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ABSTRACT

A cooperative plan was developed by the U. S. Forest Service, Alaska Department of Fish and Game, and Southern Southeast Regional Aquaculture Association to develop a natural sockeye salmon (*Oncorhynchus nerka*) run into Virginia Lake. In 1988, a fishpass was installed in the outlet of Virginia Lake in order to allow unimpeded passage of adult salmon into the lake. In April 1989, ~1.9 million juvenile sockeye fry were outplanted into Virginia Lake. However, freshwater survivals were much lower than expected and were attributed to insufficient forage (zooplankton) during the time of early-spring release. As a result, in 1990 the number of outplants was reduced to ~888,000 fry and the release was delayed until May when zooplankton populations were more abundant. With the lower fry densities and more favorable rearing conditions, freshwater survivals tripled, but remained below expectations. In addition, limnological studies were initiated in 1988 and indicated Virginia Lake to be nutrient poor; and as a result, primary production (chlorophyll a) and zooplankton biomass were low. The lower than expected fry-to-smolt survivals were attributed to asynchrony between peak zooplankton levels and timing of the fry release and a low forage base. Thus, because current productivity is low and a desire exists to stock sockeye salmon fry in Virginia Lake, a nutrient enrichment project is recommended to increase the forage base for rearing sockeye juveniles.

INTRODUCTION

A natural barrier on the outlet of Virginia Lake prevented the migration of anadromous fish, except during times of unusually high water levels. Consequently, a cooperative plan was developed in 1987 among the U.S. Forest Service (USFS), the Division of Fisheries Rehabilitation, Enhancement and Development (FRED) of the Alaska Department of Fish and Game (ADF&G), and the Southern Southeast Regional Aquaculture Association (SSRAA) to develop a natural run of sockeye salmon into Virginia Lake. In 1988, the USFS installed a fishpass in the outlet of Virginia Lake in order to allow unimpeded passage of adult salmon into the lake. In turn, ADF&G and SSRAA initiated a fry stocking program in 1989 based on the euphotic volume model developed by Koenings et al. (1989), in conjunction with baseline limnological studies.

Limited limnological studies in 1986 and 1988 showed Virginia Lake to be a very nutrient poor system with a fairly rapid flushing rate. As a result, primary productivity levels and zooplankton biomass were lower than expected, and the increased planktivory resulting from the juvenile outplants further reduced the rearing capacity for sockeye salmon juveniles. Consequently, continuation of stocking under existing forage conditions offered little enhancement opportunities for Virginia Lake. It has been demonstrated that increasing lake fertility through nutrient enrichment techniques provides more food for rearing sockeye fry, resulting in larger numbers of smolts and ultimately an increase in the number of returning adults (LaBrasseur et al. 1978; Shortreed and Stockner 1981; Koenings and Burkett 1987; Koenings et al. 1989; Burkett et al. 1989). This report summarizes the results of the 1989 and 1990 fisheries and limnological investigations conducted at Virginia Lake, and provides further recommendations regarding fry stocking, lake fertilization, and limnological and fishery investigations.

Study Site Description -- Virginia Lake (56°20"N, 132°10"W) located ~ 15 km east of the City of Wrangell lies within the Tongass National Forest at an elevation of 32 m (Figure 1). The lake outlet (Mill Creek) is <1 km in length and empties into the Eastern Passage of Sumner Strait. Virginia Lake has a surface area of 2.57×10^6 m^2 (634 acres), a mean lake depth of 27.5 m, a maximum depth of 54 m, and a total volume of 70.7×10^6 m^3 (Figure 2). Mean annual precipitation is an estimated 280 cm (U.S.D.A. 1979), and as the lake watershed area encompasses ~ 83 km^2, the hydraulic residence time or flushing rate is an estimated 0.35 yr. Resident fish species include sockeye salmon, cutthroat trout (*Oncorhynchus clarki*), Dolly Varden (*Salvelinus malma*), kokanee, stickleback (*Gasterosteus aculeatus*) and cottids (*Cottidae* sp.).

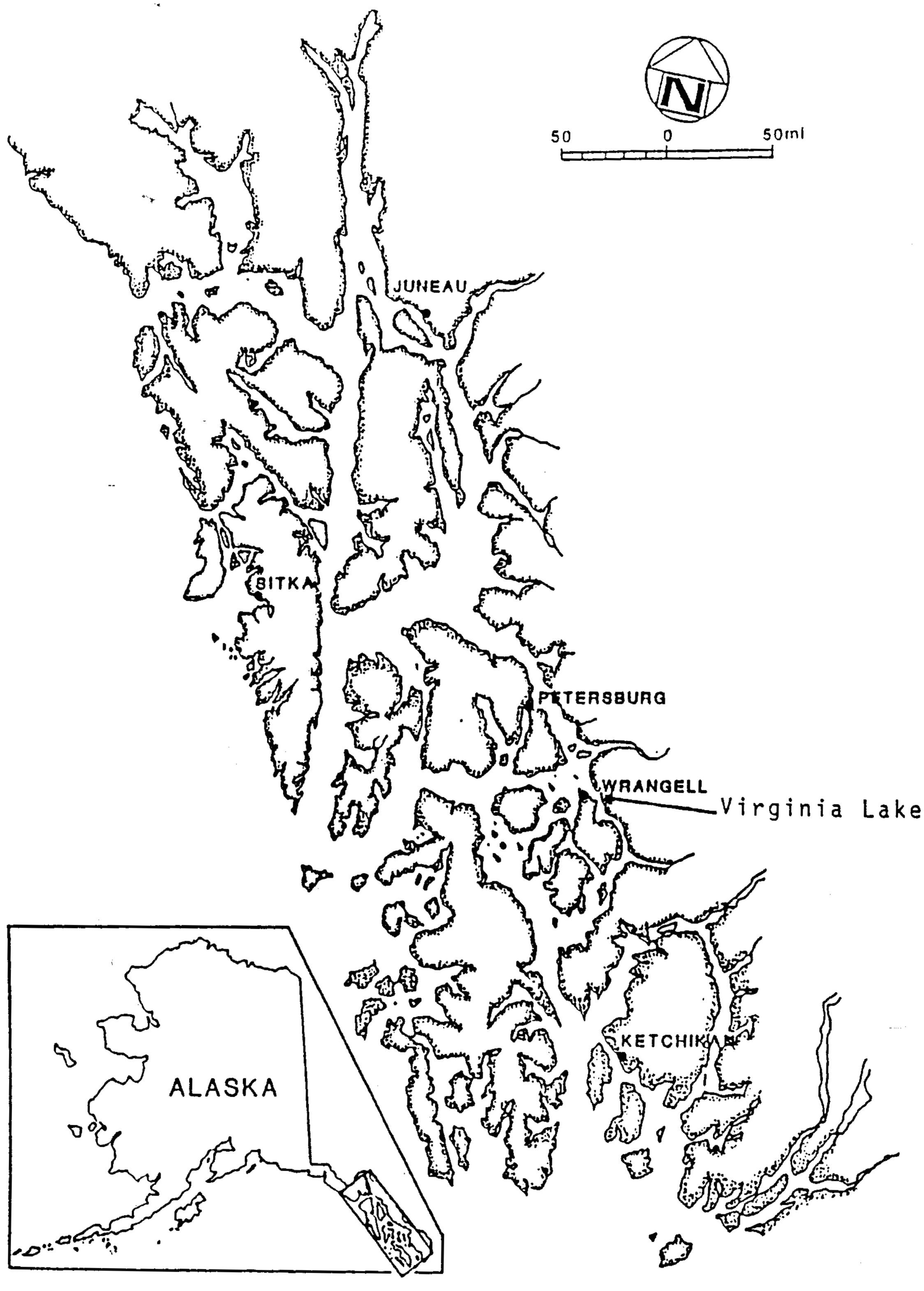

Figure 1. Geographic location of Virginia Lake relative to to the cities of Wrangell and Ketchikan in southeast Alaska.

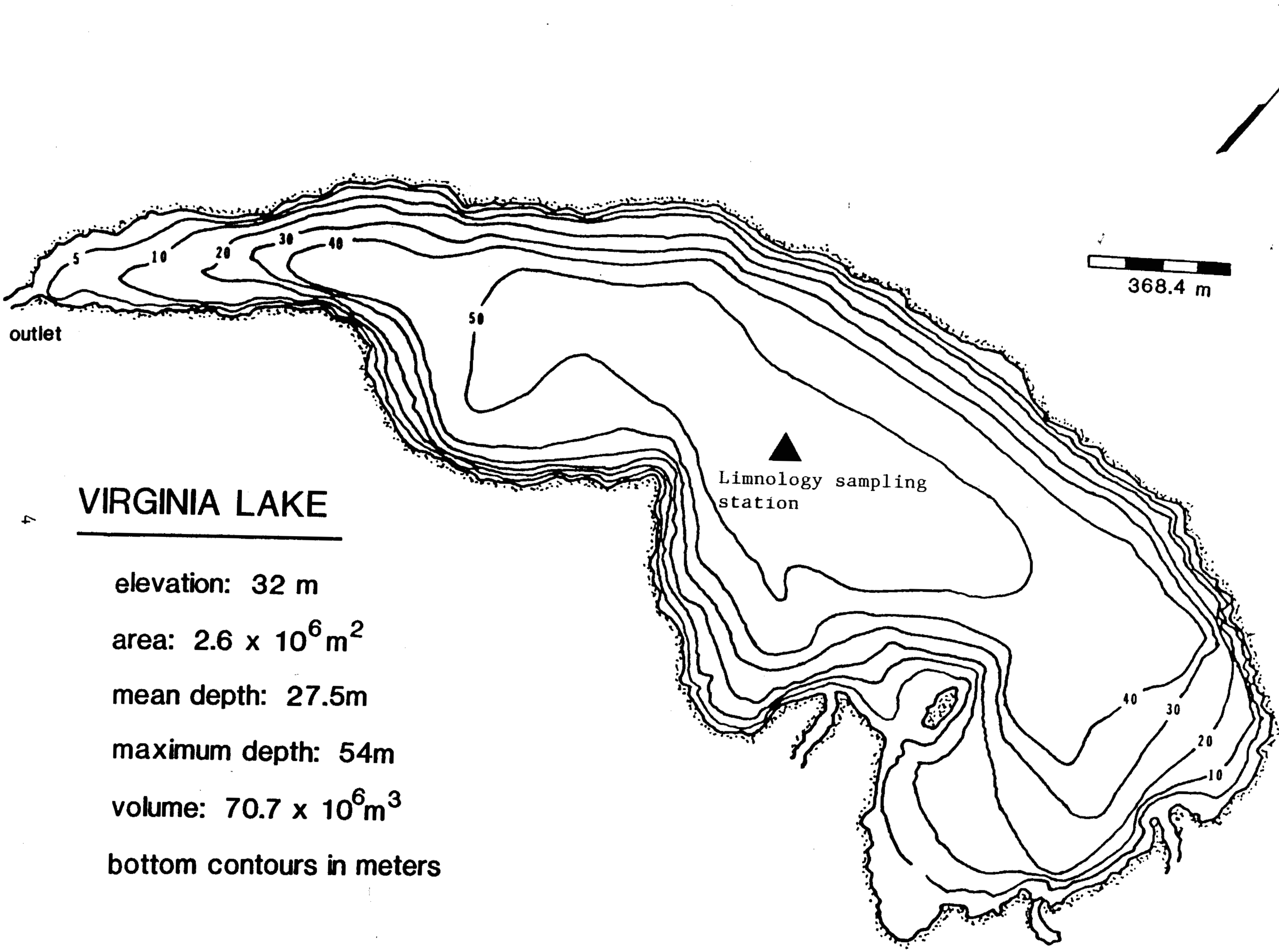

Figure 2. Morphometric map of Virginia Lake showing the location of the limnological sampling station.

METHODS AND MATERIALS

Limnological Sampling

Limnological sampling was conducted at Virginia Lake by ADF&G and USFS personnel during May through November of 1989 and 1990 at a single mid-lake station (Figure 2). In addition to obtaining physical data (e.g., light penetration, temperature profiles and dissolved oxygen levels), water-quality and biological samples were collected and analyzed by the ADF&G Limnology Laboratory in Soldotna, Alaska.

Physical Parameters -- Measurements of light penetration (footcandles) were recorded at 0.5-m intervals from the surface to a depth equivalent to 1% of the subsurface light reading using a Protomatic® submarine photometer. The euphotic zone depth (EZD), the depth to which 1% of the subsurface light [photosynthetically available radiation (400-700 nm)] penetrates (Schindler 1971), was calculated as the y-intercept derived by regressing depth against the logarithm (ln) of the percent subsurface light. Euphotic volume (EV) is the product of the euphotic zone depth (EZD) and the lake surface area and represents the volume of water capable of photosynthesis. In addition, the vertical attenuation coefficient (K_d; light retained per meter) was calculated as the reciprocal of the regression slope (Koenings et al. 1987). Secchi disk (SD) transparency was determined by recording the depths at which the disk becomes invisible upon descent and visible upon ascent. Temperatures and dissolved oxygen levels were recorded at 1-m intervals from the lake surface to the bottom or to a maximum depth of 50 m using a YSI model-57 meter.

Water Quality -- Water-quality samples were collected from the epilimnion at the 1-m depth and the mid-hypolimnion using a Van Dorn sampler. Eight-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

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were: 1) refrigerated for general tests and metals; 2) frozen for nitrogen and phosphorus analyses; and 3) filtered through a Whatman 4.5-cm GFF glass-fiber filter and frozen for analysis of dissolved nutrients (Koenings et al. 1987).

Phytoplankton -- Samples for the analysis of the algal pigment chlorophyll a (chl a) were prepared by filtering 1-2 L of lake water through a Whatman 4.25-cm GFF glass-fiber filter to which 1-2 ml of 1N magnesium carbonate were added prior to completion. Filters were stored frozen in individual plexiglas holders until analyzed.

Zooplankton -- Replicate bottom-to-surface vertical zooplankton tows were taken using a 0.2-m diameter, 153 um mesh, conical net. The net was pulled at a constant speed (~ 1 m$\cdot$sec^{-1}), rinsed prior to removing the organisms, and all specimens were preserved in neutralized 10% formalin (Koenings et al. 1987).

Laboratory Analysis

General Water Quality -- Conductivity (temperature compensated to 25° C) was measured using a YSI model-32 conductance meter, and the Ph was measured with an Orion 399A ionanalyzer following standard calibrations. Alkalinity was determined by sulfuric acid (0.02N) titration to a Ph of 4.5 (APHA 1985). Turbidity, expressed in nephelometric turbidity units (NTU) was determined using a DRT-100 turbidimeter. Water color was determined on a filtered sample by measuring the spectrophotometric absorbance at 400 nm and converting to equivalent platinum cobalt (Pt) units (Koenings et al. 1987).

Metals -- Calcium and magnesium were determined from separate EDTA (0.01 N) titrations after Golterman (1970). Total iron was determined by reduction of ferric iron with hydroxylamine during hydrochloric acid digestion after Strickland and Parsons (1972).

Nutrients -- Filterable reactive phosphorus (orthophosphate) was determined using the molybdenum-blue method as modified by Eisenreich et al. (1975). Total and total filterable phosphorus utilized the same procedure following acid-persulfate digestion. Estimates of yearly phosphorus (P) loading into Virginia Lake were calculated after Vollenweider (1976):

Surface specific loading:

$$Lp(mgP/m^2/yr) = \frac{[P]^{sp} \times \bar{z}(1 + \sqrt{T_w})}{T_w}$$

Surface critical loading:

$$Lc(mgP/m^2/yr) = \frac{10\ mgP/m^3 \times \bar{z}(1 + \sqrt{T_w})}{T_w}$$

Permissible supplemental P ($mg/m^2/yr$) loading = $L_c \cdot 90\% - L_p$

Where: $[P]^{sp}$ = spring overturn period total P (mg/m^3)
z = mean depth (m)
T_w = water resident time (yr)
10 mgP/m^3 = lower critical phosphorous level.

Total ammonia ($NH_3 + NH^+{}_4$) was determined using the phenolhypochlorite procedure; and nitrate (NO^{-3}) + nitrite ($NO^-{}_2$) were determined as nitrite following cadmium reduction and diazotization with sufanilamide after Stainton et al. (1977). Total Kjeldahl nitrogen (TKN) was determined as ammonia after sulfuric acid block digestion (Crowther et al. 1980). Total nitrogen was calculated as the sum of TKN and nitrate + nitrite. Reactive silicon was determined using the ascorbic acid reduction to molybdenum-blue methodology after Stainton et al. (1977).

Phytoplankton -- Phytoplankton biomass (primary production) was estimated from the algal pigment chlorophyll a (chl a). Chl a was extracted from glass-fiber filters after homogenizing the filters in 90% acetone (Koenings et al. 1987). Chl a concentrations (corrected for inactive phaeophytin) were then determined using the direct fluorometric procedure of Strickland and Parsons (1972) with a dilute acid (0.02 N Hcl) addition after Reimann (1978).

Zooplankton -- *Daphnia* sp. were identified according to Brooks (1957) and copepods were identified after Wilson (1959) and Yeatman (1959). Zooplankton were enumerated from three separate 1-ml subsamples taken with a Hensen-Stemple pipet and placed in a 1-ml Sedgewick-Rafter counting chamber. Zooplankton body sizes from 30 organisms of each species were measured to the nearest 0.01 mm along a transect in each of the 1-ml subsamples using a calibrated ocular micrometer. Zooplankton biomass was estimated using species-specific dry weight vs zooplankter length regression equations (Koenings et al. 1987).

Juvenile Fisheries Assessment

Hydroacoustic Surveys -- Juvenile fish populations and distributions were estimated from hydroacoustic surveys conducted in November 1989, and from surveys conducted in May and October 1990. The May surveys were conducted both prior to and after the spring smolt outmigration. A Simrad EY-M recorder with a 22° wide-beam transducer was used to record downward-looking acoustic data at night along several transects oriented perpendicular to the longitudinal axis of the lake. Fish signals were recorded electronically using a Technics SV-MD1 digital audio (DAT) cassette recording system. Analysis of recorded hydroacoustic tapes followed procedures described by Kyle (1988) and was conducted by Dr. Richard Thorne of BioSonics, Inc.

A 7.5-m long mid-water trawl with a 2 x 2 m opening was used in conjunction with hydroacoustic surveys to determine species composition and age structure of the hydroacoustic population estimates. Fish were preserved in 10% formalin, and measured after complete shrinkage (6 weeks) to the nearest millimeter and weighed to the nearest 0.1 g. In addition, a scale smear was taken from each fish, affixed to a glass slide, and aged using a microfische projector. Fish population estimates were determined by direct proportion from representative trawl samples. The sockeye smolt populations estimated from the pre- and post-emigration hydroacoustic surveys and the age structure was determined from samples of smolts collected by townetting.

RESULTS and DISCUSSION

Limnological Assessment

Light penetration -- During 1988-1989, the euphotic zone depth (EZD) ranged from 5.4 - 10.0 m and averaged 7.6 m (Table 1). In both years, the EZD was deepest in the summer (July - August), shallowest in the fall (October - November), and intermediate in the spring (May). Based on the average EZD (7.6 m), the euphotic volume (EV) of Virginia Lake was estimated at 19.5 x 10^6 m^3 or 19.5 EV units which comprises 28% of the total lake volume. In addition, the vertical attenuation coefficient (K_d) ranged from 0.80-0.44 m^{-1} and averaged 0.61 m^{-1}. Secchi disk (SD) transparency ranged from 3.3-5.3 m and averaged 4.7 m. SD transparencies followed the same seasonal trends as the EZD.

Temperature and Dissolved Oxygen Regimes -- By early May, surface temperatures in Virginia Lake had warmed to 6° C and 7.5° C in 1989 and 1990, respectively (Figures 3A and 3B). During the summer, Virginia Lake exhibited a partial thermocline (stratification) which was more distinct in 1989 compared to 1990. In July (1990) and August (1989) temperatures reached ~15° C near the surface, cooled rapidly between 10 and 20 m to 5° C, and then remained at ~5° C at depths >20 m. Thus, during summer stratification the surface to ~10 m stratum was defined as the epilimnion which comprised 33% of the total lake volume. The thermocline extended from ~10 to 20 m, and the hypolimnion was formed at depths >20 m. Finally, by late October-November Virginia Lake was isothermal at 5° C.

Dissolved oxygen (D.O.) concentrations ranged between 11 and 13 $mg \cdot L^{-1}$ (85->100% saturation) within the epilimnion, but decreased slightly within the hypolimnion (Figures 3A and 3B). The reduced oxygen levels near the lake bottom were most obvious during the

Table 1. Comparison of Secchi disk (SD) depth, euphotic zone depth (EZD), and vertical attenuation coefficient (K_d) in Virginia Lake during 1989-1990.

Sampling date	Secchi disk depth (m)	Euphotic zone depth (m)	Vertical attenuation coefficient (m^{-1})
05/18/89	4.9	7.7	0.57
08/10/89	5.3	9.2	0.49
11/16/89	4.3	5.8	0.77
05/04/90	5.3	7.5	0.57
07/12/90	4.8	10.0	0.44
10/30/90	3.3	5.4	0.80
Mean	4.7	7.6	0.61

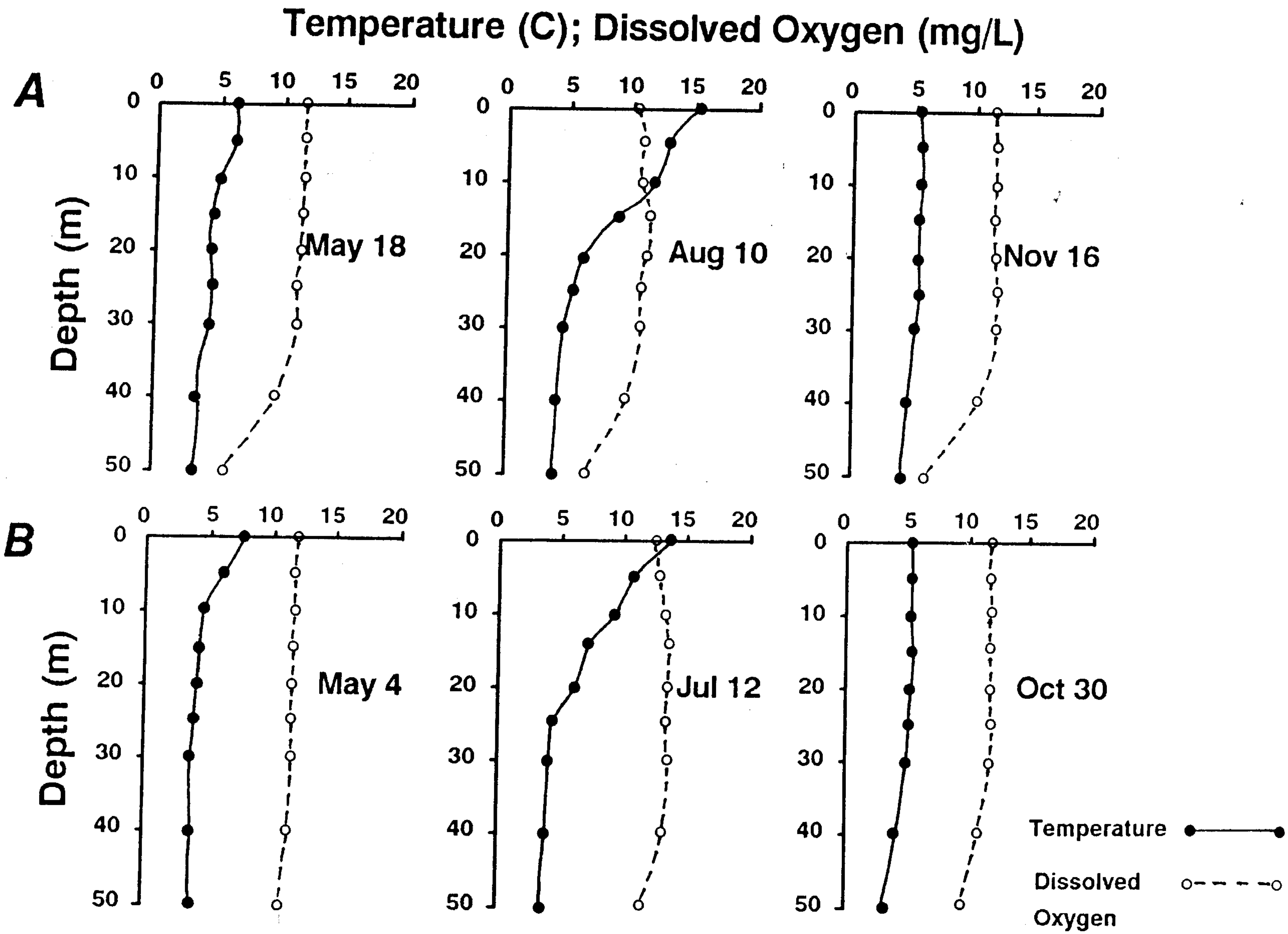

Figure 3. Seasonal temperature (C) and dissolved oxygen (mg/L) profiles in Virginia Lake during (A) 1989 and (B) 1990.

1988 sampling period as concentrations at 50 m dropped to as low as 5.5 $mg \cdot L^{-1}$ (42% saturation); however, the lower D.O. concentrations were confined to only ~1% of the total lake volume and thus, do not represent a serious concern.

General Water Quality -- Virginia Lake is a soft-water system as evidenced by low conductivities ranging from 20-28 $umhos \cdot m^{-1}$ (Table 2). Moreover, alkalinities varied from 6.5-11.0 $mg \cdot L^{-1}$ (as $CaCO_3$) which indicates moderately low levels of inorganic carbon (Wetzel 1975). Additionally, the Ph was slightly acidic and ranged from 6.2-7.0 units. Turbidities in Virginia Lake were very low and ranged from 0.5-2.4 NTU; whereas, color ranged from 8-22 Pt units which characterizes Virginia Lake as a slightly stained system (Koenings and Edmundson 1991).

Metals -- Calcium levels in Virginia Lake are considered low to moderate (3.5-5.2 $mg \cdot L^{-1}$) for oligotrophic Alaskan lakes (Table 2); whereas, magnesium concentrations were at or near the limit of detection (<0.2 $mg \cdot L^{-1}$). Unlike clearwater lakes, which typically exhibit iron levels <20 $ug \cdot L^{-1}$ (Stumm and Lee 1960), concentrations within the epilimnion and hypolimnion in Virginia Lake ranged from 57-212 $ug \cdot L^{-1}$, and averaged 153 $ug \cdot L^{-1}$ which is characteristic of organically stained lakes (Koenings 1976).

Nutrient Levels -- During 1989-1990, ammonia nitrogen levels in Virginia Lake remained relatively low and were consistent between the epilimnion and hypolimnion (Table 2). Concentrations ranged from 3.8-18.6 $ug \cdot L^{-1}$, and averaged 6.1 $ug \cdot L^{-1}$. In contrast, nitrate + nitrite levels within the hypolimnion averaged ~90 $ug \cdot L^{-1}$, but epilimnetic concentrations decreased to ~20 $ug \cdot L^{-1}$ during the summer which signals a nitrogen deficit. Total Kjeldahl nitrogen (TKN) levels (equivalent to ammonia + organic nitrogen) were consistent with depth and over time, and averaged 54 $ug \cdot L^{-1}$. Total nitrogen (TN) levels within the epilimnion were lowest in the summer compared to the spring and fall ranging from 73 -155 $ug \cdot L^{-1}$ and averaging 116 $ug \cdot L^{-1}$ (Table 2).

Table 2. General water quality parameters, metal concentrations, nutrient concentrations and atom ratios, and algal pigments within the epilimnion (1 m) and hypolimnion of Virginia Lake, 1989-1990.

Date	05/18/89		08/10/89		11/17/89		05/04/90		07/12/90		10/30/90	
Station	A		A		A		A		A		A	
Parameter/Depth	1 m	Hypolimnion	1 m	Hypolimnion	1 m	Hypolimnion	1 m	Hypolimnion	1 m	Hypolimnion	1 m	Hypolimnion
Conductivity (umhos/cm)	23	28	23	28	25	26	26	27	20	27	24	26
pH (units)	6.2	6.2	7.0	6.7	6.6	6.6	6.9	6.8	6.4	6.6	6.3	6.3
Alkalinity (mg/L)	6.5	8.5	9.0	9.0	10.0	11.0	10.0	11.0	6.5	10.0	8.0	8.5
Turbidity (NTU)	0.8	0.9	0.5	0.6	1.0	1.0	2.4	1.0	0.6	0.6	1.2	1.0
Color (Pt units)	15	15	8	12	22	20	NA \a	NA	NA	NA	NA	NA
Calcium (mg/L)	NA	NA	5.2	4.3	3.7	4.1	4.1	4.1	3.5	4.8	4.0	4.0
Magnesium (mg/L)	NA	NA	<0.2	<0.2	<0.2	<0.2	<0.2	0.7	NA	NA	0.6	0.6
Total iron (ug/L)	57	176	62	161	141	183	162	205	87	200	212	184
Total-P (ug/L)	6.4	5.2	3.8	3.5	4.0	3.2	7.3	5.1	5.2	3.8	5.8	NA
TFP (ug/L)	3.6	3.7	2.2	2.1	4.0	2.5	4.8	3.8	2.4	1.8	3.9	3.3
FRP (ug/L)	3.7	4.3	1.2	1.3	2.4	2.0	4.2	2.9	1.1	1.8	2.5	2.8
TKN (ug/L)	45	46	58	52	53	67	54	57	55	42	61	NA
Total N (ug/L)	140	141	73	155	121	141	146	149	81	136	132	NA
N:P atom ratio	48:1	49:1	43:1	101:1	66:1	101:1	43:1	66:1	34:1	81:1	49:1	NA
Ammonia (ug/L)	5.5	5.5	7.9	7.4	18.6	3.2	3.8	4.4	3.8	4.7	4.4	3.8
Nitrate + Nitrite (ug/L)	94.9	95.4	15.2	102.7	67.9	73.8	91.5	91.5	25.6	94.4	71.3	86.1
Reactive silicon (ug/L)	1,022	1,143	1,025	1,179	1,186	1,186	1,144	1,177	739	1,010	486	504
Chl a (ug/L)	0.19	<0.10	0.17	<0.01	NA	NA	0.35	0.01	0.31	0.01	0.10	0.01
Phaeo a (ug/L)	0.09	0.10	0.11	0.06	NA	NA	0.16	0.04	0.12	0.06	0.10	0.06

/a NA indicates not avialable.

During 1989-1990, total phosphorus (TP) levels ranged from 3.8-7.3 $ug \cdot L^{-1}$ and averaged 5.4 ug·L-1 within the epilimnion; whereas, during the spring period (May) TP concentrations were slightly higher and averaged 6.9 $ug \cdot L^{-1}$ (Table 2). The current phosphorus (P) loading rate in Virginia Lake is 860 mg $P/m^2/yr$ and the critical P loading rate is 1,250 mg $P/m^2/yr$. As a result, permissible supplemental P loading (90% of the critical P loading rate) is 260 mg $P/m^2/yr$. Total filterable (TFP) and filterable reactive phosphorus (FRP) levels were consistent within depth and averaged 3.2 and 2.5 $ug \cdot L^{-1}$, respectively (Table 2). Finally, during 1989-1990, reactive silicon (Si) levels averaged 983 $ug \cdot L^{-1}$; however, concentrations on 30 October 1990 were only ~50% of the two-year average (Table 2).

In considering nutrients and lake productivity, not only are the concentrations of the algal nutrients nitrogen, phosphorus, and silicon important to primary production (phytoplankton), but so are their relative ratios (Wetzel 1975). In particular, optimal production of diatoms and green (favorable) algae occurs at a Si:TN:TP ratio of 17:16:1 (Schindler 1978; Smith 1982). In Virginia Lake the Si:TN:TP ratios (by atomic weight) averaged 206:49:1 indicating phosphorus to be a primary limiting nutrient to phytoplankton production (Table 2). That is, both Si and TN levels are considerably higher relative to TP, and Si concentrations are higher relative to the amount of nitrogen.

Phytoplankton -- During 1989-1990, chl a concentrations within the epilimnion were extremely low ranging from 0.10-0.35 $ug \cdot L^{-1}$ and averaging 0.22 $ug \cdot L^{-1}$ (Table 2). Moreover, concentrations within the hypolimnion were below our analytical detection limits (<0.01 $ug \cdot L^{-1}$). Thus, chl a levels within Virginia Lake are considered very low compared to other oligotrophic lakes in Alaska.

Zooplankton Abundance and Body Size -- The total macrozooplankton community in Virginia Lake was comprised of two species of copepods and three species of cladocerans (Table 3). The copepod community consisted of *Diaptomus* sp. and *Cyclops* sp. The cladocerans were represented primarily by *Bosmina* sp.; however, *Chydorinae* sp. and *Daphnia longiremis* were also present. The total macrozooplankton density averaged 22,700/m^2 and 53,200/m^2 in 1989 and 1990, respectively.

Table 3. Macrozooplankton densities (number/m^2) and species composition in Virginia Lake, 1989-1990. Numbers in parentheses are the corresponding weighted mean body sizes (mm).

Date / Species	05/18/89	08/10/89	11/17/89	05/04/90	07/12/90	10/30/90
Diaptomus sp.	7,387 (0.94)	679 (1.42)	212 (1.81)	4,118 (0.79)	3,736 (1.69)	1,274 (1.81)
Cyclops sp.	6,028 (0.95)	4,840 (0.96)	1,571 (1.02)	1,189 (0.41)	15,622 (0.72)	3,439 (0.84)
Bosmina sp.	20,462 (0.53)	19,783 (0.34)	7,132 (0.34)	28,825 (0.56)	66,398 (0.44)	34,938 (0.46)
Chydorinae sp.	255 (0.36)	425 (0.32)	297 (0.31)	NP[a]	NP	NP
Daphnia longiremis	NP	NP	P	NP	NP	NP

[a] P indicates zooplankters present, but too few to enumerate. NP indicates not present.

As a group, the copepods comprised ~22% of the total macrozooplankton density. Of the copepods, *Cyclops* was the numerically dominant species. During 1989-1990, densities ranged from 1,571-15,622/m^2 and averaged 5,450/m^2; whereas, *Diaptomus* sp. populations ranged from 212-7,387/m^2 and averaged 2,900/m^2 (Table 3). *Diaptomus* densities decreased sharply during 1989, concomitant with the introduction of rearing sockeye juveniles indicating extreme predation. In contrast, *Cyclops* densities remained relatively consistent through the summer. Finally, the weighted mean body sizes of *Cyclops* and *Diaptomus* were 0.83 and 1.18 mm, respectively.

Within the cladoceran community, *Bosmina* was by far the most abundant species with densities ranging from 7,132-66,398/m^2 (Table 3). The highest density of *Bosmina* occurred during July 1990 and was responsible for the doubling of the seasonal mean total macrozooplankton density in 1990 compared to 1989. In 1989, *Bosmina* densities remained at ~20,000/m^2 during May and June; however, the mean body sizes decreased from 0.53 to below 0.40 mm, which is considered the minimum threshold size for elective feeding by sockeye salmon fry (Koenings and McDaniel 1983; Kyle et al. 1988). This suggests that *Bosmina* zooplankters were also being preyed upon quite severely. Moreover, during 1990 when fewer juveniles were rearing in the lake, *Bosmina* densities rebounded and the mean body sizes increased to ~0.50 mm. Finally, *Chydorinae* populations averaged ~325/m^2 in 1989, but were not present in 1990; whereas, *Daphnia* were present during November of 1989, but in too few numbers to enumerate. The weighted mean body size of *Chydorinae* was 0.33 mm (Table 3).

Zooplankton Biomass -- The total weighted macrozooplankton biomass in Virginia Lake varied significantly between 1989 and 1990 averaging 55 and 131 $mg \cdot m^{-2}$ respectively (Table 3). In 1989, *Bosmina* populations comprised 51% (28 $mg \cdot m^{-2}$) of the total biomass; whereas, *Diaptomus* and *Cyclops* populations each comprised ~25% (14 $mg \cdot m^{-2}$). In contrast, *Bosmina* populations comprised nearly 70% (91 $mg \cdot m^{-2}$) of the total macrozooplankton biomass in 1990, and *Diaptomus* and *Cyclops* populations comprised 20% and 11% of the total biomass, respectively.

Juvenile Fisheries Assessment

Hydroacoustic Population Estimates and Juvenile Survival -- In April 1989, ~1.9 million sockeye fry from the Beaver Falls Hatchery near Ketchikan were outplanted in Virginia Lake. However, the fall hydroacoustic survey conducted in November 1989 determined a population estimate of ~270,000 limnetically-rearing fish. This represented a spring-to-fall fry survival of 14% (Table 4). In turn, subsequent hydroacoustic surveys and tow net sampling conducted in May 1990 revealed a population of only ~71,000 age-1 smolts, which represented a survival of 3.7% from the 1989 spring fry outplant (Table 4). The poor survival was attributed to stocking juvenile sockeye well before sufficient forage (zooplankton) developed in the lake (Table 3). As a result, in 1990 the number of released fry was reduced to ~888,000 and the release was delayed until May when zooplankton were more abundant. The October 1990 hydroacoustic survey estimated a total population of ~139,000 fish which represented a spring-to-fall fry survival of 14.7% (Table 4). Given a 70% overwinter survival from fall fry (Zadina 1991 pers. comm.), we would predict the 1991 smolt outmigration to equal ~97,000 age-1 smolts. This would equate to only a 10.3% survival from the 1990 post smolt population estimate (Table 4).

In addition to the lower than expected fry-to-smolt survivals, age-1 smolt sizes averaged only 55 mm in length and weighed 1.7 g and thus, were below the minimum 'threshold size' (2.2 g, 60 mm). Furthermore, smolts produced from Virginia Lake were considerably smaller in size compared to smolts produced from other southeast lakes (Table 5). Thus, both smolt population characteristics suggest that Virginia Lake is currently rearing-limited relative to sockeye salmon production (Koenings and Burkett 1987).

Potential Sockeye Salmon Production -- Assuming rearing limitation, maximum stocking levels for sockeye salmon nursery lakes were empirically derived based on euphotic volume (Koenings and Burkett 1987). Koenings and Burkett (1987) established a relationship between EV and sockeye salmon production. Specifically, the maximum fry stocking densities per EV unit were estimated at 110,000 fry which would yield 23,000 age-1, threshold-sized (2.2 g) smolts; whereas, the optimal stocking density at 54,000 fry per EV

Table 5. Comparison of mean age-1 smolt lengths and weights for various sockeye salmon stocks in southeast Alaska compared to the mean size of age-1 smolt in Virginia Lake.

Lake	Mean age-1 smolt length (mm)	Mean age-1 smolt weight (g)
Badger	70.2	3.63
Heckman	67.0	2.26
Hugh Smith	77.9	4.07
McDonald	66.0	2.26
Virginia	**54.9**	**1.72**

unit would produce larger sized (4.5 g) age-1 smolts. Applying the optimal rearing-capacity model, Virginia Lake (19.5 EV units) could potentially support ~1.1 million sockeye salmon fry. Based on a 21% survivorship from spring fry to smolt (Koenings et al. 1989), ~230,000 smolts would be produced. Finally, using a smolt-to-adult survivorship of 12% (Koenings et al. 1989; Geiger and Koenings 1991), Virginia Lake would be expected to produce ~27,000 adult sockeye salmon.

We have also developed a relationship between zooplankton biomass and sockeye biomass for several Alaskan lakes whereby smolt biomass ($kg \cdot km^{-2}$) = 2 x zooplankton biomass ($mg \cdot m^{-2}$). Based upon the zooplankton biomass estimate for 1990 (131 $mg \cdot m^{-2}$, we would expect Virginia Lake to produce a total of 680 kg smolt which translates to 310,000 threshold-sized (2.2 g) smolts or ~150,000 optimum-sized (4.5 g) smolts. However, age-1 smolt biomass in 1990 equalled only 165 kg. Thus, because of the existing low zooplankton levels (Table 3) and retarded juvenile growth rates (Table 5), targeted smolt production cannot be realized through juvenile stocking at the existing level of forage.

RECOMMENDATIONS

Nutrient enrichment of Virginia Lake during the 1991 field season is recommended in order to increase the amount of forage available to rearing sockeye salmon juveniles. Currently, the introduction of juvenile sockeye outplants along with the natural production of juvenile fry fully utilize the zooplankton standing crop (Table 5). Thus, increasing the forage base (zooplankton biomass) through nutrient enrichment, concomitant with annual outplants of juvenile fry, represents the most appropriate strategy to develop the run of sockeye salmon in Virginia Lake.

1) Apply seven 30-gal barrels (13 tons) of 20-5-0 fertilizer and three 30-gal barrels (6 tons) of 32-0-0 fertilizer weekly from 15 May to 15 August. This would increase phosphorus concentrations within the epilimnion and maintain inorganic nitrogen levels at ~ 75 $ug \cdot L^{-1}$.

2) Fry stocking should be conducted from mid-June to early July and total of ~750,000 hatchery-fed fry should be released.

3) Limnological sampling should be intensified; i.e., conduct sampling every 4 weeks to monitor the nutrient levels and productivity parameters in Virginia Lake to evaluate the effect(s) of lake fertilization.

4) Continue the pre- and post-emigration hydroacoustic/townet surveys and conduct qualitative smolt sampling to determine populations estimates, sizes, age distribution, and yearly smolt production.

5) Investigate the extent of predation on juvenile sockeye by resident cutthroat trout.

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