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September 1991

CHIGNIK SALMON STUDIES

POTENTIAL FACTORS INFLUENCING THE LARGE ANNUAL FLUCTUATIONS OF ADULT SOCKEYE SALMON RETURNING TO BLACK LAKE, ALASKA

GREGORY T. RUGGERONE, DOUG HELTON AND DONALD E. ROGERS

ANNUAL REPORT
ANADROMOUS FISH PROJECT

to

NATIONAL MARINE FISHERIES SERVICE
CONTRACT NO. NA90-HFM673

PROJECT PERIOD: 1 JULY 1990 TO 30 JUNE 1991

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FISHERIES RESEARCH INSTITUTE
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Marsha L Landolt
Director

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INTRODUCTION

The Chignik Lake system (63 km^2) is one of the most productive sockeye salmon (*Oncorhynchus nerka*) systems in North America based on adults returning per km^2 of lake surface area. Sockeye salmon run size has averaged 2 million fish since 1965. Nearly equal numbers of sockeye have typically returned to Black Lake (early run fish) and Chignik Lake (late run fish), although variation in annual run size to Black Lake (± 740,000 fish, S.D.) is greater than that to Chignik Lake (± 440,000 fish). Variation in run size to Black Lake has been especially great during the 1980s. In 1984, 1986 and 1987 the runs ranged from 1.9 million to 3.2 million fish, whereas during 1980, 1988 and 1989 only 0.5 million to 0.7 million fish returned to Black Lake. The large fluctuations of sockeye salmon returning to Black Lake are of great concern to Chignik fishermen and processors.

Ruggerone and Rogers (1989) hypothesized that the large fluctuations of sockeye returning to Black Lake are linked to the lake's morphological characteristics, which create highly variable conditions for fish. Unlike Chignik Lake, which has an average depth of ~30 m, Black Lake is a shallow depression in the tundra plains along the northern portion of the Alaska Peninsula. A water depth survey conducted on 18 June 1989 indicated that most of the lake was <2.5 m deep; maximum depth was 3.8 m. The outlet portion of the lake was <1.5 m. Because of the shallow depth and lack of shading by mountains, water temperature in Black Lake increases rapidly during spring. Surface water temperature on 18 June 1989 was 15°C in the center of the lake and up to 19°C along the shoreline. Frequent winds and shallow depth inhibit thermal stratification, thereby eliminating a refuge for sockeye from potential thermal stress. Thus, the shallow depth of Black Lake reduces the buffering capacity of the lake to changing environmental conditions. This characteristic is atypical of most major sockeye lakes.

Two important features of the Black Lake system are a sand bar extending from the Alec River delta to within ~75 m of Sand Pt and a deep channel connecting Alec River to the outlet of Black Lake (Fig. 1). The sand bar is above water during spring, and it separates the main body of the lake (~80 % of lake surface area) from the outlet area. During brief visits to the lower Alec River during June 1985, 1986 and 1987, we visually estimated that ~60% of the river water flowed through the channel leading to the outlet of Black Lake; only ~40% of the water entered Alec Bay and the main body of the lake. On the basis of these observations of Black Lake's physical characteristics, Ruggerone and Rogers (1989) hypothesized that significant mortality of juvenile sockeye in Black Lake may occur at three time periods:

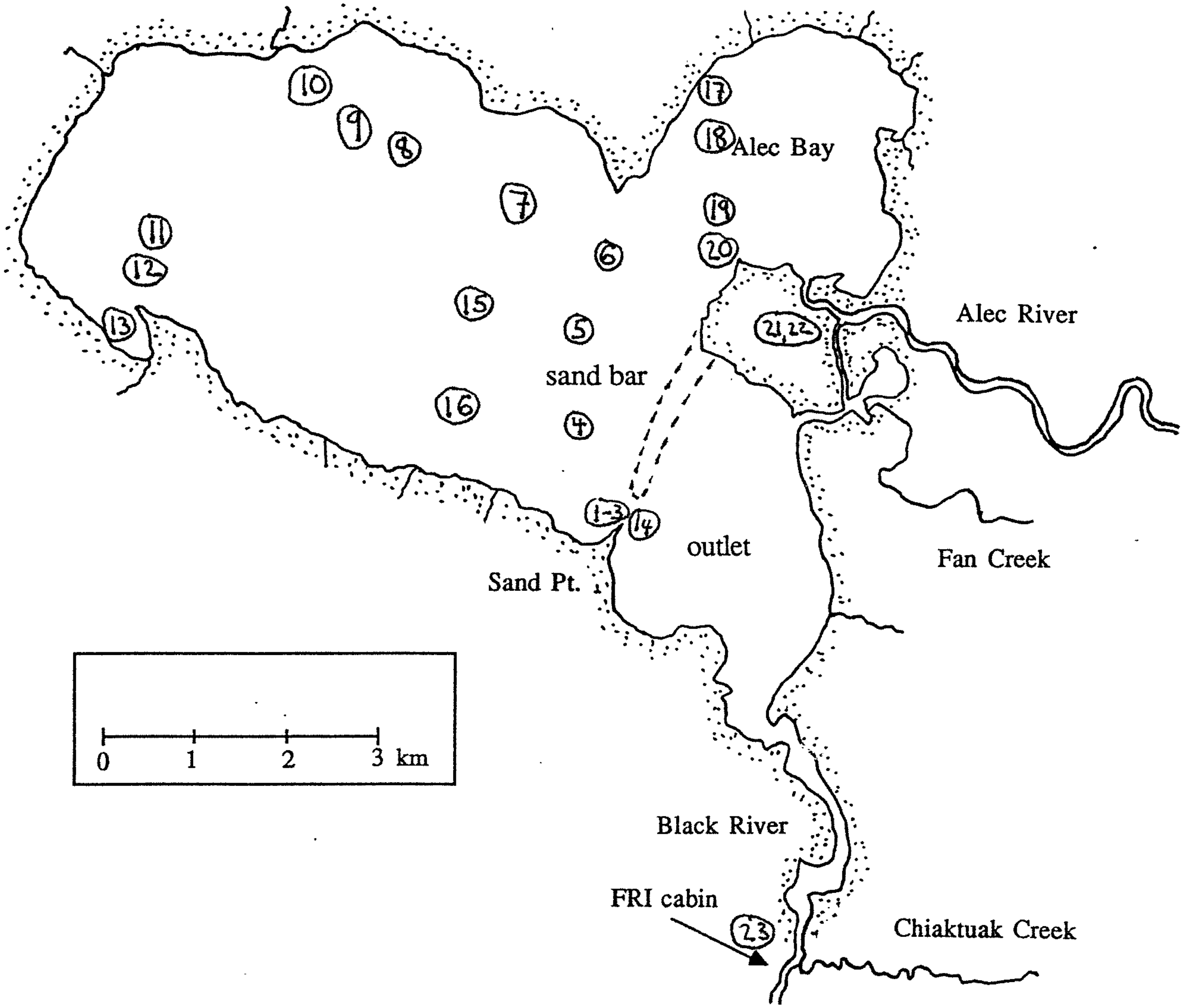

Figure 1. Black Lake in the Chignik lake system. Note the channel connecting Alec River with the outlet area and the sand bar that separates the main lake from the outlet during low water.

1. during late April to early June when newly emerged fry enter Black Lake from Alec River and presumably crowd the outlet area;
2. during summer when water temperatures may reach stressful levels; and
3. during late winter when low dissolved oxygen may result from poor mixing during ice cover, minimal water flow into the shallow lake, and oxygen consumption by decaying aquatic vegetation and respiring vertebrates.

Exceptionally variable survival of sockeye during the incubation period does not appear likely because most tributaries to Alec River have low gradient, few fines, and do not appear to be affected by scouring (M. Dahlberg, NMFS, Auke Bay, Alaska).

The purpose of this report is to summarize the results of our winter investigation of Black Lake during 16 February–3 March, 1990. This study represents the first attempt to investigate salmon at Chignik during winter; therefore, our overall objective was to explore the lake system and provide descriptive information. More specifically, we characterized the physical characteristics of Black Lake, including dissolved oxygen, temperature, depth, and ice thickness. Basic biological information, including chlorophyll concentration, zooplankton abundance and composition, and fish food habits, was also collected.

METHODS

PHYSICAL CHARACTERISTICS

Sampling of the water beneath the ice of Black Lake was accomplished by drilling 10 inch diameter holes with a power ice auger. Measurements of dissolved oxygen, temperature, depth and ice thickness were recorded at 20 stations, including Alec Bay, Alec River and Black River. Vertical profiles of dissolved oxygen and temperature were recorded when depth exceeded 1 m. Dissolved oxygen and temperature were measured using an Orion Model 840 dissolved oxygen meter. Dissolved oxygen, temperature and ice thickness were also recorded at two stations in Chignik Lake (Clark Bay and South Hatchery Beach) for comparison with values in Black Lake.

The volume of water flowing from Alec River to Alec Bay and Black Lake outlet was approximated by drilling holes in the ice at 5-10 m intervals and measuring water depth and velocity. Water velocity was approximated by recording the time for a piece of paper to travel across the 10 inch diameter of the hole at mid water.

CHLOROPHYLL, ZOOPLANKTON AND FISH FOOD HABITS

Chlorophyll density (mg m^{-3}) in the surface water of Black Lake was sampled at two locations (# 15 and 16, Fig. 1) using filtered water samples (1.2 μ) and a Bausch and Lomb Spectronic 20 spectrophotometer (Hardy 1979). Zooplankton density and species composition was estimated at two stations (# 6 and 8) and two depths (surface and 1.2 m) by pumping water (900 g h^{-1}) into a 100 μ zooplankton net for 5 min.

In Chignik Lake, chlorophyll density was measured in Clark Bay (0, 3, 5, 10, and 20 m) and the South Hatchery Beach area (surface). Zooplankton were sampled by 0-40 m vertical plankton net (0.5 m dia., 223 μ mesh) hauls at each location.

Fishes and their stomach contents were sampled primarily in Chignik Lake where it was logistically easier to develop and conduct beach seine, electroshocking and minnow trapping operations. The beach seine (35 m x 4 m, 17 m lead line, 3 mm mesh) was set under the ice by drilling holes with the ice auger every 3 m and moving a line under the ice with a "jigger board". The net was then pulled under the ice and set in the typical U-shape. Captured fishes were removed through a large hole near shore and preserved by freezing. The net was reset under the ice by pulling on two lines leading to the offshore corners. By leaving the net underwater, we reduced the time to set the net (~2-3 hr). Three beach seine set were made in the outlet area of Chignik Lake across from the village (station B). A single beach seine set was made at Black Lake (Sand Pt) using a smaller beach seine (9 m x 2 m with 30 m line, 3 mm mesh).

Minnow traps baited with salmon eggs in a small container were used to sample fishes under ice in the outlet area, Clark Bay, Chignik River and Black River. In Clark Bay, traps were set on the bottom (1 m) near shore and 1 m below the ice approximately 200 m offshore (~40 m deep). We attempted to examine diel foraging patterns by capturing fishes during 1 h soak periods. Fishes were also captured by soaking the traps overnight. In Black Lake (Sand Pt), three traps baited with chopped fish were set overnight. Electroshocking was also used to capture fishes at the head of Chignik River.

All fish samples were preserved by instantaneous freezing in the cold wind, then transported to Seattle for further analyses. Juvenile sockeye, coho and Dolly Varden char were thawed in water, measured (fork length) and examined for stomach contents, which were identified and weighed to the nearest mg. About 20% of the fish were weighed and scales were removed from the preferred area of sockeye and coho for age determination. Dry weight was also measured on 20 sockeye and coho salmon.

RESULTS

PHYSICAL CHARACTERISTICS

The surface of Black Lake initially froze in November and by late February ice covered over 90% of the lake surface area. Open water occurred where water movement was greatest: (1) along the southeastern shore extending from Silver Creek to Black River, and (2) the area between and southeast of Sand Pt and the sand spit extending from the Alec River delta. The surface of Alec River, Fan Creek and Chiaktuak Creek was frozen whereas Black River was ice-free. The thickness of ice on Black Lake averaged 0.42 m (range: 0.27-0.55 m, Table 1).

The water height of Black Lake was about 0.8 m less during February than during mid-June, 1989. Depth of water below the ice averaged 1 m prior to weighting the values by lake area. Average depth of water below the ice was estimated by developing depth contours from surveys during February and June, 1989. Average depth during February was 1.2 m compared to 1.7 m during spring, 1989. Average depth during winter declined only 0.5 m rather than 0.8 m because much of the shallow area during spring was frozen to the bottom during winter (e.g. portions of Alec Bay). Surface area and water volume of the lake during winter declined approximately 17% and 42%, respectively. Approximately 61% of the available water was ≤ 1 m.

Water temperature in Black Lake ranged from 0.1-2.8 °C and significantly increased with depth ($n = 25$, $p < 0.001$, $r^2 = 0.84$, Fig. 2). Dissolved oxygen ranged from 0.4-17.4 mg l^{-1} or 4–144% saturation depending on location and water depth (Table 1). In areas ≥ 1 m, dissolved oxygen significantly declined from an average 10.1 mg l^{-1} just below the ice to 2.8 mg l^{-1} at the bottom ($n = 25$, $p < 0.001$, $r^2 = 0.77$, Fig. 2). Dissolved oxygen relative to saturation at a given temperature also declined from approximately 72% just below the ice to 20% at the bottom ($n = 25$, $p < 0.001$, $r^2 = 0.76$, Fig. 2). In areas where total depth exceeded 1 m, the lower 46% of the water column was below the oxygen threshold reportedly needed to maintain healthy salmon (57% of saturation, Davis 1975). Oxygen in shallow areas of the lake (<1 m) average 10.1 mg l^{-1} or 71.7 % of saturation (Table 1). Approximately 64% of the total water volume during February was usable by salmon, based on reduced O_2 in deep areas and sufficient O_2 in water <1 m. Available habitat (water volume) during February relative to June 1989 was reduced by approximately 63%.

The thickness of ice on Alec River, measured at the point of branching towards Alec Bay and the lake outlet, ranged from 13 to 24 cm. Water flowing to Alec Bay and the outlet was approximately 63 $ft^3\ s^{-1}$ and 111 $ft^3\ s^{-1}$, respectively, based on measurements of water depth,

Table 1. Physical characteristics of Black Lake, Black River and Alec River during February, 1990.

Station	Time	Dist. to shore (m)	Ice thickness (m)	Water depth (m)*	Measurement depth (m)*	Temperature (°C)	Oxygen (mg l^{-1})	Oxygen (%)
1	1400	50	0.34	0.02	0.02	0.5	ND	ND
2	1430	100	0.27	0.31	0	0.4	8.8	60
					0.31	1.0	3.9	33
3	1500	5	0	0.75	0	1.1	8.1	58
					0.75	1.2	8.1	58
4	1600	300	0.50	0.65	0	0.9	8.5	59
					0.65	1.4	4.1	31
5	1700	1500	0.44	2.0	0	0.5	10.0	72
					0.8	1.4	8.4	62
					2	2.4	6.4	47
6	1030	1000	0.37	2.1	0	0.4	10.0	72
					0.7	1.5	11.1	83
					2	2.8	0.4	4
7	1115	1000	0.38	2.4	0	0.2	8.9	63
					0.7	1.1	8.3	58
					1.2	1.7	6.0	43
					2.4	2.8	1.6	12
8	1200	300	0.43	2.9	0	0.2	12.3	85
					1.2	1.9	7.0	51
					2.9	2.8	2.5	18
9	1230	400	0.48	1.9	0	0.4	7.8	52
					1.2	1.2	5.4	38
					1.9	2.3	3.0	15
10	1300	200	0.40	0.8	0	0.2	10.0	68
					0.8	1.2	9.2	64
11	1330	1000	0.49	0.25	0	0.3	9.7	67
					0.25	0.5	10.2	69
12	1400	400	0.45	0.3	0	0.2	17.2	144
13	1430	20	0.48	0.17	0	0.1	17.4	125
14	1500	5	0	0.5	0	0.5	11.1	74
15	1600	2000	0.55	2.2	0	0.2	11.2	77
					0.6	0.5	10.0	69
					1.1	1.0	10.3	72
					1.6	1.0	10.0	72
					2.2	1.8	4.3	30

Table 1— cont.

Station	Time	Dist. to shore (m)	Ice thick-ness (m)	Water depth (m)*	Measurement depth (m)*	Temperature (°C)	Oxygen (mg l^{-1})	Oxygen (%)
16	1630	1000	0.46	1.2	0	0.3	11.2	76
					0.6	0.9	10.1	71
					1.0	1.7	5.3	45
					1.2	2.1	1.5	10
17	1030	300	0.40	0.6	0	0.3	11.8	81
					0.6	0.8	11.2	80
18	1100	750	0.36	0.7	0	0.2	11.8	85
					0.7	0.5	10.1	63
19	1115	900	0.43	0				
20	1130	400	0.25	0				
21**	1330	–	0.24	0.5	0.2	0.0	14.3	96
22**	1400	–	0.20	0.1	0	0.0	13.6	95
23***	1245	–	0	0.2	0.2	0.5	10.2	70

*Measurements taken from bottom of ice.
**Alec River.
***Black River just above FRI station and Chiaktuak Creek.

channel width and water velocity. Approximately 64% of Alec River flowed to the outlet and 34% to the main body of the lake. River water was just above freezing (0.0°C) and saturated with oxygen (14 mg l^{-1} or 95%, Table 1). In contrast, water in Black River was 0.5°C and contained less oxygen (10.2 mg l^{-1} or 70%) after passing through Black Lake.

Ice thickness on Chignik Lake was approximately 0.5 m (Table 2). Temperature increased from 0.1°C just below the ice to 0.4 °C at 4 m and 0.7°C at 40 m. Dissolved oxygen was nearly saturated from the surface to 40 m (>12.2 mg l^{-1} or 84%).

CHLOROPHYLL, ZOOPLANKTON AND FISH FOOD HABITS

Density of chlorophyll *a* just below the surface of Black Lake ranged from 0.84 to 2.16 mg m^{-3}. Zooplankton were scarce in the four samples, averaging 3 cyclopoid, 16 *Bosmina* sp. and 2 harpacticoid zooplankton per m^3.

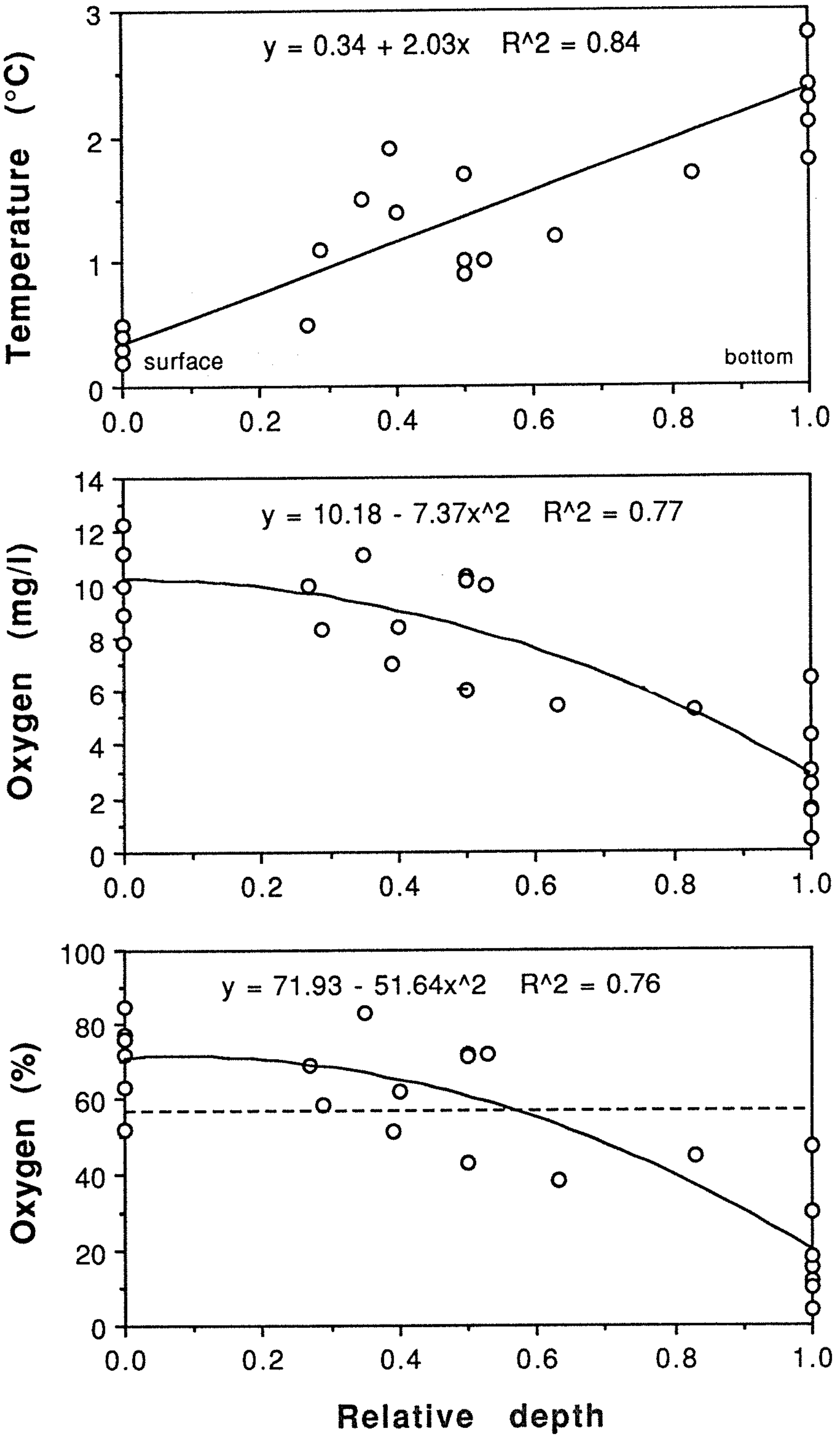

Figure 2. Relationships between temperature, dissolved oxygen and percent oxygen saturation and relative depth (0 = surface, 1 = bottom) of Black Lake in areas exceeding 1 m.

Table 2. Physical characteristics of Chignik Lake during February, 1990.

Station	Time	Dist. to shore (m)	Ice thick-ness (m)	Water depth (m)*	Measure-ment depth (m)*	Temperature (°C)	Oxygen (mg l^{-1})	Oxygen (%)
Clark Bay**	1630	1500	0.5	~50	0	0.1	13.0	90
					1	0.3	13.0	89
					2	0.3	13.0	89
					3	0.4	13.2	88
Cucumber Creek**	1730	1000	0.42	~50	0	0.2	12.2	84
					1	0.3	12.3	84
					2	0.3	12.3	85
					3	0.3	12.6	85
Clark Bay ***	1730	1500	0.5	~50	0	0.1	13.2	93
					3	0.4	13.8	93
					5	0.4	13.3	92
					10	0.4	13.0	89
					20	0.5	13.7	91
					40	0.7	13.4	92

*Measurements taken from bottom of ice.
**0-3 cm snow on ice.
***10 cm snow on ice.

Density of chlorophyll *a* in Chignik Lake ranged from 0.58 mg m^{-3} just below the ice to 0.41 mg m^{-3} at 40 m. Chlorophyll density peaked at 3 m (1.05 mg m^{-3}). Chlorophyll density during February average only 17% of that measured during late June 1989. Zooplankton were scarce in Chignik Lake, averaging only 70 zooplankters per m^3 or 1% of that during late June.

The food habits of 161 sockeye, 90 coho and 17 chinook salmon and 66 Dolly Varden char captured in Chignik Lake indicated that almost no food was consumed by the fish (Table 3). Only 5% of sockeye, 24% of coho, 12% of chinook and 2% of char contained food. The average weight of prey (chironomid larvae, bivalves, copepods and insects) consumed by sockeye was 0.1 mg or <0.01% of their body weight. Weight of prey consumed by coho, chinook and char was <0.3% of their body weight. Coho consumed chironomid larvae and unidentified fish, char consumed fish (sockeye), and chinook consumed Oligocheate worms. Debris (rocks and wood) was frequently found in coho (21%), chinook (18%), char (9%) and, to a lesser extent, sockeye (3.7%). These non-food items were more abundant than food in the fishes' stomachs.

Table 3. Food habits of sockeye, coho and chinook salmon and Dolly Varden char in Chignik Lake during February 1990.

	Sockeye	Coho	Chinook	Char
No. sampled	161	90	17	66
Ave. length (mm)	63	93	76	117
Range (mm)	45-88	47-144	61-84	80-157
Ave. weight (g)	2.0	9.3	4.3	15.5
% feeding	5	24	12	2
Total prey wt. (mg)	0.1	2.2	9.4	12.7
Geom. prey wt. (mg)	<0.1	0.2	<0.1	<0.1
% of body wt.	<0.01	0.04	0.22	0.07
Chironomid larvae	<0.1	0.8	0	0
Stonefly nymph	0	<0.1	0	0
Insecta	<0.1	0.3	<0.1	0
Oligocheate	0	0	9.4	0
Bivalve	<0.1	0.1	0	0
Copepod	<0.1	0	0	0
Gastropod	0	0	0	0
Fish	0	0.7	0	12.7
U.I.	<0.1	0.2	0	0
Debris	0.1	2.7	2.6	5.5

An experiment was conducted to determine whether coho and char would feed in the cold Chignik Lake water (0.1°C) by placing fish in a container with salmon eggs. After 1 h, 17 of 21 coho (81%) and 8 of 19 char (42%) had consumed salmon eggs. The coho and char averaged 127 mg and 121 mg of eggs per fish, respectively. Thus, few coho, char and sockeye captured in the lake contained food apparently because food was not available.

DISCUSSION

PHYSICAL CHARACTERISTICS

The relatively low levels of dissolved oxygen near the bottom of Black Lake during February suggests that organic material (e.g. *Potamogeton* sp., periphyton, filamentous phytoplankton and terrestrial plant material) and possibly inorganic compounds (e.g. sulfates) were consuming oxygen. *Potamogeton* is a large aquatic plant that thrives in the shallow, warm areas of Black Lake during summer and it is an important food source for amphipods and other prey of salmon. However, during fall and winter, *Potamogeton* and algae die and decay under the ice, a process that consumes oxygen and has been responsible for fish kills in small, shallow lakes in other regions (Greenbank 1945; Moorman 1956; Johnson and Moyle 1969; Barcia and Mathias 1979). Sulfates are common to volcanic sediments such as those in the Chignik region and may also consume oxygen during oxidation processes (R. Wissmar, Univ. Washington, Seattle, WA).

The oxygen threshold for causing reduced health among salmonids is estimated to be 57% saturation[1] or 7.3-8.3 mg l^{-1} at 0-5°C (Davis 1975), based on studies of trout and salmon at a variety of life stages. This criterion was derived from studies having temperatures greater than 5°C; extrapolation to 0-5°C was accomplished by considering the oxygen tension needed to move O_2 across the gill membrane and into the blood, and sufficient oxygen (per unit of water breathed) to fulfill requirements of metabolism. Severe effects resulting from short-term exposure (3 h) to low O_2 may occur at 38% saturation (5.6-4.8 mg l^{-1} at 0-5°C).

The February survey of Black Lake suggests that a large percentage (36%) of the potential salmon habitat during winter was not suitable because of low O_2 near the bottom of the shallow lake. Available habitat during winter relative to spring was further reduced by low water level, resulting in a 63% loss of habitat between spring and winter. Assuming 15 million sockeye overwinter in Black Lake[2] (Narver 1966) and 26 million m^3 of water was available to salmon, then approximately 2 m^3 were available to each fish. This density of sockeye is high for a wild population, especially given that threespine stickleback and other fishes were also abundant.

The amount of available habitat for sockeye salmon in Black Lake is affected by low dissolved oxygen and reduced water level during winter. The effect of habitat availability on

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[1] Exposure would likely need to exceed 24 h at this level before detrimental affects would occur, although the interaction between time and concentration is still being debated.

[2] Only ~10% of juvenile sockeye survive after entering the ocean and run size to Black Lake during the 1980s has averaged 1.6 million fish, therefore 15 million juvenile sockeye in Black Lake is a reasonable estimate.

sockeye survival will vary from year to year depending on environmental conditions. For example, Chignik Lake may not freeze during mild winters and snow may not accumulate in dry years. Residents of Chignik noted that temperatures during winter 1989-90 were typical but snowfall was above average (we experienced ~0.5 m of snow in two weeks). Conditions that would reduce salmon habitat include 1) low water level, 2) prolonged cold temperatures that reduce waterflow into the lake from Alec River and increase the thickness of lake ice, and 3) heavy snowfall and calm wind causing snow to accumulate on the lake. Accumulation of snow on the lake would reduce O_2 production by photosynthetic phytoplankton (Greenbank 1945). The interaction between the morphology of Black Lake and weather conditions appears to influence the quality of salmon habitat and could therefore influence the survival of overwintering salmon or cause salmon to prematurely emigrate to Chignik Lake.

A problem with this assessment is that we do not know what proportion of the sockeye population overwinters in Black Lake. Narver (1966) hypothesized that there is a density-dependent migration of age-0 sockeye fry from Black Lake to Chignik Lake but that most sockeye overwinter in Black Lake. During several years of sampling, fyke net catches of age-0 sockeye in Black River were low in late June (<25 per 24 h), high in July and early August (up to ~600-15,000 per 24 h) and variable in late August (Burgner and Marshall 1974), indicating large numbers of fry emigrate to Chignik Lake. Periodic catches of yearling sockeye in beach seine hauls and gill nets during summer suggest that some sockeye overwinter in Black Lake. Extensive sampling of Black Lake yearlings during winter and smolts during May and early June has not been conducted. The early emigration of sockeye from Black Lake might be related to the low buffering capacity of the lake to changing environmental conditions.

Salmon habitat in Black Lake might be improved by (1) stabilizing the water level of Black Lake and (2) rechanneling Alec River water to Alec Bay and the main portion of the lake. Stabilizing water level near the high water level (~1 m above low water during winter) would nearly double the water volume during the low water period (early spring, late summer and winter) and enhance the buffering capacity of the lake. Stabilizing water level would greatly enhance available habitat by increasing water volume and by allowing juvenile sockeye to occupy shallow areas presently not utilized. For example, over 50% of the lake was <1 m during low water and juvenile sockeye, which are sensitive to low dissolved oxygen and turbulent conditions, generally avoid shallow areas. Stabilizing the lake level would allow sockeye to better utilize the abundant food resources (e.g. insects) in shallow areas. Additionally, Chignik Lake sockeye might also benefit from the stabilization of Black Lake if fewer Black Lake sockeye fry immigrate to Chignik Lake.

Sockeye in Black Lake might also benefit by rechanneling Alec River water to Alec Bay and the main portion of the lake. Presently, approximately 60% of Alec River water flows to the lake outlet, which is nearly isolated from the lake at low water by a long sand bar. We believe that a greater proportion of water might flow to the lakes' outlet in years to come based on the observed changes in channel morphology during recent years. Rechanneling Alec River water to the lake would increase the volume of oxygen-rich water, increase circulation, and reduce the residence time of water in the main lake area. Additional potential benefits of rechanneling the river were suggested by Ruggerone and Rogers (1989). Further research is needed to evaluate the stabilization of Black Lake and the rechannelization of Alec River as methods to stabilize and enhance the Black Lake sockeye run.

CHLOROPHYLL, ZOOPLANKTON AND FISH FOOD HABITS

Zooplankton abundance in Black and Chignik lakes was exceptionally low and analysis of sockeye stomach contents indicated that fish in Chignik Lake did not consume food. The lack of food in sockeye stomachs probably resulted from few available prey rather than reduced appetite. For example, coho and Dolly Varden char also consumed few prey, but readily consumed salmon eggs in an aquarium.

The daily ration needed to maintain body weight of juvenile sockeye at 0.1 to 3°C is estimated to be 0.32% to 0.43% body weight per day, respectively (Brett et al. 1969). A 2 g sockeye would require 6-9 mg food per day at these cold temperatures. Without feeding, sockeye would lose approximately 0.1% to 0.14% body weight per day at 0° to 1°C or an average of 3.6%, 7.2% and 10.8% body weight after 30, 60 and 90 days, respectively. A slight loss of body weight during winter would probably not adversely affect most sockeye populations but the Chignik Lake stock is unique. Chignik sockeye experience a relatively high density of fish and grow slowly. If the condition of Chignik sockeye is weak when they enter the winter period, then the lack of food, even at these cold temperatures, might affect their survival.

During early May 1990, Mike Thompson (pers. comm., ADFG, Kodiak, Alaska) observed several thousand dead juvenile sockeye in the upper portion of Chignik Lake[3]. The fish did not appear emaciated. Bill Lind (pers. comm., Chignik Lake) also noted dead sockeye in Chignik River in early May. Upon arrival on 1 June, FRI personnel observed dead sockeye in Chignik River. Factors causing these fish kills are unknown, however live sockeye collected in Chignik Lake and River by FRI were exceptionally thin for their length. For example, 60 mm sockeye

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[3] A comprehensive survey of dead fish was not conducted and total mortality was unknown.

captured in Chignik Lake (1.36 g) on 5 June were 30% lighter than those captured in the Wood River Lakes during fall (1.95 g, Rogers 1964). Further research is needed to evaluate the relationship between condition of sockeye entering the winter period, feeding during winter and survival to spring. If low food production during winter is shown to affect sockeye survival, then steps may be taken to mitigate food availability. Preliminary analyses of sockeye bioenergetics during near freezing temperatures suggests that supplemental feeding of sockeye under the ice (~160 lbs per day) could maintain the body weight of sockeye in Chignik Lake.

RECOMMENDATIONS

Research should continue to answer the following questions:

1. Do many sockeye overwinter in Black Lake?
2. Does dissolved oxygen and lake level vary from year to year? If so, then how much?
3. Does the low O_2 near the bottom of Black Lake adversely affect sockeye?
4. Do sockeye in Black Lake avoid areas of low dissolved oxygen? (An avoidance reaction might stimulate emigration to Chignik Lake during winter).
5. How much food do sockeye consume in Black and Chignik lakes during winter?
6. How many sockeye smolts (and fry) emigrate from Black Lake during May and early June?

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