FRED Reports

Limnological and Fisheries Evaluation of Sockeye Salmon Production (*Oncorhynchus nerka*) in Malina Lakes for Fisheries Development

by
G. B. Kyle and S. G. Honnold

Number 110

Alaska Department of Fish & Game
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ABSTRACT

Adult sockeye salmon (*Oncorhynchus nerka*) escapements from Upper and Lower Malina Lakes, located on the southwest side of Afognak Island, have fluctuated widely (0 to 40,000) and averaged 7,648 during 1968-1990. Excluding two years of larger-than-average escapements (1979 and 1980), since 1968 escapements in the Malina Lake system have averaged 5,148. In addition, of the 23 years of escapement surveys, only one year (1979) had a return (40,000) approaching a model-projected level based on euphotic volume. Furthermore, in years when parental escapements were higher than the average, returns did not increase. Limnological and fishery investigations of Malina Lakes were conducted during 1989 and 1990 to determine the rearing and adult production potential of sockeye salmon. The results of these investigations indicate that the spawning area could support 20,000 spawners, the rearing area is capable of producing an estimated 225,000 smolts, which in turn, could produce ~50,000 adults. Based on the current carrying capacity (zooplankton biomass), the Malina Lakes system is forecasted to produce only 27,000 optimal-size smolts and an estimated 6,200 adults. Finally, our findings indicate that nutrient additions to Upper Malina Lake over five years would provide desired nutrient ratios, elevate primary and secondary productivity levels, and stabilize the production of sockeye salmon at a higher level consistent with the lake's rearing capacity.

INTRODUCTION

Malina Lakes are located 65 km northwest of the city of Kodiak on Afognak Island (Figure 1). Recent sockeye salmon (*Oncorhynchus nerka*) returns (escapement and harvest) for this system have been as high as 40,202 (1979), and as low as <3,500 (1985). Such highly fluctuating returns of sockeye salmon to the Malina Lakes system have occurred since the late 1960's. As a result, the Kodiak Regional Planning Team (KRPT) and the Kodiak Regional Aquaculture Association (KRAA) currently consider the Malina Lakes system as the highest priority rehabilitation project for sockeye salmon on Afognak Island.

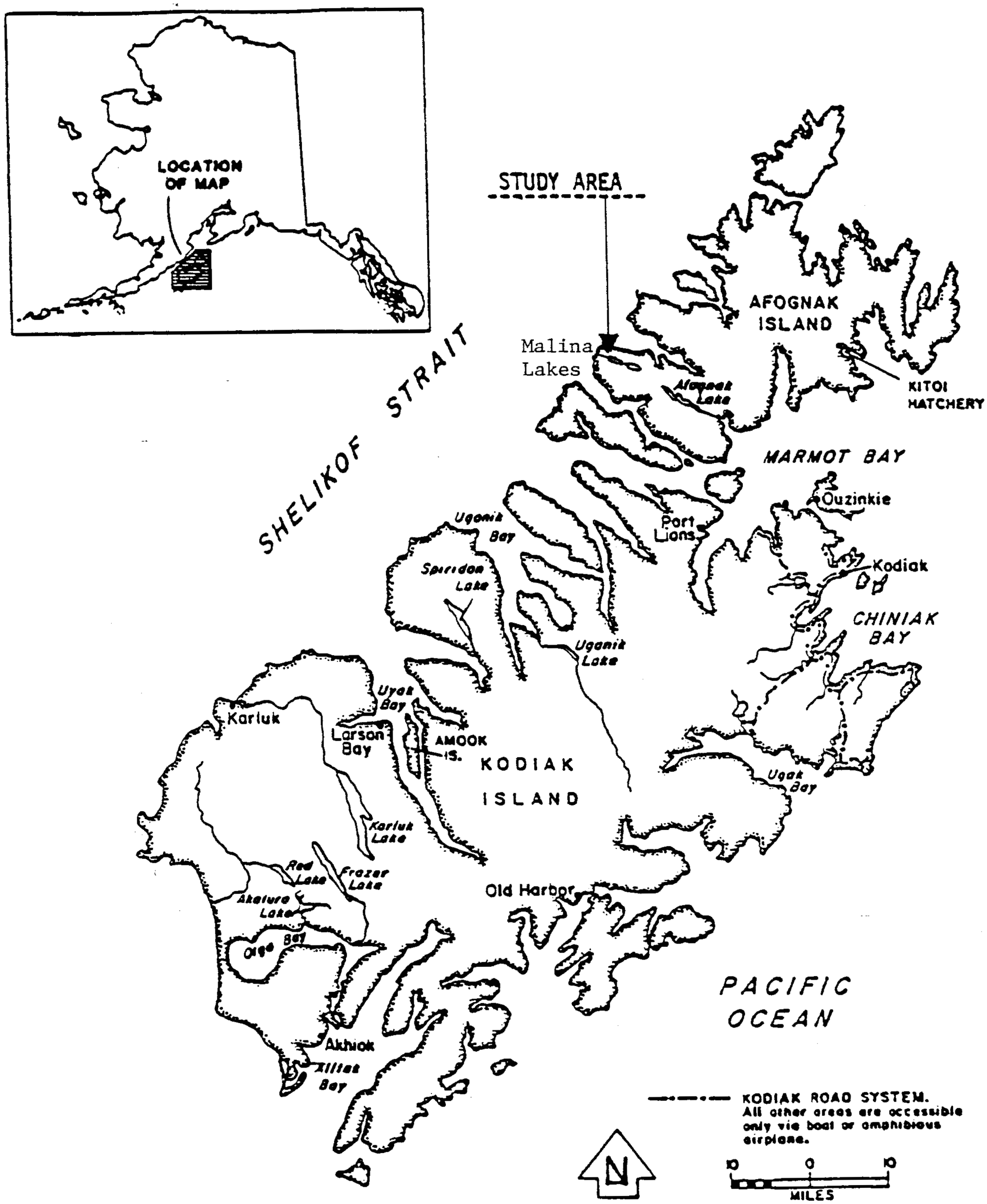

Figure 1. Area map of Kodiak and Afognak Islands showing location of Malina Lakes.

In 1989, the Division of Fisheries Rehabilitation, Enhancement, and Development (FRED) of the Alaska Department of Fish and Game (ADF&G), in cooperation with KRAA, began pre-fertilization fisheries and limnological investigations of Malina Lakes. These studies continued through 1990 and included assessment of all trophic levels of production in Lower and Upper Malina Lakes. In 1990, juvenile fish sampling (trapping) was conducted in both lakes as well as a hydroacoustic survey in Upper Malina Lake to determine the population and distribution of rearing fish. In addition, during 1990 spawning area in the major stream systems was surveyed and spawner distribution surveys were conducted. Adult age and length data were collected by Commercial Fisheries Division of ADF&G in 1990, and adult sockeye salmon were sampled for disease screening in the event this stock is used for stocking in the future.

The purpose of this report is to summarize the results of fisheries and limnological investigations relative to assessment of current sockeye salmon production. In addition, we estimate the potential production of sockeye salmon in the Malina Lakes system, and recommend the appropriate rehabilitative strategy relative to the current production of sockeye salmon within the Malina Lakes system.

Description of Study Area-- Malina lakes (58° 10'N; 153° 05'W), are located on the southwestern end of Afognak Island 65 km northwest of the city of Kodiak. Upper Malina Lake is 2.8 km long, up to 1.1 km wide, and has a total surface area of 1.2 million m^2 (Figure 2), and the lower lake is about half the size (0.7 million m^2) of the upper lake (Figure 3). The maximum depths of the upper and lower lakes are 34 m and 15 m respectively, and both lakes are classified as oligotrophic. The annual precipitation on Afognak Island averages 155 cm, and the lake-water residence time for Upper and Lower Malina lakes is 0.59 and 0.46 years, respectively.

Sockeye salmon begin migrating into the Malina Lakes system in mid- to late-May and continue entering the system until mid-September. Escapement estimates for the Malina Lakes system have been conducted since 1968. Excluding the two recent years of larger-than-average returns (1979-1980), escapements during 1968-1990 averaged 5,148. The

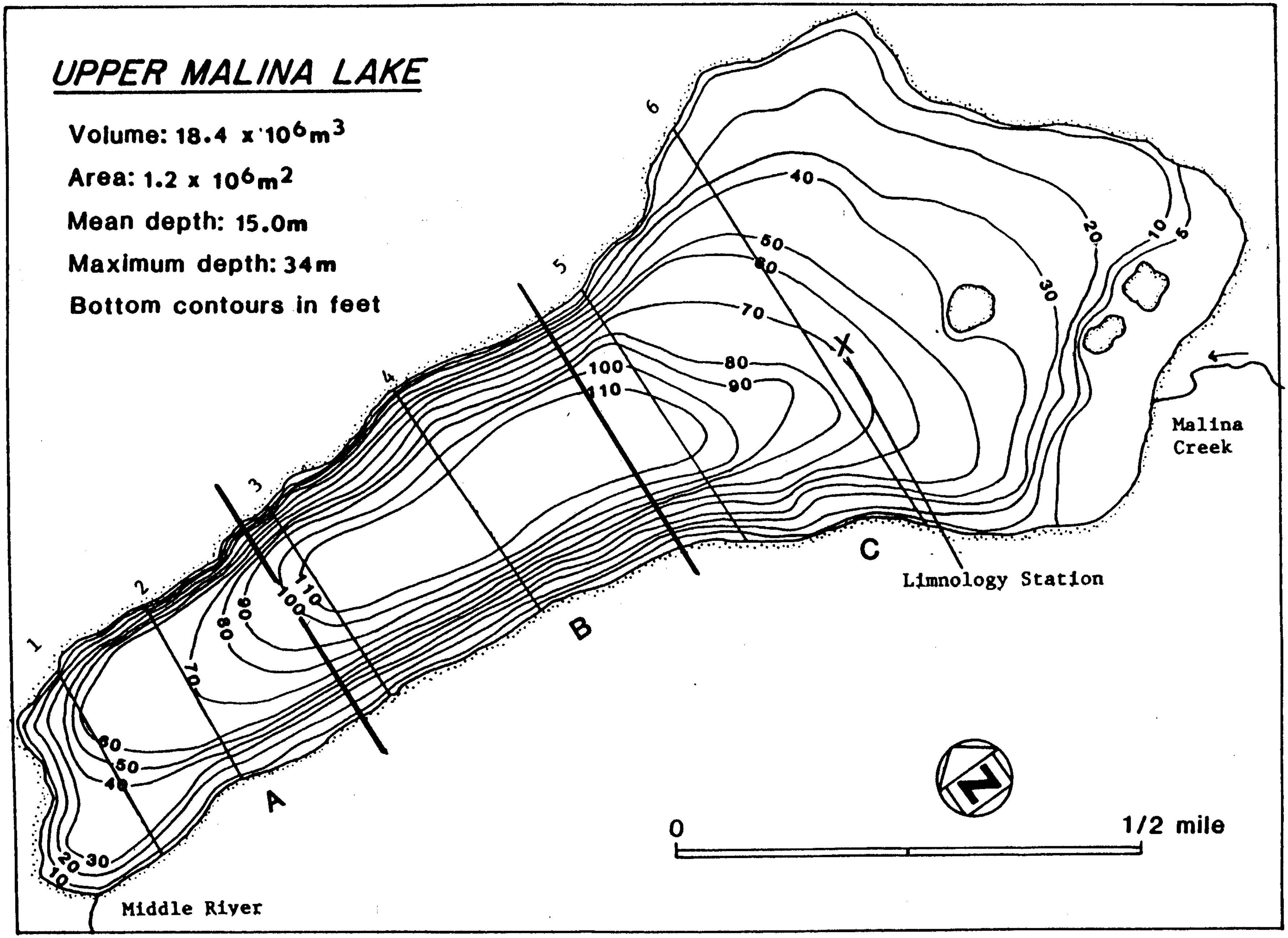

Figure 2. Morphometric map of Upper Malina Lake showing location of the limnology sample station, hydroacoustic areas (A-C) and transects (1-6), and the two streams with spawning populations of sockeye salmon.

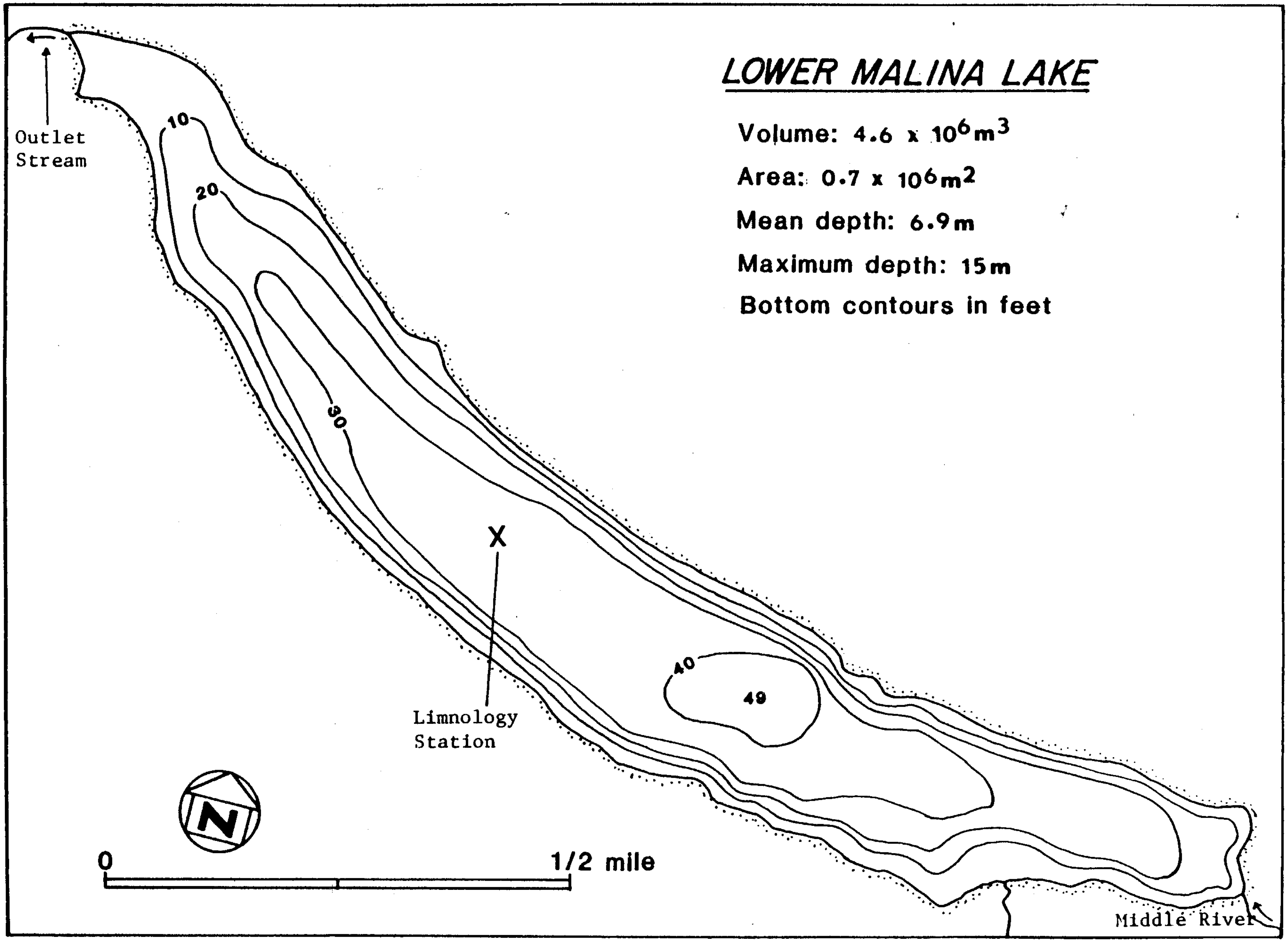

Figure 3. Morphometric map of Lower Malina Lake showing location of the limnological sampling station.

fish spawn from late-July to mid-October, and early spawners utilizing mainly Malina Creek (upper lake) and the later spawners utilizing both the lakeshore and stream habitat between the two lakes to spawn.

Other fish within the Malina Lakes drainage include: pink salmon (*Oncorhynchus gorbuscha*), coho salmon (*Oncorhynchus kisutch*), chum salmon (*Oncorhynchus keta*), rainbow or steelhead trout (*Oncorhynchus mykiss*), Dolly Varden char (*Salvelinus malma*), three-spine stickleback (*Gasterosteus aculeatus*), and freshwater sculpin (*Cottus aleuticus*).

METHODS AND MATERIALS

Juvenile and Adult Salmon Assessment

Smolt and Juvenile Fish Sampling-- A fyke net was placed at the outlet of the upper lake for one week in mid-June and after catching only one sockeye salmon smolt, was moved to the outlet of the lower lake (Figures 2 and 3). Sampling for rearing fish was also conducted in mid-June of 1990 to determine species composition and relative abundance. Minnow traps were placed in the upper lake as well as tributaries of the upper lake, in Malina Creek, in the river between the lakes (Middle River), and in the lower lake. All fish collected were enumerated by species, and in addition, sockeye salmon fry were measured for length (nearest 1.0 mm) and weight (0.01 g) and calculation of the condition coefficient (Bagenal 1978).

Hydroacoustic Surveys-- A fall (October) hydroacoustic survey was conducted in 1990 to estimate the number and distribution of juvenile fish (sockeye salmon fry) rearing in Upper Malina Lake. Six transects perpendicular to the longitudinal axis of the lake were surveyed (Figure 2). The lake was divided into 3 equal areas (A-C) and 2 transects per area were selected randomly. The recording of down-looking acoustic data along the transects was done at night when juvenile sockeye salmon are more evenly dispersed. Flashing strobe lights were placed at one end of each transect to assist in maintaining transect course. A BioSonics® model-105 echosounder with a model-171 tape recorder interface system with a 6/15° dual-beam transducer was used. Fish signals were recorded electronically using a Sony digital audio tape recorder (model TCD-D10) and on chart paper using a BioSonics model-115 chart recorder. Analysis was conducted under a state contract with BioSonics, Inc. using procedures described by Kyle (1990).

Identification of fish species from the acoustic target data was accomplished with the use of a 2 m by 2 m tow net (Gjernes 1979). Three 20-minute tows were conducted along the axis of the lake. Species composition and abundance were recorded for each tow and samples were preserved in 75% isopropyl alcohol. All captured sockeye salmon juveniles were sampled for age, length, weight, and condition coefficient.

Spawning Area Assessment-- Areas where spawning has been observed in the Malina Lake drainage were measured and evaluated to estimate the number of sockeye salmon that could be supported. Malina Creek, Middle River, and the lower section of Malina Lake Creek (outlet stream) were surveyed. Two transects were randomly selected in each section of the stream surveyed and the cross-section was measured. The distance between each transect on each bank was measured, thus giving rectangular dimensions. The dimensions of the two banks as well as the two transects were averaged. The resulting average dimension of width and length were multiplied to estimate the total area (m^2) of the spawning section. The total useable spawning area was determined by estimating the percentage of usable spawning area in each survey section, and multiplying by the estimated total area. Useable spawning area was defined as flows of approximately 0.5 m/sec, water depth of 0.3-0.5 m, gravel size of 6-150 mm with <25% by volume of the gravel ≤6 mm, and minimal compactness (Chambers *et al.* 1955).

The lakeshore spawning area was estimated based on the following assumptions/ techniques: 1) spawning area was limited to a depth of 1.5 m; 2) the 1.5 m shoreline

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area was determined by planimetry of established morphometric map; and 3) approximately 25% of the shoreline spawning area has useable spawning area as defined above.

Adult Surveys and Sampling-- Aerial spawning surveys have been conducted since 1968 by Commercial Fish Division of ADF&G, and peak aerial counts were doubled based on Barrett *et al.* (1984) for estimation of escapements. In addition, FRED personnel conducted a foot survey of Malina Creek in 1990 to determine spawner distribution. In 1989 and 1990, aerial surveys were conducted in September and October to enumerate the late spawners. Scales were taken from 600 fish in 1990, acetate impressions were made, and ages were determined using a microfiche projector. Also, in 1990 ~60 adult sockeye salmon were sampled for the incidence of hematopoietic necrosis virus (IHNV) and another 60 were sampled for bacterial kidney disease (BKD). Finally, stock separation techniques (Barrett and Swanton 1991) were used to estimate the historical contribution of Malina Lakes sockeye salmon commercially caught in the southwest sections (251-10 and 251-20) of the Afognak fishing district that were nearest to Malina Lakes.

Limnological Assessment

Water Sampling-- Limnological surveys were conducted three times during 1989 and five times during 1990. Transportation to and from Malina Lakes was provided by a float-equipped aircraft; limnological samples were collected after mooring to permanent sampling stations (Figures 2 and 3). The frequency of sampling was designed to characterize the lake from May-September. Lake water was sampled at the 1 m (epilimnion) and 10-25 m (hypolimnion) zones for algal nutrients (nitrogen, phosphorus, and silicon) as well as general water quality parameters. 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 Kodiak for filtering and preservation. Subsequent filtered and unfiltered water samples were stored either refrigerated or frozen in pre-rinsed polybottles. The pre-processed water samples were then sent to the

ADF&G Limnology Laboratory in Soldotna for analysis.

Physical Features-- The collection of physical data included the measurement of lake temperatures and light penetration. Lake temperature/dissolved oxygen measurements were taken using a YSI model-57 meter. These measurements 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 defines the depth at which 1% of the subsurface light (photosynthetically available radiation [400-700 mm]) penetrates (Schindler 1971), and it was measured using a Protomatic submersible photometer. Recordings were taken every 0.5 m to 5 m, and every 1 m 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.

Morphometry and Water Residence Time-- Bottom profiles were recorded with a fathometer along numerous lake transects, and used to develop a bathymetric map. The area of each depth strata was determined with a polar planimeter, the lake volume (V) was computed by summation of successive strata (Hutchinson 1957), and the mean lake depth was determined:

$$z = V/A_L$$

Where: z = lake mean depth (m)
V = lake volume ($\cdot 10^6 m^3$)
A_L = lake surface area ($\cdot 10^6 m^2$).

The theoretical water residence time was calculated using the following formula (Koenings *et al.* 1987):

$$T_w \text{ (yr)} = V/TLO$$

Where: T_w = theoretical water residence time (years)
V = total lake volume ($\cdot 10^6 m^3$)
TLO = total lake outflow ($\cdot 10^6 m^3/yr$).

General Water Quality Parameters-- Water samples were analyzed for the following parameters as detailed by Koenings *et al.* (1987). Conductivity (μmhos/cm) was measued 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 (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-- All chemical and biological samples were analyzed by methods detailed 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 was determined using the 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). Total nitrogen was calculated as the sum of TKN and NO_3 + NO_2. Reactive silicon was determined using the method of ascorbic acid reduction to molybdenum-blue after Stainton *et al.* (1977).

Estimation of the yearly phosphorus loading in Upper Malina Lake was 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.

Chlorophyll a-- Algal standing crop 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 were enumerated from duplicate 25-m (Upper Malina Lake) and 10-m (Lower Malina Lake) vertical tows 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. 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). Finally, zooplankter biomass was estimated from an empirical regression between zooplankter body-length and dry weight, and was weighted by organism density (Koenings *et al.* 1987).

RESULTS AND DISCUSSION

Juvenile and Adult Salmon Assessment

Smolt and Juvenile Fish Sampling-- Only one sockeye salmon smolt (age-1) was captured during the 1990 sampling period (Table 1). This smolt was 63 mm in length, weighed 1.5 g, and had a condition coefficient of 0.60. The size of this smolt is well below the desired size of 85-90 mm (5 g) recommended by Koenings and Burkett (1987) for optimum marine survival. If this smolt represents the average size for the entire population, this may indicate that the plankton community is not sufficient to produce smolts of the desired size. Obviously, further sampling is needed to determine the average size of smolts migrating from Malina Lakes.

It is apparent from the smolt sampling conducted in 1990, that the migration occurs prior to mid-June and thus approximates the timing of other Afognak Island smolt populations. Roelofs (1964) and White *et al.* (1990) found that the peak smolt migration at Afognak Lake occurred between May 27 and June 10. Malina Lake smolts probably begin their migration in late-May and evidently end by mid-June.

Fyke net trapping resulted in the collection (and percent composition) of 2,965 (87.0%) three-spine stickleback, 5 (0.1%) Dolly Varden char, 116 (10.5%) sockeye salmon fry, 19 (1.7%) coho salmon fry, 1 (0.1%) freshwater sculpins, 1 rainbow trout, 1 sockeye salmon smolt, and 1 coho salmon smolt (Table 1). The 116 sockeye salmon fry averaged 30 mm in length and 0.19 g in weight, and the mean condition factor was 0.70. Minnow trap catches were similar in composition in that the highest catch was three-spine sticklebacks (88.3%); however, a greater number of Dolly Varden char were collected (Table 1).

Limnetic Fish Population Estimate and Distribution-- The October 01 1990 hydroacoustic survey conducted in Upper Malina Lake revealed a population estimate of 481,694 $\pm$ 104,459 juvenile/small fish (Table 2). Transects 1 and 2 (Figure 2) representing lake area A near the outlet had the highest density of fish. The majority of

Table 1. Summary of catch resulting from fyke and minnow trapping within the Malina Lakes drainage, 1990.

Sample location	Date	Trap type	Sockeye smolt	Sockeye fry	Coho smolt	Coho fry	Rainbow trout	Dolly Varden	Stickle-back	Sculpin
Lower Malina Cr.	6/16	Fyke	0	41	0	2	1	5	145	1
Total			0	41	0	2	1	5	145	1
Percent of total			0.0	21.0	0.0	1.0	0.5	2.6	74.4	0.5
Middle River	6/12	Fyke	0	25	0	7	0	0	18	0
	6/13	Fyke	1	17	1	8	0	0	317	0
	6/14	Fyke	0	32	0	2	0	0	352	0
	6/15	Fyke	0	1	0	0	0	0	133	0
Total			1	75	1	17	0	0	820	0
Percent of total			0.1	8.2	0.1	1.9	0.0	0.0	89.7	0.0
Grand Total			1	116	1	19	1	5	965	1
Percent of total			0.1	10.5	0.1	1.7	0.1	0.5	87.0	0.1
Lower Lake	6/14	Minnow	0	0	0	0	0	0	49	0
	6/15	Minnow	0	0	0	0	0	0	120	0
	6/16	Minnow	0	0	0	0	1	0	82	0
Total			0	0	0	0	1	0	251	0
Percent of total			0.0	0.0	0.0	0.0	0.4	0.0	99.6	0.0
Upper Lake	6/12	Minnow	0	0	0	0	0	0	200	0
	6/13	Minnow	0	0	0	2	0	0	283	0
Total			0	0	0	2	0	0	483	0
Percent of total			0.0	0.0	0.0	0.4	0.0	0.0	99.6	0.0
Middle River	6/12	Minnow	0	0	0	1	0	39	16	0
(between lakes)	6/13	Minnow	0	0	0	2	0	12	7	0
	6/14	Minnow	0	0	0	9	0	47	332	4
Total			0	0	0	12	0	98	355	4
Percent of total			0.0	0.0	0.0	2.6	0.0	20.9	75.7	0.9
Upper Creek	6/12	Minnow	0	0	0	14	0	16	49	0
	6/13	Minnow	0	0	0	9	0	16	128	0
Total			0	0	0	23	0	32	177	0
Percent of total			0.0	0.0	0.0	9.9	0.0	13.8	76.3	0.0
Malina Creek	6/16	Minnow	0	0	0	1	0	0	39	0
Total			0	0	0	1	0	0	39	0
Percent of total			0.0	0.0	0.0	2.5	0.0	0.0	97.5	0.0
Grand Total			0	0	0	38	1	130	1,305	4
Percent of total			0.0	0.0	0.0	2.6	0.1	8.8	88.3	0.3

Table 2. Fish population estimates and variances for paired transect areas of Upper Malina Lake, October 01 1990.

Area	Transect	Mean fish density (no./1000 m^2)	Area (X 1000 m^2) transect	Area (X 1000 m^2) total	Weighted mean fish density (no./1000 m^2)	Variance	Fish population	Variance
	1	777	133					
A				289	598.9	2.71E+04	173,073	2.3E+09
	2	447	156					
	3	451	147					
B				319	398.7	2.34E+03	127,185	2.4E+08
	4	354	172					
	5	267	232					
C				593	306.0	9.76E+02	181,435	3.4E+08
	6	331	361					
							481,693	2.84E+09
					95% confidence interval (+/-)		104,459	

fish (73.7%) were found in the upper depth interval 2-9 m, and showed a strong orientation alongshore (the transect thirds nearshore) (Table 3). Thus, as sockeye salmon juveniles prefer the limnetic area for rearing at this time of year, it appears a majority of the population estimate comprised of other species. Townetting supported this observation as 503 or 84% of the total catch comprised of sticklebacks and 97 or 16% of the total comprised of juvenile sockeye salmon (Table 4). These catch proportions were similar for tows 1 and 3; however, tow 2 had a greater number (and percentage) of sticklebacks. Of the total sockeye salmon catch, 87% were age-1 fingerlings and 13% were age-2 (Table 5). Both age-1 and age-2 fingerlings were relatively small; averaging 46 mm and 0.8 g, and 62 mm and 2.3 g, respectively. The condition coefficient was smaller for the age-1 fingerlings (0.83) compared to the age-2 fingerlings (0.91).

Spawning Area Estimate-- The total stream spawning area in the Malina Lakes system was estimated at 8,376 m^2, comprising of 4,214 m^2 in Malina Creek, 3,570 m^2 in Middle River and 590 m^2 in Lower Malina Creek. Based on an optimum spawning density of 2.0 m^2 per female (Burgner *et al.* 1969), Malina Creek would support 2,107 females; Middle River 1,785 females, and Lower Malina Creek 295 females. The desired escapement at a 50:50 sex ratio would be 4,214 for Malina Creek, 3,570 for Middle River, and 590 for Lower Malina Creek (outlet stream), for a system total of 8,376 stream spawners. In addition, the useable lakeshore spawning area was an estimated 12,500 m^2, which would equate to 6,225 females or a total of 12,500 lakeshore spawners.

Adult Returns and Age Composition-- Escapement surveys and harvest estimates indicate that returns to the Malina Lakes system have been cyclic. For example, escapements decreased from 5,200 in 1970 to 600 in 1972, slowly increased to 12,000 in 1976, then in 1978 no fish were found (Table 6). The next year (1979), the escapement set a new record at 40,000, but decreased again in 1985. With the exception of 1988 when at most there was a small return (aerial survey revealed no fish), it appears that since 1986 the escapement is on an increasing trend. The Commercial Fish Division of ADF&G has set a mid-point escapement goal for this system at 8,000 sockeye salmon, with 10,000 as the

Table 3. Density of fish (no. per m^3) by depth and one-third sections along the 6 transects on Upper Malina Lake, October 01 1990.

		Depth interval (m)			
Tansect	Section \a	2–9	9–18	18–27	27–36
1	S	98.8	13.6	0.0	0.0
	M	38.7	38.8	0.0	0.0
	N	120.8	5.8	0.0	0.0
2	N	94.5	5.6	0.0	0.0
	M	17.7	7.5	0.0	0.0
	S	43.3	15.0	0.0	0.0
3	S	13.8	15.6	1.9	0.0
	M	39.4	25.0	8.6	0.0
	N	63.8	8.2	0.0	0.0
4	N	30.9	11.0	2.4	0.0
	M	7.3	14.4	11.4	0.0
	S	18.6	26.2	8.3	0.0
5	S	23.6	17.5	4.3	0.0
	M	15.8	14.3	5.6	0.0
	N	21.7	0.0	0.0	0.0
6	N	70.9	1.6	0.0	0.0
	M	21.7	3.4	0.0	0.0
	S	30.2	6.2	3.7	0.0
Distribution by depth for all transects (%)		73.7	21.9	4.4	0.0

\a One-third sections where S = south, M = middle, and N = north.

Table 4. Catch of juvenile fish by townetting in Upper Malina Lake, October 02 1990.

Tow no.	Time Start	End	Total minutes	No. sockeye caught	Percent sockeye	Sockeye CPUE \a	No. stickleback caught	Percent stickleback	Stickleback CPUE
1	21:23	21:43	20	50	20.7	2.5	191	79.3	9.6
2	22:23	22:43	20	38	12.0	1.9	278	88.0	13.9
3	22:57	23:17	20	9	20.9	0.5	34	79.1	1.7
		Total	60	97			503		
		Mean			16.2	1.6		83.8	8.8

\a Catch–per–unit–effort.

Table 5. Age, size, and condition coefficient of juvenile sockeye salmon collected by townetting in Upper Malina Lake, October 02 1990.

Tow no.	No. sampled	Age	Age composition	Mean weight (g)	Mean length (mm)	Condition coefficient (K)
1	43	0	95.6	1.0	48.4	0.88
	2	1	4.4	2.0	60.0	0.92
2	24	0	77.4	0.9	46.4	0.90
	7	1	22.6	3.0	67.8	0.96
3	6	0	75.0	0.6	43.6	0.72
	2	1	25.0	1.8	59.5	0.85
Tows	73	0	86.9	0.8	46.1	0.83
1–3	11	1	13.1	2.3	62.4	0.91

Table 6. Summary of sockeye salmon escapement surveys, harvest estimates, and total returns for the Malina Lakes system, 1968–1990.

Survey date	Survey method	Survey count	Escapement estimate \a	Harvest estimate \b	Total return	Exploitation rate (%)
08/05/68	aerial	0	0	ND	–	
08/10/69	aerial	2,500	5,000	ND	–	
08/09/70	aerial	2,600	5,200	ND	–	
07/29/71	aerial	2,000	4,000	ND	–	
08/11/72	aerial	300	600	ND	–	
08/23/73	aerial	0	0	ND	–	
08/08/74	aerial	4,200	8,400	ND	–	
07/28/75	aerial	3,500	7,000	273	7,273	4
07/30/76	aerial	6,000	12,000	697	12,697	5
08/29/77	aerial	2,700	5,400	607	6,007	10
08/13/78	aerial	0	0	–	–	–
08/22/79	aerial	20,000	40,000	202	40,202	1
08/25/80	aerial	13,900	27,800	174	27,974	1
07/31/81	aerial	900	1,800	ND	–	–
08/16/82	aerial	7,000	14,000	405	14,405	3
07/28/83	aerial	3,400	6,800	1,400	8,200	17
07/31/84	aerial	3,100	6,200	1,046	7,246	14
07/25/85	aerial	1,600	3,200	183	3,383	5
08/28/86	aerial	4,000	8,000	2,596	10,596	24
08/21/87	aerial	4,000	8,000	8,010	16,010	50
09/09/88	aerial	0	0	–	–	–
09/13/89	aerial	2,450	4,900	0 \c	4,900	0
08/13/90	aerial	3,800	7,600	10,230	17,830	57
		Mean	7,648	1,986	13,594	15
		Mean \d	5,148	2,313	9,868	17

\a Based on the doubling of survey counts from Barrett et al. 1984.
\b Based on a 7% Malina Lake contribution for statistic areas 251–10 and 251–20 harvest (Barrett and Swanton 1991).
\c No commercial fishery due to Exxon Valdez oilspill.
\d Excludes 1979 and 1980.
ND = no data.

desired escapement and 5,000 as the minimum escapement (Barrett *et al.* 1990). This escapement goal is consistent when considering that the estimated spawning area of the streams can support 8,376 sockeye salmon; however, when the estimated number of potential lake spawners are included, this goal appears to be low.

The historical commercial harvest of Malina Lakes sockeye salmon is difficult to delineate due to a mixed-stock fishery. However, stock separation studies in 1990 showed that approximately 7% of the sockeye salmon harvested in sections 251-10 and 251-20 of the Afognak fishing district is composed of Malina Lake stock (Barrett and Swanton 1990). This would equate to a catch of 10,230 sockeye salmon of Malina Lakes origin in 1990. Using the 7% contribution rate for all years results in a mean historic harvest of 1,986 sockeye salmon for the Malina Lakes system or an exploitation rate of only 15% (Table 6). As, Chapman (1986) indicates that a fishing exploitation rate of approximately 60% is optimum for Alaska sockeye salmon stocks, the Malina Lake sockeye harvest appears to be diminished four-fold.

Malina Creek, which drains into Upper Malina Lake, and the Middle River which is between the two lakes, are the major areas of stream spawning, with the former accounting for approximately 85% of the total stream spawners (Table 7). In addition, during September and October of 1989 and 1990, aerial surveys indicated that the late spawners primarily utilized the lakeshore spawning areas. Sockeye salmon began migrating into Malina Lakes in late-May and reach Malina Creek by early-August. Spawning in Malina Creek began in mid-August and ended by early-September. The later spawning fish entered the system below the lakes in mid-July, and reached the lakes by late-August, and spawning occurred from early-September to early-October.

Finally, the majority of fish that returned to Malina Lakes in 1990 were five-year-old fish (Table 8). Adult samples indicate that 75% of the early fish were age-2.2 with a smaller portion (21.5%) being age-1.2. The remainder of the fish sampled comprised of 2.4% age-2.1, 0.8% age-3.2, 0.2% age-2.3, and 0.2% age-2.4. It should be noted that additional samples will be needed in future years to verify these initial age compositions and to

Table 7. Stream spawning distribution of sockeye salmon within the Malina Lakes system.

Survey date	Location	Survey count	Percent of total
8/22/79	Malina Cr.	32,000	100
	Middle R.	0	0
8/25/80	Malina Cr.	3,200	84
	Middle R.	600	16
9/13/89	Malina Cr.	1,500	70
	Middle R.	650	30
Mean	Malina Cr.		85
	Middle R.		15

Table 8. Age composition of Malina Lake adult sockeye salmon sampled during statistical week 31 in 1990.

Age class	Number sampled	Percent of total
1.2	109	21.5
2.1	12	2.4
2.2	381	75.0
2.3	1	0.2
2.4	1	0.2
3.2	4	0.8
Total	508	100.0

compile age data on the later returning fish. Finally, disease screening of adult sockeye salmon collected from Malina Lakes indicated no incidence of either IHNV or BKD.

Limnological Assessment

Light Penetration-- During 1989-1990, the one percent light level which defines the compensation depth (euphotic zone depth [EZD]) for algal photosynthesis penetrated to a depth ranging from 11.0-16.0 m in Upper Malina Lake and a projected depth of 10.5-15.0 m in Lower Malina Lake (Table 9). The seasonal average (1990) EZD was 13.6 m or 91% of the mean depth of the upper lake and in the lower lake the mean depth (6.9 m) functionally defines the EZD. In addition, the Secchi disk depth ranged from 3.8-5.8 m, and averaged 4.5 m in the upper lake and 4.9 m (3.6-5.8 m) in the lower lake. The euphotic volume (EZD x lake area) for the upper lake is 16.3 x 10^6 m^3 (or 16.3 EV units), and for the lower lake is 4.8 units, for a total of 21.1 EV units.

Temperature and Dissolved Oxygen Regimes-- In Upper Malina Lake, a thermocline was evident during June and July of 1990 (Figure 4); however, no thermocline was apparent during 1990 in Lower Malina Lake (Figure 5). Thus, during June-September 1990, the upper lake heated (>4° C) to the bottom, with temperatures above 10° C at depths down to ~15 m. In the lower lake although there was no thermocline, temperatures were isothermal at ~13° C from the surface to the bottom. Thus, because of the depth to which mixing occurs, a relatively large volume of water in both lakes is heated. Surface temperatures reached 13.5° C in July of both lakes, but unlike the lower lake, surface temperatures in the upper lake dropped in September.

For most of the 1990 season, dissolved oxygen concentrations by depth ranged between 10-12 mg/L (90 - >100% saturation); however, near the bottom in July and September in the upper lake and at all depths in the lower lake, concentrations decreased to as low as 6 mg/L (~60% saturation). The lower concentration is not that unusual considering the deep mixing and higher temperatures during the summer season; however, the lower concentrations were usually within the 8-9 mg/L range which does not warrant serious

Table 9. Euphotic zone depth (one percent light level) and Secchi disk depths by sample date in Malina Lakes, 1989–1990.

Sample date	Secchi disk (m) upper lake	Secchi disk (m) lower lake	1% light level (m) upper lake	1% light level (m) lower lake \a
1989				
06/28	4.5	ND	14.5	10.5
08/03	ND	ND	ND	ND
09/21	5.8	5.8	15.5	11.0
1990				
05/02	5.5	4.5	14.5	12.0
06/01	4.3	4.3	12.0	11.5
06/28	3.8	3.6	11.0	10.5
07/30	4.0	6.5	14.5	13.5
09/13	4.8	5.5	16.0	15.0
Seasonal mean	4.5	4.9	13.6	12.5

\a The projected EZD exceeded the mean depth of the lower lake (6.9 m), so the mean depth functionally defines the EZD.

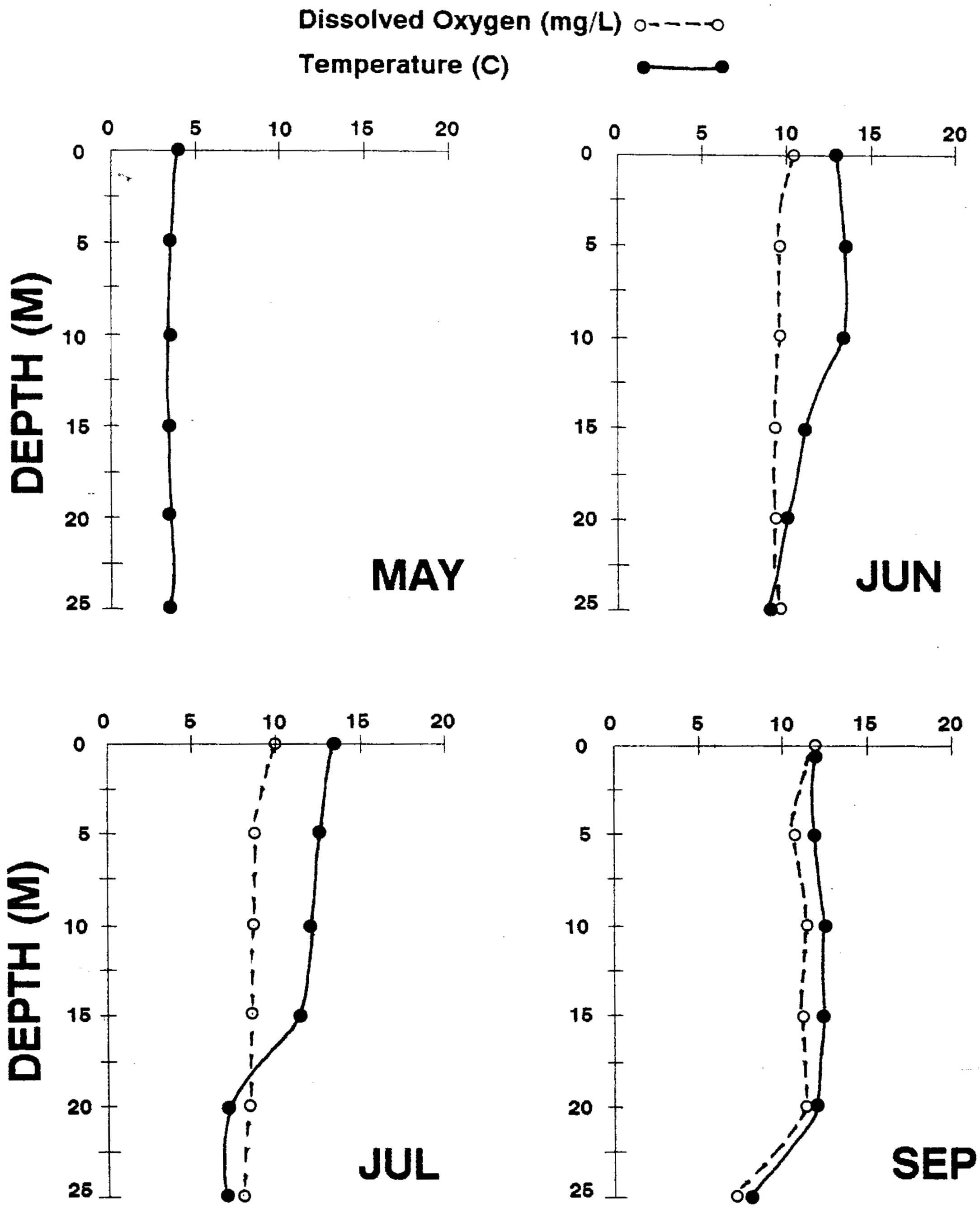

Figure 4. Seasonal temperature and dissolved oxygen profiles for Upper Malina Lake, 1989-1990.

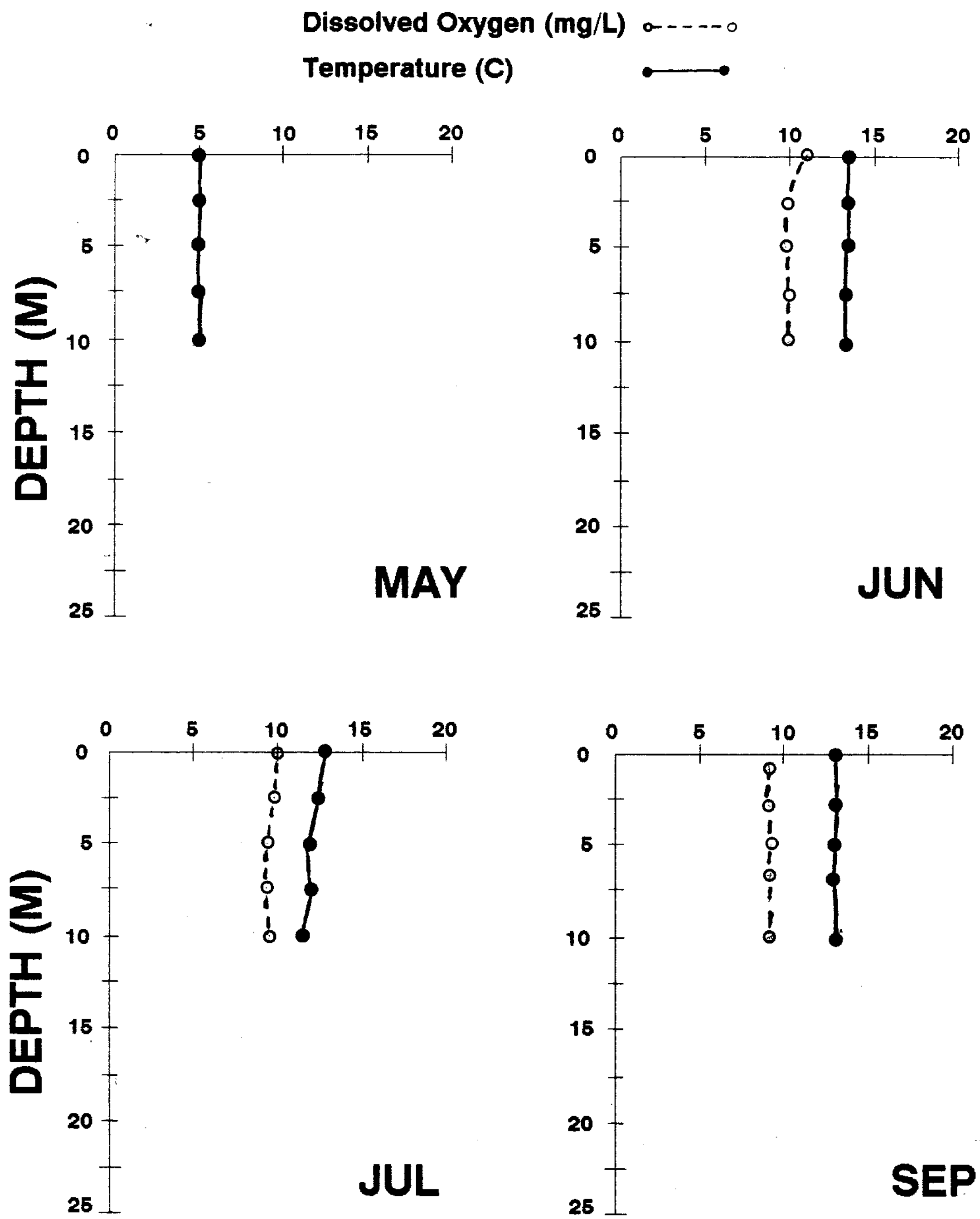

Figure 5. Seasonal temperature and dissolved oxygen profiles for Lower Malina Lake, 1989-1990.

concern relative to oxygen depletion.

General Water Quality Parameters-- Turbidity levels in both lakes ranged between 0.4 and 1.1 NTUs which define the lakes as clearwater without organic stain (Tables 10 and 11). Color ranged between 4 and 14 Pt units, and was usually between 5 and 8 units. Conductivities were relatively high averaging ~80 µmhos/cm for both lakes and depths, Ph varied between 6.8 and 7.5 units, and alkalinity ranged between 18 and 33 mg/L (as $CaCO_3$), averaging ~22 mg/L. Iron concentrations for both lakes ranged between 8 and 86 µg/L, and were higher in the upper lake both within the epilimnion and hypolimnion. The concentrations of both calcium (5.5-8.9 mg/L) and magnesium (<0.2-2.7 mg/L) were within the general range for Alaska lakes.

Nutrients-- Reactive silicon (Si) in the epilimnion ranged between 2,239 and 3,812 µg/L in both lakes and averaged 3,006 µg/L in the upper lake and 2,790 µg/L in the lower lake (Tables 10 and 11). Concentrations in the epilimnion generally equalled those within the hypolimnion, and seasonal cycles were not evident. Such consistency is not surprising given the relatively deep euphotic depth, deep-water mixing throughout the season, and the oligotrophic nature of the lakes. Compared to other Alaskan lakes, silicon levels in the Malina Lakes represent high concentrations.

In Upper Malina Lake, total Kjeldahl nitrogen (TKN) in the epilimnion averaged 136 µg/L in 1989, 85 µg/L in 1990, and 104 µg/L during both years (Table 10). Nitrate + nitrite ranged between 37.8 and 160.1 µg/L and averaged 93 µg/L, while ammonium ranged from 5.7 to 9.7 µg/L and averaged 6 µg/L. Thus, epilimnetic nitrogen comprised 50% organic N, 3% ammonium, and 47% nitrate + nitrite.

In Lower Malina Lake (Table 11), the composition of epilimnetic nitrogen was similar to the upper lake, with 52% being organic N, 5% ammonium, and 43% nitrate + nitrite. In addition, the epilimnetic TKN concentration in the lower lake was similar to the upper lake in that during 1989 the seasonal average was higher than in 1990 (139 µg/L vs 85 µg/L), and the average over both years was 105 µg/L. Epilimnetic nitrate +

Table 10. General water quality parameters, nutrient concentrations, and chlorophyll a concentrations within the epilimnion (1 m) and hypolimnion (17–26 m) by sample date for Upper Malina Lake, 1989–1990.

Year	1989						1990									
Date	6/28		8/03		9/21		5/01		6/01		6/28		7/30		9/13	
Depth	1m	17m	1m	18m	1m	23m	1m	26m	1m	25m	1m	25m	1m	26m	1m	25m
Conductivity (umhos/cm)	80	80	79	103	81	79	80	79	79	79	79	79	76	77	77	81
pH	7.5	7.5	7.5	7.8	7.4	7.5	7.2	7.2	7.4	7.4	7.5	7.4	7.4	7.0	7.3	6.8
Alkalinity (mg/L)	18	18	21	33	20	20	19	19	20	22	22	22	22	22	22	21
Turbidity (NTU)	0.7	0.7	1.0	0.6	0.6	0.6	0.8	1.0	1.1	1.0	0.6	0.8	0.8	0.5	1.0	0.4
Color (Pt)	8.0	8.0	NA	8.0	9.0	9.0	6.0	6.0	6.0	6.0	6.0	8.0	5.0	14.0	9.0	8.0
Calcium (mg/L)	6.9	6.5	7.5	6.9	6.7	7.2	6.9	6.9	5.5	5.5	7.9	7.9	7.6	6.7	7.4	7.4
Magnesium (mg/L)	<0.2	1.5	1.5	1.5	2.7	1.3	1.5	0.7	1.5	1.5	1.8	1.8	1.5	1.5	1.4	1.4
Iron (ug/L)	62	67	41	13	43	57	73	86	24	48	26	31	37	18	33	32
TP (ug/L)	6.0	7.2	6.3	5.3	5.7	5.7	5.7	4.7	5.5	6.7	4.2	3.8	7.2	5.1	4.6	3.6
TFP (ug/L)	4.4	3.1	NA	2.8	3.7	3.7	2.6	2.2	3.5	3.0	4.5	5.3	3.6	8.9	5.6	3.2
FRP (ug/L)	5.1	4.2	NA	4.0	3.3	3.4	1.8	2.1	2.8	2.3	3.3	4.7	2.5	7.3	4.1	2.6
TKN (ug/L)	144.5	150.9	152.5	132.4	112.3	117.2	45.9	55.7	56.6	54.8	65.5	50.4	119.5	54.0	137.2	142.0
Ammonium (ug/L)	4.2	<1.1	NA	21.5	8.8	9.3	6.4	5.9	5.9	6.4	5.9	9.7	5.7	23.4	7.4	40.5
Nitrate + Nitrite (ug/L)	160.1	159.6	NA	154.2	96.8	95.8	127.3	125.8	104.0	104.0	74.7	100.0	53.5	96.5	37.8	91.4
Reactive Si (ug/L)	2,697	2,628	2,618	2,808	2,907	2,932	3,811	3,859	2,757	2,757	3,444	3,274	3,166	3,386	2,648	2,946
Chl a (ug/L)	1.11	0.38	0.44	0.30	0.85	0.26	0.84	0.91	1.03	0.76	0.88	0.43	1.71	0.19	2.41	0.23
Phaeo a (ug/L)	1.20	0.53	1.30	0.52	1.30	0.52	0.35	0.40	0.45	0.54	0.77	0.49	0.73	0.28	0.83	0.31

Table 11. General water quality parameters, nutrient concentrations, and chlorophyll concentrations a within the epilimnion (1 m) and hypolimnion (10–11 m) by sample date for Lower Malina Lake, 1989–1990.

Year	1989						1990									
Date	6/28		8/03		9/21		5/01		6/01		6/28		7/30		9/13	
Depth	1m	10m	1m	11m	1m	11m	1m	11m	1m	10m	1m	10m	1m	10m	1m	10m
Conductivity (umhos/cm)	82	83	82	81	82	80	81	81	81	81	82	82	79	79	81	82
pH	7.5	7.6	7.5	7.3	7.4	7.4	7.3	7.3	7.4	7.2	7.3	7.5	7.4	7.4	7.3	7.2
Alkalinity (mg/L)	21	21	22	23	20	21	20	20	24	21	25	24	23	23	22	23
Turbidity (NTU)	0.4	0.5	0.5	0.5	0.4	0.4	0.8	0.8	0.8	0.8	0.9	0.7	0.5	0.4	0.4	0.4
Color (Pt)	10.0	9.0	10.0	8.0	6.0	9.0	5.0	5.0	6.0	5.0	5.0	5.0	4.0	5.0	5.0	5.0
Calcium (mg/L)	8.4	7.4	7.9	7.0	7.2	7.7	6.9	6.9	5.5	5.5	7.9	8.9	7.6	7.6	7.4	7.4
Magnesium (mg/L)	1.5	1.1	1.5	1.5	1.7	1.7	1.5	1.5	1.5	1.5	1.8	2.7	1.5	1.5	1.4	1.4
Iron (ug/L)	51	53	30	42	34	30	46	53	20	11	45	19	8	12	18	18
TP (ug/L)	5.9	6.1	5.3	4.7	5.9	6.2	4.7	7.0	4.8	6.8	5.9	4.9	5.0	4.6	4.6	4.8
TFP (ug/L)	3.1	2.9	4.5	3.2	3.5	3.6	3.4	3.3	3.7	2.3	3.6	3.2	2.1	3.9	3.1	4.6
FRP (ug/L)	3.7	3.6	4.4	3.5	4.0	3.1	2.8	2.4	2.5	2.6	2.7	3.0	1.8	2.1	2.0	2.5
TKN (ug/L)	140.5	134.8	137.3	138.1	139.7	122.0	66.3	71.7	65.5	74.3	83.2	78.8	78.8	77.9	130.8	134.8
Ammonium (ug/L)	<1.1	2.9	9.3	18.3	12.2	15.4	5.7	5.9	5.9	5.9	5.7	5.9	10.4	12.4	18.3	21.8
Nitrate + Nitrite (ug/L)	105.7	104.7	63.2	67.6	86.4	80.5	121.2	120.2	93.4	91.9	61.6	61.6	46.9	46.4	53.0	53.0
Reactive Si (ug/L)	2,437	2,499	2,417	2,523	2,644	2,656	3,812	3,716	2,482	2,564	3,105	3,347	2,874	2,239	2,549	2,549
Chl a (ug/L)	0.72	0.76	0.67	0.24	0.43	0.41	1.39	1.53	1.12	0.94	1.84	1.61	0.85	0.44	0.53	0.62
Phaeo a (ug/L)	0.41	0.54	0.44	0.26	0.27	0.33	0.42	0.48	0.72	0.61	0.67	0.62	0.40	0.33	0.39	0.55

nitrite ranged between 46.9 and 121.2 μg/L and averaged 79 μg/L, which compared to the upper lake is somewhat lower. Ammonium ranged from <1.1 to 18.3 μg/L in the epilimnion and averaged 8.6 μg/L over both years. Finally, compared to other Alaskan lakes, inorganic nitrogen levels in both Upper and Lower Malina lakes are intermediate in concentration.

Throughout the season of 1989 and 1990, the epilimnetic total phosphorus (TP) concentration in the upper lake ranged between 4.2 and 7.2 μg/L and averaged 5.7 μg/L. Reactive or (inorganic) phosphorus (FRP) ranged between 1.8 and 5.1 μg/L in the epilimnion and averaged 3.3 μg/L. Thus, FRP comprised 58% of TP and was above detectable levels (0.7 μg/L) throughout the entire sampling season. In the lower lake, TP concentrations were similar ranging between 4.6 and 5.9 μg/L and averaging 5.3 μg/L. Reactive phosphorus ranged between 1.8 and 4.4 μg/L in the lower lake and averaged 3.0 μg/L over both years.

Finally, nutrient ratios (by atoms) in the epilimnion during the open-water period equalled 77:1 for TN:TP, 582:77:1 for Si:N:P, and 7.6:1 for Si:N in the upper lake, and were very similar in the lower lake; 77:1 for TN:TP, 584:77:1 for Si:N:P, and 7.6:1 for Si:N. The desired Si:N:P for phytoplankton growth is 17:16:1. Thus, phosphorus concentrations in both lakes are low relative to the supply of nitrogen, and conversely, reactive silicon concentrations were high relative to nitrogen.

Chlorophyll a-- With few exceptions, the algal standing crop (chl a) was low in both lakes during 1989-1990 (Tables 10 and 11). In the epilimnion of both lakes, chl a ranged between 0.43 and 2.41 μg/L, with the higher concentrations found in late-June and mid-September (upper lake). The seasonal concentration of chl a in the epilimnion averaged 1.16 μg/L in the upper lake and 0.94 μg/L in the lower lake. In the hypolimnion of both lakes, chl a concentrations ranged between 0.19 and 1.61 μg/L, and averaged 0.43 μg/L in the upper lake and 0.81 μg/L in the lower lake.

Zooplankton Abundance, Size and Biomass-- In both lakes, the macro-zooplankton community consisted of the following cladocerans: *Daphnia longiremus*, *Bosmina longirostris*, *Holopedium* sp., *Chydorinae* sp., and the following copepods: *Cyclops columbianus*, *Diaptomus pribilofensis*, *Epischura nevadensis*, *Harpacticoida* sp., with trace numbers of *Egrasilus* sp. (Table 12). Seasonal density of cladocerans in Upper Malina Lake averaged 35,076/m^2 or 95% of the composition in 1989, and 44,904/m^2 or 88% of the composition in 1990. In Lower Malina Lake, the seasonal density of cladocerans was less (17,162/m^2 in 1989; 9,404/m^2 in 1990); however, the annual percent compositions were similar (96% in 1989; 87% in 1990).

The macro-zooplankton in both lakes were characterized by the dominance of *Bosmina* beginning in early-June, with densities peaking inconsistently during July-September of both years. During both years, *Bosmina* accounted for ~85% of the total density of macro-zooplankton in the upper lake and 90% in the lower lake. Of the copepods, *Diaptomus* generally dominated in both lakes but accounted for <10% of the total macro-zooplankton.

Body sizes of *Bosmina* (Table 13) were quite small averaging ≤0.34 mm and never exceeded 0.4 mm, which is considered the threshold size for elective consumption by sockeye salmon fry (Koenings and McDaniel 1983). Thus, full utilization of the this food item is apparent. In addition, body sizes of the copepods, which are generally not consumed when adequate numbers of cladocerans are present, were also small, suggesting intense utilization by foraging fish. For example, the body size of *Diaptomus* ranged between 0.60-0.86 mm and *Cyclops* ranged between 0.44-0.90 mm. Finally, the seasonal weighted biomass of macro-zooplankton averaged 53 mg/m^2 in the upper lake and 13 mg/m^2 in the lower lake (Table 14).

EVALUATION

Potential Sockeye Salmon Production-- Considering that the mortality of spawners in small tributaries can be as high as 10% due to brown bear (*Ursus arctos*) predation

Table 12. Macro-zooplankton density (no./m^2) by sample date and seasonal means for Malina Lakes, 1989–1990.

Lake / Zooplankton taxa	Density (no./m^2)						Seasonal mean (no./m^2)
	May	Early Jun	Late Jun	Jul	Aug	Sep	
Upper Malina Lake				1989			
Bosmina longirostris	NA	NA	14,597	NA	40,472	41,667	32,245
Epischura nevadensis	NA	NA	398	NA	6,768	531	2,566
Daphnia longiremus	NA	NA		NA	0	0	0
Cyclops columbianus	NA	NA	531	NA	265	531	442
Diaptomus pribilofensis	NA	NA	3,583	NA	0	0	1,194
Holopedium sp.	NA	NA	133	NA	0	0	44
Chydorinae sp.	NA	NA	398	NA	0	265	221
Harpacticoida sp.	NA	NA	0	NA	0	0	0
				Total seasonal mean			36,712
Upper Malina Lake				1990			
Bosmina longirostris	398	9,952	12,739	94,286	NA	93,286	42,251
Epischura nevadensis	0	0	3,715	2,521	NA	4,910	2,229
Daphnia longiremus	0	0	0	0	NA	0	0
Cyclops columbianus	0	1,327	929	398	NA	1,990	929
Diaptomus pribilofensis	0	5,042	12,739	5,839	NA	929	4,910
Holopedium sp.	0	133	0	663	NA	265	212
Chydorinae sp.	133	133	0	133	NA	663	212
Harpacticoida sp.	0	133	0	133	NA	0	0
				Total seasonal mean			50,743
Lower Malina Lake				1989			
Bosmina longirostris	NA	NA	10,085	NA	30,918	9,421	16,808
Epischura nevadensis	NA	NA	663	NA	663	133	486
Daphnia longiremus	NA	NA	0	NA	0	0	0
Cyclops columbianus	NA	NA	265	NA	265	0	177
Diaptomus pribilofensis	NA	NA	0	NA	398	0	133
Holopedium sp.	NA	NA	133	NA	531	0	221
Chydorinae sp.	NA	NA	265	NA	0	133	133
Harpacticoida sp.	NA	NA	0	NA	0	0	0
				Total seasonal mean			17,958
Lower Malina Lake				1990			
Bosmina longirostris	159	4,793	4,552	23,392	NA	13,137	9,207
Epischura nevadensis	0	0	255	1194	NA	239	338
Daphnia longiremus	0	0	0	16	NA	0	3
Cyclops columbianus	32	255	430	32	NA	80	166
Diaptomus pribilofensis	0	2,500	764	1,131	NA	0	879
Holopedium sp.	0	32	48	32	NA	80	38
Chydorinae sp.	0	239	350	191	NA	0	156
Harpacticoida sp.	48	16	16	16	NA	0	19
				Total seasonal mean			10,806

Table 13. Macro-zooplankton size (mm) by sample date and seasonal weighted means for Malina Lakes, 1989-1990.

Lake Zooplankton taxa	Size (mm) May	Early Jun	Late Jun	Jul	Aug	Sep	Seasonal weighted mean
Upper Malina Lake				1989			
Bosmina longirostris	NA	NA	0.31	NA	0.28	0.28	0.28
Epischura nevadensis	NA	NA	0.55	NA	0.80	0.97	0.80
Daphnia longiremus	NA	NA	ND	NA	ND	ND	ND
Cyclops columbianus	NA	NA	0.58	NA	0.53	0.51	0.54
Diaptomus pribilofensis	NA	NA	0.80	NA	ND	ND	ND
Holopedium sp.	NA	NA	0.62	NA	ND	ND	ND
Chydorinae sp.	NA	NA	0.26	NA	ND	ND	ND
Harpacticoida sp.	NA	NA	ND	NA	ND	ND	ND
Upper Malina Lake				1990			
Bosmina longirostris	0.34	0.40	0.37	0.33	ND	0.33	0.34
Epischura nevadensis	ND	ND	1.17	1.31	ND	1.28	1.25
Daphnia longiremus	ND	ND	ND	0.46	ND	ND	ND
Cyclops columbianus	0.51	0.51	0.65	0.49	ND	0.52	0.54
Diaptomus pribilofensis	ND	0.60	0.81	0.86	ND	0.60	0.77
Holopedium sp.	ND	0.52	ND	0.54	ND	0.57	0.54
Chydorinae sp.	0.26	0.24	0.32	0.28	ND	0.33	0.30
Harpacticoida sp.	ND	0.37	ND	0.58	ND	ND	0.48
Lower Malina Lake				1989			
Bosmina longirostris	NA	NA	0.30	NA	0.27	0.29	0.28
Epischura nevadensis	NA	NA	0.74	NA	0.79	0.83	0.77
Daphnia longiremus	NA	NA	ND	NA	ND	ND	ND
Cyclops columbianus	NA	NA	0.71	NA	0.90	ND	0.81
Diaptomus pribilofensis	NA	NA	ND	NA	0.84	ND	ND
Holopedium sp.	NA	NA	0.48	NA	0.46	ND	0.46
Chydorinae sp.	NA	NA	0.24	NA	ND	0.24	0.24
Harpacticoida sp.	NA	NA	ND	NA	ND	ND	ND
Lower Malina Lake				1990			
Bosmina longirostris	0.31	0.38	0.32	0.30	ND	0.29	0.31
Epischura nevadensis	ND	ND	1.19	1.07	ND	1.09	1.09
Daphnia longiremus	ND	ND	ND	0.37	ND	ND	ND
Cyclops columbianus	0.71	0.61	0.58	0.50	ND	0.44	0.58
Diaptomus pribilofensis	ND	0.61	0.86	0.64	ND	ND	0.66
Holopedium sp.	ND	0.47	0.43	0.53	ND	0.61	0.53
Chydorinae sp.	ND	0.28	0.27	0.28	ND	ND	0.28
Harpacticoida sp.	0.52	0.45	0.52	0.54	ND	ND	0.51

Table 14. Seasonal weighted biomass (mg/m^2) of macro-zooplankton for Malina Lakes, 1989-1990.

Sample month/year		Seasonal weighted biomass (mg/m^2) Upper lake	Lower lake
May-Sep/89		33	14
May-Sep/90		72	11
	Mean	53	13

(Barrett[1] personal communication), a total of 21,850 viable spawners would be needed for the Malina Lake system to fully utilize the available spawning area. Furthermore, using a 50:50 sex ratio and 2,500 eggs/female fecundity; a total of 24 million eggs would be deposited in the spawning substrate. Using an egg deposition-to-emergent fry survival of 4% to 10% (Drucker 1970; Koenings *et al.* 1988), the fry recruitment for Malina Lakes would range from 1.0 to 2.7 million juvenile sockeye salmon each year.
In comparison, the estimated number of juvenile sockeye salmon that Malina Lakes can support based on the euphotic volume (EV) model (Koenings and Burkett 1987) ranges from 1.1 million for production of optimum-size smolts (85 mm/5 g), to 2.3 million for threshold-size smolts (60 mm/2.2 g). Thus, with a goal of producing optimum-size smolts relative to marine survival (Koenings *et al.* 1991), the Malina Lakes system should be able to support 1.1 million juvenile sockeye salmon.

Based on the EV model, approximately 20% (~225,000) of the 1.1 million fry should survive to the smolt stage, and as the average marine survival of 85 mm smolts approximates 23% (Koenings *et al.* 1991), 50,000 adults should survive to the adult stage. However, of the 23 years of escapement surveys (Table 6), only one year (1979) had a return (40,000) approaching the potential adult production. In addition, based upon the relationship between seasonal mean zooplankton biomass and smolt biomass for numerous lakes throughout Alaska (Koenings[2] unpublished data); Malina Lakes, with a combined mean zooplankton biomass of 66 mg/m^2 (1989-1990) would be predicted to produce only 27,000 (5 g) sockeye salmon smolts. Based on a 23% smolt-to-adult survival (for 85 mm/5 g smolts), an estimated 6,200 adult sockeye salmon would be produced from 27,000 smolts. This is considerably less than the estimated average total return in recent years (Table 6), and reveals the current (1989-1990) production of juvenile and adult sockeye salmon in Malina Lakes is quite low compared to the potential production.

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[2]ADF&G, FRED Division, 34828 Kalifornsky Beach Road, Suite B, Soldotna, AK 99669.

Moreover, the escapement into the Malina Lakes system has averaged well below the spawning capacity (~20,000), and in years when parental escapements were higher than average, returns did not increase. Yet, for the Malina Lake system, production estimates based on the EV model and optimum-size smolt survival, indicate annual production (harvest and escapement) should approximate 50,000 sockeye salmon. In addition, for a broad category of sockeye-producing lakes, maximum fry recruitment was estimated at 800-900 spawners/EV (Koenings and Burkett 1987). For the Malina Lakes system, an estimated 16,900-19,000 adults would be required (which is very near the spawning area capacity) to maximize the rearing capacity. Thus, juvenile production is not limited by spawning-area in Malina Lakes but by too few returning spawners and a very low forage base (rearing-limited).

A technique that has proven successful to naturally develop and/or expand a lake's rearing area for increased sockeye production is nutrient enrichment. Koenings and Burkett (1987) have reported that the prevailing rearing capacity can double from lake fertilization. The benefits of nutrient enrichment for this system would be significant. A project of this type and size would cost approximately $40,000 annually. The benefit would be realized by increased adult production and the estimated annual harvest of 25,000 sockeye salmon which would equate to $250,000 (ex-vessel value).

RECOMMENDATIONS

Nutrient enrichment for the Malina Lake system is recommended based on the following:

1) The light regime and the deep mixing within both lakes basically encompasses the entire lake depths, and as such nutrients are thoroughly recirculated within the euphotic zone and not loss to the bottom sediment.

2) The short residence time for both lakes, especially during the summer growing period, rapidly depletes the supply of nutrients needed by

phytoplankton.

3) The natural production of sockeye salmon fry and/or other resident juvenile fish fully utilize the current standing crop of macro-zooplankton, thereby reducing the zooplankton grazing pressure on phytoplankton.

4) The reduction of zooplankton and the consequent reduction of grazing pressure on phytoplankton would place a larger demand on available nutrients.

5) Nutrient enrichment would alleviate an increase in phytoplankton demand for nutrients.

6) Respective to phytoplankton growth, phosphorous concentrations are low relative to nitrogen, but silicon values are high relative to nitrogen.

7) Nutrient enrichment would increase primary and secondary production levels which would result in an increase in the rearing capacity for juvenile sockeye salmon.

8) Throughout the process of expanding the rearing capacity and increasing escapements of sockeye salmon, the biological escapement goal should be evaluated and set commensurate with a higher rearing potential and the existing spawning capacity.

The objective of nutrient enrichment of lakes in Alaska is to apply sufficient phosphorus each year to reach 90% of the minimum critical loading (Vollenweider 1976). Similarly, a loading rate of 90% of the minimum loading rate is suggested for Upper Malina Lake. The existing loading rate of phosphorus (P) into Upper Malina Lake averages 256 mg $P/m^2/yr$. The 90% rate of the critical loading of P is 405 mg $P/m^2/yr$; thus, a total of 149 mg $P/m^2/yr$ or 179 kg P can be added. Additions of phosphorus to Upper Malina

Lake would comprise of adding 3,630 kg (4.0 tons) of a liquid product (20-5-0) containing 20% nitrogen, 5% phosphorus, and 0% potash during 15 May-01 July. In addition, because nitrogen in Upper Malina Lake becomes deficient in mid-summer relative to phosphorus, 1,630 kg (1.8 tons) of nitrogen (32-0-0), in a composition of one-third inorganic nitrogen, organic nitrogen, and ammonium would be applied during 01 July-01 September. Finally, fertilizer would be applied only to the upper lake, as it has a longer water residence time, and added nutrients would eventually drain into the lower lake. Fertilizer would be applied every three days to the central area of the upper lake, and we recommend nutrient additions for five years in order to restore desired nutrient ratios for increased production of successive trophic levels, including the stabilization of sockeye salmon production at a higher level consistent with the lake's rearing capacity.

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