Stock Assessment and Restoration of the Afognak Lake Sockeye Salmon Run

Final Report for Study 04-412

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April 2007

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ABSTRACT

Afognak Lake sockeye salmon Oncorhynchus nerka runs declined substantially in 2001 and subsequent escapements from 2002 to 2004 were well below the escapement goal. Responding to concerns from local subsistence users, the Alaska Department of Fish and Game began investigations of the lake's rearing environment. With successful completion of a one-year mark-recapture feasibility study to estimate smolt abundance in 2003, a three-year study (2004-2006) to continue the smolt abundance estimates and assess rearing and spawning habitats was funded. This report summarizes the fishery and limnological results from the 2004 to 2006 season and compiles all of the available historical data associated with the Afognak Lake system.

During 2006, 43,824 sockeye salmon smolt were captured using a Canadian fan trap operated from 16 May to 29 June. Using mark-recapture techniques, we estimated that 205,153 sockeye salmon smolt (95% C.I. 180,952 – 229,353) emigrated from Afognak Lake. The population was composed of 146,527 age-1. and 58,626 age-2. smolt. Age-1. smolt had a mean weight of 3.0 g, a mean length of 70.8 mm, and a mean condition factor of 0.83. Age-2. smolt had a mean weight of 3.8 g, a mean length of 79.6 mm, and a mean condition factor of 0.75.

Five limnology surveys were conducted in Afognak Lake from May to September, 2006. Seasonal water chemistry and nutrients concentrations were consistent with historical data collected from Afognak Lake. Afognak Lake is considered phosphorus limited. Seasonal zooplankton density averaged 117,614 animals per m^{-2}, and cladocerans comprised 62.4% of the zooplankton sampled. The cladoceran *Bosmina* was the most abundant zooplankter, while *Epischura* was the most abundant copepod.

Rearing conditions within Afognak Lake appear to be stable or improving since lake water chemistry and nutrients were similar to historic levels, and zooplankton abundance did not suggest overgrazing. Favorable rearing conditions were also reflected in the relatively high condition factor of the smolt (>0.75) that enabled most juveniles to emigrate at age-1.

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

Citation: Baer, R.T., S.T. Schrof, and S.G. Honnold. 2007. Stock Assessment and restoration of the Afognak Lake sockeye salmon run. Fisheries Resource Monitoring Program. U.S. Fish and Wildlife Service, Office of Subsistence Management, Fisheries Resource Monitoring Program, 2006 Final Project Report (Project No. 04-412). Alaska Department of Fish and Game, Division of Commercial Fisheries, Kodiak, Alaska.

INTRODUCTION

Afognak Lake sockeye salmon *Oncorhynchus nerka* runs substantially declined in 2001 and subsequent escapements from 2002 through 2004 were well below the established sustainable escapement goal (SEG) range of 40,000 to 60,000 sockeye salmon (Baer et al. 2006; Dinnocenzo et al. 2006; Spalinger 2006). As a result of these poor runs, the commercial sockeye salmon fishery in Afognak Bay was closed in 2001 and commercial fishing remained closed until 2005 when a five day opening occurred and 356 fish were harvested. The sockeye salmon fishery never opened in 2006, although there were six fish harvested in August due to incidental catch. Sport fishing restrictions were also implemented in 2001, and in-season closures and reduced bag limits have occurred each year through 2004. The sport fishery remained open through the 2005 and 2006 seasons. In conjunction with commercial and sport fishing closures, State and Federal managers closed subsistence fishing in early June during the 2002 season, and in-season closures have occurred each year through 2004 in an attempt to achieve the escapement goals for sockeye salmon into Afognak Lake. The subsistence fishery remained open throughout the 2005 and 2006 season with minimal harvests. The 2002 to 2004 subsistence fishing closure was unprecedented in the Kodiak Management Area and has caused subsistence fishing efforts to shift to other systems. Although the closures restricted harvest of sockeye salmon, subsistence salmon fishing has been allowed every year in Afognak Bay for pink *O. gorbuscha* and coho *O. kisutch* salmon starting 1 August.

The Afognak Lake sockeye salmon run has historically provided for the largest subsistence salmon fishery on Afognak Island and the second largest in the Kodiak Archipelago (Baer et al. 2006). Local villagers from Port Lions and Ouzinkie as well as Kodiak area residents have traditionally harvested Afognak Lake bound sockeye salmon. The subsistence fishery is prosecuted within the boundaries of the Alaska Maritime National Wildlife Refuge. Subsistence harvests in Afognak Bay from 1990 to 2006 have ranged from 567 (2004) to 12,412 (1997) sockeye salmon (Table 1). The four smallest annual subsistence harvests have occurred during the past five years (2001-2005).

After Afognak Lake experienced poor runs and fisheries closures in 2002, local subsistence users, represented by the Kodiak-Aleutian Islands Regional Advisory Council, Kodiak Fish and Game Advisory Committee, and Kodiak Tribal Council, contended that a continued closure of the Afognak system would make it more difficult for local residents to harvest sockeye salmon and would shift fishing effort to small sockeye salmon runs in the area and the Buskin River. The Regional Advisory Council, Kodiak Advisory Committee, and Kodiak Tribal Council informed the Alaska Department of Fish and Game (ADF&G) and U.S. Fish and Wildlife Service that the Afognak Lake sockeye salmon run failure constituted an emergency situation for their constituents. In response to this problem, the ADF&G received funding through the Office of Subsistence Management, Fishery Resources Monitoring Program to determine the feasibility of estimating sockeye salmon smolt production from Afognak Lake. This initial feasibility study, conducted 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). The ADF&G had little information on juvenile sockeye salmon during their freshwater life history stage, when sockeye salmon mortality rates are usually greatest (Burgner

1991). Thus, smolt abundance studies are important in that they assess survival during the entire freshwater rearing stage; encompassing egg deposition to subsequent smolt emigration.

In addition to smolt production estimates, ADF&G felt it was important to collect limnology data to determine the smolt production capacity of Afognak Lake. The ADF&G and Kodiak Regional Aquaculture Association (KRAA) had fertilized (1990-2000) and stocked juveniles into (1992, 1994, 1996-1998) Afognak Lake to restore the sockeye salmon run. As part of the evaluation process, limnological data (phosphorus-nitrogen, chlorophyll *a*, and zooplankton) were collected three years prior to, during, and three years after rehabilitation activities. The limnology sampling program was scheduled to end after 2003, unless the ADF&G obtained additional funding to continue collecting limnological data to examine factors that would limit sockeye salmon production in the freshwater rearing environment. Based on the findings from the 2003 feasibility study, the Office of Subsistence Management provided funding for a three-year study (2004-2006) that would continue smolt assessment work, examine rearing and spawning capacity, and estimate the sockeye salmon production potential of Afognak Lake. This report is intended to consolidate historical fishery and limnological data, provide results of the sockeye salmon escapement goal review and production analysis conducted in 2004-2005, and document results from 2006, the third and final year of this project.

Objectives of the Project

1. Consolidate historical fishery and limnology data, perform the appropriate analyses, and write a report summarizing sockeye salmon production in the Afognak Lake system.
2. Estimate the number, age, and average size at age of sockeye salmon smolt emigrating from Afognak Lake from 2004 to 2006.
3. Evaluate the water chemistry, nutrient status, and plankton production of Afognak Lake from 2004 to 2006.
4. Measure the useable spawning habitat available for sockeye salmon in the Afognak Lake drainage.
5. Estimate the rearing and spawning capacity, and calculate potential adult production for sockeye salmon in Afognak Lake upon completion of objectives 1-4.

Background

Federal and State agencies have operated weirs to count salmon on various systems within the Kodiak Management Area since the early 1920s (Spalinger 2006). A weir has been operated on the Afognak River annually since 1978 and a portion of sockeye salmon escapements have been sampled for age, length and sex (ALS) each year since 1985. Catch data have been documented through the ADF&G commercial landing fish ticket system, statewide sport fish surveys since the late 1970s, and return of subsistence fishing permits (Dinnocenzo et al. 2006; Jennings et al. 2006).

From 1988 through 2004 the Afognak Lake sockeye salmon escapement goal range was 40,000 to 60,000 fish (informally used in 1978; Nelson and Lloyd 2001). Escapements in 1987 and 1988 did not reach the lower end of the range, and little commercial fishing effort was directed at this stock through the mid to late 1980s (White et al. 1990). In the mid 1980s, Kodiak Island residents surveyed by the Kodiak Regional Planning Team (KRPT) indicated that sockeye salmon were the preferred species for commercial and subsistence fishers in the area (KRPT

1987). These results, coupled with the declining sockeye salmon production from Afognak Lake, resulted in the system being listed by the KRPT and KRAA as the highest priority sockeye salmon enhancement project on Afognak Island. In 1987, the ADF&G, in cooperation with KRAA, initiated pre-fertilization fisheries and limnological investigations at Afognak Lake (White et al. 1990; Schrof et al. 2000; Honnold and Schrof 2001). Results of these investigations indicated that sockeye salmon production was limited by rearing capacity (White et al. 1990). Nutrient enrichment was recommended and then implemented in 1990 to increase primary and secondary production, which was intended to increase sockeye salmon rearing capacity in the lake.

Adult sockeye salmon from Afognak Lake were screened for disease in 1987 and 1988 as part of an evaluation of the stock as a candidate for an early-run brood source for future KRAA enhancement projects (White et al. 1990; Schrof et al. 2000). The Afognak Lake sockeye salmon stock was selected as a brood stock for barren lake stocking projects on Afognak Island, with the first ones stocked in Little Waterfall, Hidden, and Crescent Lakes in 1992 (McCullough et al. 2000; McCullough et al. 2001; McCullough and Clevenger 2002). Hatchery survivals were higher than anticipated in 1992 and resulted in more fry being available than had been planned. Rather than increasing stocking levels into the barren lakes, which had not been stocked previously, the ADF&G allowed KRAA to stock the excess fry back into Afognak Lake. Although the escapement in 1992 (and from 1989-1991) exceeded the sustainable escapement goal, stocking a fairly small number of juveniles (less than 500,000) was considered acceptable as long as the lake fertilization program continued and zooplankton (primary forage for juvenile sockeye) levels remained stable. Afognak Lake stocking was repeated in 1994, and from 1996-1998 along with continued lake fertilization to alleviate concerns about increasing predation pressure on the zooplankton population by stocking of fry. However, the ADF&G recommended that fry should not be stocked back into Afognak Lake and the back stocking program was discontinued in 1998 (Honnold et al. 1999). The number of sockeye salmon eggs that could be taken from Afognak Lake by KRAA was reduced, and fertilization of Afognak Lake was also discontinued after 2000 (Honnold and Schrof 2001).

Beginning in 2000, the Alaska Board of Fisheries adopted two policies into regulation to ensure that the state's salmon stocks would be conserved, managed and developed using the sustained yield principle. In 2000 the Policy for the Management of Sustainable Salmon Fisheries (5 AAC 39.222) was adopted and in 2001 the Policy for Statewide Salmon Escapement Goals (5 AAC 39.223) was put into regulation.

Two important terms defined in the Policy for the Management of Sustainable Salmon Fisheries are:

> "*Biological escapement goal* (BEG): the escapement that provides the greatest potential for maximum sustained yield (MSY)" and,
>
> "S*ustainable escapement goal* (SEG): a level of escapement, indicated by an index or an escapement estimate, that is known to provide for sustained yield over a 5 to 10 year period, used in situations where a BEG cannot be estimated due to the absence of a stock-specific catch estimate."

In 2004, using these new policies, a team of ADF&G biologists re-evaluated the existing Afognak Lake sockeye salmon escapement goal. They recommended changing it from an SEG of 40,000 to 60,000 sockeye salmon (Nelson and Lloyd 2001) to a BEG of 20,000 to 50,000 sockeye salmon (Nelson et al. 2005). The recommendation was based on analysis of spawner recruit and limnology data, excluding data from years in which the lake was fertilized. In January 2005, the Directors of

Commercial Fisheries and Sport Fish Divisions approved these recommendations. Based on the new BEG, which was not adopted until 2005, escapements during last six years have been just below (2002 and 2004) to just above (2001, 2003, 2005, 2006) the lower end of the new range (Table 1). However, the Policy for Sustainable Salmon Management instructs ADF&G "to maintain evenly distributed salmon escapements within the bounds of the BEG."

Juvenile production studies have been conducted in conjunction with limnological investigations at a number of sockeye salmon systems in the Kodiak archipelago (Kyle et al. 1988; Kyle et al. 1990; White et al. 1990; Kyle and Honnold 1991; Barrett et al. 1993a, b; Honnold and Edmundson 1993; Edmundson et al. 1994a, b; Swanton et al. 1996; Honnold 1997; Coggins 1997; Coggins and Sagalkin 1999; Sagalkin 1999; Schrof et al. 2000; Sagalkin and Honnold 2003). Some of these studies estimated smolt abundance and size by age through trapping and mark-recapture techniques. Several studies also counted the entire smolt emigration by use of a weir and trap. Rearing juveniles in lakes were enumerated using hydroacoustics and trawl surveys. Smolt abundance and size studies provide estimates of overall freshwater survival, covering the time between egg deposition in the gravel and smolt emigration to the ocean.

Prior to 2003, ADF&G efforts to collect juvenile sockeye salmon data from Afognak Lake had met with limited success (Schrof et al. 2000). Estimates of lake rearing juveniles using hydroacoustics proved inaccurate due to the presence of large numbers of sticklebacks, which created difficulties in species identification, and these surveys were discontinued after 1995. Smolt abundance data were collected in 1990 and 1991, but reliable smolt estimates could not obtained due to low trap efficiencies identified during mark-recapture trials, which were probably caused by poor trap design. In 1992, funding for the mark-recapture project was discontinued and only smolt age, weight, and length data collection was continued. Further funding reductions resulted in smolt age, weight, and length data collection being limited to one annual sample after 1995. It was not until 2003 that smolt abundance and age composition estimates again became available with implementation of a feasibility study for a Fishery Resource Monitoring Program project (Honnold and Schrof 2004).

In addition to smolt abundance and size data, additional information on the rearing conditions within Afognak Lake is needed to determine where potential bottlenecks to sockeye salmon production occur. Such work is essential because sockeye salmon mortality rates are highest during the freshwater life history stage (Burgner 1991). A lake's physical parameters (solar illumination, temperature, and dissolved oxygen) greatly affect nutrient cycling (Schlesinger 1991). Lake nutrients, specifically phosphorous and nitrogen, are prerequisites for photosynthesis; and their concentrations can be used to assess the potential for primary production within a system (Spalinger and Bouwens 2003). Chlorophyll *a* levels are indicators of the standing crop of primary producers that provide food for zooplankton, which are prey for sockeye salmon. Estimating zooplankton population attributes is crucial to understanding the progression of a lacustrine food chain. Zooplankton abundance, individual size, and species composition can be regulated from the bottom-up by phytoplankton availability (Stockner and MacIsaac 1996), or from the top-down by predation pressures such as grazing by juvenile sockeye salmon (Kyle 1992). Fortunately, historical limnology data for Afognak Lake exists and includes periods when the sockeye salmon stock was abundant. Comparisons with data collected under current stock conditions could further elucidate potential causes for the decline of sockeye salmon production within Afognak Lake.

Sockeye salmon freshwater production and potential is also limited by the amount and quality of available spawning habitat (Honnold and Edmundson 1993; Willette et al. 1995). White et al. (1990) reported results of a spawning habitat survey conducted sometime during the 1970s at Afognak Lake, but were unable to describe the methods used since they had not been documented. In 2005, spawning habitat surveys were conducted on the streams and tributaries of Afognak Lake (Baer et al. 2006). Estimating available lake shore spawning habitat was attempted, but has proven to be difficult to assess.

Description of Study Area

The Afognak Lake system is located on the southeast side of Afognak Island approximately 50 km northwest of the city of Kodiak (Figure 1). Afognak Native Corporation owns the land surrounding the system, but most subsistence fishing occurs in Afognak Bay, which is part of the Alaska Maritime National Wildlife Refuge. Afognak Lake (58^o 07' N, 152^o 55' W) lies about 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 (White et al. 1990; Schrof et al. 2000). The lake has a mean depth of 8.6 m, a maximum depth of 23.0 m, and a lake-water residence time of 0.4 years (Figure 2). Runoff from Afognak Lake flows in an easterly direction into the 3.2 km long Afognak River, which in turn flows into Afognak Bay.

In addition to sockeye salmon, resident fish in the Afognak Lake drainage include pink salmon, coho salmon, rainbow trout (anadromous and non-anadromous) *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 viable spawning populations (White et. al 1990).

METHODS

Smolt Assessment

Trap Deployment and Assembly

An inclined-plane Canadian fan trap (Ginetz 1977; Todd 1994) was installed on 16 May 2006 approximately 32 m upstream from the confluence of the Afognak River and Afognak Bay. The trap was positioned towards the middle of the river, where water velocity was great enough to make it difficult for smolt to avoidance capture (Figure 3). A live box (1.2 m x 1.2 m x 0.5 m) was attached to the cod end of the trap, and the entire trapping device was suspended from a cable attached to a come-along. The trap was secured to an aluminum pipe frame, which allowed vertical trap position to be adjusted in response to water level fluctuations. Perforated (3.2 mm) aluminum sheeting (1.2 m x 2.4 m) supported by a Rackmaster®[1] pipe frame was placed at the entrance of the trap in a "V" configuration to divert smolt into the live box. Trapping ceased, and the trap was removed from the river, on 29 June, after smolt abundance declined and the number captured was

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

less than 100 per day for three consecutive days. Detailed methods for trap installation, operation, and maintenance are described in ADF&G (2006).

Smolt Enumeration

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

Age, Weight, and Length Sampling

A total of 200 sockeye salmon smolt were sampled each statistical week to obtain age, weight, and length data. To reach the weekly total, daily samples of 40 sockeye salmon smolt were collected for five days within each statistical week. Smolt were collected throughout the night and held in the in-stream live box. The number of smolt collected each hour was proportional to emigration abundance. Forty smolt were randomly collected from those retained in the live box and sampled to obtain daily age, weight, and length data. After sampling, all smolt were released downstream from the trap.

Tricaine methanesulfonate was used to anesthetize smolt prior to sampling. Fork lengths were measured to the nearest 1 mm, and weights were recorded to the nearest 0.1 g. Scales were removed from the preferred area (INPFC 1963) and mounted on a microscope slide for age determination. After sampling, smolt were held in aerated buckets of water until they recovered from the anesthetic, and subsequently released downstream from the trap. Age was estimated from scales viewed with a microfiche reader at 60X magnification, and recorded in European notation (Koo 1962).

Condition factor (Bagenal and Tesch 1978), a quantitative measure of "fatness," was determined for each smolt as:

$$K = \frac{W}{L^3} 10^5 \qquad (1)$$

where,

K	=	smolt condition factor;
W	=	weight in g;
L	=	fork length in mm.

Trap Efficiency and Population Estimates

Mark-recapture experiments were performed to measure smolt trap efficiency (e). Sockeye salmon smolt were collected, marked with Bismark Brown Y dye, and released about once per week as well as when changes were made to the trapping system. Based on smolt studies at

Akalura Lake (Coggins and Sagalkin 1999; Sagalkin and Honnold 2003), we attempted to achieve trap efficiencies between 15 to 20%. To estimate the desired trap efficiency and be within the relative error (r) of 25% in estimating total abundance, we needed to mark and release 300-500 smolt for each experiment (Robson and Regier 1964; Carlson et al. 1998). Once collected, smolt were placed in an aerated 33-gallon trashcan filled with water and transported, in a trailer pulled by an all terrain vehicle, to the release site approximately 1,240 m upstream. At the release site, smolt to be marked were placing in a continuously oxygenated solution of Bismark Brown Y dye (1.9 g of dye to 15 gallons of water) for 30 minutes. These smolt were then transferred to a holding box at the release site. Between 2100-2300 hours, most of the dyed smolt (~400) were randomly selected from the holding box, counted, and released across the width of the stream. The remaining dyed smolt (~100) were counted and left in the holding box for five days to estimate delayed mortality resulting from capture and marking process. Dyed smolt from both groups that displayed unusual behavior (labored breathing, flared gills, side swimming, etc.) were removed from the experiment and released downstream of the trap. The proportion of smolt that died during the five day holding period was used to estimate the actual number marked smolt available for recapture in the experiment (M_h). All dyed smolt recaptured at the trap site were counted and assigned to a capture period and corresponding trap efficiency trial (hereafter referred to as a stratum).

Trap efficiency for each stratum (*h*) was calculated by dividing the total number of dyed smolt recaptured by the number of dyed smolt released within the stratum:

$$e_h = \frac{m_h}{M_h} \tag{2}$$

where,

e_h = trap efficiency or smolt capture probability in stratum *h*;
M_h = number of marked smolt released in stratum *h* and adjusted for estimated delayed mortality;
m_h = number of marked smolt recaptured in stratum *h*.

A modification of the stratified Peterson estimator (Carlson et al. 1998) was used to estimate the number of smolt emigrating within each stratum:

$$\hat{U}_h = \frac{u_h (M_h + 1)}{m_h + 1} \tag{3}$$

where,

U_h = total number of smolt in stratum *h*, excluding marked releases and minus observed mortality;
u_h = number of unmarked smolt recaptured in stratum *h;*

Variance of the smolt abundance estimate was calculated as:

$$v\left(\hat{U}_h\right) = \frac{(M_h + 1)(u_h + m_h + 1)(M_h - m_h)u_h}{(m_h + 1)^2 (m_h + 2)} \tag{4}$$

Smolt age, weight, and length samples for each stratum were used to estimate the number and size of smolt within each age class. The percentage for each age class was multiplied by the smolt estimate in each stratum to determine the number of smolt in each age class within each stratum. Each age class of smolt in each stratum was summed to provide a total estimate by age, and total estimates by age were summed to provide an estimate of the total smolt emigration.

Life History-Based Population Estimates

We also estimated the number of smolt we expected to emigrate in 2006 based on what we felt were realistic assumptions concerning various life history parameters. Using parent spawning escapements in 2003 and 2004, we assumed a 1:1 sex ratio, an average egg deposition of 2,000 per female (Roelofs 1964), 7% egg-to-fry survival (Drucker 1970 and Koenings and Kyle 1997), and 21% fry-to-smolt survival (Koenings and Kyle 1997).

Limnological Assessment

Lake Sampling Protocol

Five limnological surveys of Afognak Lake were conducted at approximately 4-5 week intervals from May to September, 2006. Two stations, marked with anchored mooring buoys and located with Global Positioning System (GPS) equipment, were sampled from a float-equipped aircraft during each survey (Figure 2). Zooplankton samples were collected at both stations, but water samples were only collected at Station 1. During each survey, water samples for general chemistry and nutrient analysis were collected at a depth of 1 m below the water surface using a 4-L Van Dorn sampler. Each water sample was emptied into a pre-cleaned polyethylene carboy, which was kept cool and dark in the float of the plane until processed at the ADF&G laboratory in Kodiak. Vertical zooplankton hauls were made at each station using a 0.2 m diameter conical net with 153 μm mesh. The net was pulled manually at a constant speed (~0.5 m sec^{-1}) from approximately 2 m off the lake bottom to the surface. The contents from each tow were emptied into a 125-ml polyethylene bottle and preserved in 10% neutralized formalin.

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. Readings were recorded at half-meter intervals to a depth of 5 m, and then at one-meter depth intervals to the lake bottom. A mercury thermometer was used to ensure temperature reading by the meter was working properly. The meter self-calibrates for dissolved oxygen levels, and samplers verified dissolved oxygen levels against the temperature and altitude conversion table on the back of the meter to ensure the meter was working properly. Results were categorized into spring (May-June), summer (July-August), and fall (September-October) sampling periods.

Measurements of photosynthetically active wavelengths were taken with a Protomatic® submersible photometer sensitive to the visible spectrum range (400-700 nanometers). Readings were taken above the water surface, at the water surface, and at half-meter intervals below the water surface until reaching a depth of 5 m, and then at one-meter intervals until either the lake bottom or a depth equivalent to 1% of the subsurface reading was reached. The mean euphotic zone depth was determined (Koenings et al. 1987) for each lake and used in a model to estimate sockeye salmon fry production (Koenings and Kyle 1997). The vertical extinction coefficient for downward light (K_d, m^{-1}) was obtained from the relation:

$$I_z = I_o e^{-K_d} \text{ or } \ln I_z = \ln I_o - K_d z \qquad (5)$$

where,

I_o = light penetration just below the surface (Wetzel and Likens 1991);
I_z = light penetration at *z* meters (Wetzel and Likens 1991); and

K_d = the linear regression coefficient of ln I_z against depth (z).

Assuming K_d is constant with depth, mean euphotic zone depth, the depth at which 1% of the subsurface light remains, is given by 4.6/K_d (Kirk 1994).

One-meter temperature and dissolved oxygen profiles were compared to assess the physical conditions in the euphotic zones of each lake. Secchi disc readings were collected from each station to measure water transparency. The depths at which the disc disappeared when lowered into the water column and reappeared when raised in the water column were recorded and averaged.

Lake primary production potential for rearing juvenile sockeye salmon was assessed through a Euphotic Volume calculation (Koenings and Burkett 1987; Nelson et al. 2005). To calculate Euphotic Volume for Afognak Lake, the average mean euphotic zone depth was multiplied by the surface area (5.3 km^2).

General Water Chemistry, Phytoplankton and Nutrients
Unfiltered water was analyzed for total phosphorus, total Kjeldahl nitrogen, pH, and Alkalinity. Sample water was filtered through a rinsed 4.25 cm diameter Whatman GF/F cellulose fiber filter and stored frozen in phosphate free soap-washed polyethylene bottles. Filtered water was also analyzed for total filterable phosphorus (TFP), filterable reactive phosphorus (FRP), nitrate + nitrite (NO_3^- + NO_2^-), ammonia (NH_4^+) and reactive silicon.

Total phosphorus (TP), TFP and FRP were analyzed using a Spectronic Genesys 5 Spectrophotometer (SGS) using the potassium persulfate-sulfuric acid digestion method described in Koenings et al. (1987) adapted from methods in Esienreich et al. (1975). Unfiltered frozen water was sent to South Dakota University for the TKN analysis. 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 nitrate + nitrite (NO_3^- + NO_2^-) were analyzed using the cadmium reduction method described in Koenings et al. (1987). Ammonia (NH_4^+) was analyzed on with a Spectronic Genesys 5 Spectrophotometer using the phenol-sodium hypochlorite method described in Koenings et al. (1987). Total nitrogen, the sum of total Kjeldahl nitrogen and nitrate + nitrite, and the ratio of total nitrogen to total phosphorus was calculated for each sample.

For chlorophyll *a* (chl *a*) analysis, 1.0 L of water from each sample was filtered through a Whatman GF/F filter under 15 psi vacuum pressure. Approximately 5 ml of magnesium chloride ($MgCO_3$) were added to the final 50 ml of water near the end of the filtration process. Filters were stored frozen on individual Plexiglas slides until analyzed. Filters were then ground in 90% buffered acetone using a mortar and pestle, and the resulting slurry was refrigerated in separate 15-ml glass centrifuge tubes for 4 hours to ensure maximum pigment extraction. Pigment extracts were centrifuged, decanted, and diluted to 15 ml with 90% acetone (Koenings et al. 1987). The extracts were analyzed with a Spectronic Genesys % spectrophotometer using methods described in ADF&G (2002).

Reactive Silicon was determined with a SG5 spectrophotometer using the ammonium molybdate – sodium sulfite method described in Koenings et al. (1987) and ADF&G (2002). 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 Koenings et al. (1987).

Zooplankton

For zooplankton analysis, cladocerans and copepods were identified using taxonomic keys in Edmondson (1959). Zooplankton lengths were measured in triplicate 1 ml subsamples taken with a Hansen-Stempel pipette and placed in a Sedgewick-Rafter counting chamber. Lengths from a minimum of 15 animals of each species or group (typically animals are grouped at the genus level) were measured to the nearest 0.01 mm, and the mean was calculated. Biomass was estimated from species-specific linear regression equations between length and dry weight derived by Koenings et al. (1987). Zooplankton data from the two stations were averaged for each survey.

Spawning Habitat Assessment

The available spawning habitat for sockeye salmon in the Afognak Lake drainage was evaluated in 2005. All tributaries that emptied into Afognak Lake were surveyed on foot in August, while lake shoal areas were assessed from fixed wing aircraft in late August and September. Methods of habitat identification, assessment and potential availability were the same as those used by Baer et al. (2006).

Potential Adult Production and Assessment

Available escapement, harvest, limnological, spawning habitat, and age data associated with the Afognak Lake sockeye salmon stock were compiled from research reports, management reports, and unpublished historical databases, and provide the basis for setting and evaluating escapement goals. The most recent escapement goal assessment for Afognak Lake sockeye salmon was that BEG determination was appropriate and an escapement for MSY should be applied as defined in the Policy for the Management of Sustainable Salmon Fisheries (5 AAC 39.222) and the Policy for Statewide Salmon Escapement Goals (5 AAC 39.223; Nelson et al. 2005). Specific methods and models used in determining the BEG and MSY are described in Nelson et al. (2005).

RESULTS

Smolt Assessment

Enumeration and Sampling

Smolt trapping was conducted a total of 45 days, from 16 May to 29 June 2006. During this period, 43,824 sockeye salmon smolt were captured (Table 2). This was the lowest total number of smolt captured for this project (2003-2005 range - 67,528 to 82,970 smolt; Appendix A1). The greatest daily sockeye salmon smolt catch was obtained on 29 May when 7,144 smolt were captured (Table 2; Figure 4).

Age, Weight, and Length Sampling

It was possible to estimate ages for all sockeye salmon smolt sampled for age, weight, and length data (Table 3). All of these were either age-1. or -2. smolt. Age-1. smolt were more abundant than age-2 smolt in all but the first emigration strata. Age-1. smolt comprised 44.1% of the sample from the first stratum (16 May - 1 June), 97.5% from the second stratum (2 - 6 June), 97.0% from the third stratum (7-16 June), and 100.0% from the fourth stratum (17-29 June).

Age-1. smolt had a mean weight of 3.0 g (range - 2.6 g to 3.7 g), a mean length of 70.8 mm (range - 68.0 mm to 75.3 mm), and a mean condition factor of 0.83 (range - 0.78 to 0.87; Table 4). Age-2. smolt had a mean weight of 3.8 g (range - 3.0 g to 4.0 g), a mean length of 79.6 mm (range - 75.4 mm to 81.0 mm), and a mean condition factor of 0.75 (range - 0.69 to 0.76). Mean weight and length of age-1. and -2. smolt were less than those for samples from the preceding three years (2003-2005 – 3.6 to 4.2 mm and 75.7 to 79.1 g for age-1. smolt; 3.6 to 4.2 mm and 78.7 to 81.4 g for age-2. smolt; Appendix B1).

Trap Efficiency and Population Estimates

Four mark-recapture experiments were conducted during the sockeye salmon smolt emigration period in 2006 (Table 2). Trap efficiencies ranged from 15.4% during the fourth experiment (17 to 29 June) to 23.6% during the first experiment (16 May to 1 June). Mean trap efficiency for the emigration period was 19.5%.

The total number of sockeye salmon smolt emigrating from the Afognak Lake system in 2006 was estimated to be 205,153 (95% C.I. 180,952 – 229,353; Table 5). The emigration was composed of 146,527 age-1. (71.4%) and 58,626 age-2. (28.6%) smolt (Table 6; Figure 5). This was much less than any of the total estimates from the preceding three years (2003-2005 - 430,104 to 564,793; Appendix A1).

Comparisons of Mark-Recapture and Life History-Based Population Estimates

In 2006 we projected that the 2003 escapement of 27,766 adults (brood year 2003) would produce approximately 510,200 smolt and the 2004 escapement of 15,181 adults (brood year 2004) would produce approximately 278,171 smolt (Table 7). The 2006 mark-recapture estimate, apportioned by the average age composition of smolt sampled (71.4% age-1. and 28.6% age-2.

smolt), was 145,917 age-2. smolt (brood year 2003) and 199,171 age-1. smolt (brood year 2004) in 2006. Thus, approximately 345,088 smolt were expected to emigrate from the system in 2006, while the mark-recapture estimate was 205,153 smolt. This was the largest difference between projected and mark-recapture estimates obtained during the four years in which this has been done (2003-2006; Figure 6). On average, projected and mark-recapture estimates for these four years were within 20,000 smolt (4%) of each other.

Limnological Assessment

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

In 2006, water temperatures ranged from 8.0° C near the bottom in the spring to 15.8° C at the surface in the summer. Temperature stratification was most noticeable in the summer when average surface temperature was 15.8° C and average bottom temperature was 12.5° C. Surface and bottom temperatures in the spring and fall were similar, with a difference of only 1.2°. This indicates that mixing occurred throughout the entire water column during the sampling period. dissolved oxygen concentrations ranged from 8.3 mg L^{-1} at the bottom in the summer to 10.9 mg L^{-1} at the surface in the spring. Historical temperature and dissolved oxygen levels for Afognak Lake surface and bottom temperatures during 2006 compared to past years were about average (Appendix C1). Lake surface and bottom dissolved oxygen levels during 2006 were also about average compared to past years, except for summer bottom levels, which were greater than average (Appendix D1).

The mean vertical extinction coefficient (Kd m^{-1}) or rate of light attenuation was measured down to -0.49 m^{-1} in 2006. The mean euphotic zone depth was 9.01 m, while the Secchi disk reading was 4.04 meters. The euphotic volume for Afognak Lake in 2006 was 47.75 $10^6 m^3$. These values were very similar to those measured in recent years (Appendix E1).

General Water Chemistry, Phytoplankton and Nutrients

Hydrogen ion concentrations (pH) averaged 6.8 units with little seasonal variation (Table 8). Alkalinity levels (measured as $CaCO_3$) ranged from 10.0 mg L^{-1} to 12.3 mg L^{-1} and averaged 11.3 mg L^{-1} for the five samples collected. Results from the pH and alkalinity tests were similar to historical data collected from Afognak Lake and from other Kodiak archipelago lakes (Schrof and Honnold 2003). Seasonal chl *a* (phytoplankton) concentrations ranged from 1.60 μg L^{-1} to 2.24 μg L^{-1} and averaged 1.92 μg L^{-1} (Table 8).

Seasonal mean total phosphorus concentrations were variable, ranging from 3.3 to 13.9 μg L^{-1} and averaged 7.2 μg L^{-1} (Table 9). Seasonal inorganic phosphorous concentrations of total filterable phosphorus ranged from 0.6 μg L^{-1} to 4.1 μg L^{-1} and averaged 2.2 μg L^{-1}(Table 9). The filterable reactive phosphorus concentrations ranged from 1.0 to 3.8 μg L^{-1} and averaged 2.3 μg L^{-1}.

Nitrogen levels were measured in three forms: Total Kjeldahl nitrogen (TKN), Nitrate and nitrite ($NO_3^- + NO_2^-$), and ammonium (NH_{4+}). The seasonal mean TKN was 97.0 μg L^{-1}, and the greatest seasonal variation was between the June (60.0 μg L^{-1}) and September (202.0 μg L^{-1}) samples (Table 9). Seasonal NH_{4+} levels averaged 7.1 μg L^{-1} and ranged from 4.0 to 8.2 μg L^{-1}.

Seasonal $NO_2 + NO_3$ levels averaged 28.0 μg L^{-1} and had a wide range of variability throughout the season, ranging from 1.0 to 77.8 μg L^{-1} (Table 9). Total nitrogen concentrations ranged from 66.0 to 224.6 μg L^{-1} and averaged 125.0 μg L^{-1}. The seasonal total nitrogen to total phosphorus ratio, by weight, averaged 50.8:1 (Table 9).

Nutrient concentrations during 2006 were somewhat below average, while algal pigment concentrations were above average (Appendix F1). The average water pH during 2006 was similar to that during past years, while average alkalinity was higher (Appendix G1).

Zooplankton

Zooplankton weighted mean density was 117,614 animals per m^{-2} (Table 10). All zooplankton identified were crustaceans commonly referred to as either cladocerans (*Order* Anomopoda and Ctenopoda) or copepods (*Order* Calanoida, Cyclopoida, and Harpacticoida). Cladocerans were the predominate zooplankter in samples (62.4% of mean), with the genus *Bosmina* being most abundant (51.4% of mean). The other cladoceran genera included, *Daphnia* (5.1% of mean), *Holopedium* (3.2% of mean), and a group we called "Other Cladocerans," which consisted of various unidentified immature cladocera which were less abundant (2.8% of mean). Of the copepods (37.6% of mean), the genus *Epischura* was most abundant (16.6% of the mean) followed in abundance by a group we called "Other copepods" (13.8% of the mean), which consisted mostly of the genus *Harpaticus* and various unidentified, nauplii (larvae). The copepod genus *Cyclops*, considered an important member of the zooplankton community in sockeye salmon lakes, were not very abundant (5.5% of mean). The genus *Diaptomus* made up the smallest portion of the copepods at 1.7% of the mean. There were nearly twice as many cladocerans and copepods found in samples collected at station 1 than in samples from station 2.

Zooplankton mean biomass was 133.7 mg per m^{-2} (Table 10). Despite only making up 37.6% of the mean density the copepods comprised 54.6% of the zooplankton mean biomass due to their larger size (Table 10). The copepod genus *Epischura* represented the greatest percentage of biomass (39.9%), followed by the cladoceran genus *Bosmina* (34.5%). The remaining biomass was mostly comprised of *Cyclops* (9.4%) and *Daphnia* (6.1%).

The copepod *Diaptomus* was the largest zooplankter, having a mean length of 0.96 mm (Table 10). Of the remaining copepods, *Epischura* had a mean length of 0.83 mm, and *Cyclops* had a mean length of 0.73 mm. *Daphnia*, the largest cladoceran, had a mean length of 0.57 mm followed by *Holopedium* (0.45 mm), *Bosmina* (0.29 mm), and the "Other Cladocerans" made up of unidentified immature cladocerans that were too small to measure.

Total zooplankton mean density and biomass were generally greater than those measured in recent years, and about average for the entire historical data set (Appendix H1). All species except for *Bosmina* had above average densities and biomasses for recent years as well as the entire historical data set. *Bosmina* density and biomass was above average for recent years, but was below average for the historical data set.

Spawning Habitat Assessment

The two main tributaries flowing into Afognak Lake, Hatchery (9,916 m^2) and Egg Take (3,448 m^2) Creeks, were estimated to be capable of supporting 13,364 spawning sockeye salmon (male and female, combined; Table 11). The remaining tributaries surveyed were estimated to be capable of supporting an additional 1,933 spawning sockeye salmon, resulting in a total tributary capacity of 15,297 spawners. These estimates were generally consistent with past counts of spawning sockeye salmon in Hatchery and Egg Take creeks (Appendix I1). While we were unable to estimate the total amount of spawning habitat within Afognak Lake, we did conduct three aerial surveys of the lake shoals on 26 August, 6 September, and 21 September, 2005. The peak count of spawning sockeye salmon made during the survey was 21 September, when we counted 770 sockeye salmon. Past counts of lake shoal spawners have ranged from 35,811 to 70,853 (Appendix I1)

Potential Adult Production and Assessment

After thorough review of all models and assessments, ADF&G biologists recommended changing the Afognak Lake SEG of 40,000 to 60,000 sockeye salmon to a BEG of 20,000 to 50,000 sockeye salmon. The change was based on results obtained from a Ricker spawner-recruit model and zooplankton biomass information. Results indicated that a lower escapement goal was needed to match the natural fry rearing capacity of the system in the absence of enhancement efforts based on lake fertilization. Detailed results of these analysis are available in Nelson et al. (2005). In January 2005, the Directors of Commercial Fisheries and Sport Fish Divisions approved the changes to the existing escapement goal.

DISCUSSION

Smolt Assessment

Prior to conducting this study, we designed and conducted a feasibility study in 2003 based on results from smolt studies conducted on the Afognak River in 1990 and 1991 (Honnold and Schrof 2004). For the pilot study, we used a different type of smolt trap than the one used in 1990 and 1991, and set it close to the middle of the river where water flow and velocity were greater. We made these changes because smolt estimates in both 1990 and 1991 seem to have been much too low, based on what we felt were reasonable survival assumptions. These changes appeared to work, since the mean trap efficiency was 19.9% in 2003 (Appendix A1). Mean trap efficiencies for the succeeding three-year study remained high (2004: 18.6%; 2005: 14.9%; 2006: 19.5%), despite very low water levels during 2005. These results suggest that reliable and comparable estimates of annual smolt production have been made each year of study.

The 2006 emigration was dominated by age-1. smolt (71.4%) while the age-2. smolt made up the remaining (28.6%) portion of the emigration. Typically, systems producing large proportions of age-1. smolt have favorable freshwater rearing conditions. An increased proportion of older smolt often indicates decreased food availability due to either declining lake productivity or increasing numbers of juvenile salmon (Barnaby 1944; Krokhin 1957; Burgner 1964; Foerster 1968; Koenings et al. 1993). The percentage of the age 1. smolt in 2006 was much less than during the previous three year period, when the average proportion of age 1. smolt was 82.5% (Figure 7). A smaller proportion of age 1. smolt was expected in 2006 because the parent brood year (2004) for this smolt age class was relatively small (15,000 spawners) while the brood year (2003) for the age 2. component 35% larger (28,000 spawners; Table 7 and Figure 7). This was similar to the 2003 smolt emigration when the age-1. component was 66.1% of the total (Table 1). The parent escapement in 2000 (54,000 spawners) for the age-2. component was almost twice as abundant as the parent escapement in 2001 (24,000 spawners) for the age-1. component.

When the juvenile population begins to exceed the rearing capacity of a system, a greater proportion of the population must spend two or more years in freshwater before growing large enough to transform into smolt (Honnold and Schrof 2004). Based on the average dominance (81.2%) of age-1. smolt emigrating from Afognak Lake in 2003-2006, freshwater rearing capacity has not been exceeded and has been sufficient to support the juvenile population produced from recent escapements (Figure 7). As expected, adult age composition data show a similar pattern of age 1. dominance in recent years (Appendix J1).

Age, weight, and length data for the 2006 smolt emigration also suggest that rearing conditions in Afognak Lake were not being exceeded (Table 4). Mean size and condition of age-1. smolt sampled in 2006 (n=765; 3.0 g, 70.8 mm, 0.83 K) indicated they were healthy and robust. The condition factor of age-1. smolt emigrating in 2006 was similar to both the previous three year average (0.82 K) as well as the average for the 15 years prior to 2003 (0.83; Appendix B1).

Emigration timing of sockeye salmon smolt from Afognak Lake in 2006 was similar to timing documented for 2003-2005 as well as to the historical timing documented for smolt emigrating from Malina Lakes, another sockeye salmon system on Afognak Island (Figure 4; Appendices K1 and L1). Smolt emigration from both systems generally begins in mid-May, peaks early to mid-June, and is essentially over by early July. Documentation from other systems (Barnaby 1944; Krogius and Krokhin 1948; Burgner 1962) indicates that older and larger smolt tend to migrate earlier, and this was also true of Afognak Lake smolt in 2006 (Figure 5).

Limnological Assessment

Seasonal mean measurements of lake physical properties in 2006 were similar to those from past years. Water temperatures recorded in 2006 were similar to seasonal average readings from 1989 to 2005 (Appendix C1). With a mean depth of 8.6 m and a maximum depth of 23.0 m, Afognak Lake is considered a shallow lake that is easily influenced and mixed by wind and ice melt (Cole 1983). As a result of these climatic events, Afognak Lake is stratified into warm hypolimnion and cool epilimnion layers for only short periods of time each year. High dissolved oxygen levels recorded in 2006 were also consistent with historical averages (Appendix D1). These high levels from top to bottom in the water column are also indicative of thorough seasonal mixing. Light and euphotic volume and zone data recorded in 2006 were also similar to historical average values from past years (1987-2005; Appendix E1).

Seasonal mean nutrient and algal pigment concentrations exhibited a good deal of annual variation, although there were some differences between the eleven-year period during which the lake was fertilized (1990-2000) and the last six years during which no fertilizer was applied (2001-2006; Appendix F1). During 2006, average surface water nutrient concentrations (total phosphorus: 7.2 μg L^{-1}; total Kjeldahl nitrogen: 97 μg L^{-1}; and nitrate+nitrate: 28 μg L^{-1}) were lower than the overall average concentration during the previous five-year post-fertilization period (total phosphorus: 7.7 μg L^{-1}; total Kjeldahl nitrogen:144 μg L^{-1}, and nitrate+nitrite: 44 μg L^{-1}) as well as during the eleven-year fertilization period (total phosphorus: 7.7 μg L^{-1}; total Kjeldahl nitrogen: 155 μg L^{-1}, and nitrate+nitrite: 55 μg L^{-1}). Reactive Silicon was not measured in 2006. Overall, however, average nutrient concentrations during fertilization years was greater than concentrations during post-fertilization years. During 2006, seasonal average algal standing crop, as measured by chl *a* concentration (1.92 μg L^{-1}) was greater than the average concentration during the previous five-year post-fertilization period (1.54 μg L^{-1}) as well as during the fertilization period (1.55 μg L^{-1}). Overall, mean chl *a* values in Afognak Lake were greater than those measured in many other oligotrophic lakes in Alaska, which typically have chl *a* concentrations less than 1.5 μg L^{-1} (Honnold et al. 1996). The largest fluctuations measured in Afognak Lake occurred during the fertilization years, during which concentrations ranged from 0.10 to 3.92 μg L^{-1}. Large fluctuations in chl *a* concentrations have been measured at other lakes on Afognak Island (Schrof and Honnold 2003).

Seasonal mean water chemistry has not varied a great deal, although average pH and alkalinity were both lower during the fertilization period (pH; 6.8; alkalinity: 9.2) than during the post-fertilization period (pH: 7.0; alkalinity: 10.6; Appendix G1). During 2006, average pH (6.8) was the same as the overall average for the fertilization period and slightly less than that for the previous five-year post-fertilization period. However, average alkalinity for 2006 (11.3) was greater than the overall averages for the fertilization and previous five-year post-fertilization periods.

During 2006, seasonal mean zooplankton density (81,352 individuals m^{-2}) and biomass (60.9 mg m^{-2}) estimates at Station 2 were much less than estimates from Station 1 (153,875 individuals m^{-2} and 206.5 mg m^{-2}; Table 10). This was likely due to Station 2 being closer to the lake outlet. Lake water residence time is estimated to be only 0.4 years for Afognak Lake, so rapid lake flushing may remove zooplankton quicker than they can be replenished through reproduction (White et al. 1990; Schrof and Honnold 2005). Rapid flushing may also affect nutrient availability for phytoplankton, which could affect zooplankton production. From 1988 to 2006, zooplankton tows were made at both stations for 13 years (1988-1997, 2004-2006; Appendix H1). During these 13 years, average total zooplankton density and biomass at Station 1 (200,221 individuals m^{-2} and 285 mg m^{-2}) were about 1.5 times greater than at Station 2 (130,201 individuals m^{-2} and 163 mg m^{-2}).

Since the zooplankton community serves as the primary forage base in lakes for juvenile sockeye salmon, total zooplankton density and biomass are often used as a measure to assess juvenile sockeye salmon production potential (Koenings et al. 1987). During 2006, Station 1 weighted mean total zooplankton density (134,204 individuals m^{-2}) and biomass (205 mg m^{-2}) were very similar to estimates for the pre-fertilization period (1987-1989: 134,747 no. m^{-2} and 194 mg m^{-2}) and greater than estimates for the previous five-year post-fertilization period (2001-2005: 103,542 individuals and 126 mg m^{-2}; Appendix H1). Overall weighted mean total zooplankton density (228,773 individuals m^{-2}) and biomass (318 mg m^{-2}) during the fertilization period (1990-2000) were much greater than those for the pre- and post-fertilization periods. Since juvenile sockeye salmon prefer to eat cladocerans rather than copepods, cladoceran abundance is viewed as a better indicator of potential juvenile sockeye salmon production (Koenings et al. 1987; Kyle 1996).

The 2006 abundance of the cladoceran *Daphnia* (8,408 individuals m^{-2} and 11 mg m^{-2}) was not very different than its overall average abundance during the fertilization period (8,834 individuals m^{-2} and 17 mg m^{-2}); but was much greater than its overall average abundance during the pre-fertilization period (1,986 individuals and 3 mg m^{-2}) and the previous five-year post-fertilization period (4,406 individuals and 6 mg m^{-2}; Appendix G1). This was an encouraging sign for future sockeye salmon production, since *Daphnia* are a primary prey for juvenile sockeye salmon (Kyle 1996; Honnold and Schrof 2001). A similar result was also observed for the cladoceran *Holopedium* in 2006. The density (6,348 individuals m^{-2}) and biomass (11 mg m^{-2}) measured for this zooplankter during 2006 were only exceeded by those measured during 1994 (7,271 individuals m^{-2} and 13 mg m^{-2}). Abundant *Daphnia* and *Holopedium* zooplankton components are usually found in lakes prior to stocking and indicate that grazing pressure by fishes is not excessive (Koenings and Kyle 1997). The cladoceran *Bosmina*, while not particularly abundant in 2006, is a more difficult prey item for juvenile salmon to locate and eat due to its small size (Koenings and Kyle 1997). *Bosmina* are about half the size of *Daphnia* and about two-thirds the size of *Holopedium.*

Spawning Habitat Assessment

We feel that the 2005 spawning habitat assessments for Eggtake, Hatchery, and the remaining inlet creeks provide a valid estimate of available spawning habitat. These estimates did not rely on observed spawning salmon to estimate available spawning habitat, as was attempted for lake shore areas. White et. al (1990) may have used a similar creek habitat assessment method, and their data closely matched our 2005 tributary results (Appendix I1). However, White et al (1990) did not document the methods they used. While we feel reasonably certain that 15,000 spawning sockeye salmon can be supported by available spawning habitat in Afognak Lake tributaries, we could not develop a corresponding estimate for lake shore spawning habitat due to limitations with physical observations, variability in escapements, and our ability to accurately assess useable habitat. To make such a determination would require a comprehensive substrate analysis, which was beyond the time and effort originally budgeted for this project. However, based on the existing biological escapement goal of 20,000 to 50,000, it would appear that the lake should be capable of supporting at least 35,000 spawning sockeye salmon.

CONCLUSION

The compilation of historical fishery and limnology data for the Afognak Lake sockeye salmon was completed in 2004 in preparation for the 2005 BOF meeting. An escapement goal team, comprised of ADF&G fishery biologists and biometricians, recommended changing the current Afognak Lake SEG of 40,000 to 60,000 sockeye salmon to a BEG of 20,000 to 50,000 sockeye salmon (Nelson et al. 2005). The lake’s rearing environment for juvenile sockeye salmon was found to be the primary factor limiting sockeye salmon production. Although sockeye salmon production has declined (beginning in 2001), emigrating sockeye salmon smolt have been healthy, robust, and predominately age 1. (81%).

RECOMMENDATIONS

We recommend the continuation of Afognak Lake smolt enumeration and lake assessment . We feel it is extremely important to collect and apply this data to assessing adult production. These data will help us identify changes in nutrient-food web dynamics and document how these changes affect growth and production of the juvenile sockeye salmon emigrating from Afognak Lake. Additionally, we recommend the continuation of adult sockeye salmon escapement monitoring along with collection of age data. Escapement information is critical for in season management as well as maintaining brood tables and evaluating the spawning escapement goal. In fact, ADF&G will be reevaluating the Afognak Lake sockeye salmon escapement goal in 2007 using information collected during the present project.

ACKNOWLEDGEMENTS

We acknowledge ADF&G personnel Jeff Wadle and Joe Dinnocenzo for logistical and field support for this project and Ivan Vining for statistical and biometrical support and review of the sampling design and the smolt population estimate. Also, the authors appreciate the efforts of the field crew, Lisa Creelman , Jason Fox, and Josephine Deguzman for their attention to project objectives. Lucinda Neel formatted the report. The U.S. Fish and Wildlife Service, Office of Subsistence Management, provided the final review and evaluation of this report and granted $69,391 in funding support for this project through the Fisheries Resource Monitoring Program, under agreement number 701814J563, as study 04-412.

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Table 1. Afognak Lake sockeye salmon escapement, harvest, and total run estimates, 1978-2006.

Year	Escapement	Harvest				Total Run
		Commercial[a]	Subsistence[b]	Sport[c]	Total	
1978	52,701	3,414	1,632	524	5,570	58,271
1979	82,703	2,146	2,069	524	4,739	87,442
1980	93,861	28	3,352	524	3,904	97,765
1981	57,267	16,990	3,648	524	21,162	78,429
1982	123,055	21,622	3,883	524	26,029	149,084
1983	40,049	4,349	3,425	524	8,298	48,347
1984	94,463	6,130	3,121	524	9,775	104,238
1985	53,563	1,980	6,804	524	9,308	62,871
1986	48,328	2,585	3,450	524	6,559	54,887
1987	25,994	1,323	2,767	524	4,614	30,608
1988	39,012	14	2,350	524	2,888	41,900
1989	88,825	0	3,859	524	4,383	93,208
1990	90,666	22,149	4,469	524	27,142	117,808
1991	88,557	47,237	5,899	524	53,660	142,217
1992	77,260	2,196	4,638	600	7,434	84,694
1993	71,460	1,848	4,580	524	6,952	78,412
1994	80,570	17,362	3,329	524	21,215	101,785
1995	100,131	67,665	4,390	524	72,579	172,710
1996	101,718	106,141	11,023	258	117,422	219,140
1997	132,050	10,409	12,412	535	23,356	155,406
1998	66,869	26,060	4,690	718	31,468	98,337
1999	95,361	34,420	5,628	237	40,285	135,646
2000	54,064	14,124	7,572	364	22,060	76,124
2001	24,271	0	4,720	169	4,889	29,160
2002	19,520	0	1,279	41	1,320	20,840
2003	27,766	0	604	0	604	28,370
2004	15,181	0	567	10	577	15,758
2005	21,577	356	696	134	1,186	22,763
2006	22,933	6	na	na	6	22,939

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

[b] Data from ADF&G subsistence catch database 1978-2005.

[c] Data from ADF&G Sport Fish Division statewide harvest survey (SWHS) for 1992, 1996-2005; SWHS data for other years did not have enough respondents to provide reliable estimates. Four years with reliable data were averaged and entered for years with no data.

na – not available

Table 2. Sockeye salmon smolt counts, number of samples collected, mark-recapture counts, and trap efficiency ratios from trapping at Afognak River, 2006.

Date	Catch Daily	Catch Cumulative	Dye Test Period Cumulative	AWL Sample Cumulative	Number Marked Releases	Marked Recoveries Cumulative	Trap Efficiency (%)
16-May	1	1					
17-May	8	9					
18-May	4	13					
19-May	42	55		20			
20-May	28	83					
21-May	88	171					
22-May	342	513		60			
23-May	580	1,093		100			
24-May	1,420	2,513		140			
25-May	1,332	3,845		180	312	56	
26-May	1,720	5,565		220		73	
27-May	2,396	7,961				73	
28-May	2,844	10,805				73	
29-May	7,144	17,949				73	
30-May	2,695	20,644		260		73	
31-May	1,808	22,452		300		73	
1-Jun	3,531	25,983	25,983	340		73	23.6%
2-Jun	4,121	30,104		380	515	82	
3-Jun	1,892	31,996				97	
4-Jun	523	32,519				97	
5-Jun	775	33,294		420		98	
6-Jun	888	34,182	8,199	460		98	19.2%
7-Jun	1,879	36,061		500	485	16	
8-Jun	2,095	38,156		523		50	
9-Jun	556	38,712		563		83	
10-Jun	375	39,087				89	
11-Jun	203	39,290				92	
12-Jun	205	39,495		603		93	
13-Jun	634	40,129		643		95	
14-Jun	497	40,626		683		95	
15-Jun	289	40,915		723		95	
16-Jun	375	41,290	7,108	763		95	19.8%

-Continued-

Table 2. (page2 of 2)

Date	Catch Daily	Catch Cumulative	Dye Test Period Cumulative	AWL Sample Cumulative	Number Marked Releases	Marked Recoveries Cumulative	Trap Efficiency (%)
17-Jun	725	42,015			492	40	
18-Jun	269	42,284				69	
19-Jun	62	42,346		783		72	
20-Jun	154	42,500		823		73	
21-Jun	107	42,607		847		74	
22-Jun	655	43,262		887		75	
23-Jun	148	43,410		927		75	
24-Jun	94	43,504				75	
25-Jun	26	43,530				75	
26-Jun	15	43,545				75	
27-Jun	80	43,625		967		75	
28-Jun	141	43,766				75	
29-Jun	58	43,824	2,534			75	15.4%
30-Jun	Trap Pulled				Average Trap Efficiency=		19.5%

Table 3. Estimated age composition of the Afognak Lake sockeye salmon smolt sampled in each dye test period, 2006.

Stratum	Sample Size		Age 1	Age 2	Age 3	Total
1 5/16-6/1	340	Percent Numbers	44.1 150	55.9 190	0 0	100.0 340
2 6/2-6/6	120	Percent Numbers	97.5 117	2.5 3	0 0	100.0 120
3 6/7-6/16	303	Percent Numbers	97 294	3 9	0 0	100.0 303
4 6/17-6/29	204	Percent Numbers	100 204	0 0	0 0	100.0 204
Total	967		765	202	0	967

Table 4. Length, weight, and condition of sockeye salmon smolt from the Afognak River, 2006.

Statistical Week	Sample Size	Weight (g) Mean	Weight (g) Standard Error	Length (mm) Mean	Length (mm) Standard Error	Condition Mean	Condition Standard Error
Age 1.							
21	17	2.6	0.09	68.9	0.74	0.78	0.013
22	69	2.6	0.04	69.0	0.39	0.79	0.009
23	181	2.6	0.02	68.0	0.21	0.81	0.005
24	174	2.8	0.03	69.9	0.24	0.82	0.005
25	180	3.1	0.03	71.7	0.23	0.84	0.004
26	144	3.7	0.04	75.3	0.25	0.87	0.005
Totals	765	3.0	0.02	70.8	0.14	0.83	0.002
Age 2.							
21	83	4.0	0.06	81.0	0.36	0.75	0.007
22	91	3.8	0.06	79.5	0.32	0.75	0.006
23	19	3.3	0.12	75.6	0.92	0.76	0.018
24	9	3.0	0.24	75.4	1.30	0.69	0.037
Totals	202	3.8	0.04	79.6	0.26	0.75	0.005

Table 5. Population estimate of the sockeye salmon smolt emigration from Afognak Lake, 2006.

Stratum (h)	Starting Date	Ending Date	Catch (u_h)	Released (M_h)	Recaptured (m_h)	Estimate (U_h)	Variance var (U_h)	95% Confidence Interval lower	upper
1	5/16	6/1	25,983	312	73	110,017	1.24E+08	88,224	131,809
2	6/2	6/6	8,199	515	98	42,726	1.49E+07	35,153	50,299
3	6/7	6/16	7,108	485	95	35,975	1.09E+07	29,519	42,432
4	6/17	6/29	2,534	492	75	16,435	3.06E+06	13,009	19,861
Total						205,153	1.52E+08	180,952	229,353
						SE=	12,347		

Table 6. The Afognak Lake sockeye salmon smolt emigration estimate based on percents by age class and dye test period, 2006.

Stratum	Dye Test Period	Age 1.	2.	3.	Total
1	(5/16-6/1)	56,925	53,092	0	110,017
2	(6/2-6/6)	38,667	4,059	0	42,726
3	(6/7-6/16)	34,501	1,475	0	35,975
4	(6/17-6/29)	16,435	0	0	16,435
Total		146,527	58,626	0	205,153
		71.4%	28.6%	0.0%	100.0%

Table 7. Afognak Lake sockeye salmon theoretical production of eggs, emergent fry, and smolt by age from brood years 2003 and 2004 and predicted smolt emigration in 2006.

Production		Brood Year		Total
Parameter	Assumption	2003	2004	
Escapement		27,766	15,181	
Females spawning	1:1 sex ratio	13,883	7,591	
Deposited Eggs	2,500 per female[a]	34,707,500	18,976,250	
Emergent Fry	7% egg-to-fry survival[b]	2,429,525	1,328,338	
Smolt	21% fry-to-smolt survival[c]	510,200	278,951	
Smolt Emigrating in 2006	71.4% age-1., 28.6% age-2. (Table 6)	145,917	199,171	345,088

[a] Roelofs (1964)
[b] Average from Drucker (1970) and Koenings and Kyle (1997)
[c] Koenings and Kyle (1997)
[d] See Table 6 for 2006 mark-recapture estimates of smolt abundance

Table 8. General water chemistry and algal pigment concentrations at 1 m water depth, station 1, Afognak Lake 2006.

Date	pH (units)	Alkalinity (mg L^{-1})	Silicon (μg L^{-1})	Chlorophyll *a* (μg L^{-1})
18-May	6.9	12.0	na	1.92
20-Jun	6.7	10.0	na	2.24
13-Jul	6.9	12.3	na	1.60
7-Aug	6.6	10.8	na	1.60
18-Sep	6.8	11.3	na	2.24
Average	6.8	11.3	na	1.92
STDEV	0.1	0.9	na	0.32

Table 9. Seasonal phosphorus and nitrogen concentrations at 1 m water depth, station 1, Afognak Lake, 2006.

Date	Total filterable-P (µg L^{-1})	Filterable reactive-P (µg L^{-1})	Total-P (µg L^{-1})	Ammonia (µg L^{-1})	Total Kjeldahl Nitrogen (µg L^{-1})	Nitrate + Nitrite (µg L^{-1})	Total Nitrogen (µg L^{-1})	TN:TP ratio
18-May	4.1	3.8	13.9	7.4	88.0	77.8	165.8	26.4
20-Jun	2.1	2.7	8.4	7.6	60.0	33.8	93.8	24.7
13-Jul	3.6	2.4	6.7	8.1	65.0	1.0	66.0	21.8
7-Aug	0.6	1.5	3.3	4.0	70.0	4.9	74.9	50.3
18-Sep	0.7	1.0	3.8	8.2	202.0	22.6	224.6	130.9
Average	2.2	2.3	7.2	7.1	97.0	28.0	125.0	50.8
STDEV	1.6	1.1	4.3	1.7	59.6	30.8	68.1	46.2

Table 10. Weighted mean zooplankton density, biomass, and size by station from Afognak Lake, 2006.

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})	29,565	3,450	9,915	13,960	76,518	8,408	6,348	5,711	56,890	96,985	153,875
		%	19.2%	2.2%	6.4%	9.1%	49.7%	5.5%	4.1%	3.7%	37.0%	63.0%	100.0%
		biomass (mg m^{-2})	92.5	9.6	19.8	1.6	61.0	10.9	11.2	na	123.4	83.0	206.5
		%	44.8%	4.7%	9.6%	0.8%	29.5%	5.3%	5.4%	na	59.8%	40.2%	100.0%
		size (mm)	0.95	0.85	0.76	0.56	0.30	0.56	0.46				
2	5	density (no. m^{-2})	9,408	510	3,083	18,448	44,282	3,571	1,274	777	31,448	49,904	81,352
		%	11.6%	0.6%	3.8%	22.7%	54.4%	4.4%	1.6%	1.0%	38.7%	61.3%	100.0%
		biomass (mg m^{-2})	14.3	1.1	5.2	1.8	31.2	5.4	1.9	na	22.4	38.5	60.9
		%	23.5%	1.8%	8.6%	2.9%	51.3%	8.8%	3.1%	na	36.8%	63.2%	100.0%
		size (mm)	0.72	1.08	0.70	0.58	0.28	0.59	0.43				
1 & 2		density (no. m^{-2})	19,486	1,980	6,499	16,204	60,400	5,989	3,811	3,244	44,169	73,445	117,614
Averaged		%	16.6%	1.7%	5.5%	13.8%	51.4%	5.1%	3.2%	2.8%	37.6%	62.4%	100.0%
		biomass (mg m^{-2})	53.4	5.3	12.5	1.7	46.1	8.1	6.5	na	72.9	60.7	133.7
		%	39.9%	4.0%	9.4%	1.3%	34.5%	6.1%	4.9%	na	54.6%	45.4%	100.0%
		size (mm)	0.83	0.96	0.73	0.57	0.29	0.57	0.45				

Table 11. Available sockeye salmon spawning habitat estimates of Afognak Lake tributaries as determined by creek size and usable habitat in 2005.

Spawning Location	Total Length (m)	Total Width (m)	Total Habitat (m2)	Usable Habitat (%)	Usable Habitat (m2)	Spawning Capacity
Hatchery Creek	3,189	114	23,050	43%	9,916	9,916
Egg Take Creek	1,300	40	8,676	40%	3,448	3,448
Minor Creeks	3,998	50	9,121	21%	1,933	1,933
Total	8,487	204	40,846	37%	15,297	15,297

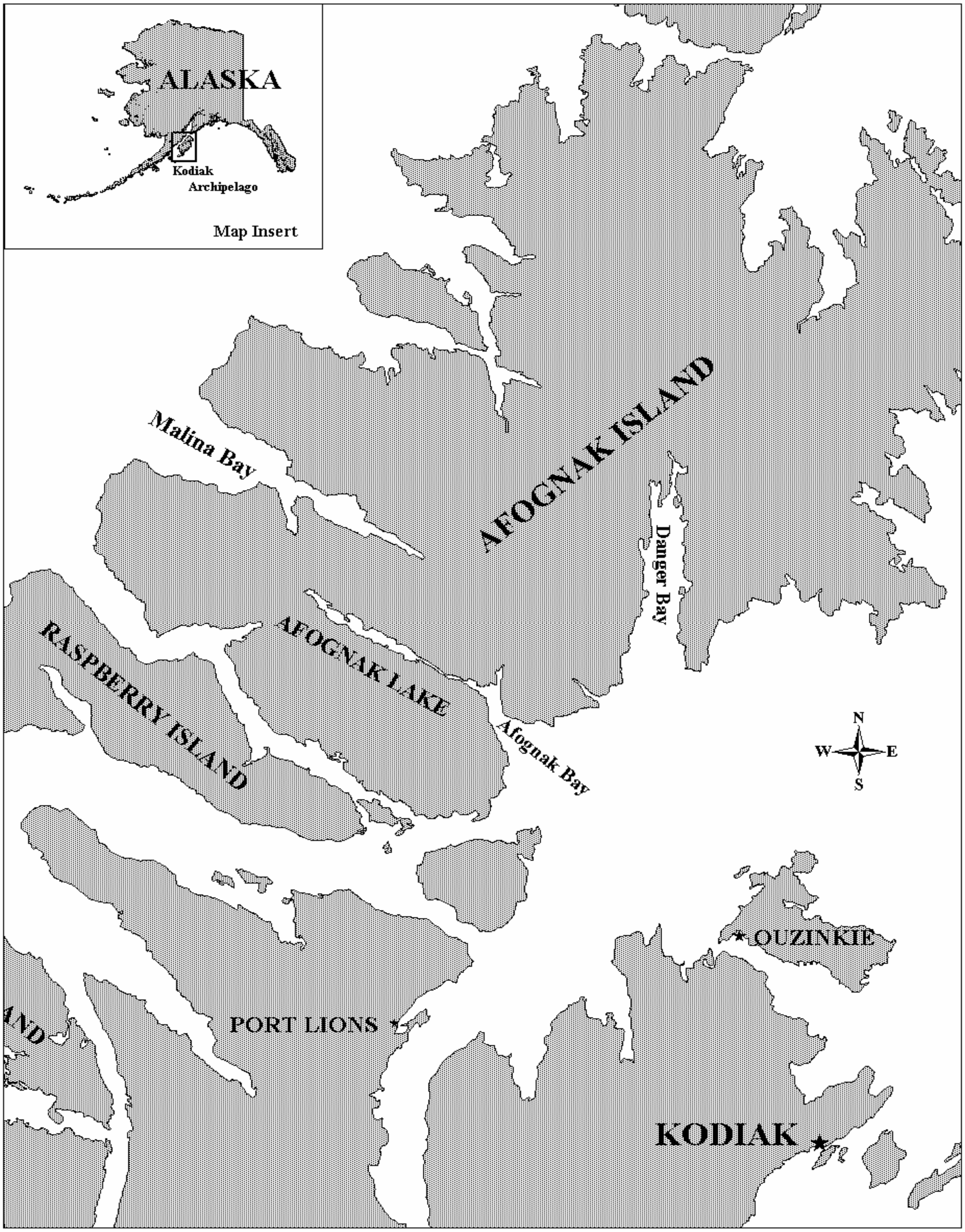

Figure 1. This map displays the location of Kodiak City, and the villages of Port Lions, and Ouzinkie and their proximity to the Afognak Lake drainage on Afognak Island.

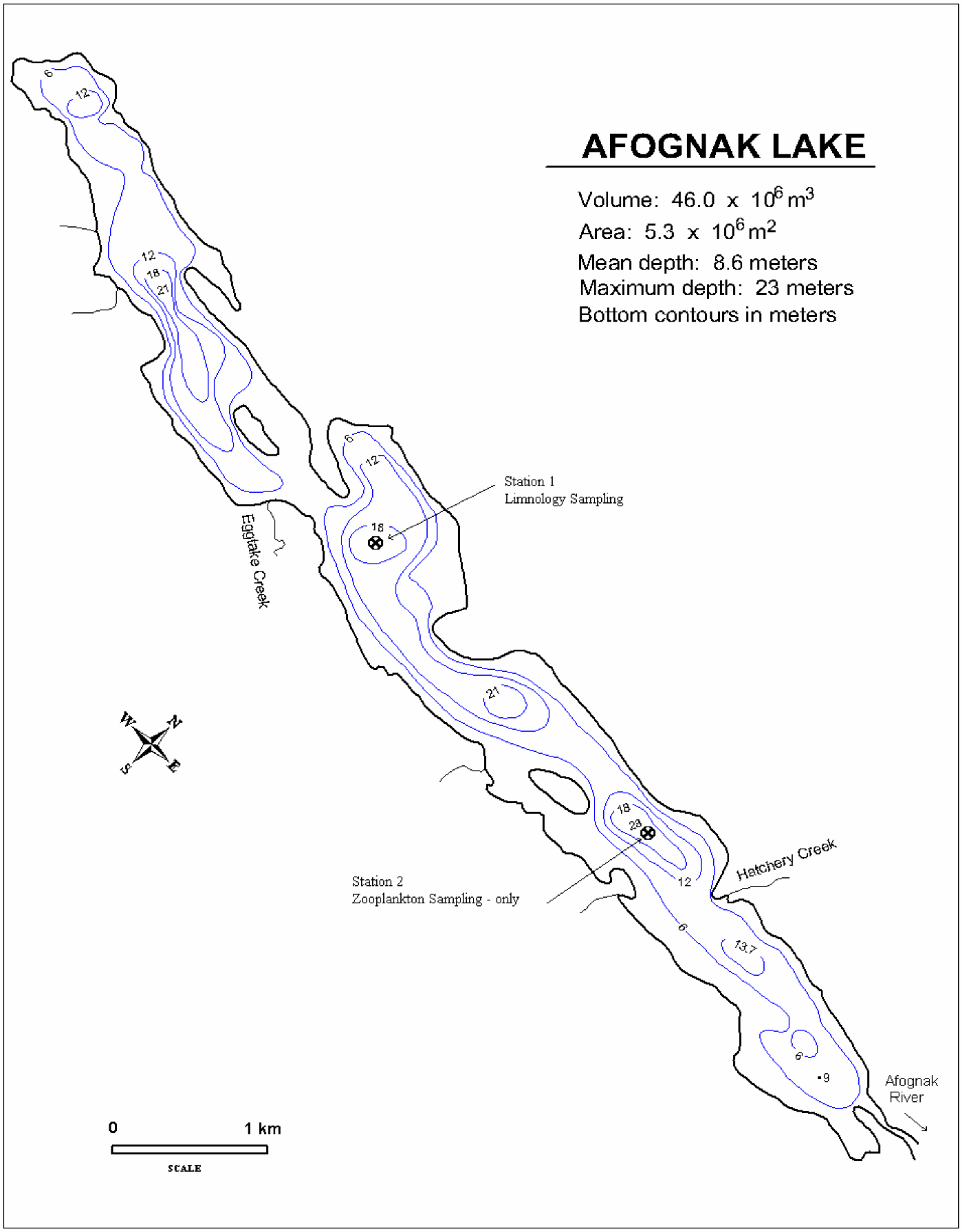

Figure 2. Bathymetric map showing the two limnology and zooplankton stations on Afognak Lake.

Figure 3. The smolt trapping system set up in the Afognak River, 2006.

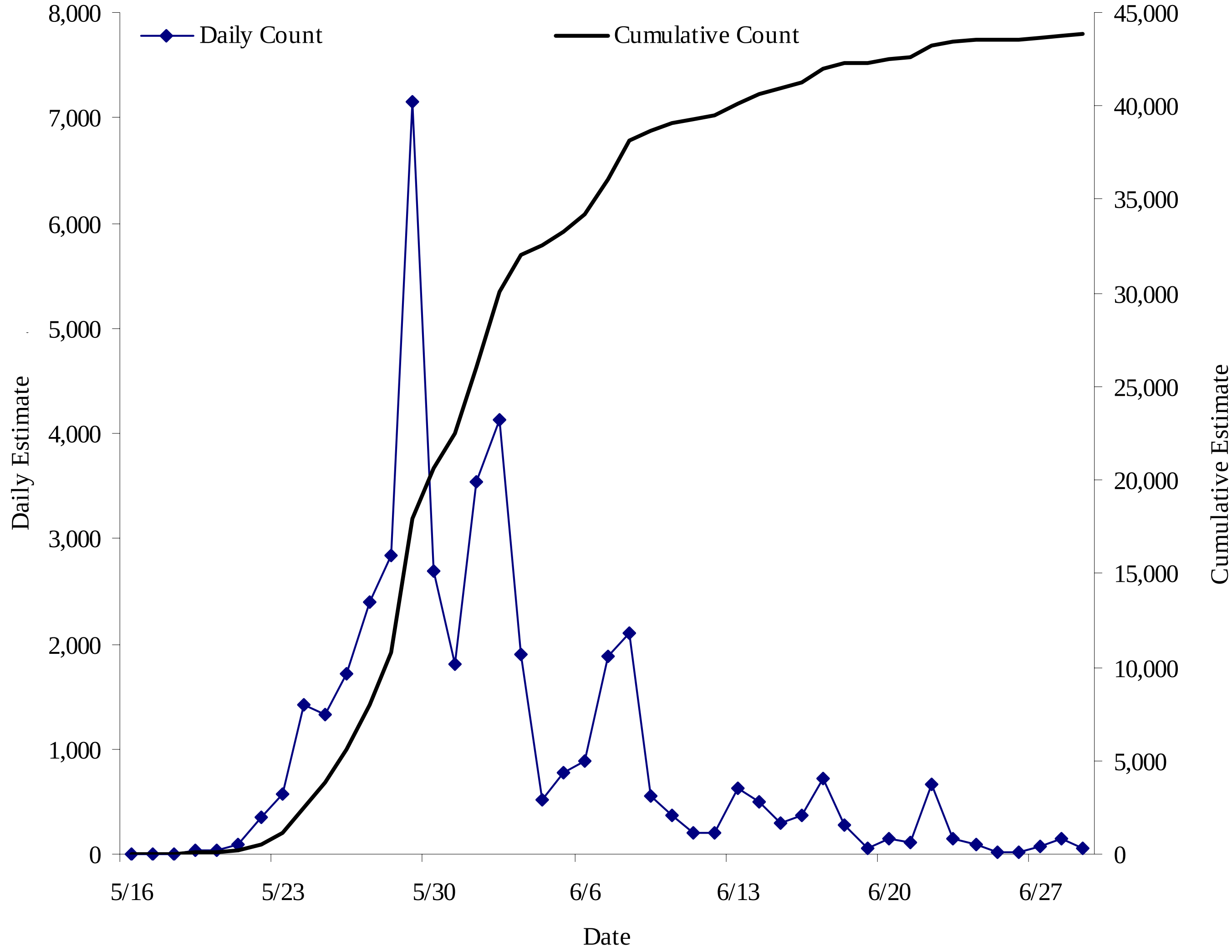

Figure 4. Daily and cumulative sockeye salmon smolt trap catch estimates from 16 May to 29 June in the Afognak River, 2006.

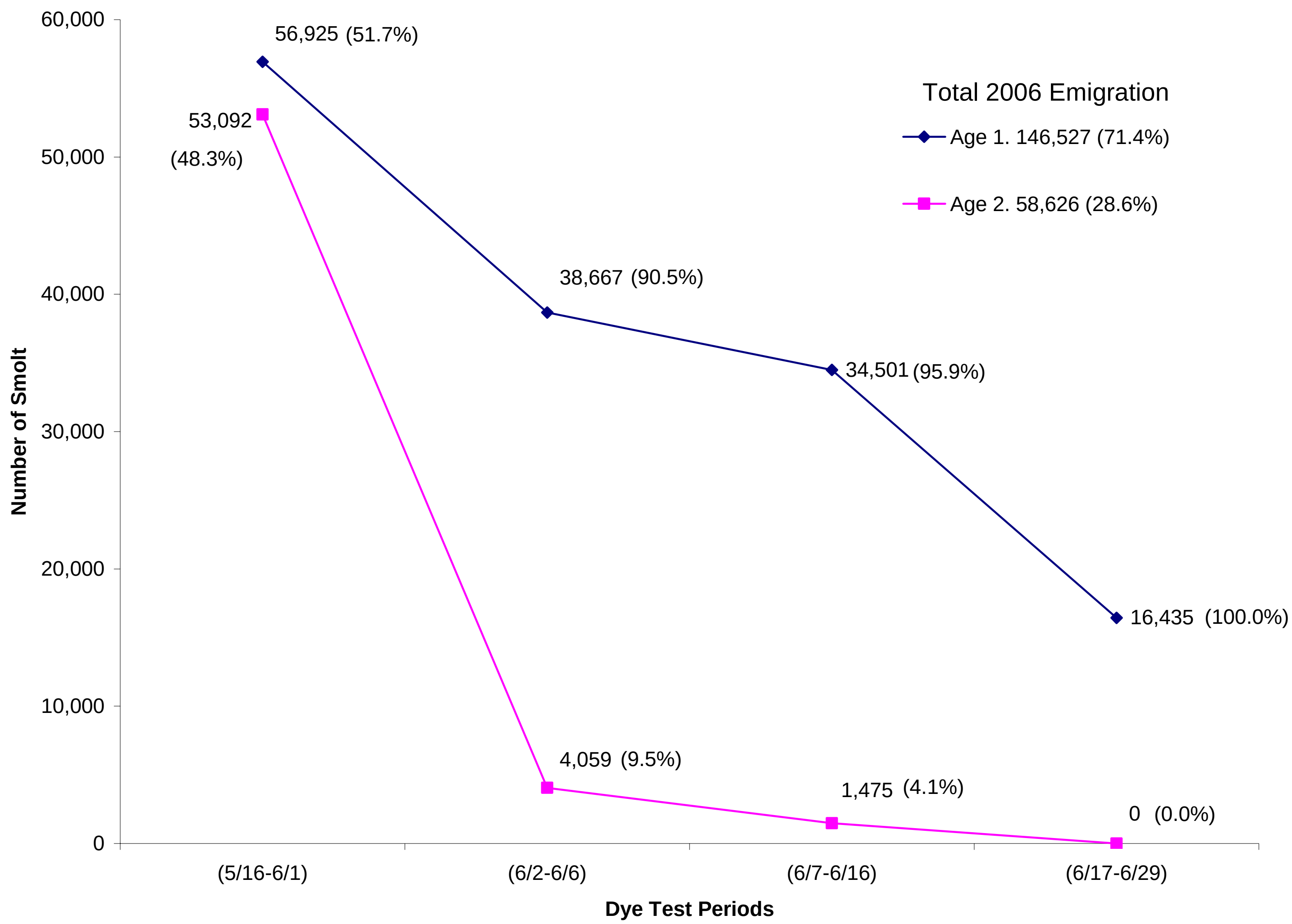

Figure 5. Afognak Lake sockeye salmon smolt emigration by age class and dye test period, 2006.

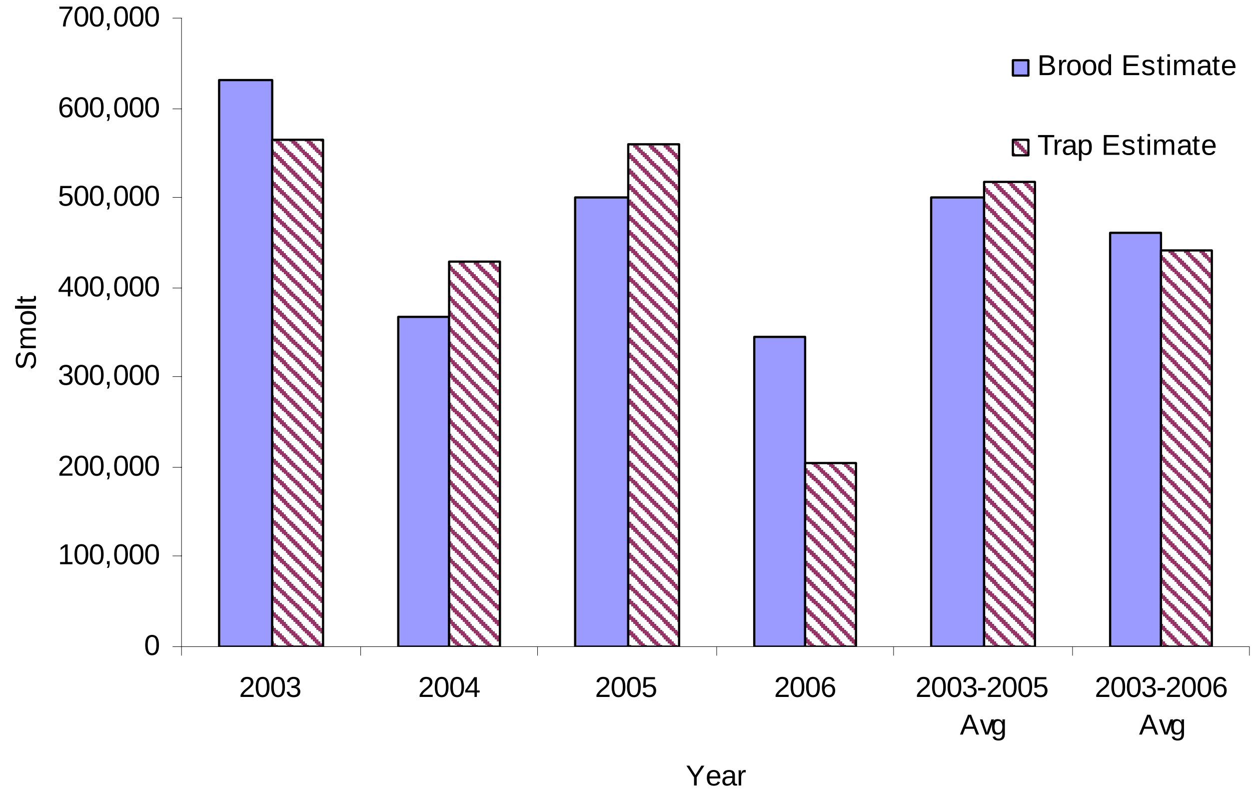

Figure 6. Afognak Lake outmigration estimates from trap catches and theoretical outmigration estimates based on brood year escapements, 2003-2006.

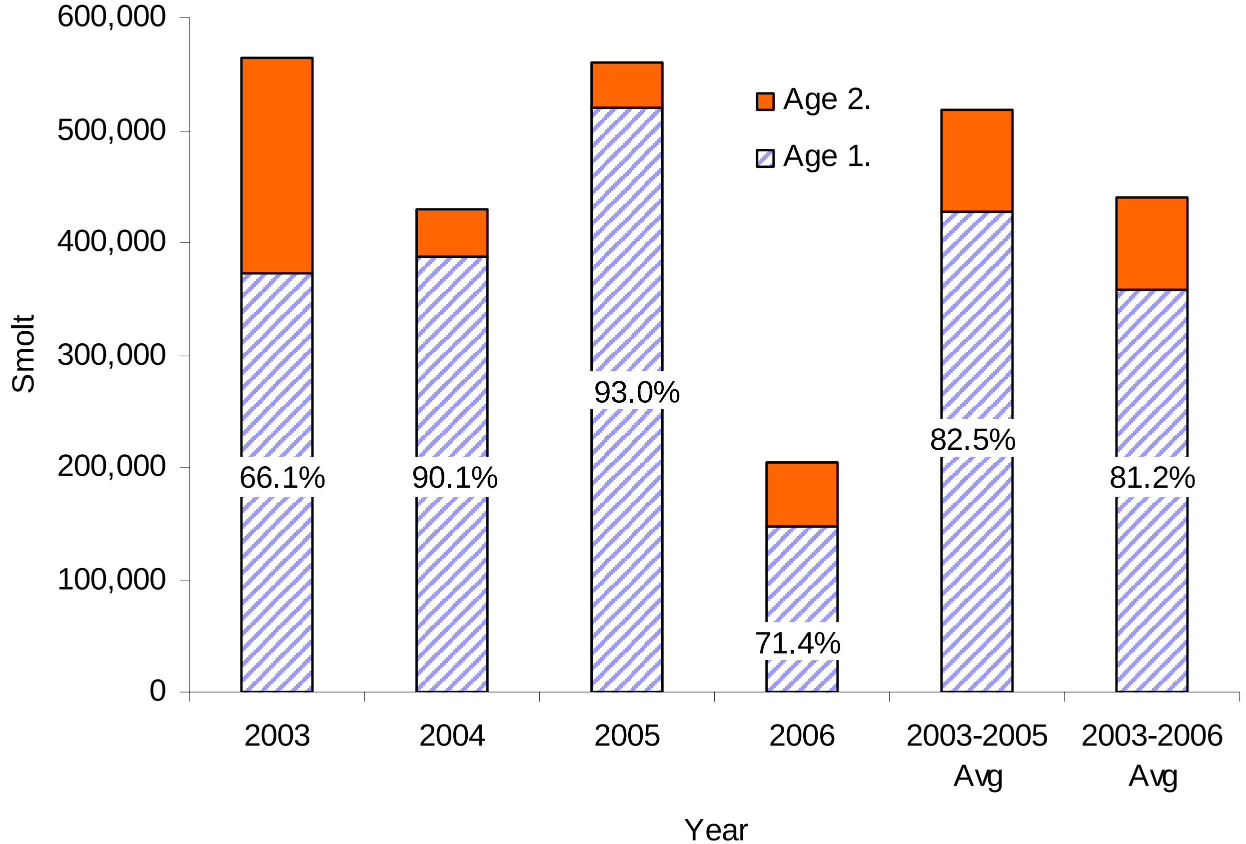

Figure 7. Sockeye salmon smolt emigration by age from Afognak Lake, 2003-2006.

Appendix A1. Population estimates of the sockeye salmon emigrations from Afognak Lake 2003-2006.

Stratum (h)	Starting Date	Ending Date	Catch (u_h)	Released (M_h)	Recaptured (m_h)	Avg.Trap Efficency (%)	Estimate (U_h)	Variance var (U_h)	95% Confidence Interval lower	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=	51,047		
					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=	29,643		

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Appendix A1. (page 2 of 2)

Stratum (h)	Starting Date	Ending Date	Catch (u_h)	Released (M_h)	Recaptured (m_h)	Avg.Trap Efficency (%)	Estimate (U_h)	Variance var (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=	37,590		
					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=	12,347		

Appendix B1. Mean weight, length, and condition coefficient by age for sockeye salmon smolt sampled at Afognak Lake, 1987-2001, and 2003-2006.

		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	May23-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
2003-2005 Avg		1,216	3.9	77.2	0.82	176	4.0	80.5	0.76
2003-2006 Avg		1,104	3.7	75.6	0.82	183	4.0	80.3	0.76

Appendix C1. 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 1989-2006.

	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
Avg 1989-2005	9.5	7.9	16.0	12.6	12.0	11.5
Avg 1989-2006	9.4	7.9	16.0	12.6	12.1	11.6

Appendix D1. 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 1989-2006.

	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
Avg 1989-2005	11.5	10.6	9.9	6.7	11.0	9.6
Avg 1989-2006	11.4	10.6	9.9	6.8	10.9	9.6

Appendix E1. Average light extinction coefficient (Kd), euphotic zone depth (EZD), Secchi disk (SD) transparency, and euphotic volume (EV) from stations 1 and 2 for Afognak Lake, 1987-2006.

	K_d (m^{-1})	Std. Dev.	EZD (m)	Std. Dev.	SD (m)	Std. Dev.	EV ($10^6 m^3$)	Std. Dev.
1987	na	na	8.43	1.14	4.67	1.44	44.65	6.05
1988	na	na	11.91	2.90	4.15	0.46	63.14	15.38
1989	-0.40	0.12	12.53	3.15	4.91	0.58	66.42	16.67
1990	-0.56	0.21	8.95	2.37	3.64	0.63	47.44	12.55
1991	-0.51	0.18	10.02	3.02	2.73	0.52	53.12	16.01
1992	-0.47	0.07	10.05	1.63	2.80	0.92	53.25	8.65
1993	-0.53	0.11	9.17	2.40	3.51	0.53	48.59	12.71
1994	-0.61	0.10	7.41	1.46	3.42	0.37	39.26	7.74
1995	-0.61	0.12	7.40	1.36	2.48	0.56	39.20	7.20
1996	-0.58	0.14	7.97	1.70	3.52	0.40	42.22	9.00
1997	-0.56	0.12	8.42	1.33	3.23	0.75	44.63	7.07
1998	-0.63	0.15	7.36	1.08	3.75	1.21	38.99	5.73
1999	-0.57	0.11	8.91	2.80	2.94	0.55	47.23	14.85
2000	-0.46	0.07	9.78	1.61	3.35	0.63	51.85	8.51
2001	-0.47	0.11	10.86	3.43	3.95	1.14	57.55	18.18
2002	-0.42	0.02	10.43	0.64	4.25	0.54	55.27	3.37
2003	-0.45	0.05	9.71	1.16	4.50	0.23	51.46	6.17
2004	-0.48	0.07	9.11	2.57	4.10	0.49	52.27	13.62
2005	-0.46	0.04	9.65	0.62	4.83	0.63	51.14	3.27
2006	-0.49	0.07	9.01	1.07	4.04	0.71	47.75	5.65
Avg 1987-2005	-0.51	0.11	9.37	1.91	3.72	0.66	49.88	10.14
Avg 1987-2006	-0.51	0.10	9.35	1.87	3.74	0.66	49.77	9.92

Appendix F1. Summary of seasonal mean nutrient and algal pigment concentrations by station and depth for Afognak Lake, 1990-2006.

Year	Station	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 +Nitrate (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
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	NA	NA	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	NA	NA	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	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	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	NA	NA	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	NA	NA	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	NA	NA	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	NA	NA	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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Appendix F1. (page 2 of 2)

Year	Station	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 +Nitrate (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	NA	3.7	NA	1.9	NA	182	NA	25	NA	63	NA	2311	NA	36	NA	0.09	NA	0.03	NA
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	NA	NA	NA	NA	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	NA	NA	NA	NA	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	NA	NA	NA	NA	1.36	0.14	0.30	0.20
2003	1	1	6.5	3.0	2.2	0.8	2.1	0.8	NA	NA	6	1.8	54	26.9	NA	NA	NA	NA	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	NA	NA	1.15	0.18	0.28	0.08
	1	18	5.9	2.3	6.2	8.3	3.5	3.5	NA	NA	19	13.2	80	28.4	2914	277.1	NA	NA	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	NA	NA	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	NA	NA	NA	NA	1.92	0.32	0.50	0.09
1990-2005 Avg		1	7.7	3.3	4.0	2.5	3.0	1.9	154	37.2	11	9.4	50	27.2	2602	314.4	199	66.4	1.70	0.91	0.59	0.32
1990-2006 Avg		1	7.7	3.3	3.9	2.4	3.0	1.9	151	38.4	11	9.0	48	27.3	2602	314.4	199	66.4	1.71	0.88	0.59	0.31
2001-2005 Avg		1	7.7	3.7	5.0	3.2	3.5	2.4	144	46.8	6	2.5	44	28.9	2732.5	293.3	NA	NA	1.54	0.35	0.32	0.20
2001-2006 Avg		1	7.6	3.8	4.5	2.9	3.3	2.2	135	49.3	6	2.4	41	29.2	2732	293.3	NA	NA	1.60	0.34	0.35	0.18

NA = not analyzed; SD = standard deviation

Appendix G1. Summary of seasonal mean water chemistry parameters by station and depth for Afognak Lake, 1990-2006.

	Station	Depth	Sp. Conductivity		pH		Alkalinity		Turbidity		Color		Calcium		Magnesium		Iron	
Year		(m)	(umhos cm^{-1})	SD	(Units)	SD	(mg L^{-1})	SD	(NTU)	SD	(Pt units)	SD	(mg L^{-1})	SD	(mg L^{-1})	SD	(ug L^{-1})	SD
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	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	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	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
1997	1	1	53	0.6	7.1	0.2	12.1	1.6	1.1	0.1	9	1.9	3.1	0.4	1.1	0.3	28	16.6
	1	18	58	6.7	6.8	0.2	13.9	3.5	1.7	0.4	10	0.8	2.9	0.5	1.7	1.1	68	37.7
	2	1	53	0.8	7.1	0.1	11.7	0.5	1.0	0.2	11	3.8	3.0	0.3	1.0	0.3	34	17.3
	2	13	53	0.5	7.0	0.1	11.9	0.3	1.3	0.5	10	3.0	2.9	0.3	1.0	0.3	44	25.8
1998	1	1	49	0.6	7.0	0.1	12.6	1.3	1.7	1.2	18	10.7	3.2	0.5	0.8	0.2	26	15.0
	1	18	48	NA	7.0	NA	11.8	NA	2.0	NA	11	NA	3.3	NA	1.0	NA	48	NA
1999	1	1	58	0	6.8	0.2	11.1	0.6	1.6	1.0	11	1.7	3.3	0.3	1.4	0.1	82	43.8
2000	1	1	NA	NA	7.1	0.2	8.7	2.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2001	1	1	NA	NA	7.2	0.4	10.1	2.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2002	1	1	NA	NA	7.2	0.5	10.1	0.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2003	1	1	NA	NA	6.9	0.1	9.8	0.6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2004	1	1	NA	NA	6.9	0.1	11.4	0.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	1	18	NA	NA	6.8	0.1	10.9	0.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2005	1	1	NA	NA	6.8	0.1	10.9	1.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2006	1	1	NA	NA	6.8	0.1	11.3	0.9	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1990-2005 Avg		1	49	2.1	6.8	0.2	9.7	1.6	1.2	0.6	11	3.6	2.9	0.6	1.0	0.3	91	30.0
1990-2006 Avg		1	49	2.1	6.8	0.2	9.8	1.5	1.2	0.6	11	3.6	2.9	0.6	1.0	0.3	91	30.0
2001-2005 Avg		1	NA	NA	7.0	0.3	9.9	1.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2001-2006 Avg		1	NA	NA	7.0	0.2	10.6	1.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

NA - not analyzed; SD - standard deviation

Appendix H1. Weighted mean zooplankton density, biomass, size by species for station 1 (1987-2006) and station 2 (1988-2006), Afognak Lake.

Station		*Epischura*			*Diaptomus*			*Cyclops*			*Bosmina*			*Daphnia*			*Holopedium*			TOTALS	
1	No.	Density	Biomass	Size	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)	(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	0.52	177,297	251
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	0.53	134,197	191
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	0.48	92,748	141
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	0.47	188,759	224
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	0.50	244,837	325
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	0.45	144,411	240
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	0.50	292,150	407
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	0.48	310,429	377
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	0.46	275,204	360
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	0.47	423,704	670
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	0.43	138,679	205
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	0.42	205,123	236
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	0.46	176,489	269
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	0.46	116,722	188
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	0.43	85,446	120
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	0.41	57,311	71
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	0.48	151,407	173
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	0.48	102,931	119
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	0.43	120,614	148
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	0.46	134,204	205
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	0.51	134,747	194
1987-2005 Avg		24,903	87	0.91	2,040	7	0.87	8,499	13	0.66	140,434	134	0.32	6,589	12	0.63	2,746	5	0.47	180,971	248
1987-2006 Avg		25,136	88	0.91	2,110	7	0.87	8,570	13	0.67	137,238	130	0.32	6,680	12	0.62	2,926	5	0.47	178,633	246
2001-2005 Avg		24,523	51	0.77	1,888	4	0.83	6,460	8	0.60	64,427	54	0.31	4,406	6	0.55	1,837	3	0.45	103,542	126
2001-2006 Avg		25,363	58	0.79	2,149	5	0.83	7,036	10	0.63	66,443	55	0.31	5,073	7	0.55	2,589	4	0.45	108,652	139

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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
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
1988-2005 Avg		15,673	55	0.92	661	2	0.97	3,470	5	0.67	110,433	101	0.31	3,568	6	0.65	2,068	4	0.45	135,874	172
1988-2006 Avg		15,191	52	0.90	650	2	0.95	3,440	5	0.67	105,344	96	0.31	3,569	6	0.65	2,006	3	0.45	130,201	163

Appendix I1. Adult sockeye salmon spawning estimates within the Afognak Lake system and useable spawning habitat estimates at Eggtake and Hatchery Creeks.

	Number of Sockeye Salmon									
	Eggtake Creek				Hatchery Creek				Lake	
Year[a]	Live	Dead	Other[b]	Sub Total	Live	Dead	Other[b]	Sub Total	Shoal[b]	Total
Observed number of spawners										
1961	3,400	200		3,600	5,000	1,580		6,580	41,743	51,923
1978			11,224	11,224			5,666	5,666	35,811	52,701
1982[c]			16,362	16,362			31,840	31,840	70,853	119,055
Spawner Estimate Average:				10,395				14,695	49,469	74,560
Estimated spawning capacity of habitat										
1990[d]				6,595				9,712	n/a	n/a
2005[e]				3,448				9,916	n/a	n/a
Available Spawning Habitat Average:				5,022				9,814	n/a	n/a

[a] Data summarized from Sheridan 1961; Roelofs 1964; Schwarz pers. comm.; Willette *unpublished* ; White et al. 1990.
[b] Data were not separated into live or dead.
[c] Data estimates were obtained from a tagging study from Willette *unpublished*.
[d] Available spawning habitat measurements were first reported in White et. al 1990 but the actual survey was conducted at an undocumented prior date.
[e] Available spawning habitat measurements were collected with methods described in Baer et al. 2005.

Appendix J1. Estimated age composition of the Afognak Lake sockeye salmon escapement, 1987-2006.

	Sample		Ages									
Year	Size		1.1	1.2	2.1	1.3	2.2	3.1	1.4	2.3	3.2	3.3
1987	281	Numbers	1,695	9,797	284	9,609	1,131	0	0	3,863	0	0
		Percent	6.4	37.0	1.1	36.3	4.3	0.0	0.0	14.6	0.0	0.0
1988	933	Numbers	263	23,059	824	9,773	4,488	0	0	429	0	0
		Percent	0.7	59.1	2.1	25.1	11.5	0.0	0.0	1.1	0.0	0.0
1989	1,088	Numbers	13,288	13,404	3,135	35,165	16,314	0	0	7,519	0	0
		Percent	15.0	15.1	3.5	39.6	18.4	0.0	0.0	8.5	0.0	0.0
1990	1,053	Numbers	597	42,314	553	20,518	7,754	0	261	18,613	0	0
		Percent	0.7	46.7	0.6	22.6	8.6	0.0	0.3	20.5	0.0	0.0
1991	1,062	Numbers	295	13,054	196	67,805	3,101	0	0	4,106	0	0
		Percent	0.3	14.7	0.2	76.6	3.5	0.0	0.0	4.6	0.0	0.0
1992	1,025	Numbers	16,362	17,115	7,681	23,096	2,938	90	394	9,526	61	0
		Percent	21.2	22.2	9.9	29.9	3.8	0.1	0.5	12.3	0.0	0.0
1993	852	Numbers	11,837	7,634	12,318	21,667	8,818	53	0	8,965	163	0
		Percent	16.6	10.7	17.2	30.3	12.3	0.1	0.0	12.5	0.2	0.0
1994	840	Numbers	7,703	24,648	3,337	28,385	8,316	125	61	7,708	64	0
		Percent	9.6	30.6	4.1	35.2	10.3	0.2	0.1	9.6	0.1	0.0
1995	848	Numbers	2,281	21,788	837	56,367	10,773	0	149	7,776	0	0
		Percent	2.3	21.8	0.8	56.3	10.8	0.0	0.1	7.8	0.0	0.0
1996	1,119	Numbers	16,340	9,398	2,184	44,744	2,095	0	185	26,427	80	0
		Percent	16.0	9.2	2.1	44.0	2.1	0.0	0.2	26.0	0.1	0.0
1997	1,168	Numbers	5,234	29,004	7,330	47,888	2,351	0	41	14,840	0	0
		Percent	4.9	27.1	6.9	44.8	2.2	0.0	0.0	13.9	0.0	0.0
1998	1,240	Numbers	13,039	5,483	5,082	31,763	7,289	134	267	3,812	0	0
		Percent	19.5	8.2	7.6	47.5	10.9	0.2	0.4	5.7	0.0	0.0
1999[a]	1,195	Numbers	661	30,350	427	6,911	30,943	72	202	5,466	456	0
		Percent	0.9	40.2	0.6	9.1	41.0	0.1	0.3	7.2	0.6	0.0
2000	1,161	Numbers	887	1,276	171	8,302	3,084	0	0	37,238	1,753	0
		Percent	1.7	2.4	0.3	15.6	5.8	0.0	0.0	70.0	3.3	0.0
2001	790	Numbers	137	2,393	833	5,473	676	1,877	0	9,328	0	0
		Percent	0.7	11.4	4.0	26.2	3.2	9.0	0.0	44.6	0.0	0.0
2002	238	Numbers	20	215	683	6,871	4,626	176	0	976	5,934	0
		Percent	0.1	1.1	3.5	35.2	23.7	0.9	0.0	5.0	30.4	0.0
2003	498	Numbers	1,148	6,273	66	233	7,141	0	0	8,229	770	3,907
		Percent	4.1	22.6	0.2	0.8	25.7	0.0	0.0	29.6	2.8	14.1
2004[b]	566	Numbers	170	6,720	25	2,888	280	0	3	4,073	0	843
		Percent	1.1	44.3	0.2	19.0	1.8	0.0	0.0	26.8	0.0	5.6

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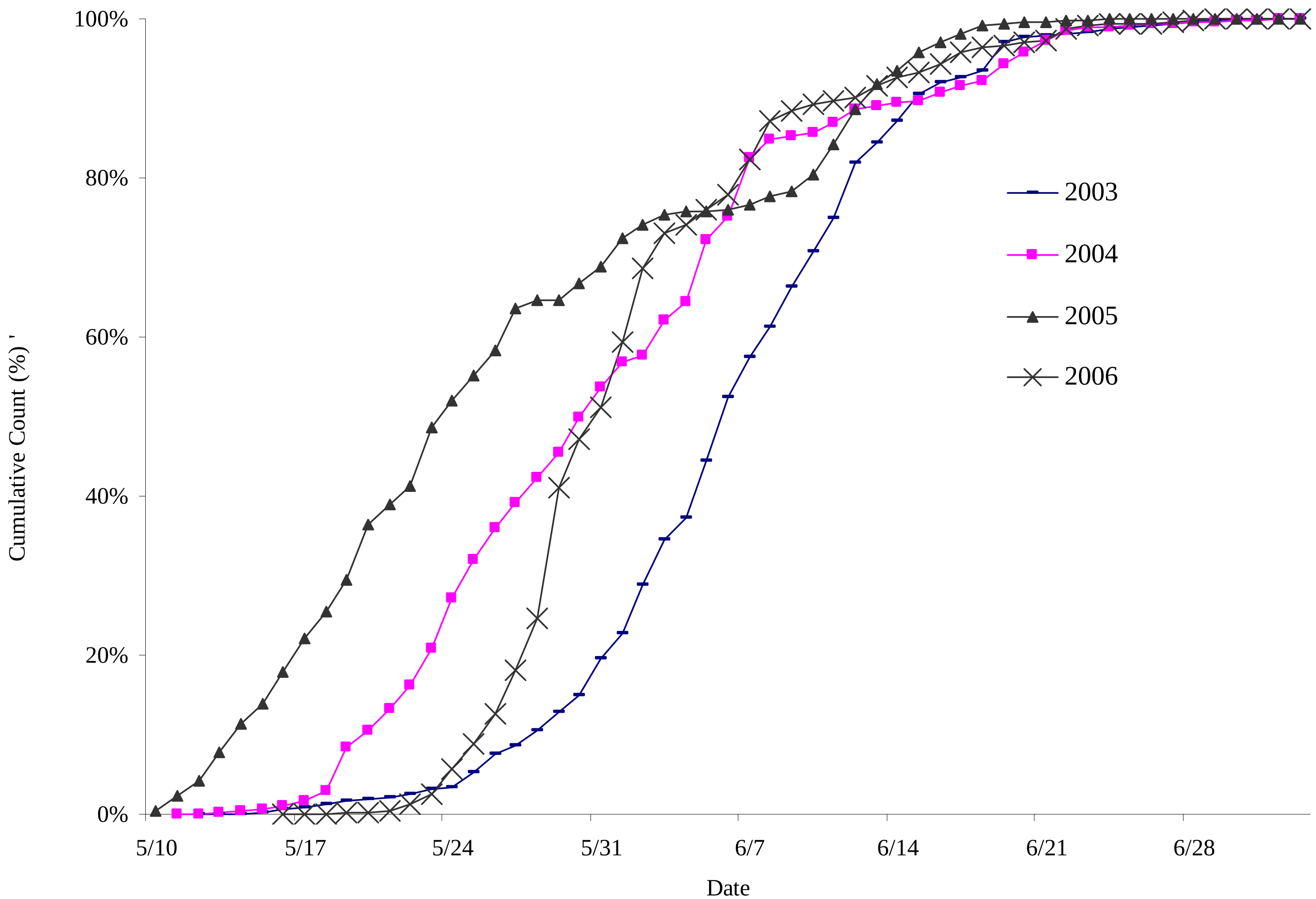
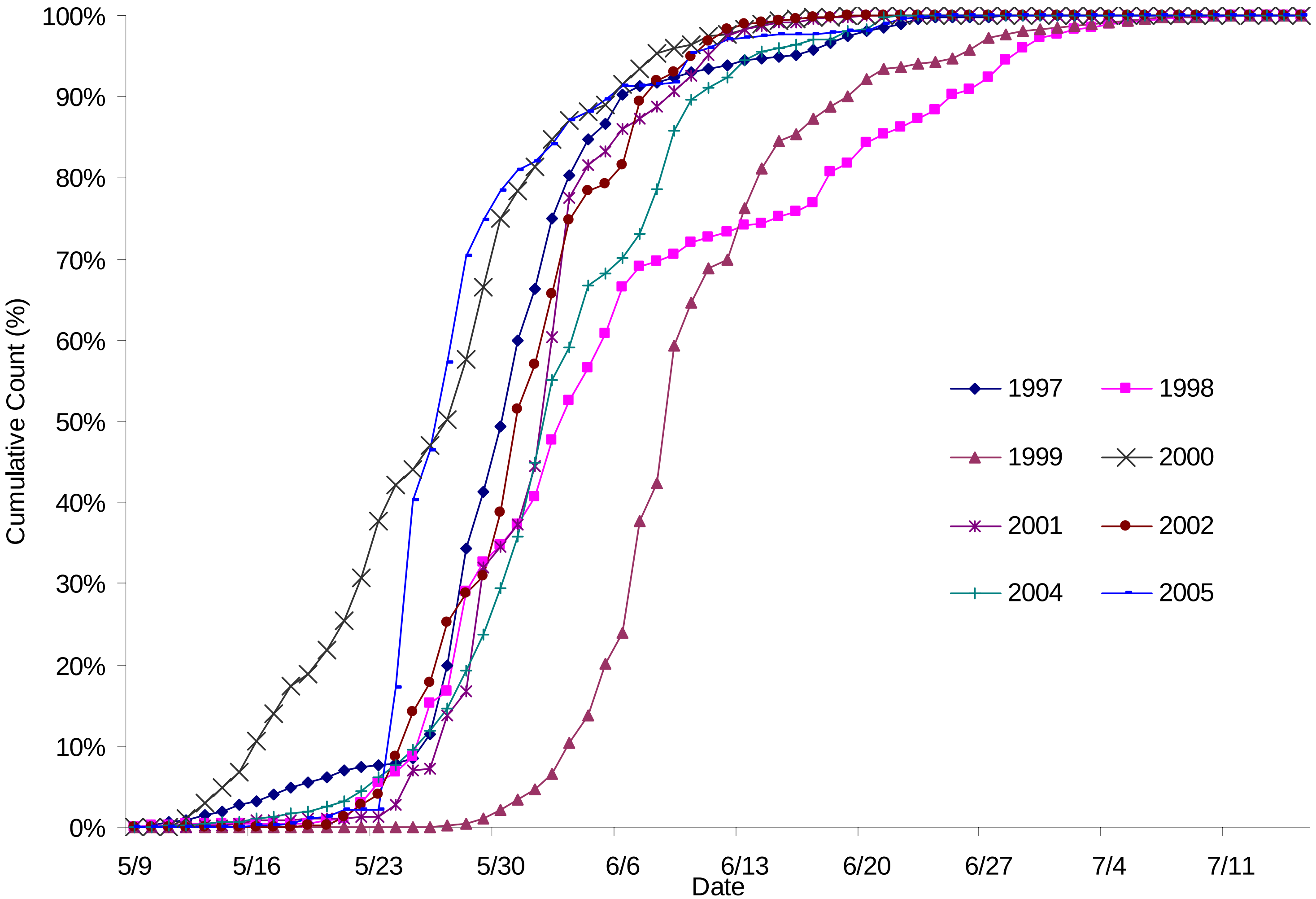
Year	Sample Size		Ages 1.1	1.2	2.1	1.3	2.2	3.1	1.4	2.3	3.2	3.3
2005[c]	572	Numbers	683	2,153	136	17,697	472	0	0	280	0	843
		Percent	3.2	10.0	0.6	82.0	2.2	0.0	0.0	1.3	0.0	5.6
2006[d]	613	Numbers	569	14,481	0	5,075	596	0	36	2,156	0	0
		Percent	2.5	63.1	0.0	22.1	2.6	0.0	0.2	9.4	0.0	0.0
Average		Numbers	4,876	14,004	2,426	23,429	6,452	133	82	9,430	488	294
1987-2005		Percent	6.6	22.9	3.4	35.6	10.6	0.6	0.1	16.9	2.0	1.3
Average		Numbers	4,660	14,028	2,305	22,511	6,159	126	80	9,066	464	280
1987-2006		Percent	6.4	24.9	3.3	34.9	10.2	0.5	0.1	16.6	1.9	1.3

[a] In 1999, 72 (0.1%) sockeye salmon were aged 0.4.
[b] In 2004, 179 (1.2%) sockeye salmon were aged 2.4.
[c] In 2005, 157 (0.7%) sockeye salmon were age 0.3.
[d] In 2006, 20 (0.1%) sockeye salmon were age 0.3.



Appendix K1. Sockeye salmon smolt emigration timing from Afognak Lake, 2003-2006.



Appendix L1. Sockeye salmon smolt emigration timing from Malina Lakes, 1997-2002, and 2004-2005.