FRED Reports

Limnological and fisheries investigations for sockeye salmon (*Oncorhynchus nerka*) enhancement in five Alaska Peninsula lakes: 1991- 1992 progress report

by

G. B. Kyle, J. A. Edmundson, and V. P. Litchfield

Number 126

Alaska Department of Fish & Game
Division of Fisheries Rehabilitation,
Enhancement and Development

Limnological and fisheries investigations for sockeye salmon (Oncorhynchus nerka) enhancement in five Alaska Peninsula lakes: 1991-1992 progress report

by
G. B. Kyle, J. A. Edmundson, and V. P. Litchfield

Number 126

Alaska Department of Fish and Game
Division of Fisheries Rehabilitation,
Enhancement, and Development

Carl L. Rosier
Commissioner

Jeffery P. Koenings
Director

P. O. Box 25526
Juneau, Alaska 99802-5526

January 1993

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract

Limnological and fisheries investigations were initiated in 1991 to assess sockeye salmon *(Oncorhynchus nerka)* production and the potential for enhancement in five lakes on the Alaska Peninsula located within fishing district Area M. This was a cooperative project between the Aleutians East Borough and the Alaska Department of Fish and Game. The five lakes selected for sampling were near the Cold Bay area. Some of these lakes are characterize as "typical" (deep, steep-sided) and "atypical" (shallow) sockeye nursery lakes. Investigations revealed that in Mortensen and Thin Point lakes it is apparent that juvenile sockeye fry rely on insects and other macroinvertebrates for food, and quite likely provide a greater portion of nutrition than the limited numbers of zooplankton. Due to the morphometry (shallowness) of these lakes, zooplankton production is limited. In Charlie Hansen and Orzinski lakes, the limited zooplankton data indicate that zooplankton is being utilized by sockeye fry, as in both lakes the zooplankton (*Bosmina*) sizes indicate intense predation pressure. However, the probability that sockeye juveniles feed exclusively on zooplankton in these lakes is low. Finally, due to a moderately high salinity of Red Cove Lake, and the inability for sockeye fry to effectively rear in a brackish environment, the rearing quality of this lake is poor. Recommendations are made concerning further study on these lakes.

Introduction

In 1991, limnological and fisheries investigations were initiated to assess sockeye salmon *(Oncorhynchus nerka)* production and the potential for enhancement in five lakes on the Alaska Peninsula located within fishing district Area M. Due to limited funding and accessibility, the five lakes selected for sampling were near the Cold Bay area (Figure 1). The lakes sampled during July 1991 and June 1992 were Charlie Hansen, Orzinski (Orzenoi), Red Cove, Thin Point, and Mortensen lakes. Some of these lakes are characterize as "typical" (deep, steep-sided) and "atypical" (shallow) sockeye nursery lakes. The purpose of these investigations is to collect data relative to determining existing sockeye production and the dynamics of shallow sockeye nursery lakes. In addition, these lakes are being investigated for the purpose of lake fertilization, fry stocking, or natural stock management. Fishery and limnological data acquired during previous years and the initial year of this study are presented, and recommendations are made for further study.

Background

Excluding Red Cove Lake, all of the other lakes currently support runs of sockeye salmon. Sockeye escapements (aerial counts) during 1970-1991 have ranged from 700-35,800 in Thin Point Lake, 0-2,300 in Charlie Hansen Lake, 800-13,000 in Mortensen Lake, and 1,200-61,500 in Orzinski Lake (Table 1). Although historically Red Cove Lake supported sockeye runs, there are currently no escapements into this lake due to an outlet barrier. Charlie Hansen, Red Cove and Orzinski lakes are relatively deep (>10 m) while Thin Point and Mortensen lakes are fairly shallow (≤ 3 m) (Figures 2 and 3). Surface areas range from 0.8 km^2 (208 acres) for Red Cove Lake to 17.2 km^2 (4,250 acres) for Thin Point Lake.

1. *Fox Bay*
2. *Orzenoi*
3. *Red Cove*
4. *John Nelson*
5. *Apollo Creek*
6. *Wosnesenski*
7. *Middle Creek*
8. *Mortensen's*
9. *Thin Point Lagoon*
10. *Morzhovoi Lake*
11. *Charlie Hansens*
12. *Whalebone*
13. *Swedes*
14. *Summer Bay*
15. *Unalaska*
16. *McLeese*
17. *Volcano Bay*
18. *Kashega*
19. *Urilia Bay*
20. *Swansons*
21. *Nelson Lagoon*
22. *Sapsuk Lake*
23. *Big Fish Lake*
24. *Coastal Lake*
25. *Bear Lake*
26. *Ocean River*
27. *Willie Creek*

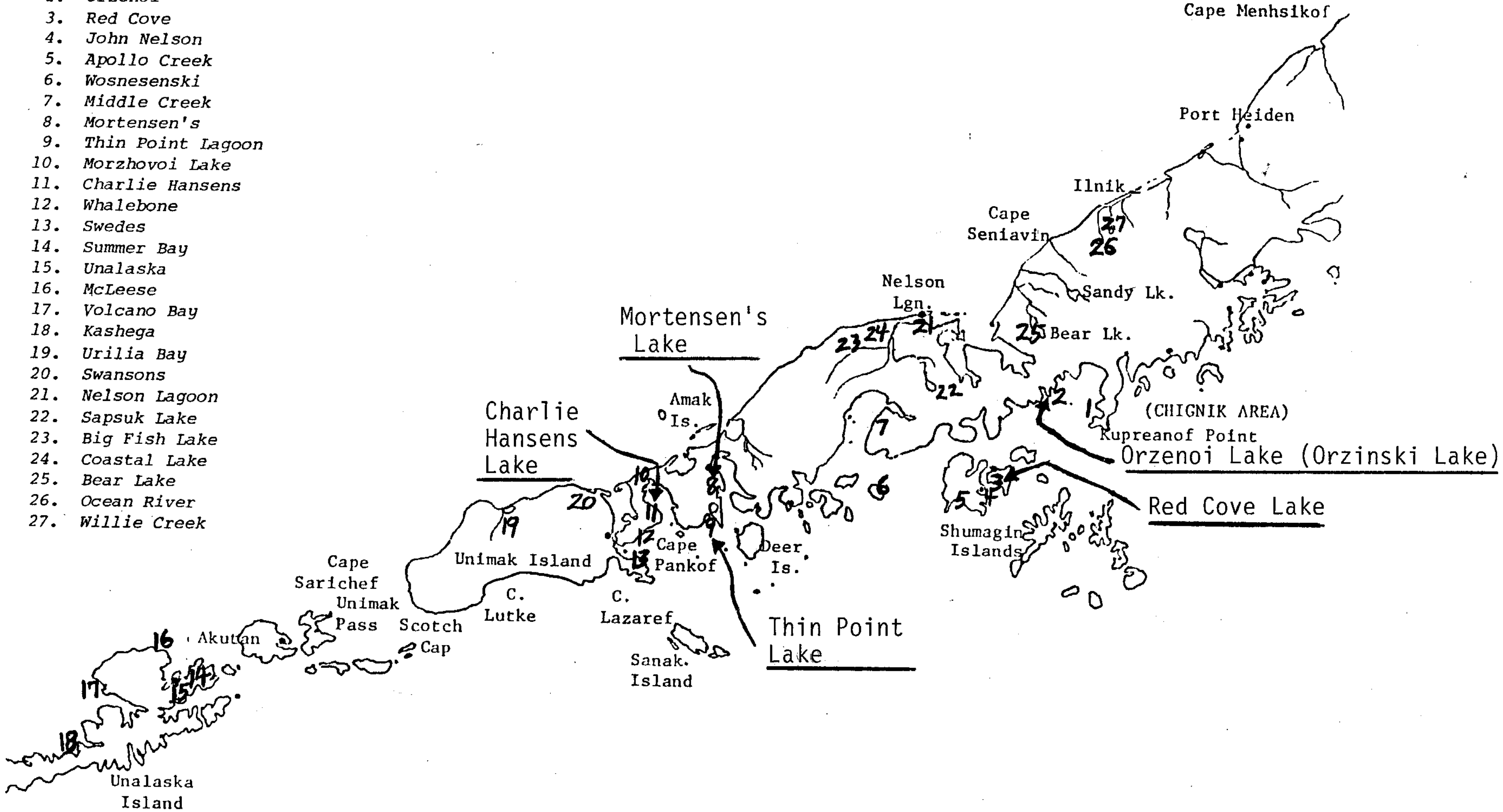

Figure 1. Geographical location of the five lakes sampled in Area M during 1991-1992.

Table 1. Sockeye escapements for Thin Point, Charlie Hansen, Mortensen, and Orzinski lakes, 1970-1991. \a

Survey year	Thin Point	Charlie Hansen	Mortensen	Orzinski
1970	1,100	ND	800	4,500
1971	1,300	800	800	11,000
1972	1,300	200	1,000	6,500
1973	700	0	1,300	1,200
1974	16,000	0	3,100	61,500
1975	6,100	100	4,000	22,300
1976	20,500	300	3,400	29,600
1977	17,700	500	5,700	17,000
1978	7,400	1,000	13,000	22,000
1979	6,900	400	5,900	20,000
1980	12,000	300	2,400	12,000
1981	7,500	200	2,900	18,000
1982	8,800	2,300	1,800	9,000
1983	6,500	100	5,000	21,300
1984	7,000	100	4,700	18,600
1985	4,600	100	3,600	14,000
1986	12,400	0	1,400	10,300
1987	8,700	0	4,000	11,400
1988	23,500	100	6,000	19,300
1989	21,500	300	4,300	16,700
1990	15,000	600	6,200	15,000
1991	35,800	2,300	7,100	40,000
Range	700-35,800	0-2,300	800-13,000	1,200-61,500
Mean	11,014	462	4,018	18,236

\a Source: Arnie Shaul, ADF&G Kodiak, Ak. pers. comm. All escapements based on aerial counts except for Orzinski Lake in 1990 and 1991 are weir counts.

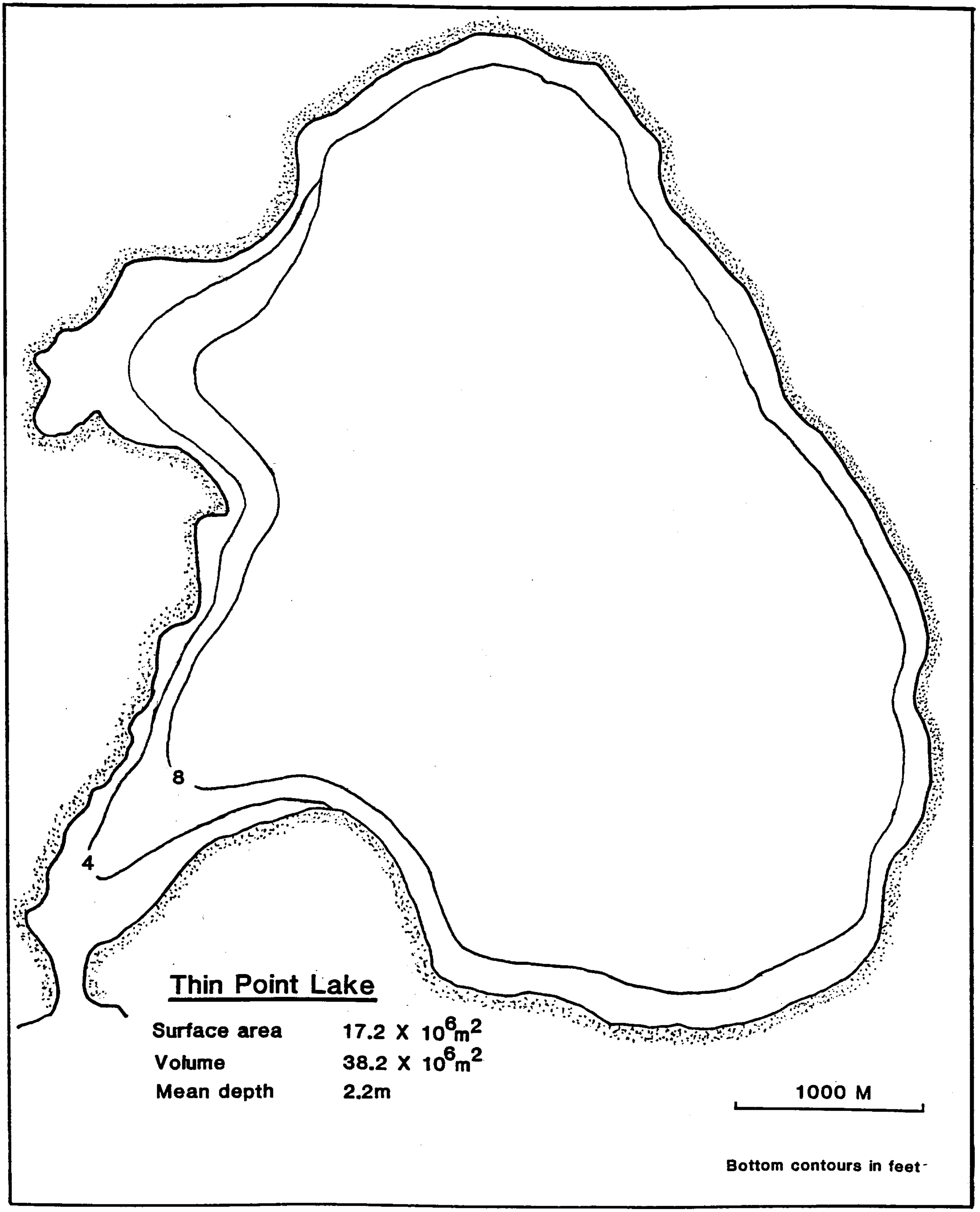

Figure 2. Morphometric map of Thin Point Lake.

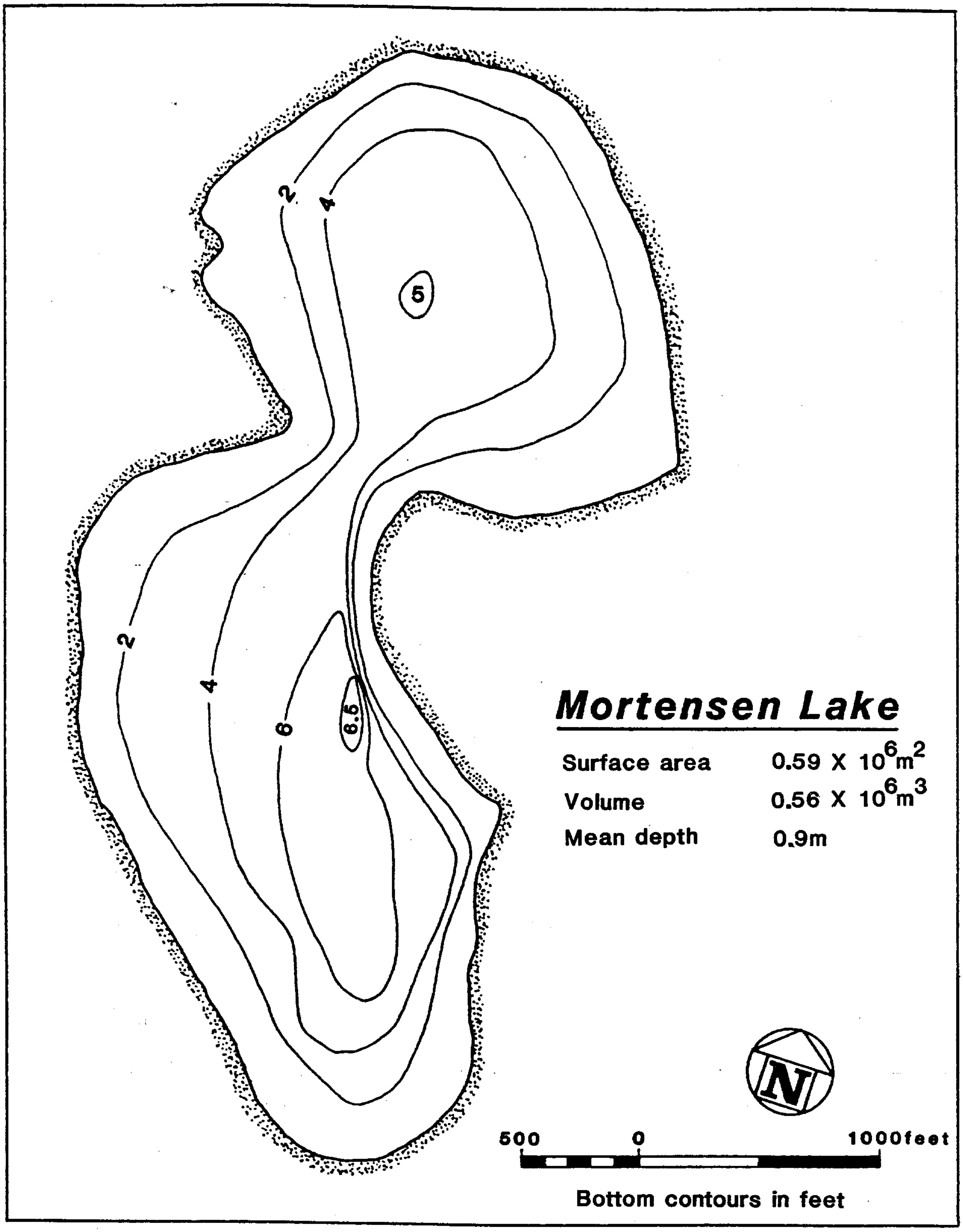

Figure 3. Morphometric map of Mortensen Lake.

Methods

Physical Features-- The collection of physical data included the measurement of lake temperature, dissolved oxygen, and light penetration. Lake temperature/dissolved oxygen profiles were measured using a YSI model-57 meter. Profiles were taken at 1-m increments from the surface to 5 m, and at 2-m increments from 6 m to the bottom of the lake. The algal light compensation point was defined as the depth at which 1% of the subsurface light (photosynthetically available radiation [400-700 mm]) penetrated (Schindler 1971), and was measured using an International® submersible photometer. Light readings were taken every 0.5 m to 5 m, and every 1 m thereafter down to the light compensation depth. Water clarity was also measured with a 20-cm Secchi disk by recording the depth at which the disk disappeared from view.

Water Sampling-- Limnological data were collected twice during 1991 (in the summer and fall) and once in the spring of 1992. Except for Orzinski Lake, at least one limnological survey was conducted prior to 1991. Sampling was conducted using ADF&G float-equipped aircraft or by raft. Lake water was sampled at 1 m and at 75% of the total depth for algal nutrients (nitrogen, phosphorus, silicon, and carbon) as well as general water quality parameters. Mortensen and Thin Point lakes were sampled only at the 1 m depth due to their shallowness. Water samples from multiple casts with a non-metallic Van Dorn sampler were pooled, stored in 8-10 L translucent carboys, and immediately transported to the Russell Creek Hatchery for filtering and preservation. Subsequent filtered and unfiltered water samples were stored either refrigerated or frozen in pre-rinsed polybottles. The pre-processed water

---

®Mention of commercial products and trade names does not constitute endorsement by ADF&G, FRED Division.

samples were then sent to the ADF&G Limnology Laboratory in Soldotna for analysis.

General Water Quality Parameters-- Water samples were analyzed for the following parameters as detailed by Koenings et al. (1987). Conductivity (µmhos/cm) was measured (compensated to 25° C) with a YSI model-32 conductance meter. Alkalinity levels (mg/L) were determined by acid titration (0.02 N H_2SO_4) to pH 4.5, using a Corning model 399A specific ion meter. Calcium and magnesium (mg/L) were determined from separate EDTA (0.01 N) titrations after Golterman (1969), turbidity (NTU) was measured with a HF model-DRT100 turbidimeter, and color (Platinum cobalt (Pt) units) was determined with a spectrophotometer. Total iron (µg/L) was analyzed by reduction of ferric iron with hydroxylamine during hydrochloric acid digestion after Strickland and Parsons (1972).

Nutrients-- Nutrients (µg/L) were analyzed by detailed methods described by Koenings et al. (1987). In general, filterable reactive phosphorus (FRP) was analyzed by the molybdate-blue/ascorbic-acid method of Murphy and Riley (1962), as modified by Eisenreich et al. (1975). Total phosphorus (TP) was determined by FRP procedure, after persulfate digestion. Nitrate and nitrite (NO_3 + NO_2) were determined as nitrite, following Stainton et al. (1977), after cadmium reduction of nitrate. Total Kjeldahl nitrogen (TKN) was determined as total ammonia following sulfuric acid block digestion (Crowther et al. 1980). Reactive silicon (Si) was determined using the method of ascorbic acid reduction to molybdenum-blue after Stainton et al. (1977).

Chlorophyll a-- Algal standing crop (µg/L) was estimated by chlorophyll a (chl a) analysis, after the fluorometric procedure of Strickland and Parsons (1972). The low-strength acid addition recommended by Riemann (1978) was used to estimate phaeophytin. Water samples (1-2 L) were filtered through 4.25-cm GF/F filters to which 1-2 mls of a saturated $MgCO_3$ solution were added just prior to the completion of filtration. The filters were then stored frozen in individual plexislides for later analysis.

Zooplankton-- Zooplankton densities (no./m^2) were enumerated from duplicate vertical tows just above the lake bottom using a 0.2-m diameter (153-µm mesh) conical net. The net was pulled at a constant 1 m/s, and all organisms were preserved in a 10% neutralized formalin solution. Identification of *Daphnia* followed Brooks (1957), *Bosmina* after Pennak (1978), and the copepods after both Wilson (1959) and Yeatman (1959). Enumeration consisted of counting triplicate 1-ml subsamples taken with a Hansen-Stempel pipette in a 1-ml Sedgewick-Rafter cell. Finally, zooplankton body sizes were obtained by measuring the length to the nearest 0.01 mm of at least 10 individuals along a transect in each 1-ml subsample (Koenings et al. 1987).

Juvenile Diet-- In July and September of 1991 a total of 42 sockeye salmon fry and 85 coho salmon (*Oncorhynchus kisutch*) fry were collected by beach seine from Mortensen Lake for the purpose of foregut analysis In addition, a fyke net was placed in the outlet of Mortensen Lake from 4 May to 15 June 1992 to sample out-migrating sockeye and coho smolts for age, size, and foregut content. The juvenile salmon were anesthetized with MS-222 to prevent regurgitation of the stomach contents, then preserved whole in 15% neutralized formalin and shipped to the Limnology Laboratory for foregut analysis. Snout-to-fork tail lengths (nearest one millimeter) and weights (nearest 0.1 g) were recorded from each fish. The stomach contents were emptied into a petri dish and all zooplankters and insects were identified and enumerated. Contents were identified (Pennak 1987; Borror and DeLong 1971) and counted as whole organisms only by distinguishable parts e.g., head capsule. The total number of individual prey organisms, the percent organism composition of the sample, and the percent frequency of occurrence for each organism in the sample were calculated.

A standard measurement of the selectivity of zooplankton prey by juvenile salmon is the electivity index (Ivlev 1961), which has a range of -1 to +1 with negative values indicating either avoidance or inaccessibility of a prey item, zero indicating random selection, and positive values indicating active selection. However, due to the low number of zooplankters found in fry collected from Mortensen Lake, this analysis could not be done for this study.

Results and Discussion

Physical Features-- In comparison to Thin Point Lake (4,250 acres) and other sockeye nursery lakes, the other four lakes sampled are relatively small (146-539 acres) (Table 2). The deeper lakes (Charlie Hansen, Red Cove, and Orzinski) as well as the two shallow lakes (Mortensen and Thin Point) are well mixed, as thermal stratification was absent or very weak, and temperatures were usually not substantially different from top to bottom (exception was Red Cove Lake on 6 August 1991). The temperature at 1 m varied from 4.0 to 15.0° C for all sample dates and lakes, and dissolved oxygen concentrations ranged from 10.0 to 14.2 mg/L (Table 2). Finally, the 1% light level exceeded the mean depth of the deeper lakes and extended to the bottom in the two shallow lakes. Thus, lake morphometry not water clarity controls the vertical extent of photosynthesis in these lakes.

General Water Quality Parameters-- Conductivities within Charlie Hansen, Thin Point, and Mortensen lakes ranged from 66 to 110 µmhos/cm (Table 3), which are typical for clearwater sockeye systems (*see* Appendix I), and indicates low to moderate concentrations of dissolved solids. In contrast, saltwater intrusion was quite evident in both Red Cove and Orzinski lakes. That is, conductivity reached as high as 33,500 µmhos/cm near the bottom of Red Cove Lake which is equivalent to ~25‰ or 70% that of seawater, and 16,310 µmhos/cm in Orzinski Lake or about 11‰. Alkalinity (the concentration of soluble mineral salts capable of neutralizing acids which is

Table 2. Morphometric information, temperature, and dissolved oxygen readings for Charlie Hansen, Orzinski, Thin Point, Mortensen, and Red Cove lakes.

Lake	Surface area (Km^2)	Surface area (Acres)	Volume (Km^3)	Mean depth (M)	Max. depth (M)	Sample date	Temp. (C) @ 1M	Dissolved oxygen (mg/L) @ 1M
						10/1/89	ND	ND
Charlie Hansen	2.18	539	ND \a	ND	14	7/28/91	11.5	10.4
						8/24/91	10.5	10.6
						6/30/92	9.8	11.7
Orzinski	1.00	247	ND	ND	13	8/6/91	12.0	10.4
						8/30/91	10.1	10.6
						6/30/92	8.8	12.7
Thin Point	17.20	4,250	38	2.2	3	8/25/89	14.1	10.0
						10/5/89	5.6	12.1
						7/28/91	12.8	10.2
						8/24/91	12.0	10.2
						6/30/92	11.4	11.1
Mortensen	0.59	146	0.56	0.9	2	8/23/88	12.5	10.7
						11/10/88	4.0	14.2
						7/26/91	13.0	10.2
						10/3/91	7.0	11.6
						5/27/92	11.0	10.2
						6/7/92	11.0	10.4
						8/24/90	ND	ND
Red Cove	0.84	208	ND	ND	13	8/6/91	15.0	10.0
						8/30/91	12.8	10.3
						6/30/92	11.5	10.9

\a No data.

Table 3. General water quality parameters, nutrient concentrations, and chlorophyll a concentrations by sample depth and date for Charlie Hansen, Orzinski, Thin Point, Mortensen, and Red Cove lakes.

Lake	Charlie Hansen							Orzinski Lake					
Sample date	10/1/89	7/28/91		8/24/91		6/30/92		8/6/91		8/30/91		6/30/92	
Depth		1 M	10 M	1 M	5 M	1 M	5 M	1 M	10 M	1 M	10 M	1 M	10 M
Conductivity (umhos/cm)	102	101	105	108	107	108	103	765	808	812	814	1,140	16,310
pH	7.3	7.2	7.3	7.2	7.2	7.4	7.3	7.0	7.3	7.2	7.1	7.3	8.0
Alkalinity (mg/L)	14.0	10.0	9.0	14.5	10.0	16.0	14.5	8.0	8.0	12.0	11.5	11.0	43.5
Turbidity (NTU)	0.4	0.7	1.0	2.4	0.7	0.8	0.8	1.2	1.0	1.0	1.4	0.5	1.0
Color (Pt)	7.5	5.0	<2	4.0	4.0	3.0	3.0	6.0	<2	<2	<2	3.0	5.0
Calcium (mg/L)	7.7	7.5	7.5	6.8	8.8	7.3	13.5	7.7	10.6	8.9	8.9	9.6	143.0
Magnesium (mg/L)	1.6	1.5	1.5	2.2	2.2	2.4	<0.2	15.0	13.6	16.5	17.2	30.8	469.0
Iron (ug/L)	43	51	60	116	100	50	72	44	32	28	60	4	12
TP (ug/L)	5.0	4.6	5.9	7.7	7.0	3.9	3.8	13.2	11.7	17.8	18.0	2.6	10.4
TFP (ug/L)	2.3	3.9	3.2	1.8	1.8	1.6	0.7	4.3	3.4	4.0	4.4	0.7	1.7
FRP (ug/L)	3.0	4.5	3.3	3.1	2.9	1.5	1.4	2.7	1.9	2.8	3.2	1.0	0.8
TKN (ug/L	47	206	123	60	48	59	72	113	92	118	107	72	160
Ammonia (ug/L)	3.4	1.9	1.3	<1.1	<1.1	<1.1	<1.1	14.4	4.8	38.7	36.6	2.0	<1.1
Nitrate + Nitrite (ug/L)	<3.4	<3.4	<3.4	<3.4	<3.4	<3.4	<3.4	5.4	3.7	28.3	31.2	76.0	10.8
Reactive Si (ug/L)	4,143	3,746	3,699	3,640	3,685	3,877	3,854	904	881	1,363	1,381	1,377	674
Chl a (ug/L)	0.22	0.38	0.54	0.77	0.84	1.30	0.74	1.46	1.40	1.08	1.07	1.03	6.39
Phaeo a (ug/L)	0.17	0.29	0.31	0.34	0.31	0.74	0.57	1.52	0.63	1.46	1.46	0.14	4.21

-continued-

Table 3 continued. General water quality parameters, nutrient concentrations, and chlorophyll a concentrations by sample depth and date for Charlie Hansen, Orzinski, Thin Point, Mortensen, and Red Cove lakes.

Lake	Thin Point Lake					Mortensen Lake						Red Cove Lake							
Sample date	8/25/89	10/5/89	7/28/91	8/24/91	6/30/92	8/23/88	11/10/88	7/26/91	10/3/91	5/27/92	6/7/92	8/24/90		8/6/91		8/30/91		6/30/92	
Depth	1 M	1 M	1 M	1 M	1 M	1 M	1 M	1 M	1 M	1M	1M	1 M	4 M	1 M	10 M	1 M	10 M	1 M	10 M
Conductivity (umhos/cm)	87	66	84	94	92	88	84	88	85	81	88	4,500	13,890	4,060	21,200	3,940	33,500	2,020	25,700
pH	7.0	6.9	7.0	7.0	6.8	7.6	6.7	7.1	7.2	6.8	7.0	7.5	8.3	7.8	7.5	7.7	7.2	7.2	7.6
Alkalinity (mg/L)	10.5	8.0	8.0	11.0	10.0	19.0	11.0	10.0	13.0	12.5	15.0	24.0	45.0	17.0	60.0	23.5	122.0	17.0	76.0
Turbidity (NTU)	2.2	9.4	3.1	23.0	8.2	3.5	4.2	1.0	4.4	4.0	1.8	0.7	1.2	1.0	1.2	0.6	2.6	0.6	1.1
Color (Pt)	3.0	9.8	3.0	5.0	8.0	13.2	14.9	9.0	11.0	11.0	13.0	11.0	10.0	4.0	6.0	4.0	9.0	8.0	9.0
Calcium (mg/L)	4.8	2.6	3.7	4.0	5.0	4.1	3.2	3.7	2.8	3.7	3.5	41.0	139.2	68.8	198.4	39.2	316.0	21.3	190
Magnesium (mg/L)	1.1	1.2	1.5	2.2	1.5	1.6	2.2	2.2	1.8	2.1	3.2	104.0	382.0	65.6	504.0	96.0	1080.0	51.6	857
Iron (ug/L)	118	688	178	2,144	691	294	286	52	378	296	206	74	51	58	61	24	66	18	42
TP (ug/L)	19.9	39.5	20.1	74.8	40.1	50.7	30.8	30.2	28.9	43.0	38.1	9.7	13.5	11.2	22.0	7.0	60.5	5.6	19
TFP (ug/L)	8.2	4.9	3.2	2.3	2.7	11.5	14.7	16.9	14.5	17.9	19.6	3.5	5.0	3.8	6.5	3.6	12.1	2.4	3.9
FRP (ug/L)	1.4	2.9	2.2	1.5	1.1	5.2	12.8	13.1	10.1	14.8	12.5	2.2	3.6	3.3	8.2	1.6	11.5	1.4	3.8
TKN (ug/L	187	208	281	424	305	360	161	184	184	196	254	241	292	167	468	140	573	158	421.8
Ammonia (ug/L)	9.9	5.7	2.4	1.3	6.6	4.3	5.4	<1.1	1.7	5.5	10.1	13.0	19.0	<1.1	80.0	10.2	54.1	7.1	3.0
Nitrate + Nitrite (ug/L)	<3.4	<3.4	<3.4	<3.4	<3.4	<3.4	<3.4	<3.4	<3.4	21	<3.4	37	15	<3.4	<3.4	3.7	<3.4	115.9	<3.4
Reactive Si (ug/L)	1,394	2,743	894	954	1,448	3,811	8,446	6,478	6,809	7,825	6,462	1,734	2,656	2,345	4,151	2,608	5,972	3,246	4,078
Chl a (ug/L)	1.54	NA	3.86	6.18	7.10	10.30	3.00	1.83	3.83	5.14	3.39	0.48	1.15	1.18	5.02	0.45	10.34	0.61	14.04
Phaeo a (ug/L)	0.49	NA	1.17	2.86	2.56	3.10	3.40	0.46	3.98	1.83	1.82	0.13	0.53	0.42	4.73	0.27	4.00	0.25	0.26

important in chemical reactions such as photosynthesis) within Charlie Hansen, Thin Point, Mortensen, and Orzinski lakes averaged <20 mg/L and indicate a low to moderate inorganic carbon supply (Stumm and Morgan 1981). In contrast, alkalinity was higher in Red Cove Lake and reached a maximum of 122 mg/L which is due to saltwater intrusion. The pH centered near neutrality for Thin Point and Mortensen lakes and was slightly above neutral for the other lakes ranging from 7.1 to 8.3 units.

Given the shallow nature and frequent wind mixing of both Thin Point and Mortensen lakes, bottom sediments and algal cells which act to scatter light are suspended throughout the water column. As such, turbidity was highest in Thin Point Lake ranging from 2.2 to 23.2 NTU, and was slightly elevated in Mortensen Lake ranging from 1.0 to 4.4 NTU. In the other lakes turbidity was very low and averaged ~1 NTU. There was little or no organic stain present in any of the lakes as color averaged <15 Pt units (Table 3).

Metals-- Calcium levels in Thin Point and Mortensen lakes were relatively low ranging from 2.6 to 5.0 mg/L, while in Charlie Hansen and Orzinski lakes concentrations ranged from 6.8 to 13.5 mg/L (Table 3), which are average for clearwater sockeye systems (*see* Appendix I). In contrast, in Red Cove Lake, calcium concentrations were well above average due to saltwater intrusion, and exceeded 300 mg/L at the deeper depths. Similarly, magnesium levels were highest in Red Cove Lake ranging from 52 to 1,080 mg/L, followed by Orzinski Lake ranging from 14 to 469 mg/L, and lowest in Thin Point, Mortensen, and Charlie Hansen lakes ranging from <0.2 to 3.2 mg/L. Iron concentrations in both Thin Point and Mortensen lakes averaged 663 and 252 μg/L respectively, and were relatively high due to large concentrations of particulate iron associated with suspended bottom sediments. In the other lakes, iron concentrations were much lower averaging <100 μg/L and were consistent with other clearwater sockeye-producing lakes (*see* Appendix I).

Nutrients-- Phosphorus is often a limiting factor for primary production (Vollenweider 1976; Schindler 1978; Smith 1979), and to fish yield (Foerster 1968; Hanson and Legget 1982). In both Thin Point and Mortensen lakes, total phosphorus (TP) concentrations were very high ranging from 19.9 to 74.8 µg/L and from 28.9 to 50.7 µg/L, respectively (Table 3). Filterable reactive phosphorus (FRP) or soluble orthophosphate which is the form readily available for algal uptake (photosynthesis) usually comprises only a small portion of TP. Indeed, in Thin Point Lake, FRP averaged only 1.8 µg/L or ~6% of TP. Given the high turbidities and iron levels it appears that much of the TP in Thin Point Lake is comprised of inorganic particulate (non-biological) phosphorus which is unavailable for algal uptake (Kuenzler et al. 1979; Edmundson and Koenings 1985). In contrast, FRP levels were much higher in Mortensen Lake averaging 11.4 µg/L and comprised nearly 30% of TP. In addition, because of the relatively high algal biomass (chlorophyll a), a large proportion of the TP in Mortensen Lake is comprised of particulate organic (cellular) phosphorus which is considered biologically active (Prepas and Vickery 1984). In brackish Red Cove Lake, and to a lesser extent in Orzinski Lake, TP concentrations were quite high and varied with the magnitude of saltwater intrusion (conductivity). In particular, TP ranged from a low of 5.6 µg/L at 1 m to a high of 60.5 µg/L near the bottom of Red Cove Lake, and from 2.6 to 18.0 µg/L in Orzinski Lake. Charlie Hansen Lake exhibited TP concentrations of 3.9 to 7.7 µg/L, which are more typical of an oligotrophic (nutrient poor) system. FRP levels at the surface (1 m) in the Charlie Hansen, Orzinski, and Red Cove lakes were relatively low ranging from 1.1 to 3.3 µg/L.

In well-oxygenated water, ammonia produced by decomposition in the sediments is quickly oxidized to nitrite and nitrate. In turn, during the summer many lakes exhibit a sharp decrease in nitrate + nitrite levels as these inorganic nitrogen reserves are assimilated by algal growth (Hutchinson 1957; Wetzel 1975; Cole 1979). In Thin Point and Mortensen lakes, ammonia nitrogen concentrations were very low and averaged 4.9 µg/L. In Charlie

Hansen Lake ammonia levels were below the limit of analytical detection (<1.1 µg/L). The nitrate + nitrite concentrations in these lakes were also below the analytical detection limit (<3.4 µg/L), except that in Mortensen Lake concentrations increased to 21 µg/L during the early spring of 1992. Ammonia levels were highest in Red Cove Lake during the summer of 1991 reaching 80 µg/L near the bottom. This is not surprising given the magnitude of algal growth in this lake; however, concentrations decreased to ~3 µg/L during the following spring turnover. A similar trend was observed for Orzinski Lake except mid-summer ammonia concentrations were ~50% (38 µg/L) that of Red Cove Lake and there was little variation with depth. In Red Cove and Orzinski lakes, nitrate + nitrite concentrations were highest in the spring (116 and 76 µg/L, respectively), and lowest in the summer (<3.4 and 3.7 µg/L. respectively). The decrease in nitrate + nitrite concentration following spring overturn is attributed presumably to nitrate assimilation by phytoplankton.

Total Kjeldahl nitrogen (TKN [ammonia plus organic nitrogen]) levels were highest in Red Cove Lake of the five lakes, and was lowest at the surface (176 µg/L) and highest near the bottom (486 µg/L). In the two shallow systems (Thin Point and Mortensen lakes), TKN averaged 281 and 223 µg/L, respectively. The lowest TKN concentrations were found in Charlie Hansen and Orzinski lakes, which averaged 108 and 100 µg/l, respectively. As ammonia nitrogen is either very low or non-existent in these lakes the relatively high TKN levels in Red Cove, Thin Point, and Mortensen lakes indicate high algal biomass. Conversely, the low TKN levels in both Charlie Hansen and Orzenoi lakes indicate low algal biomass.

Chlorophyll a-- Chlorophyll a (chl a) concentrations, an index of algal biomass, were very high within the deep strata of Red Cove Lake ranging from 5.0 to 14.0 µg/L (Table 3). In contrast, near the surface, concentrations were much lower ranging from 0.5 to 1.2 µg/L. In Thin Point and Mortensen lakes chl a levels averaged 4.7 and 4.6 µg/L, respectively or nearly four times the mean concentration for other clearwater sockeye lakes (*see* Appendix I). This is presumably due to morphometry, sufficient nutrient levels, and light which combine to provide optimal conditions for phytoplankton growth. Chl a levels in Orzinski Lake were near the mean for other clearwater sockeye lakes and averaged 1.2 µg/L near the surface, whereas, concentrations in Charlie Hansen Lake averaged only 0.7 µg/L. Thus, in terms of algal standing crop (biomass), the shallow Thin Point and Mortensen lakes are the most productive systems, followed by the brackish Red Cove and Orzinski lakes, and the least productive is the deeper Charlie Hansen Lake.

Zooplankton Density and Size-- Table 4 lists zooplankton densities by taxa for all samples collected from the five study lakes. The limited data indicates relatively low densities of zooplankton in Thin Point Lake (16 to 796/m^2) and for most survey dates in Mortensen Lake (64 to 9,554/m^2); the exception was the July 1991 survey during which 40,600/m^2 of *Eurytemora* (the freshwater form) were observed. The low zooplankton standing stock in these lakes explain the high chl a concentrations, and is most likely the result of these lake's morphometry (shallow depths). In Orzinski and Charlie Hansen lakes, higher zooplankton densities were observed, which is consistent with low chl a concentrations, but because of sporadic sampling the seasonal density is unknown. That is, the peak zooplankton density could have been missed and the seasonal density could be higher than the observed sample densities. For the surveys conducted in Orzinski Lake, *Eurytemora* (the freshwater form) dominated with a density as high as 450,000/m^2; while in Charlie Hansen Lake, *Bosmina* dominated with densities as high as 21,000/m^2. In Red Cove Lake, all zooplankton taxa are of marine origin and indicates that this lake is a brackish environment. *Acartia* were most abundant with densities exceeding 100,000/m^2, followed by *Eurytemora* (the marine form) with a density as high as 5,500/m^2.

Table 4. Density (no./m^2) of zooplankton sampled in Charlie Hansen, Orzinski, Thin Point, Mortensen, and Red Cove lakes.

Lake/ Taxa	Sample date/ Density (no./m^2)							
Charlie Hansen	10/1/89	7/28/91	8/24/91	6/30/92				
Cyclops	1,911	10,828	1,592	2,389				
Bosmina	9,554	20,860	10,669	589				
Chydorinae			32	223				
Orzinski	8/6/91	8/30/91	6/30/92					
Eurytemora	452,760	25,478	73,673					
Cyclops	531		318					
Bosmina	present							
Thin Point	8/25/89	10/5/89 Sta-1	10/5/89 Sta-2	7/28/91	8/24/91	6/30/92		
Eurytemora				32	32	32		
Cyclops		663	796	127	16			
Bosmina			133					
Daphnia			531					
Mortensen	8/23/88 Sta-1	8/23/88 Sta-2	11/10/88 Sta-1	11/10/88 Sta-2	7/26/91	10/3/91	5/27/92	6/7/92
Egrasilus				106	1,433	64		127
Eurytemora					40,605	748	3,662	1,783
Diaptomus	1,699	955		531				
Cyclops	9,554	9,873	425	1,168				64
Bosmina	637		425	955		80		
Daphnia			106	106				
Chydorinae				106				
Red Cove \a	8/24/90	8/6/91	8/30/91	6/30/92				
Evadne		239	425					
Podon	143							
Acartia	4,538	43,949	103,609	11,592				
Eurytemora		5,494	425	159				
Ergasilus	143			318				
Copepod		5,015	0					
Polychaete		2,866	3,397					

\a All zooplankton are marine organisms, Red Cove Lake is essentially a marine environment

The body-length of zooplankton collected from the five study lakes is presented in Table 5. In Charlie Hansen, Orzinski, and Thin Point lakes, *Bosmina* were below the minimum threshold size (0.40 mm) for elective feeding by sockeye salmon fry (Koenings and McDaniel 1983; Kyle et al. 1988), and suggests intense predation pressure. In addition, the size of other zooplankton in these lakes were moderate in size compared to other sockeye nursery lakes. In Mortensen Lake, the size of *Bosmina* in 1988 was >0.40 mm indicating low predation pressure; however the size sample of October 1991 was 0.27 mm, indicating intense predation pressure by juvenile sockeye. This could be due to the combination of natural production and the stocking of hatchery fry into Mortensen Lake; however, it is difficult to make this conclusion based on a sample from one date.

Juvenile Diet--In July 1991, 31 sockeye fry were collected from Mortensen Lake and analyzed for foregut contents (Tables 6). These sockeye fry fed predominately on *Eurytemora* (freshwater copepod) and neomysis (freshwater shrimp), and to a lesser extent on midges (chironomidae; *see* Appendix II). In contrast, during September sockeye fry (n = 11) fed mainly on insects (chironomidae and trichoptera [caddisflies]), and to a lesser extent on neomysis (Table 7). The 85 coho fry collected from Mortensen Lake in July and September fed mainly on insects (chironomidae) and to a lesser extent on hydrachnidia (water spiders) in July and neomysis in September (Tables 6 and 7).

During 4 May-15 June 1992, a total of only 15 (sockeye and coho) smolts were collected at Mortensen Lake, and consequently the peak of migration is believed to be in April (Butch Cobb, ADF&G, Russell Creek Hatchery, pers. comm.). The eight sockeye smolts averaged 77 mm and 5.3 g, and the coho averaged 92 mm and 10.4 g in size (Table 8). The most dominant organisms found in the stomachs of sockeye and coho smolts were snails and fish (unidentified), respectively.

Table 5. Body length (mm) of zooplankton sampled in Charlie Hansen, Orzinski, Thin Point, Mortensen, and Red Cove lakes.

Lake/ Taxa	Sample date/ Body length (mm)							
Charlie Hansen	**10/1/89**	**7/28/91**	**8/24/91**	**6/30/92**				
Cyclops	0.50	0.50	0.46	0.48				
Bosmina	0.34	0.33	0.33	0.33				
Chydorinae				0.37				
Orzinski	**8/6/91**	**8/30/91**	**6/30/92**					
Eurytemora	0.77	0.71	0.67					
Cyclops	0.47	0.43	0.50					
Bosmina	0.32							
Thin Point	**8/25/89**	**10/5/89 Sta-1**	**10/5/89 Sta-2**	**7/28/91**	**8/24/91**	**6/30/92**		
Eurytemora				1.02	1.02	1.32		
Cyclops		0.53	0.75	0.47	0.74			
Bosmina			0.31					
Daphnia			0.61					
Mortensen	**8/23/88 Sta-1**	**8/23/88 Sta-2**	**11/10/88 Sta-1**	**11/10/88 Sta-2**	**7/26/91**	**10/3/91**	**5/27/92**	**6/7/92**
Egrasilus				0.52	0.53	0.54		0.52
Eurytemora					0.71	0.63	0.73	0.70
Diaptomus	0.72	0.66		0.88				
Cyclops	0.51	0.50	0.84	0.65				0.50
Bosmina	0.56		0.50	0.49		0.27		
Daphnia			0.57	0.76				
Chydorinae				0.60				
Red Cove \a	**8/24/90**	**8/6/91**	**8/30/91**	**6/30/92**				
Evadne								
Acartia								
Eurytemora	no lengths taken from marine zooplankton							
Copepod								
Polychaete								

\a All zooplankton are marine organisms, Red Cove Lake is essentially a marine environment

Table 6. Diet content of juvenile sockeye and coho salmon sampled from Mortensen Lake, July, 1991.

Taxonomic group	Sockeye Fry n=31 FL = 50 mm WT = 2.0 g N	%N	%FO	\a	Coho Fry n=30 FL = 37 mm WT = 0.9 g N	%N	%FO
Empty	3	0.2	9.7		1	0.4	3.2
Nematoda (unidentified)	15	0.9	22.6		1	0.4	3.2
Arthropoda							
Insecta							
Diptera							
Chironomidae (pupa)							
Chironomidae (larvae)	173	10.2	54.8		147	57.4	77.4
Chironomidae (adult)	9	0.5	19.4		42	16.4	63.3
Empididae					5	2.0	13.3
Trichoptera					1	0.4	3.2
Odontoceridae (pupa)	2	0.1	6.5		2	0.8	6.7
Collembola					3	1.2	10.0
Crustacea							
Copepoda							
Calanoida							
Temoridae							
Eurytemora	521	30.8	54.8				
Harpacticoida					33	12.9	6.7
Branchiopoda							
Cladocera							
Chydoridae	1	0.1	3.2		3	1.2	6.7
Malocostraca							
Mysidacea							
Neomysis	967	57.2	83.9				
Arachnida							
Hydrachnidia					18	7.0	10.0

\a N = number of diet organisms found, %N = percent number found, %FO = percent frequency of occurrence.

Table 7. Diet content of juvenile sockeye and coho salmon sampled from Mortensen Lake, September, 1991.

Taxonomic group	Sockeye Fry n=11 FL = 63 mm WT = 3.2 g			\a	Coho Fry n=55 FL = 61 mm WT = 3.9 g		
	N	%N	%FO		N	%N	%FO
Empty	3	1.1	5.5		1	2.7	9.1
Salmon eggs	6	2.1	5.5				
Nematoda							
(unidentified)	2	0.7	3.6		1	2.7	9.1
Annelida							
Oligochaeta	2	0.7	3.6				
Arthropoda							
Insecta							
Diptera							
Chironomidae (pupa)	3	1.1	3.6				
Chironomidae (larvae)	28	9.8	16.4		7	18.9	9.1
Chironomidae (adult)	44	15.4	23.6		3	8.1	36.4
Ephydridae	10	3.5	10.9		1	2.7	9.1
Empididae	2	0.7	3.6				
Bibionidae	9	3.2	14.6		1	2.7	9.1
Tipulidae	2	0.7	3.6				
Phoridae	2	0.7	1.8				
Sphaeroceridae	2	0.7	3.6				
Pipunculidae	1	0.4	1.8				
Trichoptera							
Odontoceridae (pupa)	105	36.7	58.2		1	2.7	9.1
Odontoceridae (larvae)	3	1.1	7.3				
Odontoceridae (adult)	2	0.7	3.6				
Hymenoptera							
Braconidae	3	1.1	5.5				
Homoptera							
Aphididae	3	1.1	7.3				
Coleoptera							
Staphylinidae	1	0.4	1.8				
Coleoptera							
larvae (unidentified)	1	0.4	1.8				
Collembola							
Arachnida							
Amaurobidae	1	0.4	1.8				
Crustacea							
Malocostraca							
Neomysis	31	10.8	25.5		20	54.1	45.5
Mollusca							
Gastropoda	5	1.8	3.6		2	5.4	18.2

\a N = number of diet organisms found, %N = percent number found, %FO = percent frequency of occurrence.

Table 8. Diet content of juvenile sockeye and coho salmon sampled from Mortensen Lake, May, 1992.

Taxonomic group \a	Sockeye Smolt n = 7 FL = 77 mm WT = 5.3 g			Sockeye Fry n = 17 FL = 30 mm WT = 0.2 g			Coho Smolt n = 8 FL = 92 mm WT = 10.4 g			Coho Fry n = 10 FL = 38 mm WT = 0.7 g		
	N	%N	%FO	N	%N	%FO	N	%N	%FO	N	%N	%FO
Empty				7	15.2	41.2	1	2.9	12.5	3	25.0	30.0
Decomposed	3	12.5	42.9				1	2.9	12.5	4	33.3	40.0
Arthropoda												
Insecta												
Parts	1	4.2	14.3							2	16.7	20.0
Diptera												
Chironomidae (pupa)	2	8.3	28.6									
Chironomidae (larvae)							1	2.9	12.5			
Chironomidae (adult)				2	4.4	11.8	1	2.9	12.5			
Ephydridae												
Empididae												
Bibionidae												
Tipulidae												
Phoridae												
Sphaeroceridae												
Pipunculidae												
Trichoptera												
Odontoceridae (pupa)										3	25.0	20.0
Odontoceridae (larvae)												
Odontoceridae (adult)												
Hymenoptera												
Braconidae												
Homoptera												
Aphididae												
Coleoptera												
Staphylinidae												
Coleoptera												
larvae (unidentified)												
Collembola												
Arachnida												
Amaurobidae												
Crustacea												
Copepoda (unidentified)				3	6.5	17.7						
Calanoida	1	4.2	14.3									
Harpacticoida	5	20.8	28.6	34	73.9	41.2						
Malocostraca												
Neomysis	1	4.2	14.3				9	26.5	50.0			
Amphipoda												
Gammaridae	1	4.2	14.3				9	26.5	25.0			
Mollusca												
Gastropoda	10	42	14.3									
Fish (unidentified)							10	29.4	37.5			

\a N = number of diet organisms found, %N = percent number found, %FO = percent frequency of occurrence.

The 17 sockeye fry collected during smolt sampling averaged 30 mm and 0.2 g in size, and fed predominantly on *Harpacticoida* zooplankton (Table 8). A total of 10 coho fry were also caught during the smolt sampling , and averaged 38 mm and 0.7 g in size. Four of the 10 coho fry stomach contents were fully decomposed and three were empty; however, the other coho fry stomachs contained insect parts.

Rearing Capacity-- In Mortensen and Thin Point lakes it is apparent that juvenile sockeye fry rely on insects and other macroinvertebrates for food, and quite likely provide a greater portion of nutrition than the limited numbers of zooplankton. Due to the morphometry (shallowness) of these lakes, zooplankton production is limited. Thus, modelling of the rearing capacity of these lakes utilizing either the euphotic volume (EV) model (Koenings and Burkett 1987) or the zooplankton biomass model (Koenings and Kyle 1991) is not meaningful. Consequently, the best approach to determine the rearing capacity of such lakes may be through relating fry recruitment (escapements) and smolt characteristics (age, weight, length), or through low-level, experimental fry stocking.

In Charlie Hansen and Orzinski lakes, the limited zooplankton data indicate that zooplankton is being utilized by sockeye fry, as in both lakes the zooplankton (*Bosmina*) sizes indicate intense predation pressure. The EV model and/or the zooplankton model could be utilized for predicting smolt production after more information is collected next year; however, the probability that sockeye juveniles feed exclusively on zooplankton in these lakes is low. Thus, similar to Thin Point and Mortensen lakes, rearing capacity may best be determined by assessing juvenile recruitment (escapements) or experimental fry stocking with resultant smolt characteristics.

Finally, due to a moderately high salinity of Red Cove Lake, and the inability for sockeye fry to effectively rear in a brackish environment, the rearing quality of this lake is poor. Although there are known age-0 sockeye smolts, these fish rear in a freshwater environment before migrating as smolts. As such, Red Cove Lake would be unsuitable for a fry stocking project, could be considered for a pre-smolt release, but would be best utilized as a smolt release site.

Recommendations

1) Discontinue investigations at Red Cove Lake for a potential fry stocking candidate.

2) Continue limnological surveys on the other four lakes once per month May-September.

3) Increase foregut sampling on theses lakes through collecting a greater sample size and specimens throughout the growing season.

4) Conduct depth sounding on Charlie Hansen and Orzinski lakes to prepare morphometric maps.

5) Collect qualitative (A-W-L) data on migrating smolts from each of the continuing study lakes.

Acknowledgements

Without assistance from the Cold Bay ADF&G Commercial Fisheries Division and FRED Division staff, the initial year of lake investigations in Area M would not have been possible. Specifically, we thank Bob Berceli and Mike Melielo for limnological sample collection and pre-processing of water samples during 1991. In addition, Gary Todd (FRED Soldotna) and Denby Lloyd (Aleutians East Borough) conducted the spring 1992 limnological surveys. Finally, the Commercial Fish Division provide transportation (ADF&G aircraft) to the lakes

for the limnological surveys, and Butch Cobb (Russell Creek Hatchery) provided laboratory space for pre-processing the water samples.

References

Borror, D. J. and D. M. Delong. 1971. An introduction to the study of insects. Third edition. Holt, Rinehart and Wilson. 812 p.

Cole, G. E. 1979. Textbook of limnology. C.V. Mosbly Co. St. Louis. 426 p.

Crowther, J., B. Wright, and W. Wright. 1980. A semi-automated determination of total phosphorus and total Kjeldahl nitrogen in surface waters. Anal. Chem. Acta. 119:313-321.

Edmundson, J. A. and J. P. Koenings. 1985. The effects of glacial silt on primary production through altered light regimes, and phosphorus levels in Alaska lakes. p. 3-19. In: L.P. Dwight [chairman] Proceedings, Resolving Alaska's Water Resources Conflicts. Report IWR-108. University of Alaska-Fairbanks, U.S.A.

Foerster, R. E. 1968. The sockeye salmon (*Oncorhynchus nerka*). Bull. Fish. Res. Board Can. 162:422 p.

Hanson, J. M. and W. C. Leggett. 1982. Empirical prediction of fish biomass and yield. Can. J. Fish. and Aquat. Sci. 41:579-590.

Hutchinson, G. E. 1957. A treatise on limnology: Vol. I. Geography, physics, and chemistry. John Wiley and Sons, Inc., New York. 1015 p.

Ivlev, V. S. 1961. Experimental ecology of the feeding of fishes. Yale Univ. Press, New Haven. 302 p.

Koenings, J. P. and R. D. Burkett. 1987. Population characteristics of sockeye salmon (*Oncorhynchus nerka*) smolts relative to temperature regimes, euphotic volume, fry density, and forage base within Alaska lakes. p. 216-234. *In* H. D. Smith, L. Margolis, and C. C. Wood [eds.]. Sockeye salmon (*Oncorhynchus nerka*) population biology and future management. Can. Spec. Publ. Fish. Aquat. Sci.

Koenings, J. P. and G. B. Kyle. 1991. Collapsed populations and delayed recovery of zooplankton in response to heavy juvenile sockeye salmon (*Oncorhynchus nerka*) foraging. Proceedings of the international symposium on biological interactions of enhanced and wild salmonids. *In* review. Spec. Publ. Can. J. Fish. Aquat. Sci.

Koenings, J. P. and J. McDaniel. 1983. Monsoon and Dickey: two phosphorus-rich brown-water lakes with little evidence of vertebrate predation pressure on the zooplankton community. Alaska Department of Fish and Game, FRED Division Report Series 21: 37 p.

Koenings, J. P., J. A. Edmundson, G. B. Kyle, and J. M. Edmundson. 1987. Limnology field and laboratory manual: methods for assessing aquatic production. Alaska Department of Fish and Game. FRED Division Report Series No. 71. Juneau, Alaska. 212 p.

Kuenzler, E. J., D. W. Stanley, and J. P. Koenings. 1979. Nutrient kinetics of phytoplankton in the Pamlico River, North Carolina. University of North Carolina, Water Resources Institute report No. UNC-WRRI-79-139. 163 p.

Kyle, G. B., J. P. Koenings, and B. M. Barrett. 1988. Density-dependent, trophic level responses to an introduced run of sockeye salmon (*Oncorhynchus nerka*) at Frazer Lake, Kodiak Island, Alaska. Can. J. Fish. Aquat. Sci. 45:856-867.

Murphy, J. and J. P. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chem. Acta. 27:3136.

Pennak, R. W. 1978. Fresh-water invertebrates of the United States, 2nd ed. John Wiley and Sons, New York, NY.

Prepas, E. E. and J. Vickery. 1984. Contribution of particulate phosphorus (>250 μm) to the total phosphorus pool in lake water. Can. J. Aquat. Sci. 41:351-363.

Reimann, B. 1978. Carotenoid interference in the spectrophotometric determination of chlorophyll degradation products from natural populations of phytoplankton. Limnol. Oceanogr. 23:1059-1066.

Schindler, D. W. 1971. Light, temperature, and oxygen regimes of selected lakes in the experimental lakes area, Northwestern Ontario. J. Fish. Res. Board Can. 28:157-169.

Schindler, D. W. 1978. Light, temperature, and oxygen regimes of selected lakes in the experimental lakes area, Northwestern Ontario. J. fish. Res. Board can. 28:157-169.

Smith, V. H. 1979. Nutrient dependence of primary productivity in lakes. Limnol. Oceanogr. 24:1051-1066.

Stainton, M. P., M. J. Capel, and F. A. J. Armstrong. 1977. The chemical analysis of freshwater. Can. Spec. Publ. No. 25, 2nd ed. 180 p.

Strickland, J. D. H., and T. R. Parsons. 1972. A practical handbook of seawater analysis. Bull. Fish. Res. Board. Canada. 167:310 p.

Stumm, W. and J. J. Morgan. 1981. Aquatic chemistry: an introduction emphasizing chemical equilibria in natural waters. John Wiley and Sons. New York. 779 p.

Vollenweider, R. A. 1976. Advances in defining critical loading levels for phosphorus in lake eutrophication. Mem. Inst. Ital. Idrobiol. 33:53-83.

Wetzel, R. G. 1975. Limnology. W.B. Saunders Co., Philadelphia. 743 p.

Wilson, M. S. 1959. Calanoida. p. 738-794. *In:* W. T. Edmondson [ed.], Fresh-water biology, 2nd ed. John Wiley and Sons, New York.

Yeatman, H. C. 1959. Cyclopida. p. 795-815. *In:* W. T. Edmondson [ed.], Fresh-water biology, 2nd ed. John Wiley and Sons, New York.

Appendices

Alaskan lakes stratified into clear, stained, and turbid classes showing the lake-class differences between the ranges and mean values of general water-quality parameters, metals, nutrients, and algal pigments.

	CLEAR (N=57)				STAINED (N=18)				TURBID (N=14)			
Parameter	(n)	Min	Max	Mean	(n)	Min	Max	Mean	(n)	Min	Max	Mean
Conductivity (umhos/cm)	657	6	173	68	201	6	211	73	311	7	134	58
pH (units)	657	5.4	8.9	7.2	201	5.1	8.9	6.7	311	5.7	9.2	7.2
Alkalinity (mg/L)	658	1.5	85.0	21.6	201	0.5	103.0	13.5	310	1.0	48.0	20.9
Turbidity (NTU)	653	0.2	5.2	0.9	202	0.1	4.6	0.9	303	0.3	84.0	17.1
Color (Pt units)	642	2	27	8	191	6	62	23	309	1	27	7
Calcium (mg/L)	655	0.7	33.2	7.9	196	0.7	37.2	4.8	293	1.0	28.4	8.6
Magnesium (mg/L)	602	<0.2	11.6	1.4	182	<0.2	22.4	2.0	273	0.7	4.0	0.9
Iron (ug/L)	628	<3	457	44	168	<3	1179	168	312	18	11476	1029
Total-P (ug/L)	652	1.0	36.6	6.8	192	1.2	23.2	8.1	311	1.2	91.8	22.2
TFP (ug/L)	642	0.1	23.1	3.7	199	0.6	20.3	4.8	312	0.8	28.5	4.4
FRP (ug/L)	647	0.2	21.3	2.5	204	0.5	12.1	2.9	312	0.6	23.3	3.7
TKN (ug/L)	659	11.1	430.9	105.3	206	32.2	493	145.3	311	15.6	204.2	46.4
Ammonia (ug/L)	598	<1.0	118.1	8.4	195	<1.0	64.5	9.1	303	<1.0	92.8	5.2
Nitrate (ug/L)	613	<1.0	634.0	99.7	175	<1.0	679.2	76.0	312	<1.0	290.2	92.7
Silica (ug/L)	642	4	6809	1722	198	26	6194	1333	312	83	3676	1508
Chl a (ug/L)	612	0.02	18.72	1.23	187	0.02	6.46	0.89	301	<0.01	5.80	0.45
Phaeo a (ug/L)	610	<0.01	10.07	0.60	189	0.05	5.32	0.68	301	0.03	6.23	0.28

Appendix II

Common names of organisms found in stomachs of juvenile sockeye and coho salmon sampled from Mortensen Lake.

Order: Diptera (flies)
- Chironomidae (midges)
- Ephydridae (shore flies)
- Bibionidae (march flies)
- Empididae (dance flies)
- Phoridae (humpbacked flies)
- Sphaeroceridae (small dung flies)
- Pipunculidae (big headed flies)

Order: Trichoptera (caddisflies)
- Odontoceridae (no common name)

Order: Hymenoptera (sawflies, ants, wasps, bees)
- Braconidae (no common name)

Order: Homoptera (cicadas, hoppers, aphids)
- Aphidadae (aphids)

Order: Coleoptera (beatles)
- Staphylinidae (rove beatles)

Order: Collembola (springtails)

Order: Arachnida (spiders)
- Amaurobidae (white-eyed spider)
- Hydrachnidia (water mites)

Order: Nematode (round worms)

Order: Mysidacea (opossum shrimp)

Order: Gastropoda (snails and limpets)