288,393	371,502
								SE= 21,201		

Table 2.–Sockeye salmon smolt catch, number of AWL samples collected, mark-recapture releases, recoveries, and trap efficiency estimates from Afognak River by stratum, 2011.

Date	Daily Catch	AWL Samples	Marked Releases[a]	Marked Recoveries	Carlson Trap Efficiency
		Stratum 1			
9-May	12	5	0	0	16.6%
10-May	50	5	0	0	16.6%
11-May	64	5	0	0	16.6%
12-May	21	3	0	0	16.6%
13-May	57	5	0	0	16.6%
14-May	69	5	0	0	16.6%
15-May	165	5	0	0	16.6%
16-May	62	5	0	0	16.6%
17-May	578	0	0	0	16.6%
18-May	649	0	0	0	16.6%
19-May	729	0	0	0	16.6%
20-May	819	0	0	0	16.6%
21-May	921	0	0	0	16.6%
22-May	1,034	0	0	0	16.6%
23-May	1,161	0	0	0	16.6%
24-May	1,304	0	0	0	16.6%
25-May	1,465	0	0	0	16.6%
26-May	1,646	0	0	0	16.6%
27-May	1,849	0	0	0	16.6%
28-May	252	5	0	0	16.6%
29-May	2,078	40	0	0	16.6%
30-May	1,790	40	511	79	16.6%
31-May	2,075	40	0	5	16.6%
1-Jun	3,088	60	0	0	16.6%
2-Jun	1,847	35	0	0	16.6%
3-Jun	1,421	30	0	0	16.6%
4-Jun	1,950	40	0	0	16.6%
5-Jun	2,545	50	0	0	16.6%
Total Stratum 1	29,701	378	511	84	16.6%
		Stratum 2			
6-Jun	1,413	30	200	25	17.9%
7-Jun	1,417	25	0	10	17.9%
8-Jun	1,161	25	0	0	17.9%
9-Jun	961	20	0	0	17.9%
10-Jun	1,112	20	0	0	17.9%
11-Jun	1,224	25	0	0	17.9%
12-Jun	1,502	30	0	0	17.9%
13-Jun	1,749	35	0	0	17.9%
Total Stratum 2	10,539	210	200	35	17.9%

-continued-

Table 2.–Page 2 of 2.

Date	Daily Catch	AWL Samples	Marked Releases[a]	Marked Recoveries	Carlson Trap Efficiency
		Stratum 3			
14-Jun	3,518	70	462	51	15.3%
15-Jun	1,817	35	0	13	15.3%
16-Jun	1,468	30	0	5	15.3%
17-Jun	562	15	0	1	15.3%
18-Jun	884	20	0	0	15.3%
19-Jun	607	10	0	0	15.3%
20-Jun	711	15	0	0	15.3%
Total Stratum 3	9,567	195	462	70	15.3%
		Stratum 4			
21-Jun	1,175	25	169	17	16.5%
22-Jun	647	15	0	8	16.5%
23-Jun	373	10	0	0	16.5%
24-Jun	204	5	0	1	16.5%
25-Jun	579	10	0	1	16.5%
26-Jun	510	10	0	0	16.5%
27-Jun	140	5	0	0	16.5%
Total Stratum 4	3,628	80	169	27	16.5%
		Stratum 5			
28-Jun	287	5	300	18	12.3%
29-Jun	142	5	0	14	12.3%
30-Jun	127	5	0	3	12.3%
1-Jul	51	5	0	1	12.3%
2-Jul	88	5	0	0	12.3%
3-Jul	144	5	0	0	12.3%
4-Jul	79	5	0	0	12.3%
5-Jul	47	0	0	0	12.3%
6-Jul	9	0	0	0	12.3%
Total Stratum 5	974	35	300	36	12.3%
Total Strata 1-5	54,409	898	1,642	252	15.7%

Note: Daily catch from 17 May through 27 May was estimated by time series.

[a] Strata 1-5 trap efficiency release tests were adjusted using the delayed mortality methods.

Table 3.–Theoretical production of Afognak Lake sockeye salmon eggs, emergent fry, and smolt by age from brood years 2008 and 2009 and predicted smolt emigration for 2011.

Production		Brood Year		Estimate 2011
Parameter	Assumption	2008	2009	Age-1. and -2. smolt
Escapement		26,874	31,358	
Females spawning	42% (2008) 51% (2009)[a]	11,287	15,993	
Deposited Eggs	2,529 (2008) 2,591 (2009)[b]	29,244,824	40,445,235	
Emergent Fry	7% egg-to-fry survival[c]	2,047,138	2,831,166	
Smolt	21% fry-to-smolt survival[d]	429,899	594,545	
2011 Smolt Emigration	76% age-1., 24% age-2.[e]	103,176	451,854	555,030

[a] Female sex composition derived from 2008 and 2009 sex data obtained from adult ALS sampling.
[b] Actual fecundity of Afognak Lake sockeye salmon as reported from Pillar Creek Hatchery (2008 and 2009).
[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 2003–2010 smolt age class estimates.

Table 4.–Estimated emigration abundance of Afognak Lake sockeye salmon smolt by time period (stratum) and age class, 2011.

Stratum	Date		Age 1.	Age 2.	Age 3.	Total
1	(5/9-6/5)	Number	107,886	70,868	0	178,754
		Percent	63.2%	36.8%	0.0%	100%
2	(6/6-6/13)	Number	54,311	4,532	0	58,843
		Percent	92.3%	7.7%	0.0%	100%
3	(6/14-6/20)	Number	59,854	2,587	0	62,442
		Percent	95.9%	4.1%	0.0%	100%
4	(6/21-6/27)	Number	21,695	285	0	21,979
		Percent	98.7%	1.3%	0.0%	100%
5	(6/28-7/6)	Number	6,995	935	0	7,930
		Percent	88.2%	11.8%	0.0%	100%
Total		Number	250,741	79,207	0	329,948
		Percent	76.0%	24.0%	0.0%	100.0%

Table 5.–Length, weight, and condition of sockeye salmon smolt from the Afognak River, 2011.

			Weight (g)		Length (mm)		Condition	
Stratum	Dates	Sample Size	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
Age 1.								
1	(5/9-6/5)	273	2.7	0.04	69.5	0.35	0.79	0.005
2	(6/6-6/13)	194	3.0	0.04	71.3	0.29	0.82	0.005
3	(6/14-6/20)	186	3.3	0.03	73.0	0.20	0.83	0.003
4	(6/21-6/27)	76	3.8	0.04	76.6	0.26	0.85	0.005
5	(6/28-7/6)	28	4.2	0.08	78.0	0.57	0.88	0.008
Totals		757	3.1	0.04	71.8	0.30	0.81	0.005
Age 2.								
1	(5/9-6/5)	99	3.7	0.10	78.4	0.64	0.76	0.011
2	(6/6-6/13)	16	3.8	0.12	78.1	0.91	0.80	0.011
3	(6/14-6/20)	8	4.0	0.16	79.0	1.00	0.80	0.010
4	(6/21-6/27)	3	3.8	0.19	77.3	1.67	0.83	0.054
5	(6/28-7/6)	2	4.6	0.40	81.0	2.00	0.86	0.011
Totals		128	3.8	0.11	78.4	0.74	0.77	0.012

Table 6.–Afognak Lake sockeye salmon escapement, harvest, and total run estimates, 1978–2011.

		Harvest[c]			
Year	Escapement	Commercial[a]	Subsistence[b]	Total	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	971	1,334	32,692
2010	52,255	9,755	2,146	11,901	64,156
2011	49,193	13,952	1,770	15,722	64,915

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

[b] Data as of 3/30/2012 from ADF&G subsistence catch database 1978–2011.

[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, 2011.

		Sample		Age							
Stat Week	Dates	Size		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	31.9	36.9	0.7	0.0	9.2	21.3	100.0
			Numbers	0	18	21	0	0	5	12	56
22	May 24 - May 30	0	Percent	0.0	31.9	36.9	0.7	0.0	9.2	21.3	100.0
			Numbers	0	769	888	17	0	222	512	2,408
23	May 31 - Jun 06	141	Percent	0.0	32.3	36.4	0.7	0.0	9.3	21.3	100.0
			Numbers	6	4,683	5,170	95	6	1,345	3,072	14,378
24	Jun 07 - June 13	291	Percent	0.5	38.2	29.7	0.4	0.4	10.2	20.7	100.0
			Numbers	47	3,796	2,937	36	40	1,017	2,059	9,932
25	Jun 14 - Jun 20	136	Percent	1.8	51.2	22.2	0.1	1.2	10.8	12.6	100.0
			Numbers	97	2,612	1,103	3	64	545	614	5,038
26	Jun 21 - Jun 27	147	Percent	5.3	49.9	21.7	0.0	3.3	9.1	10.6	100.0
			Numbers	251	2,721	1,153	0	151	507	581	5,364
27	Jun 28 - Jul 04	35	Percent	12.1	44.5	22.6	0.0	9.4	6.5	4.9	100.0
			Numbers	203	725	371	0	158	105	76	1,638
28	Jul 05 - Jul 11	0	Percent	14.3	42.9	22.9	0.0	11.4	5.7	2.9	100.0
			Numbers	263	788	420	0	210	105	53	1,839
29	Jul 12 - Jul 18	0	Percent	14.3	42.9	22.9	0.0	11.4	5.7	2.9	100.0
			Numbers	51	153	82	0	41	20	10	358
30	Jul - 19 - Jul 25	0	Percent	14.3	42.9	22.9	0.0	11.4	5.7	2.9	100.0
			Numbers	8	23	12	0	6	3	2	53
31	Jul 26 - Aug 01	0	Percent	14.3	42.9	22.9	0.0	11.4	5.7	2.9	100.0
			Numbers	125	375	200	0	100	50	25	874
32	Aug 02 - Aug 08	0	Percent	14.3	42.9	22.9	0.0	11.4	5.7	2.9	100.0
			Numbers	264	792	423	0	211	106	53	1,849
33	Aug - 09 - Aug 15	0	Percent	14.3	42.9	22.9	0.0	11.4	5.7	2.9	100.0
			Numbers	112	337	180	0	90	45	22	786
34	Aug 16 - Aug 22	0	Percent	14.3	42.9	22.9	0.0	11.4	5.7	2.9	100.0
			Numbers	660	1,980	1,056	0	528	264	132	4,620
Totals		750	Percent	4.2	40.2	28.5	0.3	3.3	8.8	14.7	100.0
			Numbers	2,086	19,771	14,015	152	1,606	4,340	7,222	49,193

Table 8.–Afognak Lake sockeye salmon escapement mean length by sex and age class, 2011.

	Age							Total
	1.1	1.2	1.3	1.4	2.1	2.2	2.3	
Males								
Mean Length (mm)	337.7	506.0	554.5	516.0	346.0	506.1	552.0	509.4
Standard Error	5.29	2.54	3.27	20.00	7.35	7.67	3.90	3.91
Range	310-382	428-575	469-598	496-536	308-378	417-587	446-591	308-598
Sample Size	15	114	63	2	10	23	43	270
Females								
Mean Length (mm)	0.0	481.7	533.2	0.0	0.0	484.1	534.8	506.9
Standard Error	0.00	2.01	2.19	0.00	0.00	3.80	2.27	2.97
Range		387-590	449-584			402-546	481-574	387-590
Sample Size	0	194	141	0	0	50	82	467
All[a]								
Mean Length (mm)	337.7	490.3	539.8	516.0	346.0	490.3	540.7	507.4
Standard Error	5.29	1.68	1.93	20.00	7.35	3.74	2.11	1.77
Range	310-382	387-590	449-598	496-536	308-378	402-587	446-591	308-598
Sample Size	15	317	205	2	10	74	126	749

[a] Includes fish not assigned a sex.

Table 9.–Temperatures (°C) logged at station 2, 1 meter, for Afognak Lake, 2011.

				Variation	
Month	Mean	Max	Min	Mean	Max
May	7.3	9.9	6.6	0.4	1.4
June	11.0	13.7	8.5	0.5	1.6
July	15.1	17.1	13.1	0.7	1.5
August	15.8	17.6	14.5	0.4	1.1
September	12.4	14.8	10.7	0.3	0.6
October	10.4	10.7	10.0	0.2	0.3

				Daily Variation	
Season	Mean	Max	Min	Mean	Max
Spring	9.1	13.7	6.6	0.5	1.6
Summer	15.4	17.6	13.1	0.5	1.5
Fall	11.4	14.8	10.0	0.2	0.6

				Daily Variation	
Season	Mean	Max	Min	Mean	Max
(May-Oct)	12.8	17.6	6.6	0.5	1.6

Note: Mean variation is the monthly mean difference between daily maximum and minimum temperatures. Max variation is the monthly maximum difference between daily maximum and minimum temperatures.

Table 10.–General water chemistry and algal pigment concentrations at 1 m water depth, station 1, Afognak Lake 2011.

Date	pH (units)	Alkalinity (mg L^{-1})	Chlorophyll *a* (µg L^{-1})	Pheophytin *a* (µg L^{-1})
9-May	7.35	13.0	2.29	0.27
14-Jun	7.27	10.3	0.96	0.83
12-Jul	7.41	12.5	0.96	0.83
8-Aug	7.49	11.5	0.96	0.61
16-Sep	7.25	10.5	0.80	0.54
Average	7.35	11.6	1.19	0.62
SD	0.10	1.2	0.62	0.23

Table 11.–Seasonal phosphorus and nitrogen concentrations at 1 m water depth, station 1, Afognak Lake, 2011.

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
9-May	3.1	6.9	6.2	17.3	187.0	65.0	252.0	90.0
14-Jun	2.1	2.3	6.7	25.9	196.0	72.8	268.8	88.8
12-Jul	2.6	6.3	5.3	23.1	228.0	30.4	258.4	108.0
8-Aug	2.2	4.6	5.7	9.9	198.0	6.2	204.2	79.3
16-Sep	2.4	3.2	5.2	12.1	235.0	33.9	268.9	114.5
Average	2.5	4.7	5.8	17.7	208.8	41.7	250.5	96.1
SD	0.4	2.0	0.6	6.9	21.3	27.2	26.8	14.6

Table 12.–Seasonal weighted mean zooplankton density, biomass, and size by individual station from Afognak Lake, 2011.

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})	16,423	1,911	4,501	16,518	43,068	446	2,972	7,091	39,353	53,577	92,930
		%	17.7%	2.1%	4.8%	17.8%	46.3%	0.5%	3.2%	7.6%	42.3%	57.7%	100.0%
		biomass (mg m^{-2})	50.1	2.1	5.6	–[a]	31.1	0.6	5.9	–[a]	57.7	37.7	95.4
		%	52.5%	2.2%	5.8%	–[a]	32.6%	0.6%	6.2%	–[a]	60.5%	39.5%	100.0%
		size (mm)	0.86	0.61	0.61	–[a]	0.28	0.57	0.49	–[a]			
2	5	density (no. m^{-2})	12,452	2,017	3,312	11,847	55,032	1,077	1,592	3,684	29,628	61,385	91,013
		%	13.7%	2.2%	3.6%	13.0%	60.5%	1.2%	1.7%	4.0%	32.6%	67.4%	100.0%
		biomass (mg m^{-2})	28.6	3.2	5.7	–[a]	35.6	1.6	2.9	–[a]	37.5	40.2	77.7
		%	36.8%	4.2%	7.4%	–[a]	45.9%	2.0%	3.8%	–[a]	48.3%	51.7%	100.0%
		size (mm)	0.78	0.71	0.70	–[a]	0.27	0.59	0.47	–[a]			
All Data		density (no. m^{-2})	14,438	1,964	3,907	14,183	49,050	762	2,282	5,388	34,491	57,481	91,972
		%	15.7%	2.1%	4.2%	15.4%	53.3%	0.8%	2.5%	5.9%	37.5%	62.5%	100.0%
		biomass (mg m^{-2})	39.3	2.7	5.6	–[a]	33.4	1.1	4.4	–[a]	47.6	38.9	86.5
		%	45.4%	3.1%	6.5%	–[a]	38.6%	1.3%	5.1%	–[a]	55.0%	45.0%	100.0%
		size (mm)	0.82	0.66	0.66	–[a]	0.28	0.58	0.48	–[a]			

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

Table 13.–Summary of Afognak Lake phytoplankton monthly and mean biomass, by phylum, 2010.

		Phylum							
		Chlorophyta (Green Algae)	Chrysophyta Golden-brown Algae	Bacillariophyta (Diatoms)	Cryptophyta (crytomonads)	Pyrrhophyta (Dinoflagellate)	Haptophyta	Cyanobacteria (Blue-green Algae)	Total
Date	Station	Biomass (mg/m^3)	Biomass (mg/m^3)	Biomass (mg/m^3)	Biomass (mg/m^3)	Biomass (mg/m^3)	Biomass (mg/m^3)	Biomass (mg/m^3)	Biomass (mg/m^3)
4-May	1	0.04	12.46	20.27	7.81	10.80	0.00	0.00	51.38
22-Jun	1	0.51	15.42	23.79	4.56	70.07	0.15	0.54	115.04
22-Jul	1	0.38	18.46	53.93	5.83	72.94	0.00	0.00	151.53
24-Aug	1	1.16	10.74	41.98	12.24	113.40	0.00	1.67	181.18
20-Sep	1	1.35	10.40	50.07	8.51	56.52	0.00	6.72	133.57
Mean		0.68	13.50	38.01	7.79	64.74	0.03	1.78	126.54

Table 14.–Stomach fullness and percentage of insects and zooplankton within the stomachs of lake rearing juvenile sockeye salmon from Afognak Lake, 2011.

Sample Dates by Month	Sample Size	Stomach Fullness (%)	Insects (%)	Zooplankton (%)
Age 0.				
May (5/19)	2	47.5	85.0	15.0
June (6/9, 6/10, 6/23, & 6/28)	6	62.5	80.0	20.0
July (7/9)				
August				
September				
October (10/6)				
May - October	8	55.0	82.5	17.5
Age 1.				
May (5/19)	2	30.0	75.0	25.0
June (6/9, 6/10, 6/23, & 6/28)	4	50.0	75.0	25.0
July (7/9)				
August				
September				
October (10/6)				
May - October	6	40.0	75.0	25.0

Table 15.–Calories and condition of lake rearing juvenile sockeye salmon from Afognak Lake, 2011.

Sample Dates by Month	Sample Size	Calorimetry (cal/g) Mean	Calorimetry (cal/g) Standard Error	Condition Mean	Condition Standard Error	Sample Size Station Shoal	Sample Size Station Mid-lake
			Age 0.				
May (5/19)	7	4957.7	36.00	0.87	0.06	0	7
June (6/9, 6/10, 6/23, & 6/28)	29	5341.5	224.54	0.97	0.08	18	11
July (7/9)							
August							
September							
October (10/6)	1	5616.9		0.83		1	0
May - October	37	5305.4	130.3	0.89	0.07	19	18
			Age 1.				
May (5/19)	13	4867.1	195.19	0.87	0.07	0	13
June (6/9, 6/10, 6/23, & 6/28)	29	5152.2	167.77	0.95	0.08	19	10
July (7/9)	2	5573.6	526.91				
August							
September							
October (10/6)							
May - October	44	5197.6	296.6	0.91	0.08	19	23

Note: Shoal = stations 1-5 and mid-water = stations 6-10. July samples were not assigned a location.

Table 16.–Length, weight, and condition of lake rearing juvenile sockeye salmon from Afognak Lake, 2011.

		Weight (g)		Length (mm)		Condition	
Sample Dates by Month	Sample Size	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
Age 0.							
May (5/19)	7	1.9	0.38	60.3	3.99	0.87	0.06
June (6/9, 6/10, 6/23, & 6/28)	29	2.3	0.46	62.1	4.97	0.97	0.08
July (7/9)	0						
August	0						
September	0						
October (10/6)	1	1.8		60.0		0.83	
May - October	37	2.0	0.42	60.8	4.48	0.89	0.07
Age 1.							
May (5/19)	13	2.9	0.68	68.7	6.22	0.87	0.07
June (6/9, 6/10, 6/23, & 6/28)	29	3.2	0.53	69.8	4.81	0.95	0.08
July (7/9)	0						
August	0						
September	0						
October (10/6)	0						
May - October	42	3.0	0.61	69.2	5.52	0.91	0.08

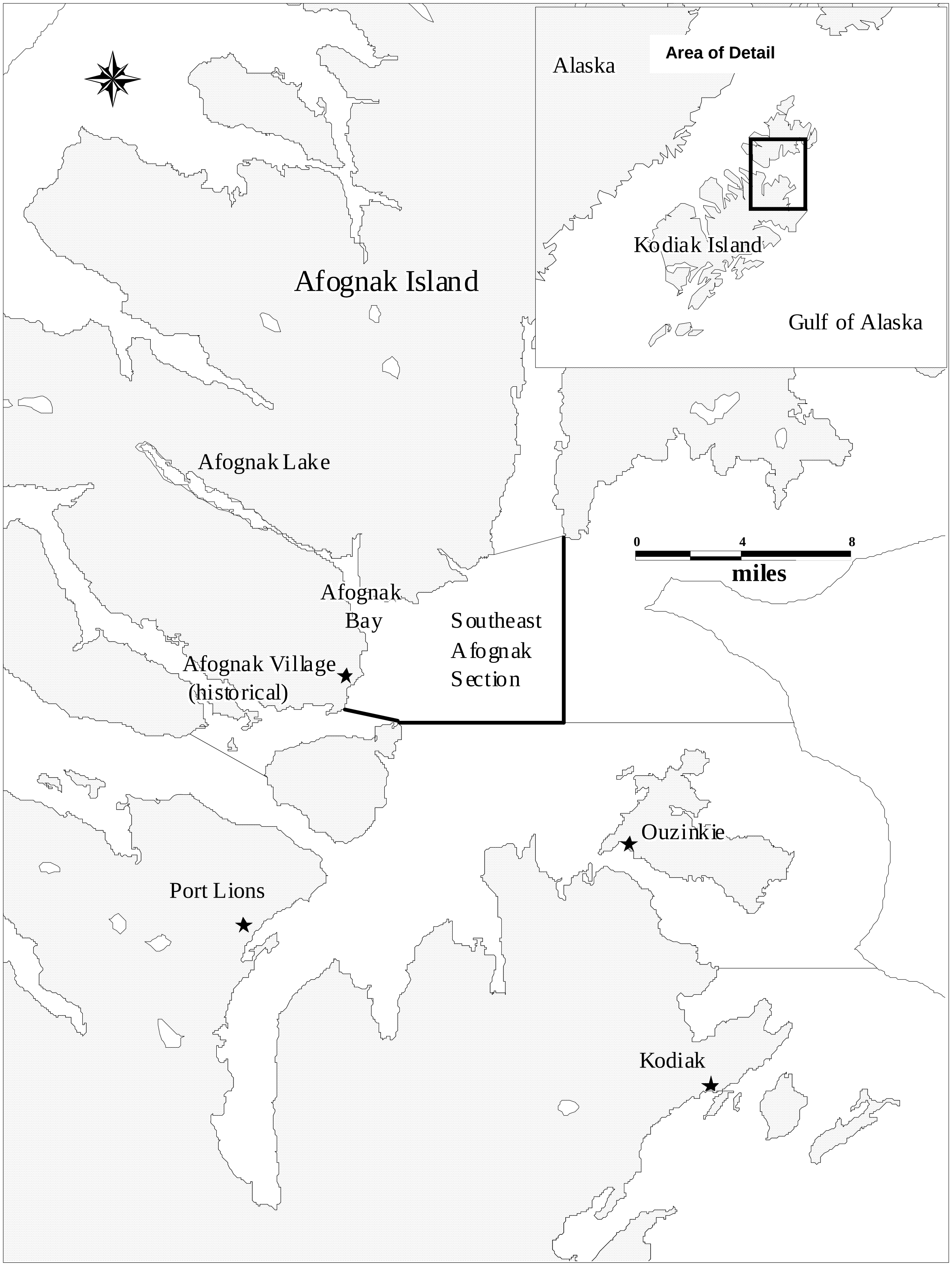


Figure 1.–Map depicting the location of Kodiak City, and the villages of Port Lions, and Ouzinkie and their proximity to the Afognak Lake drainage on Afognak Island.

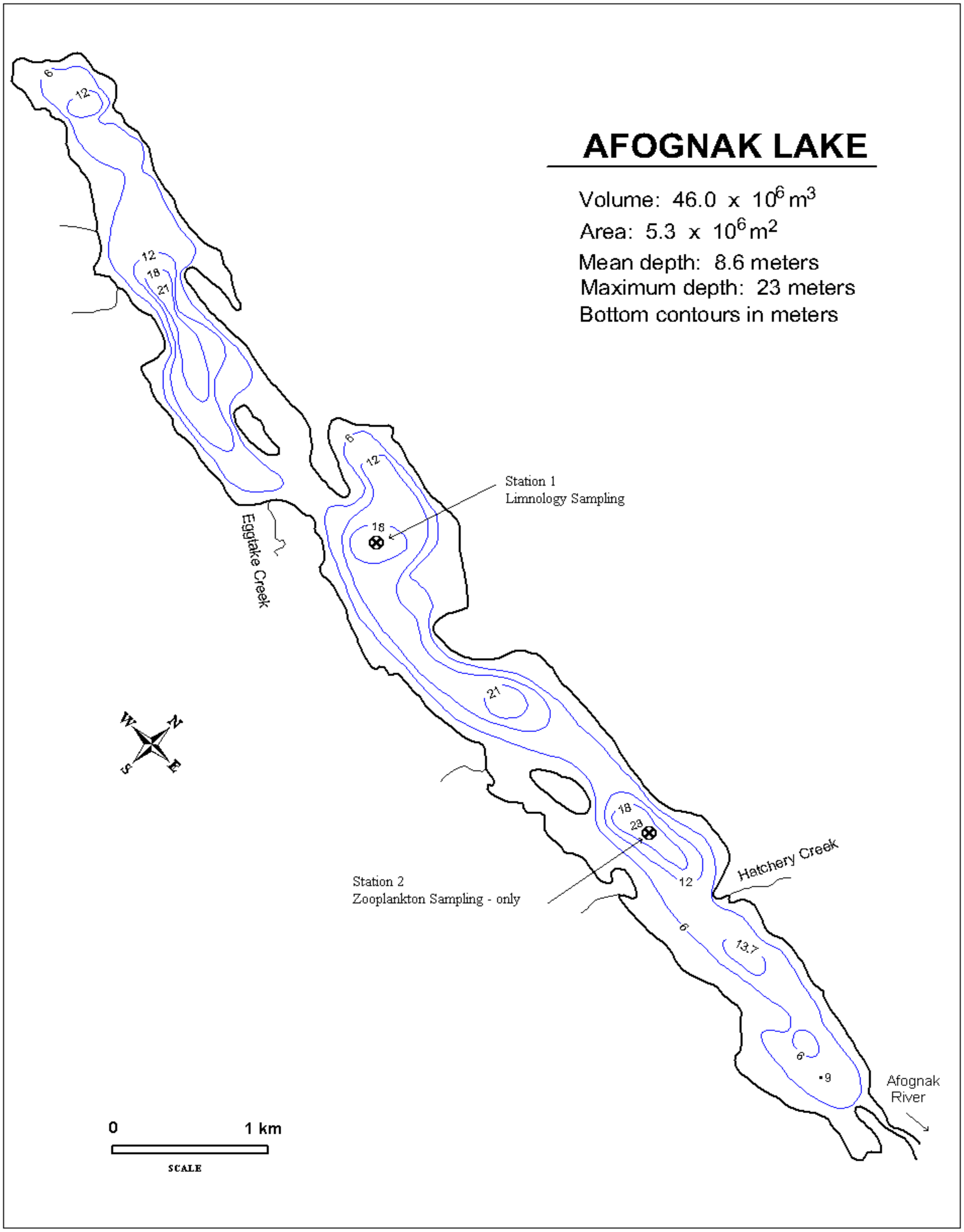


Figure 2.–Bathymetric map showing the limnology and zooplankton sampling stations on Afognak Lake.

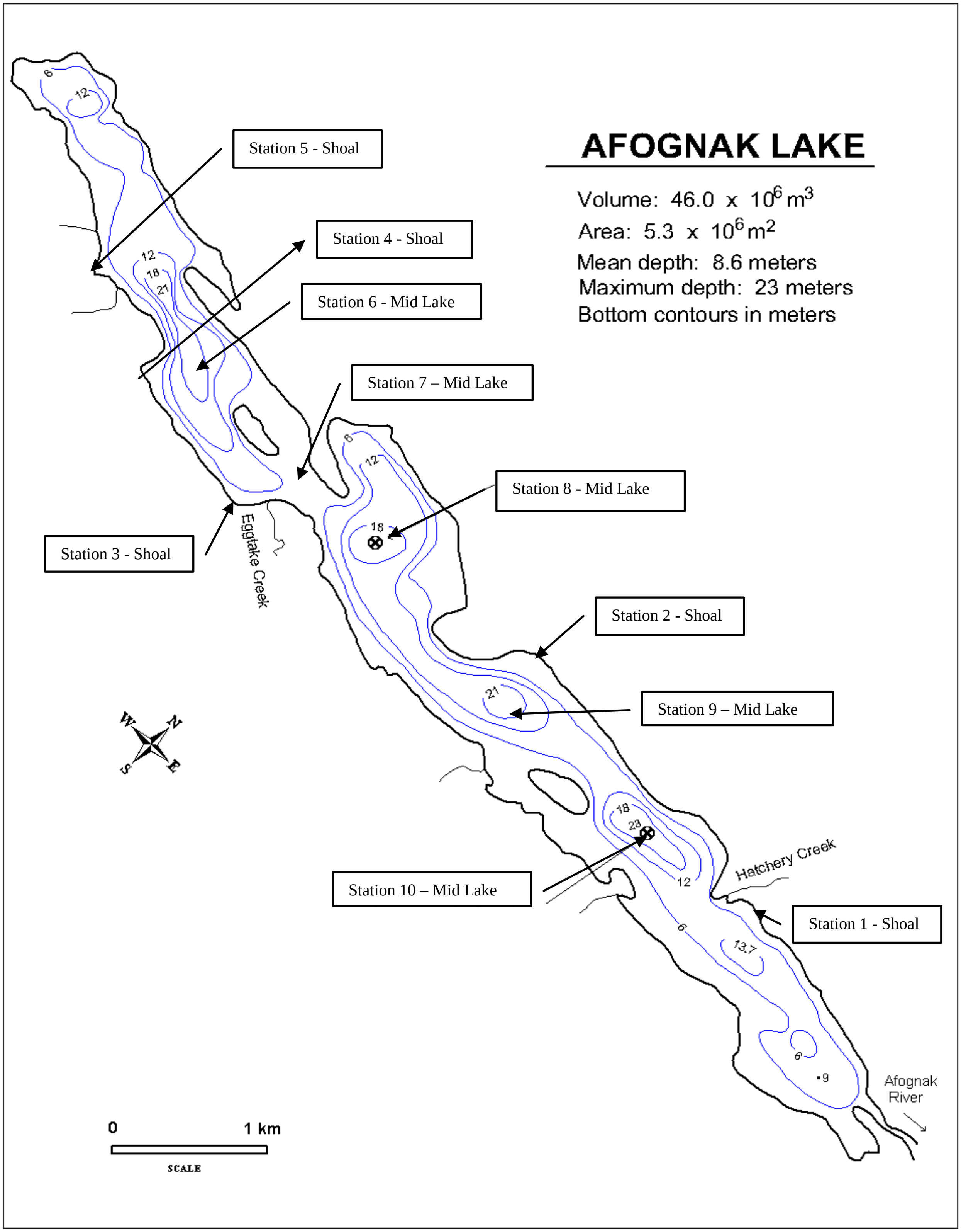
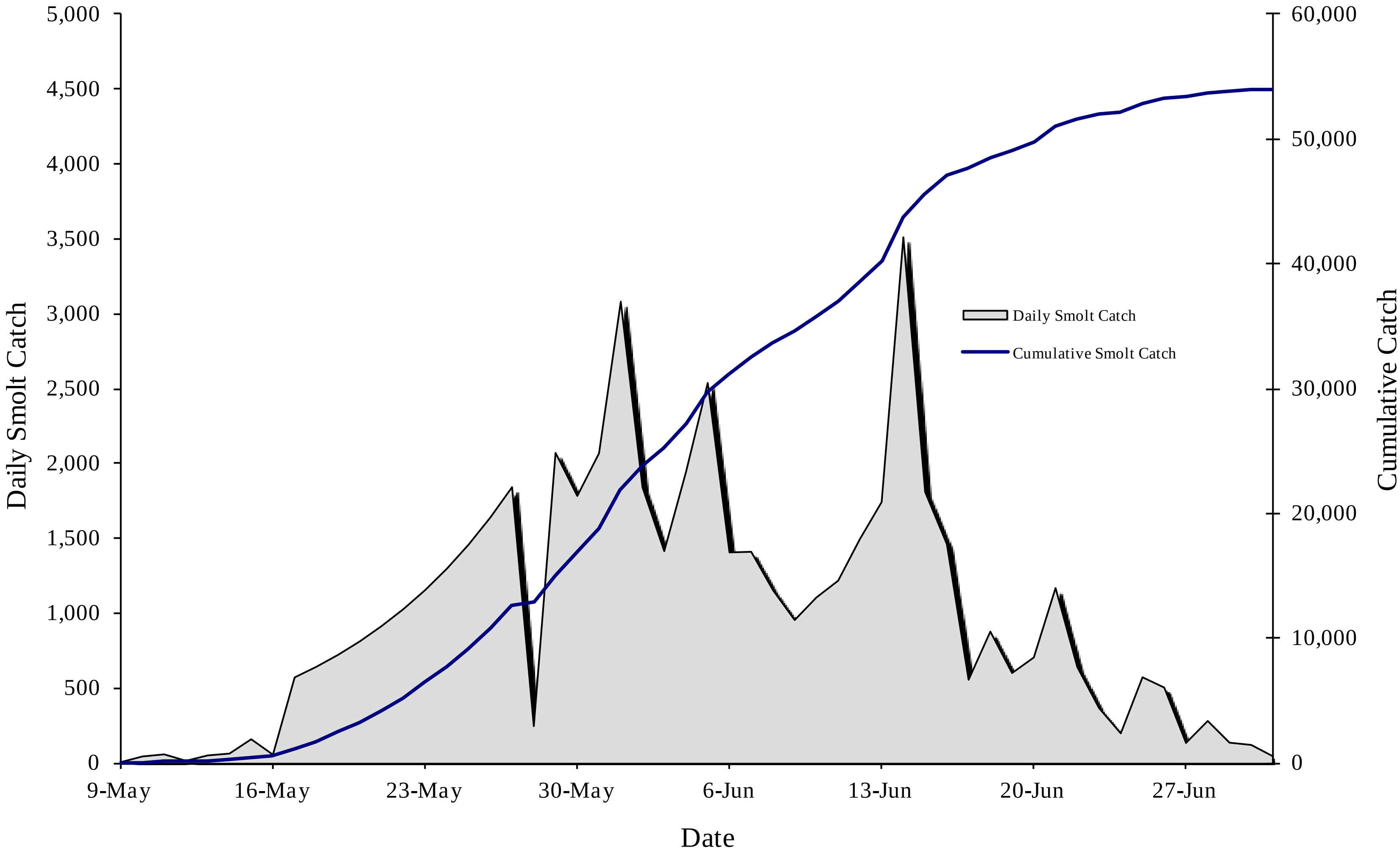


Figure 3.–Bathymetric map showing the juvenile lake sampling stations on Afognak Lake.

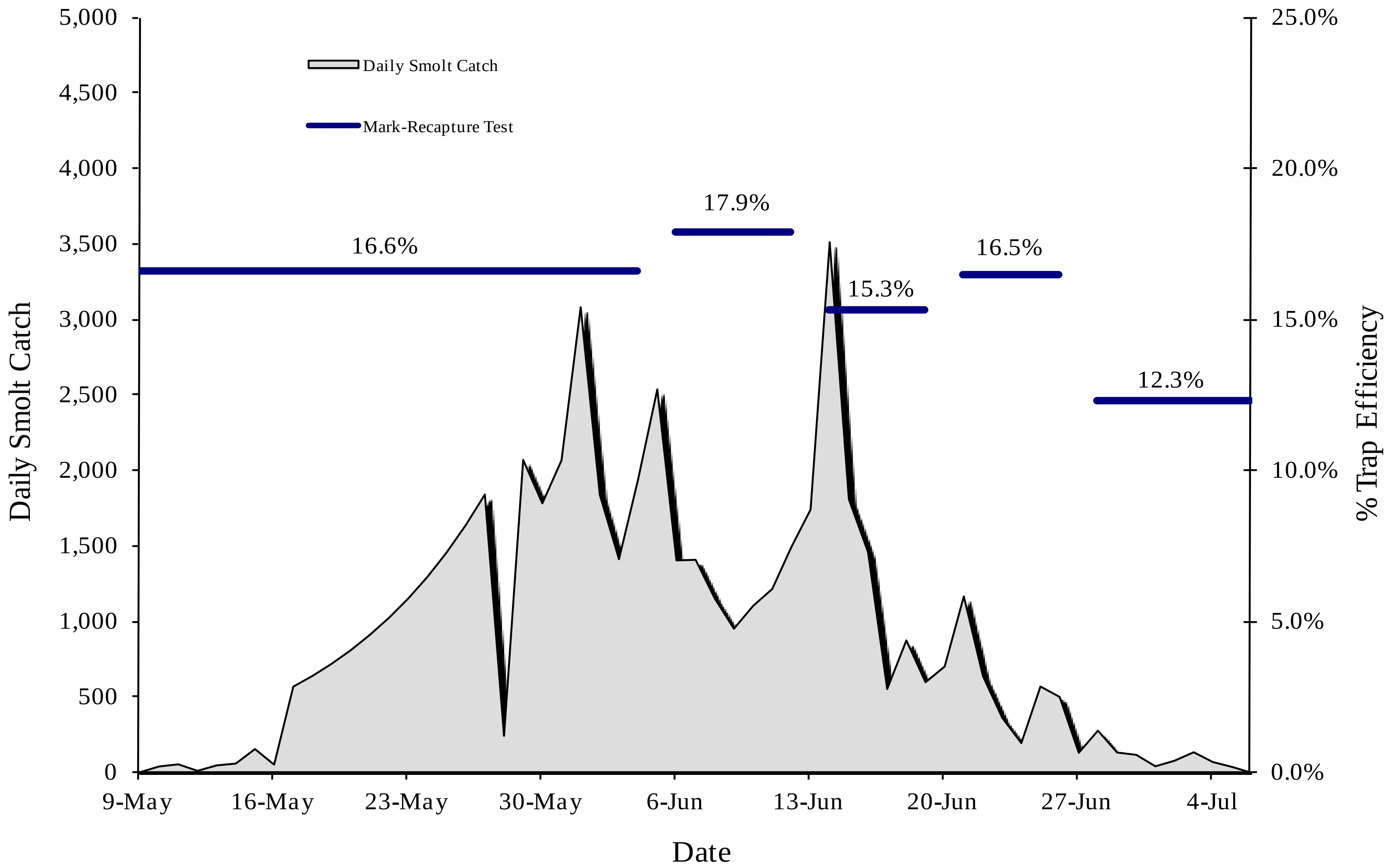
Figure 4.–The downstream juvenile sockeye salmon trapping system, 2011.

Figure 5.–The adult salmon enumeration weir in Afognak River, 2011.



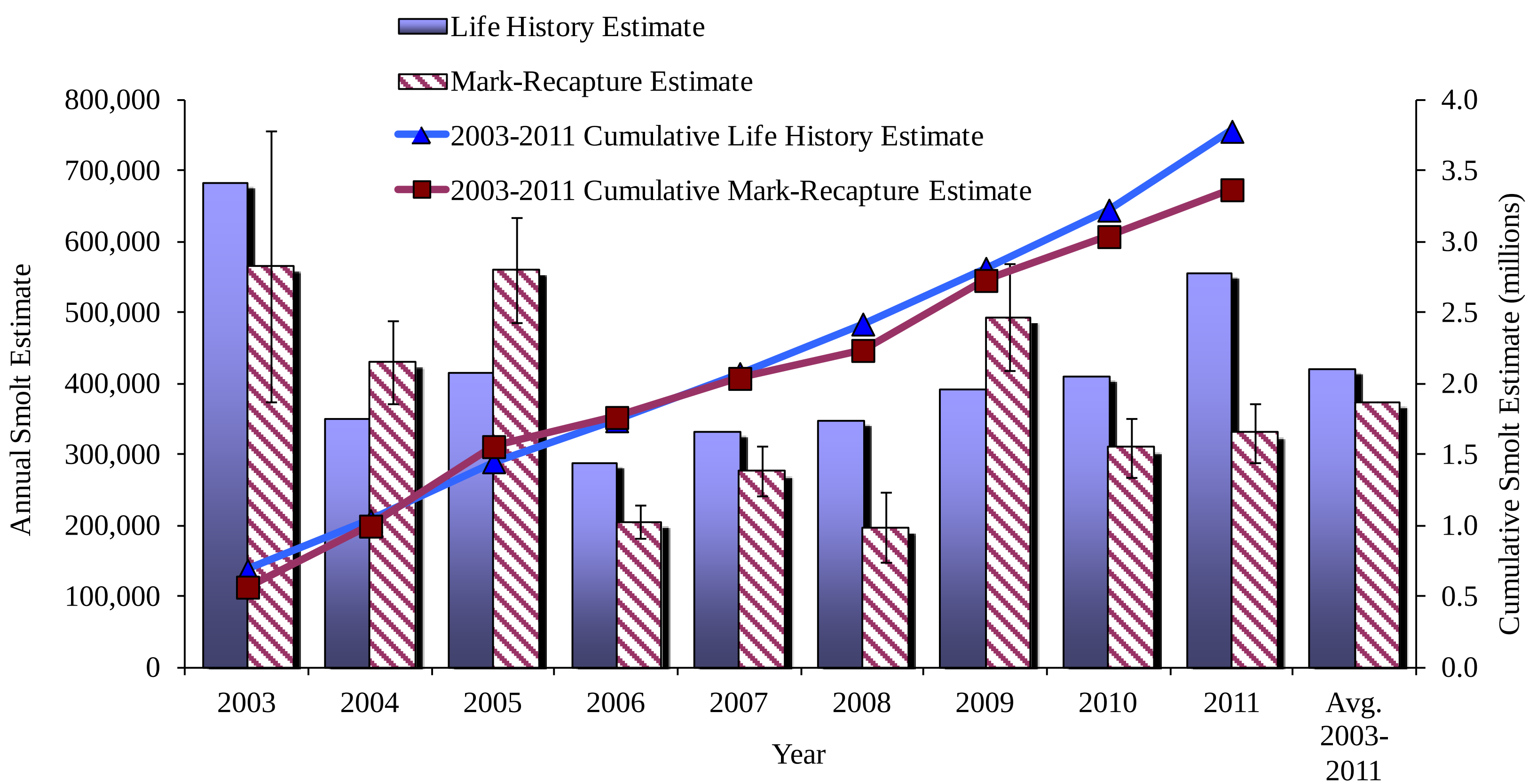
Note: Daily catch from 17 May through 27 May was estimated by time series.

Figure 6.–Daily and cumulative sockeye salmon smolt trap catch from 9 May to 1 July in the Afognak River, 2011.



Note: Daily catch from 17 May through 27 May was estimated by time series.

Figure 7.–Daily sockeye salmon smolt trap catch and trap efficiency estimates by strata from 9 May to 1 July in the Afognak River, 2011.



Note: For mark-recapture estimates, the 95% CI is shown as a vertical line superimposed on each bar.

Figure 8.–Comparison of sockeye salmon smolt abundance estimates from life history and mark-recapture models, 2003–2011.

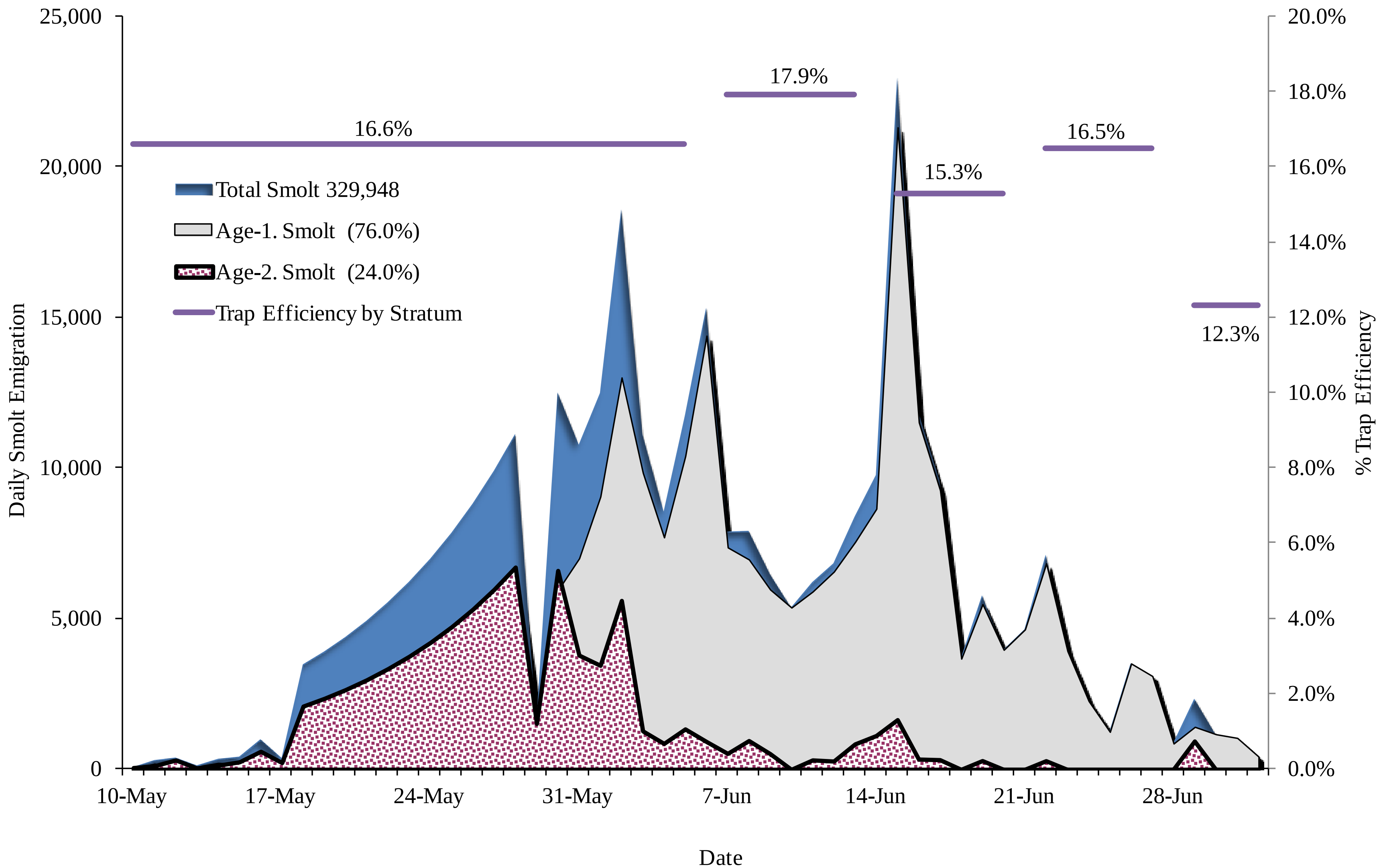


Figure 9.–Afognak Lake sockeye salmon smolt daily emigration estimates by age class, 2011.

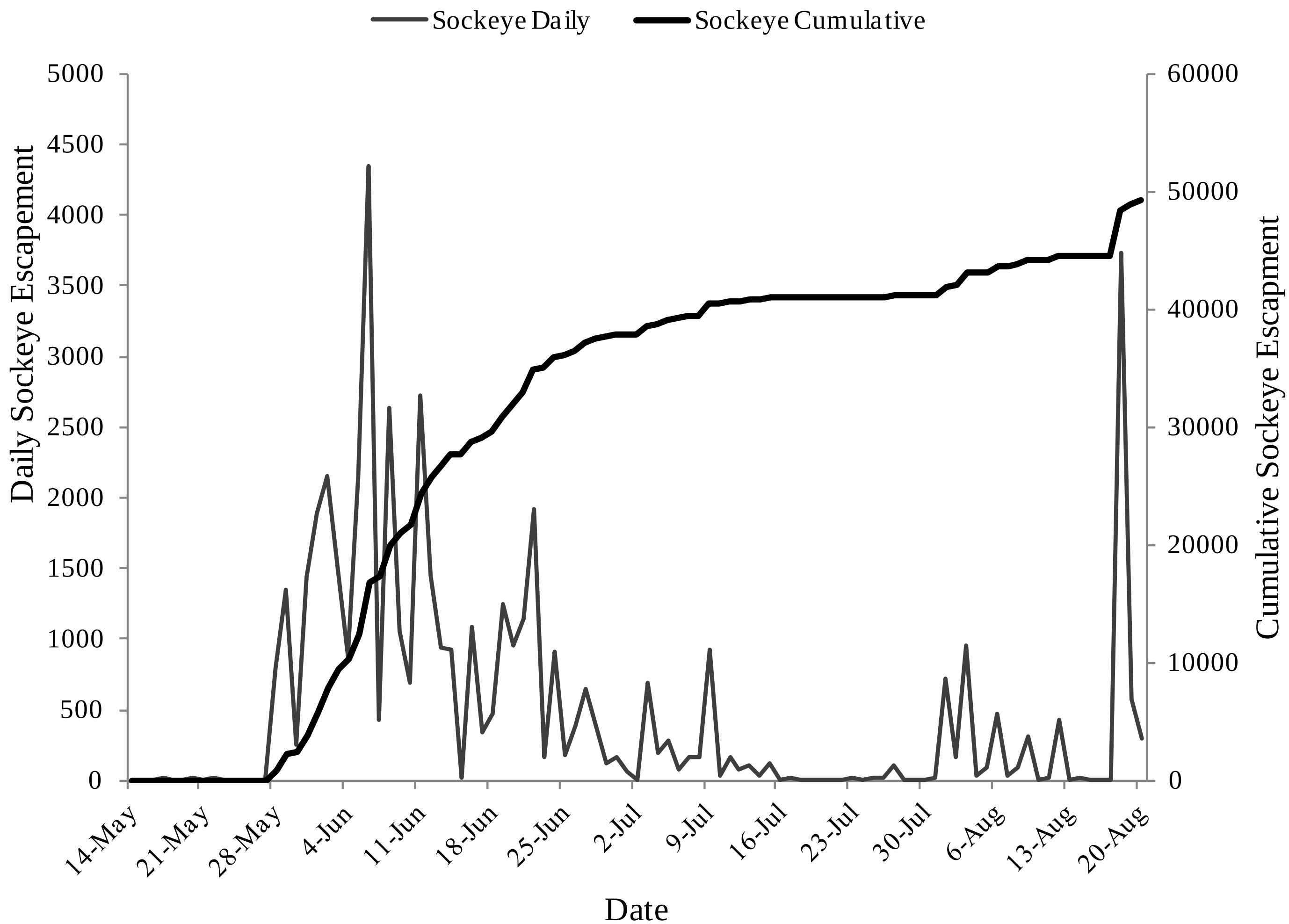


Figure 10.–Afognak Lake adult sockeye salmon daily and cumulative escapement, 2011.

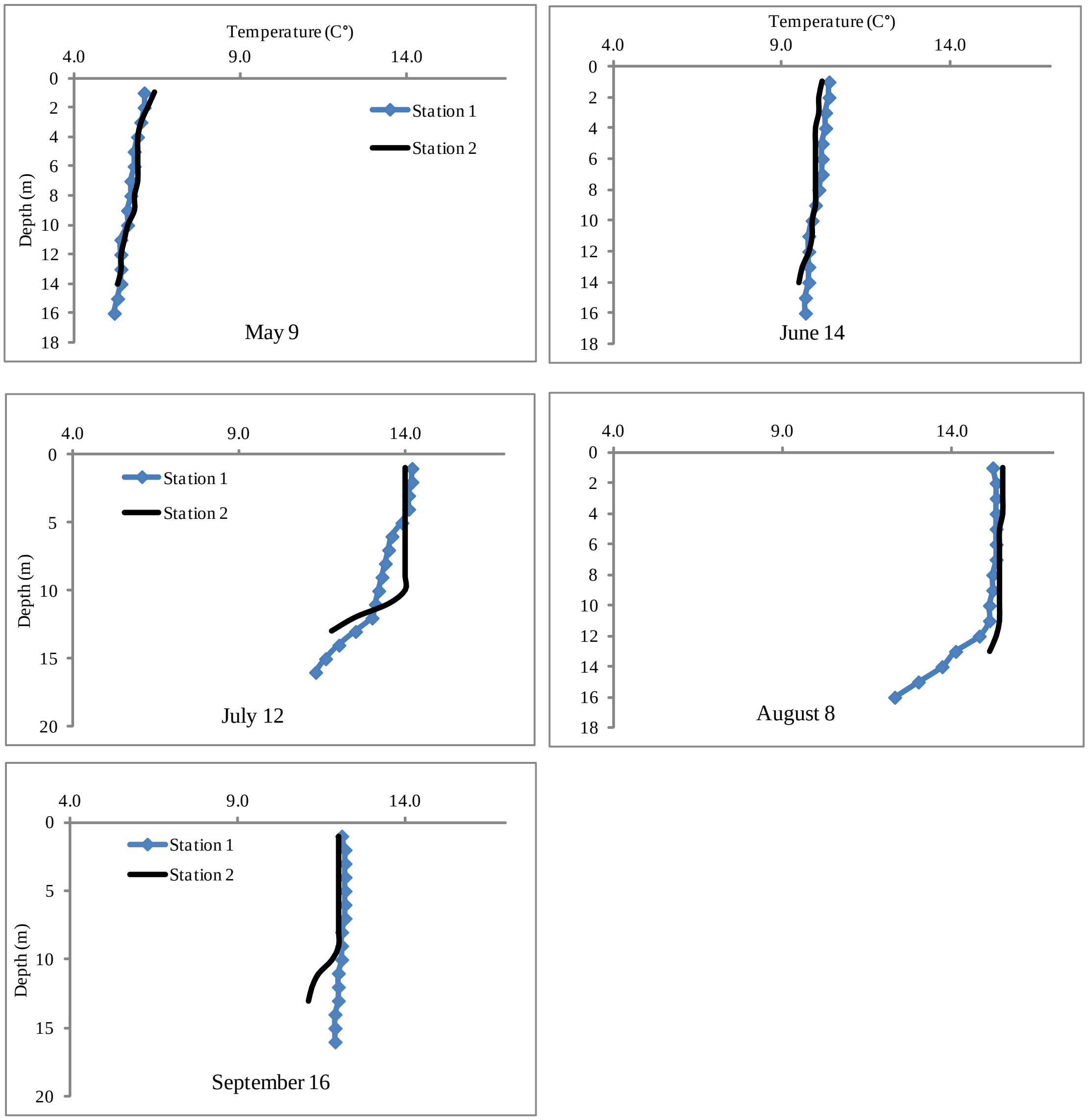


Figure 11.–Temperature profiles by station, by sampling date from Afognak Lake, 2011.

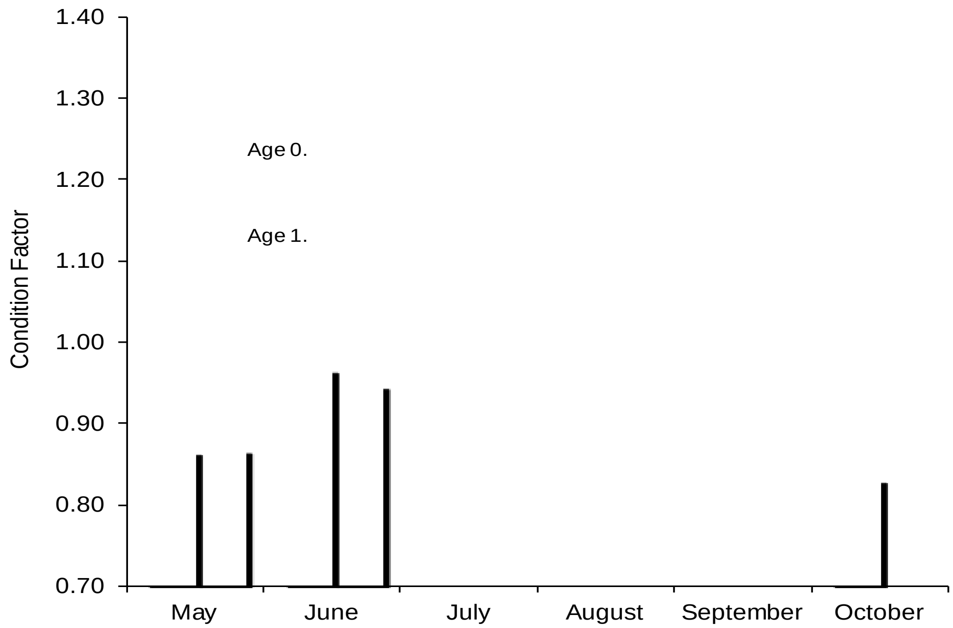


Figure 12.–Condition of lake rearing juvenile sockeye salmon by month from Afognak Lake, 2011.

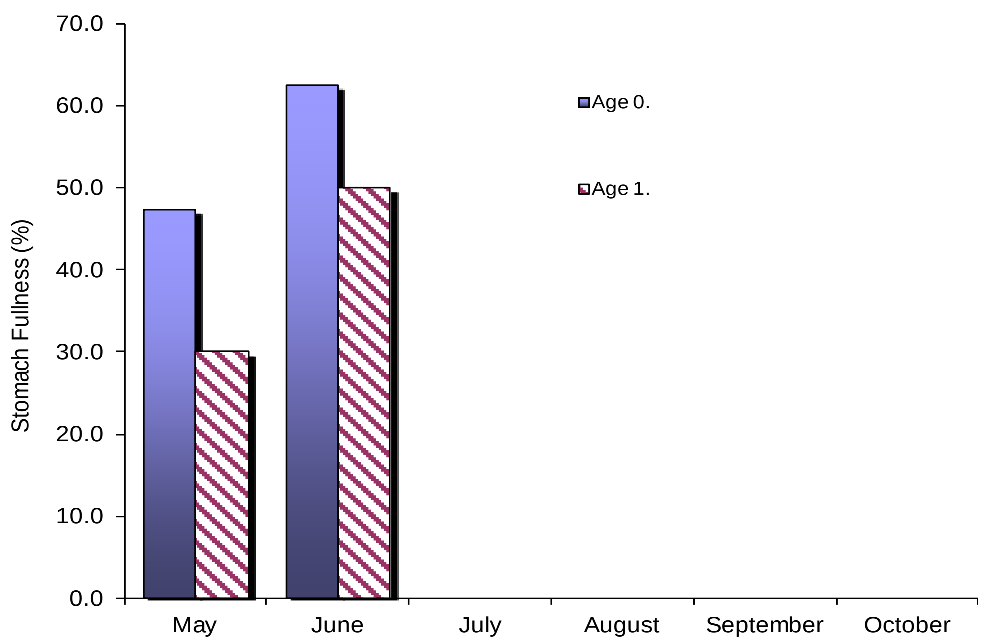


Figure 13.–Stomach fullness of lake rearing juvenile sockeye salmon by month from Afognak Lake, 2011.

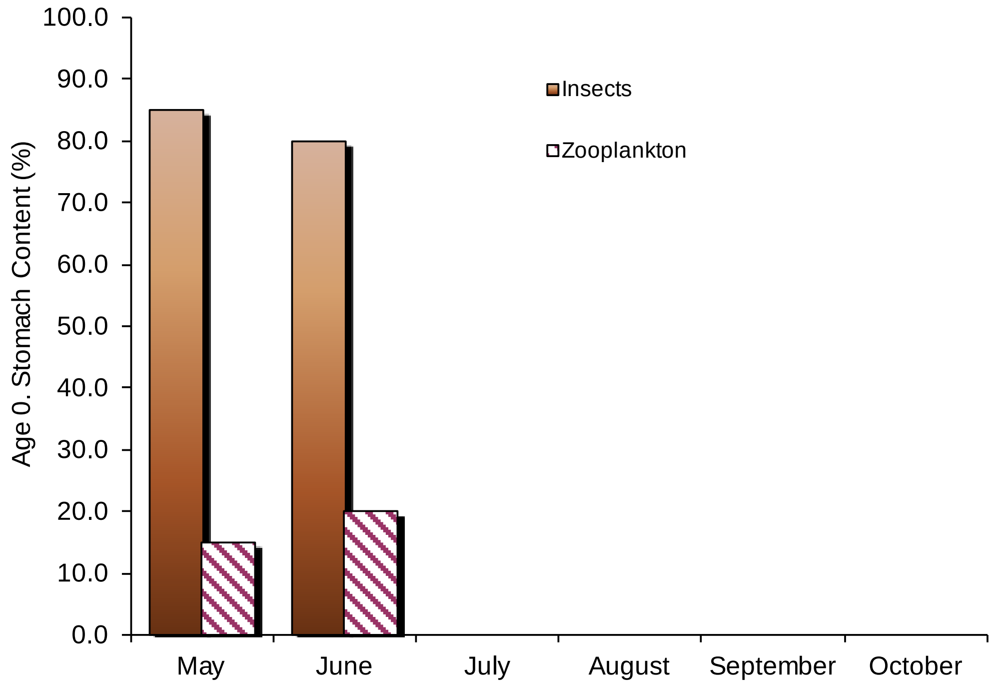


Figure 14.–Percentage of insects and zooplankton within the stomachs of lake rearing age 0. juvenile sockeye salmon from Afognak Lake, 2011.

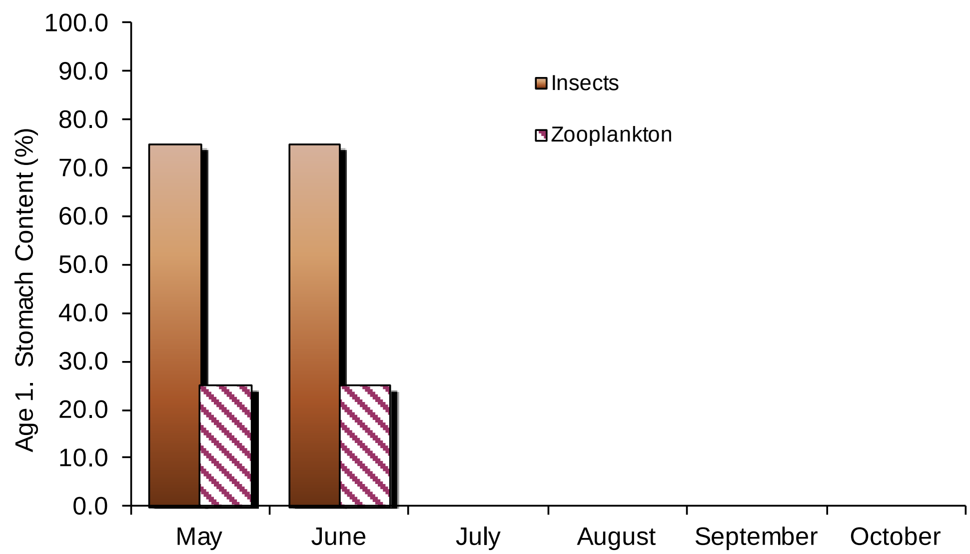


Figure 15.–Percentage of insects and zooplankton within the stomachs of lake rearing age 1. juvenile sockeye salmon from Afognak Lake, 2011.

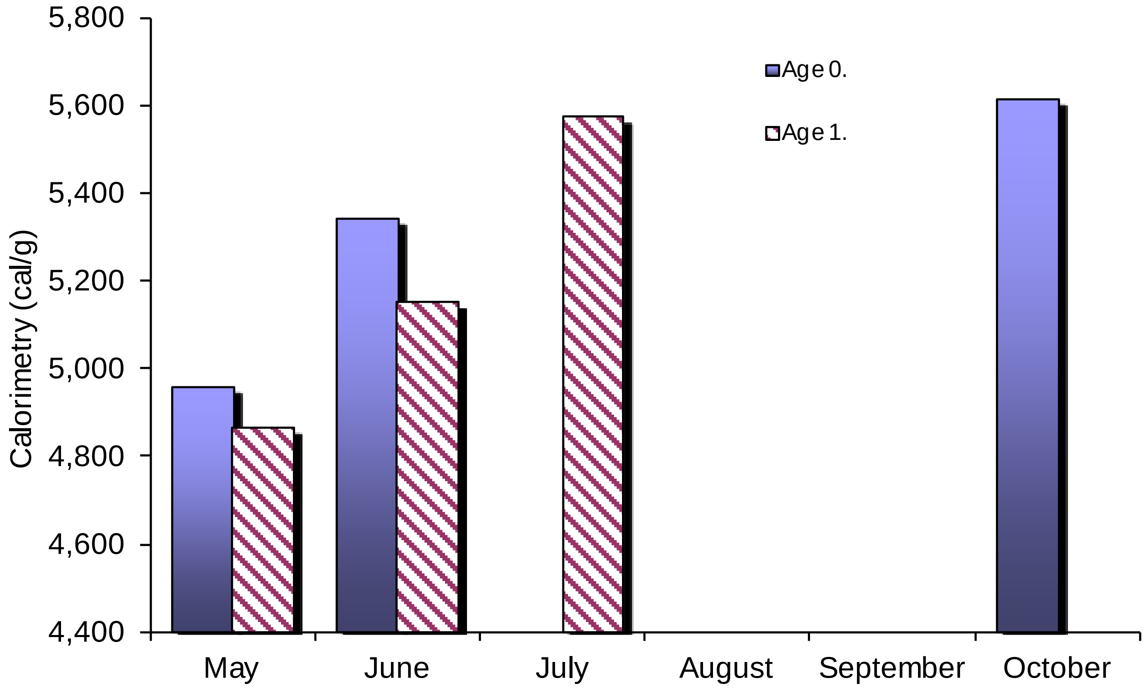


Figure 16.–Calorie content of lake rearing juvenile sockeye salmon by month from Afognak Lake,2011.

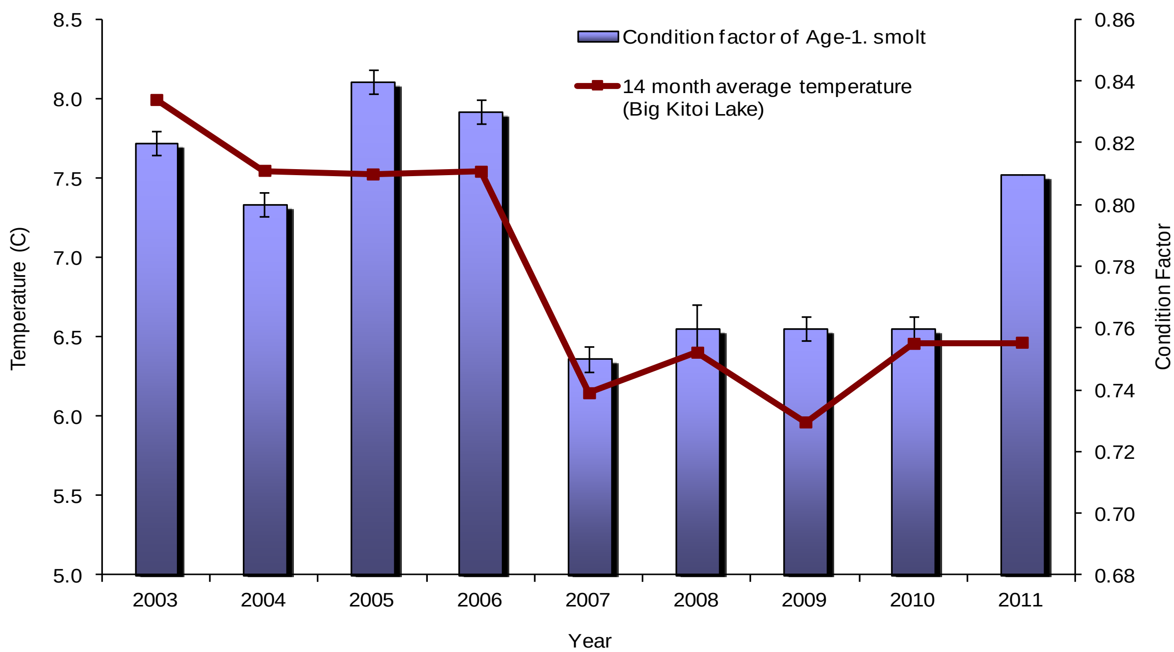


Figure 17.–Seasonal averages of age-1. Sockeye salmon smolt body condition (95% CI) and water temperatures recorded from Big Kitoi Lake, which was used as a surrogate for Afognak Lake water temperature, 2003-2011.

APPENDIX A. SUPPORTING HISTORICAL INFORMATION

Appendix A1.–Population estimates of the sockeye salmon emigrations from Afognak Lake 2003–2011.

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

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Appendix A1.–Page 2 of 4.

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	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 4.

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	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		

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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
						2011				
1	5/9	6/5	29,701	511	84	16.6%	178,755	3.11E+08	144,206	213,303
2	6/6	6/13	10,539	200	35	17.9%	58,843	7.71E+07	41,635	76,051
3	6/14	6/20	9,567	462	70	15.3%	62,442	4.62E+07	49,120	75,763
4	6/21	6/27	3,628	169	27	16.5%	21,979	1.40E+07	14,641	29,317
5	6/28	7/6	974	300	36	12.3%	7,930	1.51E+06	5,524	10,336
Total						15.7%	329,949	4.50E+08	288,393	371,502
								SE= 21,201		
Mean						16.7%				
SD						3.3%				

Appendix A2.–Mean weight, length, and condition factor by age for sockeye salmon smolt sampled at Afognak Lake, 1987–2001, and 2003–2011.

		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
2011	May 9 - July 6	757	3.1	71.8	0.81	128	3.7	78.4	0.77
1987-2010		11,626	3.6	75.3	0.81	119	4.2	80.3	0.80
2003-2010		7,197	3.4	74.4	0.79	1,427	4.1	81.3	0.74
2003-2011		7,954	3.3	74.1	0.79	1,555	4.0	80.9	0.75

Appendix A3.–Temperatures (°C) measured at the 1-meter and near bottom strata in the spring (May-June), summer (July-August), and fall (September-October) for Afognak Lake, 1989–2011.

	Spring		Summer		Fall	
Year	Surface	Bottom	Surface	Bottom	Surface	Bottom
1989	7.8	7.0	16.3	12.8	15.3	13.6
1990	9.4	8.3	14.8	13.6	11.9	11.4
1991	6.2	5.7	15.1	12.5	12.4	12.1
1992	10.0	8.9	15.5	13.9	11.1	11.0
1993	11.9	10.4	17.6	14.5	13.5	12.6
1994	10.8	8.8	15.5	13.5	10.2	9.7
1995	8.8	7.3	15.2	12.8	12.5	11.9
1996	11.5	9.7	15.2	13.9	11.1	10.5
1997	10.3	7.5	17.6	10.6	14.1	12.4
1998	7.9	7.7	14.3	13.0	11.8	11.6
1999	7.0	6.2	15.1	11.4	10.4	10.1
2000	9.7	8.7	15.0	13.1	10.1	10.0
2001	9.1	7.0	17.1	10.2	12.9	12.5
2002	10.0	7.8	16.0	10.8	9.3	9.2
2003	9.7	5.5	18.3	12.9	11.5	11.3
2004	9.2	8.2	15.1	11.7	13.1	12.9
2005	11.8	9.5	18.1	13.5	13.6	13.5
2006	9.2	8.0	15.8	12.5	12.6	12.5
2007	9.2	6.7	15.4	9.5	12.4	12.3
2008	8.6	6.9	14.7	13.3	11.9	11.4
2009	11.1	8.4	17.4	13.9	12.4	12.2
2010	8.7	8.1	15.1	14.2	14.9	14.1
2011	8.2	7.4	14.7	12.6	12.1	11.5
Avg 1989-2010	9.4	7.8	15.9	12.6	12.2	11.8

Appendix A4.–Dissolved oxygen concentrations (mg L-1) measured at the 1-meter and near bottom strata in the spring (May-June), summer (July-August), and fall (September-October) for Afognak Lake, 1989–2011.

	Spring		Summer		Fall	
Year	Surface	Bottom	Surface	Bottom	Surface	Bottom
1989	11.7	11.2	10.3	9.2	13.1	10.3
1990	14.0	11.8	9.5	8.6	9.6	8.9
1991	12.6	11.1	10.9	8.2	10.5	9.4
1992	11.5	10.8	10.1	8.7	10.8	10.8
1993	10.9	9.8	9.5	7.5	10.5	10.1
1994	11.0	9.8	10.0	8.1	11.3	10.9
1995	11.4	11.3	10.0	8.4	10.5	9.8
1996	10.9	10.5	10.0	7.7	11.2	11.1
1997	10.5	10.7	9.0	4.6	10.2	7.6
1998	11.8	11.7	10.2	6.1	10.2	10.0
1999	11.9	11.5	9.6	6.2	10.9	10.4
2000	11.0	9.1	9.7	6.8	10.5	10.1
2001	9.7	9.6	9.3	4.7	9.0	8.1
2002	10.8	9.3	9.8	0.1	10.5	10.1
2003	12.0	11.1	9.2	5.5	18.0	10.3
2004	12.9	11.2	11.5	8.1	10.5	6.4
2005	10.8	10.2	9.5	5.1	9.5	8.7
2006	10.9	10.0	9.8	8.3	10.5	10.0
2007	11.4	10.8	9.2	6.6	10.6	9.9
2008	12.5	10.7	9.5	8.9	9.5	9.9
2009	10.9	10.3	9.0	7.9	8.9	8.6
2010	10.8	9.8	9.7	8.8	10.2	9.8
2011	12.2	11.9	10.2	8.4	10.2	9.9
Avg						
1989-2010	11.4	10.5	9.8	7.0	10.7	9.6

Appendix A5.–Average euphotic zone depth (EZD), light extinction coefficient (K_d), Secchi disk transparency, and euphotic volume (EV) for Afognak Lake, 1989–2011.

Year	EZD (m)	SD	K_d (m^{-1})	SD	Secchi (m)	SD	EV ($10^6 m^3$)	SD
1987	8.43	1.14	NA	NA	4.7	1.4	44.65	6.04
1988	11.91	2.78	NA	NA	4.2	0.5	63.14	14.73
1989	13.30	3.28	-0.38	0.10	4.80	0.41	70.50	17.40
1990	9.05	2.90	-0.56	0.23	3.58	0.60	47.98	15.37
1991	10.05	2.80	-0.50	0.18	2.71	0.53	53.28	14.86
1992	10.24	1.78	-0.45	0.07	2.75	0.87	54.27	9.45
1993	9.32	2.32	-0.51	0.11	3.43	0.51	49.38	12.31
1994	7.40	1.40	-0.60	0.10	3.42	0.38	39.20	7.41
1995	7.40	1.33	-0.61	0.12	2.45	0.56	39.21	7.06
1996	7.96	1.70	-0.58	0.14	3.52	0.40	42.19	9.03
1997	8.48	1.32	-0.56	0.12	3.23	0.75	44.92	7.00
1998	7.49	0.76	-0.59	0.07	3.69	1.23	39.68	4.04
1999	8.81	2.92	-0.57	0.12	3.00	0.61	46.71	15.49
2000	9.82	1.60	-0.46	0.07	3.35	0.63	52.07	8.47
2001	11.04	3.35	-0.46	0.12	3.95	1.14	58.52	17.74
2002	10.52	0.57	-0.41	0.02	4.25	0.54	55.75	3.03
2003	9.80	1.31	-0.44	0.05	4.50	0.23	51.95	6.94
2004	9.13	1.27	-0.47	0.06	4.15	0.58	48.39	6.71
2005	9.80	0.83	-0.45	0.05	4.78	0.64	51.96	4.41
2006	9.02	1.02	-0.49	0.07	4.04	0.71	47.83	5.43
2007	9.47	1.17	-0.49	0.08	4.15	0.71	50.17	6.23
2008	9.07	1.47	-0.51	0.08	4.38	0.38	48.08	7.81
2009	9.37	0.41	-0.48	0.03	4.40	0.72	49.65	2.19
2010	10.03	1.29	-0.44	0.06	4.50	0.80	53.16	6.84
2011	8.20	1.12	-0.55	0.09	4.25	0.59	43.46	5.94
Avg 1987-2010	9.45	1.70	-0.50	0.09	3.83	0.66	50.11	9.00

Note: Values are updated to reflect current database calculations.

Appendix A6.–Summary of seasonal mean water chemistry parameters by station and depth for Afognak Lake, 1987–2011.

Year	Station	Depth (m)	Sp. Conductivity (umhos cm^{-1})	SD	pH (Units)	SD	Alkalinity (mg L^{-1})	SD	Turbidity (NTU)	SD	Color (Pt units)	SD	Calcium (mg L^{-1})	SD	Magnesium (mg L^{-1})	SD	Iron (ug L^{-1})	SD
1987	1	1	47	2.6	6.7	0.2	10.0	0.8	0.8	0.3	8	1.7	3.6	0	0.6	0	76	34.9
	1	17	46	2.8	6.7	0.4	9.5	1.0	0.7	0.4	8	2.6	4	0	1	0	58	17.3
1988	1	1	51	5.9	6.7	0.5	10.8	1.3	1.4	1.0	12	2.4	4.7	ND	1.6	ND	50	13.6
	1	15	50	0.5	6.9	0.2	11.3	1.0	1.1	0.8	10	1.3	ND	ND	ND	ND	81	77.7
	2	1	51	3.7	6.9	0.1	10.5	1.7	1.4	1.1	12	3.2	ND	ND	ND	ND	63	22.3
	2	10	50	2.3	6.8	0.1	10.3	0.6	1.5	1.2	9	2.9	ND	ND	ND	ND	96	52.7
1989	1	1	64	1.9	7.0	0.5	10.6	1.5	2.4	3.5	8	4.4	4.0	0.6	1.1	0.9	44	10.5
	1	15	63	1.0	6.9	0.2	10.2	1.6	0.7	0.1	10	0.7	4.3	0.2	1.2	0.8	51	19.3
	2	1	63	0.8	7.0	0.3	10.4	1.3	0.8	0.2	10	1.1	3.8	0.4	1.5	0.6	53	9.1
	2	12	65	3.3	6.9	0.4	10.6	2.2	0.8	0.2	10	1.4	4.4	0.1	1.4	0.3	91	39.1
1990	1	1	41	1.7	6.8	0.1	6.3	0.5	0.8	0.4	14	3.4	2.9	1.4	0.4	0.3	121	24.3
	1	16	41	1.0	6.7	0.2	6.1	0.6	0.7	0.4	11	2.2	3.2	1.8	0.4	0.3	128	38.7
1991	1	1	38	0.8	6.7	0.1	10.4	7.8	0.9	0.3	13	0.8	2.1	0.3	0.8	0.5	210	31.1
	1	14	38	1.0	6.6	0.2	6.9	0.3	0.9	0.2	16	3.9	1.9	0.1	0.8	0.5	190	45.0
1992	1	1	35	1.2	6.6	0.2	5.8	1.0	0.9	0.5	12	3.4	2.5	0.9	0.6	0.3	157	9.3
	1	24	35	0.5	6.3	0.1	4.9	1.0	0.8	0.6	11	1.5	2.5	1.2	0.6	0.3	162	56.9
1993	1	1	37	1.0	6.6	0.1	7.5	2.7	0.5	0.1	7	7.5	2.2	0.4	1.3	1.1	104	34.9
	1	25	39	4.0	6.4	0.4	7.8	2.1	0.5	0.2	10	10.7	2.6	0.9	0.8	0.1	134	52.0
1994	1	1	39	6.5	6.6	0.2	6.2	2.0	1.1	0.8	5	3.2	2.2	0.9	0.6	0.2	141	44.0
	1	2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	1	26	36	0.9	6.3	0.3	6.5	2.5	0.7	0.3	6	4.7	2.2	0.5	0.6	0.2	197	87.7
1995	1	1	60	5.6	6.6	0.2	9.8	1.0	2.0	0.8	11	2.6	3.7	1.4	1.3	0.4	85	45.6
	1	17	60	5.4	6.5	0.2	10.0	1.3	2.3	1.2	9	2.0	3.4	0.5	1.6	0.5	101	33.0
	2	1	58	4.9	6.6	0.2	9.7	1.1	1.9	0.9	11	4.3	3.2	0.3	1.1	0.3	87	55.9
	2	11	58	4.3	6.5	0.2	9.6	1.1	2.0	0.8	10	5.5	3.5	0.4	1.3	0.3	101	53.9
1996	1	1	56	1.5	6.7	0.2	10.5	0.7	1.4	1.0	10	2.5	3.2	0.5	1.3	0.2	54	25.9
	1	18	57	2.7	6.6	0.1	11.2	1.9	1.5	0.7	9	0.5	3.1	0.5	1.1	0.3	72	33.2
	2	1	56	1.4	6.7	0.1	10.7	1.0	1.2	0.6	9	1.3	3.1	0.5	1.1	0.3	54	25.7
	2	11	57	1.1	6.7	0.1	10.7	1.0	1.5	0.6	11	2.6	2.9	0.5	1.5	0.3	89	43.4

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Year	Statio	Depth (m)	Total Phosphorus (ug L^{-1})	SD	Total filterable-P (ug L^{-1})	SD	Filterable reactive-P (ug L^{-1})	SD	Total Kjeldahl Nitrogen (ug L^{-1})	SD	Ammonia (ug L^{-1})	SD	Nitrate +Nitrite (ug L^{-1})	SD	Reactive Silicon (ug L^{-1})	SD	Organic Carbon (ug L^{-1})	SD	Chlorophyll *a* (ug L^{-1})	SD	Phaeophytin *a* (ug L^{-1})	SD
1998	1	1	9.0	1.7	3.3	0.8	1.9	0.0	193	7.7	21	13.9	38	15.9	2387	73.0	152	118.8	0.10	0.04	0.04	0.02
	1	18	7.5	ND	3.7	ND	1.9	ND	182	ND	25	ND	63	ND	2311	ND	36	ND	0.09	ND	0.03	ND
1999	1	1	17.7	18.3	8.6	10.2	6.8	10.0	247	147.2	36	42.6	124	35.2	2390	431.5	261	122.2	2.94	3.19	0.56	0.35
2000	1	1	9.5	4.3	3.1	1.6	1.8	1.6	57	36.6	19	12.5	72	36.1	ND	ND	ND	ND	2.43	1.46	1.10	0.80
2001	1	1	7.8	5.1	6.4	5.2	8.2	6.7	115	22.2	5	3.6	38	32.5	ND	ND	ND	ND	2.37	0.53	0.30	0.20
2002	1	1	6.4	2.3	4.5	3.1	1.5	0.9	131	15.4	5	2.5	27	18.8	ND	ND	ND	ND	1.36	0.14	0.30	0.20
2003	1	1	6.5	3.0	2.2	0.8	2.1	0.8	ND	ND	6	1.8	54	26.9	ND	ND	ND	ND	1.20	0.20	0.50	0.40
2004	1	1	6.2	3.5	4.3	3.2	2.0	0.7	169	103.8	9	2.8	61	31.5	2764	342.8	ND	ND	1.15	0.18	0.28	0.08
	1	18	5.9	2.3	6.2	8.3	3.5	3.5	ND	ND	19	13.2	80	28.4	2914	277.1	ND	ND	0.70	0.35	0.19	0.11
2005	1	1	11.4	4.4	7.6	3.6	3.6	3.1	161	45.6	4	2.0	41	34.8	2701	243.7	ND	ND	1.60	0.68	0.24	0.11
2006	1	1	7.2	4.3	2.2	1.6	2.3	1.1	97	59.6	7	1.7	28	30.8	ND	ND	ND	ND	1.92	0.32	0.50	0.09
2007	1	1	3.6	0.4	1.1	0.3	1.1	0.6	115	32.4	6	0.7	56	39.5	ND	ND	ND	ND	1.47	0.43	0.21	0.08
2008	1	1	3.8	1.1	2.3	1.5	1.6	0.9	113	28.6	6	0.6	65	42.3	ND	ND	ND	ND	1.22	0.66	0.58	0.37
2009	1	1	4.8	1.1	1.3	0.3	1.8	1.0	131	29.7	4	0.8	39	40.0	ND	ND	ND	ND	1.92	0.64	0.63	0.33
2010	1	1	4.4	0.8	2.5	0.4	1.7	0.3	19	15.7	4	0.8	23	32.1	2363	682	ND	ND	1.12	0.16	0.63	0.25
2011	1	1	5.8	0.6	2.5	0.4	4.7	2.0	209	21.3	18	6.9	42	27.2	2440	255	ND	ND	1.19	0.62	0.62	0.23
Averages:																						
Pre-fertilization																						
1987-1989		1	8.0	2.6	4.4	1.8	2.5	0.5	133	14.0	3.6	2.8	79	43.5	2766	321.2	191	42.2	1.10	0.61	0.59	0.21
Fertilization																						
1990-2000		1	7.7	3.1	3.6	2.2	2.9	1.7	156	34.5	12.8	11.8	51	26.5	2581	317.6	199	66.4	1.76	1.12	0.69	0.36
1987-2010		1	7.2	2.9	3.7	2.1	2.7	1.5	139	32.3	8.7	6.8	53	31.7	2629	333.5	197	60.8	1.57	0.78	0.58	0.28
1987-2011		1	7.2	2.8	3.7	2.0	2.8	1.5	142	32.0	9.0	6.8	53	31.5	2621	329.9	197	60.8	1.56	0.77	0.58	0.28
Post-fertilization		1	6.2	2.6	3.4	2.0	2.6	1.6	117	39.2	5.5	1.7	43	32.9	2609	422.9	ND	ND	1.53	0.39	0.42	0.21
2001-2011		1	6.2	2.4	3.4	1.9	2.8	1.6	126	37.4	6.6	2.2	43	32.4	2567	380.9	ND	ND	1.50	0.41	0.44	0.21

Appendix A7.–Summary of seasonal mean nutrient and algal pigment concentrations by station and depth for Afognak Lake, 1987–2011.

Year	Statio	Depth (m)	Total Phosphorus (ug L^{-1})	SD	Total filterable-P (ug L^{-1})	SD	Filterable reactive-P (ug L^{-1})	SD	Total Kjeldahl Nitrogen (ug L^{-1})	SD	Ammonia (ug L^{-1})	SD	Nitrate +Nitrite (ug L^{-1})	SD	Reactive Silicon (ug L^{-1})	SD	Organic Carbon (ug L^{-1})	SD	Chlorophyll *a* (ug L^{-1})	SD	Phaeophytin *a* (ug L^{-1})	SD
1987	1	1	8.8	3.6	3.1	1.5	1.6	0.3	130	5.6	5	2.6	135	57.8	3255	719.8	144	30	0.64	0.21	0.54	0.19
	1	17	6.7	1.0	2.8	0.6	1.4	0.2	116	14.5	13	11.7	148	51.6	3313	706.9	102	26	0.32	0.21	0.41	0.02
1988	1	1	8.1	2.2	4.7	1.9	2.7	0.6	140	18.9	4	2.0	60	36.0	2509	344.9	247	52	1.64	1.02	0.74	0.17
	1	15	7.8	1.2	4.1	0.8	2.6	0.1	124	10.6	7	6.3	67	32.9	2528	200.4	179	27	2.13	3.17	0.99	0.83
	2	1	8.0	2.8	5.7	4.4	3.1	0.8	128	17.6	3	1.9	60	31.3	2602	134.1	183	44	1.58	1.22	0.72	0.33
	2	10	7.9	2.3	3.5	1.6	2.3	0.1	133	9.6	8	5.7	54	13.2	2499	107.6	300	176	2.76	3.50	1.02	0.32
1989	1	1	8.3	2.8	4.2	0.6	2.4	0.4	139	17.8	3	3.4	67	47.0	2714	197.7	ND	ND	0.92	0.39	0.54	0.17
	1	15	6.5	0.7	3.9	0.5	2.5	0.2	134	11.1	9	10.8	77	32.3	2803	150.6	ND	ND	0.65	0.34	0.51	0.26
	2	1	7.1	1.6	4.2	0.7	2.8	0.5	126	10.0	3	4.1	70	45.6	2752	209.4	ND	ND	0.75	0.18	0.41	0.18
	2	12	8.8	4.5	4.8	2.1	2.5	0.3	131	30.4	13	16.0	77	40.9	2813	161.1	ND	ND	0.67	0.20	0.51	0.22
1990	1	1	4.5	1.5	2.9	4.2	3.7	1.7	128	16.5	8	3.0	40	29.1	3250	247.5	145	13.0	0.34	0.19	0.17	0.03
	1	16	5.1	2.3	1.3	1.3	2.8	1.1	118	22.7	10	4.2	65	29.1	3390	154.5	144	30.6	0.21	0.03	0.28	0.07
1991	1	1	5.0	2.8	3.2	0.6	2.3	0.4	151	22.6	11	1.8	57	21.3	2865	108.6	ND	ND	0.31	0.21	0.27	0.07
	1	14	4.6	1.5	6.0	3.5	4.5	3.2	138	12.3	14	5.0	70	23.2	2966	156.3	ND	ND	0.22	0.14	0.22	0.08
1992	1	1	3.8	0.5	4.1	2.5	3.1	2.4	135	13.9	3	1.7	62	26.1	3163	158.9	199	64.1	0.44	0.29	0.28	0.13
	1	24	3.9	1.7	4.0	3.2	2.6	1.7	127	12.8	10	4.1	93	23.1	3182	198.0	163	52.9	0.31	0.25	0.28	0.12
1993	1	1	4.5	0.8	3.7	1.3	2.8	0.5	148	18.5	5	2.2	49	30.4	3132	220.6	147	53.3	1.01	0.31	0.36	0.03
	1	25	4.9	1.3	8.5	11.7	6.8	9.9	136	17.3	19	10.1	98	31.7	3380	244.0	121	47.5	0.52	0.21	0.45	0.14
1994	1	1	5.7	0.7	4.5	3.3	3.6	2.3	160	23.8	3	1.7	40	21.4	2843	122.4	114	33.0	0.56	0.26	0.28	0.08
	1	2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.56	0.34	0.34	0.10
	1	26	5.3	1.1	4.8	3.9	4.2	3.2	160	17.7	15	9.7	74	23.8	3177	285.5	128	52.1	0.36	0.21	0.27	0.09
1995	1	1	8.7	2.7	3.0	1.5	2.0	1.1	168	21.6	9	14.1	66	22.1	1873	735.0	ND	ND	3.92	2.44	1.13	0.62
	1	17	8.1	2.0	1.9	1.1	1.1	0.4	187	47.1	35	44.3	45	35.0	2046	618.4	ND	ND	3.13	1.75	1.10	0.54
	2	1	7.4	2.1	2.1	1.2	1.7	1.0	169	31.0	9	14.0	54	33.2	1942	753.9	ND	ND	4.20	2.90	1.05	0.65
	2	11	7.2	1.7	2.2	2.0	1.6	1.1	157	26.0	16	17.4	52	34.1	2143	805.6	ND	ND	3.27	2.18	1.05	0.62
1996	1	1	9.2	2.6	3.4	0.7	2.8	0.3	161	34.0	18	13.9	40	29.2	2465	297.2	225	80.3	2.39	1.16	0.82	0.38
	1	18	8.2	2.7	2.4	0.7	2.2	0.3	161	56.5	36	37.6	51	27.8	2663	176.1	190	73.1	1.40	0.56	0.81	0.37
	2	1	8.8	2.6	2.7	0.8	2.2	0.4	160	37.3	8	14.6	41	25.9	2466	275.0	226	52.5	1.77	0.50	0.85	0.36
	2	11	8.4	2.8	3.4	1.6	2.9	1.3	147	41.3	29	24.5	50	25.9	2630	220.7	169	55.7	1.07	0.29	0.77	0.31
1997	1	1	7.3	1.9	2.7	1.0	2.6	0.9	155	33.9	14	14.2	22	23.9	2347	354.4	273	63.8	2.56	1.42	1.51	0.66
	1	18	7.2	1.5	2.6	0.5	2.3	0.4	194	68.6	64	53.3	55	14.5	2995	503.5	197	28.8	1.12	0.50	1.08	0.38
	2	1	6.9	1.7	3.6	1.8	3.1	1.5	156	37.8	13	15.8	17	21.8	2435	351.3	252	62.8	1.68	1.25	1.19	0.83
	2	13	6.5	1.4	2.8	1.9	2.3	0.8	148	38.7	21	12.4	30	20.1	2584	433.5	156	50.6	1.33	1.17	1.06	0.76

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Year	Statio	Depth (m)	Total Phosphorus (ug L^{-1})	SD	Total filterable-P (ug L^{-1})	SD	Filterable reactive-P (ug L^{-1})	SD	Total Kjeldahl Nitrogen (ug L^{-1})	SD	Ammonia (ug L^{-1})	SD	Nitrate +Nitrite (ug L^{-1})	SD	Reactive Silicon (ug L^{-1})	SD	Organic Carbon (ug L^{-1})	SD	Chlorophyll *a* (ug L^{-1})	SD	Phaeophytin *a* (ug L^{-1})	SD
1998	1	1	9.0	1.7	3.3	0.8	1.9	0.0	193	7.7	21	13.9	38	15.9	2387	73.0	152	118.8	0.10	0.04	0.04	0.02
	1	18	7.5	ND	3.7	ND	1.9	ND	182	ND	25	ND	63	ND	2311	ND	36	ND	0.09	ND	0.03	ND
1999	1	1	17.7	18.3	8.6	10.2	6.8	10.0	247	147.2	36	42.6	124	35.2	2390	431.5	261	122.2	2.94	3.19	0.56	0.35
2000	1	1	9.5	4.3	3.1	1.6	1.8	1.6	57	36.6	19	12.5	72	36.1	ND	ND	ND	ND	2.43	1.46	1.10	0.80
2001	1	1	7.8	5.1	6.4	5.2	8.2	6.7	115	22.2	5	3.6	38	32.5	ND	ND	ND	ND	2.37	0.53	0.30	0.20
2002	1	1	6.4	2.3	4.5	3.1	1.5	0.9	131	15.4	5	2.5	27	18.8	ND	ND	ND	ND	1.36	0.14	0.30	0.20
2003	1	1	6.5	3.0	2.2	0.8	2.1	0.8	ND	ND	6	1.8	54	26.9	ND	ND	ND	ND	1.20	0.20	0.50	0.40
2004	1	1	6.2	3.5	4.3	3.2	2.0	0.7	169	103.8	9	2.8	61	31.5	2764	342.8	ND	ND	1.15	0.18	0.28	0.08
	1	18	5.9	2.3	6.2	8.3	3.5	3.5	ND	ND	19	13.2	80	28.4	2914	277.1	ND	ND	0.70	0.35	0.19	0.11
2005	1	1	11.4	4.4	7.6	3.6	3.6	3.1	161	45.6	4	2.0	41	34.8	2701	243.7	ND	ND	1.60	0.68	0.24	0.11
2006	1	1	7.2	4.3	2.2	1.6	2.3	1.1	97	59.6	7	1.7	28	30.8	ND	ND	ND	ND	1.92	0.32	0.50	0.09
2007	1	1	3.6	0.4	1.1	0.3	1.1	0.6	115	32.4	6	0.7	56	39.5	ND	ND	ND	ND	1.47	0.43	0.21	0.08
2008	1	1	3.8	1.1	2.3	1.5	1.6	0.9	113	28.6	6	0.6	65	42.3	ND	ND	ND	ND	1.22	0.66	0.58	0.37
2009	1	1	4.8	1.1	1.3	0.3	1.8	1.0	131	29.7	4	0.8	39	40.0	ND	ND	ND	ND	1.92	0.64	0.63	0.33
2010	1	1	4.4	0.8	2.5	0.4	1.7	0.3	19	15.7	4	0.8	23	32.1	2363	682	ND	ND	1.12	0.16	0.63	0.25
2011	1	1	5.8	0.6	2.5	0.4	4.7	2.0	209	21.3	18	6.9	42	27.2	2440	255	ND	ND	1.19	0.62	0.62	0.23
Averages:																						
Pre-fertilization																						
1987-1989		1	8.0	2.6	4.4	1.8	2.5	0.5	133	14.0	3.6	2.8	79	43.5	2766	321.2	191	42.2	1.10	0.61	0.59	0.21
Fertilization																						
1990-2000		1	7.7	3.1	3.6	2.2	2.9	1.7	156	34.5	12.8	11.8	51	26.5	2581	317.6	199	66.4	1.76	1.12	0.69	0.36
All yrs.																						
1987-2010		1	7.2	2.9	3.7	2.1	2.7	1.5	139	32.3	8.7	6.8	53	31.7	2629	333.5	197	60.8	1.57	0.78	0.58	0.28
1987-2011		1	7.2	2.8	3.7	2.0	2.8	1.5	142	32.0	9.0	6.8	53	31.5	2621	329.9	197	60.8	1.56	0.77	0.58	0.28
Post-																						
fertilization		1	6.2	2.6	3.4	2.0	2.6	1.6	117	39.2	5.5	1.7	43	32.9	2609	422.9	ND	ND	1.53	0.39	0.42	0.21
2001-2011		1	6.2	2.4	3.4	1.9	2.8	1.6	126	37.4	6.6	2.2	43	32.4	2567	380.9	ND	ND	1.50	0.41	0.44	0.21

Appendix A8.–Weighted mean zooplankton density, biomass, size by species for station 1, Afognak Lake, 1987–2011.

Station		*Epischura*			*Diaptomus*			*Cyclops*			*Bosmina*			*Daphnia*			*Holopedium*	
1	No.	Density	Biomass	Size	Density	Biomass	Size	Density	Biomass	Size	Density	Biomass	Size	Density	Biomass	Size	Density	Biomass
Year	Samples	(no/m^2)	(mg/m^2)	(mm)	(no/m^2)	(mg/m^2)	(mm)	(no/m^2)	(mg/m^2)	(mm)	(no/m^2)	(mg/m^2)	(mm)	(no/m^2)	(mg/m^2)	(mm)	(no/m^2)	(mg/m^2)
1987	4	28,835	100	0.91	173	1	1.01	4,127	6	0.65	138,370	134	0.33	3,218	4	0.54	2,574	6
1988	4	22,360	77	0.91	0	0	-	3,185	5	0.69	106,462	104	0.33	962	2	0.71	1,228	3
1989	5	16,322	71	0.99	0	0	-	3,663	5	0.66	69,638	59	0.31	1,778	3	0.64	1,347	3
1990	7	15,378	60	0.95	7	0	0.90	9,987	16	0.68	155,051	134	0.31	3,392	5	0.61	4,944	9
1991	6	21,278	102	1.02	265	1	0.79	6,606	12	0.74	208,574	193	0.32	4,089	9	0.72	4,025	8
1992	7	23,468	104	0.99	485	1	0.88	4,807	8	0.68	106,832	108	0.33	5,513	13	0.74	3,306	6
1993	7	33,893	127	0.94	76	0	0.83	5,960	11	0.72	240,817	247	0.34	7,689	14	0.66	3,715	8
1994	8	23,713	66	0.85	1,844	7	0.98	10,231	17	0.69	257,749	256	0.33	9,621	18	0.66	7,271	13
1995	7	16,758	84	1.04	5,596	16	0.87	24,932	39	0.68	212,768	197	0.32	13,740	22	0.62	1,410	2
1996	5	42,112	223	1.06	191	0	0.49	11,614	19	0.69	350,806	378	0.34	16,072	44	0.78	2,909	5
1997	6	14,367	69	1.02	5,520	11	0.75	24,567	41	0.69	81,591	66	0.30	11,720	17	0.58	915	1
1998	4	15,672	62	0.96	1,088	5	1.05	2,070	3	0.67	169,971	144	0.31	10,881	14	0.56	5,441	8
1999	4	18,737	78	0.97	5,945	24	0.97	6,688	12	0.71	133,175	130	0.33	9,449	20	0.68	2,495	5
2000	5	57,643	180	0.88	8,121	44	1.09	10,743	16	0.66	114,297	126	0.35	5,042	9	0.64	1,408	2
2001	5	30,122	66	0.77	2,548	6	0.79	8,121	10	0.61	40,764	33	0.30	1,253	1	0.49	2,638	4
2002	4	8,174	21	0.82	1,009	3	0.92	6,380	7	0.56	38,256	36	0.32	2,935	3	0.51	557	1
2003	4	39,743	73	0.73	3,782	7	0.74	3,185	4	0.62	102,110	85	0.30	1,393	2	0.60	1,194	2
2004	5	23,206	37	0.69	510	1	0.86	6,374	8	0.62	58,598	52	0.31	11,472	16	0.58	2,771	5
2005	5	21,369	59	0.84	1,592	4	0.83	8,238	10	0.60	82,409	65	0.30	4,979	7	0.57	2,027	3
2006	5	29,565	92	0.88	3,450	10	0.85	9,915	20	0.76	76,518	61	0.30	8,408	11	0.56	6,348	11
2007	5	10,913	24	0.78	2,930	9	0.88	7,718	13	0.70	74,257	66	0.31	3,386	5	0.58	1,730	3
2008	5	16,561	45	0.84	823	2	0.83	2,670	3	0.61	66,762	55	0.30	4,231	7	0.62	3,079	6
2009	5	13,402	42	0.88	0	0		1,409	2	0.60	31,539	24	0.29	2,866	4	0.54	1,208	2
2010	5	14,841	48	0.89	212	1	0.82	987	1	0.59	64,830	49	0.29	1,327	2	0.53	1,624	3
2011	5	16,423	50	0.86	1,911	2	0.61	4,501	6	0.61	43,068	31	0.28	446	1	0.57	2,972	6
Pre-fertilization yrs.																		
1987-1989 Avg		22,506	83	0.94	58	0	1.01	3,658	5	0.67	104,823	99	0.32	1,986	3	0.63	1,716	4
Fertilization yrs.																		
1990-2000 Avg		25,729	105	0.97	2,649	10	0.87	10,746	18	0.69	184,694	180	0.33	8,837	17	0.66	3,440	6
1987-2010 Avg		23,268	80	0.90	1,924	6	0.86	7,674	12	0.66	124,256	117	0.31	6,059	10	0.61	2,757	5
1987-2011 Avg		22,994	78	0.90	1,923	6	0.85	7,547	12	0.66	121,008	113	0.31	5,834	10	0.61	2,765	5
Post-fertilization yrs.																		
2001-2010 Avg		20,790	51	0.81	1,686	4	0.84	5,500	8	0.63	63,604	53	0.30	4,225	6	0.56	2,318	4
2001-2011 Avg		20,393	51	0.82	1,706	4	0.81	5,409	8	0.63	61,737	51	0.30	3,881	5	0.56	2,377	4

Appendix A9.–Weighted mean zooplankton density, biomass, size by species for station 2, Afognak Lake, 1988–2011.

Station 2 Year	No. Samples	*Epischura* Density (no/m^2)	*Epischura* Biomass (mg/m^2)	*Epischura* Size (mm)	*Diaptomus* Density (no/m^2)	*Diaptomus* Biomass (mg/m^2)	*Diaptomus* Size (mm)	*Cyclops* Density (no/m^2)	*Cyclops* Biomass (mg/m^2)	*Cyclops* Size (mm)	*Bosmina* Density (no/m^2)	*Bosmina* Biomass (mg/m^2)	*Bosmina* Size (mm)	*Daphnia* Density (no/m^2)	*Daphnia* Biomass (mg/m^2)	*Daphnia* Size (mm)	*Holopedium* Density (no/m^2)	*Holopedium* Biomass (mg/m^2)	*Holopedium* Size (mm)	TOTALS Density (no/m^2)	TOTALS Biomass (mg/m^2)
1988	4	10,656	45	0.98	40	0	1.44	809	1	0.70	108,838	110	0.33	1,405	3	0.65	942	3	0.55	122,690	162
1989	5	10,306	35	0.90	0	0	-	1,261	2	0.66	48,235	40	0.30	420	1	0.63	553	1	0.46	60,775	79
1990	7	12,610	48	0.94	0	0	-	3,460	5	0.66	128,277	108	0.31	2,350	4	0.64	4,026	7	0.47	150,723	172
1991	6	19,285	80	0.97	1,274	4	0.89	4,277	8	0.74	154,341	132	0.31	3,347	6	0.65	5,083	10	0.49	187,607	240
1992	7	8,948	34	0.94	144	1	1.00	1,436	2	0.67	82,879	84	0.33	2,521	5	0.70	1,579	3	0.45	97,507	129
1993	7	19,033	70	0.93	773	1	0.69	3,882	5	0.62	175,106	157	0.32	2,570	5	0.67	3,988	7	0.47	205,352	245
1994	8	11,006	40	0.93	783	3	0.91	2,736	4	0.65	125,352	116	0.32	4,321	7	0.64	2,468	4	0.46	146,666	174
1995	7	12,193	44	0.92	1,168	4	0.94	9,054	11	0.61	111,525	98	0.31	8,902	12	0.58	1,152	1	0.4	143,994	170
1996	5	20,892	99	1.02	255	2	1.17	2,930	6	0.77	219,747	239	0.35	4,331	11	0.76	1,571	2	0.46	249,726	359
1997	6	13,677	57	0.97	3,468	7	0.75	3,822	5	0.64	86,060	63	0.29	9,652	13	0.56	924	1	0.41	117,601	146
1998	0																				
1999	0																				
2000	0																				
2001	0																				
2002	0																				
2003	0																				
2004	5	27,192	44	0.70	32	0	0.95	5,125	8	0.66	34,843	27	0.29	2,187	4	0.62	1,624	3	0.44	71,003	84
2005	5	22,282	60	0.83	0	0	-	2,850	4	0.63	49,992	37	0.29	815	2	0.73	900	1	0.38	76,839	104
2006	5	9,408	14	0.68	510	1	0.78	3,083	5	0.70	44,282	31	0.28	3,571	5	0.59	1,274	2	0.43	62,128	59
2007	5	16,269	63	0.95	1,141	4	0.93	6,693	12	0.71	57,065	49	0.31	934	1	0.55	2,049	4	0.50	84,151	133
2008	5	20,786	51	0.81	1,592	8	1.04	2,484	3	0.59	49,260	38	0.29	786	2	0.67	1,314	2	0.44	76,222	103
2009	5	5,149	11	0.77	106	0	0.70	1,645	2	0.64	16,189	10	0.27	1,380	2	0.51	902	2	0.46	25,371	27
2010	5	4,273	6	0.67	0	0		504	1	0.55	25,653	16	0.26	191	0	0.65	1,205	2	0.41	31,826	24
2011	5	12,452	29	0.78	2,017	3	0.71	3,312	6	0.70	55,032	36	0.27	1,077	2	0.59	1,592	3	0.47	75,482	78
Pre-fertilization yrs.																					
1988-1989 Avg		10,481	40	0.94	20	0	1.44	1,035	2	0.68	78,537	75	0.32	913	2	0.64	748	2	0.51	91,733	121
Fertilization yrs.																					
1990-2000 Avg		14,705	59	0.95	983	3	0.91	3,950	6	0.67	135,411	125	0.32	4,749	8	0.65	2,599	4	0.45	162,397	204
All yrs.																					
1988-2010 Avg		14,351	47	0.88	664	2	0.94	3,297	5	0.66	89,273	80	0.30	2,923	5	0.64	1,856	3	0.45	112,364	142
1988-2011 Avg		14,245	46	0.87	739	2	0.92	3,298	5	0.66	87,371	77	0.30	2,820	5	0.63	1,841	3	0.45	110,315	138
Post-fertilization yrs.																					
2001-2010 Avg		15,051	36	0.77	483	2	0.88	3,198	5	0.64	39,612	30	0.28	1,409	2	0.62	1,324	2	0.44	61,077	76
2001-2011 Avg		14,726	35	0.77	675	2	0.85	3,212	5	0.65	41,540	30	0.28	1,368	2	0.61	1,358	2	0.44	62,878	76

Appendix A10.–Sockeye salmon escapement and adult returns by age for Afognak, 1982–2011.

Brood Year	Escapement	Age Class Returns 0.1	0.2	1.1	0.3	1.2	2.1	0.4	1.3	2.2	3.1	1.4	2.3	3.2	4.1	2.4	3.3	Total Return	R/S
1982	123,055	2	0	17	112	5,504	112	0	13,845	762	0	0	371	0	0	0	0	20,726	0.17
1983	40,049	0	0	337	0	9,828	297	0	10,013	4,627	0	0	1,707	0	0	35	0	26,844	0.67
1984	94,463	0	0	1,588	54	24,634	1,307	0	47,110	22,360	0	339	24,078	0	0	0	0	121,471	1.29
1985	53,563	36	96	272	0	10,583	2,902	0	26,542	10,030	0	0	6,568	0	0	65	0	57,094	1.07
1986	48,328	0	0	8,022	35	54,737	717	0	108,494	4,958	0	428	10,370	0	0	0	0	187,760	3.89
1987	25,994	0	0	773	0	20,889	313	0	25,139	3,198	99	0	9,772	177	0	0	0	60,359	2.32
1988	39,012	0	0	472	0	18,628	8,360	0	23,626	9,607	57	77	9,686	80	0	0	0	70,593	1.81
1989	88,825	0	0	17,807	0	8,321	13,427	0	35,677	10,450	157	253	13,374	0	0	397	0	99,863	1.12
1990	90,666	0	0	12,902	0	30,978	4,194	0	96,927	18,526	0	397	56,869	175	0	0	199	221,167	2.44
1991	86,819	0	280	9,681	277	37,463	1,440	0	96,284	4,507	0	48	22,573	0	0	0	0	172,552	1.99
1992	75,370	0	0	3,925	175	20,223	4,698	0	70,857	3,087	0	365	5,377	0	0	0	0	108,706	1.44
1993	68,782	0	0	35,159	0	40,046	10,200	0	47,921	10,364	222	330	8,915	646	0	0	680	154,484	2.25
1994	79,380	0	0	7,863	0	7,842	6,959	74	12,841	57,821	74	0	52,384	2,531	0	0	205	148,593	1.87
1995	98,609	0	0	18,569	0	52,527	718	0	11,888	4,523	0	0	11,396	0	75	0	0	99,696	1.01
1996	100,266	0	0	1,463	0	1,888	264	0	6,789	925	4,213	0	996	6,818	0	0	3,992	27,348	0.27
1997	129,481	0	30	1,571	0	3,202	1,787	0	6,775	5,147	171	0	8,408	787	0	186	875	28,938	0.22
1998	65,809	0	0	399	0	207	666	0	238	7,296	0	3	4,225	0	0	0	0	13,033	0.20
1999	94,011	0	0	20	0	6,409	67	0	2,996	291	0	0	293	0	0	0	0	10,076	0.11
2000	52,648	0	0	1,173	0	6,971	26	0	18,560	495	0	36	2,199	0	0	0	0	29,460	0.56
2001	23,940	0	0	177	164	2,258	142	0	5,176	608	0	8	1,202	0	0	0	0	9,735	0.41
2002	19,334	0	0	716	20	14,769	0	0	11,665	435	0	0	188	0	0	0	0	27,794	1.44
2003	27,448	0	0	580	0	7,074	71	0	13,806	1,013	0	2	1,021	0	0	0	0	23,567	0.86
2004	15,181	0	0	1,105	0	11,184	86	0	17,838	817	0	64	140	0	0	0	0	31,234	2.06
2005	20,281	0	0	1,191	0	15,097	1,046	0	51,698	328	0	189	8,969	0	0				
2006	21,488	0	0	1,714	0	10,108	127	0	17,406	5,390	0								
2007	20,066	0	0	1,691	0	24,555	1,995												
2008	26,052	0	0	2,591															
2009	30,818	0																	
2010	51,831																		
2011	48,588																		
Averages:																			
Pre-fertilization 1982-1989	64,161	5	12	3,661	25	19,141	3,429	0	36,306	8,249	39	137	9,491	32	0	62	0	80,589	1.54
Fertilization 1990-2000	85,622	0	28	8,430	41	18,887	2,820	7	33,825	10,271	425	107	15,785	996	7	17	541	92,187	1.12
All yrs. 1982-2004	67,001	2	18	5,417	36	17,225	2,554	3	30,913	7,906	217	102	10,961	488	3	30	259	76,134	1.28
Post-fertilization 2001-2004	21,476	0	0	645	46	8,821	75	0	12,121	718	0	19	638	0	0	0	0	23,083	1.19

Note: Escapement reflects egg take removals. Years after 2004 not fully recruited.

Appendix A11.–Calories and condition of lake rearing juvenile sockeye salmon from Afognak Lake, 2010.

Sample Dates by Month		Sample Size	Calorimetric (cal/g) Mean	Calorimetric (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

Appendix A12.–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

Appendix A13.–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 (%) Mean	Stomach Fullness (%) Standard Error	Insects (%) Mean	Insects (%) Standard Error	Zooplankton (%) Mean	Zooplankton (%) Standard Error
			Age 0.					
June	(6/10 & 6/24)	7	93.6	0.00	96.3	0.00	3.7	0.00
July	(7/8, 7/26, & 7/28)	6	69.2	0.00	63.2	0.00	36.8	0.00
August	(8/11, 812, 8/13, 8/26, & 8/27)	25	52.4	0.00	44.8	0.00	55.2	0.00
September	(9/8)	8	50.6	0.00	11.3	0.00	88.8	0.00
June - September		46	60.5	0.00	49.2	0.00	50.8	0.00
			Age 1.					
June	(6/10 & 6/24)	5	90.0	0.00	99.2	0.00	0.57	0.00
July	(7/8, 7/26, & 7/28)	6	75.0	0.00	78.7	0.00	21.33	0.00
August	(8/11, 812, 8/13, 8/26, & 8/27)	10	51.0	0.00	53.9	0.00	46.10	0.00
September	(9/8)	0	na	0.00		0.00		0.00
June - September		23	62.6	0.00	74.2	0.00	25.78	0.00

Appendix A14.–Temperatures (°C) logged at station 2, 1 meter, for Afognak Lake, 2010.

				Daily Variation	
Month	Mean	Max	Min	Mean	Max
May	7.3	9.2	5.9	0.5	1.3
June	11.3	13.5	8.8	0.5	1.6
July	14.0	15.7	12.4	0.5	1.4
August	14.8	16.1	14.0	0.5	1.1
September	14.3	15.7	11.8	0.3	1.0
October	9.9	11.8	8.2	0.3	0.4

				Daily Variation	
Season	Mean	Max	Min	Mean	Max
Spring	9.3	13.5	5.9	0.5	1.6
Summer	14.4	16.1	12.4	0.5	1.4
Fall	12.1	15.7	8.2	0.3	1.0

				Daily Variation	
Season	Mean	Max	Min	Mean	Max
(May-Oct)	12.3	16.1	5.9	0.4	1.6

Note: Mean variation is the monthly mean difference between daily maximum and minimum temperatures. Max variation is the monthly maximum difference between daily maximum and minimum temperatures.