LIMNOLOGICAL AND FISHERIES INVESTIGATIONS AT VIRGINIA LAKE, SOUTHEAST ALASKA

2003

by

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ABSTRACT

Fisheries research has been conducted at Virginia Lake for the past 17 years, primarily to monitor the progress of a sockeye salmon enhancement project, cooperatively implemented by the U. S. Forest Service**,** the Alaska Department of Fish and Game (ADF&G), and Southern Southeast Regional Aquaculture Association in 1988. In 2003, we conducted our final season of limnological sampling at Virginia Lake in order to assess the lake's reaction to the end of the nutrient enrichment program, which was first implemented in 1991. The levels of several key nutrients, along with primary production, declined in 2003 to the low levels observed in past years where fertilization did not take place. Zooplankton densities were below the 17-year average in 2003, but an increase in the copepod *Diaptomus franciscanus* led to total zooplankton biomass being above the 17-year average. The original goal of the Virginia Lake enhancement project was to enhance the small, naturally occurring run of sockeye salmon to a level that would allow targeted fisheries harvests on this stock. Sockeye fry of McDonald Lake stock were planted in the Lake from 1989 to 1996, but these fry planting efforts were apparently not successful in establishing a larger sockeye salmon run in the lake. Virginia Lake's natural productivity is sufficient to support the very low sockeye fry densities observed in recent years.

KEY WORDS: sockeye salmon, *Oncorhynchus nerka*, Virginia Lake, Mill Creek, Porterfield Creek, Southeast Alaska, limnology, zooplankton, lake fertilization, nutrient enrichment, controlled release fertilizer, survival, rearing, hydroacoustics, mid-water trawl, fish pass.

INTRODUCTION

Historically, Virginia Lake had a flow limiting natural barrier located just above tidewater that was size specific to the passage of fish, and allowed only a very small population of sockeye salmon *Oncorhynchus nerka* to utilize the lake (Zadina and Haddix 1993). In a cooperative effort to enhance the small population of sockeye salmon, and create a larger naturally spawning run of sockeye salmon into Virginia Lake, the U. S. Forest Service installed a fish pass in 1988, and the Alaska Department of Fish and Game and Southern Southeast Regional Aquaculture Association stocked the lake with sockeye salmon fry from 1989 to 1996 (Edmundson et al. 1991; Zadina and Haddix 1993; Zadina 1997). Eggs from the McDonald Lake stock of sockeye salmon were used for the fry-stocking project. A nutrient enrichment program was added in 1991, in an effort to remedy secondary production problems experienced in 1989 and 1990 when emergent sockeye salmon fry were planted in April and May, prior to when the lake's food supply was ready for this introduction (Edmundson et al. 1991). Fertilizer was applied at 50-60% of the critical phosphorus load (after Vollenweider 1976) while sockeye salmon fry were planted in the lake, from 1991 to 1996. After a hiatus in 1997, the nutrient enrichment program was reimplemented in 1998, with the total phosphorus additions loaded at 50% of the critical loading rate (Zadina and Weller 1999). The intent of the lower loading rate was to increase lower trophic level production in Virginia Lake, primarily to the benefit of the resident cutthroat trout *Oncorhynchus clarki* population. Increasing the forage base for rearing sockeye salmon fry was a secondary goal of this portion of the lake fertilization program.

In 1999, fertilizer was applied at 60% of the critical phosphorus load into Virginia Lake, only this time all of the phosphorus added to the lake was contained in solid controlled release fertilizer (CRF) that was primarily distributed in the littoral zone of the upper half of the lake (Zadina and Heinl 2000). The fertilizer was damaged by a flood prior to application, and was not added to the lake in the desired time frame or method. The fertilizer appeared to have dissolved and passed through the lake by late-June. In 2000, the lake was again fertilized with a combination of liquid and solid fertilizers; again at 60% of the critical phosphorus load, with 25% of the solid fertilizer distributed in upper Porterfield Creek, approximately 6.4 km above the confluence with Virginia Lake. In 2001, the nutrient enrichment program returned solely to liquid fertilizer and the application amount was again lowered to 50% of the estimated critical loading rate. During the 2002 season, applications were raised back to 60% of the estimated critical loading range using liquid fertilizer. In addition, a new prototype solid fertilizer was stocked in the lake raising the critical loading rate to 65%. This new solid fertilizer was also evaluated for dissolution rate and nutrient release timing. Again, enhancement of the sockeye salmon population was not the primary goal of lake fertilization from 1999 to 2002.

Accurate estimates of total return and escapement of sockeye salmon at Virginia Lake are lacking. Regular escapement counts of sockeye salmon were not conducted at Virginia Lake prior to the beginning of research at the lake in 1986, and little is known about this system's historical run size. Subsistence catches at the mouth of Mill Creek in years prior to lake stocking suggest that the run must have been at least several hundred fish (ADF&G unpublished data). The fry-stocking program that ran from 1989 to 1996 increased returns to Virginia Lake, but to what extent is difficult to say. Cady and Reed (2003) estimated that fry plants of 7.6 million fish

(1989-1995) contributed a minimum of 16,000 adult sockeye salmon to the commercial fisheries of districts 101-108 for the period 1994-2000. Foot surveys of Virginia Lake's two major tributaries, Glacier and Porterfield Creeks, in September of 1984, and again from 1993-2002, showed peak counts ranging from less than 100 fish to approximately 2,000 fish. Escapements appeared to be highest between 1993 and 1996, but it is not known how these peak foot survey counts relate to total escapement. A foot survey conducted on September 11, 1984 documented 104 sockeye salmon in a partial survey of Porterfield Creek. This count is higher than the peak escapement counts of Porterfield Creek from 2000 to 2002 and suggests that current escapements are probably similar to pre-enhancement levels. Recent attempts to estimate escapement into Virginia Lake from counts at the Mill Creek fishpass have documented minimum escapement estimates ranging from 829 sockeye salmon in 2000, to 2,073 sockeye salmon in 2002; however, fish counts at the fishpass may not be complete counts and none of these counts were successfully verified by mark-recapture studies due to difficulties in locating fish on the spawning grounds (Cady and Reed 2003).

Lake fertilization did not take place in 2003. Research conducted in 2003 involved assessing primary and secondary production in the lake for a post fertilization evaluation. The escapement of adult sockeye salmon at Virginia Lake was evaluated by U. S. Forest Service personnel and is not included in this report. Here I report the results of limnological studies at Virginia Lake during the 2003 field season, and also offer a brief analysis of the past 17 years of study at the lake.

Study Site

Virginia Lake (56° 28' N, 132° 10' W) is located 16 km east of Wrangell on mainland Southeast Alaska at an elevation of 32 m (Figure 1). The lake is organically stained with a surface area of 256.7 ha, mean depth of 27.5 m, maximum depth of 54 m, and volume of $70.7 \cdot 10^6$ m^3 (Figure 2). The lake empties into Eastern Passage via Mill Creek (<1 km). There are two inlet streams: Porterfield Creek (ADF&G stream number 10740-10070-0010-2010) flows southwest 11 km to the east end of Virginia Lake, and Glacier Creek (ADF&G stream number 10740-10070-0010-2006) flows west 13 km to the south side of Virginia Lake (Orth 1967). Mean annual precipitation is an estimated 280 cm, the lake watershed area encompasses approximately 83 km^2, and the hydraulic residence time or flushing rate is estimated at 4.2 months (Edmundson et al. 1991). Water and zooplankton samples have been collected at two stations near the center, and deepest part of the lake: station A (GPS coordinates 56^o 28.79' N; 132^o 10.07' W) and station B (GPS coordinates 56^o 28.72'N, 132^o 10.34'W; Figure 2).

Project Sponsorship

The United States Forest Service through the Alaska Department of Fish and Game provided funding to evaluate the limnological and nutrient and nutrient enrichment assessment program in 2003. This is the final report fulfilling contract obligations for USDA-Forest Service Sikes Act Contract 53-0109-3-62400.

METHODS

2003 Limnological Assessment

Sampling to evaluate the lake water chemistry characteristics and the in-lake biotic response to the end of the fertilization program was conducted at station A, with a replicate zooplankton sample collected at Station B (Figure 2). Physical data, water quality, and zooplankton samples were collected on May 3, June 5, July 1, August 5, September 8, and October 7. All samples were analyzed at the ADF&G, Division of Commercial Fisheries, Limnology Laboratory in Soldotna, Alaska.

Physical Parameters

Measurements of underwater light penetration (foot-candles) were recorded at 0.5 m intervals, from the surface to a depth equivalent to one percent of the subsurface light reading, using an International Light[2] IL1350 submarine photometer. Vertical light extinction coefficients (K_d) were calculated as the slope of the light intensity (ln of percent subsurface light) versus depth. The euphotic zone depth (EZD), the depth to which 1% of the subsurface light (photosynthetically available radiation [400-700 nm]) penetrates the lake surface (Schindler 1971), was calculated from the equation: $EZD = 4.6205/ K_d$ (Kirk 1994). Euphotic volume (EV) is the product of the EZD and lake surface area and represents the volume of water capable of photosynthesis. Temperature and dissolved oxygen concentrations were recorded at 1 m depth intervals, from the lake surface to 50 m, using a Yellow Springs Instruments (YSI) model 58 meter calibrated each sampling trip with a 60 ml Winkler field titration (Koenings et al. 1987).

Water Quality

A Van Dorn sampler was used to collect water quality samples from the epilimnion at the 1 m depth, and from the mid-hypolimnion (generally about 40 m depth). Ten liters of water were collected from each depth, stored in pre-cleaned polyethylene carboys, transported to Ketchikan, and then filtered or preserved for laboratory analysis. Separate subsamples from each carboy were: (1) refrigerated for general tests and metals; (2) frozen for nitrogen and phosphorus

[2] Mention of trade names does not constitute endorsement by ADF&G but are included for scientific completeness.

analysis; and (3) filtered through a 0.7 μm particle retention glass fiber filter and frozen for analysis of dissolved nutrients (Koenings et al. 1987). Samples were analyzed for general qualities, metals, nutrients, and primary production by methods detailed in the Alaska Department of Fish and Game Limnology Field and Laboratory Manual (Koenings et al. 1987), and summarized in Edmundson et al. (1991). Additional water samples were collected from the euphotic (EZD) and mid-euphotic (MEU) zone depths for primary productivity analysis.

Secondary Production

Zooplankton samples were collected at station A and B, using a 0.5 m diameter, 153 μm mesh conical net. Vertical zooplankton tows were pulled from a depth of 50 m to the surface at a constant speed of 0.5 m · sec^{-1}. The net was rinsed prior to removing the organisms, and all specimens were preserved in neutralized 10% formalin (Koenings et al. 1987). Samples were analyzed by methods detailed in the Alaska Department of Fish and Game Limnology Field and Laboratory Manual (Koenings et al. 1987), and summarized in Edmundson et al. (1991). Density and biomass of taxa were averaged between station A and B, for each date of sampling.

Juvenile Sockeye Salmon Assessment

No hydroacoustic surveys were conducted in 2003. Hydroacoustic results from 1997 to 2000 were re-analyzed in March of 2004 by Malcolm McEwen of ADF&G, using methods described in detail in the Hydroacoustics Lake Survey Procedure Manual for Southeast Alaska (McEwen et.al. in prep). Results of this reanalysis – total estimates of the limnetic fish population – are included in this report.

Hydroacoustic and mid-water trawl sampling were used to estimate the fall abundance of limnetic fish in Virginia Lake in 1989-1992, 1995, and 1997 through 2002. Virginia Lake was divided into ten sampling areas of approximately equal width, from east to west. Each sampling area was represented by one randomly chosen north-south transect across the lake. Each north-south transect was sampled twice – once starting on the north shore and heading south along the transect to the south shore, and then a replicate survey conducted immediately in the opposite direction, over the same transect, back to the north shore. Thus, 20 transects were conducted in all, two from each sampling area. 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. 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. Biosonics Visual Analyzer© version 4.0.2 software was used to analyze hydroacoustic data and to estimate the total population of limnetic fish in the lake (McEwen et al. in prep). We attempted to estimate species composition of the limnetic fish population in the lake by extrapolating from the trawl catches.

RESULTS

2003 Limnological Assessment

Physical Parameters

The euphotic zone depth (EZD) ranged from 7.01 m (7 Oct) to 10.26 m (1 Jul); with a seasonal mean depth of 8.64 m (Table 1). Euphotic volume (EV) was estimated at 22.18 · 10^6 m^3 or 22.18 EV units. This volume, capable of photosynthesis, represents 31.4% of the total lake volume. Due to a warm spring, the lake was already stratified on May 8, with a thermocline depth of approximately 5 m (Figure 3). By October, the depth of the thermocline had dropped to approximately 27 m. Dissolved oxygen levels were normal throughout the season (Figure 3).

General Water Quality and Nutrient Concentrations

As in all the past years of this study, Virginia Lake's general water quality parameters and metal concentrations were within the range regarded as normal for stained, oligotrophic, coastal Alaska lakes (Tables 2 and 3; see Edmundson et al. 1991; Zadina et al. 1992). The slightly acidic pH (mean 6.1), low conductivity, and low alkalinity indicated soft water; and the color (mean 13.5 Pt units) and iron concentrations (mean 91.3 µg · L^{-1}) were also characteristic of an organically stained lake.

The concentration of total phosphorus in 2003 was well below the 17-year average and slightly below the average for non-fertilized years. Concentrations varied from lows in May (2.6 µg · L^{-1}) and August (2.4 µg · L^{-1}) to a high of 4.3 µg · L^{-1} in September (Table 3). The concentrations of filterable reactive phosphorus (FRP), the most available form of phosphorus for algal uptake (Koenings et al. 1987), and total filterable phosphorus (TFP) were at some of the lowest levels since the beginning of the Virginia Lake project (Table 2).

The total nitrogen level (TKN and nitrate + nitrite) was highest in May, at 229 µg · L^{-1}, and remained stable from June through October at a slightly lower range of 169-188 µg · L^{-1} (Table 3). The atomic ratio of nitrogen to phosphorus varied from a high of 195:1 in May, to a low of 60:1 in September (Figure 4). The mean seasonal total nitrogen concentration of 184.2 µg · L^{-1} was the third highest since 1989. Ammonia, which contains both the ammonium ion and ammonia, is the preferred form of nitrogen for uptake by phytoplankton (Koenings et al. 1987). Ammonia levels varied from a low of 1.3 µg · L^{-1} in June, to a high of 6.6 µg · L^{-1} in July (Table 3). The mean seasonal ammonia concentration of 3.6 µg · L^{-1} was the fourth lowest level since the start of the project (Table 2). The mean annual nitrate + nitrite concentration (78.8 µg · L^{-1}) was near the average for all years, and above the levels for all previous years where fertilization did not take place. The total Kjeldahl nitrogen (TKN) concentration was the third highest since the start of the project (105.4 µg · L^{-1}).

Concentrations of reactive silicon (required for the formation of frustrule cell structure by diatoms) remained fairly stable throughout the season. Concentrations in the epilimnion showed a slight decline to a low of 973 µg · L^{-1} in July and then gradually rose throughout the rest of the season (Table 3). The mean level of reactive silicon for the season was one of the highest observed during our 17 years of sampling (Table 2). The summer concentration of organic carbon, which estimates the total amount and energy content of organic material in the lake (Koenings et al. 1987), was well below average.

Primary and Secondary Production

The mean epilimnion concentration of chlorophyll *a* in 2003 ranged from 0.10 to 1.45 µg · L^{-1} (seasonal mean 0.55 µg · L^{-1}; Table 4). The total average of chlorophyll *a*, at all depths, throughout the season, was 0.32 µg · L^{-1} (Table 2). This was the second lowest level since lake fertilization began in 1991, but was higher than the levels found in the four years of sampling prior to fertilization, from 1987-1990 (0.18 µg · L^{-1} average), and very similar to 1997 levels, a year when the lake was not fertilized.

In 2003, the macrozooplankton community of Virginia Lake comprised two species of copepods (*Cyclops* sp. and *Diaptomus franciscanus*) and four species of Cladocerans, primarily *Bosmina longirostr*is, but including *Daphnia longiremus*, Chydorinae sp., and *Holopedium* sp (Table 5). The mean seasonal macrozooplankton density was below average in 2003, but increased numbers of the relatively large *Diaptomus franciscanus* increased the total zooplankton biomass to above the 17-year average (Figures 5 and 6). The total zooplankton biomass of 208 mg. · m^{-2} was well above the 17-year average. Copepods accounted for 92% of the total zooplankton biomass, with *Diaptomus franciscanus* representing 80% of the total (Figure 7). The proportion of total zooplankton biomass (8%) and density (29%) represented by Cladocerans was the lowest since sampling began at Virginia Lake (Figure 7 & 8).

Rearing Fry Population Estimates

New estimates of the total limnetic fish population in the lake (with standard errors), from 1997 to 2002, are presented in Table 6. The species composition and age proportions determined by the midwater trawl sampling were applied to the total fish population estimate to calculate species-specific population sizes. However, the trawl net catches tend to be biased towards smaller fish, and when fish densities are low, the net has been ineffective at capturing any fish at all. Although trawl catches during fall hydroacoustic surveys were 100% sockeye fry for all years except 1989, 1992, and 2002, stickleback were almost certainly present in all years. For example, trawls conducted in 2001 captured only 3 sockeye fry and no other species, and it was assumed that all targets within the appropriate target strength range of –50 to –68 dB were sockeye salmon fry (Hollowell and Zadina 2002). However, the catch from the trawl net tows in 2002 included 20 sockeye fry, 16 sticklebacks, and 6 sculpins. The sockeye fry estimate for 2002 was based on the assumption that only 48% of the targets within the appropriate target strength range were sockeye fry (Hollowell and Zadina 2003). It is unlikely that the species composition of Virginia Lake would change this dramatically in one year. The variability in species composition in the trawl catches probably reflects the limitations of our current trawl sampling gear, rather than actual changes in species composition in the lake. Thus, it would probably be more appropriate to use the estimates of total limnetic fish populations, rather than the estimates of sockeye fry populations as shown in Table 6 and in previous ADF&G reports.

DISCUSSION

Limnological Sampling 1986-2003

Limnological sampling in 2003 provided data on how Virginia Lake has responded since nutrient additions ceased in 2002. The data also allow us to compare these results with other years, when nutrient additions to the lake did not take place. There was no assessment of the lake's sockeye fry population in 2003, but based on an estimated very low adult escapement in 2002 (Cady and Reed 2003) sockeye fry numbers probably remained low and had minimal effects on macrozooplankton populations. The 2002 escapement estimate of 2,073 sockeye salmon was based on counts at the Mill Creek fishpass. However, it is important to note that this adult escapement estimate was not verified by mark-recapture methods due to an apparent lack of fish in the spawning tributaries and the inability to detect and sample lake spawners (Cady and Reed 2003). There are no reliable estimates of total run size and escapements for any year at Virginia Lake.

The implementation of the nutrient enrichment program in 1991 resulted in a dramatic increase in phytoplankton biomass at Virginia Lake (Table 2). Levels of chlorophyll *a* and phaeophytin *a* increased substantially from 1991 to 1996, underwent a steep drop in 1997 when no nutrient additions took place, rose again in 1998 when the enrichment program was re-implemented, remained below the 17-year average for the years 1999-2001, and increased to slightly above average levels in 2002. Phytoplankton biomass in Virginia Lake declined in 2003, with levels of chlorophyll *a*, and its degradation product phaeophytin *a*, returning to the lower levels observed in past years when no nutrient additions occurred (1986, 1988-1990, and 1997), lower loading rates were employed (2001), or solid, controlled release fertilizer was applied (1999-2000, Table 7). Overall macrozooplankton densities and biomass followed a similar pattern, except for an increase in total biomass observed in 2003.

Although levels of several key nutrients, chlorophyll *a*, and macrozooplankton densities in 2003 were below average (Table 2 and Figure 5), total zooplankton biomass was above average, primarily because of an increase in the copepod *Diaptomus franciscanus* (80% of total zooplankton biomass, 30% of density in $n \cdot m^{-2}$). *Diaptomus franciscanus* is the largest, and presumably one of the more important food sources for Virginia Lake sockeye fry, given the lack of large cladocerans in the lake. Although no stomach content analysis has been conducted on Virginia Lake sockeye fry, studies at other lakes have shown that *Diaptomus* can be an important prey item for juvenile sockeye salmon (Koenings and Kyle 1997; McDonald 1973). *Cyclops* sp. and *Bosmina longirostris* accounted for 12% and 6.5% of the remaining zooplankton biomass, and 41.5% and 24.3% of densities respectively. These 3 species accounted for over 98% of the total macrozooplankton biomass and 95% of the total macrozooplankton density at Virginia Lake in 2003. The increase in the larger *Diaptomus* may be a reaction to reduced predation by sockeye fry, as fry populations have declined to low levels over the past few years. In 1986 and 1988, zooplankton sampling was only conducted during July (1986) and early August (1988). Comparing these samples with July and August samples in later years shows that as a percent of total zooplankton biomass, *Diaptomus* levels quickly dropped in 1989 (the first year of fry plants), declined to very low levels in the mid-90s, and then began increasing after fry plants ended in 1996, reaching a high of 72% in early August 2003. The nutrient enrichment program that was implemented in 1991 resulted in substantial increases in *Bosmina* and *Cyclops* densities, at a time when fry plants of up to 1.2 million sockeye salmon were taking place (Figures 9 and 10). Densities of Bosmina dropped sharply in 1997 and 2003, two years where nutrient enrichment did not take place. Densities of *Diaptomus* reacted in a nearly opposite way by decreasing during years of both fry plants and nutrient enrichment, gradually increasing after fry plants ended in 1996, and then rising sharply in 2003, a year with no nutrient enrichment (Figure 11). The increased dominance of *Bosmina* and *Cyclops* during years of higher fry abundance may have been partly a result of sockeye fry selectively feeding on the much larger *Diaptomus*. The mean weighted lengths of *Diaptomus*, *Cyclops*, and *Bosmina* did not show any obvious trends throughout the 17-year history of the project (Figure 12). The mean weighted length of Bosmina has fluctuated from slightly above to slightly below 0.40 mm (17-year average 0.396 mm), which is considered the minimum threshold size for elective feeding by sockeye salmon fry (Koenings and McDaniel 1983; Kyle et al. 1988). The macrozooplankton biomass in Virginia Lake is likely to remain at average levels, even without fertilization, given the current low densities of sockeye fry in the lake.

Project Summary

The original goal of the Virginia Lake project was to enhance the small, natural run of sockeye salmon in the system to a level that would allow targeted fisheries on this stock. Initial plants of sockeye fry to the lake in 1989 and 1990 experienced poor survival rates due to problems associated with early planting and the effects it had on the lakes macrozooplankton productivity (Edmundson et al. 1991, Zadina and Haddix 1993). These negative effects on lake productivity led to the implementation of the lake fertilization program in 1991. Nutrient additions to Virginia Lake, from 1991-1996, and again from 1998-2002, increased primary and secondary production in Virginia Lake. Despite this increase in productivity, the sockeye salmon population was unable to maintain itself at higher levels without additional fry plants, possibly indicating an unknown limiting factor to sockeye salmon productivity at Virginia Lake. The final two years of fry population studies, involving hydroacoustic surveys at Virginia Lake (2001 and 2002), indicated low limnetic fish populations of 83,000 and 113,000 respectively (Table 6). Adult sockeye salmon escapements were also estimated to be low in 2002 and 2003 (Cady and Reed 2003; Cady 2004), indicating a high probability of continued low fry densities. We do not know what kind of fry densities were typical of Virginia Lake prior to the start of fry plants in 1989, but they are assumed to have been very low. A hydroacoustic survey conducted on April 26, 1989, prior to the first stocking of sockeye fry, gave a total limnetic fish population estimate of 98,000 fish (1 fish/ 721 m^3), which is comparable to recent estimates. We have no information about the escapement size range of this stock prior to the initiation of enhancement efforts in 1988 because regular escapement counts were not conducted at this system. Foot surveys conducted in 1965 and 1984 documented the presence of this species in the system, but they do not provide us with total escapements. Subsistence catches from 1977-1992, prior to the first returns of the stocked adults, suggest that escapements must have been at least several hundred fish (ADF&G unpublished data). It is possible that since fry stocking was ended in 1997, sockeye salmon numbers have been returning to their former low levels. The overall results of this project are clouded by the lack of reliable estimates of total run size and escapements. Benefits to Virginia Lakes' resident cutthroat trout population, a stated goal of the nutrient addition program after 1998, were not assessed by ADF&G and any benefits the nutrient additions may have had on this species are unknown. There does not appear to be a need for further nutrient enrichment at Virginia Lake. If new enhancement efforts are conducted in the future at Virginia Lake, great effort should be put into achieving reliable escapement estimates and collecting detailed information on characteristics of the fry and smolt populations.

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TABLES

Table 1. Virginia Lake monthly euphotic zone depth (EZD) based on light intensity profiles, 2003.

Date	EZD (m)
8-May-03	7.82
5-Jun-03	9.54
1-Jul-03	10.26
5-Aug-03	10.20
8-Sep-03	7.04
7-Oct-03	7.01
Mean	**8.64**

Table 2. Comparison of the seasonal mean general water quality parameters, metal concentrations, and nutrient concentrations, at Virginia Lake, Station A, all depths, 1986-2003.

Year	1986	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	*Mean*
pH	6.5	6.4	6.6	6.6	6.6	6.4	6.5	6.3	6.4	6.3	6.8	6.8	6.5	6.4	6.4	6.4	6.1	*6.5*
Conductivity (umhos*cm $^{-1}$)	24	24	26	25	25	23	24	26	29	29	27	26	26	26	24	26	26	*26*
Alkalinity (mg*L $^{-1}$)	9.3	7.0	9.0	9.0	9.6	6.8	9.0	8.6	10.9	10.0	11.7	11.1	10.8	9.9	9.3	11.6	10.1	*9.6*
Turbidity (NTU)	0.4	1.1	0.8	1.1	1.0	1.0	2.2	1.1	1.3	0.9	0.7	0.7	0.9	0.9	0.8	0.8	0.5	*1.0*
Color (Pt units)	19	19	15	17	19	13	12	16	13	16	15	14	14	15	16	13	14	*15*
Calcium (ug*L $^{-1}$)	5.5	3.9	4.3	4.1	4.1	3.9	4.0	4.1	4.4	4.1	4.0	3.9	4.1	4.0	3.7	3.9	4.0	*4.1*
Magnesium (mg*L $^{-1}$)	0.6	0.2	0.2	0.4	0.3	0.7	0.5	0.6	0.7	0.4	0.4	0.3	0.4	0.4	0.5	0.6	0.4	*0.4*
Total Iron (ug*L $^{-1}$)	91	138	130	175	146	121	257	152	161	146	87	67	123	101	110	144	91	*132*
Total-P (ug*L $^{-1}$)	2.2	4.9	4.4	5.1	4.1	5.0	9.5	5.5	4.6	5.4	2.6	4.2	5.3	3.5	4.2	6.4	3.2	*4.7*
Total Filterable-P (ug* $^{-1}$ L)	5.2	1.9	3.1	3.3	2.8	2.5	3.2	4.3	2.9	3.5	2.6	3.0	3.2	2.7	3.8	3.8	2.2	*3.2*
Filterable Reactive -P (ug/L $^{-1}$)	4.9	1.6	2.5	2.6	2.6	1.1	1.8	2.2	1.4	2.3	2.5	2.1	3.0	1.6	2.1	3.0	1.5	*2.3*
Total Kjeldahl N (ug*L $^{-1}$)	45.5	57.5	53.3	54.5	67.4	68.4	134.3	79.2	67.6	97.9	65.8	69.9	78.3	106.0	58.3	83.6	105.4	*76.1*
Ammonia (ug*L $^{-1}$)	3.4	1.5	6.6	4.2	4.8	9.1	11.9	6.8	3.3	9.9	7.7	4.2	10.2	12.5	7.5	11.5	3.6	*7.0*
Nitrate+nitrite (ug*L $^{-1}$)	50.0	67.2	75.0	76.7	78.8	64.4	65.6	60.6	82.9	71.0	68.7	59.3	73.0	101.2	103.8	90.7	78.8	*74.6*
Total - N (ug*L $^{-1}$)	48.9	124.8	128.2	131.3	127.0	132.8	199.9	139.8	150.5	168.9	134.5	129.2	151.4	207.2	162.1	167.8	184.2	*146.4*
Reactive Silicon (ug*L $^{-1}$)	1,199	966	1,124	843	1,073	883	1,029	976	1,073	834	1,159	1,082	1,209	1,188	1,144	1,074	1,199	*1062*
Carbon (ug*L $^{-1}$)		92		136	120	151						111	129	101	110	145	82	*120*
Total Average of Chlorophyll a (ug*L $^{-1}$)	0.23	0.14	0.15	0.20	0.45	0.60	0.91	1.02	1.89	3.47	0.33	0.74	0.27	0.39	0.36	0.88	0.32	*0.73*
Total Average of Phaeophytin a (ug*L $^{-1}$)	0.24	0.13	0.12	0.12	0.21	0.41	0.42	0.34	0.64	0.50	0.24	0.34	0.10	0.14	0.14	0.17	0.10	*0.25*

Table 3. Summary of general water quality parameters, metal concentrations, and nutrient concentrations within the epilimnion (Epi = 1m) and mid-hypolimnion (Hypo) at Virginia Lake, Station A, 2003.

Date	8-May		5-Jun		1-Jul		5-Aug		8-Sep		7-Oct		*avg*	
Depth (m)	1m	Hypo	1m	Hypo	1m	Hypo	1m	Hypo	1m	Hypo	1m	Hypo	*1m*	*Hypo*
pH	6.0	6.3	6.3	6.2	6.2	6.1	6.1	5.6	5.7	6.0	6.2	6.0	*6.1*	*6.0*
Conductivity (umhos/cm)	26	25	25	27	23	27	25	28	23	29	25	28	*24.5*	*27.3*
Alkalinity (mg/L)	10.7	10.2	10.4	11.2	8.0	10.6	10.5	10.2	9.0	11.3	9.5	10.0	*9.7*	*10.6*
Turbidity (NTU)	1.0	0.7	0.6	0.4	0.2	0.3	0.3	0.4	0.7	0.4	0.9	0.5	*0.6*	*0.5*
Color (Pt units)	12	14	10	13	11	13	11	17	19	13	15	14	*13.0*	*14.0*
Calcium (ug/L)	4.2	4.1	4.1	4.2	3.5	4.3	4.1	4.3	3.5	4.2	3.8	4.1	*3.9*	*4.2*
Magnesium (mg/L)	0.4	0.4	0.3	0.4	0.3	0.3	0.3	0.3	0.4	0.6	0.4	0.4	*0.4*	*0.4*
Iron (ug/L)	84	119	51	84	46	112	56	120	68	147	76	132	*63.5*	*119.0*
Total-P (ug/L P)	2.6	2.6	2.2	3.1	2.9	5.1	1.9	2.8	5.6	3.0	3.0	3.5	*3.0*	*3.4*
Total filterable-P (ug/L P)	3.8		1.6	2.3	2.7	1.9	1.6	2.3	1.5	2.1	1.8	2.1	*2.3*	*2.1*
Filterable reactive -P (ug/L P)	1.9		1.0	1.6	2.0	1.5	1.2	1.6	1.0	1.5	1.3	1.6	*1.4*	*1.6*
Total Kjeldahl N (ug/L N)	110.0	109.0	90.0	103.0	77.0	107.0	112.0	111.0	113.0	96.0	112.0	125.0	*102.3*	*108.5*
Ammonia (ug/L N)	3.1	3.8	1.7	0.9	5.2	8.0	4.4	8.5	1.7	2.7	1.7	1.7	*3.0*	*4.3*
Nitrate+nitrite (ug/L N)	119.0	120.0	60.0	85.0	46.0	116.0	27.0	92.0	38.0	103.0	42.0	97.0	*55.3*	*102.2*
Total - N (ug/L N)	229.0	229.0	150.0	188.0	123.0	223.0	139.0	203.0	151.0	199.0	154.0	222.0	*157.7*	*210.7*
Reactive silicon (ug/L Si)	1,249	1,310	1,084	1,263	972	1,323	1,060	1,235	1,112	1,328	1,182	1,269	*1109.8*	*1288.0*
Carbon (ug/L C)	94	73	113	38	76	94	88	79	85	60	88	91	*90.7*	*72.5*

Table 4. Summary of algal pigment concentrations (µg · L^{-1}) of chlorophyll *a* (Chl *a*) and phaeophytin *a* (Phaeo *a*) at Virginia Lake, Station A, 1992-2003. Depths are: 1 = 1 meter, MEU = mid-euphotic zone, EZD = euphotic zone, HYP = mid-hypolimnion.

		1992		1993		1994		1995		1996		1997		1998		1999		2000		2001		2002		2003		*avg*	
Month	Depth	Chl a	Phaeo a	Chl a	Phaeo a	Chl a	Phaeo a	Chl a	Phaeo a	Chl a	Phaeo a	Chl a	Phaeo a	Chl a	Phaeo a	Chl a	Phaeo a	Chl a	Phaeo a	Chl a	Phaeo a	Chl a	Phaeo a	Chl a	Phaeo a	Chl a	Phaeo a
Apr	1	0.43	0.16			0.3	0.13																			0.37	0.15
	MEU	0.38	0.13			0.28	0.15																			0.33	0.14
	EZD	0.26	0.14			0.18	0.1																			0.22	0.12
	HYP		0.04			0.02	0.05																			0.01	0.05
May	1			0.17	0.12			0.31	0.12	0.28	0.17	0.45	0.26			0.16	0.02	0.32	0.21	0.13	0.02	0.33	0.11	0.7	0.18	0.32	0.13
	2							0.32	0.12	0.24	0.17	0.45	0.29			0.54	0.09	0.33	0.22					0.51	0.18	0.40	0.18
	MEU			0.19	0.09			0.34	0.12	0.27	0.17	0.45	0.26			0.36	0.15	0.27	0.14	0.19	0.07	0.07	0.04	0.39	0.01	0.28	0.12
	EZD			0.09	0.05			0.31	0.11	0.03	0.09	0.35	0.26			0.19	0.05	0.11	0.09	0.14	0.08	0.06	0.04	0.03	0.05	0.15	0.09
	HYP			0.02	0.03			0.03	0.04	0.25	0.18	0.33	0.24			0	0.02	0.02	0.05	0.01	0.09	0.05	0.04	0.01	0.04	0.08	0.08
Jun	1	0.84	0.47	1.2	0.38	3.57	0.03	1.8	0.47	6.36	1.26	0.16	0.09	0.19	0.2	0.54	0.24	0.38	0.12	0.93	0.11			0.1	0.04	1.34	0.28
	2					2.58	0.15							0.38	0.33											1.48	0.24
	MEU	1.01	0.46	0.76	0.43	2.56	0.54	0.96	0.46	6.91	1.44	0.41	0.2	0.88	0.71	0.57	0.15	0.56	0.11	0.81	0.15			0.87	0.09	1.36	0.40
	EZD	0.66	0.35	0.48	0.37	2.76	0.56	0.93	0.36	7.09	1.16	0.48	0.27	2.06	1.5	0.48	0.12	0.27	0.15	0.28	0.07			0.55	0.08	1.34	0.42
	HYP	0.01	0.08			0.03	0.06	0.03	0.05	0.09	0.07	0.23	0.15	0.04	0.08	0.02	0.04	0.02	0.06	0.10	0.47			0.02	0.03	0.05	0.10
Jul	1	1.06	0.52	6.24	1.73	0.47	0.64	1.63	0.35	2.8	0.95	0.26	0.17	1.81	0.6	0.19	0.12	0.59	0.17	0.64	0.12	1.89	0.05	0.09	0.08	1.61	0.50
	2							1.56	0.39			0.23	0.17	2.23	0.32	0.34	0.2					1.81	0.37	0.14	0.05	1.05	0.25
	MEU	1.24	0.85	0.99	0.61	0.47	0.5	1.97	0.88	1.99	0.83	0.29	0.25	3.14	0.05	0.23	0.09	0.79	0.13	0.43	0.12	1.92	0.15	0.23	0.1	1.14	0.38
	EZD	0.72	1.21	3.59	0.62	1.04	1.04	3.93	3.3	1.55	1.05	0.52	0.46	0.63	0.46	0.43	0.09	1.53	0.36	0.25	0.14	0.90	0.07	0.06	0.06	1.26	0.74
	HYP	0.08	0.14	0.09	0.12	0.13	0.15	0.23	0.24	0.39	0.23	0.15	0.08	0.1	0.17	0.05	0.08	0.03	0.07	0.02	0.07	0.02	0.03	0.01	0.02	0.12	0.12
Aug	1	1.13	0.99	1.14	0.87	2.15	0.73	1.83	0.44	3.59	0.7	0.38	0.27	0.29	0.19	0.12	0.11	0.76	0.16	0.03	0.09	1.37	0.11	0.53	0.16	1.11	0.40
	2					1.86	0.59	2.09	0.57	3.35	0.6			0.55	0.4	0.1	0.03	0.69	0.12	0.56	0.14	1.24	0.16	0.24	0.06	1.19	0.33
	MEU	1.25	1.11	0.76	0.69	1.82	0.51	1.9	0.7	2.87	0.63	0.52	0.39	0.25	0.23	0.35	0.09	0.63	0.14	0.41	0.18	1.66	0.05	0.43	0.26	1.07	0.42
	EZD	1.71	1.34	1.48	0.77	1.47	0.49	1.37	0.71	2.26	1.29	0.62	0.47	0.24	0.16	0.29	0.28	0.48	0.16	0.33	0.19	6.08	1.64	0.41	0.27	1.40	0.65
	HYP	0.05	0.23	0.22	0.27	0.55	0.39	0.1	0.22	0.35	0.31	0.12	0.14	0.03	0.09	0.04	0.05	0.14	0.32	0.70	0.17	0.17	0.11	0.11	0.05	0.22	0.20
Sep	1	0.5	0.19	0.37	0.21	0.82	0.34	6.3	1.33	9.82	0.01	0.34	0.29	0.55	0.32	0.49	0.1	0.13	0.09	0.62	0.17	0.51	0.05	0.44	0.07	1.74	0.26
	2					0.88	0.36			12.71	0.21	0.31	0.28	0.69	0.38	0.51	0.12			0.76	0.16			0.01	0.03	2.27	0.22
	MEU	0.63	0.31	0.34	0.19	1.06	0.2	7.2	0.42			0.43	0.31	0.43	0.31	0.68	0.16	0.51	0.1	1.04	0.25	0.63	0.16	0.41	0.14	1.21	0.23
	EZD	0.48	0.29	0.48	0.36	1.76	0.74	9.21	3.06	11.23	0.5	0.21	0.26	0.28	0.11	0.24	0.11	0.39	0.26	0.40	0.20	0.23	0.13	0.01	0.03	2.08	0.50
	HYP	0.05	0.19	0.01	0.4	0.16	0.19	0.42	0.46	0.17	0.12	0.05	0.07	0.04	0.09	0.02	0.03	0.01	0.03	0.03	0.10	0.03	0.05	0.2	0.11	0.10	0.15
Oct	1	0.19	0.15	0.23	0.35	0.24	0.13	2.36	0.87	5	0.28					0.23	0.06	0.56	0.13	0.18	0.09	0.24	0.06	1.45	0.21	1.07	0.23
	2							2.15	0.77							0.19	0.12									1.17	0.45
	MEU	0.22	0.14			0.23	0.13	1.8	0.76	5.05	0.36					0.14	0.09	0.31	0.13	0.22	0.08	0.14	0.10	0.56	0.19	0.96	0.22
	EZD	0.19	0.13	0.18	0.31	0.16	0.14	1.69	0.62	0.24	0.1					0.18	0.1	0.16	0.11	0.19	0.09	0.09	0.06	0.15	0.09	0.34	0.16
	HYP	0.03	0.12	0.08	0.24	0.04	0.07	0.17	0.15	5.22	0.01					0.02	0.04	0.03	0.06	0.07	0.10	0.02	0.05	0.23	0.03	0.65	0.07
avg	1	*0.69*	*0.41*	*1.56*	*0.61*	*1.26*	*0.33*	*2.37*	*0.60*	*4.64*	*0.56*	*0.32*	*0.22*	*0.71*	*0.33*	*0.29*	*0.11*	*0.46*	*0.15*	*0.42*	*0.10*	*0.87*	*0.08*	*0.55*	*0.14*	1.20	0.30
	2	*0.00*	*0.00*	*0.00*	*0.00*	*1.77*	*0.37*	*1.53*	*0.46*	*5.43*	*0.33*	*0.33*	*0.25*	*0.96*	*0.36*	*0.34*	*0.11*	*0.51*	*0.17*	*0.66*	*0.15*	*1.53*	*0.27*	*0.23*	*0.06*	1.26	0.28
	MEU	*0.79*	*0.50*	*0.57*	*0.38*	*1.07*	*0.34*	*2.36*	*0.56*	*3.42*	*0.69*	*0.42*	*0.28*	*1.18*	*0.33*	*0.39*	*0.12*	*0.51*	*0.13*	*0.52*	*0.14*	*0.88*	*0.10*	*0.48*	*0.14*	1.00	0.29
	EZD	*0.67*	*0.58*	*1.04*	*0.41*	*1.23*	*0.51*	*2.91*	*1.36*	*3.73*	*0.70*	*0.44*	*0.34*	*0.80*	*0.56*	*0.30*	*0.13*	*0.49*	*0.19*	*0.27*	*0.13*	*1.47*	*0.39*	*0.20*	*0.10*	1.09	0.43
	HYP	*0.04*	*0.13*	*0.08*	*0.21*	*0.16*	*0.15*	*0.16*	*0.19*	*1.08*	*0.15*	*0.18*	*0.14*	*0.05*	*0.11*	*0.03*	*0.04*	*0.04*	*0.10*	*0.16*	*0.17*	*0.06*	*0.06*	*0.10*	*0.05*	0.20	0.12

Table 5. Seasonal mean macrozooplankton density and weighted mean biomass distribution at Virginia Lake, 2003.

Species		Date						Mean Density		Weighted Mean Biomass	
		8-May	**5-Jun**	**1-Jul**	**5-Aug**	**8-Sep**	**7-Oct**	n · m^{-2}	Percent	(mg. · m^{-2})	Percent
Copepoda											
Diaptomus	Density (No. · m^{-}	4,678	4,611	51,622	4,186	425	382	10,984	28.7%	158.0	75.8%
	Size (mm)	0.92	1.10	1.61	1.72	1.81	1.82				
Diaptomus-ovig.	Density (No. · m^{-2})				1384	221	179	297	0.8%	8.0	3.9%
	Size (mm)			2	1.93	1.90	1.86				
Cyclops	Density (No. · m^{-}	6,954	42,147	22,033	15,130	2,751	5,578	15,765	41.2%	25.0	12.0%
	Size (mm)	0.57	0.60	0.66	0.80	0.89	0.94				
Cyclops-ovig.	Density (No. · m^{-}	51		170	136	43	280	113	0.30%	0.5	0.2%
	Size (mm)	0.99		1.06	0.90	1.13	1.16				
Total Copepoda	Density (No. · m^{-}	11,683	46,758	73,825	20,836	3,440	6,419	27159	71.0%	191.5	91.9%
Cladocera											
Bosmina	Density (No. · m^{-}	6,003	6,529	18,212	6,631	6,097	9,552	8,837	23.1%	13.5	6.5%
	Size (mm)	0.43	0.36	0.41	0.43	0.40	0.42				
Bosmina-ovig.	Density (No. · m^{-}	51	102	298	238	493	1,605	464	1.2%	1.2	0.6%
	Size (mm)	0.54	0.47	0.49	0.47	0.46	0.54				
Chydorinae	Density (No. · m^{-}	94	221	3,269	1,851	1,274	535	1207	3.2%	1.3	0.6%
	Size (mm)	0.35	0.35	0.35	0.34	0.34	0.36				
Chydorinae-ovig.	Density (No. · m^{-2})		204	679	77	68		171	0.4%	0.2	0.1%
	Size (mm)		0.39	0.37	0.39	0.38					
	Density (No. · m^{-2})		1426					238	0.6%	0.60	0.3%
	Size (mm)		0.54								
	Density (No. · m^{-}	68	951					170	0.4%	0.23	0.1%
	Size (mm)	0.78	0.55								
Total Cladocera	Density (No. · m^{-}	6,216	9,433	22,458	8,797	7,932	11,692	11,087	29.0%	17.0	8.1%
Total Plankters	Density (No. · m^{-}	17,899	56,191	96,283	29,633	11,372	18,111	38,246		208.4	

Table 6. Fall total limnetic fish population and sockeye salmon fry population estimates at Virginia Lake, 1989-2002.

Year	Total Limnetic Fish Population	Sockeye Fry Population[a]	m^3 per Sockeye Fry	Total Limnetic Fish Population Reanalyzed, March 2004 [c]	SE
1989[b]	282,147	270,128	262		
1990[b]	138,800	138,800	509		
1991[b]	121,000	121,000	584		
1992[b]	150,250	127,562	554		
1993[b]	no fall survey				
1994[b]	no fall survey				
1995[b]	312,966	312,966	226		
1996[b]	no fall survey				
1997	109,539	109,539	645	113,913	9,271
1998	102,220	102,220	692	110,266	15,814
1999	115,592	115,592	612	87,870	19,806
2000	168,571	168,571	419	173,054	15,937
2001	55,000	55,000	1,285	83,079	6,791
2002	68,000	32,000	2,209	113,139	17,943

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

[b] Fry stocked in lake.

[c] Data was reanalyzed in March 2004 by Malcom McEwen of ADF&G using methods outlined in Hydroacoustics Lake Survey Procedures Manual for Southeast Alaska (*in prep*.).

Table 7. Historical phosphorus applications and levels at Virginia Lake, 1986-2002.

Year	1986	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Target fertilization level based on previous years October P level					64%	60%	50%	49%	66%	64%	0%	47%	69%	60%	50%	61%
Actual fert level % based actual May P level					34%	38%	59%	62%	50%	49%	0%	51%	77%	48%	46%	65%
October P level [a/]			3.6	5.5	4.6	3.2	2.9	4.2	4.0	3.5	3.0	5.4	4.5	3.9	3.3	5.2
May P level [b/]			5.8	5.2	2.5	2.4	4.1	4.2	2.6	2.5	3.5	3.4	6.1	3.3	3.5	3.7
Liquid 20-5-0 applied (gallons)					2,640	4,320	5,490	6,060	7,440	7,290	0	5,280	0	0	3,360	8,640
Liquid 32-0-0 applied (gallons)					1,080	0	2,000	2,220	0	0	0	0	2,700	2,590	0	0
Solid CRF applied (lbs) [c/]					0	0	0	0	0	0	0	0	6,200	6,000	0	2,840
Total phosphorus applied (lbs)					610	998	1,268	1,400	1,719	1,684	0	1,220	1,097	1,062	776	2,368
Number of weeks applied					14.0	13.3	13.3	13.0	12.9	15.9	0.0	16.1	16.6	17.0	16.4	16.9
Average lbs per wk of phosphorus applied					43	75	95	107	133	106	0	75	37	35	47	140
Average summer P level	2.2	4.9	4.4	5.1	4.1	5.0	9.5	5.5	4.6	5.4	2.6	4.2	5.3	3.5	4.2	7.0

[a/] all October P values were collected in October except in 1993, 1997 and 1998 which were collected in early September.

[b/] all May P values were collected in May except 1992 and 1994 which were late April and 1998 which was collected in June.

[c/] 1999 and 2000 consisted of 8-24-8 fertilizer and 2002 consisted of 16-30-0 fertilizer

FIGURES

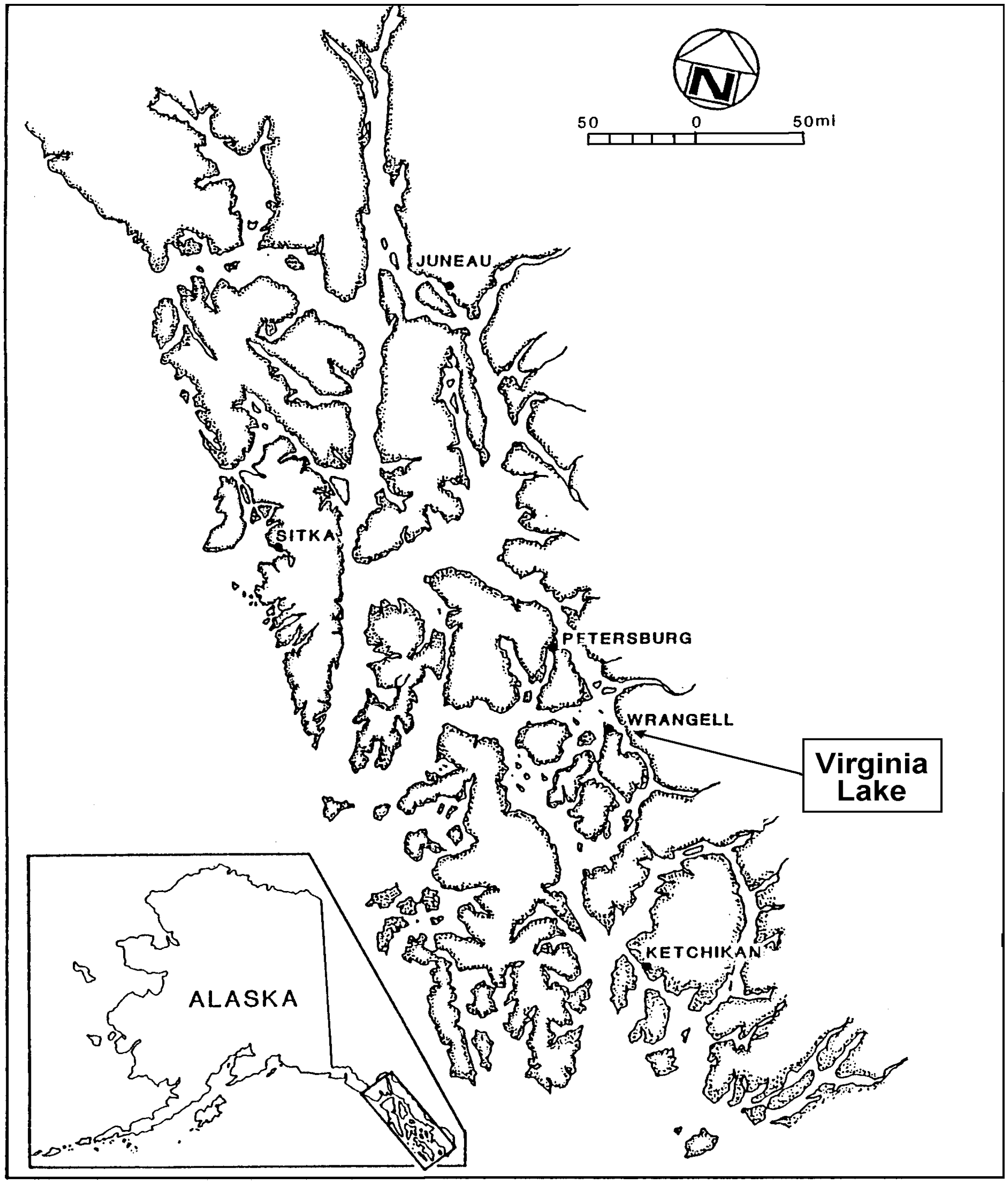

Figure 1. The geographic location of Virginia Lake, within the State of Alaska, and relative to cities within Southeast Alaska.

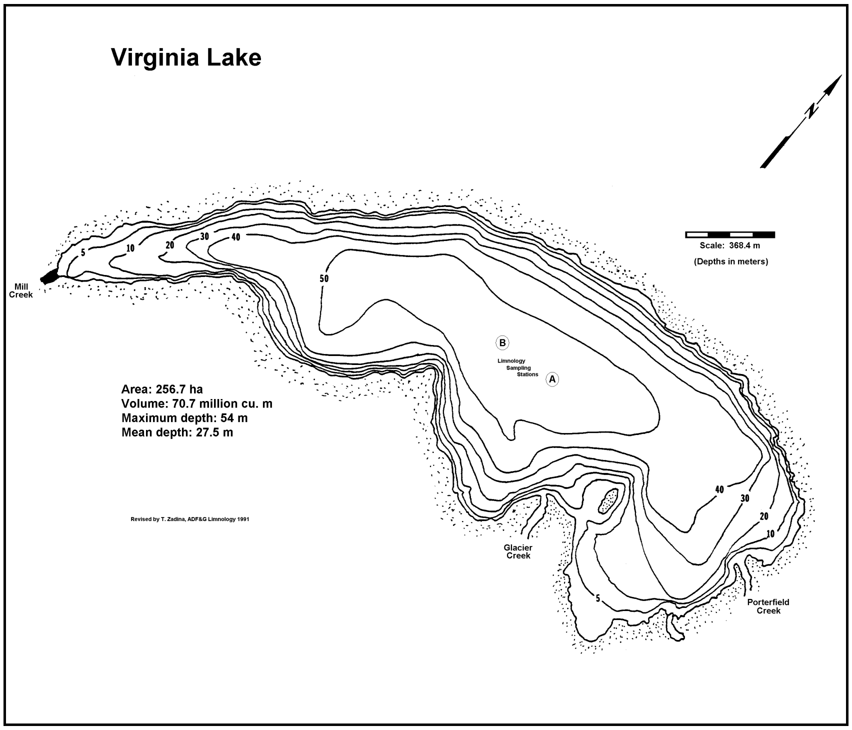

Figure 2. Bathymetric map of Virginia Lake, Southeast Alaska with limnology sampling stations.

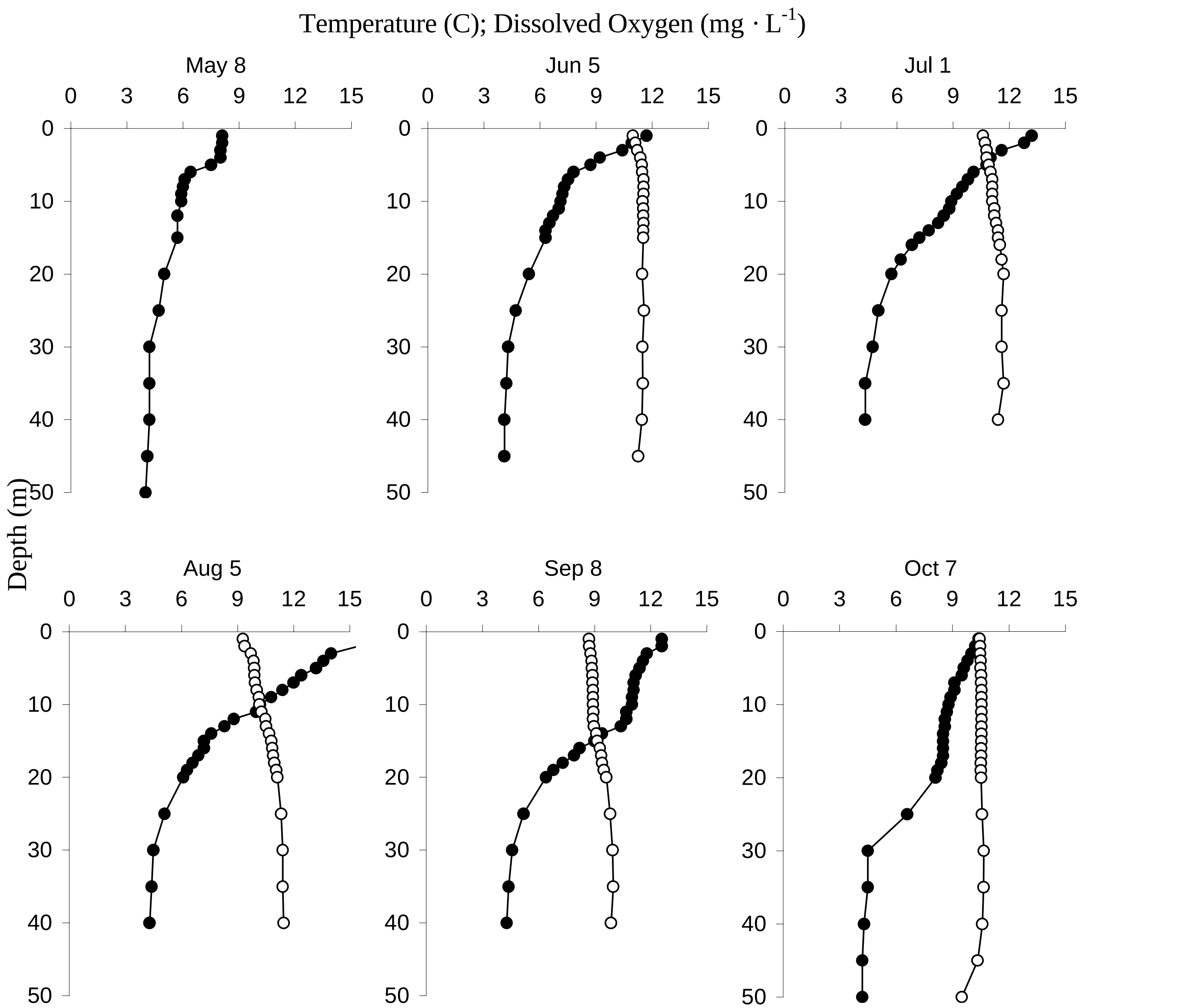

Figure 3. Seasonal temperature (C; closed circles) and dissolved oxygen (mg · L^{-1}; open circles) profiles in Virginia Lake, 2003.

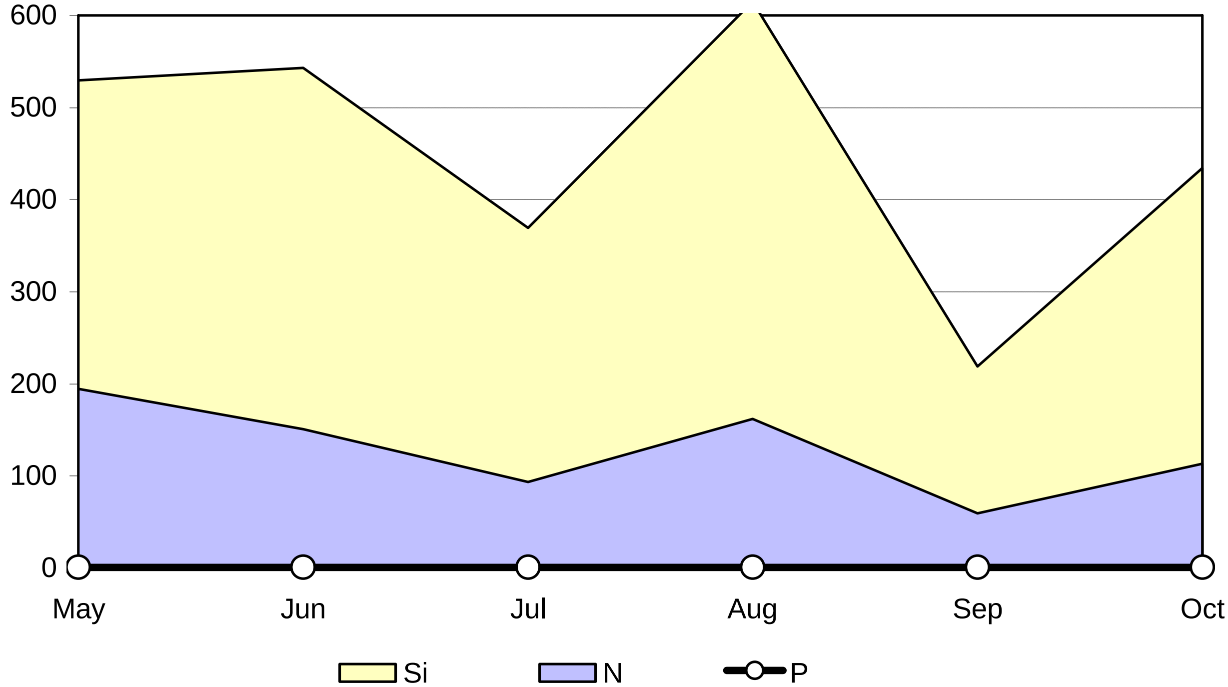

Figure 4. Monthly atomic concentration ratios of nitrogen (N), phosphorus (P; where P=1), and reactive silicon (Si) in the epilimnion at Virginia Lake, 2003.

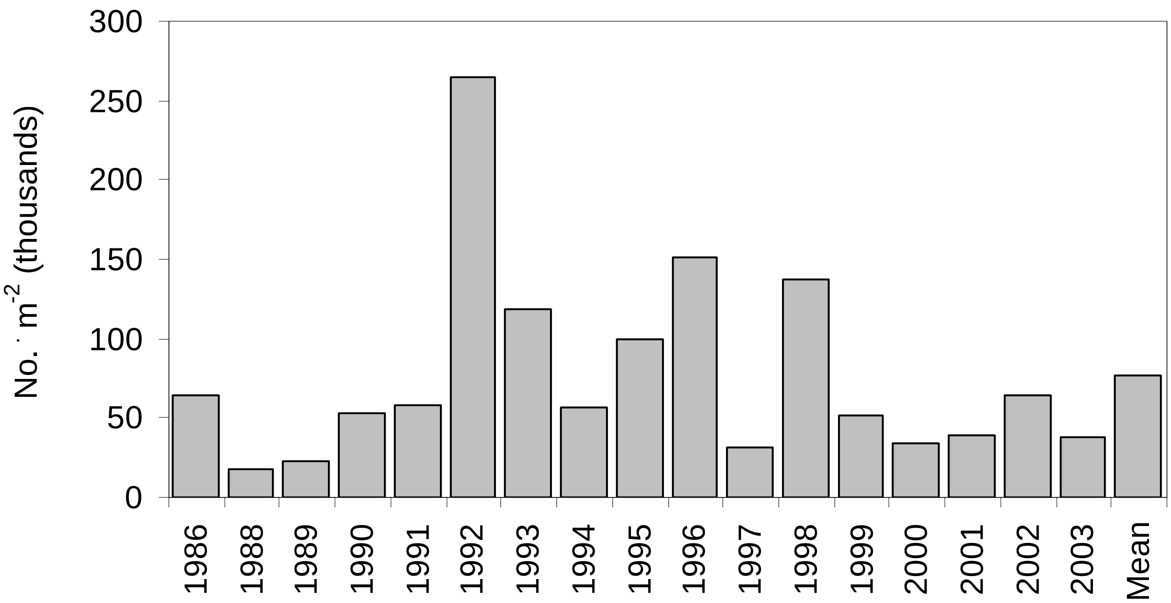

Figure 5. Mean seasonal macrozooplankton density at Virginia Lake, from 1986 to 2003, and for the 17-year mean.

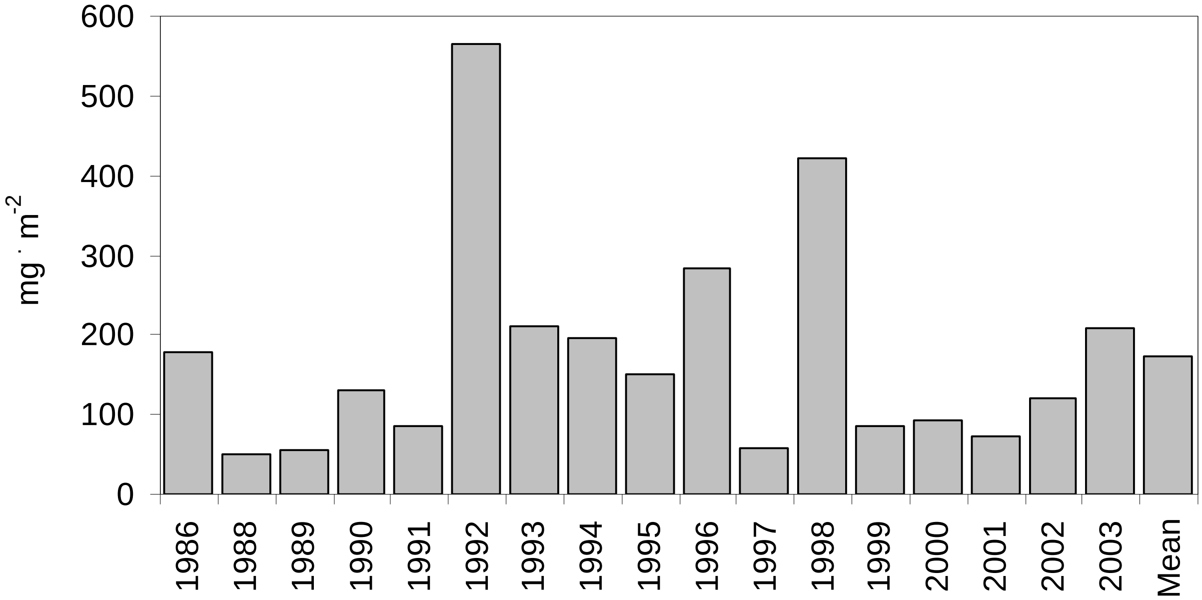

Figure 6. Mean seasonal macrozooplankton biomass at Virginia Lake from 1986 to 2003, and for the 17-year mean.

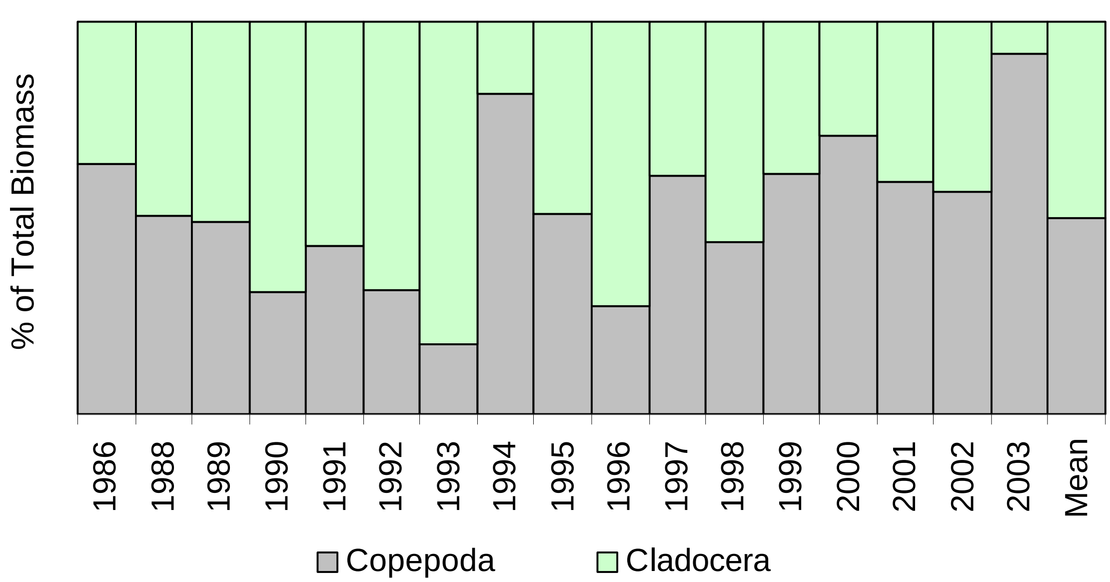

Figure 7. Mean seasonal macrozooplankton biomass distribution by plankter order at Virginia Lake, from 1986 to 2003, and for the 17-year mean.

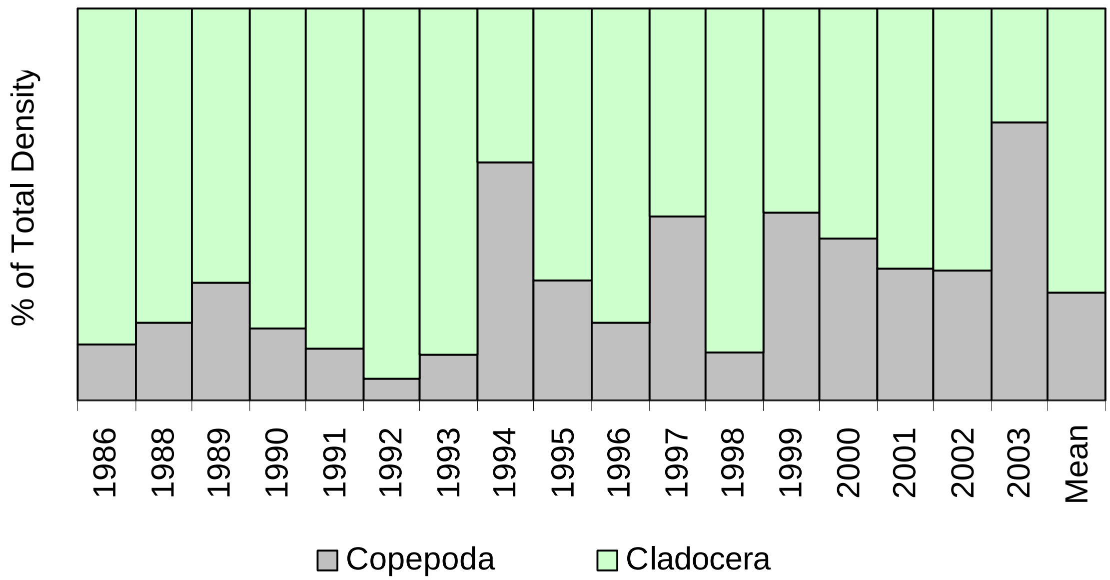

Figure 8. Mean seasonal macrozooplankton density distribution by plankter order at Virginia Lake, from 1986 to 2003, and for the 17-year mean.

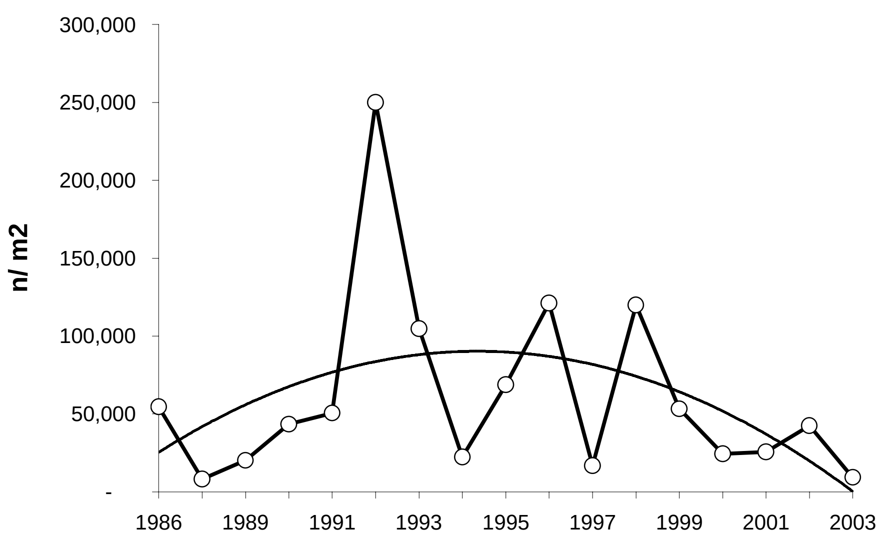

Figure 9. Bosmina densities per m^2 at Virginia Lake, from 1986-2003. A quadratic regression is used to show the trend.

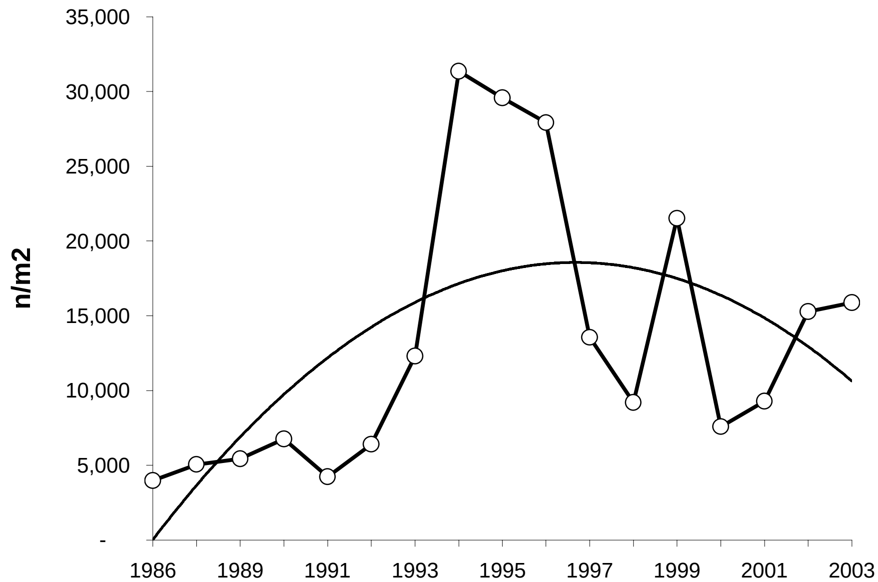

Figure 10. Cyclops densities per m^2 at Virginia Lake, from 1986-2003. A quadratic regression is used to show the trend.

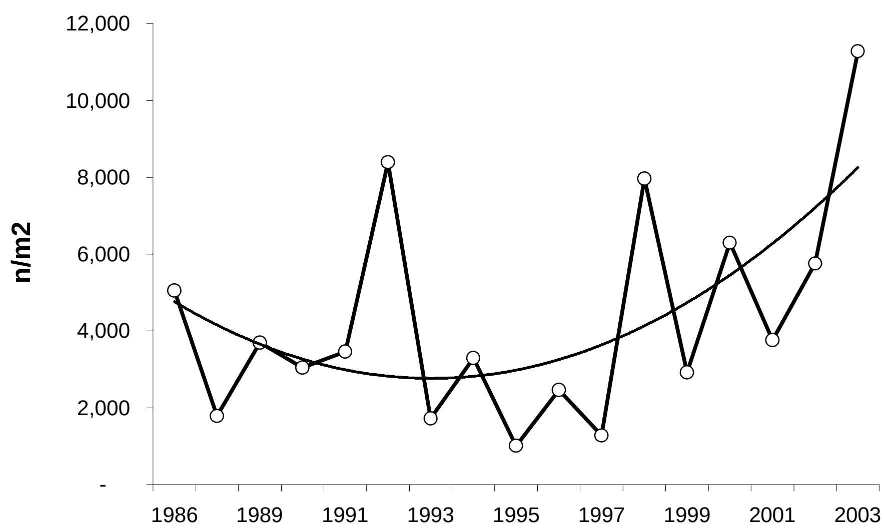

Figure 11. *Diaptomus* densities per m^2 at Virginia Lake, from 1986-2003. A quadratic regression is used to show the trend.

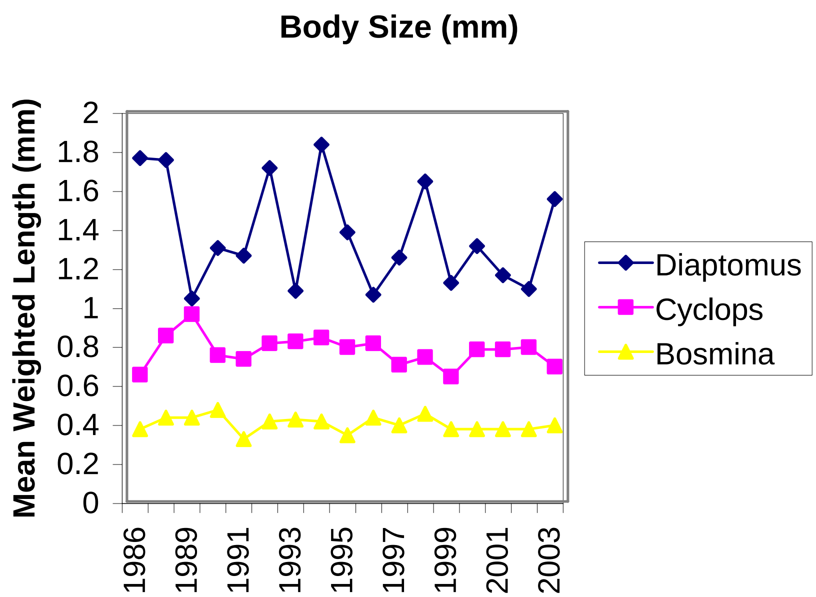

Figure 12. Seasonal mean weighted length of 3 primary macrozooplankton species at Virginia Lake, Station A, 1986-2003.

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