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Virginia Lake Sockeye Juvenile Survival and Adult Escapement Monitoring

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Report Summary Page

Title: Virginia Lake Sockeye Juvenile Survival and Adult Escapement Monitoring

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Investigator(s)/Affiliation(s): Tom Cady/USDA Forest Service, Wrangell Ranger District (2001-2002); Dennis Reed/USDA Forest Service, Wrangell Ranger District (2001)

Management Region: Southeast (1)

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Abstract: Virginia Lake adult sockeye escapement was monitored at a top-of-fishpass weir on Mill Creek in 2001 and 2002. A mark-recapture experiment was attempted with visual counts of tagged fish in 2001 and by seining in 2002 to verify weir counts. Nutrient enrichment of the lake to boost primary production occurred in both 2001 and 2002. Lake physical, chemical, and biological parameters were monitored concurrently with the enrichment in both years, as well. Fall hydroacoustic surveys attempted to estimate pelagic fish abundance. The weir escapement was 1,003 in 2001 and 2,073 in 2002, far below the 10,000-40,000 fish returns estimated at the onset of the Virginia Lake enhancement program in 1986. Escapement verification at the lake was unsuccessful, in part, due to extremely low counts observed at the lake. Nutrient enrichment had a dramatic positive effect on primary and, subsequently, secondary production. Hydroacoustic surveys estimated 56,000 sockeye salmon fry in 2001 and only 32,000 sockeye salmon fry in 2002. Our observations identified several potential bottlenecks limiting sockeye salmon success in Virginia Lake that warrant further investigation.

Key Words: escapement, fishpass, lake enrichment, Mill Creek, *Oncorhynchus nerka*, scales, sockeye, subsistence fishery, survival, Virginia Lake, weir, zooplankton

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INTRODUCTION

Virginia Lake (Alaska Department of Fish and Game stream number 107-45-007) produces a small run of sockeye salmon (*Oncorhynchus nerka*) that is an important subsistence resource to Wrangell residents. Virginia Lake and its outlet stream, Mill Creek, are located on the mainland approximately 8 km east of the community of Wrangell, which is situated at the northern tip of Wrangell Island near the mouth of the Stikine River. Mill Creek empties into a small, unnamed cove or lagoon where most of the subsistence harvest occurs. Reportedly, Mill Creek was the location of the first village of the Stikine Tlingit as well as the first winter village for the Kiksadi and the Katcadi (United States Department of Agriculture, Wrangell Ranger District, unpublished data). Sealaska Native Corporation investigated the site and found that a sawmill had obliterated any apparent evidence of the village. The sawmill was owned by the Alaska Metals and Power Company and operated from 1944-1953. The sawmill burned to the ground in 1954.

Use of Virginia Lake for subsistence harvest of sockeye salmon has increased substantially since 1986 (Appendix A.1). From 1985-2002, the number of subsistence permits issued ranged from a low of 1 in 1988 to a high of 52 in 1995 (ADF&G, Alexander Database, 2002). The total reported harvest ranged from a low of 10 in 1988 to a high of 657 in 1995. The average subsistence harvest for the 1985-2002 period was approximately 240 fish per year. The 2002 season saw the highest catch per permit rate of 15.42 fish per permit. This data provides a simple catch per unit of effort (CPUE) that illustrates the fishery's effect on the population. This change may be partly explained by changes in the permit system and increased familiarity with the reporting system. Regardless, subsistence use is increasing, possibly due to socioeconomic factors.

Virginia Lake sockeye contribute to the annual commercial fisheries salmon harvest in Southeast Alaska (Appendix A.2). The initial fry plants included a marked (i.e., coded-wire tag) component that were later captured and identified as adults in the commercial catch in waters around the southern portion of the Tongass National Forest (ADF&G districts 101-108). From these records, we estimate the contribution to commercial fisheries from the initial fry plants of approximately 7.6 million fish to be roughly 16,000 adults for the period 1994-2000. These commercial harvest numbers are not complete as commercial recoveries of sockeye coded wire tags has not been complete for this time period due to budgetary constraints. Although sport fishing is a popular activity at Mill Creek and Virginia Lake, only generic sport fish harvest data are available for the Wrangell area and only for the year 2000. We are unable to estimate how many, if any, sockeye contribute to the Virginia Lake and Mill Creek sport fishery at this time.

The Virginia Lake bioenhancement and enrichment program was a collaborative endeavor initiated and implemented by the commercial fishing community in Wrangell, Alaska Department of Fish and Game (ADF&G), United States Forest Service (USFS), and the Southern Southeast Regional Aquaculture Association (SSRAA) in the 1980's. The system has a fairly extensive manipulation history commencing with a preliminary limnological survey in 1986 and includes additional limnological evaluations, sockeye fry plants from McDonald Lake stock

(Cleveland Peninsula, Tongass National Forest, Alaska), nutrient enrichment, stream channel modification (i.e., fishpass construction in 1988) to aid salmon migration, and adult escapement evaluations (Table 1). Adult weir counts were conducted from 2000-2002 (Appendix B.1). However, adult sockeye age-at-return data were collected from 1998-2002 (Appendix B.2). Prior to the 1980's, only two ADF&G foot surveys were conducted on Virginia Lake tributaries (Appendix B.3). These surveys were not quantifiable, but verified the presence of an endemic stock of sockeye salmon. More discrete surveys conducted in 2001 and 2002 estimated less than 10% of the Mill Creek weir escapement was documented at the spawning tributaries (Appendix B.4).

Table 1. Chronology of management history at Virginia Lake and Mill Creek, 1986-2002.

Action	**1986**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Limnology	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Enhancement[a]		X													X	
Bioenhancement[b]			X	X	X	X	X	X	X							
Enrichment[c]					CL50	CL60	CL60	CL60	CL60	CL60		CL50	CL50	CL50	CL50	CL60
Stream surveys[d]								X	X	X	X	X	X	X	X	X
Fish counter									X	X	X					
Weir operation[e]											**S**	**S**	**S**	**E**	**E**	**E**

[a]Fishpass construction and modification.
[b]Sockeye fry plants.
[c]Percent critical load – phosphorus.
[d]Forest service conducted surveys
[e]S=samples only; E=escapement estimate and samples.

Data on lake physical and chemical characteristics, zooplankton populations, and sockeye fry populations were collected between 1989-2002[1]. Although fluctuations were evident in the data, phytoplankton and nutrient levels responded to the enrichment, and general water quality parameters were within a range considered normal for stained, oligotrophic, coastal Alaska lakes (Appendix C.1-3). Average total macro-zooplankton density was approximately 79,000·m^{-2}, and average total macro-zooplankton biomass was approximately 172 mg m^{-2} between 1986-2002 (Hollowell and Zadina 2002, 2003). Aside from initial population swings brought on by the early fry plants, zooplankton densities and sizes fluctuated considerably between 1991-2002 (Appendix C.4-5). The primary species identified in monthly water samples were the cladoceran *Bosmina longirostris*, and copepods *Diaptomus franciscanus* and *Cyclops* species. Copepod densities dominated the macro-zooplankton community through mid-summer, and cladoceran densities became dominant in late summer. Overall, *Bosmina* were dominant numerically, with a high mean annual density of 250,000 m^{-2} in 1992, but declined recently to between 19,000-

[1] No fry density data collected in 1993, 1994, or 1996.

41,000 m^{-2} from 1999-2002. Mean annual biomass was evenly split between copepods (50%) and cladocerans (50%). However, copepod biomass dominated samples from 1999-2002. In 11 years of sampling, estimated sockeye fry densities ranged from a low of 0.013 m^{-2} in 2002 to a high of 0.133 m^{-2} in 1995[2] (Appendix C.6). A total of 7,619,104 sockeye salmon fry were planted into Virginia Lake from 1989-1995 (Appendix C.7).

The Virginia Lake Sockeye Salmon Project was initiated in 2001 and funded through the Federal Subsistence Fisheries Resource Monitoring Program. The importance of the Virginia Lake sockeye salmon resource to the community of Wrangell points to the need for quantifiable escapement estimates to facilitate subsistence harvest regulation. The primary purpose of this study is to gather stock information, which will be used to manage the subsistence sockeye fishery in Virginia Lake and its outlet, Mill Creek.

In addition to escapement data, fisheries harvest and lake ecology data were collected at Virginia Lake. A holistic assessment of the lake's physical, chemical, and biological characteristics and assessment of the enrichment program, which directly affects lake productivity, will determine the effect of the freshwater rearing environment on future returns. Nutrient enrichment increases the basic elemental phosphorus and nitrogen loads in the lake thus assuming an increase in the entire lower food chain, which, in turn, bolsters fry production. Zooplankton are the main food source for juvenile sockeye salmon, and juvenile sockeye prefer cladocerans, which provide a more nutritious food source within the zooplankton community (Bugayev et. al. 1995, Beauchamp et. al. 1995, Koenings and Kyle 1997, Shortreed et. al. 1998, Edmundson and Mazumder 2001, Mazumder 2002). By estimating the biomass and number of zooplankton by species, we can evaluate whether food is a limiting factor for juvenile sockeye salmon in Virginia Lake. The species composition over the season and between years may provide insight into how the zooplankton community responds to nutrient enrichment and different fry densities. Harvest and escapement data from returning adults will enable run reconstruction by brood year, and will indicate the overall status of the Virginia Lake sockeye salmon stock. The stock status and trend information gathered by this study will help determine what changes in stock management and subsistence harvest regulations, if any, might be needed in the future to protect or further exploit the Virginia Lake sockeye stock. This report summarizes the sockeye salmon stock assessment data collected in 2001 and 2002.

Companion reports submitted by ADF&G fully describe the results from limnological surveys conducted in 2001 and 2002 (Hollowell and Zadina 2002, 2003). Results from this work are summarized and discussed herein.

OBJECTIVES

As presented in the Final Investigation Plan, the project has four objectives to characterize the production and return of Virginia Lake sockeye: 1) limnology; 2) escapement; 3) spawner data;

[2] Coincides with the last year of fry stocking.

and 4) use of spawning habitat. The first objective addresses the freshwater rearing phase, and the other three objectives address the adults upon their return to freshwater from ocean rearing.

1) The limnology objective is to determine the periodic levels of nitrogen, phosphorous, and silicon, among other nutrients, and to estimate the zooplankton and juvenile sockeye populations in Virginia Lake. Freshwater rearing conditions are monitored in order to determine relative fry-to-smolt production. The question to be answered is "What are the freshwater rearing conditions producing in terms of fall sockeye salmon fry populations?"

2) The escapement objective determines the abundance of the spawning escapement to Mill Creek/Virginia Lake. Escapement numbers help provide the necessary information to establish harvest seasons and bag limits, and to estimate the sockeye fry population expected in the subsequent brood using standard survival assumptions. The question to be answered is "How many sockeye comprise the spawning escapement of the 2001 and 2002 adult returns?"

3) The spawner data objective describes the length, sex, and age composition of the sockeye spawning escapement to Mill Creek/Virginia Lake. Sample data helps estimate relative ocean survival, subsequent fry production, and generally estimates subsequent adult progeny returns. The question to be answered is "What is the composition of the spawning escapement?"

4) The spawning habitat objective evaluates the temporal and spatial distribution of sockeye spawning in the Virginia Lake system. This information will be used to relate strength of return, water conditions, and use of habitats to fry recruitment and survival. The question to be answered is "How is the spawning habitat being utilized, both temporally and spatially?

METHODS

Study Site

The Virginia Lake system is on the mainland approximately 8 km to the east of the Wrangell community. It lies in a steep mountain cirque basin ranging in elevation from sea level to over 1000 m. The entire watershed encompasses approximately 10,495 ha (Figure 1). Spruce-hemlock forest, interspersed with pockets of muskeg, comprises the majority of the sub-alpine terrestrial environment. Mill Creek, Virginia Lake, the mid-lower portion Glacier Creek, and the mid-lower reaches of Porterfield Creek provide spawning and rearing habitat to anadromous and resident fish. Sockeye salmon are the most abundant salmon species in the Virginia Lake system. Pink (*O. gorbuscha*), chum (*O. keta*), coho (*O. kisutch*), and chinook (*O. tshawytscha*)

salmon have all been documented in the system. The lake also supports populations of anadromous and resident Dolly Varden char (*Salvelinus malma*) and cutthroat trout (*O. clarki*), and resident populations of stickleback (*Gasterosteus aculeatus*) and sculpin (*Cottus* sp.).

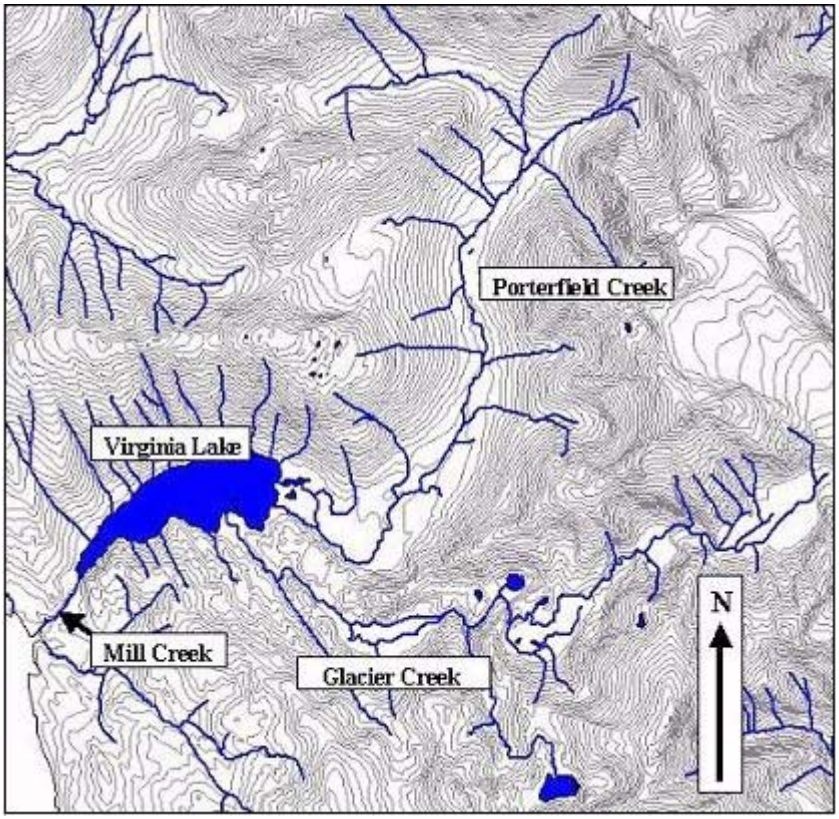

Figure 1. Virginia Lake watershed.

Virginia Lake is 257 ha in size and has a perimeter of 9.9 km. The lake has a general east-west profile and is organically stained. Glacier Creek and Porterfield Creek are the two main tributaries to Virginia Lake; both are mostly clearwater/stained systems. Both creeks derive most of their annual flow volume from precipitation, but small permanent icefields in the headwaters provide a minimal contribution, as well. Porterfield enters the lake at the eastern end, and Glacier enters at the southeast end of the lake. Porterfield Creek drains the main valley and possesses four known sockeye salmon spawning reaches: 1) the South Arm (2.6 km); 2) the North Arm (2.2 km); 3) an arm which connects the North and South Arms (0.5 km), flowing from south to north; and 4) upper Porterfield Creek (1.1 km). Glacier Creek drains an icecap and glacier basin, but is largely a clearwater and stained system. The anadromous reach has four distinct sub-reaches. Moving progressively upstream from the lake, these include: 1) a low-gradient 0.8 kilometer floodplain reach; 2) a moderate gradient bedrock and boulder riffle reach approximately 2.0 kilometers in length; 3) a low gradient highly braided floodplain reach with a total channel length of 8.3 km; and 4) a moderate gradient cobble and boulder riffle with a length of 0.6 km.

Mill Creek exits the west end of the lake and flows approximately 1.2 km to saltwater. Mill Creek possesses limited sockeye salmon spawning habitat due to its moderate-deep channel incision and bedrock containment, abundance of bedrock and boulder substrate, and moderate gradient. However, there are two sites where spawning is suspected: 1) the lake outlet at the juncture where Virginia Lake becomes Mill Creek; and 2) the tailout of the Flume Pool, approximately 0.3 km upstream from saltwater.

Limnology and Juvenile Sockeye Population Estimate

Limnology

Limnology sampling and analysis were contracted to the Alaska Department of Fish and Game, Division of Commercial Fisheries. Personnel from the Ketchikan office performed water and plankton sampling, hydroacoustic surveys, and mid-water trawls. Water and plankton samples were sent to the ADF&G Limnology Laboratory in Soldotna for analysis. Limnology sampling

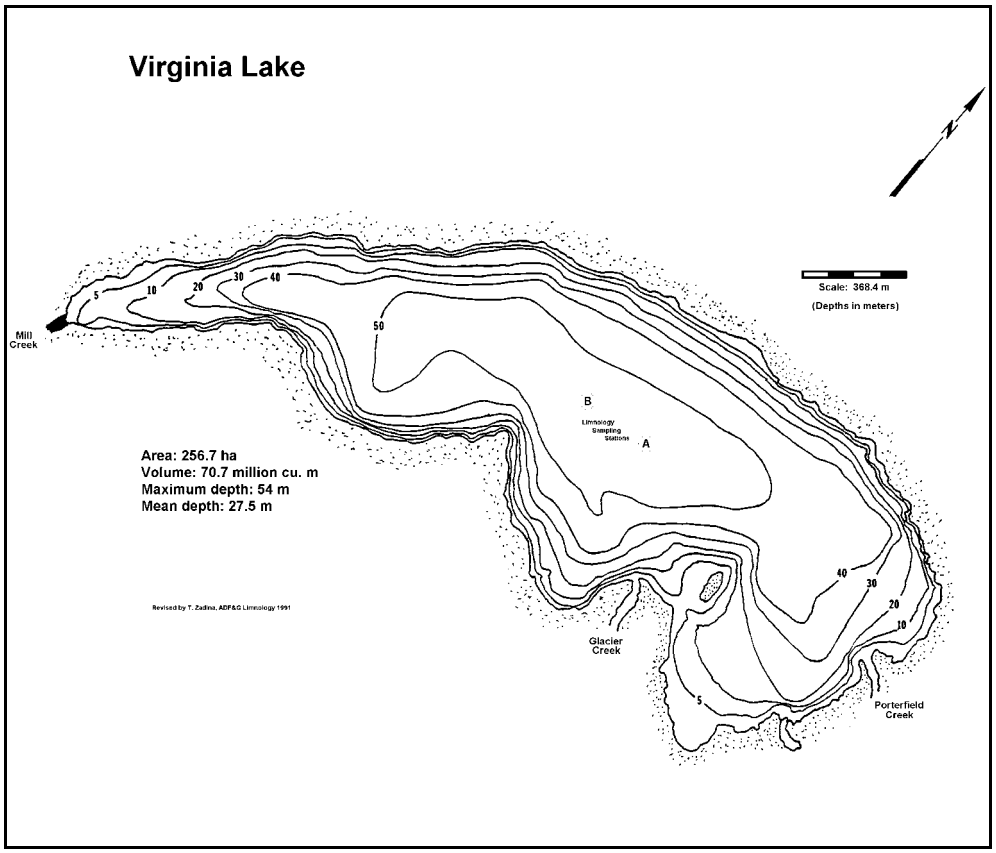

Figure 2. Bathymetric map of Virginia Lake illustrating the limnology sampling stations.

was scheduled at four-week intervals from May through October, for a total of six sampling dates. Two stations were set up in the deepest part of the lake (Figure 2). All limnological samples were only collected at Station A. Zooplankton samples were collected from both stations on each sampling date. Information on the limnological methodologies and results can be found in Hollowell and Zadina (2002, 2003).

Juvenile Sockeye Population Estimate

Distribution and abundance of rearing sockeye salmon fry were estimated by hydroacoustic and mid-water trawl sampling using the same methods described below and by Zadina and Weller (1999). Virginia Lake was divided into ten sampling areas based on surface area. Sample design consisted of a series of ten, randomly chosen orthogonal transects across the lake, one from each sampling area. Transect sampling was conducted during post-sunset darkness in one night. A constant boat speed of about 2.0 m sec^{-1} was attempted for all transects. A Biosonics DT-4000™ scientific echosounder (420 kHz, 6° single beam transducer) with Biosonics Visual Acquisition © version 4.0.2 software was used to collect data. Ping rate was set at 5 pings sec^{-1} and pulse width at 0.4 ms. Data were analyzed using Biosonics Visual Analyzer © version 4.0.2 software after returning to the office. A 2 m × 2 m elongated trawl net was used for pelagic fish sampling. Trawl depths and duration were determined by fish densities and distributions throughout the lake based on observations during the hydroacoustic survey.

Adult Escapement Estimates

The escapement objective had two phases: 1) upgrade of the Mill Creek fishway to achieve complete interception of the escapement; and 2) counting the escapement. Two methods were employed to determine the escapement: 1) the weir count at the tidewater fishpass, and 2) a mark-recapture estimate on the spawning grounds.

Mill Creek Fishpass Upgrade

Let it be understood that the Mill Creek fishpass was designed to facilitate adult salmon migration above the lowermost barrier falls in Mill Creek – it is not a trap or weir. Considerable modifications were added during the early spring of 2001 to improve interception of migrating adults. The combination pool-and-weir and Alaska steeppass fishway in Mill Creek was augmented with five short reinforced concrete walls. One training wall extension at the top of the steeppass forms the capture and holding site; one notched weir upstream of the fishpass controls flow into the capture site; and three short walls along the edge of the thalweg deflect flows away from the fishpass. The training wall extension was designed with a notch to accommodate a removable gate to regulate fish movements (i.e., removable top of fishpass trap).

The upstream weir was designed with a notch to accommodate dam boards to facilitate periodic de-watering of the entire structure for maintenance purposes. The three outer walls were designed to deflect higher flows out of the interior of the fishway site as well as limit entry by upstream migrants attempting the waterfall.

Enumeration

A crew of three persons administered the fishpass trap at Mill Creek at least twice daily from mid-July through the summer and into the fall (mid-September). The crew was comprised of a Forest Service crew leader, a Tribal crew member, and a Forest Service crew member. Operations were based out of a tent camp situated on the south shore of Virginia Lake.

Migrating fish that ascended the Mill Lake fishpass entered the top pool that formed the trap where they were contained until the crew's arrival. Upon arrival, a gate was immediately placed in front of the steeppass exit to prevent escape[3]. Fish were counted, marked, measured and sampled, and passed into an upstream resting pool. In addition to counting fish that passed through the trap, a mark-recapture experiment was conducted to make a separate estimate of total escapement, given the possibility that fish may have passed into the lake uncounted. Biological sampling was conducted at the trap, including species identification and sockeye salmon length measurements and scale collection for aging. The sampling and marking protocol followed the methodologies described in the documents "Sampling Procedures Weir Mark-Recapture Studies: 2001 Subsistence Sockeye Salmon Stock Assessment" and "Length, Sex, And Scale Sampling Procedure for Sampling Using the ADF&G Adult Salmon Age-Length Mark-Sense Form, Version 3.0 - Region I, Commercial Fisheries, June 2002".

Adult Population Age and Size Distribution

Age, sex, and length data were collected from adult sockeye salmon at the weir to describe the biological structure of the returning population. Based on the number of fish in the trap on each day, the crew pre-determined the number of fish to be sampled to reduce bias in sample selection and to ensure the population was sampled across the breadth of the run. Three scales were taken from the "preferred area" of each fish (i.e., on a line diagonal from the dorsal to the anal fin and two scale rows above the lateral line). Scale samples were analyzed at the ADF&G salmon aging laboratory in Douglas, Alaska. Age and length data were paired for each fish sample. Age classes were designated by the European aging system where freshwater and saltwater years are separated by a period (e.g. 1.3 denotes 1-year freshwater and 3-years saltwater). Brood year tables were compiled by sex and brood year to describe the age structure of the returning adult sockeye salmon population. The length of each fish was measured from mid-eye to tail fork to the nearest millimeter (mm).

[3] A block-gate was used only in 2002.

Mark-Recapture

In 2001, sampled sockeye were implanted with a color-coded and numbered spaghetti tag as a primary mark. Sampled/marked fish were placed in a wooden, hinged and foam-padded restraint cradle without anesthesia. While in the restraint cradle, a spaghetti tag was attached to the back just below the posterior portion of the dorsal fin using a solid, barbed canula. The tag was secured with an overhand/square knot near, but not tight to, the back. Spaghetti-tagged fish were also given a secondary mark consisting of a hole punched in the left operculum in case of tag loss discovered upon carcass recovery.

Green tags were used initially and yellow tags were used after the supply of green tags was exhausted. No artificial separation in the use of the two colors was selected. It was estimated, from monitoring recent escapements, that the supply of green tags on hand would be totally utilized approximately midway through the return. Such differential tagging was employed to determine whether or not any differential use of spawning habitat could be observed between those fish from the first half of the return versus the second half of the return.

In 2002, it was determined that the application of an artificial tag was probably causing added stress to the fish and was subsequently abandoned. Marked fish for the 2002 sampling season simply received an adipose clip and a secondary fin clip according to the protocol described in the aforementioned documents pertaining to sockeye escapement monitoring.

Lake and Stream Surveys. Escapement surveys were made by boating the lake perimeter, including that area of the outlet, and foot surveys of Glacier and Porterfield Creeks, the primary lake tributaries. Most surveys occurred from mid-morning to early afternoon, and during normal or low flow conditions. For safety reasons, each survey was performed by a crew of at least two persons. Since the overall extent of the survey area precluded completion in one day, surveys were completed in combination over two or more days. In addition to visual counts, attempts were made in 2002 to beach seine sockeye staging at the stream inlets and other likely beach locations (see below).

Attempts were made to recover mortalities for examination for possible marks (adipose clip, spaghetti retention or loss, opercle punch). In both lake and stream surveys, carcasses were recovered with the aid of a telescoping handle fitted with a forked spearhead. The caudal fin of recoveries was cut off with a knife before returning the carcass to water with depth to avoid a second “recapture” or double counting of the same carcass.

Lake surveys were made by slowly cruising along the shoreline in a skiff. The boat followed the contour where the littoral area drops off to depth in order to get better views of fish on the littoral side of the skiff. The distance from boat to shoreline was typically less than 20 m. An observer on the bow of the boat was helpful, but not absolutely necessary. Any shallow beach spawning would be readily evident to observers. Deep beach spawning, though it likely occurs in Virginia Lake, would not be visible from the surface. When the survey came to the outlet, the boat was

beached at the trailhead and the survey of the area immediate to the lake was made on foot. Snorkel surveys were also conducted at the outlet in 2002 (see below).

Escapement surveys of Porterfield and Glacier Creeks were conducted on foot by a crew of two to four persons with at least one person walking along each streambank. Thirteen surveys were conducted in 2001. Surveys continued almost daily from 10 September through 6 October. Two surveys beginning on 26 September and 30 September were conducted in 2002. Each arm of Porterfield Creek and a connector channel were walked either unidirectionally (2001) or by a crew of two starting at each arm and meeting at a point midway (2002). The entirety of the Porterfield Creek survey covered approximately 2.4 km of suitable stream channel spawning habitat. Glacier Creek surveys were initiated at the single inlet and walked to a point where the channel takes on a large-riffle/cascade morphology, which is approximately 0.5 km upstream from the inlet. Except for the area immediate to the lake outlet, Mill Creek was not surveyed on a regular basis because of its large substrate, turbulence, and deep, dark pools. However, some spawning has been observed in previous years at one location during summer base flows.

Snorkel Surveys. Snorkel surveys of Mill Creek were not included in the Final Investigation Plan because of their perceived limited utility and reliability due to flows, turbulence, and water clarity. Mill Creek is the only stream requiring this method of survey for spawning activity because of its deep channel incision, large substrate, moderate gradient, and subsequent turbulence, and average depth. One survey was performed during summer base flow in 2001 (15 August) to determine whether fish were using Mill Creek for spawning. Snorkel surveys were conducted throughout the run when flows permitted in 2002. Pools and glides were the targeted observation reaches.

Beach Seining. Seining efforts concentrated at the mouths Porterfield and Glacier Creeks with the intent of completing a second mark-recapture study. At least six other locations were sampled over the course of the spawning period. The mark-recapture study was conducted only within this area during subsequent trips. The beginning dates of the two trips were 13 September and 23 September 2002**.**

A 60 m long by 4 m deep knotted nylon mesh beach seine was used to surround sockeye salmon, pulled by a small skiff with outboard motor and crew members on foot. All sockeye salmon caught were first inspected for previous marks, then marked with a dorsal fin clip, and released with a minimum of stress. The total sample size, the number of new fish marked, and the number of recaptured fish with each type of mark were recorded.

RESULTS

Limnology and Juvenile Sockeye Population Estimate

Water and plankton tow samples were taken on 4 May, 9 June, 10 July, 6 August, 18 September, and 16 October in 2001, and 7 May, 6 June, 3 July, 6 August, 6 September, and 7 October in 2002. Hydroacoustic and mid-water trawl sampling of the rearing sockeye fry population occurred on 1 October 2001 and 20 September 2002. The following text contains results from information collected by Forest Service fisheries crews and further interpretation of the results presented in the contracted analyses and reports by Hollowell and Zadina (2002, 2003).

Physical/Chemical Parameters

The general climatic pattern in 2001 was typical for SE Alaska, except for slightly drier conditions experienced during the summer. The region experienced a cooler and prolonged spring followed by a warm, wet summer in 2002.

Virginia Lake exhibited similar physical and chemical characteristics in 2001 and 2002 compared to past year's data (Appendix C.1-2). The maximum lake surface (to 3 m depth) temperature was 14.2 ^{o}C on 7 August, 2002. Figure 3 illustrates the 2002 late-spring to early-fall lake and tributary temperature pattern. The lake exhibited a moderate thermocline near 10 m depth from June-September (Figure 4). Dissolved oxygen ranged between 10-12 ppm at depths less than 30 m during the course of the sampling periods.

The annual fertilizer application periods lasted from 19 May to 4 September in 2001 and from 16 May to 19 September in 2002 (Appendix C.3). Epilimnetic nutrient concentrations followed a pattern that corresponded to the fertilizer application – generally, low concentrations early and late in the application season and highs during the summer. Low concentrations of total phosphorous varied from 3.5 and 5.8 µg L^{-1} in May and October to highs of 6.8 and 12.9 µg L^{-1} in early August of both years. Total nitrogen levels were highest in May and June (average=180 µg L^{-1}), decreased to a low in August (<125 µg L^{-1}), and then increased again in October (143 µg L^{-1}) in 2001. Total nitrogen concentrations followed a slightly different pattern in 2002 with a high of 163 µg L^{-1} in May and a low of 112 µg L^{-1} in July. Concentrations rebounded slightly in August and September, but declined again in October. Total phosphorus concentrations did not exceed EPA recommended water quality criterion (criterion=8.75 µg L^{-1} TP; EPA 2000), but exceeded EPA recommended criterion for total nitrogen (criterion=0.10 mg L^{-1} TN; EPA 2000). Filterable reactive phosphorus (FRP), probably the most critical component determining primary productivity, in 2001 and 2002 averaged (epilimnion) 2.22 µg L^{-1} FRP and 3.28 µg L^{-1} FRP, respectively. Ammonia concentrations, also important to primary productivity, remained well below levels considered acutely and chronically toxic to organisms found in Virginia Lake (acute~33 mg N L^{-1}, chronic~6.7 mg N L^{-1}; EPA 1999). The reader should note that these data

are compared with EPA criteria established for lakes in EPA Region II, which includes forested areas in the western United States. There are presently no established nutrient water quality criteria for Alaskan lakes.

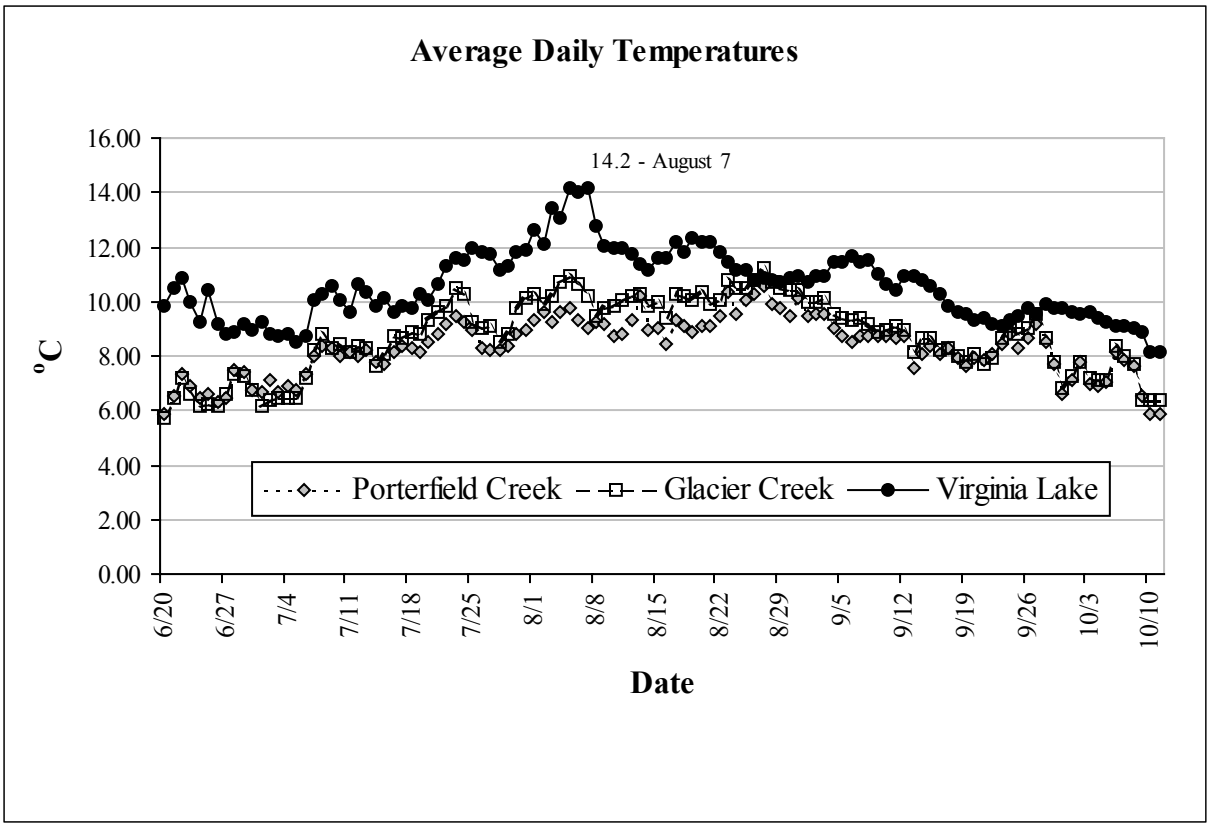

Figure 3. Average daily temperature regimes at Virginia Lake, Porterfield Creek, and Glacier Creek from late-spring to early-fall, 2002. Lake temperature taken at 3 m depth.

Primary and Secondary Production

Phytoplankton and zooplankton communities tracked the increased summer nutrient levels in 2001 and 2002. The average seasonal epilimnetic chlorophyll *a* concentrations in 2001 and 2002 were 0.48 µg L^{-1} and 0.99 µg L^{-1}, respectively. Chlorophyll a concentrations peaked in June 2001 and July 2002 (Figure 5). The phytoplankton species composition was unknown for both 2001 and 2002. However, filamentous algae were clearly present. Dense mats of filamentous algae were observed on bottom substrates by fisheries crews while snorkeling in shallow littoral areas in Virginia Lake and in low-moderate velocity areas of Mill Creek. The algal bloom was most obvious from mid-June to mid-September.

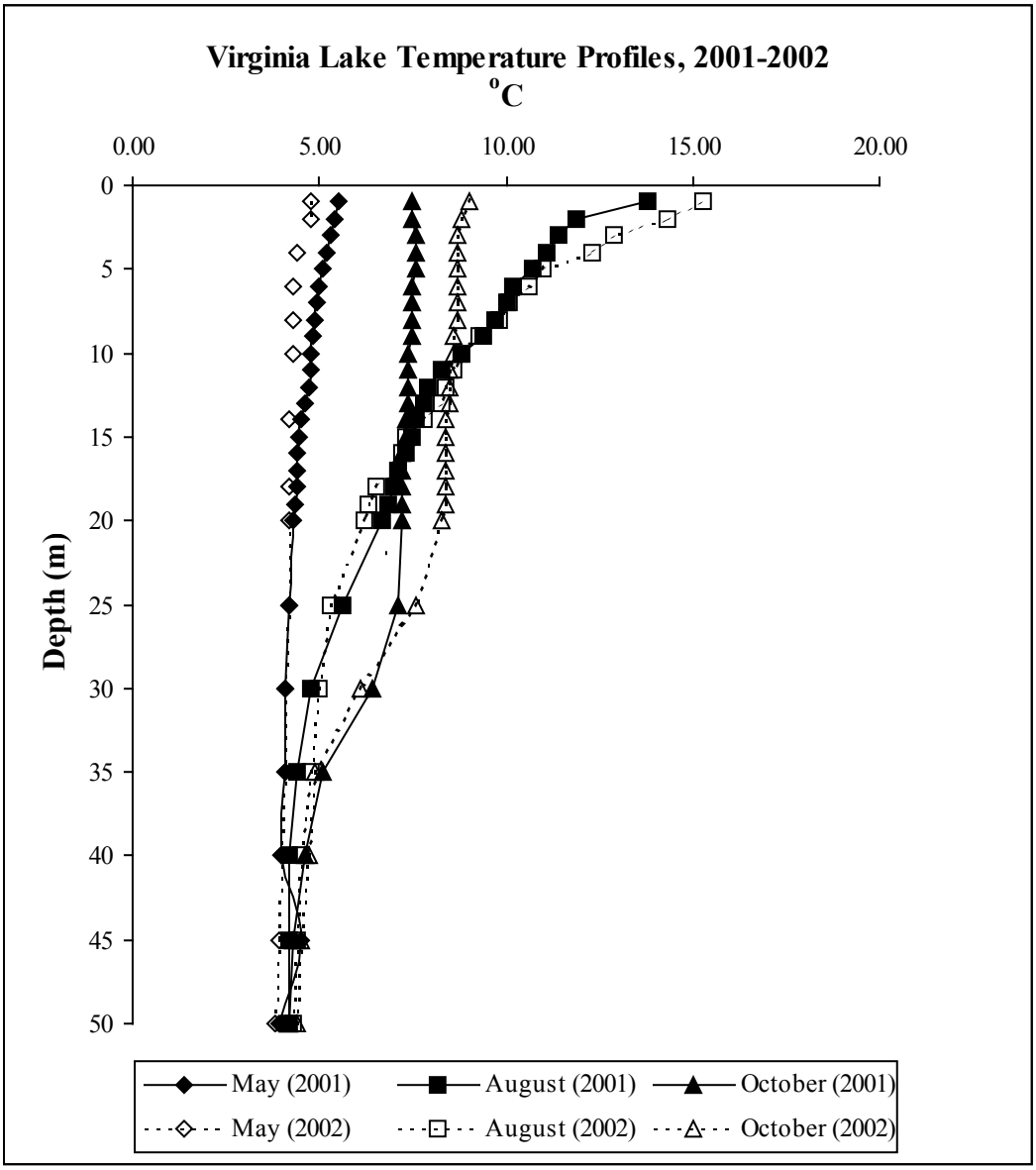

Figure 4. Temperature profiles from Virginia Lake, Station A, 2001 and 2002.

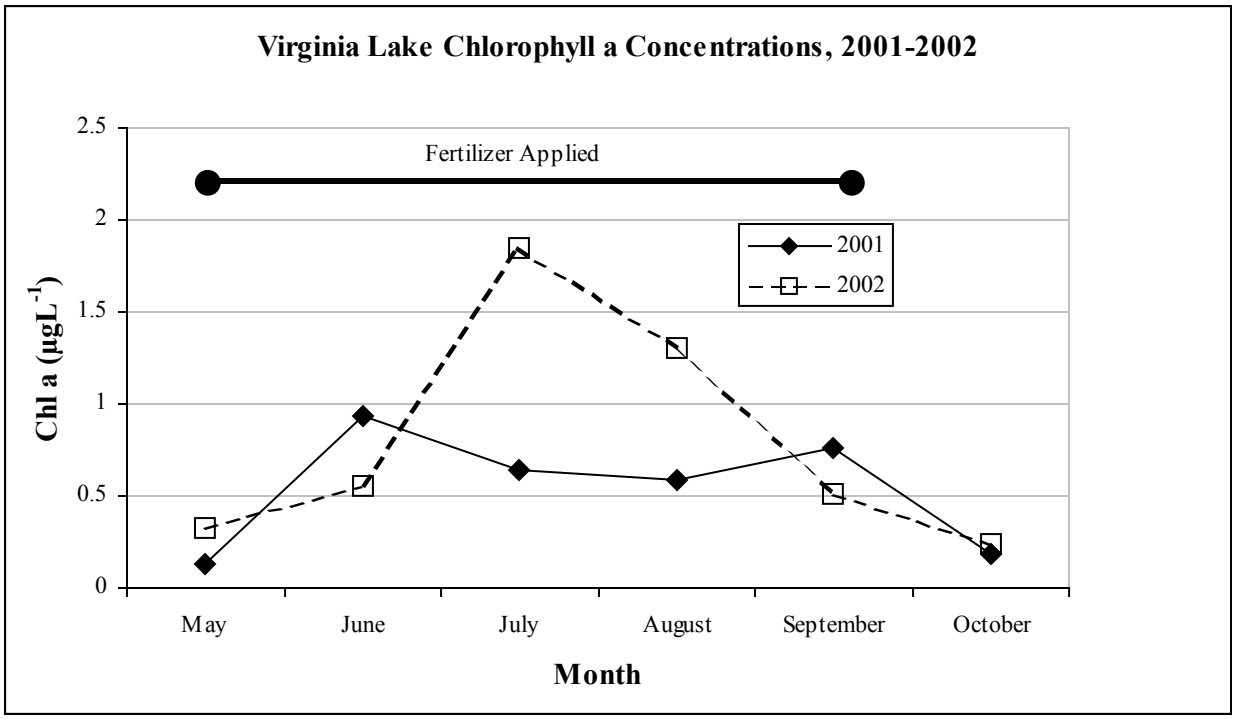

Figure 5. Average monthly epilimnetic chlorophyll *a* concentrations in Virginia Lake, 2001 and 2002.

The macrozooplankton community of Virginia Lake was dominated by three species: two copepods (*Cyclops* sp. and *Diaptomus franciscanus*) and the cladoceran *Bosmina longirostris*. Copepods were most abundant from May through July followed by *Bosmina* dominance in August and September (Figure 6). *Bosmina* reached the highest overall densities in both years. August densities averaged 84,000 m^{-2} in 2001, and 2002 densities averaged 100,000 m^{-2} in September. However, *Bosmina* was consistently the smallest zooplankton species, averaging 0.38 mm in both years (Figure 7). *Diaptomus* was the largest zooplankter in 2001 (1.54 mm) and 2002 (1.40 mm). It was the most abundant organism in May of both years but also exhibited the lowest monthly densities of the three zooplankton species beyond May. *Cyclops* densities fluctuated considerably throughout the sampling period in both years. *Cyclops* size averaged 0.78 mm in 2001 and 0.73 mm in 2002 – in between the size range of the other two organisms. Interestingly, *Diaptomus* average size increased over the season as numbers decreased.

Copepods comprised 34% of the total mean density of zooplankton and 59% of the mean biomass in 2001, and 33% of the total mean density and 57% of the mean biomass in 2002. Cladocerans, primarily *Bosmina*, comprised 66% of the total mean density and 41% of the mean biomass in 2001, and 67% of the total mean density and 43% of the mean biomass in 2002.

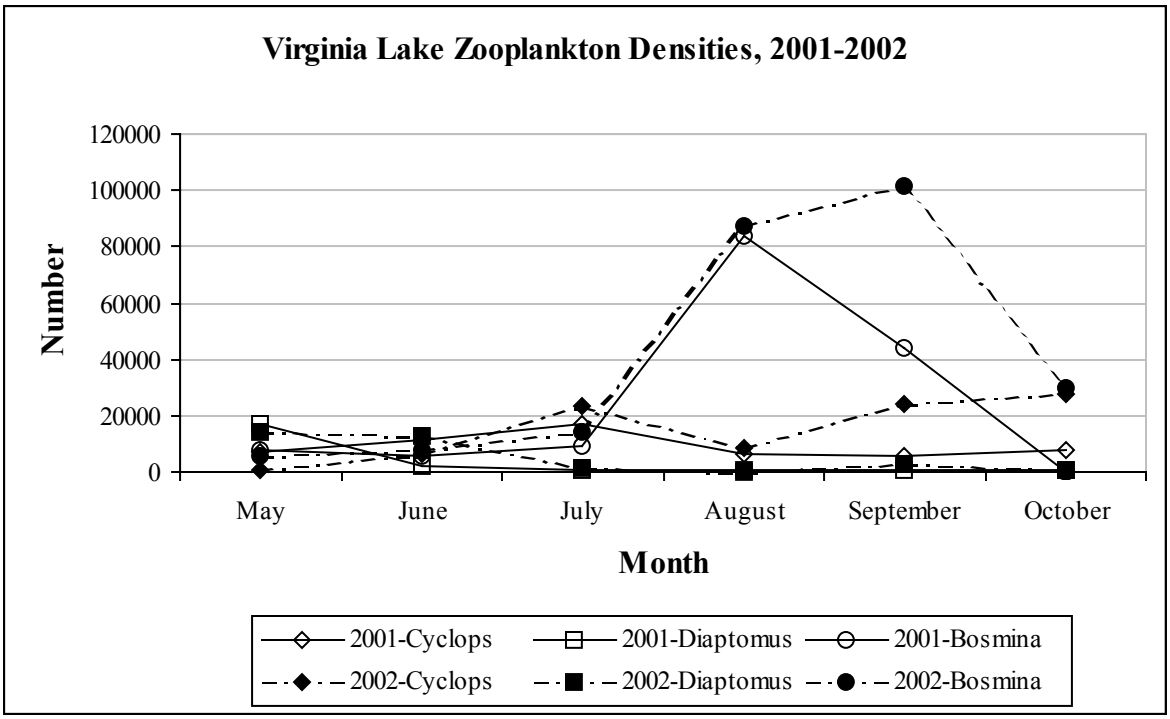

Figure 6. Average monthly zooplankton densities by species in Virginia Lake, 2001 and 2002.

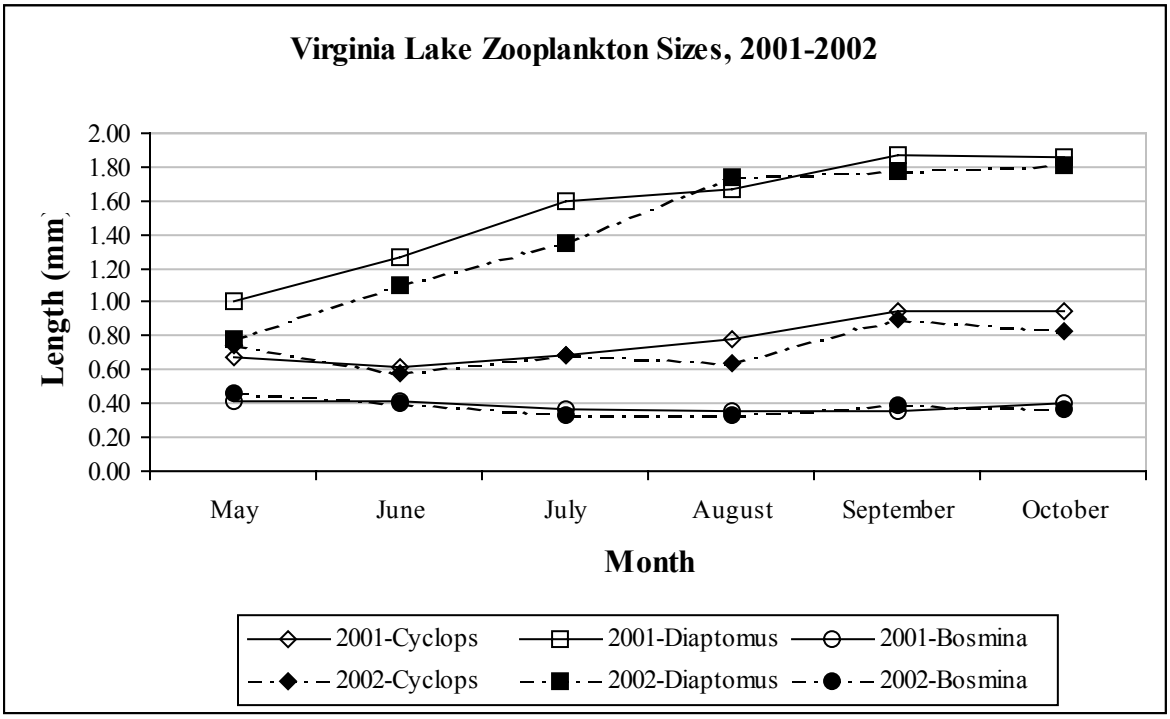

Figure 7. Average monthly zooplankton sizes by species in Virginia Lake, 2001 and 2002.

Juvenile Sockeye Population Estimate

The fall sockeye salmon fry population was estimated at 56,000 from the hydroacoustic survey and mid-water trawl conducted on 1 October 2001. This estimate equates to approximately 0.022 fry m^{-2} of lake surface area. The fall sockeye salmon fry population was estimated at 32,000 from the hydroacoustic survey and mid-water trawl conducted on 20 September 2002. This estimate equates to approximately 0.013 fry m^{-2} of lake surface area. These estimates are markedly lower than estimates generated during fry stocking years and reflect a continued decline in fall fry abundance (Appendix C.6).

Adult Sockeye Escapement

Weir/Trap

Weir operations began on 24 July and ceased 22 September in 2001, and 15 July and 15 September in 2002. Daily weir tallies are listed in Appendix D. The total number of sockeye passed over the weir in 2001and 2002 was 1,003 and 2,073, respectively. The peak of freshwater entry occurred during statistical week 33(493), 12-18 August 2001. Forty-nine percent of the weir count occurred that week in 2001. Weekly returns in 2002 were more irregular with three peaks occurring in statistical weeks 32(647), 4-10 August, 34(667), 18-24 August, and 36(362), 1-7 September. Table 2 summarizes the results of Mill Creek fishpass counts.

The periodicity of extreme rain events, which had dramatic influence on Mill Creek flows, was much higher in 2002, and these events likely influenced sockeye entering Mill Creek. The weir was not administered because of high flows in Mill Creek from 2-4 September 2001, and 9 August, 13-14 August, 26-29 August, 31 August-2 September, and 9-10 September 2002. It is highly likely that adult sockeye migrated through the fish trap without being handled at times when flow patterns were returning to normal, but still high enough to prevent safe working conditions for the crew. However, it is also likely that high flow events prevented the migration of adult sockeye much beyond the three pools upstream of the fishpass, and high flows could have washed both handled and un-handled fish out of the system. Fisheries crews observed adult sockeye concentrated below the second and third upstream waterfalls during elevated flows while conducting foot and snorkel surveys in 2002. In addition, adult sockeye were observed attempting and failing to ascend these falls at elevated flows.

Table 2. Weir counts, marking, and sampling statistics for Virginia Lake/Mill Creek sockeye salmon and other salmonids during 2001 and 2002.

Species	Count	Number and Percent Marked	Number and Percent Sampled[a]
2001			
Sockeye	1,003	503(50%)	503(50%)
Chinook	50		
Pink	10		
Chum	44		
Coho	4		
Dolly Varden[b]	0		
Cutthroat[b]	0		
2002			
Sockeye	2,073	1,087(52%)	656(32%)
Chinook	56		
Pink	2		
Chum	4		
Coho	6		
Dolly Varden	669		
Cutthroat	19		

[a]Age, length and sex.
[b]Species present but not tabulated.

Adult Sockeye Population Age and Size Distribution

A total of 503 samples were collected from randomly selected sockeye salmon between 24 July and 30 August 2001. A total of 654 samples were collected from randomly selected sockeye salmon between 20 July and 8 September 2002, slightly surpassing the goal of 600 samples. More females entered Mill Creek in both 2001 and 2002. Of the 1,003 sockeye handled at Mill Creek in 2001, 422 (42%) were male and 581 (58%) were female. Of the 2,073 sockeye that entered Mill Creek in 2002, 1,580 individuals were sexed, of which 612 (39%) were male and 968 (61%) were female. However, due to the location of the fishtrap directly above tidewater, sex misidentification was highly likely in both years because the cues that elicit sexual dimorphism in salmon largely depend upon freshwater entry. These characters were largely unapparent in the fish handled at the weir due to their brief exposure to freshwater. Males tended to be larger than females of the same age, but older females were more abundant in both years' samples (Table 3-4). The majority of fish, 80 and 94 percent in 2001 and 2002, respectively, spent at least two growing seasons in saltwater. All scale samples and length measurements were taken at the fishpass trap.

Table 3. Mean fork length (mm) of adult sockeye salmon in the Mill Creek escapement by sex, age and brood year for 2001 (n=445 of 503 sampled).

Brood Year	1998	1997	1997	1996	1996	1995	
Age	1.1	1.2	2.1	1.3	2.2	2.3	Total
Male							
Avg. Length	358	493	374	565	529	584	
Sample Size (%)	46(21)	11(5)	45(21)	23(10)	58(26)	37(17)	220(49)
Female							
Avg. Length		503		551	514	569	
Sample Size (%)	0(0)	28(12)	0(0)	18(9)	151(67)	28(12)	225(51)
All Fish							
Avg. Length	358	500	374	559	518	577	
Sample Size (%)	46(10)	39(9)	45(10)	41(9)	209(47)	65(15)	445(100)

Table 4. Mean fork length (mm) of adult sockeye salmon in the Mill Creek escapement by sex, age and brood year for 2002 (n=654 of 656 sampled).

Brood Year	2000	1999	1998	1998	1997	1997	1996	1996	
Age	1.1	0.3	1.2	2.1	1.3	2.2	2.3	3.2	Total
Male									
Avg. Length	346	514	524	369	612	548	615	590	
Sample Size (%)	19(3)	23(4)	38(6)	17(3)	21(3)	101(15)	30(5)	1(0)	250(38)
Female									
Avg. Length		530	505	415	583	526	582	511	
Sample Size (%)	0(0)	26(4)	70(11)	1(<.05)	19(3)	230(35)	38(6)	20(3)	404(62)
All Fish									
Avg. Length	346	523	512	372	599	533	597	515	
Sample Size (%)	19(3)	49(7)	108(17)	18(3)	40(6)	331(51)	68(10)	21(3)	654(100)

Subsistence Harvest

Virtually all (over 95%) of the subsistence harvest of Virginia Lake sockeye occurs in or just outside of the lagoon in what is currently interpreted as State of Alaska jurisdiction. A total of 30 returned permits in 2001 and 38 permits in 2002 reported a total harvest of 346 and 586 sockeye, respectively (Appendix A.1). Incidental catch reported was 70 chum, 36 chinook, 10 pink, and 3 coho in 2001 and 57 chum, 61 chinook, and 14 pink in 2002. Gillnet, dipnet, and hook-and-line (i.e., snagging) were the primary methods used (unpublished data, ADF&G). A minor portion of the harvest was taken, via hook-and-line from the pools along Mill Creek and at the lake outlet. No federal permits were issued for Virginia Lake sockeye in 2001 or 2002.

Visual Surveys and Mark-Recapture Escapement Estimates

Fisheries crews conducted spawning and escapement verification surveys by foot on Porterfield Creek and Glacier Creek and by boat on Virginia Lake in 2001. In addition to the stream and lake surveys, lake recapture methods were employed to verify escapement estimates from the weir count in 2002. Counts from each sampling event were to be used in a mark-recapture analysis to verify the escapement count at the weir. Lake seining was not part of the work plan described in the original investigation plan. However, based on observations in 2001, we felt a spawning survey that required the handling of adult spawners would provide better information concerning the actual escapement into Virginia Lake. In general, both years' data suggest very poor lake and spawning tributary recruitment. Our survey data are largely inconclusive, and, in fact, pose more questions than answers pertaining to the life cycle and spawning success of Virginia Lake sockeye salmon. The data and results of the 2001 and 2002 efforts are presented below in further detail and in Appendix B.4.

In addition to the aforementioned surveys, fisheries crews conducted opportunistic (i.e., when time permitted) snorkel surveys in Mill Creek. These surveys were not structured to systematically collect data, but merely to observe migrating sockeye in the outlet stream. Two primary observations resulted from these surveys. The most important observation was the high incidence of adult sockeye below the second and third upstream waterfalls in Mill Creek, particularly at elevated flows (Figure 8). Subsequent observations from the surface confirmed sockeye attempting and failing to ascend at least the second upstream waterfall. Although the ultimate fate of these fish is unknown, our observations imply that these falls may pose significant migration barriers to Virginia Lake sockeye. The second observation does not relate to adult sockeye, but has definite implications pertaining to the overall salmon production capabilities of Virginia Lake. An extraordinarily high density (possibly more than 500 per 100 m of stream) of sub-adult and adult sized cutthroat trout were observed in the first 200 m of Mill Creek immediately downstream from the lake outlet (Figure 8). If these cutthroat trout remained in this area during spring smolt migration, they were of sufficient size to consume outmigrating sockeye fry/smolt, which may, subsequently, have a dramatic effect on the overall Virginia Lake juvenile sockeye output.

Spawning Surveys

Porterfield Creek was visually surveyed on 14 dates from 10 September to 6 October in 2001. Fish were only observed in the lowermost reaches of each arm and the connector channel (Figure 1). A total of 100 fish (live and dead) were observed on 24 September of which only 24 had a visible mark. This count most likely describes the peak spawning escapement to Porterfield Creek in 2001. Porterfield Creek was visually surveyed on 26 and 30 September in 2002. A maximum of 33 fish were observed on 26 September. Fish were again only present in the lowermost reaches.

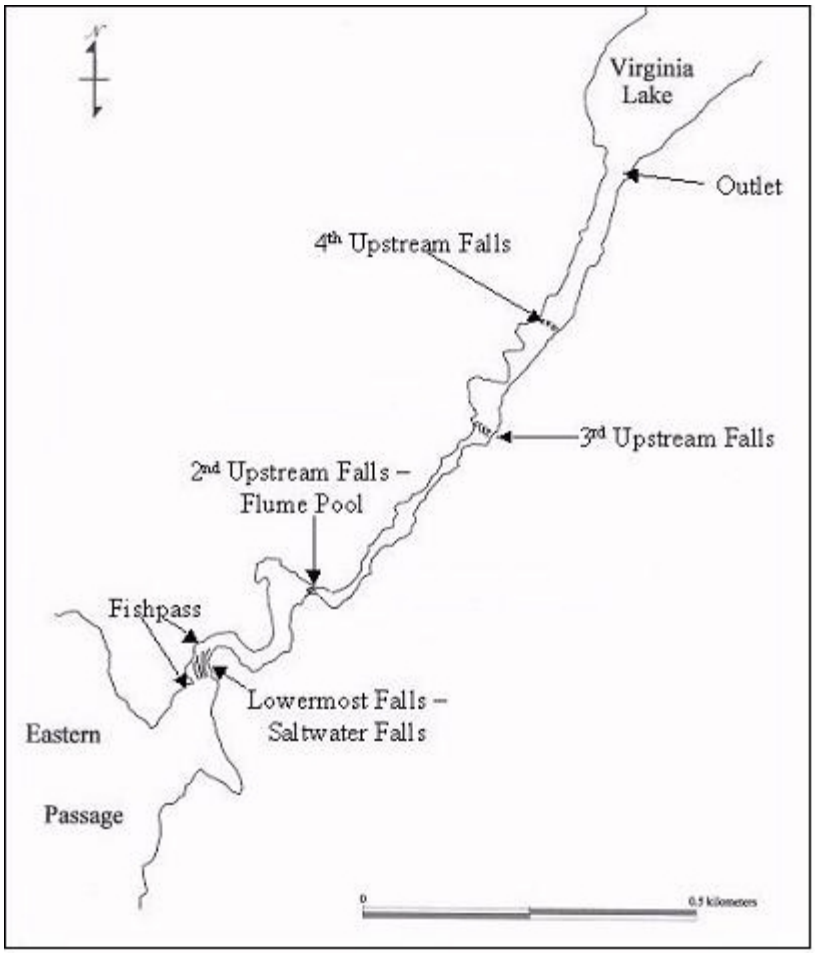

Figure 8. Mill Creek from lake outlet to saltwater. High cutthroat trout densities were observed from the lake outlet to the fourth upstream waterfall.

Glacier Creek was visually surveyed on 14 dates from 10 September to 6 October in 2001. A total of 7 fish were reported on 14 September, which was the maximum number observed over the course of the surveys. Glacier Creek was visually surveyed on 26 and 30 September in 2002. A maximum of 29 fish were observed on 26 September. Fish were only observed in the lowermost reach during both years.

Evidence of shallow beach spawning was observed at the Virginia Lake stream inlets in 2001, and it was possible that deep beach spawning occurred in the lake, as well. However, spawning pairs were not observed in the lake in 2001 or 2002. Fisheries crews stationed at the lake reported seeing sockeye jumping at the outlet and the mouths of Porterfield and Glacier Creeks from August through September in 2001 and 2002. A total of 14 carcasses of mostly unspawned fish were encountered from mid-August to mid-October during 2002 while in transit on the lake, during beach seining operations, or while conducting other operations on the lake shoreline. These fish were not counted as part of any survey as these fish were observed outside of normal

survey operations. Due to its physical characteristics and limited habitat, no spawning surveys occurred on Mill Creek in 2001 or 2002.

The numbers of fish observed in the spawning tributaries were dramatically lower than the numbers of fish passed upstream of the Mill Creek weir in both years. Due to the apparent inadequate escapement to Virginia Lake, the uncertainty surrounding the potential for lake spawning, and because of several apparent violations to mark-recapture assumptions, we feel an escapement estimate/verification based on mark-recapture analyses with this data is inappropriate (Karen Hyer, Statistician, Fisheries Information Service, Anchorage, Alaska, personal communication, 2003). All stream survey data are displayed in Appendix B.4.

Lake Mark-Recapture

A mark-recapture evaluation was attempted on Virginia Lake in 2002. Fisheries crews used a large beach seine to capture sockeye staging at the tributary inlets on five dates between 13 and 24 September. Seining commenced on 13 September after sighting a school of more than 20 fish at the Glacier Creek inlet on 12 September. A total of 35 seine hauls across these dates yielded only 35 sockeye of which 33 were one-time captures. Only two fish initially captured on an early sampling date were subsequently recaptured on later samplings. A total of 25 fish were captured at North Porterfield Creek on 14 September and 10 fish on 15 September at South Porterfield. No other fish were captured in the remaining seine hauls. Clearly, these data are grossly inadequate to even begin to calculate any sort of escapement estimate using mark-recapture methodologies (Karen Hyer, Statistician, Fisheries Information Service, Anchorage, Alaska, personal communication, 2003).

DISCUSSION

The limnology and Mill Creek escapement objectives were satisfactorily met in 2001 and 2002. We attempted to meet the Virginia Lake spawner escapement and habitat use objectives, but our data preclude us from making any satisfactory conclusions about sockeye spawning success in the system (Karen Hyer, Statistician, Fisheries Information Service, Anchorage, Alaska, personal communication, 2003). The apparent lack of a sufficient number of fish reaching the lake and tributaries, and our inability to verify shallow or deep lake spawning are two primary factors limiting our conclusions. However, due to the limited scope of the hydroacoustic surveys for sockeye fry and the lack of smolt outmigration data, a great deal of uncertainty surrounds the overall sockeye production ability of Virginia Lake. Fortunately, sockeye salmon biology and ecology is well known, and we have considerable knowledge on individual and population performance/response under a variety of conditions (Burgner 1991, Halupka, et. al. 1995). Work in upcoming years will focus on examining factors affecting sockeye spawning and juvenile rearing success in Virginia Lake.

A number of significant perturbations in the Virginia Lake sockeye enhancement/enrichment program may have likely upset the equilibrium of the lake ecosystem resulting, in part, to the effects still seen in 2001 and 2002. Unfortunately, many of our explanatory hypotheses can only be substantiated by conjecture due to our lack of quality base-line data on the fish populations and lake ecosystem dynamics. The addition of chemical fertilizers has had an obvious positive affect on the plankton communities of Virginia Lake, and, in fact, has been widely proposed and practiced as a means of enhancing, specifically, sockeye salmon production in North America and Russia (Bugayev et. al. 1995, Koenings and Kyle 1997, Budy et. al. 1998, Conitz et. al. 2002; Rod Neterer, Production Manager, Southern Southeast Regional Aquaculture Association, Ketchikan, Alaska, personal communication, 2003).

In Virginia Lake, the phytoplankton community begins to respond almost immediately after enrichment induction, but declines prior to enrichment cessation probably as a result of decreasing water temperature and daylight reduction through normal seasonal progression. Also, several certainties are obvious in the zooplankton response, these include: 1) *Cyclops* sp., *Diaptomus franciscanus,* and *Bosmina longirostris* are the dominant and, quite literally, the only species present in the zooplankton community; 2) these species were present before and after fry introductions – a large Cladoceran (i.e., *Daphnia* sp.) was virtually absent from all zooplankton sample data; and 3) zooplankton abundance peaks, though dramatic during enrichment years, are short-lived with the *Diaptomus franciscanus* population peaking in May, the *Cyclops* sp. population peaking in June-July, and the *Bosmina longirostris* population reaching it's peak in August. With this in mind, we are able to infer that primary production does not appear to be a bottleneck to secondary production (i.e. limited bottom-up control). Herein lie two primary questions complicating our ability to understand specific mechanisms driving the zooplankton-sockeye production relationship in Virginia Lake, namely:

1. Is the zooplankton community in Virginia Lake of the appropriate density (temporally) and composition to support sockeye growth and survival (i.e., production) to meet our preconceived expectations?; and,

2. Is there another mechanism directly or indirectly (i.e., temperature, lake chemistry, competition and/or predation) affecting this interrelationship?

A substantial amount of literature points to the preference of zooplankton prey by juvenile sockeye and kokanee (Burgner 1991, Bugayev et. al. 1995, Buktenica and Larson 1996, Budy et. al. 1998, Shortreed et. al. 1998, Edmundson and Mazumder 2001, Mazumder 2002), and that their preference is for the larger of these organisms (Beauchamp et. al. 1995, Koenings and Kyle 1997, Shortreed et. al. 1998). Edmundson and Mazumder (2001) found that zooplankton biomass explained 52% of juvenile sockeye growth variation in an analysis of 36 Alaskan sockeye lakes. They also state that zooplankton biomass combined with smolt density and water temperature explains approximately 70% of the growth variation in juvenile sockeye. In effect, they assert that this small suite of biological and physical factors regulate juvenile sockeye growth and survival, and a thorough understanding of these dynamics throughout the freshwater residency period is crucial to the development of accurate and reliable stock escapement goals.

Zooplankton populations were possibly overcropped in 1989 and 1990 by the initial fry plants, which occurred prior to the late-spring phytoplankton bloom and subsequent zooplankton recruitment. If this occurred, then the zooplankton community may still be in a state of disequilibria and is imparting a negative growth and survival control on juvenile Virginia Lake sockeye. Koenings and Kyle (1997) describe just such a situation. In their evaluation of several Alaska sockeye lakes that underwent enrichment and sockeye enhancement, zooplankton communities were overcropped by intense predation that resulted in lower biomasses, smaller more evasive organisms, and an overall restructuring of the zooplankton community that did not return to pre-management levels even with chemical enrichment. Also, the absence of a large cladoceran in the Virginia Lake zooplankton community may have a significant effect on the growth and subsequent overwinter survival of juvenile sockeye. Bugayev et. al. (1995) found that Lake Kuril'skoye sockeye growth was largely regulated by *Cyclops* abundance, but *Daphnia* consumption provided a significantly higher growth rate and served as a "finishing" food at the end of the growing season. Shortreed et. al. alludes to a similar phenomenon in several British Columbia sockeye systems. It can be inferred that this growth boost at the end of the season imparted greater survivorship to these fish. Quite simply, Virginia Lake, even when artificially enriched, may not be well suited for large-scale sockeye salmon production aside from pen rearing and direct feeding to boost growth and subsequent overwinter survival (Rod Neterer, Production Manager, Southern Southeast Regional Aquaculture Association, Ketchikan, Alaska, personal communication, 2003).

Pointing to the enrichment program, we may be failing to fully appreciate, or understand, the plankton community response to nutrient additions. Specifically, the enrichment program may induce production of undesirable species. Hollowell and Zadina (2003) state, "the atomic ratio of nitrogen to phosphorus varied from a high of 103:1 in May to a low of 23:1 in August (2002), but (was) still within the desired range for promotion of growth by the appropriate phytoplankton." This assertion lacks the hard data to explore it further. Another concern where further exploration may be warranted, that may affect fry survival in the earliest life history stages, is the possibility of chemical contamination in the system. The upper Porterfield basin has been subject to past mineral extraction, and, because of the area's natural geologic disposition, arsenic may be present at concentrations sufficient to decrease the survival of developing sockeye fry.

The tools we use to estimate sockeye production may confound our ability to accurately predict overall fry survival and subsequent adult returns. The original sockeye salmon production potential of 26,000-37,000 adult sockeye was based on the EV (Euphotic Volume) model. This model had limitations, which resulted in an unrealistic productivity index when applied to Virginia Lake and other lakes in Southeast Alaska. Application of the current ZB-EZD (Zooplankton Biomass-Euphotic Zone Depth) model suggests the sockeye production potential of Virginia Lake may only achieve an annual return of 10,000-17,000 fish, which is still substantially more than the numbers of returning adults observed from 2000-2002 (Hollowell and Zadina, 2002, 2003). In addition, the sockeye fall fry population fell by almost 80%, from 169,000 in 2000 to 32,000 in 2002, the lowest estimate since project inception. However, the density estimate is projected from only one hydroacoustic and trawl survey per year. Regardless, this reduction is likely due, in part, to the weak spawning escapement of the preceding years. We also lack data on smolt outmigration densities and smolt condition at time of outmigration,

from which we could characterize overwinter survival dynamics. Better fry density and growth data, coupled with outmigrating smolt data are critical to our development of realistic escapement goals for Virginia Lake sockeye (Edmundson and Mazumder 2001, Mazumder 2002).

Given the relatively small size of Virginia Lake, predation by cutthroat trout and feeding competition by three-spine stickleback may also play critical roles in tempering sockeye fry populations. Coastal cutthroat trout are well established in Virginia Lake, and their populations, at times, can be robust (Freeman et. al. 1998). Cutthroat trout have significantly affected sockeye enhancement efforts in Margaret Lake, another very small (55 ha) sockeye enhanced system in Southeast Alaska (Cartwright et al. 1998). This research suggested that predation by cutthroat trout accounted for 32-100% of the observed fry mortality in two years of sampling. Though their predatory cutthroat population assessment was incomplete, Beauchamp et. al. (1995), indirectly, through diet analysis and bioenergetics modeling, predicted that for every 1,000 large cutthroat in Lake Ozette, Washington, roughly 17% of the sockeye fry population was consumed. Needless to say, cutthroat trout are predacious and appear to be abundant in Virginia Lake. We need to further explore this relationship as it may play a pivotal role in the overall fry to smolt production capabilities in this system. As an aside, however, predation probably serves to regulate sockeye foraging on zooplankton and likely inhibits severe overcropping to some degree. As far as interspecific competition by stickleback, this dynamic and its influence on sockeye fry growth and survival is poorly understood (Mazumder, 2002).

Virginia Sockeye Escapement

We documented a return of 1,003 sockeye salmon in 2001 and only twice this number in 2002. These returns are significantly smaller than the 60,000 fish returns projected on the Mill Creek trail interpretive sign. Our return in 2002 was especially disconcerting considering the apparent overall sockeye run strength in other nearby non-enhanced and non-enriched systems (i.e., Thom's Lake, Luck Lake, and Salmon Bay Lake; Paul Rushmore, Wrangell Cooperative Association, personal communication, 2002). In fact, even Falls Lake, which is approximately one-third the size of Virginia Lake but having a similar disposition, experienced a return of over 2,500 fish in 2001 (Conitz, et. al. 2002). However, caution is warranted when making such generalizations.

Our attempts to fully describe the Mill Creek escapement and subsequent Virginia Lake escapement verification were problematic, but the situation was exacerbated by the apparent lack of spawning fish in the tributaries and/or our inability to detect lake staging and spawning. Nonetheless, our observations suggest less than 10% of the fish counted at the Mill Creek fishpass successfully spawned in the locations we assessed. At these densities, generation of a reliable population estimate is impossible. Although some tag loss (2001) and handling mortality is known to have occurred, they are suggestive, but not quantifiable, as factors in the observed difference in Mill Creek and Virginia Lake densities. Another factor that would complicate mark-recapture efforts could be the lack of complete interception at the weir, which

is certainly plausible based on our observations, but, again, non-quantifiable. Several other possibilities which may have confounded our efforts include: 1) the weir was not installed early enough to intercept all of the escapement; 2) handling and marking decreased survival such that there was not an equal opportunity for marked and unmarked fish to be counted on the spawning areas; 3) the weir arrangement at the fishway did not intercept all upstream migrants during the entire range of flows; and 4) the sample size was too low. Any or all of these possibilities could play a role in our observations, and would contribute to violations in mark-recapture assumptions (Karen Hyer, Statistician, Fisheries Information Service, Anchorage, Alaska, personal communication, 2003).

One last item that may contribute to low initial spawning success and low numbers of fish in the spawning tributaries lies in the genetic/behavioral disposition of sockeye in general. Sockeye homing traits/patterns have been found to be the most precise of the Pacific salmon, maybe to the point of individual fish returning to their natal redd site (Burgner 1991). With all of the fry releases occurring in the lentic area of the lake, and assuming the McDonald-stock fish are inlet stream spawners, it is possible the returning adults from the fry plants were unsuccessful at spawning because they never imprinted on one of the lake tributaries.

The subsistence harvest window may limit the interception of the target stock (i.e., McDonald stock). We do not know how long the early arrivals hold in or near the lagoon to ripen before entering freshwater, nor do we know the physical and genetic composition of these fish. Review of recent (1985-2002) reported subsistence harvest data (unpublished data, ADF&G) revealed that sockeye have been reportedly harvested as early as the first week in June. Sockeye harvest was first documented during the last week of June in 2001 and 2002. The weir was installed on 24 July 2001 and 15 July 2002, without the benefit of subsistence harvest data. Post-subsistence season data revealed 225 and 117 sockeye or 64% of the 2001 and 20% of the 2002 Virginia Lake sockeye subsistence harvest had been taken by the weir installation date. Without a weir in place during the entire duration of the subsistence fishery, the relationship of subsistence harvest to total escapement cannot be determined. In addition, we lack harvested salmon size-class data, which might shed light on fishery stock selectivity.

CONCLUSIONS

There is little doubt that the Virginia Lake sockeye salmon population is declining considerably from the initial fry plant period. All observations and the limited data we have indicate survivorship and production has been on the decline since 1991 – the last year of fry plants. Several conclusions are readily apparent from our work, these include:

1. We are grossly lacking data on fry to smolt and subsequent smolt to adult survival. It is unlikely at this point that we will obtain any reliable ocean survival and/or commercial harvest information on this stock, other than hypothesized values produced by state or

Federal agencies. In light of this, our best bet focuses on a better understanding of Virginia Lake fry to smolt success/survivorship.

2. Escapement estimates remain an important component to the management of this stock, but we need to eliminate Mill Creek migration concerns and more closely examine mechanisms contributing to the apparent low spawning success. Once we are more comfortable with the parameters governing adult sockeye dynamics, we can then develop a means to best assess the escapement and reinstate a monitoring program for this system.

3. We need a better understanding of the effects of the enrichment program on plankton dynamics. We know fertilization accelerates production, but we question whether the outcome has a beneficial effect directly to growing sockeye. It may be the case that Virginia Lake is simply not suited to producing large numbers of sockeye, and the only way to achieve returns approaching 60,000 would be to pen-rear fry at the lake and release them as pre-smolts. This, in effect, would mimic a hatchery operation.

4. We could be overlooking some very simple but obscure governing mechanism such as an unobserved contaminant that is profoundly limiting survival at some early life-history stage.

RECOMMENDATIONS

The previous two season's work has made it abundantly clear that our understanding of the dynamics governing Virginia Lake sockeye salmon production is surrounded by a cloud of uncertainties. We must begin to look more closely at the situation as a whole and start at the beginning, as it were, to systematically answer the unknowns. We are in obvious deficit in two areas, these are: 1) a lack of hard data about juvenile sockeye growth and survival in Virginia Lake, and 2) a lack in our ability to accurately describe the adult escapement to Virginia Lake. Ocean survival and commercial fishing are beyond the scope of this project, but may certainly play into the situation, as well. The subsistence fishery is within our 'realm of control', and may also limit the overall success of this population. The political ramifications of strict regulatory limitations are not withstanding of intense deliberation. With this in mind, our work in 2003 will focus primarily on the second component. First, we will not operate the fishpass weir/trap to eliminate the concern handling stress-induced mortality on fish immediately entering Mill Creek from saltwater. Second, we will conduct a radio telemetry study and track tagged adult sockeye through the system to answer more definitely, if any or all of the upstream barriers on Mill Creek restrict salmon migration, and to determine more accurately the ultimate fate of sockeye entering Virginia Lake (i.e., Is there lake spawning and where?). Once we have a better understanding (data) related to the adult escapement, we will then turn our attention in subsequent years towards gathering more accurate and useful information related to juvenile survival and growth. Finally, we will pursue contracting with an outside source in an attempt to gain greater insight on subsequent management strategies.

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APPENDICIES

Appendix A. Historical sockeye salmon harvest information from the Mill Creek vicinity and nearby waters.

Appendix A.1. Reported subsistence harvest of salmon on returned permits from Mill Creek, Virginia Lake, 1985-2002 (ADF&G Alexander Database, 2002).

Year	Permits Returned	Sockeye Harvest	Sockeye Catch/Permit	Chinook Harvest	Coho Harvest	Pink Harvest	Chum Harvest
1985	22	200	9.09	0	0	0	1
1986	5	50	10.00	0	0	0	0
1987	8	49	6.13	0	0	0	0
1988	1	10	10.00	0	0	0	0
1989	9	87	9.67	0	0	3	3
1990	19	139	7.32	32	0	12	13
1991	5	37	7.40	4	0	0	1
1992	15	159	10.60	3	0	4	21
1993	15	189	12.60	2	0	0	4
1994	40	442	11.05	5	1	4	42
1995	52	657	12.63	15	1	4	110
1996	41	441	10.76	19	1	6	341
1997	27	229	8.48	5	2	17	85
1998	23	121	5.26	3	2	0	103
1999	32	289	9.03	20	1	3	74
2000	32	267	8.34	7	1	0	22
2001	30	346	11.53	36	3	10	70
2002	38	586	15.42	61	0	14	57
Average	**23**	**238.78**	**9.74**	**11.78**	**0.67**	**4.28**	**52.61**

Appendix A.2. Projected commercial harvest contribution from the initial Virginia Lake fry plants, 1994-2000 (ADF&G Alexander Database, 2002).

	Harvest Year							
District	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**Total**
101		534	781			639	147	**2,101**
102		198	520	900				**1,618**
104		364	796	82		216		**1,458**
106	518	1,163	4,463	411	298	1,651	513	**9,017**
107		154				398		**552**
108		158	412		52	792		**1,414**
Total	**518**	**2,571**	**6,972**	**1,393**	**350**	**3,696**	**660**	**16,160**

Appendix B. Sockeye salmon escapement data for Virginia Lake.

Appendix B.1. Summary of weir counts of sockeye salmon entering Mill Creek, 2000-2002.

Year	Weir Dates	Sockeye Count
2000	7/18-9/4	829
2001	7/24-9/22	1,003
2002	7/15-9/15	2,073

Appendix B.2. Sample sizes (a), age (b), and length (c) composition of sockeye salmon sampled in 1998-2002 at Mill Creek fishpass.

a) Sample sizes of sockeye salmon from the Mill Creek fishpass, 1998-2002, by age class.

	Sample Sizes by Age Class and Return Year					
Age Class	**1998**	**1999**	**2000**	**2001**	**2002**	**Total**
0.3	0	2	0	0	49	51
1.1	23	4	10	47	19	103
1.2	53	61	56	39	108	317
1.3	81	92	239	42	40	494
1.4	2	0	0	0	0	2
2.1	12	10	19	45	18	104
2.2	68	156	70	212	331	837
2.3	13	64	146	65	68	356
3.2	0	0	0	0	21	21
3.3	0	1	0	0	0	1
Total	252	390	540	450	654	2,286

b) Age composition (percent) of sockeye salmon sampled at the Mill Creek fishpass, Virginia Lake, 1998-2002.

	Percent in Age Class by Return Year					
Age Class	**1998**	**1999**	**2000**	**2001**	**2002**	**% Total**
0.3	0.0	0.5	0.0	0.0	7.5	2.23
1.1	9.1	1.0	1.9	10.4	2.9	4.51
1.2	21.0	15.6	10.4	8.7	16.5	13.87
1.3	32.1	23.6	44.3	9.3	6.1	21.61
1.4	0.8	0.0	0.0	0.0	0.0	0.09
2.1	4.8	2.6	3.5	10.0	2.8	4.55
2.2	27.0	40.0	13.0	47.1	50.6	36.61
2.3	5.2	16.4	27.0	14.4	10.4	15.57
3.2	0.0	0.0	0.0	0.0	3.2	0.92
3.3	0.0	0.3	0.0	0.0	0.0	0.04

c) Mean lengths (mm) of sockeye salmon sampled at the Mill Creek fishpass, Virginia Lake, 1998-2002, by age class.

	Average Length by Age Class and Return Year					Overall	
Age Class	**1998**	**1999**	**2000**	**2001**	**2002**	**Average**	**SD**
0.3		563			523	524	70.7
1.1	352	343	363	358	346	354	25.7
1.2	517	511	508	500	512	510	31.3
1.3	570	569	598	559	599	585	34.3
1.4	543					543	46.0
2.1	366	348	375	374	372	370	21.3
2.2	522	519	497	518	533	523	33.1
2.3	569	572	595	577	597	587	33.7
3.2					515	515	33.6
3.3		575				575	na
Overall Average	516	532	563	498	529	530	
SD	74.6	52.3	68.2	75.6	62.0	69.9	

Appendix B.3. ADF&G escapement surveys conducted opportunistically and prior to bioenhancement at Virginia Lake, 1965-1986. These surveys estimated an unknown portion of the escapement in each year. These counts do not convey in any way, peak escapement (ADF&G Alexander Database, 2002).

Year	Dates	No. Sockeye Obs.	No. Surveys	Type
1965	8/21 & 9/4	50	2	Foot
1976	7/30 & 8/23	301	2	Aerial
1978	8/18	75	1	Aerial
1982	7/23	0	1	Aerial
1984	9/11	104	1	Foot
1985	7/31 & 8/30	0	2	Aerial
1986	8/20	0	2	Aerial

Appendix B.4. Visual survey counts of a) Glacier Creek, b) Porterfield Creek, and c) Virginia Lake, 2001 and 2002.

a) Glacier Creek

					Marked		Unmarked	
DATE	**REACH**	**TOTAL**	**LIVE**	**DEAD**	**LIVE**	**DEAD**	**LIVE**	**DEAD**
9/10/01	Lower	0	0	0	0	0	0	0
9/12/01	Lower	0	0	0	0	0	0	0
9/14/01	Lower	0	0	0	0	0	0	0
9/16/01	Lower	7	7	0	1	0	6	0
9/18/01	Lower	0	0	0	0	0	0	0
9/20/01	Lower	0	0	0	0	0	0	0
9/24/01	Lower	5	5	0	1	0	4	0
9/26/01	Lower	6	6	0	1	0	5	0
9/28/01	Lower	6	6	0	1	0	5	0
9/30/01	Lower	4	4	0	1	0	3	0
10/4/01	Lower	3	3	0	0	0	3	0
10/6/01	Lower	2	2	0	0	0	2	0
	2001 Total	**33**	**33**	**0**	**5**	**0**	**28**	**0**
9/26/02	Lower	29	26	0	0	0	3	0
9/30/02	Lower	5	5	0	0	0	0	0
	2002 Total	**34**	**31**	**0**	**0**	**0**	**3**	**0**
	Grand Total	**67**	**64**	**0**	**5**	**0**	**31**	**0**

b) Porterfield Creek

					Marked		Unmarked	
DATE	**REACH**	**TOTAL**	**LIVE**	**DEAD**	**LIVE**	**DEAD**	**LIVE**	**DEAD**
9/10/01	SArm	20	20	0	5	0	15	0
9/10/01	NArm	5	4	1	1	1	3	0
9/10/01	Connector	0	0	0	0	0	0	0
9/12/01	SArm	11	11	0	2	0	9	0
9/12/01	NArm	21	21	0	3	0	18	0
9/12/01	Connector	0	0	0	0	0	0	0
9/14/01	SArm	9	8	1	3	0	5	1
9/14/01	NArm	52	52	0	7	0	45	0
9/14/01	Above Fork	16	16	0	5	0	11	0
9/14/01	Connector	0	0	0	0	0	0	0
9/16/01	SArm	6	6	0	2	0	4	0
9/16/01	NArm	41	41	0	5	0	36	0
9/16/01	Connector	0	0	0	0	0	0	0
9/18/01	SArm	27	27	0	4	0	23	0
9/18/01	NArm	25	24	1	3	1	21	0
9/18/01	Connector	6	6	0	1	0	5	0
9/20/01	SArm	29	29	0	3	0	26	0
9/20/01	NArm	24	24	0	6	0	18	0
9/20/01	Connector	4	4	0	3	0	1	0
9/24/01	SArm	30	29	1	6	1	23	0
9/24/01	NArm	53	51	2	11	0	40	2
9/24/01	Connector	17	17	0	6	0	11	0
9/26/01	SArm	25	25	0	3	0	22	0
9/26/01	NArm	44	43	1	8	1	35	0
9/26/01	Connector	28	28	0	7	0	21	0
9/28/01	SArm	10	10	0	1	0	9	0
9/28/01	NArm	31	30	1	5	0	25	1
9/28/01	Connector	0	0	0	0	0	0	0
9/30/01	SArm	8	8	0	3	0	5	0
9/30/01	NArm	10	10	0	2	0	8	0
9/30/01	Connector	0	0	0	0	0	0	0
10/2/01	SArm	13	13	0	2	0	11	0
10/2/01	NArm	19	19	0	3	0	16	0
10/2/01	Connector	0	0	0	0	0	0	0
10/4/01	SArm	6	6	0	2	0	4	0
10/4/01	NArm	8	8	0	0	0	8	0
10/4/01	Connector	0	0	0	0	0	0	0
10/6/01	SArm	6	6	0	2	0	4	0
10/6/01	NArm	8	7	1	0	0	7	1
10/6/01	Connector	0	0	0	0	0	0	0
	2001 Total	**612**	**603**	**9**	**114**	**4**	**489**	**5**

					Marked		Unmarked	
DATE	**REACH**	**TOTAL**	**LIVE**	**DEAD**	**LIVE**	**DEAD**	**LIVE**	**DEAD**
9/26/02	NArm	29	26	0	1	1	1	0
9/26/02	SArm	1	0	0	1	0	0	0
9/26/02	Connector	3	0	0	1	0	2	0
9/30/02	NArm	16	16	0	0	0	0	0
9/30/02	SArm	1	1	0	0	0	0	0
9/30/02	Connector	0	0	0	0	0	0	0
	2002 Total	**50**	**43**	**0**	**3**	**1**	**3**	**0**
	Grand Total	**662**	**646**	**9**	**117**	**5**	**492**	**5**

c) Virginia Lake

					Marked		Unmarked	
DATE	**REACH**	**TOTAL**	**LIVE**	**DEAD**	**LIVE**	**DEAD**	**LIVE**	**DEAD**
9/10/01	Outlet	2	2	0	0	0	2	0
9/11/01	Shoreline	11	1	10	0	3	1	7
9/11/01	Outlet	0	0	0	0	0	0	0
9/13/01	Shoreline	2	0	2	0	0	0	2
9/13/01	Outlet	4	4	0	1	0	3	0
9/15/01	Shoreline	4	1	3	1	2	0	1
9/15/01	Outlet	4	4	0	0	0	4	0
9/17/01	Shoreline	2	0	2	0	2	0	0
9/17/01	Outlet	4	4	0	1	0	3	0
9/19/01	Shoreline	0	0	0	0	0	0	0
9/19/01	Outlet	0	0	0	0	0	0	0
9/21/01	Shoreline	0	0	0	0	0	0	0
9/21/01	Outlet	0	0	0	0	0	0	0
9/23/01	Shoreline	0	0	0	0	0	0	0
9/23/01	Outlet	0	0	0	0	0	0	0
9/25/01	Shoreline	0	0	0	0	0	0	0
9/25/01	Outlet	1	1	0	0	0	1	0
9/27/01	Shoreline	30	30	0	0	0	30	0
9/27/01	Outlet	4	4	0	1	0	3	0
9/29/01	Shoreline	1	0	1	0	1	0	0
9/29/01	Outlet	2	2	0	0	0	2	0
10/1/01	Shoreline	0	0	0	0	0	0	0
10/1/01	Outlet	0	0	0	0	0	0	0
10/2/01	Lower	2	2	0	0	0	2	0
10/3/01	Shoreline	3	2	1	0	1	2	0
10/3/01	Outlet	0	0	0	0	0	0	0
10/5/01	Shoreline	0	0	0	0	0	0	0
10/5/01	Outlet	0	0	0	0	0	0	0
	2001 Total	**76**	**57**	**19**	**4**	**9**	**53**	**10**

					Marked		Unmarked	
DATE	**REACH**	**TOTAL**	**LIVE**	**DEAD**	**LIVE**	**DEAD**	**LIVE**	**DEAD**
9/26/02	Shoreline	0	0	0	0	0	0	0
9/30/02	Shoreline	0	0	0	0	0	0	0
	2002 Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	Grand Total	**76**	**57**	**19**	**4**	**9**	**53**	**10**

Appendix C. Virginia Lake ecology and productivity, 1986-2002.

Appendix C.1. Virginia Lake water chemistry seasonal mean values sampled at Station A epilimnion (sampled at 1 m), 1986-2002.

Fertilizer Applied					**CL50**	**CL60**	**CL60**	**CL60**	**CL60**	**CL60**		**CL50**	**CL50**	**CL50**	**CL50**	**CL60**
Parameter	**1986**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Specific conductance (umhos/cm)	20	21	24	23	23	22	23	24	26	26	24	23	23	24	22	24
pH (Units)	6.6	6.4	6.6	6.5	6.7	6.4	6.5	6.5	6.5	6.5	6.9	7.0	6.5	6.5	6.5	6.57
Alkalinity (mg/L)	7.5	6.5	8.5	8.2	8.8	6.4	8.6	8.0	9.7	8.9	11.0	10.3	10.2	9.2	8.5	10.7
Turbidity (NTU)	0.3	1.2	0.8	1.4	1.0	1.2	2.5	1.2	1.3	1.2	0.7	0.6	0.9	0.8	0.8	0.9
Color (Pt units)	11	18	15	15	21	12	11	15	10	15	15	13	11	15	15	14
Calcium (ug/L)	2.9	3.6	4.5	3.9	3.7	3.8	3.7	3.9	4.2	3.6	3.8	3.6	3.8	3.8	3.5	3.52
Magnesium (mg/L)	0.9	0.2	0.2	0.3	0.2	0.7	0.5	0.6	0.7	0.3	0.4	0.3	0.3	0.4	0.5	0.58
Iron (ug/L)	67	75	87	154	104	107	225	118	83	98	68	35	92	74	86	88
Total-P (ug/L P)	2.0	5.1	4.7	5.4	4.5	7.0	12.5	6.2	4.2	7.8	2.5	4.7	5.7	3.6	4.7	7.2
Total filterable-P (ug/L P)	2.8	1.9	3.3	3.7	3.1	3.1	3.6	4.3	2.8	3.1	2.6	3.4	2.5	2.4	4.4	5.92
Filterable reactive -P (ug/L P)	2.3	1.6	2.4	2.6	2.8	1.5	1.8	2.0	1.0	1.4	2.4	2.2	2.2	1.3	2.2	3.28
Total Kjeldahl nitrogen (ug/L N)	45.5	59.6	51.8	56.8	80.7	81.6	173.9	92.8	82.5	125.0	62.8	76.0	81.4	105.8	65.2	93.9
Ammonia (ug/L N)	13.9	1.2	7.7	4.0	5.1	6.5	11.9	7.9	2.6	10.0	8.0	5.2	9.4	11.2	6.0	11.9
Nitrate+nitrite (ug/L N)	3.4	53.6	59.3	62.8	60.0	45.1	39.9	33.8	44.9	24.5	98.9	19.1	54.9	76.7	78.7	51.4
Total - N (ug/L N)	48.9	113.2	111.1	119.6	117.7	126.7	213.7	126.6	127.4	149.5	161.7	95.1	136.4	182.5	143.9	145
Reactive silicon (ug/L Si)	991	889	1,078	790	984	770	874	760	739	406	1,067	810	1,086	1,064	1,018	768
Carbon (ug/L C)		94		139	129	178						141	140	111	135	186
Chlorophyll a (ug/L)	0.35	0.24	0.17	0.25	0.75	0.69	1.56	1.43	2.04	4.91	0.32	0.84	0.31	0.47	0.48	0.99
Phaeophytin a (ug/L)	0.21	0.21	0.10	0.13	0.22	0.41	0.61	0.34	0.54	0.48	0.22	0.34	0.11	0.15	0.11	0.15

Appendix C.2. Virginia Lake water chemistry seasonal mean values sampled at Station A hypolimnion (sampled at 50 m), 1986-2002.

Fertilizer Applied					**CL50**	**CL60**	**CL60**	**CL60**	**CL60**	**CL60**		**CL50**	**CL50**	**CL50**	**CL50**	**CL60**
Parameter	**1986**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Specific conductance (umhos/cm)	28	26	27	27	28	24	26	29	33	33	30	29	28	29	27	28.8
pH (Units)	6.4	6.4	6.5	6.6	6.5	6.3	6.4	6.2	6.3	6.1	6.6	6.6	6.4	6.3	6.4	6.3
Alkalinity (mg/L)	11.0	7.5	9.5	9.8	10.4	7.2	9.3	9.2	12.1	11.2	12.3	11.9	11.3	10.6	10.1	12.5
Turbidity (NTU)	0.5	1.0	0.8	0.9	1.1	0.9	1.9	1.0	1.2	0.7	0.8	0.8	0.9	1.0	0.8	0.63
Color (Pt units)	26	20	16	18	17	13	14	17	16	16	14	15	17	16	16	12.3
Calcium (ug/L)	8.1	4.1	4.2	4.3	4.4	4.1	4.3	4.3	4.6	4.6	4.1	4.2	4.4	4.2	4.0	4.37
Magnesium (mg/L)	0.2	0.2	0.2	0.5	0.3	0.7	0.4	0.6	0.7	0.4	0.4	0.3	0.4	0.5	0.6	0.67
Iron (ug/L)	114	201	173	196	187	137	289	186	239	195	105	98	154	129	134	200
Total-P (ug/L P)	2.4	4.7	4.0	4.7	3.6	2.7	6.5	4.8	5.1	2.9	2.7	3.8	4.9	3.4	3.8	5.4
Total filterable-P (ug/L P)	7.6	1.9	2.8	3.0	2.6	1.9	2.9	4.3	3.0	3.9	2.6	2.5	4.0	3.1	3.1	3.77
Filterable reactive -P (ug/L P)	7.4	1.7	2.5	2.5	2.5	0.8	1.8	2.4	1.8	3.2	2.6	2.1	3.8	2.0	2.0	2.68
Total Kjeldahl nitrogen (ug/L N)	45.5	55.5	54.7	52.3	54.1	53.1	94.7	65.7	52.8	70.8	68.8	63.8	75.2	106.3	51.3	71.2
Ammonia (ug/L N)	86.1	1.8	5.4	4.3	4.6	11.7	12.0	5.8	3.8	9.9	7.4	3.2	10.9	13.9	9.0	11.2
Nitrate+nitrite (ug/L N)	3.4	80.9	90.6	90.7	97.6	86.9	91.4	87.3	120.9	117.5	38.5	99.6	91.2	125.7	129.0	130
Total - N (ug/L N)	48.9	136.4	145.3	142.9	136.3	140.0	186.0	153.0	173.6	188.3	107.3	163.3	166.4	232.0	180.3	189
Reactive silicon (ug/L Si)	1,407	1,044	1,169	897	1,161	1,016	1,184	1,192	1,406	1,262	1,250	1,355	1,332	1,312	1,269	1381
Carbon (ug/L C)		91		133	111	124						81	119	92	85	104
Chlorophyll a (ug/L)		0.01	0.10	0.01	0.03	0.05	0.10	0.16	0.16	0.21	0.18	0.05	0.03	0.04	0.16	0.05
Phaeophytin a (ug/L)		0.07	0.10	0.05	0.14	0.13	0.21	0.15	0.19	0.15	0.14	0.11	0.04	0.10	0.17	0.06

Appendix C.3. Summary of fertilizer application at Virginia Lake, 1988-2002.

Year	Type (N-P-K)	Gallons
1988	none	none
1989	none	none
1990	none	none
1991	20-5-0 & 32-0-0	2,640 & 1,880
1992	20-5-0	4,320
1993	20-5-0 & 32-0-0	5,490 & 2,000
1994	20-5-0 & 32-0-0	6,060 & 2,220
1995	20-5-0	7,440
1996	20-5-0	7,710
1997	none	none
1998	20-5-0	5,280
1999	32-0-0	2,862
2000	32-0-0	2,580
2001	20-5-0	3,360
2002	20-5-0	8,430

Appendix C.4. Zooplankton density (number m^{-2}) by season of the three most prominent species at Virginia Lake, 1991-2002.

Season	Year											
	1991	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Diaptomus												
May	1,443		32,051		5,604	3,991	1,053		909	2,930	7,795	5,969
June	1,274	13,839	12,821	824	6,427	12,125	1,528	45,509	1,979	3,346	5,978	7,947
July	7,047	202,751	28,549	12,778	218,034	126,209	17,083	132,485	4,373	14,977	8,898	14,306
August	224,232	999,321	299,202	73,526	110,248	554,756	35,651	168,238	25,658	77,688	84,021	87,180
September	96,069	164,544	241,722		52,641	5,748	25,030	85,966	68,603	11,505	44,218	101,308
October	13,415	106,639	13,670	22,042		484			49,924	3,821	238	30,073
Cyclops												
May	5,264		1,804		1,053	10,847	2,140		272	19,656	17,074	14,476
June	5,307	1,274	4,840	1,444	2,768	3,515	2,896	4,670	12,039	10,978	2,157	12,940
July	11,887	23,434	1,061	1,019	3,057	255	306	4,551	1,112	3,600	646	1,630
August	509	10,188	2,038	12,460	255		374	7,811	1,248	1,333	442	136
September	807	5,264	509		170	85	238	4,649	764	637	688	2,700
October	442	4,670	85	552		255			1,291	77	815	985
Bosmina												
May	1,868		2,866		7,896	5,370	6,453		7,166	6,283	7,107	1,019
June	2,292	5,689	11,207	25,956	19,189	42,079	14,773	15,495	20,352	15,784	11,360	6,046
July	7,726	10,188	17,299	38,589	63,338	27,891	17,847	7,888	47,139	6,572	16,871	23,468
August	4,840	4,245	26,152	41,582	24,410	45,424	18,616	4,797	26,983	1,562	6,385	8,830
September	5,222	4,585	14,009		43,811	17,737	9,595	5,859	14,264	6,113	5,366	24,283
October	4,585	4,755	2,293	31,033	16,862	27,747			12,931	8,227	7,964	27,560

Appendix C.5. Zooplankton average size (mm) by season of the three most prominent species at Virginia Lake, 1991-2002.

Season	Year											
	1991	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Diaptomus												
May	0.76		0.94		0.85	1.00	1.13		0.86	0.97	1.01	0.78
June	0.93	1.25	0.79	1.42	1.15	1.31	1.19	1.45	0.94	1.30	1.27	1.11
July	1.54	1.84	1.48	1.83	1.71	1.71	1.08	1.77	1.15	1.60	1.60	1.35
August	1.83	1.83	1.51	1.88	1.90	1.82	1.88	1.77	1.54	1.79	1.67	1.74
September	1.86	1.86	1.71		1.93	1.78	1.86	1.77	1.81	1.85	1.87	1.78
October	1.79	1.85	1.74	1.83	2.00	1.73			1.80	1.85	1.86	1.82
Cyclops												
May	0.91		0.92		0.82	0.87	0.67		0.57	0.90	0.68	0.75
June	0.86	0.66	0.64	0.67	0.73	0.76	0.66	0.62	0.54	0.64	0.61	0.59
July	0.64	0.83	0.72	0.84	0.71	0.75	0.63	0.94	0.61	0.62	0.69	0.69
August	0.73	0.96	0.89	0.92	0.75	0.79	0.72	0.98	0.71	0.78	0.79	0.64
September	0.77	1.02	0.92		0.93	0.85	0.83	0.87	0.78	0.90	0.95	0.90
October	0.78	1.07	0.87	0.92	0.93	0.94			0.79	0.87	0.95	0.83
Bosmina												
May	0.44		0.43		0.44	0.44	0.35		0.42	0.49	0.42	0.46
June	0.41	0.43	0.45	0.46	0.42	0.44	0.39	0.41	0.40	0.41	0.41	0.40
July	0.31	0.37	0.42	0.45	0.32	0.42	0.34	0.40	0.35	0.39	0.37	0.33
August	0.30	0.40	0.38	0.41	0.35	0.43	0.36	0.48	0.33	0.38	0.35	0.34
September	0.37	0.44	0.47		0.37	0.41	0.44	0.48	0.36	0.46	0.36	0.39
October	0.36	0.51	0.52	0.45		0.46			0.38	0.44	0.40	0.37

Appendix C.6. Juvenile sockeye populations in Virginia Lake estimated using hydroacoustic and mid-water trawl sampling, 1989-2002. Total fish populations were estimated with hydroacoustics, and species apportionments were determined with trawl samples; densities are the estimated number of sockeye fry m^{-2} of lake surface area.

Year	Total Limnetic Fish Population	Fry Population[a]	Fry m^{-2}
1989[b]	282,000	270,000	0.115
1990[b]	139,000	139,000	0.059
1991[b]	121,000	121,000	0.051
1992[b]	150,000	128,000	0.054
1993[b]	no fall survey		
1994[b]	no fall survey		
1995[b]	313,000	313,000	0.133
1996[b]	no fall survey		
1997	110,000	110,000	0.047
1998	102,000	102,000	0.043
1999	116,000	116,000	0.049
2000	169,000	169,000	0.072
2001	56,000	56,000	0.022
2002	68,000	32,000	0.013

[a] Population of fish based on trawl samples - some stickleback captured in 1989, 1992, and 2002.
[b] Fry stocked in lake.

Appendix C.7. Sockeye salmon fry plants at Virginia Lake, 1989-1995.

Year	No. Fry Stocked
1989	1,925,179
1990	888,800
1991	736,750
1992	620,800
1993	1,144,572
1994	1,055,365
1995	1,247,638
Total	**7,619,104**

Appendix D. Daily and cumulative (sockeye) counts of adult salmon at the Mill Creek fishpass, Virginia Lake, for a) 2001 and b) 2002.

a) 2001 daily fish counts.

Date	Sockeye	Cumulative	Chinook	Coho	Chum	Pink	Steelhead	Cutthroat	Dolly Varden
7/24/2001	6	6							
7/25/2001	7	13	2						
7/26/2001	35	48							
7/27/2001	1	49							
7/28/2001	1	50	3						
7/29/2001	19	69							
7/30/2001	20	89							
7/31/2001	33	122			1				
8/1/2001	11	133	2						
8/2/2001	10	143							
8/3/2001	38	181							
8/4/2001	16	197	2						
8/5/2001	8	205	1		2				
8/6/2001	13	218	1						
8/7/2001	31	249	6						
8/8/2001	3	252	4						
8/9/2001	12	264	2						
8/10/2001	5	269	4		1				
8/11/2001	19	288	2						
8/12/2001	88	376	2		3				
8/13/2001	104	480	1						
8/14/2001	129	609							
8/15/2001	64	673	1						
8/16/2001	40	713							
8/17/2001	39	752	1						
8/18/2001	29	781	1						
8/19/2001	29	810	3						
8/20/2001	77	887	6			6			
8/21/2001	62	949	3		7				
8/22/2001	12	961		1	8	2			
8/23/2001	14	975			3	2			
8/24/2001	12	987	2		16				
8/25/2001	3	990	1		1				
8/26/2001		990							
8/27/2001		990							
8/28/2001		990							
8/29/2001		990							
8/30/2001	13	1,003		1					
8/31/2001									
9/1/2001									
9/2/2001									
9/3/2001									

Date	Sockeye	Cumulative	Chinook	Coho	Chum	Pink	Steelhead	Cutthroat	Dolly Varden
9/4/2001									
9/5/2001									
9/6/2001									
9/7/2001									
9/8/2001									
9/9/2001									
9/10/2001				1					
9/11/2001					2				
9/12/2001									
9/13/2001									
9/14/2001									
9/15/2001									
9/16/2001									
9/17/2001									
9/18/2001				1					
9/19/2001									
9/20/2001									
9/21/2001									
9/22/2001									
Totals	**1,003**		**50**	**4**	**44**	**10**		**NA**	**NA**

b) 2002 daily fish counts.

Date	Sockeye	Cumulative	Chinook	Coho	Chum	Pink	Steelhead	Cutthroat	Dolly Varden
7/15/2002		0							
7/16/2002		0							
7/17/2002		0							
7/18/2002		0							
7/19/2002		0							
7/20/2002	1	1							
7/21/2002	3	4							
7/22/2002		4							
7/23/2002		4							
7/24/2002		4							
7/25/2002	6	10							
7/26/2002	7	17			1				
7/27/2002	10	27			1				9
7/28/2002	26	53			1			1	4
7/29/2002	8	61	1						1
7/30/2002	7	68							29
7/31/2002	2	70							3
8/1/2002	18	88							15
8/2/2002	76	164	10						27
8/3/2002	37	201	1						35
8/4/2002	113	314	3						17
8/5/2002	132	446	5						48
8/6/2002	63	509	6						162
8/7/2002	254	763	10		1		1		72

Date	Sockeye	Cumulative	Chinook	Coho	Chum	Pink	Steelhead	Cutthroat	Dolly Varden
8/8/2002	83	846	5						2
8/9/2002		846							
8/10/2002	2	848	1						
8/11/2002	44	892	10					1	56
8/12/2002	44	936	3						63
8/13/2002		936							
8/14/2002		936							
8/15/2002	1	937							
8/16/2002	18	955							6
8/17/2002	1	956							11
8/18/2002	122	1,078	1					1	18
8/19/2002	166	1,244							15
8/20/2002	14	1,258							7
8/21/2002	240	1,498				2		2	9
8/22/2002	122	1,620		1					3
8/23/2002		1,620							
8/24/2002	3	1,623							
8/25/2002	1	1,624							
8/26/2002		1,624							
8/27/2002		1,624							
8/28/2002		1,624							
8/29/2002		1,624							
8/30/2002	2	1,626							
8/31/2002		1,626							
9/1/2002		1,626							
9/2/2002		1,626							
9/3/2002	4	1,630		1					
9/4/2002	18	1,648						1	
9/5/2002	169	1,817		2				3	7
9/6/2002	104	1,921						3	6
9/7/2002	67	1,988		2				4	14
9/8/2002	82	2,070						1	21
9/9/2002		2,070							
9/10/2002		2,070							
9/11/2002		2,070							
9/12/2002		2,070							
9/13/2002	2	2,072						2	9
9/14/2002	1	2,073							
9/15/2002									
Totals	**2,073**		**56**	**6**	**4**	**2**	**1**	**19**	**669**

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