**Fishery Data Series No. 09-17**

# Stock Assessment and Restoration of the Afognak Lake Sockeye Salmon Run, 2007

**by**

**Robert T. Baer,**

**Stephen T. Schrof,**

**Birch M. Foster**

**and**

**Steven G. Honnold**

**March 2009**

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

# Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used without definition in the following reports by the Divisions of Sport Fish and of Commercial Fisheries: Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications. All others, including deviations from definitions listed below, are noted in the text at first mention, as well as in the titles or footnotes of tables, and in figure or figure captions.

**Weights and measures (metric)**

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

**Weights and measures (English)**

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

**Time and temperature**

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

**Physics and chemistry**

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

**General**

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

**Measures (fisheries)**

| | |
|---|---|
| fork length | FL |
| mideye to fork | MEF |
| mideye to tail fork | METF |
| standard length | SL |
| total length | TL |

**Mathematics, statistics**

| | |
|---|---|
| *all standard mathematical signs, symbols and abbreviations* | |
| alternate hypothesis | $H_A$ |
| base of natural logarithm | *e* |
| catch per unit effort | CPUE |
| coefficient of variation | CV |
| common test statistics | (F, t, $\chi^2$, etc.) |
| confidence interval | CI |
| correlation coefficient (multiple) | R |
| correlation coefficient (simple) | r |
| covariance | cov |
| degree (angular ) | ° |
| degrees of freedom | df |
| expected value | *E* |
| greater than | > |
| greater than or equal to | ≥ |
| harvest per unit effort | HPUE |
| less than | < |
| less than or equal to | ≤ |
| logarithm (natural) | ln |
| logarithm (base 10) | log |
| logarithm (specify base) | $log_2$, etc. |
| minute (angular) | ' |
| not significant | NS |
| null hypothesis | $H_O$ |
| percent | % |
| probability | P |
| probability of a type I error (rejection of the null hypothesis when true) | α |
| probability of a type II error (acceptance of the null hypothesis when false) | β |
| second (angular) | " |
| standard deviation | SD |
| standard error | SE |
| variance | |
| population | Var |
| sample | var |

*FISHERY DATA SERIES NO. 09-17*

# STOCK ASSESSMENT AND RESTORATION OF THE AFOGNAK LAKE SOCKEYE SALMON RUN, 2007

by


Robert T. Baer,
Alaska Department of Fish and Game, Division of Commercial Fisheries, Kodiak

and

Stephen T. Schrof,
Alaska Department of Fish and Game, Division of Commercial Fisheries, Kodiak

Birch M. Foster,
Alaska Department of Fish and Game, Division of Commercial Fisheries, Kodiak

Steven G. Honnold,
Alaska Department of Fish and Game, Division of Commercial Fisheries, Kodiak



Alaska Department of Fish and Game
Division of Sport Fish, Research and Technical Services
333 Raspberry Road, Anchorage, Alaska, 99518-1565

March 2009

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

*Robert T. Baer,*
*Alaska Department of Fish and Game, Commercial Fisheries,*
*211 Mission Road, Kodiak, AK 99615 USA*

*Stephen T. Schrof,*
*Alaska Department of Fish and Game, Commercial Fisheries,*
*211 Mission Road, Kodiak, AK 99615 USA*

*Birch M. Foster,*
*Alaska Department of Fish and Game, Commercial Fisheries,*
*211 Mission Road, Kodiak, AK 99615 USA*

*and*

*Steven G. Honnold,*
*Alaska Department of Fish and Game, Commercial Fisheries,*
*211 Mission Road, Kodiak, AK 99615 US*

*This document should be cited as:*
*Baer, R. T., S. T. Schrof, M. B. Foster, and S. G. Honnold. 2009. Stock assessment and restoration of the Afognak Lake sockeye salmon run, 2007. Alaska Department of Fish and Game, Fishery Data Series No. 09-17, Anchorage.*

# TABLE OF CONTENTS

# LIST OF TABLES



# LIST OF FIGURES



# LIST OF APPENDICES

# ABSTRACT

Beginning in 2001 the Afognak Lake sockeye salmon *Oncorhynchus nerka* runs substantially declined. Concerns expressed by local subsistence users to the Alaska Department of Fish and Game and the US Fish and Wildlife Service Office of Subsistence Management prompted a seasonal investigation of the lake's rearing environment beginning in 2003, which has continued until the present. This report provides the 2007 fishery and limnology results from the Afognak Lake study and fulfills annual reporting requirements to the US Fish and Wildlife Service Office of Subsistence Management, the funding agent for this project (project 07-401).

During 2007, 55,315 sockeye salmon smolt were captured using a Canadian fan trap operated from 10 May to 4 July. Using mark-recapture techniques, we estimated that 275,450 sockeye salmon smolt (95% CI 240,388 – 310,512) emigrated from Afognak Lake. The population was composed of 237,383 age-1. and 38,067 age-2. smolt. Age-1. smolt had a mean weight of 2.6 g, a mean length of 70.4 mm, and a mean condition factor of 0.75. Age-2. smolt had a mean weight of 3.4 g, a mean length of 76.5 mm, and a mean condition factor of 0.74.

Five limnology surveys were conducted in Afognak Lake from May to September, 2007. Seasonal physical conditions and water chemistry values were generally consistent with historical data collected from Afognak Lake: however phosphorus concentrations in 2007 were the lowest recorded levels of phosphorus in Afognak Lake. Seasonal zooplankton density averaged 112,480 animals per $m^2$, and cladocerans comprised 64.2% of the zooplankton sampled. The cladoceran *Bosmina* was the most abundant zooplankter, while *Epischura* was the most abundant copepod.

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

# 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. 2007; Caldentey 2007; Dinnocenzo et al. 2007). 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 (Figure 1). The sockeye salmon commercial fishery remained closed in 2006 and 2007. 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 throughout the 2005 and 2006 seasons without any restrictions but was closed again in 2007. 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 seasons with minimal harvests while a closure occurred in 2007 through the month of July. Although the subsistence fishing closures restricted harvest of sockeye salmon and caused fishing efforts to shift to other systems, 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. 2007). Local villagers from Port Lions and Ouzinkie as well as Kodiak area residents have traditionally harvested fish in Afognak Bay (Figure 1). The subsistence fishery is prosecuted within the boundaries of the Alaska Maritime National Wildlife Refuge. Subsistence harvests in Afognak Bay from 1990 to 2007 have ranged from 417 (2007) to 12,412 (1997) sockeye salmon (Table 1). The smallest annual sockeye salmon subsistence numbers on record are from the most recent six years (2002-2007).

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 (OSM), 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 considered it 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 (1992, 1994, 1996-1998) into Afognak Lake to enhance the sockeye salmon run (White et al. 1990). 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 fertilization 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 OSM provided funding for a three-year study (2004-2006) that enabled the continuation of smolt assessment work, examination of rearing and spawning capacity, and estimation of the sockeye salmon production potential of Afognak Lake. A final report in 2007 consolidated historical fishery and limnological data, provided results of a sockeye salmon escapement goal review and production analysis conducted in 2004-2005, and documented the final results of the project. The three year study indicated that rearing conditions within Afognak Lake appeared to be stable or improving 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 (86%) to emigrate at age-1.

Continued analysis of Afognak Lake and annual smolt emigration studies were determined to be of high importance to evaluate if there were changes in the nutrient-food web dynamics (e.g., if the structure of consumer communities have modified nutrient transfer along the food web) and how these changes may have affected the growth and production of the juvenile sockeye salmon emigrating from Afognak Lake. Recognizing the importance of continued analysis on Afognak Lake sockeye salmon production, the OSM extended funding to ADF&G for an additional three-year study (2007-2009). This annual report summarizes the 2007 fishery and limnological results associated with the Afognak Lake system.

## OBJECTIVES OF THE PROJECT

1. Estimate the number, age, and average size at age of sockeye salmon smolt emigrating from Afognak Lake for 2007 through 2009.
   - Estimate the number (achieving 25% relative error) with a 95% confidence.
   - Estimate the age proportion within d=0.03 of the true proportion with 95% confidence.
   - Estimate the average length within 0.5 mm of the true average length and the average weight within 0.25 g of the true average weight with a 95% confidence.
2. Evaluate the water chemistry, nutrient status, and plankton production of Afognak Lake from 2007-2009.
3. Assess the rearing conditions for juvenile sockeye salmon in Afognak Lake based upon completion of objectives 1 and 2.

## BACKGROUND

A counting weir was first established just below the lake outlet on the upper reaches of the Afognak River in 1921 and was operated intermittently through 1977. Since 1978 to the present, escapement data has been collected annually. In 1986, the weir was relocated to its current location, just before terminating into the bay, and ADF&G has maintained annual weir counts in conjunction with sockeye salmon age, length and sex (ALS) sampling. Catch data have been documented through the ADF&G commercial landing fish ticket system, statewide sport fish surveys, and return of subsistence fishing permits since the late 1970s (Dinnocenzo et al. 2007).

Prior to 2005 the Afognak Lake sockeye salmon escapement goal range was 40,000 to 60,000 fish (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 (Honnold and Schrof 2001; Schrof et al. 2000; White et al. 1990). 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 (Schrof et al. 2000; White et al. 1990). The Afognak Lake sockeye salmon stock was selected as a brood stock for barren lake stocking projects on Afognak Island, with the first fish 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 to 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 to 1998. To alleviate concerns of increasing the grazing pressure exerted by stocked fry on the zooplankton population, lake fertilization was continued. In 1999, the ADF&G wanted the KRAA to follow the established egg take goals in order to avoid stocking excess fry into Afognak Lake (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. The team recommended changing the escapement goal from a 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. In 2007, the escapement goal was reevaluated with three additional years of data and was recommended to remain a BEG of 20,000 to 50,000 fish (Honnold et al. 2007). Escapements during the last seven years have been just below (2002 and 2004) to just above (2001, 2003, 2005-2007) the lower end of the new BEG range (Table 1). However, the Policy for Sustainable Salmon Management instructs the 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 (Barrett et al. 1993a, 1993b; Coggins 1997; Coggins and Sagalkin 1999; Edmundson et al. 1994a, 1994b; Honnold 1997; Honnold and Edmundson 1993; Kyle et al. 1988, 1990; Kyle and Honnold 1991; Sagalkin 1999; Sagalkin and Honnold 2003; Schrof et al. 2000; Swanton et al. 1996; White et al. 1990). 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. Due to difficulties associated with species separation, the hydroacoustic surveys were discontinued after 1995. Smolt abundance data were collected in 1990 and 1991, but reliable smolt estimates were 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 under the Fishery Resource Monitoring Program (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 what other factors may be affecting sockeye salmon production. 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 is also limited by the amount and quality of available spawning habitat (Honnold and Edmundson 1993; Willette et al. 1995). In 2005, spawning habitat surveys were conducted on the streams and tributaries of Afognak Lake (Baer et al. 2007). 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). The Afognak Native Corporation owns the land surrounding the Afognak Lake system down to tidewater. Afognak Lake (58$^{o}$ 07' N, 152$^{o}$ 55' W) lies 21.0 m above sea level, is 8.8 km long, has a maximum width of 0.8 km, and has a surface area of 5.3 km$^2$ (Schrof et al. 2000; White et al. 1990). The lake has a mean depth of 8.6 m, a maximum depth of 23.0 m, and a 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, which is part of the Alaska Maritime National Wildlife Refuge and where most subsistence fishing occurs.

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 10 May 2007 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 avoid 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 the vertical trap position to be adjusted in response to water level fluctuations. Perforated (3.2 mm) aluminum sheeting (1.2 m x 2.4 m) supported by a Rackmaster®[1] pipe frame was placed at the entrance of the trap in a "V" configuration to divert smolt into the live box. Trapping ceased and the trap was removed from the river on 4 July, after smolt abundance declined and the number captured was less than 100 smolt per day for three consecutive days. Detailed methods for trap installation, operation, and maintenance are described in Baer (2007).

### 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 mortality counts, were entered on a reporting form each time the trap was checked.

### 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 to 500 smolt for each experiment (Carlson et al. 1998; Robson and Regier 1964;). 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

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

the release site, smolt were exposed to a continuously oxygenated solution of Bismark Brown Y dye (1.9 g of dye to 15 gallons of water) for 30 minutes. The smolt were then transferred to a holding box at the release site. Between 2100 and 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 the 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:

$$e_h = \frac{m_h}{M_h} \tag{1}$$

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:

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

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:

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

Within each stratum $h$, the total population size by age class $j$ is estimated as,

$$\hat{U}_{jh} = \hat{U}_h \hat{\theta}_{jh}, \tag{4}$$

where $\hat{\theta}_{jh}$ is the proportion of age class $j$ during each stratum $h$. Variance of $\hat{\theta}_{jh}$ was calculated using the standard variance of a population proportion (Thompson 1987). The variance of $\hat{U}_{jh}$ was calculated as,

$$v\left(\hat{U}_{jh}\right) = \hat{U}_h^{\,2} v\left(\hat{\theta}_{jh}\right) + v\left(\hat{U}_h\right)\hat{\theta}_{jh}^{\,2} \tag{5}$$

The total number of emigrating smolt by age class was calculated by summing the individual strata. Variance of the total emigration estimates was calculated by summing the individual variances.

## Age, Weight, and Length Sampling

Approximately 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 sampled smolt as:

$$K = \frac{W}{L^3} 10^5 \tag{6}$$

where,

| | | |
|---|---|---|
| $K$ | = | smolt condition factor; |
| $W$ | = | weight in g; |
| $L$ | = | snout to fork length in mm. |

## Life History-Based Population Estimates

We also estimated the number of smolt expected to emigrate in 2007 using Afognak Lake escapement data along with actual fecundity estimates and egg to smolt survival rates reported from other clear water lake systems (Bradford 1995; Drucker 1970; Koenings and Kyle 1997). This alternative method of estimating Afognak Lake smolt emigration incorporated sockeye salmon escapement data, female fecundity data, egg-to-smolt survival estimates, and age composition data to generate a theoretical smolt production estimate by year. Using parent spawning escapements in 2004 and 2005, we assumed a 1:1 sex ratio, an average egg deposition of 2,112 per female (average number of eggs per female as determined from 2003-2006 fecundity estimates by Pillar Creek Hatchery), 7% egg-to-fry survival (Bradford 1995; Drucker 1970; 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, 2007. Collected data and water samples were returned to the ADF&G Near Island Laboratory and analyzed as described in Thomsen (2008). 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. Surface readings were calibrated against a hand-held mercury thermometer. Readings were recorded at half-meter intervals to a depth of 5 m, and then at one-meter depth intervals to the lake bottom. Results were categorized into spring (May-June), summer (July-August), and fall (September-October) sampling periods.

Measurements of photosynthetically active wavelengths (PAR) 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 (Kd, m-1) was obtained from the relation:

$$I_z = I_o e^{-Kd} \text{ or } \ln I_z = \ln I_o - K_d z \qquad (7)$$

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 the 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, 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 (TP), total Kjeldahl nitrogen (TKN), 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.

TP, TFP and FRP were analyzed using a Spectronic Genesys 5 Spectrophotometer (SG5) using the potassium persulfate-sulfuric acid digestion method described in Thomsen (2008). 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 $NO_3^-$ + $NO_2^-$ were analyzed using the cadmium reduction method described in Thomsen (2008). $NH_4^+$ was analyzed with a SG5 using the phenol-sodium hypochlorite method described in Thomsen (2008). Total nitrogen, the sum of TKN and $NO_3^-$ + $NO_2^-$, and the ratio of total nitrogen to TP 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 to act as a preservative. 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. The extracts were analyzed with a SG5 using methods described in Thomsen (2008).

Reactive Silicon was determined with a SG5 spectrophotometer using the ammonium molybdate – sodium sulfite method described in Thomsen (2008). Total filterable phosphorus was determined using the same methods as those for TP utilizing filtered water. Filterable reactive phosphorus was determined using the potassium persulfate- sulfuric acid method described in Thomsen (2008).

## Zooplankton

Cladocerans and copepods were identified to the genus 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 averaged. Biomass was estimated from species-specific linear regression equations of length and dry weight derived by Koenings et al. (1987). Zooplankton density and biomass data from the two stations were averaged for each survey.

# RESULTS

## SMOLT ASSESSMENT

### Enumeration and Sampling

Smolt trapping was conducted for a total of 56 days, from 10 May to 4 July, 2007. During this period, 55,315 sockeye salmon smolt were captured (Table 2). The greatest daily sockeye salmon smolt catch was obtained on 6 June when 4,294 smolt were captured (Table 2; Figure 4). During the trapping period a total of 1,090 smolt were collected for biological sampling purposes, of which 1,089 were usable for age, weight, and length data (Table 2).

### Trap Efficiency and Population Estimates

Five mark-recapture experiments were conducted during the sockeye salmon smolt emigration period in 2007 (Table 2). Trap efficiencies ranged from 11.2% during the fifth experiment (28 June - 4 July) to 61.5% during the second experiment (6 - 12 June). Mean trap efficiency for the entire emigration was 19.9%. The total number of sockeye salmon smolt emigrating from the Afognak Lake system in 2007 was estimated to be 275,450 (95% CI 240,388 – 310,512; Table 3).

### Age, Weight, and Length Sampling

Summing the emigration estimates by age over the strata resulted in an estimated emigration estimate of 237,383 age-1. (86.2%) and 38,067 age-2. (13.8%) smolt (Table 4; Figure 5). Age-1. smolt comprised 69.1% of the sample from the first stratum (10 May - 5 June), the second stratum (6 - 12 June) was composed of 94.0% age-1. smolt, the third stratum (13-20 June) contained 99.6% age 1. fish, and the fourth (21-27 June) and fifth strata (28 June - 4 July) both contained 100.0% Age 1. fish.

The sampled age-1. smolt had a mean weight of 2.6 g, a mean length of 70.4 mm, and a mean condition factor of 0.75 (Table 5). The sampled age-2. smolt had a mean weight of 3.4 g, a mean length of 76.5 mm, and a mean condition factor of 0.74 (Table 5).

### Comparisons of Mark-Recapture and Life History-Based Population Estimate Methods

Using the life history-based population estimate method we projected that the 2004 escapement of 15,181 adults (brood year 2004) would produce 32,521 age-2. smolt and the 2005 escapement of 21,577 adults (brood year 2005) would produce 288,722 age-1. smolt (Table 6). A total of 321,243 smolt was projected to emigrate from Afognak Lake in the spring of 2007 (Figure 6).

## LIMNOLOGICAL ASSESSMENT

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

In 2007, water temperatures ranged from 6.7° C near the lake bottom in the spring (May-June) to 15.4° C at the surface in summer (July-August). Temperature stratification was most noticeable in the summer when the average surface temperature was 15.4° C and the average bottom temperature was 9.5° C. Surface and bottom temperatures in the spring and fall (September-October) were similar, indicating that mixing occurred throughout the entire water column during the spring and fall sampling periods. Dissolved oxygen concentrations ranged from 6.6 mg $L^{-1}$ at the bottom in the summer to 11.4 mg $L^{-1}$ at the surface in the spring.

The mean vertical extinction coefficient (Kd $m^{-1}$) or rate of light attenuation was -0.50 $m^{-1}$ in 2007. The mean euphotic zone depth was 9.36 m, while the Secchi disk reading was 4.15 meters. The euphotic volume for Afognak Lake in 2007 was 49.61 $10^6 m^3$.

## General Water Chemistry, Phytoplankton and Nutrients

The pH averaged 6.77 units with little seasonal variation (Table 7). Alkalinity levels (measured as $CaCO_3$) ranged from 10.0 mg $L^{-1}$ to 12.5 mg $L^{-1}$ and averaged 10.9 mg $L^{-1}$ for the five samples collected. Seasonal chl *a* (phytoplankton) concentrations ranged from 0.96 μg $L^{-1}$ to 2.24 μg $L^{-1}$ and averaged 1.47 μg $L^{-1}$ (Table 7).

Seasonal mean TP concentrations ranged from 3.2 to 3.7 μg $L^{-1}$ and averaged 3.6 μg $L^{-1}$ (Table 8). Seasonal inorganic phosphorous concentrations of TFP ranged from 0.6 μg $L^{-1}$ to 1.6 μg $L^{-1}$ and averaged 1.1 μg $L^{-1}$(Table 8). The FRP concentrations ranged from 0.4 to 1.9 μg $L^{-1}$ and averaged 1.1 μg $L^{-1}$.

Nitrogen levels were measured in three forms: TKN, $NO_3^-$ + $NO_2^-$, and $NH_{4+}$. The seasonal mean TKN was 115.0 μg $L^{-1}$, and the greatest seasonal difference was between the September (86.0 μg $L^{-1}$) and May (178.0 μg $L^{-1}$) samples (Table 8). Seasonal $NH_{4+}$ levels averaged 5.6 μg $L^{-1}$ and ranged from 4.6 to 6.5 μg $L^{-1}$. Seasonal $NO_2$ + $NO_3$ levels averaged 55.5 μg $L^{-1}$ and had a wide range of variability throughout the season, from 21.3 to 124.5 μg $L^{-1}$ (Table 8). Total nitrogen concentrations ranged from 118.3 to 302.5 μg $L^{-1}$ and averaged 170.5 μg $L^{-1}$. The seasonal total nitrogen to total phosphorus ratio, by weight, averaged 107.7:1 (Table 8).

## Zooplankton

Zooplankton weighted mean density was 112,480 animals per $m^2$ at Afognak Lake (Table 9). 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 dominant zooplankter in samples (64.2% of mean), with the genus *Bosmina* being most abundant (58.4% of mean). The other cladoceran genera included, *Daphnia* (1.9% of mean), *Holopedium* (1.7% of mean), and a group we called "other cladocerans," which consisted of various unidentified immature cladocera (2.3% of mean). Of the copepods (35.8% of mean), the most abundant group consisted of what we called "other copepods" (15.5% of the mean), which was made up mostly of the genus *Harpaticus* and various unidentified nauplii (larvae), followed in abundance by the genus *Epischura* (12.1% of the mean). The copepod genus *Cyclops*, considered an important member of the zooplankton community in sockeye salmon lakes, were not very abundant (6.4% of mean). The genus *Diaptomus* made up the smallest portion of the copepods at 1.8% of the mean.

Zooplankton mean biomass was 127.9 mg per $m^2$ (Table 9). Despite only making up 35.8% of the mean density the copepods comprised 50.0% of the zooplankton mean biomass due to their larger size (Table 10). The cladoceran genus *Bosmina* represented the greatest percentage of biomass (44.9%), followed by the copepod genus *Epischura* (34.0%). The remaining biomass was mostly comprised of *Cyclops* (9.8%) and *Diaptomus* (5.0%).

The copepod *Diaptomus* was the largest zooplankter, having a mean length of 0.91 mm (Table 9). Of the remaining copepods, *Epischura* had a mean length of 0.87 mm, and *Cyclops* had a mean length of 0.71 mm. *Daphnia*, the largest cladoceran, had a mean length of 0.57 mm followed by *Holopedium* (0.49 mm), *Bosmina* (0.31 mm), and the "other cladocerans" made up of unidentified immature cladocerans that were too small to measure.

# DISCUSSION

## SMOLT ASSESSMENT

This was the fifth consecutive year of the Afognak Lake smolt assessment study in which the same methods and materials were used. The data collected from the prior years indicated that average trap efficiencies were consistent from year to year, despite the fact that seasonal conditions, water levels, and field personnel operating the system varied annually. The annual mean trap efficiencies for the preceding four-year study were within 5.0% of each other (2003: 19.9% 2004: 18.6%; 2005: 14.9%; 2006: 19.5%; Appendix A1). In 2007, the total trap efficiency (19.9%) also fell within the range of prior years. These results suggest that reliable and comparable estimates of annual smolt production have been made each year of the study.

Confidence in the annual estimates is strengthened through an alternative and distinctly different life history method of estimating smolt numbers by using known escapement and fecundity data with egg-to-smolt survival rates as reported from other sockeye salmon lake systems. The life history method derived theoretical production estimates, which is the number of smolt expected to have emigrated from Afognak Lake, from 2003-2007 and estimated an average of 432,962 smolt per year (Figure 6). The life history production estimates were compared to the average trap catch estimates of 407,126 smolt (total 2,035,630) for the same five year period. The difference between the two methods was considered minor (6%). Our confidence in the two estimates is strengthened by the fact that these two methods of estimating production are distinctly different and yet produced very similar results. Moreover, the theoretical estimation method utilized survival (egg-to-fry and fry-to-smolt) estimates that were based on multi-year data sets obtained from 18 different sockeye salmon systems (Koenings and Kyle 1997). These results suggest that the rearing conditions in Afognak Lake are supporting the current escapement level and that freshwater survival and production is at expected levels.

The 2007 emigration was dominated by age-1. smolt (86.2%) while the age-2. smolt made up the remaining (13.8%) 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; Burgner 1964; Foerster 1968; Koenings et al. 1993 Krokhin 1957). 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 (81.8%) of age-1. smolt emigrating from Afognak Lake during 2003-2007, freshwater rearing capacity does not appear to have been exceeded and has been sufficient to support the juvenile population produced from recent escapements (Figure 7).

Mean size and condition of age-1. smolt sampled in 2007 (n=960; 2.6 g, 70.4 mm, 0.75 K) indicated a drop in comparison to recent year (2003-2006) averages of age-1. smolt (n=1,104; 3.7 g, 75.6 mm, 0.82 K; Appendix A2). In 2007, there was a late spring break up and a colder start to the summer, which may have led to a later development of phytoplankton resulting in later growth and development of zooplankton for foraging smolt. Smolt migrating out of Afognak Lake in the later portion of the sampling period were larger and had improved condition factors (age-1. smolt 0.80 K; Table 5).

Emigration timing of sockeye salmon smolt from Afognak Lake in 2007 was slightly later than the timing observed from 2003-2006 (Appendix A3). Smolt emigration typically begins in mid-May, peaks early to mid-June, and is over by early July. Smolt emigration in 2007 did not begin until the end of May, but as in prior years, it peaked in mid-June and ended in early July. Documentation from other systems salmon (Barnaby 1944; Burgner 1964; Foerster 1968; Koenings et al. 1993 Krokhin 1957) indicates that older and larger smolt tend to migrate earlier. This later start of the emigration and smaller smolt size corroborates the theory that colder spring conditions led to later plankton development and slower smolt growth.

## LIMNOLOGICAL ASSESSMENT

Most of the seasonal mean measurements of lake physical properties in 2007 were consistent with those from past years. Water temperatures were the exception with colder than the seasonal average readings from 1989 to 2006 (Appendix A4). 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 mixing events, Afognak Lake is typically stratified into warm epilimnion and cool hypolimnion layers for only short periods of time each year. In 2007, a delay in lake turn-over and mixing was observed; the summer bottom temperature was nearly three degrees colder (9.5°C) than the average summer bottom temperature (12.5°C; Appendix A4). High dissolved oxygen levels recorded in 2007 were consistent with historical averages (Appendix A5). Light, euphotic volume and euphotic zone data recorded in 2007 were also similar to recent ten year averages (1987-2006; Appendix A6).

Historical nutrient and algal pigment concentrations have exhibited high levels of annual variation and irregular fluctuations, although notable differences were discernable between the eleven-year period in which the lake was fertilized (1990-2000) and the last seven years when the lake was not artificially fertilized (2001-2007; Appendix A7). The average TP, TKN, and $NH_{4+}$ were higher during the fertilization years as compared to the non-fertilization years. During 2007, some surface water nutrient concentrations (TP: 3.6 μg $L^{-1}$ and TKN: 115 μg $L^{-1}$) were lower than the overall average concentration during the previous six-year (2001-2006) post-fertilization period (TP: 7.6 μg $L^{-1}$ and TKN: 135 μg $L^{-1}$), while the $NO_3^-$ + $NO_2^-$ (56 μg $L^{-1}$) concentrations in 2007 were higher than the post fertilization year averages (41 μg $L^{-1}$). Seasonal average algal standing crop in 2007, as measured by chl *a* concentration (1.47 μg $L^{-1}$), was slightly less than the average concentration during the previous six-year post-fertilization period (1.60 μg $L^{-1}$) and slightly less than the average standing crop during the fertilization period (1.54 μg $L^{-1}$). The largest chl *a* fluctuations measured in Afognak Lake occurred during the fertilization years, during which concentrations ranged from 0.10 (in 1998) to 3.92 (in 1995) 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: 9.8) than during the post-fertilization period (pH: 7.0; alkalinity: 10.3; Appendix A8). During 2007, average pH (6.8) was the same as the overall average for the fertilization period and slightly less than the previous six-year post-fertilization period. Average alkalinity for 2007 (10.9 mg $L^{-1}$) was greater than the overall averages for the fertilization and previous six-year post-fertilization periods.

During 2007, seasonal mean zooplankton density (84,151 individuals $m^{-2}$) and biomass (133 mg $m^{-2}$) estimates at Station 2 were much less than estimates from Station 1 (100,934 individuals $m^{-2}$ and 120 mg $m^{-2}$; Appendix A9). 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

(Schrof and Honnold 2005; White et al. 1990). Rapid flushing may have also affected nutrient availability for phytoplankton, which could affect zooplankton production.

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). In evaluating these annual zooplankton estimates, the “other cladocerans” and “other copepods”, which are mostly composed of copepod larvae and unidentified immature cladoceran, were not included in the total estimates. During 2007, Station 1 weighted mean total zooplankton density (100,934 individuals $m^{-2}$) and biomass (120 mg $m^{-2}$) levels were slightly less than estimates for the pre-fertilization period (1987-1989: 134,747 no. $m^{-2}$ and 194 mg $m^{-2}$) and very similar to the previous six-year post-fertilization period (2001-2006: 108,652 individuals and 139 mg $m^{-2}$; Appendix A9). Since juvenile sockeye salmon prefer 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 2007 abundance of the cladoceran *Daphnia* at station 1 (3,386 individuals $m^{-2}$ and 5 mg $m^{-2}$) was much greater than the overall average abundance during the pre-fertilization period (1,986 individuals and 3 mg $m^{-2}$) but was less than the previous six-year post-fertilization period (5,073 individuals and 7 mg $m^{-2}$; Appendix A9). The presence and abundance of *Daphnia*, a primary prey item for juvenile sockeye salmon, is considered an important indicator of lake forage activity (Honnold and Schrof 2001; Kyle 1996). Similar to *Daphnia*, the cladoceran *Holopedium* had a density (1,730 individuals $m^{-2}$) and biomass (3 mg $m^{-2}$) in 2007 that was just slightly less than the pre-fertilization years (1,716 individuals $m^{-2}$ and 4 mg $m^{-2}$) and the post-fertilization years (2,589 individuals $m^{-2}$ and 4 mg $m^{-2}$ Appendix A9). The abundance and the biomass of the cladoceran *Bosmina* (74,257 individuals $m^{-2}$ and 66 mg $m^{-2}$) in 2007 was less than the average from the pre-fertilization years (104,823 individuals $m^{-2}$ and 99 mg $m^{-2}$) but was more than the average from the post-fertilization years (66,443 individuals $m^{-2}$ and 55 mg $m^{-2}$). Despite *Bosmina* comprising the vast majority of the cladocerans (89% of total Cladoceran biomass), it may not be a good indicator of available forage. Being about half the size of *Daphnia* and about two-thirds the size of *Holopedium*, *Bosmina* (0.31 mm) is a more difficult prey item for juvenile salmon to locate and eat due to its small size in the lake (Koenings and Kyle 1997).

# ACKNOWLEDGEMENTS

We acknowledge ADF&G personnel Jeff Wadle and Iris Caldentey 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, Jason Fox, Nathan Shoutis, Brandon Wright and Josephine Deguzman for their attention to project objectives and Lisa Marcato for publications formatting and assistance. The U.S. Fish and Wildlife Service, Office of Subsistence Management, provided the final review and evaluation of this report and granted $76,700 in funding support for this project through the Fisheries Resource Monitoring Program, under agreement number 701817J643, as study FIS 07-401.

# REFERENCES CITED


Baer, R. T. 2007. Afognak Lake sockeye salmon smolt project operational plan. [*In*] Salmon research operational plans for the Kodiak Area, 2007. Alaska Department of Fish and Game, Regional Information Report 4K07-7.

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, Fishery Resource Monitoring Program, 2006 Final Project Report (Project No. 04-412). Alaska Department of Fish and Game, Division of Commercial Fisheries, Kodiak, Alaska.

Bagenal, T. B., and F. W. Tesch. 1978. Age and growth. pp. 101-136 *in*: T. Bagenal, editor. Methods for assessment of fish production in fresh waters. IBP Handbook No. 3, third edition. Blackwell Scientific Publications. London.

Barnaby, J. T. 1944. Fluctuations in abundance of red salmon *Oncorhynchus nerka* (Walbaum) in Karluk Lake, Alaska. U.S. Fish Wildlife Service Fishery Bulletin 39: 235-295. Technical Bulletin Number 154. Department of Natural Resources, Madison.

Barrett, B. M., P. A. Nelson, and C. O. Swanton. 1993a. Sockeye salmon *Oncorhynchus nerka* smolt investigations at Red, Akalura, and Upper Station Lakes conducted in response to the 1989 M/V Exxon Valdez Oil Spill, 1990-1992. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K93-1, Kodiak.

Barrett, B. M., C. O. Swanton and P. A. Nelson. 1993b. Sockeye salmon smolt abundance, timing, and growth characteristics for Red, Akalura, Upper Station, and Frazer Lakes, 1993. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K93-32, Kodiak.

Bradford, M. J. 1995. Comparative review of Pacific salmon survival rates 1995. Canadian Journal of Fisheries and Aquatic Sciences 52:1327-1338.

Burgner, R. L. 1962. Studies of red salmon smolts from the Wood River Lakes, Alaska, p 247-314 In: T.S.Y. Koo (ed.) Studies of Alaska Red Salmon. University of Washington Publications in Fisheries. New Series 1.

Burgner, R. L. 1964. Factors influencing production of sockeye salmon (*Oncorhynchus nerka*) in lakes of southwestern Alaska. Int. Ver. Theor. Angew. Limnol. Verh. 15:504-513.

Burgner, R. L. 1991. Life history of sockeye salmon (*Oncorhynchus nerka*). [*In*]: C. Groot and L. Margolis, editors: Pacific salmon life histories. UBC Press. Vancouver, Canada. 5:504-513.

Caldentey, I. 2007. Kodiak Area Management salmon escapement cumulative counts 1998-2007 Alaska Department of Fish and Game, Fisheries Management Report No. 07-57, Anchorage.

Carlson, S. R., L. G. Coggins Jr., C. O. Swanton. 1998. A simple stratified design for mark-recapture estimation of salmon smolt abundance. Alaska Fisheries Research Bulletin 5:88-102.

Coggins Jr., L. G. 1997. Summary data from the 1996 sockeye salmon smolt investigations at Red, Akalura, and Frazer Lakes. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K97-50, Kodiak.

Coggins Jr., L. G. and N. H. Sagalkin. 1999. Akalura Lake sockeye salmon restoration. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K99-64, Kodiak.

Cole, G. A. 1983. Textbook of Limnology. The C.V. Mosby Company, St. Louis, Missouri.

Dinnocenzo, J., G. Spalinger, and J. Wadle. 2007. Kodiak management area commercial salmon annual management report, 2006. Alaska Department of Fish and Game, Fishery Management Report No. 07-25, Anchorage.

Drucker, B. 1970. Red salmon studies at Karluk Lake, 1968. U.S. Bureau of Commercial Fisheries, Auke Bay Biological Laboratory Administrative Report 55p.

Edmondson, W. T. 1959. Fresh-water biology. Second edition. John Wiley and sons, New York.

Edmundson, J. A., S. G. Honnold, and G. B. Kyle. 1994a. Trophic responses to juvenile sockeye salmon stocking and nutrient enrichment in barren Little Waterfall Lake. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Regional Information Report 4J94-13, Juneau.

# REFERENCES CITED (Continued)


Edmundson, J. A., L. E. White, S. G. Honnold, and G. B. Kyle. 1994b. Assessment of sockeye salmon production in Akalura Lake. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Regional Information Report 4J94-17, Juneau.

Foerster, R. E. 1968. The Sockeye Salmon, *Oncorhynchus nerka*. Bulletin of the Fisheries Research Board of Canada. 162:422p.

Ginetz, R. M. J. 1977. A review of the Babine Lake development project 1961-1976. Environment Canada. Fish and Marine Services Technical Report Service Number Pac-T-77-6, 192 p.

Honnold, S. G., M. J. Witteveen, M. B. Foster, I. Vining, and J. J. Hasbrouck. 2007. Review of escapement goals for salmon stocks in the Kodiak Management Area, Alaska. Alaska Department of Fish and Game, Fishery Manuscript No. 07-10, Anchorage.

Honnold, S. G. 1997. The results of sockeye salmon *Oncorhynchus nerka* stocking into Spiridon Lake on the Kodiak National Wildlife Refuge: juvenile and adult production, commercial harvest, and ecosystem effects, 1987-1996. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K97-47, Kodiak.

Honnold, S. G. and J. A. Edmundson. 1993. Limnological and fisheries assessment of sockeye salmon (*Oncorhynchus nerka*) production in the Laura Lake system. Alaska Department of Fish and Game, FRED Division Report Series 130, Juneau.

Honnold S. G, C. Clevenger, J. N. McCullough and S. T. Schrof. 1999. Pillar Creek Hatchery annual management plan, 1999. Alaska Department of fish and game, Division of Commercial Fisheries, Regional Information Report 4K99-45, Kodiak.

Honnold, S. G. and S. Schrof. 2004. 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, Fishery Information, Services Division, Final Project Report No. FIS 03-047, Anchorage, Alaska.

Honnold, S. G. and S. T. Schrof. 2001. A summary of salmon enhancement and restoration in the Kodiak Management Area through 2001: a report to the Alaska Board of Fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K01-65, Kodiak.

INPFC (International North Pacific Fisheries Commission). 1963. Annual Report 1961. Vancouver, British Columbia.

Kirk, J. T. O. 1994. Light and photosynthesis in aquatic systems. Cambridge University Press, Cambridge, United Kingdom.

Koenings, J. P., and G. B. Kyle. 1997. Consequences to juvenile sockeye salmon and the zooplankton community resulting from intense predation. Alaska Fishery Research Bulletin 4(2): 120-135.

Koenings, J. P., H. Geiger, and J. Hasbrouck. 1993. Smolt-to-adult survival patterns of sockeye salmon: effects of length and latitude after entering sea. Canadian Journal of Fisheries and Aquatic Sciences 50:600-611.

Koenings, J. P., J. A. Edmundson, G. B. Kyle, and J. M. Edmundson. 1987. Limnology field and laboratory manual: methods for assessing aquatic production. Alaska Department of Fish and Game, FRED Division Report Series 71, Juneau.

Koenings, J. P. and R. D. Burkett. 1987. Populations characteristics of sockeye salmon (*Oncorhynchus nerka)* smolts relative to temperature regimes, euphotic volume, fry density, and forage base within Alaska lakes. Pages 216-234 [*In*] H.D. Smith, L. Margolis, and C. C. Woods, editors. Sockeye salmon (*Oncorhynchus nerka)* population biology and future management. Canadian Special Publication of Fisheries and Aquatic Sciences 96.

Koo, T. S. Y. 1962 Age designation in salmon. Pages 37-48 [*In*] T.S.Y. Koo, editor. Studies of Alaska red salmon. University of Washington Publications in Fisheries, New Series, Volume I, Seattle.

Krokhin, E. M. 1957. Determination of the daily food ration of young sockeye and three-spined stickleback by the respiration method. Izvestiia TINRO, 44: 97-110. [FRB Translation No. 209].

Krogius, F. V. and E. M. Krokhin. 1948. On the production of young sockeye salmon (*Oncorhynchus nerka* Walb.). Izv. Tikhookean. Nauchno-Issled. Inst. Rybn. Khoz. Okeanogr. 28:3-27. (Translation from Russian; Fisheries Research Board of Canada Translation Series 109).

# REFERENCES CITED (Continued)

KRPT (Kodiak Regional Planning Team). 1987. Kodiak Regional comprehensive Salmon Plan, 1982-2002. Alaska Dept. of Fish and Game, Office of the Commissioner, Juneau.

Kyle, G. B. 1992. Assessment of lacustrine productivity relative to juvenile sockeye salmon *Oncorhynchus nerka* production in Chignik and Black Lakes: results from 1991 surveys. Alaska Department of Fish and Game, FRED Division Report Series 119, Juneau.

Kyle, G. B. 1996. Stocking sockeye salmon *Oncorhynchus nerka* in barren lakes of Alaska: effects on the zooplankton community. Fisheries Research 28 (1996) 29-44.

Kyle, G. B. and S. G. Honnold. 1991. Limnological and fisheries evaluation of sockeye salmon production *Oncorhynchus nerka* in Malina Lakes for fisheries development. Alaska Department of Fish and Game, Regional Information Report 110, Kodiak.

Kyle, G. B., J. P. Koenings, and B. M. Barrett. 1988. Density-dependent, trophic level responses to an introduced run of sockeye salmon (*Oncorhynchus nerka*) at Frazer Lake, Kodiak Island, Alaska. Canadian Journal Fisheries and Aquatic Sciences. 45:1-12.

Kyle, G. B., L. E. White, and J. P. Koenings. 1990. Limnological and fisheries assessment of the potential production of sockeye salmon (*Oncorhynchus nerka*) in Spiridon Lake. Alaska Department of Fish and Game, FRED Division Report 108, Juneau.

McCullough, J. N., C. Clevenger, S. G. Honnold, and S. T. Schrof. 2000. Pillar Creek Hatchery annual management plan, 2000. Alaska Department of fish and game, Division of Commercial Fisheries, Regional Information Report 4K00-39, Kodiak.

McCullough, J. N. C. Clevenger, and S. T. Schrof. 2001. Pillar Creek Hatchery annual management plan, 2001. Alaska Department of fish and game, Division of Commercial Fisheries, Regional Information Report 4K01-43, Kodiak.

McCullough, J. N. and C. Clevenger. 2002. Pillar Creek Hatchery annual management plan, 2002. Alaska Department of fish and game, Division of Commercial Fisheries, Regional Information Report 4K02-38, Kodiak.

Nelson P. A., M. J. Witteveen, S. G. Honnold, I. Vining, and J. J. Hasbrouck. 2005. Review of salmon escapement goals in the Kodiak Management Area. Alaska Department of Fish and Game, Fishery Manuscript No. 05-05, Anchorage.

Nelson, P. A., and D. S. Lloyd. 2001. Escapement goals for Pacific salmon in the Kodiak, Chignik, and Alaska Peninsula/Aleutian Islands Areas of Alaska. Alaska Department of Fish and Game, Division of commercial Fisheries, Regional Information Report 4K01-66, Kodiak.

Pollard, W. R., C. F. Hartman, C. Groot, and P. Edgell. 1997. Field Identification of Coastal Juvenile Salmonids. Harbour Publishing. Maderia Park, British Columbia, Canada. 31p.

Robson, D. S., and H. A. Regier. 1964. Sample size in Peterson mark-recapture experiments. Transactions of the American Fisheries Society 93:215-226.

Sagalkin, N. 1999. Frazer Lake fish pass sockeye salmon smolt and adult research, 1997 and 1998. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K99-59, Kodiak.

Sagalkin, N. H. and S. G. Honnold. 2003. Evaluation of sockeye salmon smolt population estimate bias from single-site mark recapture experiments. Alaska Department of Fish and Game, Commercial Fisheries Division, Regional Information Report 4K03-40, Kodiak.

Schlesinger, W. H. 1991. Biogeochemistry: an analysis of global change. San Diego. Academic Press, Inc.

Schrof, S. T. and S. G. Honnold. 2003. Salmon enhancement, rehabilitation, evaluation, and monitoring efforts conducted in the Kodiak management area through 2001. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K03-41, Kodiak.

# REFERENCES CITED (Continued)

Schrof, S. T. and S. G. Honnold. 2005. 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, Fishery Resource Monitoring Program, 2005 Annual Project Report (Project No. 04-412). Alaska Department of Fish and Game, Division of Commercial Fisheries, Kodiak, Alaska.

Schrof, S. T., S. G. Honnold, C. J. Hicks and J. A. Wadle. 2000. A summary of salmon enhancement, rehabilitation, evaluation, and monitoring efforts conducted in the Kodiak management area through 1998. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K00-57, Kodiak.

Spalinger K. and K. A. Bouwens. 2003. The roles of phosphorus and nitrogen in lake ecosystems. Alaska Department of Fish and Game, Division of Commercial Fisheries. Regional Information Report 4K03-42, Kodiak.

Stockner, J. G. and E. A. MacIssac. 1996. British Colombia lake enrichment programme: Two decades of habitat enhancement for sockeye salmon. Regulated Rivers: Research and Management, Vol. 12, 547-561.

Swanton, C. O., P. A. Nelson, and L. G. Coggins. 1996. Sockeye smolt population estimates, outmigration timing, and size at age characteristics for Red, Akalura, and Frazer Lakes, 1995. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Regional Information Report 4K96-16. Kodiak.

Thompson, S. K. 1987. Sample size for estimating multinomial proportions. The American Statistician 41(1):42-46.

Thomsen, S. E. 2008. Kodiak Island lake assessment/limnology project and laboratory analysis operational plan. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 4K08-4, Kodiak.

Todd, G. T. 1994. A lightweight, inclined-plane trap for sampling salmon smolt in rivers. Alaska Fisheries Research Bulletin 1(2):168-175.

Wetzel, R. G. and G. E. Likens. 1991. Limnological analyses. Springer-Verlag. 391 p

White, L. E., G. B. Kyle, S. G. Honnold, and J. P. Koenings. 1990. Limnological and fisheries assessment of sockeye salmon (*Oncorhynchus nerka)* production in Afognak Lake. Alaska Department of Fish and Game. FRED Division Report 103, Juneau.

Willette, T. M., N. C. Dudiak, S. G. Honnold, G. Carpneter, and M. Dickson. 1995. Survey and evaluation of instream habitat and stock restoration techniques for wild pink and chum Salmon. *Exxon Valdez* Oil Spill State/Federal Natural Resource Damage Assessment Final Report. Restoration Study Number 105-1.

# TABLES AND FIGURES

Table 1.–Afognak Lake sockeye salmon escapement, harvest, and total run estimates, 1978-2007.

| | | Harvest | | | | |
|---|---|---|---|---|---|---|
| Year | Escapement | Commercial[a] | Subsistence[b] | Sport[c] | Total | Total Run |
| 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 | 451 | 36 | 493 | 23,426 |
| 2007 | 21,070 | 0 | 417 | ND | 417 | 21,487 |

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

[b] Data from ADF&G subsistence catch database 1978-2007.

[c] Data from ADF&G Sport Fish Division statewide harvest survey (SWHS) for 1992, 1996-2006; 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.

Table 2.–Sockeye salmon smolt counts, number of samples collected, mark-recapture counts, and trap efficiency ratios from trapping at Afognak River, 2007.

| Date | Catch Daily | Catch Cumulative | Dye Test Period Cumulative | AWL Sample Cumulative | Number Marked Releases[a] | Marked Recoveries Cumulative | Trap Efficiency (%) |
|---|---|---|---|---|---|---|---|
| 10-May | 1 | 1 | | | | | |
| 11-May | 5 | 6 | | | | | |
| 12-May | 0 | 6 | | | | | |
| 13-May | 5 | 11 | | | | | |
| 14-May | 2 | 13 | | | | | |
| 15-May | 4 | 17 | | | | | |
| 16-May | 7 | 24 | | | | | |
| 17-May | 18 | 42 | | | | | |
| 18-May | 7 | 49 | | | | | |
| 19-May | 19 | 68 | | | | | |
| 20-May | 33 | 101 | | 20 | | | |
| 21-May | 34 | 135 | | 30 | | | |
| 22-May | 117 | 252 | | 70 | | | |
| 23-May | 307 | 559 | | 110 | | | |
| 24-May | 145 | 704 | | 110 | | | |
| 25-May | 64 | 768 | | 110 | | | |
| 26-May | 41 | 809 | | 110 | | | |
| 27-May | 41 | 850 | | 110 | | | |
| 28-May | 73 | 923 | | 130 | | | |
| 29-May | 722 | 1,645 | | 170 | | | |
| 30-May | 729 | 2,374 | | 210 | 415 | 51 | |
| 31-May | 1,353 | 3,727 | | 250 | | 51 | |
| 1-Jun | 1,853 | 5,580 | | 250 | | 51 | |
| 2-Jun | 2,043 | 7,623 | | 250 | | 51 | |
| 3-Jun | 1,357 | 8,980 | | 290 | | 51 | |
| 4-Jun | 2,273 | 11,253 | | 330 | | 51 | |
| 5-Jun | 3,197 | 14,450 | 14,450 | 370 | | 51 | 12.5% |
| 6-Jun | 4,294 | 18,744 | | 410 | 202 | 88 | |
| 7-Jun | 2,352 | 21,096 | | 450 | | 111 | |
| 8-Jun | 2,183 | 23,279 | | 450 | | 124 | |
| 9-Jun | 2,946 | 26,225 | | 450 | | 124 | |
| 10-Jun | 1,174 | 27,399 | | 490 | | 124 | |
| 11-Jun | 3,251 | 30,650 | | 530 | | 124 | |
| 12-Jun | 3,269 | 33,919 | 19,469 | 570 | | 124 | 61.5% |

-continued-

Table 2.–(page 2 of 2)

| Date | Catch Daily | Catch Cumulative | Dye Test Period Cumulative | AWL Sample Cumulative | Number Marked Releases[a] | Marked Recoveries Cumulative | Trap Efficiency (%) |
|---|---|---|---|---|---|---|---|
| 13-Jun | 2,072 | 35,991 | | 610 | 510 | 38 | |
| 14-Jun | 3,213 | 39,204 | | 650 | | 77 | |
| 15-Jun | 1,704 | 40,908 | | 650 | | 81 | |
| 16-Jun | 2,156 | 43,064 | | 650 | | 82 | |
| 17-Jun | 2,222 | 45,286 | | 690 | | 82 | |
| 18-Jun | 987 | 46,273 | | 730 | | 82 | |
| 19-Jun | 1,674 | 47,947 | | 770 | | 82 | |
| 20-Jun | 1,253 | 49,200 | 13,209 | 810 | | 82 | 16.2% |
| 21-Jun | 1,399 | 50,599 | | 850 | 541 | 81 | |
| 22-Jun | 1,099 | 51,698 | | 850 | | 107 | |
| 23-Jun | 1,072 | 52,770 | | 890 | | 108 | |
| 24-Jun | 684 | 53,454 | | 890 | | 108 | |
| 25-Jun | 419 | 53,873 | | 930 | | 108 | |
| 26-Jun | 399 | 54,272 | | 970 | | 108 | |
| 27-Jun | 144 | 54,416 | 5,216 | 1,010 | | 108 | 20.1% |
| 28-Jun | 349 | 54,765 | | 1050 | 401 | 36 | |
| 29-Jun | 294 | 55,059 | | 1050 | | 43 | |
| 30-Jun | 140 | 55,199 | | 1,090 | | 44 | |
| 1-Jul | 55 | 55,254 | | | | 44 | |
| 2-Jul | 8 | 55,262 | | | | 44 | |
| 3-Jul | 34 | 55,296 | | | | 44 | |
| 4-Jul | 19 | 55,315 | 899 | | | 44 | 11.2% |
| 5-Jul | Trap Pulled | | | | Average Trap Efficiency= | | 19.9% |

[a] Adjusted number released using the delayed mortality formulation.

Table 3.–Population estimate of the sockeye salmon smolt emigration from Afognak Lake, 2007.

| Stratum (h) | Beginning Date | Ending Date | uh Unmarked | Mh Released | mh Recovered | Uh Estimate | var(Uh) Variance | 95% Confidence Interval lower | upper |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 5/10 | 6/5 | 14,450 | 415 | 51 | 115,690 | 2.22E+08 | 86,501 | 144,879 |
| 2 | 6/6 | 6/12 | 19,469 | 202 | 124 | 31,680 | 3.09E+06 | 28,235 | 35,125 |
| 3 | 6/13 | 6/20 | 15,281 | 510 | 82 | 94,135 | 8.88E+07 | 75,660 | 112,609 |
| 4 | 6/21 | 6/27 | 5,216 | 541 | 108 | 25,914 | 4.98E+06 | 21,541 | 30,288 |
| 5 | 6/28 | 7/4 | 899 | 401 | 44 | 8,031 | 1.31E+06 | 5,790 | 10,272 |
| Total | | | | | | **275,450** | 3.20E+08 | **240,388** | **310,512** |
| | | | | | | SE= | 17,889 | | |

Table 4.–The Afognak Lake sockeye salmon smolt emigration estimate based on percents by age class and dye test period, 2007.

| Stratum | | Age 1. | 2. | 3. | Total |
|---|---|---|---|---|---|
| 1 | Number | 79,916 | 35,774 | 0 | 115,690 |
| (5/10-6/5) | Percent | 69.1% | 30.9% | 0.0% | 100.0% |
| 2 | Number | 29,779 | 1,901 | 0 | 31,680 |
| (6/6-6/12) | Percent | 94.0% | 6.0% | 0.0% | 100.0% |
| 3 | Number | 93,742 | 392 | 0 | 94,135 |
| (6/13-6/20) | Percent | 99.6% | 0.4% | 0.0% | 100.0% |
| 4 | Number | 25,914 | 0 | 0 | 25,914 |
| (6/21-6/27) | Percent | 100.0% | 0.0% | 0.0% | 100.0% |
| 5 | Number | 8,031 | 0 | 0 | 8,031 |
| (6/28-7/4) | Percent | 100.0% | 0.0% | 0.0% | 100.0% |
| Total | Number | 237,383 | 38,067 | 0 | 275,450 |
| | Percent | 86.2% | 13.8% | 0.0% | 100.0% |

Table 5.–Length, weight, and condition of sockeye salmon smolt from the Afognak River, 2007.

| Stratum | Dates | Sample Size | Weight (mm) Mean | Weight (mm) Standard Error | Length (g) Mean | Length (g) Standard Error | Condition Mean | Condition Standard Error |
|---|---|---|---|---|---|---|---|---|
| Age 1. | | | | | | | | |
| 1 | 5/10-6/5 | 213 | 2.4 | 0.02 | 69.1 | 0.24 | 0.73 | 0.006 |
| 2 | 6/6-6/12 | 188 | 2.3 | 0.02 | 69.1 | 0.17 | 0.70 | 0.005 |
| 3 | 6/13-6/20 | 239 | 2.5 | 0.02 | 69.6 | 0.14 | 0.74 | 0.004 |
| 4 | 6/21-6/27 | 160 | 2.9 | 0.03 | 71.2 | 0.20 | 0.79 | 0.005 |
| 5 | 6/28-7/4 | 160 | 3.3 | 0.04 | 74.0 | 0.25 | 0.80 | 0.005 |
| Totals | | 960 | 2.6 | 0.02 | 70.4 | 0.11 | 0.75 | 0.002 |
| Age 2. | | | | | | | | |
| 1 | 5/10-6/5 | 116 | 3.4 | 0.08 | 77.1 | 0.46 | 0.74 | 0.01 |
| 2 | 6/6-6/12 | 12 | 2.6 | 0.11 | 71.3 | 0.79 | 0.72 | 0.025 |
| 3 | 6/13-6/20 | 1 | 3.2 | 0.00 | 73.0 | 0.00 | 0.82 | 0 |
| 4 | 6/21-6/27 | 0 | — | — | — | — | — | — |
| 5 | 6/28-7/4 | 0 | — | — | — | — | — | — |
| Totals | | 129 | 3.4 | 0.07 | 76.5 | 0.44 | 0.74 | 0.009 |

Table 6.–Afognak Lake sockeye salmon theoretical production of eggs, emergent fry, and smolt by age from brood years 2004 and 2005 and predicted smolt emigration in 2007.

| Production | | Brood Year | | 2007 Estimate |
|---|---|---|---|---|
| Parameter | Assumption | 2004 | 2005 | Age 1. and 2. smolt |
| Escapement | | 15,181 | 21,577 | |
| Females spawning | 1:1 sex ratio | 7,591 | 10,789 | |
| Deposited Eggs | 2,112 per female[a] | 16,031,136 | 22,785,312 | |
| Emergent Fry | 7% egg-to-fry survival[b] | 1,122,180 | 1,594,972 | |
| Smolt | 21% fry-to-smolt survival[c] | 235,658 | 334,944 | |
| Emigration in 2007 | 86.2% age-1., 13.8% age-2.[d] | 32,521 | 288,722 | 321,243 |

[a] Average fecundity as reported from Pillar Creek Hatchery (2003-2006)
[b] Averages from Drucker (1970), Bradford (1995) and Koenings and Kyle (1997)
[c] Koenings and Kyle (1997)
[d] Based on 2007 smolt age class estimates (Table 4)

Table 7.–General water chemistry and algal pigment concentrations at 1 m water depth, station 1, Afognak Lake 2007.

| Date | pH (units) | Alkalinity (mg $L^{-1}$) | Silicon (µg $L^{-1}$) | Chlorophyll *a* (µg $L^{-1}$) |
|---|---|---|---|---|
| 18-May | 6.70 | 10.0 | ND | 0.96 |
| 26-Jun | 6.63 | 10.0 | ND | 1.28 |
| 2-Aug | 6.89 | 10.3 | ND | 2.24 |
| 29-Aug | 6.79 | 11.8 | ND | 1.60 |
| 25-Sep | 6.84 | 12.5 | ND | 1.28 |
| Average | 6.77 | 10.9 | ND | 1.47 |
| SD | 0.11 | 1.2 | ND | 0.49 |

Table 8.–Seasonal phosphorus and nitrogen concentrations at 1 m water depth, station 1, Afognak Lake, 2007.

| Date | Total filterable-P ($\mu g\ L^{-1}$) | Filterable reactive-P ($\mu g\ L^{-1}$) | Total-P ($\mu g\ L^{-1}$) | Ammonia ($\mu g\ L^{-1}$) | Total Kjeldahl Nitrogen ($\mu g\ L^{-1}$) | Nitrate + Nitrite ($\mu g\ L^{-1}$) | Total Nitrogen ($\mu g\ L^{-1}$) | TN:TP ratio |
|---|---|---|---|---|---|---|---|---|
| 18-May | 1.3 | 1.9 | 3.4 | 5.3 | 178.0 | 124.5 | 302.5 | 197.0 |
| 26-Jun | 1.6 | 0.7 | 3.3 | 5.2 | 99.0 | 75.1 | 174.1 | 116.8 |
| 2-Aug | 1.0 | 0.8 | 3.7 | 4.6 | 102.0 | 21.3 | 123.3 | 73.8 |
| 29-Aug | 0.6 | 0.4 | 4.3 | 6.3 | 110.0 | 24.5 | 134.5 | 69.3 |
| 25-Sep | 1.1 | 1.9 | 3.2 | 6.5 | 86.0 | 32.3 | 118.3 | 81.9 |
| Average | 1.1 | 1.1 | 3.6 | 5.6 | 115.0 | 55.5 | 170.5 | 107.7 |
| SD | 0.4 | 0.7 | 0.4 | 0.8 | 36.3 | 44.2 | 77.0 | 53.3 |

Table 9.–Weighted mean zooplankton density, biomass, and size by station from Afognak Lake, 2007.

| Station | *n* | | *Epischura* | *Diaptomus* | *Cyclops* | Other Copepods | *Bosmina* | *Daphnia* | *Holopedium* | Other Cladocerans | Total Copepods | Total Cladocerans | Total all zooplankton |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 5 | density (no. $m^{-2}$) | 10,913 | 2,930 | 7,718 | 18,631 | 74,257 | 3,386 | 1,730 | 3,397 | 40,192 | 82,770 | 122,962 |
| | | % | 8.9% | 2.4% | 6.3% | 15.2% | 60.4% | 2.8% | 1.4% | 2.8% | 32.7% | 67.3% | 100.0% |
| | | biomass (mg $m^{-2}$) | 24.0 | 8.9 | 13.0 | 2.3 | 66.0 | 5.0 | 3.0 | 0.1 | 48.2 | 74.1 | 122.3 |
| | | % | 19.6% | 7.3% | 10.6% | 1.9% | 54.0% | 4.1% | 2.5% | 0.1% | 59.8% | 60.6% | 100.0% |
| | | size (mm) | 0.78 | 0.88 | 0.70 | 0.58 | 0.31 | 0.58 | 0.47 | 0.41 | | | |
| 2 | 5 | density (no. $m^{-2}$) | 16,269 | 1,141 | 6,693 | 16,174 | 57,065 | 934 | 2,049 | 1,672 | 40,277 | 61,720 | 101,997 |
| | | % | 16.0% | 1.1% | 6.6% | 15.9% | 55.9% | 0.9% | 2.0% | 1.6% | 39.5% | 60.5% | 100.0% |
| | | biomass (mg $m^{-2}$) | 63.0 | 4.0 | 12.0 | 0.7 | 49.0 | 1.0 | 4.0 | na | 79.7 | 54.0 | 133.7 |
| | | % | 47.1% | 3.0% | 9.0% | 0.5% | 36.7% | 0.7% | 3.0% | na | 59.6% | 40.4% | 100.0% |
| | | size (mm) | 0.95 | 0.93 | 0.71 | 0.58 | 0.31 | 0.55 | 0.50 | | | | |
| 1 & 2 | | density (no. $m^{-2}$) | 13,591 | 2,036 | 7,206 | 17,403 | 65,661 | 2,160 | 1,890 | 2,535 | 40,235 | 72,245 | 112,480 |
| Averaged | | % | 12.1% | 1.8% | 6.4% | 15.5% | 58.4% | 1.9% | 1.7% | 2.3% | 35.8% | 64.2% | 100.0% |
| | | biomass (mg $m^{-2}$) | 43.5 | 6.5 | 12.5 | 1.5 | 57.5 | 3.0 | 3.5 | na | 63.9 | 64.0 | 127.9 |
| | | % | 34.0% | 5.0% | 9.8% | 1.2% | 44.9% | 2.3% | 2.7% | na | 50.0% | 50.0% | 100.0% |
| | | size (mm) | 0.87 | 0.91 | 0.71 | 0.58 | 0.31 | 0.57 | 0.49 | | | | |

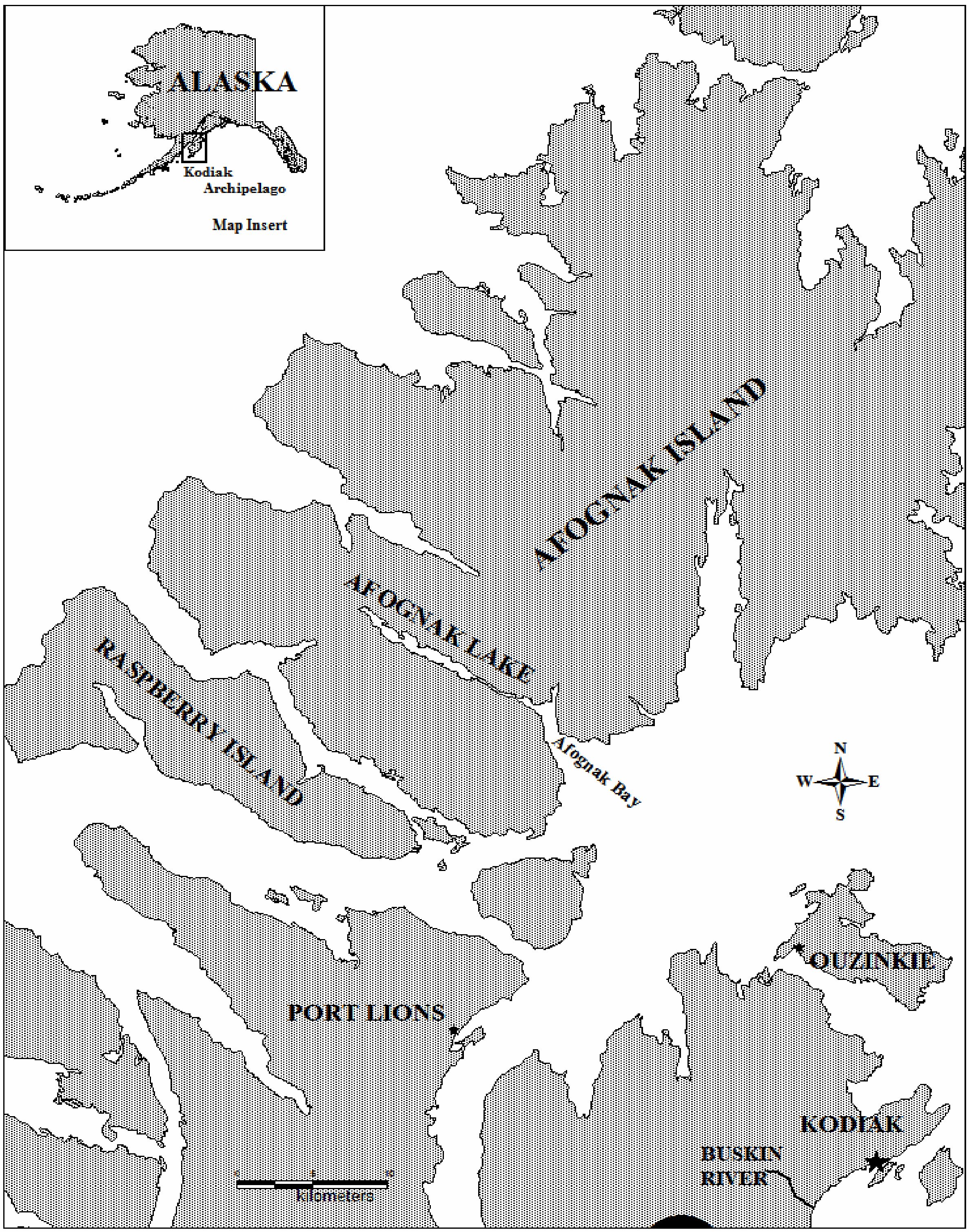



Figure 1.–This map displays the location of Kodiak City, and the villages of Port Lions, and Ouzinkie and their proximity to the Afognak Lake drainage on Afognak Island.

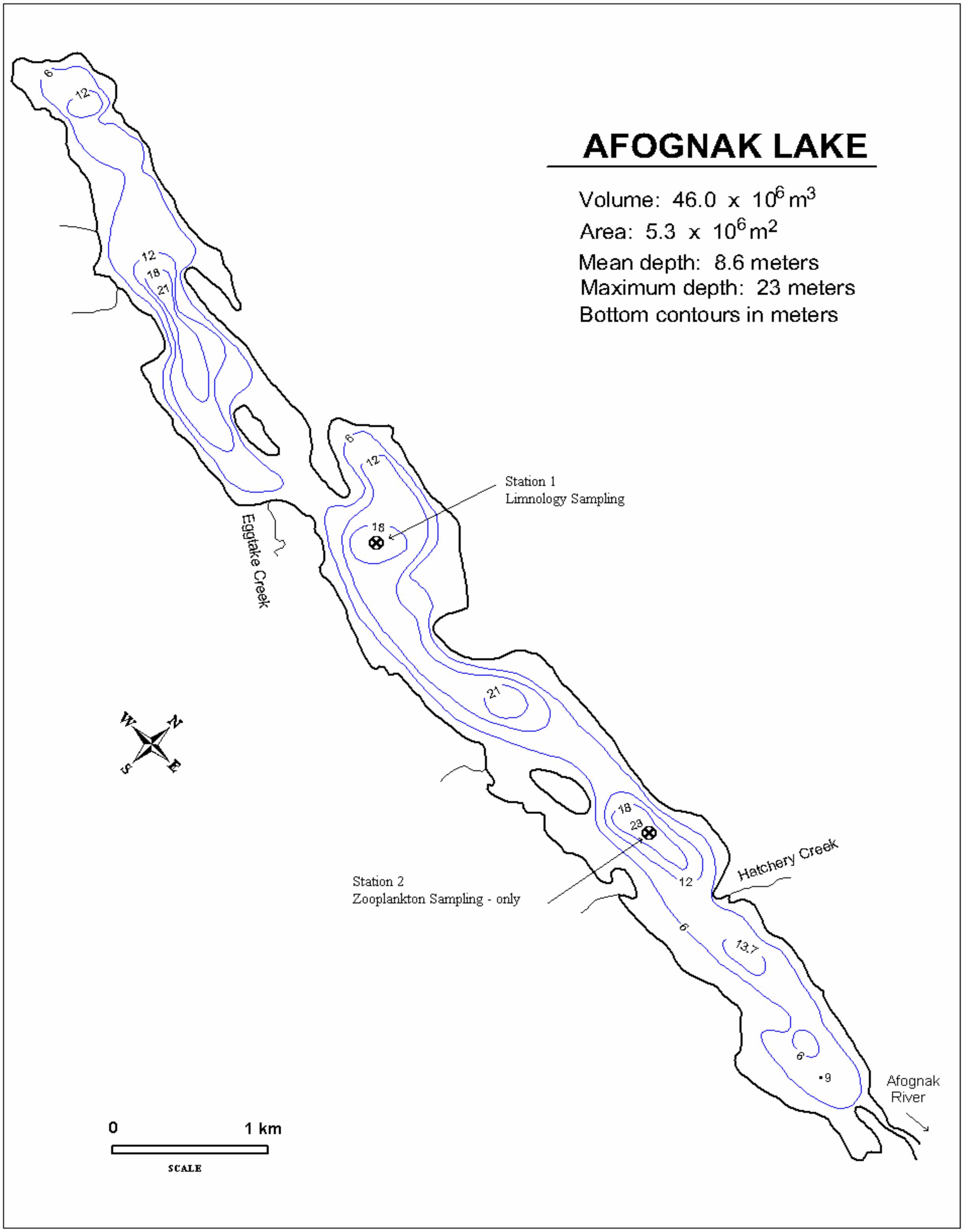



Figure 2.–Bathymetric map showing the two limnology and zooplankton stations on Afognak Lake.

Figure 3.–The smolt trapping system set up in the Afognak River, 2007.

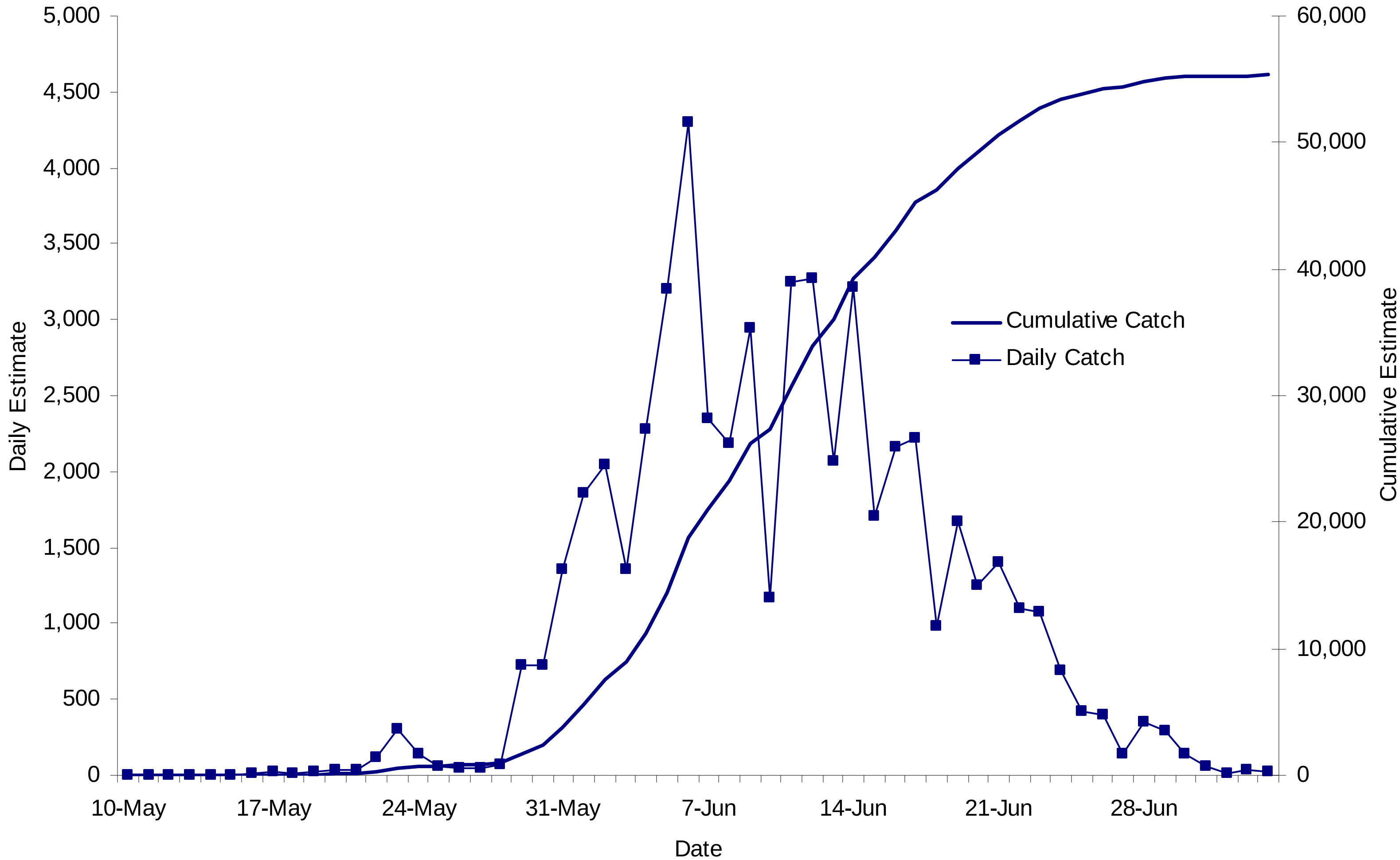



Figure 4.–Daily and cumulative sockeye salmon smolt trap catch estimates from 10 May to 4 July in the Afognak River, 2007.

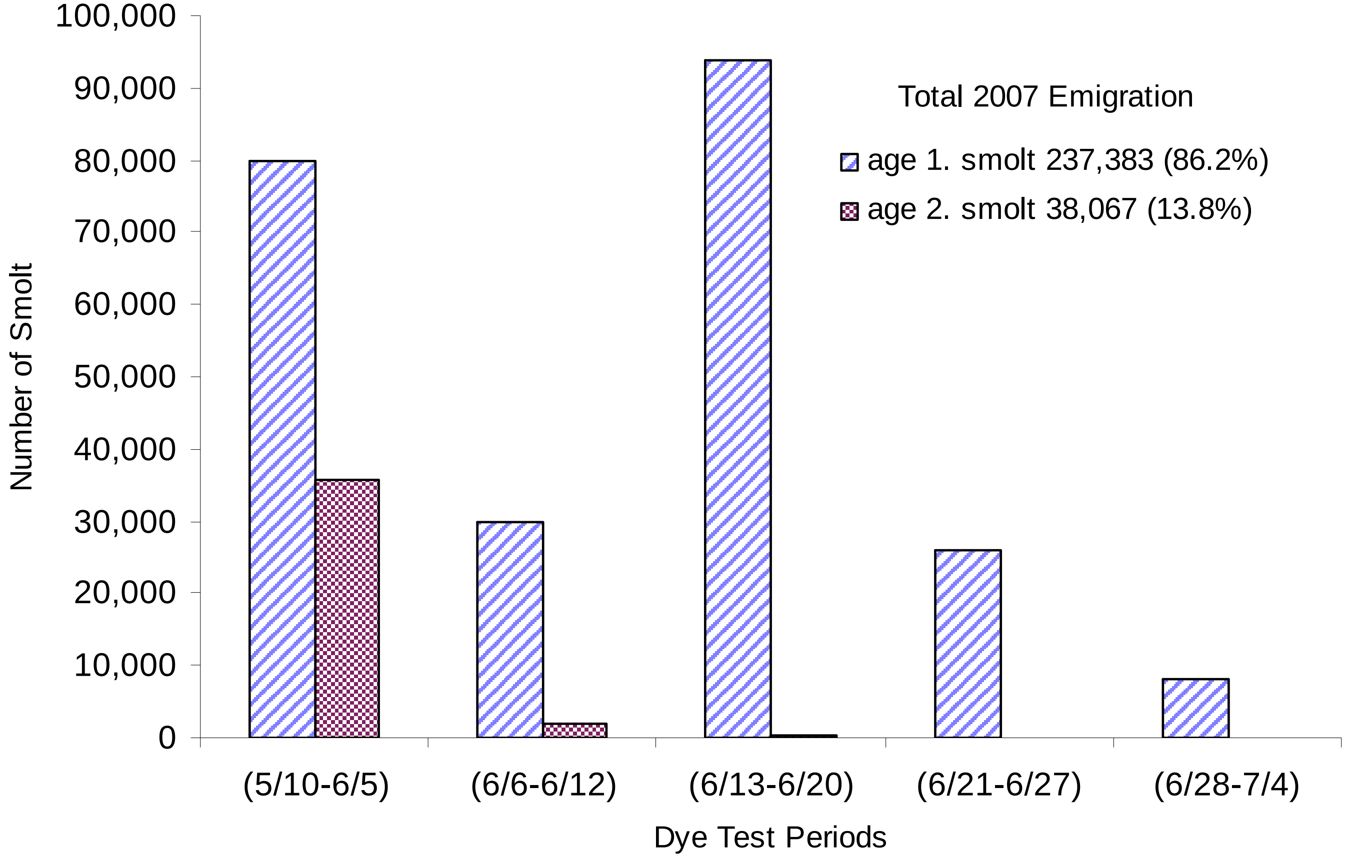



Figure 5.–Afognak Lake sockeye salmon smolt emigration by age class and dye test period, 2007.

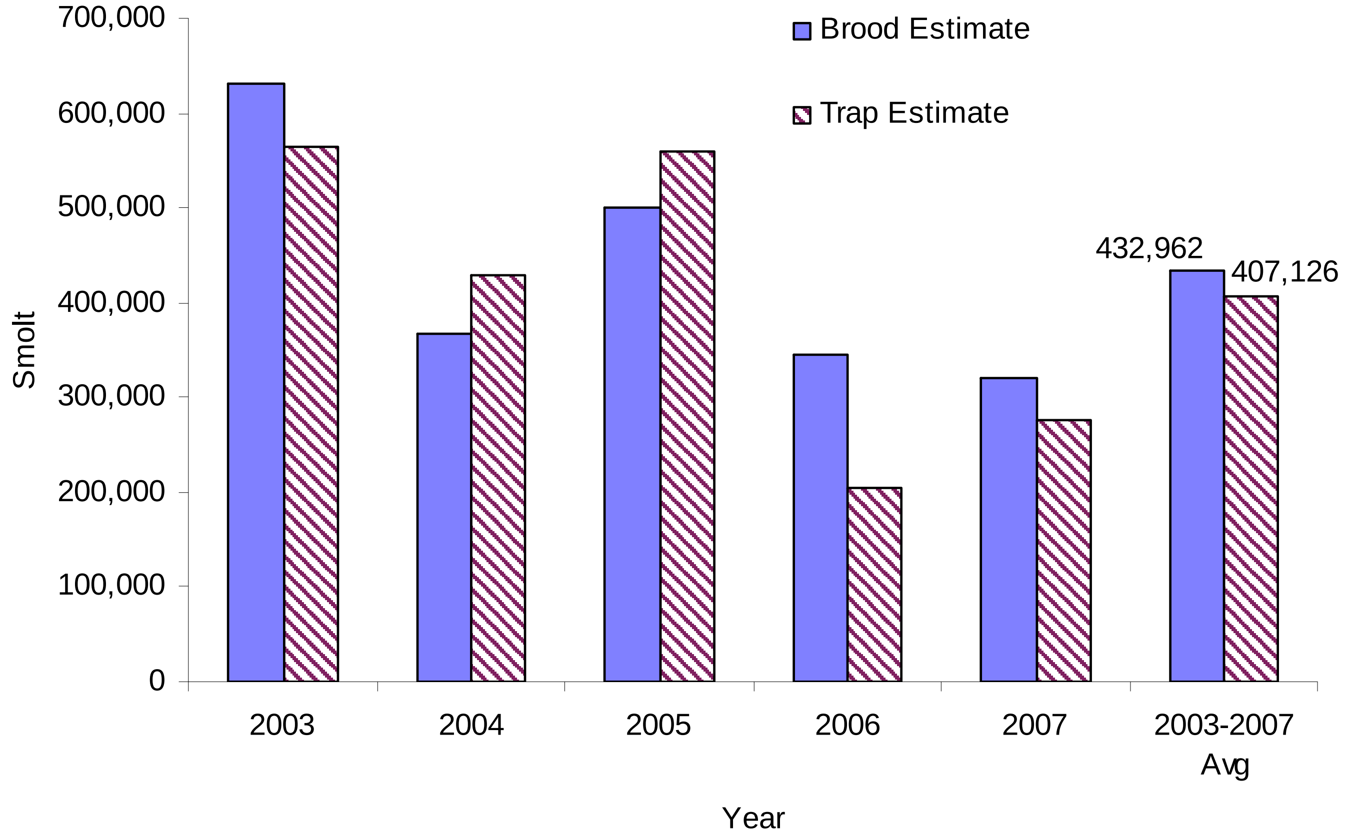



Figure 6.–Afognak Lake emigration estimates from trap catches and theoretical emigration estimates based on brood year escapements, 2003-2007.

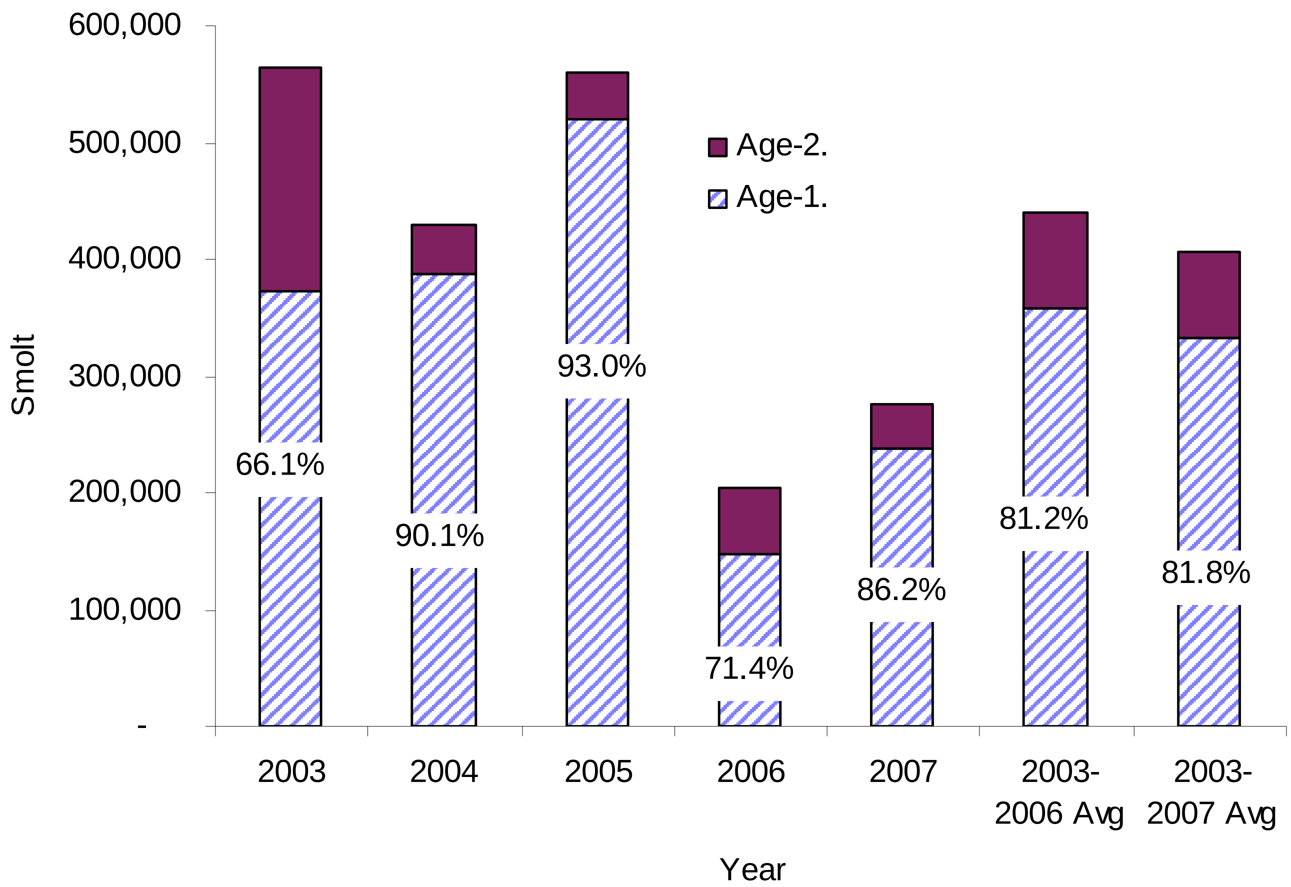



Figure 7.–Sockeye salmon smolt emigration by age from Afognak Lake, 2003-2007.

# APPENDIX A. SUPPORTING HISTORICAL INFORMATION

Appendix A1.–Population estimates of the sockeye salmon emigrations from Afognak Lake 2003-2007.

| 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 | 95% Confidence Interval upper |
|---|---|---|---|---|---|---|---|---|---|---|
| 2003 | | | | | | | | | | |
| 1 | 5/12 | 5/19 | 1,387 | 239 | 5 | 2.1% | 55,480 | 4.31E+08 | 14,809 | 96,151 |
| 2 | 5/20 | 5/25 | 2,912 | 239 | 5 | 2.1% | 116,480 | 1.89E+09 | 31,188 | 201,772 |
| 3 | 5/26 | 5/31 | 11,966 | 706 | 161 | 22.8% | 52,222 | 1.31E+07 | 45,136 | 59,308 |
| 4 | 6/1 | 6/7 | 31,358 | 638 | 133 | 20.8% | 149,536 | 1.31E+08 | 127,063 | 172,008 |
| 5 | 6/8 | 6/10 | 11,153 | 686 | 257 | 37.5% | 29,698 | 2.18E+06 | 26,807 | 32,589 |
| 6 | 6/11 | 6/18 | 18,696 | 679 | 103 | 15.2% | 122,243 | 1.21E+08 | 100,663 | 143,823 |
| 7 | 6/19 | 6/26 | 4,762 | 506 | 79 | 15.6% | 30,179 | 9.63E+06 | 24,097 | 36,261 |
| 8 | 6/27 | 7/3 | 736 | 218 | 17 | 7.8% | 8,955 | 3.97E+06 | 5,050 | 12,859 |
| Total | | | 82,970 | 3,911 | 760 | 19.9% | 564,793 | 2.61E+09 | 374,814 | 754,772 |
| | | | | | | | SE= | 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 | | |

-continued-

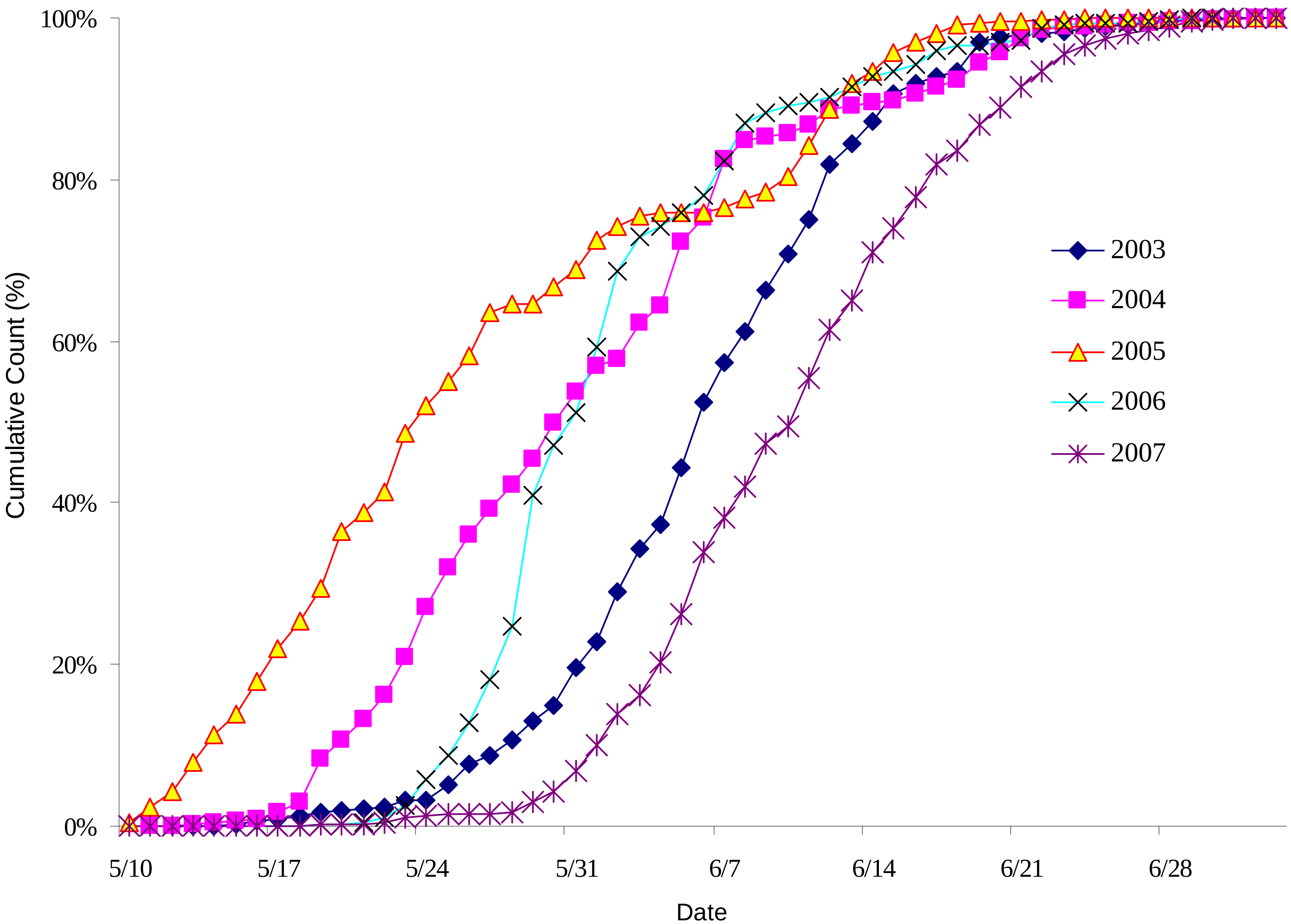
Appendix A1.–Page 2 of 2.

| 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 | 95% Confidence Interval upper |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 2005 | | | | | |
| 1 | 5/10 | 5/21 | 27,226 | 489 | 70 | 14.3% | 184,879 | 4.05E+08 | 145,443 | 224,314 |
| 2 | 5/22 | 5/26 | 13,627 | 518 | 43 | 8.3% | 155,259 | 4.89E+08 | 111,932 | 198,587 |
| 3 | 5/27 | 6/5 | 15,210 | 482 | 44 | 9.1% | 158,499 | 4.94E+08 | 114,948 | 202,050 |
| 4 | 6/6 | 6/27 | 17,634 | 368 | 103 | 28.0% | 61,593 | 2.58E+07 | 51,640 | 71,546 |
| Total | | | 73,697 | 1,857 | 260 | 14.9% | 560,230 | 1.41E+09 | 486,554 | 633,906 |
| | | | | | | | SE= | 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 | | |
| | | | | | 2007 | | | | | |
| 1 | 5/10 | 6/5 | 14,450 | 415 | 51 | 12.5% | 115,690 | 2.22E+08 | 86,501 | 144,879 |
| 2 | 6/6 | 6/12 | 19,469 | 202 | 124 | 61.5% | 31,680 | 3.09E+06 | 28,235 | 35,125 |
| 3 | 6/13 | 6/20 | 15,281 | 510 | 82 | 16.2% | 94,135 | 8.88E+07 | 75,660 | 112,609 |
| 4 | 6/21 | 6/27 | 5,216 | 541 | 108 | 20.1% | 25,914 | 4.98E+06 | 21,541 | 30,288 |
| 5 | 6/28 | 7/4 | 899 | 401 | 44 | 11.2% | 8,031 | 1.31E+06 | 5,790 | 10,272 |
| Total | | | 55,315 | 2,070 | 409 | 19.9% | 275,450 | 3.20E+08 | 240,388 | 310,512 |
| | | | | | | | SE= | 17,889 | | |

Appendix A2.–Mean weight, length, and condition coefficient by age for sockeye salmon smolt sampled at Afognak Lake, 1987-2001, and 2003-2007.

| | | Age-1 | | | | Age-2 | | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | Sampling Period | n | Weight (g) | Length (mm) | Condition (K) | n | Weight (g) | Length (mm) | Condition (K) |
| 1987 | 8-Jun | 36 | 3.6 | 74.9 | 0.85 | 186 | 3.6 | 79.3 | 0.86 |
| 1988 | 15-Jun | 202 | 4.1 | 77.9 | 0.90 | 0 | | | |
| 1989 | 15-Jun | 208 | 4.1 | 76.8 | 0.91 | 2 | 5.2 | 78.0 | 1.10 |
| 1990 | May 23-June 24 | 544 | 2.5 | 68.8 | 0.76 | 21 | 3.4 | 77.3 | 0.73 |
| 1991 | May 13-June 26 | 1,895 | 3.1 | 72.9 | 0.78 | 176 | 3.9 | 78.3 | 0.81 |
| 1992 | June 7-20 | 268 | 3.8 | 77.0 | 0.82 | 37 | 3.8 | 76.9 | 0.83 |
| 1993 | May 24-30 | 274 | 3.0 | 72.7 | 0.78 | 21 | 3.3 | 74.8 | 0.79 |
| 1994 | May 17-23 | 138 | 3.0 | 72.0 | 0.81 | 142 | 4.7 | 84.3 | 0.79 |
| 1995 | May 31-June 13 | 394 | 2.8 | 69.4 | 0.84 | 5 | 3.6 | 78.8 | 0.74 |
| 1996 | June 5-11 | 54 | 4.6 | 80.9 | 0.87 | 339 | 4.8 | 81.6 | 0.88 |
| 1997 | May 24-30 | 76 | 4.3 | 81.7 | 0.78 | 122 | 4.4 | 82.1 | 0.79 |
| 1998 | May 24-30 | 116 | 2.6 | 66.4 | 0.82 | 46 | 6.6 | 88.0 | 0.90 |
| 1999 | May 31-June 6 | 96 | 2.8 | 74.6 | 0.66 | 98 | 2.1 | 66.6 | 0.69 |
| 2000 | May 31-June 13 | 84 | 4.9 | 81.5 | 0.89 | 100 | 5.6 | 85.3 | 0.89 |
| 2001 | June 11-13 | 44 | 7.0 | 90.1 | 0.93 | 17 | 5.8 | 85.6 | 0.92 |
| 2003 | May 12-July 3 | 1,031 | 4.2 | 79.1 | 0.82 | 383 | 4.2 | 81.4 | 0.77 |
| 2004 | May 11-July 3 | 1,370 | 3.6 | 75.7 | 0.80 | 81 | 3.6 | 78.7 | 0.74 |
| 2005 | May 10-June 27 | 1,248 | 3.9 | 76.8 | 0.84 | 65 | 4.2 | 81.3 | 0.77 |
| 2006 | May 16-June 29 | 765 | 3.0 | 70.8 | 0.83 | 202 | 3.8 | 79.6 | 0.75 |
| 2007 | May 21 - July 2 | 960 | 2.6 | 70.4 | 0.75 | 129 | 3.4 | 76.5 | 0.74 |
| 2003-2006 Avg | | 1,104 | 3.7 | 75.6 | 0.82 | 183 | 4.0 | 80.3 | 0.76 |
| 2003-2007 Avg | | 1,075 | 3.5 | 74.6 | 0.81 | 172 | 3.8 | 79.5 | 0.75 |

Appendix A3.–Sockeye salmon smolt emigration timing from Afognak Lake, 2003-2007.



Appendix A4.–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 1989-2007.

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

Appendix A5.–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 1989-2007.

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

Appendix A6.–Average euphotic zone depth (EZD), light extinction coefficient (Kd), Secchi disk transparency, and euphotic volume (EV) from stations 1 and 2 for Afognak Lake, 1987-2007.

| | EZD | | $K_d$ | | Secchi Disk | | EV | |
|---|---|---|---|---|---|---|---|---|
| | (m) | SD | ($m^{-1}$) | SD | (m) | SD | ($10^6 m^3$) | SD |
| 1990 | 7.47 | 2.46 | -2.01 | 0.53 | 3.6 | 0.6 | 39.60 | 13.02 |
| 1991 | 8.36 | 2.40 | -2.25 | 0.68 | 2.7 | 0.5 | 44.32 | 12.75 |
| 1992 | 9.39 | 2.79 | -2.28 | 0.35 | 2.8 | 0.9 | 49.77 | 14.77 |
| 1993 | 9.27 | 2.23 | -2.09 | 0.52 | 3.5 | 0.5 | 49.14 | 11.81 |
| 1994 | 7.73 | 1.45 | -1.86 | 0.33 | 3.4 | 0.4 | 40.97 | 7.67 |
| 1995 | 7.56 | 1.18 | -1.79 | 0.27 | 2.5 | 0.6 | 40.08 | 6.23 |
| 1996 | 8.19 | 1.53 | -1.92 | 0.37 | 3.5 | 0.4 | 43.41 | 8.13 |
| 1997 | 6.15 | 1.75 | -1.68 | 0.59 | 3.2 | 0.7 | 32.61 | 9.27 |
| 1998 | 7.64 | 0.82 | -1.76 | 0.25 | 3.8 | 1.2 | 40.50 | 4.36 |
| 1999 | 9.12 | 2.67 | -1.82 | 0.35 | 2.9 | 0.6 | 48.36 | 14.14 |
| 2000 | 9.93 | 1.65 | -2.28 | 0.39 | 3.4 | 0.6 | 52.62 | 8.76 |
| 2001 | 10.87 | 3.24 | -2.24 | 0.40 | 4.0 | 1.1 | 57.61 | 17.17 |
| 2002 | 10.15 | 0.69 | -2.43 | 0.17 | 4.3 | 0.5 | 53.80 | 3.66 |
| 2003 | 9.91 | 1.11 | -2.36 | 0.25 | 4.5 | 0.2 | 52.51 | 5.87 |
| 2004 | 10.27 | 2.57 | -2.32 | 0.31 | 4.0 | 0.3 | 54.42 | 13.60 |
| 2005 | 9.77 | 0.64 | -2.28 | 0.20 | 4.7 | 0.6 | 51.77 | 3.37 |
| 2006 | 9.18 | 1.05 | -2.16 | 0.36 | 4.0 | 0.7 | 48.67 | 5.54 |
| 2007 | 9.36 | 1.27 | -2.05 | 0.36 | 4.1 | 0.7 | 49.61 | 6.73 |
| Avg 1990-2006 | 8.88 | 1.78 | -2.09 | 0.37 | 3.58 | 0.63 | 47.07 | 9.42 |
| Avg 1990-2007 | 8.91 | 1.75 | -2.09 | 0.37 | 3.61 | 0.63 | 47.21 | 9.27 |

Appendix A7.–Summary of seasonal mean nutrient and algal pigment concentrations by station and depth for Afognak Lake, 1990-2007.

| 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 | ND | ND | 0.31 | 0.21 | 0.27 | 0.07 |
| | 1 | 14 | 4.6 | 1.5 | 6.0 | 3.5 | 4.5 | 3.2 | 138 | 12.3 | 14 | 5.0 | 70 | 23.2 | 2966 | 156.3 | ND | ND | 0.22 | 0.14 | 0.22 | 0.08 |
| 1992 | 1 | 1 | 3.8 | 0.5 | 4.1 | 2.5 | 3.1 | 2.4 | 135 | 13.9 | 3 | 1.7 | 62 | 26.1 | 3163 | 158.9 | 199 | 64.1 | 0.44 | 0.29 | 0.28 | 0.13 |
| | 1 | 24 | 3.9 | 1.7 | 4.0 | 3.2 | 2.6 | 1.7 | 127 | 12.8 | 10 | 4.1 | 93 | 23.1 | 3182 | 198.0 | 163 | 52.9 | 0.31 | 0.25 | 0.28 | 0.12 |
| 1993 | 1 | 1 | 4.5 | 0.8 | 3.7 | 1.3 | 2.8 | 0.5 | 148 | 18.5 | 5 | 2.2 | 49 | 30.4 | 3132 | 220.6 | 147 | 53.3 | 1.01 | 0.31 | 0.36 | 0.03 |
| | 1 | 25 | 4.9 | 1.3 | 8.5 | 11.7 | 6.8 | 9.9 | 136 | 17.3 | 19 | 10.1 | 98 | 31.7 | 3380 | 244.0 | 121 | 47.5 | 0.52 | 0.21 | 0.45 | 0.14 |
| 1994 | 1 | 1 | 5.7 | 0.7 | 4.5 | 3.3 | 3.6 | 2.3 | 160 | 23.8 | 3 | 1.7 | 40 | 21.4 | 2843 | 122.4 | 114 | 33.0 | 0.56 | 0.26 | 0.28 | 0.08 |
| | 1 | 2 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.56 | 0.34 | 0.34 | 0.10 |
| | 1 | 26 | 5.3 | 1.1 | 4.8 | 3.9 | 4.2 | 3.2 | 160 | 17.7 | 15 | 9.7 | 74 | 23.8 | 3177 | 285.5 | 128 | 52.1 | 0.36 | 0.21 | 0.27 | 0.09 |
| 1995 | 1 | 1 | 8.7 | 2.7 | 3.0 | 1.5 | 2.0 | 1.1 | 168 | 21.6 | 9 | 14.1 | 66 | 22.1 | 1873 | 735.0 | ND | ND | 3.92 | 2.44 | 1.13 | 0.62 |
| | 1 | 17 | 8.1 | 2.0 | 1.9 | 1.1 | 1.1 | 0.4 | 187 | 47.1 | 35 | 44.3 | 45 | 35.0 | 2046 | 618.4 | ND | ND | 3.13 | 1.75 | 1.10 | 0.54 |
| | 2 | 1 | 7.4 | 2.1 | 2.1 | 1.2 | 1.7 | 1.0 | 169 | 31.0 | 9 | 14.0 | 54 | 33.2 | 1942 | 753.9 | ND | ND | 4.20 | 2.90 | 1.05 | 0.65 |
| | 2 | 11 | 7.2 | 1.7 | 2.2 | 2.0 | 1.6 | 1.1 | 157 | 26.0 | 16 | 17.4 | 52 | 34.1 | 2143 | 805.6 | ND | ND | 3.27 | 2.18 | 1.05 | 0.62 |
| 1996 | 1 | 1 | 9.2 | 2.6 | 3.4 | 0.7 | 2.8 | 0.3 | 161 | 34.0 | 18 | 13.9 | 40 | 29.2 | 2465 | 297.2 | 225 | 80.3 | 2.39 | 1.16 | 0.82 | 0.38 |
| | 1 | 18 | 8.2 | 2.7 | 2.4 | 0.7 | 2.2 | 0.3 | 161 | 56.5 | 36 | 37.6 | 51 | 27.8 | 2663 | 176.1 | 190 | 73.1 | 1.40 | 0.56 | 0.81 | 0.37 |
| | 2 | 1 | 8.8 | 2.6 | 2.7 | 0.8 | 2.2 | 0.4 | 160 | 37.3 | 8 | 14.6 | 41 | 25.9 | 2466 | 275.0 | 226 | 52.5 | 1.77 | 0.50 | 0.85 | 0.36 |
| | 2 | 11 | 8.4 | 2.8 | 3.4 | 1.6 | 2.9 | 1.3 | 147 | 41.3 | 29 | 24.5 | 50 | 25.9 | 2630 | 220.7 | 169 | 55.7 | 1.07 | 0.29 | 0.77 | 0.31 |
| 1997 | 1 | 1 | 7.3 | 1.9 | 2.7 | 1.0 | 2.6 | 0.9 | 155 | 33.9 | 14 | 14.2 | 22 | 23.9 | 2347 | 354.4 | 273 | 63.8 | 2.56 | 1.42 | 1.51 | 0.66 |
| | 1 | 18 | 7.2 | 1.5 | 2.6 | 0.5 | 2.3 | 0.4 | 194 | 68.6 | 64 | 53.3 | 55 | 14.5 | 2995 | 503.5 | 197 | 28.8 | 1.12 | 0.50 | 1.08 | 0.38 |
| | 2 | 1 | 6.9 | 1.7 | 3.6 | 1.8 | 3.1 | 1.5 | 156 | 37.8 | 13 | 15.8 | 17 | 21.8 | 2435 | 351.3 | 252 | 62.8 | 1.68 | 1.25 | 1.19 | 0.83 |
| | 2 | 13 | 6.5 | 1.4 | 2.8 | 1.9 | 2.3 | 0.8 | 148 | 38.7 | 21 | 12.4 | 30 | 20.1 | 2584 | 433.5 | 156 | 50.6 | 1.33 | 1.17 | 1.06 | 0.76 |

-continued-

Appendix A7.–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 | ND | 3.7 | ND | 1.9 | ND | 182 | ND | 25 | ND | 63 | ND | 2311 | NA | 36 | ND | 0.09 | NA | 0.03 | ND |
| 1999 | 1 | 1 | 17.7 | 18.3 | 8.6 | 10.2 | 6.8 | 10.0 | 247 | 147.2 | 36 | 42.6 | 124 | 35.2 | 2390 | 431.5 | 261 | 122.2 | 2.94 | 3.19 | 0.56 | 0.35 |
| 2000 | 1 | 1 | 9.5 | 4.3 | 3.1 | 1.6 | 1.8 | 1.6 | 57 | 36.6 | 19 | 12.5 | 72 | 36.1 | ND | ND | ND | ND | 2.43 | 1.46 | 1.10 | 0.80 |
| 2001 | 1 | 1 | 7.8 | 5.1 | 6.4 | 5.2 | 8.2 | 6.7 | 115 | 22.2 | 5 | 3.6 | 38 | 32.5 | ND | ND | ND | ND | 2.37 | 0.53 | 0.30 | 0.20 |
| 2002 | 1 | 1 | 6.4 | 2.3 | 4.5 | 3.1 | 1.5 | 0.9 | 131 | 15.4 | 5 | 2.5 | 27 | 18.8 | ND | ND | ND | ND | 1.36 | 0.14 | 0.30 | 0.20 |
| 2003 | 1 | 1 | 6.5 | 3.0 | 2.2 | 0.8 | 2.1 | 0.8 | ND | ND | 6 | 1.8 | 54 | 26.9 | ND | ND | ND | ND | 1.20 | 0.20 | 0.50 | 0.40 |
| 2004 | 1 | 1 | 6.2 | 3.5 | 4.3 | 3.2 | 2.0 | 0.7 | 169 | 103.8 | 9 | 2.8 | 61 | 31.5 | 2764 | 342.8 | ND | ND | 1.15 | 0.18 | 0.28 | 0.08 |
| | 1 | 18 | 5.9 | 2.3 | 6.2 | 8.3 | 3.5 | 3.5 | ND | ND | 19 | 13.2 | 80 | 28.4 | 2914 | 277.1 | ND | ND | 0.70 | 0.35 | 0.19 | 0.11 |
| 2005 | 1 | 1 | 11.4 | 4.4 | 7.6 | 3.6 | 3.6 | 3.1 | 161 | 45.6 | 4 | 2.0 | 41 | 34.8 | 2701 | 243.7 | ND | ND | 1.60 | 0.68 | 0.24 | 0.11 |
| 2006 | 1 | 1 | 7.2 | 4.3 | 2.2 | 1.6 | 2.3 | 1.1 | 97 | 59.6 | 7 | 1.7 | 28 | 30.8 | ND | ND | ND | ND | 1.92 | 0.32 | 0.50 | 0.09 |
| 2007 | 1 | 1 | 3.6 | 0.4 | 1.1 | 0.3 | 1.1 | 0.6 | 115 | 32.4 | 6 | 0.7 | 56 | 39.5 | ND | ND | ND | ND | 1.47 | 0.43 | 0.21 | 0.08 |
| Fertilization yrs. 1990-2000 Avg | | 1 | 7.7 | 3.4 | 3.9 | 2.5 | 3.0 | 1.9 | 155 | 34.2 | 13 | 11.0 | 55 | 26.4 | 2672 | 275 | 189 | 68.6 | 1.54 | 1.00 | 0.59 | 0.29 |
| 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 | 199 | 66.4 | 1.71 | 0.88 | 0.59 | 0.31 |
| 1990-2007 Avg | | 1 | 7.5 | 3.2 | 3.8 | 2.3 | 2.9 | 1.8 | 149 | 38.1 | 10 | 8.6 | 49 | 27.9 | 2602 | 314 | 199 | 66.4 | 1.70 | 0.86 | 0.57 | 0.29 |
| Post-fertilization yrs. 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 | ND | ND | 1.60 | 0.34 | 0.35 | 0.18 |
| Post-fertilization yrs. 2001-2007 Avg | | 1 | 7.0 | 3.3 | 4.0 | 2.5 | 3.0 | 2.0 | 131 | 46.5 | 6 | 2.2 | 43 | 30.7 | 2732 | 293 | ND | ND | 1.58 | 0.35 | 0.33 | 0.17 |

Appendix A8.–Summary of seasonal mean water chemistry parameters by station and depth for Afognak Lake, 1990-2007.

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1990 | 1 | 1 | 41 | 1.7 | 6.8 | 0.1 | 6.3 | 0.5 | 0.8 | 0.4 | 14 | 3.4 | 2.9 | 1.4 | 0.4 | 0.3 | 121 | 24.3 |
| | 1 | 16 | 41 | 1.0 | 6.7 | 0.2 | 6.1 | 0.6 | 0.7 | 0.4 | 11 | 2.2 | 3.2 | 1.8 | 0.4 | 0.3 | 128 | 38.7 |
| 1991 | 1 | 1 | 38 | 0.8 | 6.7 | 0.1 | 10.4 | 7.8 | 0.9 | 0.3 | 13 | 0.8 | 2.1 | 0.3 | 0.8 | 0.5 | 210 | 31.1 |
| | 1 | 14 | 38 | 1.0 | 6.6 | 0.2 | 6.9 | 0.3 | 0.9 | 0.2 | 16 | 3.9 | 1.9 | 0.1 | 0.8 | 0.5 | 190 | 45.0 |
| 1992 | 1 | 1 | 35 | 1.2 | 6.6 | 0.2 | 5.8 | 1.0 | 0.9 | 0.5 | 12 | 3.4 | 2.5 | 0.9 | 0.6 | 0.3 | 157 | 9.3 |
| | 1 | 24 | 35 | 0.5 | 6.3 | 0.1 | 4.9 | 1.0 | 0.8 | 0.6 | 11 | 1.5 | 2.5 | 1.2 | 0.6 | 0.3 | 162 | 56.9 |
| 1993 | 1 | 1 | 37 | 1.0 | 6.6 | 0.1 | 7.5 | 2.7 | 0.5 | 0.1 | 7 | 7.5 | 2.2 | 0.4 | 1.3 | 1.1 | 104 | 34.9 |
| | 1 | 25 | 39 | 4.0 | 6.4 | 0.4 | 7.8 | 2.1 | 0.5 | 0.2 | 10 | 10.7 | 2.6 | 0.9 | 0.8 | 0.1 | 134 | 52.0 |
| 1994 | 1 | 1 | 39 | 6.5 | 6.6 | 0.2 | 6.2 | 2.0 | 1.1 | 0.8 | 5 | 3.2 | 2.2 | 0.9 | 0.6 | 0.2 | 141 | 44.0 |
| | 1 | 2 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| | 1 | 26 | 36 | 0.9 | 6.3 | 0.3 | 6.5 | 2.5 | 0.7 | 0.3 | 6 | 4.7 | 2.2 | 0.5 | 0.6 | 0.2 | 197 | 87.7 |
| 1995 | 1 | 1 | 60 | 5.6 | 6.6 | 0.2 | 9.8 | 1.0 | 2.0 | 0.8 | 11 | 2.6 | 3.7 | 1.4 | 1.3 | 0.4 | 85 | 45.6 |
| | 1 | 17 | 60 | 5.4 | 6.5 | 0.2 | 10.0 | 1.3 | 2.3 | 1.2 | 9 | 2.0 | 3.4 | 0.5 | 1.6 | 0.5 | 101 | 33.0 |
| | 2 | 1 | 58 | 4.9 | 6.6 | 0.2 | 9.7 | 1.1 | 1.9 | 0.9 | 11 | 4.3 | 3.2 | 0.3 | 1.1 | 0.3 | 87 | 55.9 |
| | 2 | 11 | 58 | 4.3 | 6.5 | 0.2 | 9.6 | 1.1 | 2.0 | 0.8 | 10 | 5.5 | 3.5 | 0.4 | 1.3 | 0.3 | 101 | 53.9 |
| 1996 | 1 | 1 | 56 | 1.5 | 6.7 | 0.2 | 10.5 | 0.7 | 1.4 | 1.0 | 10 | 2.5 | 3.2 | 0.5 | 1.3 | 0.2 | 54 | 25.9 |
| | 1 | 18 | 57 | 2.7 | 6.6 | 0.1 | 11.2 | 1.9 | 1.5 | 0.7 | 9 | 0.5 | 3.1 | 0.5 | 1.1 | 0.3 | 72 | 33.2 |
| | 2 | 1 | 56 | 1.4 | 6.7 | 0.1 | 10.7 | 1.0 | 1.2 | 0.6 | 9 | 1.3 | 3.1 | 0.5 | 1.1 | 0.3 | 54 | 25.7 |
| | 2 | 11 | 57 | 1.1 | 6.7 | 0.1 | 10.7 | 1.0 | 1.5 | 0.6 | 11 | 2.6 | 2.9 | 0.5 | 1.5 | 0.3 | 89 | 43.4 |

-continued-

Appendix A8.–Page 2 of 2.

| 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 | ND | 7.0 | ND | 11.8 | ND | 2.0 | ND | 11 | ND | 3.3 | ND | 1.0 | ND | 48 | ND |
| 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 | ND | ND | 7.1 | 0.2 | 8.7 | 2.4 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| 2001 | 1 | 1 | ND | ND | 7.2 | 0.4 | 10.1 | 2.3 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| 2002 | 1 | 1 | ND | ND | 7.2 | 0.5 | 10.1 | 0.5 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| 2003 | 1 | 1 | ND | ND | 6.9 | 0.1 | 9.8 | 0.6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| 2004 | 1 | 1 | ND | ND | 6.9 | 0.1 | 11.4 | 0.7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| | 1 | 18 | ND | ND | 6.8 | 0.1 | 10.9 | 0.7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| 2005 | 1 | 1 | ND | ND | 6.8 | 0.1 | 10.9 | 1.1 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| 2006 | 1 | 1 | ND | ND | 6.8 | 0.1 | 11.3 | 0.9 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| 2007 | 1 | 1 | ND | ND | 6.8 | 0.1 | 10.9 | 1.2 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| 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 | 90.8 | 30.0 |
| 1990-2007 Avg | | 1 | 49 | 2.1 | 6.8 | 0.2 | 9.9 | 1.5 | 1.2 | 0.6 | 10.7 | 3.6 | 2.9 | 0.6 | 1.0 | 0.3 | 90.8 | 30.0 |
| 2001-2006 Avg | | 1 | ND | ND | 7.0 | 0.2 | 10.3 | 1.2 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| 2001-2007 Avg | | 1 | ND | ND | 6.9 | 0.2 | 10.6 | 1.0 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |

Appendix A9.–Weighted mean zooplankton density, biomass, size by species for station 1 (1987-2007) and station 2 (1988-2007), Afognak Lake.

| Station 1 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 ($mg/m^2$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 |
| 2007 | 5 | 10,913 | 24 | 0.78 | 2,930 | 9 | 0.88 | 7,718 | 13 | 0.70 | 74,257 | 66 | 0.31 | 3,386 | 5 | 0.58 | 1,730 | 3 | 0.47 | 100,934 | 120 |
| 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 |
| 1987-2006 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 |
| 1987-2007 Avg | | 24,458 | 85 | 0.90 | 2,149 | 7 | 0.87 | 8,529 | 13 | 0.67 | 134,239 | 127 | 0.32 | 6,523 | 11 | 0.62 | 2,869 | 5 | 0.47 | 174,933 | 240 |
| 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 |
| 2001-2007 Avg | | 23,299 | 53 | 0.79 | 2,260 | 6 | 0.84 | 7,133 | 10 | 0.64 | 67,559 | 57 | 0.31 | 4,832 | 6 | 0.56 | 2,466 | 4 | 0.45 | 107,550 | 136 |

-continued-

Appendix A9.–Page 2 of 2.

| Station 2 Year | No. Samples | *Epischura* Density (no/m²) | *Epischura* Biomass (mg/m²) | *Epischura* Size (mm) | *Diaptomus* Density (no/m²) | *Diaptomus* Biomass (mg/m²) | *Diaptomus* Size (mm) | *Cyclops* Density (no/m²) | *Cyclops* Biomass (mg/m²) | *Cyclops* Size (mm) | *Bosmina* Density (no/m²) | *Bosmina* Biomass (mg/m²) | *Bosmina* Size (mm) | *Daphnia* Density (no/m²) | *Daphnia* Biomass (mg/m²) | *Daphnia* Size (mm) | *Holopedium* Density (no/m²) | *Holopedium* Biomass (mg/m²) | *Holopedium* Size (mm) | TOTALS Density (no/m²) | TOTALS Biomass (mg/m²) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 |
| 2007 | 5 | 16,269 | 63 | 0.95 | 1,141 | 4 | 0.93 | 6,693 | 12 | 0.71 | 57,065 | 49 | 0.31 | 934 | 1 | 0.55 | 2,049 | 4 | 0.50 | 84,151 | 133 |
| 1988-2006 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 |
| 1988-2007 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 |