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CHIGNIK SALMON STUDIES
Investigations of Salmon Populations, Hydrology,
and Limnology of the Chignik Lakes, Alaska

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Final Report
Anadromous Fish Project

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KEY WORDS

Alec River, beach seine, Black Lake, Chignik Lake, escapement goals, fry emergence, hydrology, limnology, long-term trends, *Oncorhynchus nerka*, Ricker recruitment curve, sockeye salmon, townet

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INTRODUCTION

The purpose of this work is to annually measure the relative abundance and size of juvenile sockeye salmon (*Oncorhynchus nerka*), relative abundance of potential competitor and predator species, and the biological and physical environment for sockeye salmon in the lakes during spring through fall. These data are complementary to sockeye smolt studies conducted by the Alaska Department of Fish & Game (ADFG) and winter ecology studies by G. Ruggerone. A long-term database resulting from these measurements provides a basis from which to evaluate changes in the production of adult sockeye salmon from the Chignik Lakes and perhaps a means of stabilizing or increasing production.

A key concern among Chignik fishermen, residents, and biologists has been the substantial change in the water volume of Black Lake since the late 1960s. This change appears to have caused greater premature outmigration of Black Lake sockeye to Chignik Lake (Ruggerone et al. 1993, Ruggerone 1994). Large emigrations of fry appear to have a significant adverse effect on adult returns to Chignik Lake. The exceptionally low water volume and adverse conditions during some winters appear to influence large annual fluctuations in adult returns to Black Lake (Ruggerone 1997).

The objectives of the 1998 research and monitoring at Chignik were to continue the basic monitoring of biological and physical characteristics that were monitored in past years plus conduct two additional projects: Alec River hydrology and reexamination of spawning escapement goals for Chignik sockeye salmon. The Alec River hydrology project stems from past measurements documenting the shifting of the Alec River from Alec Bay to the Black Lake outlet (Ruggerone 1997). The reexamination of spawning escapement goals stems from the concern that the productivity of the system may be changing. In addition to these projects, a Master's thesis on the effects of

egg predation on beach spawning sockeye was completed in 1998 (Miller 1999).

The 1998 field work was done in two periods: June 18 through July 18, and September 1 through September 7. The following work was done:

- Water transparency (Secchi depth), phytoplankton (chlorophyll *a*), and zooplankton densities were measured to assess the summer standing crop of primary producers and zooplankton (the main source of food for sockeye salmon in Chignik Lake).
- Emergent fry traps were employed along Hatchery Beach and Delta Beach. The traps were set in mid-June and checked about every 6 days to assess the relative abundance and timing of emergent sockeye fry.
- Beaches were seined weekly at seven established stations on Chignik Lake from June to July to assess the relative abundance of juvenile sockeye salmon and associated species nearshore.
- Townnetting was conducted in both Black and Chignik lakes during early September to assess the relative abundance and lengths of juvenile sockeye salmon in the pelagic region.
- Water content of sockeye smolts collected during May was measured as an index of fish health.
- Measurements of discharge in the south and north forks of the Alec River were made on five occasions and bank erosion of the south fork was monitored.

LIMNOLOGY

Methods

Water temperature, water transparency, phytoplankton, and zooplankton samples were collected four times on both Black Lake (three stations, Fig. 1) and Chignik Lake (two stations, Fig. 2). Water clarity was estimated with a Secchi disk. Water temperatures were taken with a pocket ther-

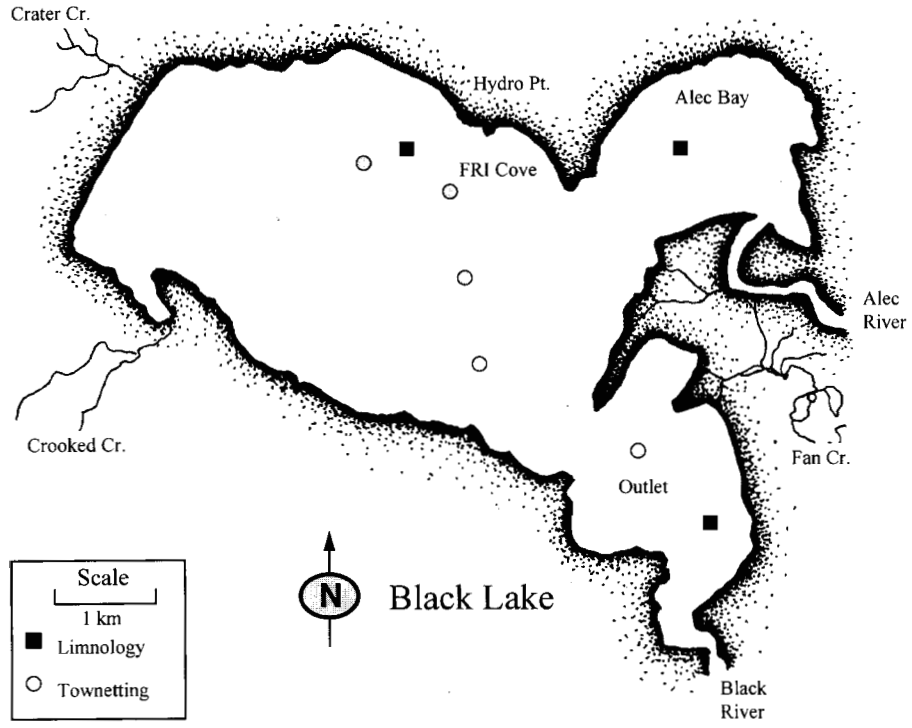


FIGURE 1. Black Lake sampling sites.

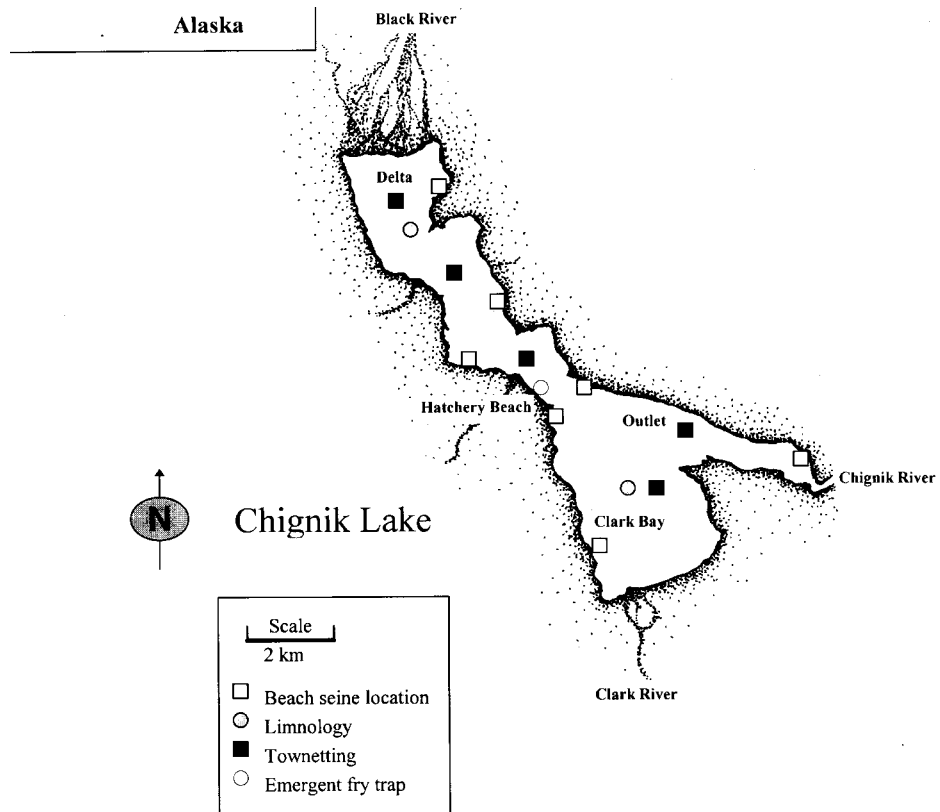


FIGURE 2. Chignik Lake sampling sites.

ometer on the lake's surface at Black Lake and from water taken with a van Dorn bottle at Chignik Lake. Water samples were taken immediately below the surface for Black Lake, which is shallow and well mixed, and at 0, 1, 5, 10, and 20 m below the surface in Chignik Lake. Chlorophyll *a* analysis was conducted on water that was sieved through Millipore filters (0.48 μ); the amount filtered depended on how much algae was in the water (i.e., denser samples clogged the filter faster). The filters were then processed with a Spectronic 20 spectrophotometer. Zooplankton samples were taken with a 153- μ mesh, .5-m diameter net in Chignik Lake by hauling the net 40 m vertically through the water. In Black Lake, zooplankton were collected by hauling the net horizontally along the lake surface for approximately 20 m.

Results

Black Lake is shallow and turbid. Water temperature responds quickly to air temperature and increases rapidly after ice-out. In 1998, water temperature exceeded 10°C by mid-June and increased to 13°C by mid-July before declining to approximately 10°C in September (Table 1). Black Lake warms more rapidly than Chignik Lake, but temperature also declines more rapidly in the fall (Ruggerone 1997).

Secchi readings in Black Lake are influenced by phytoplankton and suspended sediments caused by wind storms. Secchi depths in 1998 (1.0 m) were somewhat lower than in previous years (1.3–2.2 m) (Tables 1 and 2). Chlorophyll *a* measurements were exceptionally high during mid-summer, averaging 3.0 mg/m³. Highest concentrations were found in the main lake area (Hydro Pt.) com-

TABLE 1. Limnological data from Black Lake, 1998.

Date	Location	Secchi depth (m)	Surface temp. (°C)	Chlorophyll <i>a</i> mg/m ³
6/20	Hydro Pt.	1.5	11.2	n/a
	Alec Bay	1.0	10.5	n/a
	Outlet	1.0	7.5	n/a
7/3	Hydro Pt.	1.3	13.0	5.68
	Alec Bay	0.7	12.0	2.20
	Outlet	1.0	12.0	4.19
7/16	Hydro Pt.	1.5	13.5	2.36
	Alec Bay	1.5	13.2	1.26
	Outlet	0.9	13.0	2.35
9/3	Hydro Pt.	0.5	10.5	n/a
	Alec Bay	0.4	9.5	n/a
	Outlet	0.5	11.0	n/a
1998 means		1.0	11.4	3.01

pared with the outlet and Alec Bay, which are both greatly influenced by runoff from Alec River. Chlorophyll *a* in Black Lake is high compared with that of other sockeye lakes in Alaska (Burgner et al. 1969, Ruggerone 1994).

Zooplankton densities in Black Lake were low compared with those in Chignik Lake (Table 3). The lower density probably reflects the shallow depth of the lake, high density of planktivores, high suspended sediments during wind events, and less efficient sampling by the plankton net, which often clogged with filamentous diatoms. Insects are important sockeye prey in Black Lake compared with Chignik Lake (Parr 1972, Ruggerone 1994).

Chignik Lake is much deeper than Black Lake and the water column is typically well-mixed by the strong, consistent winds. Water temperature averaged approximately 8.2°C in June and remained near 11°C through early September (Table 4). Secchi readings ranged from 1.4–3.5 m. Lower transparency occurred near the northwest portion of the lake where the relatively turbid Black River enters the lake.

Chignik Lake typically has an exceptionally high concentration of phytoplankton compared with other major sockeye lakes. In 1998, chlorophyll *a* averaged 2.4 mg/m³, which is similar to past years (Tables 4 and 5).

TABLE 2. Averages of limnological data from Black Lake, 1992–98.

Date			Secchi depth (m)	Surface water temp. (C)	Chlorophyll <i>a</i> mg/m ³
Mo	Day	Year			
6	20	92	n/a	n/a	3.24
7	8	92	n/a	n/a	2.28
9	3	92	n/a	n/a	4.59
5	18	93	1.6	8.8	1.26
6	16	93	1.7	9.7	0.98
7	16	93	1.8	15.5	0.60
8	15	93	0.9	12.7	4.33
9	9	93	0.7	12.5	3.32
6	9	95	1.4	11.2	3.67
6	20	95	1.4	10.7	1.34
7	11	95	1.5	12.3	1.15
7	23	96	1.8	13.8	2.26
6	2	97	2.2	12.5	1.75
6	20	98	1.2	9.7	n/a
7	3	98	1.0	12.3	4.02
7	16	98	1.3	13.2	1.99
9	3	98	0.5	10.3	n/a

TABLE 3. Zooplankton densities in Chignik and Black Lakes (1,000 m²), 1998.

Lake	Location	Date		Category							Total
		Mo	Day	Calanoids	<i>Cyclops</i>	<i>Daphnia</i>	<i>Bosmina</i>	<i>Chydoris</i>	Nauplii	<i>Asplanchna</i>	
Chignik	Clark Bay	6	22	13	162	5	10	1	25	140	356
		7	4	26	88	12	16	0	17	334	493
		7	14	52	77	4	13	1	29	148	324
		9	15	49	70	17	91	8	78	5	318
Chignik	Delta	6	24	19	94	3	5	1	16	76	214
		7	4	22	97	1	20	1	22	109	272
		7	14	29	53	12	11	0	9	275	389
		9	15	259	126	129	270	1	97	9	891
Black	Hydro Pt.	6	20	4	33	0	5	0	3	2	47
		7	3	17	44	0	15	2	10	5	93
		7	16	84	202	1	391	45	39	20	782
		9	3	7	20	0	81	5	6	11	130
Black	Alec Bay	6	20	2	15	0	2	0	5	1	25
		7	3	8	21	0	5	1	7	2	44
		7	16	5	5	0	14	0	6	1	31
		9	3	1	1	0	32	2	1	3	40
Black	Outlet	6	20	1	1	0	0	0	0	0	2
		7	3	4	22	0	13	1	2	3	45
		7	16	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
		9	3	6	30	0	74	6	7	9	132

Chignik Lake: From 40-m vertical hauls with a .5-m net of 153- μ m mesh. Two hauls per date and station.

Black Lake: From 20-m horizontal hauls with a .5-m net of 153- μ m mesh. Two hauls per date and station.

TABLE 4. Limnological data from Chignik Lake, 1998.

Date	Clark Bay				Delta			
	Secchi depth (m)	Depth (m)	Water temp. ($^{\circ}$ C)	Chloro-phyll a mg/m ³	Secchi depth (m)	Depth (m)	Water temp. ($^{\circ}$ C)	Chloro-phyll a mg/m ³
6/22	1.7	0	8.5	n/a	1.4	0	8.7	n/a
		1	8.2	n/a		1	8.6	n/a
		5	8.0	n/a		5	8.2	n/a
		10	8.0	n/a		10	8.2	n/a
		20	7.8	n/a		20	8.2	n/a
7/4	3.0	0	10.5	n/a	1.8	0	10.8	n/a
		1	10.0	2.76		1	11.0	4.63
		5	9.5	2.69		5	10.8	4.26
		10	9.0	2.03		10	10.7	2.87
		20	9.0	1.59		20	9.4	1.57
7/14	3.5	0	11.0	1.79	1.5	0	12.5	2.70
		1	11.0	2.28		1	12.5	1.14
		5	11.0	2.62		5	11.0	2.31
		10	10.5	2.32		10	10.5	2.22
		20	10.0	1.13		20	10.0	1.50
9/5	1.8	0	n/a	n/a	2.0	0	n/a	n/a
		1	11.5	n/a		1	11.5	n/a
		5	11.3	n/a		5	11.0	n/a
		10	11.0	n/a		10	11.0	n/a
		20	11.0	n/a		20	11.0	n/a

TABLE 5. Averages of limnological data from Chignik Lake, 1992–98.

Date			Secchi depth (m)	Averages over 1-20 m	
Mo	Day	Year		Temp. (C)	Chlorophyll <i>a</i> (mg/m ³)
6	23	92	1.8	9.6	3.27
7	11	92	2.6	9.9	2.68
9	3	92	n/a	10.8	5.42
5	10	93	2.2	4.3	7.96
6	17	93	1.4	9.1	0.88
7	26	93	0.6	12.4	0.81
8	18	93	0.8	11.7	1.49
9	10	93	0.8	11.6	1.71
6	8	95	1.7	7.5	4.89
6	17	95	1.6	9.0	3.23
6	29	95	2.5	9.1	2.61
7	7	95	2.4	10.1	1.85
7	17	95	2.7	11.1	2.91
6	17	96	2.0	9.0	3.22
7	4	96	2.7	n/a	1.50
7	12	96	2.6	9.6	2.03
7	30	96	2.8	12.3	1.94
8	8	96	4.2	11.2	1.92
5	26	97	3.15	7.0	2.93
6	11	97	2.25	9.2	3.64
8	15	97	1.6	13.1	1.73
8	28	97	2.1	12.3	2.10
6	22	98	1.55	8.2	n/a
7	4	98	2.4	10.1	2.80
7	14	98	2.5	11.0	2.00
9	5	98	1.9	11.2	n/a

Zooplankton in Chignik Lake displayed the typical seasonal pattern of relatively high abundance of *Cyclops* spp. during spring followed by an increase in numbers of cladocerans during late summer and fall. Abundance of zooplankton was somewhat low in 1998 (407,000 m⁻²) compared with past years (range: 393,000 to 4 million m⁻²) (Table 6). Zooplankton abundance in Chignik Lake was high compared with sockeye lakes in central and south-east Alaska (228,000 ± 48,000 m⁻²) (Kyle 1991) and western Alaska (250,000 m⁻² for 60-m haul) (D.E. Rogers, Univ. Washington School of Fisheries, unpubl. data).

The exceptional zooplankton abundance in 1997 (4.0 million m⁻²) was associated with the exceptionally abundant smolt outmigration in 1998 (Perez-Fuentetaja et al. 1999). The 1998 smolts were predominantly age-2 fish, indicating probable origin from Chignik Lake. The smolts were also large for their age, indicating zooplankton prey were abundant.

Environmental factors influencing the exceptional zooplankton abundance in 1997 are unknown. However, the weather pattern encompassing southwestern Alaska in 1997 was unusual and was apparently atmospherically linked to the El Niño event off South America. In Chignik, wind was unusually calm, the sky was clear and water temperature was relatively warm. These conditions may have been ideal for zooplankton production in Chignik Lake, which is typically well-mixed and relatively cool.

EMERGENT FRY

Since 1986, numbers of emergent fry have been estimated on two beach spawning areas of Chignik Lake using conical shaped traps (see Ruggerone 1994 for methodology). Peak emergence appears to be in early June, but many fry can emerge in May. The fry emergence index period consistently used in the historical database spans the month of June. No field work was done in 1994, but our sampling resumed in 1995 on the Hatchery and Delta beaches.

In 1998, sampling did not begin until June 18. A total of 20 traps were deployed from June 18 to July 18. Monthly fry counts (number/m²) during June were 5.1 along Hatchery Beach and 6.4 along Delta Beach (Table 7). The counts undoubtedly underestimated the rate of emergence because peak emergence occurs in early June. These estimates were below average but not exceptionally low compared with several past years.

The exceptionally high emergence rate at Hatchery Beach (a major spawning ground) in 1996 corresponds with the exceptionally large smolt emigration in 1998. Thus, high emergence rates in 1996 and an abundance of zooplankton prey in 1997 appeared to influence the exceptionally large age-2 smolt production from Chignik Lake in 1998.

Too few data are available for the purpose of comparing emergence rates with adult returns. However, available data suggest adult returns to Chignik Lake may be positively correlated with emergence rates and negatively correlated with large returns to Black Lake (multiple regression, $n = 8$, overall $p = 0.08$). These preliminary results are consistent with other data that suggest large emigration of fry from Black Lake to Chignik Lake has an adverse effect of adult returns to Chignik Lake (Ruggerone 1996).

TOWNET SAMPLING

Townet hauls were made annually in the Chignik Lakes from 1960 to 1973 (Rogers et al. 1996). Although tow lengths sometimes varied, all catches were standardized

TABLE 6. Historical zooplankton densities in Chignik Lake (1,000 m²), 1992–98.

Category							Total
Calanoids	<i>Cyclops</i>	<i>Daphnia</i>	<i>Bosmina</i>	<i>Asplanchna</i>	Nauplii	<i>Chydoris</i>	
1	488	29	1	7	11	0	537
2	292	12	1	19	6	0	332
17	251	18	4	66	11	0	367
22	199	34	16	231	9	0	511
285	177	206	338	37	133	0	1176
74	144	2	4	0	0	0	224
48	77	0	22	0	0	0	147
380	239	16	423	0	0	0	1058
82	67	35	120	0	0	0	304
17	26	82	109	0	0	0	234
9	115	7	7	6	24	2	170
5	124	6	7	10	20	3	175
7	155	16	20	38	16	4	256
15	205	25	56	68	44	7	420
39	258	32	107	78	52	3	569
356	224	537	498	43	108	18	1784
33	69	4	19	59	20	11	215
51	131	4	27	116	78	24	431
286	258	10	97	152	215	34	1052
108	96	10	62	176	13	34	499
182	117	36	159	159	62	17	732
21	1866	24	55	11	304	19	2300
77	1892	55	29	0	135	55	2243
1449	422	2342	1951	399	825	6	7394
677	509	1079	1642	223	299	13	4442
16	128	4	8	1	21	108	285
24	93	7	18	1	20	222	383
41	65	8	12	1	19	212	357
154	98	73	181	5	88	7	605

TABLE 7. Sockeye fry emergence rates during June, 1998 (fry per m² per 30 days) on Chignik Lake beaches.

Year	South Hatchery		
	north	Delta	Average
1986	26.3	12.8	19.6
87	40.3	25.1	32.7
88	43.5	40.4	42.0
89	2.9	15.8	9.4
90	6.2	12.3	9.3
91	13.4	2.7	8.1
92	5.0	6.3	5.7
93	2.6	2.1	2.4
94			n/a
95	7.5	20.3	13.9
96	70.4	2.9	36.7
97	31.4	19.4	25.4
98	5.1	6.4	5.8
1986-1997	22.7	14.6	18.6
Averages			

Calculations based on Ruggerone et al. 1993,1994.

1998 estimates are low because sampling occurred only during last half of June and early July

to 10 min (Parr 1972). Arithmetic and geometric means have been calculated in the past; however, only arithmetic means are presented here. Since 1973, townetting has been sporadic; however, we have sampled both lakes since 1992, except for 1994 (Table 8). Catches of juvenile sockeye salmon were relatively high in both Black Lake and Chignik Lake during 1998. Catches of yearling sockeye in Chignik Lake were exceptionally high in 1997, corresponding with the large age-2 smolt outmigration in 1998.

BEACH SEINING

Beach seining was conducted in Chignik Lake in several years prior to 1973 (Rogers et al. 1996). Catches of juvenile sockeye salmon have been recorded as larger or smaller than 45 mm. The small fish were likely to be fry (age 0) whereas the larger fish likely were a mixture of small yearlings from Chignik Lake and large fry from Black Lake. Beach seining has been done intermittently since 1980 in Chignik Lake (Table 9). Juvenile coho salmon are usually more abundant in beach seine catches than in townet catches, which reflects their preference for the nearshore habitat (Ruggerone 1989).

Catches of juvenile sockeye salmon were relatively high in 1998, especially for the larger fish that probably origi-

nated from Chignik Lake spawning areas. The larger size class of sockeye salmon was also abundant in 1997, corresponding with the great abundance of age-2 smolts in 1998.

ALEC RIVER HYDROLOGY

Previous research has shown that the south channel of the lower Alec River leading into the lake outlet is becoming larger relative to the north channel leading into the main lake (Ruggerone 1994, 1997). The cause of the shifting Alec River channels appears to be related to the lowering of Black Lake elevation, which was apparently caused by downstream migration of the West Fork River and subsequent degradation of Black River since the late 1960s. The migration of Alec River channels is important to sockeye salmon because greater discharge to the south channel during early spring will carry larger numbers of emerging sockeye fry to the outlet of Black Lake and may encourage more fry to emigrate to Chignik Lake. During low-water periods, a sandspit crosses approximately 80% of the lake and separates the main lake from the outlet.

Erosion of the banks along the south channel of Alec River has been monitored since 1991 (Ruggerone and Denman 1991), and in 1993 the relationship between total

TABLE 8. Average tow net catches for Chignik and Black Lakes (10-min tows), 1980-98.

Date		No. of tows	Species						
			Sockeye salmon		Juvenile coho	Juvenile king	Pond smelt	Stickleback	
Mo	Year	Fry	Yearling						
Chignik Lake									
7	80	20	52	50	0	0	20	2	8
7	82	5	8	1	2	0	0	1	1
6	83	5	33	87	0	0	0	0	1
7	83	10	173	101	0	0	1	0	1
9	92	9	65	9	0	0	5	2	3
8	93	7	61	23	0	0	39	47	11
9	93	8	44	18	0	0	108	19	16
9	95	5	38	17	0	0	17	8	3
9	96	6	16	24	0	0	4	58	4
9	97	5	95	200	0	0	58	59	24
9	98	5	53	156	0	0	6	1618	12
Black Lake									
9	92	7	347	0	1	0	110	70	78
6	93	2	3260	0	0	0	148	10	30
7	93	1	478	0	0	0	13	0	0
8	93	9	143	0	11	0	729	910	1148
9	93	4	126	0	23	0	1914	565	269
6	95	6	28	4	0	0	19	4	2
9	95	5	176	1	0	0	49	15	12
9	96	3	82	(All other fishes released)					
9	97	3	80	0	3	0	173	217	64
9	98	5	303	0	15	0	92	219	128

TABLE 9. Average beach seine catches for Chignik Lake, 1980-98.

Date		No. of sets	Species								
Mo	Year		Sockeye salmon		Juvenile	Juvenile	Char	Stickleback		Sculpin	Pygmy whitefish
		< 45mm	> 45mm	coho	king	3-spine		9-spine			
6	80	5	47	0	2	0	7	16	1	28	0
7	80	12	52	9	3	1	2	22	1	16	1
5	85	10	113	189	103	2	6	3317	53	12	2
6	85	18	15	71	112	3	36	1031	136	18	28
7	85	17	9	217	30	4	104	399	28	11	6
8	85	6	20	183	9						
9	85	6	0	2	7	0	18	943	18	25	6
5	86	33	33	85	48	8	10	499	33	22	7
6	86	49	49	3	31	8	17	111	15	14	7
7	86	46	46	4	12	2	12	162	9	13	5
8	86	12	2	15	6	2	24	154	5	14	11
5	87	12	1048	714	136	7	25	639	54	13	19
6	87	54	6	230	113	9	65	260	6	13	15
7	87	58	16	51	17	0	8	44	5	14	3
6	92	15	10	15	13	0	7	123	22	13	2
7	92	6	9	2	20	2	23	192	16	7	7
5	93	6	1	173	57	0	13	224	7	9	41
6	93	6	1	20	6	0	15	24	0	8	13
6	95	21	27	9	11	1	13	244	26	18	8
7	95	21	16	13	13	1	10	49	6	17	6
6	96	7	12	121	39	1	15	117	3	22	<1
7	96	21	9	47	30	0	24	215	9	7	19
8	96	7	3	16	41	0	22	82	7	1	9
5	97	6	77	324	15	7	19	1367	24	61	0
6	97	6	5	125	7	0	6	14	3	6	2
6	98	11	140	436	104	43	58	4488	214	74	16
7	98	9	31	359	307	11	374	4106	219	79	17

river discharge and the percentage of river water entering the south channel was quantified. During low flows, such as those occurring during fry emergence, approximately 70% of the river flow (and presumably 70% of fry) entered the lake outlet. During exceptionally high flow events, the percentage of total discharge to the outlet declined to approximately 40%.

The purpose of the 1998 Alec River investigations was to continue monitoring river bank erosion and to measure river discharge in the two channels to determine the extent to which discharge was shifting toward the south channel and the lake outlet. Methods used to complete these tasks are described by Ruggerone (1994, 1997).

Results

Annual measurements of erosion along the south channel river bank at nine locations indicated that approximately 0.32 m to 0.53 m of the bank is lost per year, depending on

location (Table 10). This represents an increase in river width of approximately 1.2% per year. Up to 1.6 m of bank was lost during the past year at the point where the river splits into two channels. This bank area of relatively high erosion (~10 m x 20 m) also sunk vertically approximately 0.5 m, a condition that may exacerbate erosion of the bank in the coming years.

We attempted to measure discharge in each channel at a variety of discharge levels, but low flow conditions were not available between June and early September 1998. River discharge was measured on five occasions. Total discharge ranged from 835 cubic feet per second (cfs) to 1,344 cfs, which is considerably less than the previously documented range of 196 cfs to 3,070 cfs. Four of the five discharge measurements in 1998 displayed slightly greater flow to the south channel compared with the regression relationship derived from 1993 and earlier data. At a given total discharge level, 1.2% more water flowed through the south channel in 1998, on average, compared with the ear-

TABLE 10. Estimates of bank erosion along the upper reach of the south channel of Alec River, 1991-98. Source: Ruggerone (1997) and this study.

Stake	Location	Minimum distance from stake to river bank (m)										Present condition	Total change (m)	Change per year (m)	
		1991	1992	1993	1994	1995	1996	1997	1998						
Wye Pt															
1	Wye Pt.			4.00	3.40	3.40	2.96	2.80	1.20				sunken	-2.80	-0.56
2				4.40	3.10	3.00	2.60	2.53	1.70				sunken	-2.70	-0.54
3	(near S. channel)			3.25	3.00	3.00	2.20	1.78	0.80				sunken	-2.45	-0.49
				-0.72	-0.03	-0.55	-0.22	-1.14						-2.65	-0.53
Straight channel															
1	(rebar)	3.3	3.10	2.85	2.53	2.20	1.10	1.08	0.60					-2.70	-0.39
2	Discharge area		2.37	2.30	1.95	1.30	0.90	0.90	0.90					-1.47	-0.25
				-0.16	-0.34	-0.49	-0.75	-0.01	-0.24					-2.09	-0.32
River bend															
1	upriver		8.30	7.65	7.60	5.40	5.32	5.32	5.35				slough	-2.95	-0.49
2			10.30	9.95	9.08	8.20	7.80	7.80	7.10					-3.20	-0.53
3			10.30	9.75	9.70	9.70	9.50	9.45	8.90					-1.40	-0.23
4			15.10	13.95	13.70	13.40	13.40	12.15	12.15				slough	-2.95	-0.49
5			12.50	12.50	11.55	11.40	11.00	10.70	10.50					-2.00	-0.33
6			9.20	8.75	8.70	7.60	7.35	7.40	6.75					-2.45	-0.41
7	down river		6.70	6.60	6.43	6.25	5.90	5.80	6.10					-0.60	-0.10
				-0.46	-0.34	-0.69	-0.24	-0.24	-0.25					-2.22	-0.37
Left bank Pt.															
1	Lt. bank Pt.	2.5	2.50	2.20	1.90	1.80	1.70	1.40	1.15					-1.35	-0.19
			0.00	-0.30	-0.30	-0.10	-0.10	-0.30	-0.25						

lier measurements (Fig. 3). Greater discharge through the south channel is consistent with measurements of bank erosion. Additional discharge measurements at low flow conditions are needed to complete this analysis because the low flow period is most critical to emerging sockeye fry in spring and to juveniles that may overwinter in the lake.

SPAWNING ESCAPEMENT GOALS

During October 1998, a workshop was held in Anchorage to examine spawning escapement goals for Chignik and Black lakes. Attending the workshop were Denby Lloyd, Alicia Perez-Fuentetaja, David Owen, Ken Tarbox, Brian Bue and Stan Carlson of ADF&G, Greg Ruggerone (Natural Resources Consultants), and Marianne McClure and Ray Hilborn (Fisheries Research Institute). Key topics discussed included (1) the premature emigration of Black Lake sockeye to Chignik Lake (see Ruggerone 1994, 1997); (2) sensitivity of adult returns to changes in escapement levels; (3) error in measuring adult harvests, escapement, and allocation between Black Lake and Chignik Lake; and (4) effects of differential escapement to each spawning ground. In general, questions and historical data were fed to Hilborn, who used a Monte Carlo

approach to examine questions regarding escapement levels and adult returns.

The preliminary analyses suggested the current escapement goals are reasonable. Slight changes in the escapement level have relatively little effect on adult returns, a result that stems from the high variation in adult returns at a given escapement level. Initial attempts to include the adverse effect on Chignik Lake sockeye of premature emigration of Black Lake fry in the recruitment analysis were not successful, possibly because there is considerable error among the less-dominant age classes in the brood table and because the effect is nonlinear (Ruggerone 1997). Some participants noted that an important approach to maximizing harvests was to avoid escapements that greatly exceed the spawning escapement goals. In recent years, spawning escapement goals have been exceeded when the weir washed out (e.g., 1986), when the *Exxon Valdez* oil spill interfered with harvests, and during fishermen strikes. Exceptionally large runs may also contribute to escapements that exceed the goal. The workshop concluded that additional effort is needed to examine the escapement goals of Black and Chignik lakes.

A reexamination of Chignik and Black lake escapement and adult recruitment trends is presented below. This analysis can be considered a first step in the evaluation of escapements goals since additional analyses are needed. The analysis follows the approach used by Dahlberg (1973). The Ricker recruitment parameters were estimated from the following linearized form of the model:

$$\ln(R/S) = a + b(S) + e$$

where R = total return from S number of spawners,
S = number of spawners in parent year,
A = parameter estimated from data,
B = parameter estimated from data,
e = error term having normal distribution.

Hilborn's equation (Hilborn 1985) was used to estimate escapements leading to maximum sustained yield (MSY).

Results

A Ricker recruitment curve was fitted to adult sockeye returns and spawning escapement to Chignik Lake, Black Lake, and the total Chignik system during brood years 1922–92. Residuals from each recruitment curve showed three distinct periods of production in the Chignik system. Sockeye production was high during the early brood years (1922–44), low during the middle brood years (1946–64), and high during the most recent brood years (1965–92) (Figs. 4, 5, 6). This pattern is consistent for both the total

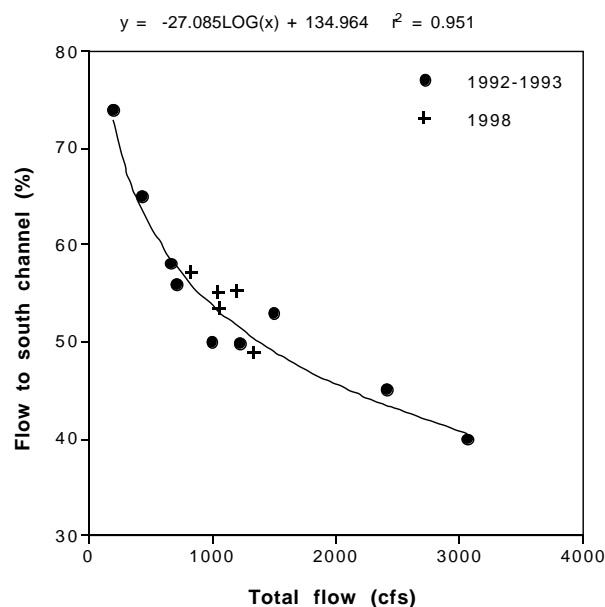


FIGURE 3. Comparison 1998 and earlier measurements of the percentage of Alec River flow entering the south channel in relation to total flow in Alec River. Flow to the south channel enters the lake outlet and bypasses the main lake area. Source for earlier measurements: Ruggerone (1994).

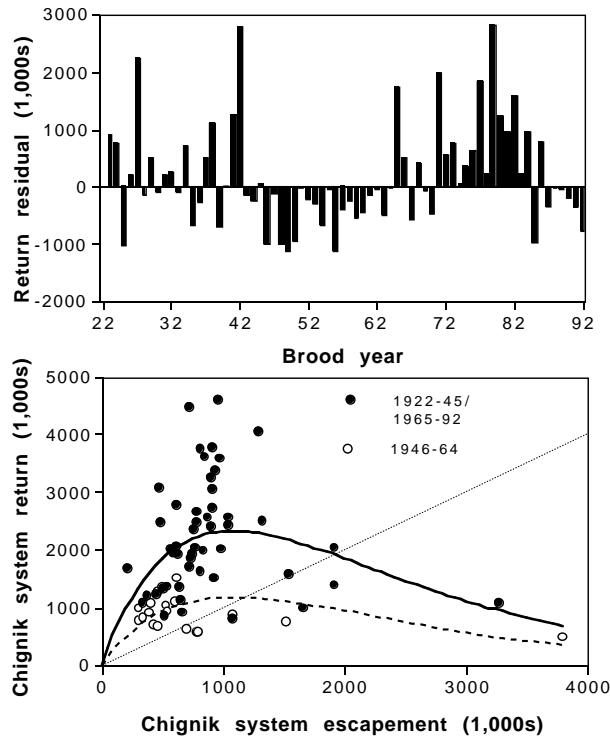


FIGURE 4. Ricker recruitment curves for Chignik System sockeye salmon during periods of high and low productivity (lower graph) and time series of residual (observed–predicted) return values based on a recruitment curve for the entire period, 1922–92 (upper graph).

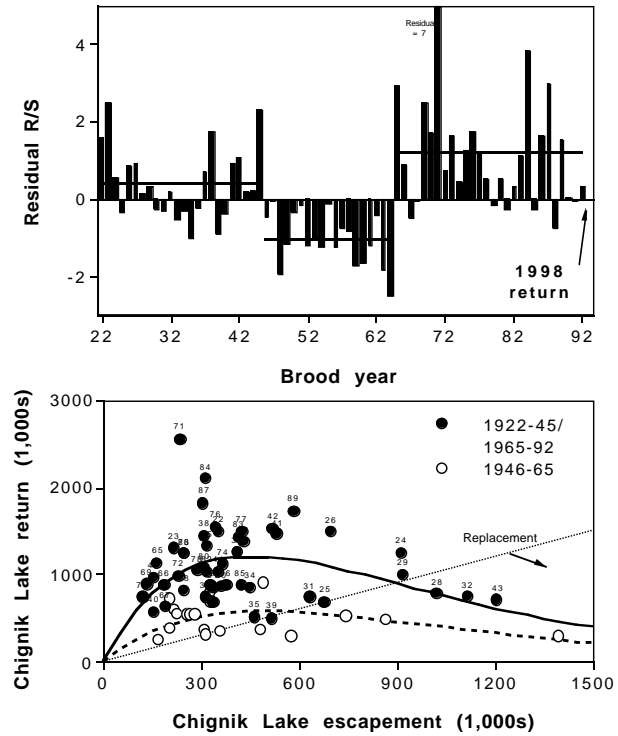


FIGURE 5. Ricker recruitment curves for Chignik Lake sockeye salmon during periods of high and low productivity (lower graph) and time series of residual (observed–predicted) return per spawner values based on a recruitment curve for the entire period, 1922–92 (upper graph). Brood year is shown above the values.

lake system and for Chignik Lake, but the pattern is less consistent for Black Lake where adult returns are less dependent on adult escapements.

Total sockeye production in the Chignik system relative to the parent spawning escapement has steadily declined during the past 7 brood years. Adult returns (adjusted for escapement) during brood years 1987–92 were consistently below the 70-year average, as shown by the negative return residuals in Fig. 4. This pattern of below-average returns in recent years is not typical of sockeye production throughout western and central Alaska although adult returns to Bristol Bay during 1997 and 1998 were approximately 50% of the preseason forecasts. Low production might reflect ongoing changes in Black Lake, which appear to impact total production in the Chignik system (Ruggerone 1997). However, the recent decline is not quite as apparent when return residuals are examined for Chignik and Black lakes separately (Figs. 5 and 6).

Spawning escapement levels leading to maximum sustained harvests (MSY) were calculated for each lake and the total system during periods of high (1922–45, 1965–92)

and low (1946–64) productivity. The MSY escapements for Chignik Lake during periods of high and low productivity were 324,000 and 239,000 sockeye salmon, respectively, and the projected average harvests from these escapements were 827,000 and 232,000 sockeye salmon (Table 11). The MSY escapements for Black Lake during periods of high and low productivity were 382,000 and 269,000 sockeye salmon, respectively, and the projected average harvests from these escapements were 645,000 and 239,000 sockeye salmon. When total adult returns to the Chignik system were compared with total parent escapement, we estimated MSY escapement levels of 721,000 and 500,000 sockeye salmon during periods of high and low productivity. The corresponding average harvests were 1.4 million fish during the high production period and only 500,000 fish during the low production period.

The MSY escapement level during the high production period was 15,000 fish higher than the sum of the MSY escapement levels for the two lakes, but yield was slightly greater when the two systems were examined separately. This suggests higher yield can be expected by managing

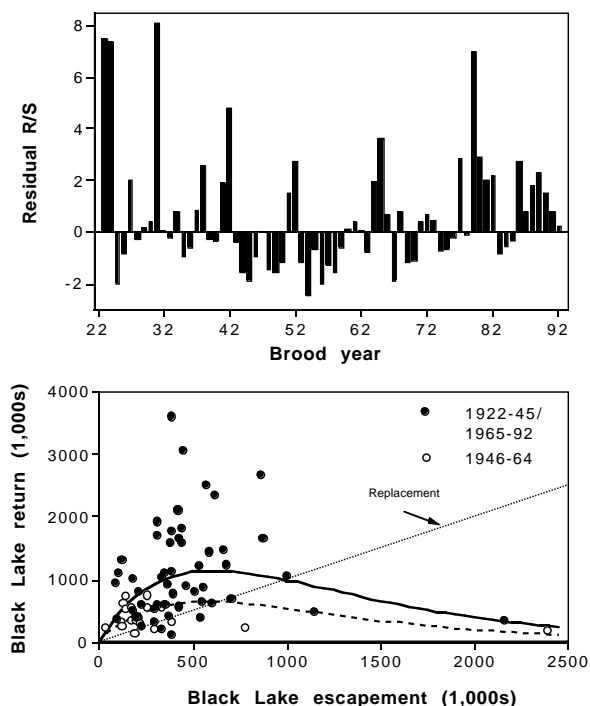


FIGURE 6. Ricker recruitment curves for Black Lake sockeye salmon during periods of high and low productivity (lower graph) and time series of residual (observed-predicted) return per spawner values based on a recruitment curve for the entire period, 1922-92 (upper graph).

escapements for each system separately (Dahlberg 1973).

This analysis indicates a threefold difference in potential harvests during periods of high compared with low production. The difference would be even greater if escapement levels during the low production period remained near that of the high production period. Reduction in spawning escapement levels during periods of low productivity may increase average harvest levels, but the risk of producing very small returns would likely be higher.

TABLE 11. Estimates of spawning escapement levels leading to maximum sustained harvests (MSY) during periods of high and low production. Estimates of spawning escapements leading to maximum adult returns (MAX) and the projected harvests are also shown. Current escapement goals are 400,000 spawners to Black Lake and 250,000-300,000 spawners to Chignik Lake.

	High Production Period (1922-45 & 1965-92)				Low Production Period (1946-64)			
	MSY Escapement	MSY Harvest	Max Escapement	Max Harvest	MSY Escapement	MSY Harvest	Max Escapement	Max Harvest
Black Lk	382	645	611	518	269	239	576	63
Chignik Lk	324	827	452	758	239	232	488	90
	706	1,472	1,063	1,276	508	471	1,064	153
Total System	721	1,438	1,088	1,236	500	430	1,092	89

Periods of high and low production levels of Chignik sockeye salmon generally correspond with periods of climate and oceanographic changes during 1947 and 1977 (Mantua et al. 1997). The relatively high production of Chignik sockeye during the late 1960s is probably associated with the changing escapement levels during this period. Escapements to Black Lake increased whereas escapements to Chignik Lake decreased.

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