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FISHERIES REHABILITATION AND ENHANCEMENT
IN BRISTOL BAY
A COMPLETION REPORT
BY
Melinda L. Rowse
and
W. Michael Kaill
Number 18

Alaska Department of Fish & Game
Division of Fisheries Rehabilitation,
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Alaska Department of Fish and Game
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ABSTRACT

Sockeye salmon (*Oncorhynchus nerka*) rehabilitation efforts in Bristol Bay are reviewed, primarily from the point of view of F.R.E.D. Division, ADF&G, and cooperating agencies (University of Washington Fisheries Research Institute, National Marine Fisheries Service). F.R.E.D. Division project activities for Bristol Bay during 1982 are reported.

Lake Nunavaugaluk Sockeye Salmon Smolt Studies estimated the 1982 emigration to be 3.2 million smolts. The estimate is to be considered approximate, because of difficulty encountered in sampling.

In 1982, we tried to confirm or deny the presence of a significant population of age 2.0 smolts during the early portion of the emigration. Large numbers of smolts were observed migrating during this time, but estimates of number or age determination were not possible. Data from observation of predation on smolts suggest a small age 2.0 component.

F.R.E.D. Division's program in Bristol Bay in past years has included adult sockeye salmon studies, East Creek Hatchery evaluation, predator competitor studies, and lake fertilization. These activities were not carried out in 1982, they are reported here in summary fashion, as are some opportunities identified as potential rehabilitation and enhancement projects.

Keywords

Bristol Bay, Rehabilitation, Enhancement, Smolt, Nunavaugaluk, predator, fertilization, hatchery, East Creek

INTRODUCTION

The Bristol Bay salmon fisheries have long been a subject of interest to fishery scientists. The area's sockeye salmon (Oncorhynchus nerka) runs have a five-year cycle of peak abundance, with an occasional shift to a four year cycle. Because of this cyclic pattern, as well as mortality due to unpredictable natural disasters, rehabilitation and enhancement practices are important considerations for this area. In the late 1950's and 1960's a considerable amount of research was begun by the following agencies: Alaska Department of Fish and Game (ADF&G); University of Washington, Fisheries Research Institute (UW-FRI); and National Marine Fisheries Service (NMFS). This research was aimed at the biology and ecology of Pacific salmon which had originated from Bristol Bay lake systems.

The objectives of this report are as follows: to review the historical and current work of ADF&G, UW-FRI, and NMFS, which has involved fisheries rehabilitation and enhancement in the Bristol Bay area; to report on the work of F.R.E.D. Division, and to identify some opportunities for rehabilitation and enhancement in Bristol Bay.

AREA ASSESSMENT

The Bristol Bay region includes all waters of Alaska that empty into the Bering Sea from Cape Newenham to Cape Menshikof. Ten major freshwater systems are included: Togiak, Igushik, Snake, Wood, Nushagak (including Nuyakuk and Mulchatna), Kvichak, Alagnak (Branch), Naknek, Egegik, and Ugashik (Fig. 1, ADF&G 1982a). All lakes within these systems are oligotrophic and have limited shoreline development (Kaill et al. 1980).

The resident civilian population of Bristol Bay is approximately five thousand people; the majority are Alaskan natives. The local economy relies heavily on the commercial fishing industry, while subsistence fishing allows the local people to supplement family income. Although in 1977, 67% of the licensed gearholders in Bristol Bay were Alaskan residents, non-Alaskan fishermen harvested only about 55% of the total catch (ADF&G 1977). Sport fishing also attracts people from outside the area, many of whom employ professional guide services. Rainbow trout (Salmo gairdneri), Arctic grayling (Thymallus arcticus), Arctic char (Salvelinus alpinus), and salmon (Oncorhynchus spp) fishing are available to the sport fishermen in many areas of the Bay; the fishing lodges located in the Tikchik-Wood River Lake system, however, provide the most intensive sport fishing effort.

Description of the Fishery

Although all five species of Pacific salmon are utilized in Bristol Bay, sockeye salmon (O. nerka) comprises about 90% of the catch. During the early 1900's, sockeye salmon catches averaged 14.7 million fish annually. From 1960 to 1975, annual sockeye salmon catches have averaged only about 7.7 million fish. Taking into account the sockeye salmon of Bristol Bay origin that were intercepted by the Japanese high seas fishery, the average annual catch for this period would have been about 10.3 million sockeye salmon per year (ADF&G 1977).

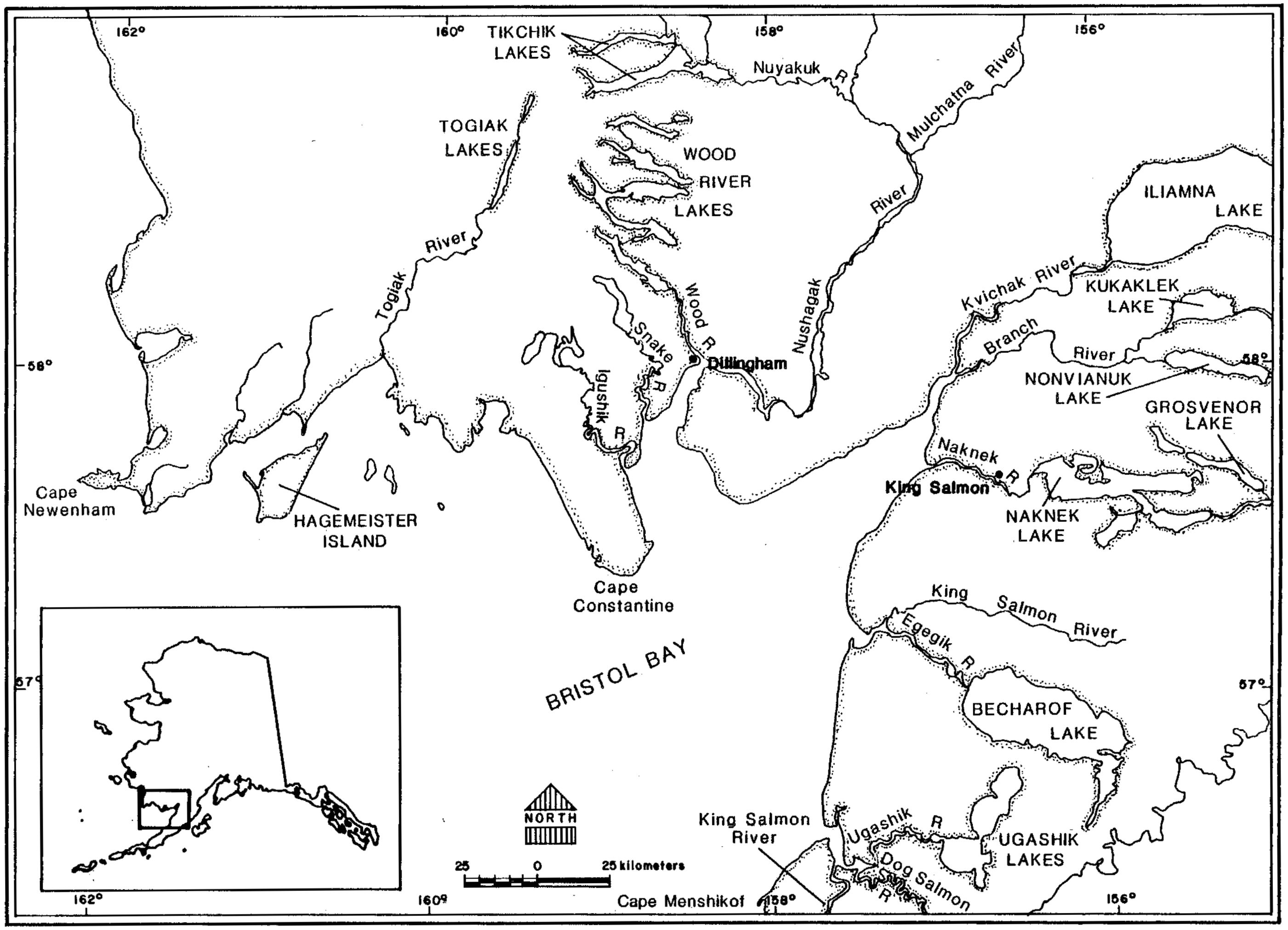

Figure 1. Bristol Bay area.

The salmon runs were greatly reduced in 1973 through 1977 because of poor juvenile salmon survival during the extremely cold winters of 1970 and 1971. Juvenile salmon production levels have been on the upswing since 1974, resulting in increased harvests from 1978 through 1982 [a yearly mean of 19.2 million sockeye salmon harvested in 1978-82 (ADF&G 1982a)]. Between 1964 and 1979, annual commercial harvests of pink salmon (O. gorbuscha), chum salmon (O. keta), coho salmon (O. kisutch) and chinook salmon (O. tshawytscha) have averaged 1.0, 0.8, 0.8 and 0.1 million fish, respectively. Subsistence harvests of sockeye salmon have averaged about 0.1 million fish per year between 1964 and 1979 (Kaill et al. 1980).

Sport fishing efforts in Bristol Bay represent only 5.6% of Alaska's total sport fishing effort. Sport fishing interest in chinook salmon and coho salmon is increasing, particularly from local commercial fishermen (M. Nelson, pers. comm.). In both the commercial and sport fisheries, chinook salmon are generally harvested before the sockeye salmon run and the arrival of nonresident fishermen in the bay, while coho salmon are harvested after the sockeye salmon run when many of the nonresident boats have left the area (M. Nelson pers. comm.).

Japanese High Seas Fishery

The Japanese high seas fishery consists of two fleets, which are the mother ship gill net fishery and the land based drift net fishery. These fleets operate in the North Pacific Ocean and Bering Sea. The Fishery Conservation and Management Act of 1976 (FCMA) conveyed exclusive fishery management authority to the United States over salmon of U.S. origin within a 200 mile fishery conservation zone. Management authority also extends throughout the salmon migratory range beyond that zone, except when they are found within any nation's territorial sea or fishery conservation zone recognized by the U.S. (Fredin et al. 1977). Despite the FCMA, the Japanese mothership fishery has still intercepted an average of 2.3 million sockeye salmon of Bristol Bay origin per year since 1956 [Fig. 2 (Fredin et al. 1977)]. From 1956 through 1975, this has amounted to about 46 million fish, or 23% of the total catch of western Alaska sockeye salmon (Fredin et al. 1977).

Fredin et al. (1977) reported that sockeye salmon catches by the high seas mothership fishery have generally followed the cyclic pattern of the Bristol Bay sockeye salmon runs. That is, catches by the mothership fishery in peak and post-peak years of the Bristol Bay cycle are higher than in years of low abundance.

In 1978, implementation of a new International North Pacific Fishery Convention (INPFC) treaty restricted, by area and time, the movements and fishing pattern of the Japanese mothership fleet. This has resulted in a drastic reduction of the high seas interception of Bristol Bay sockeye salmon runs. Thus it has increased the potential for larger catches by the land based fleet. This in itself may represent gains in the rehabilitation and enhancement of Bristol Bay salmon runs. Japanese mothership high seas commercial catches of Bristol Bay sockeye salmon between 1962 and 1981 ranged from 0.8 to 25.6% of the total run (Table 1).

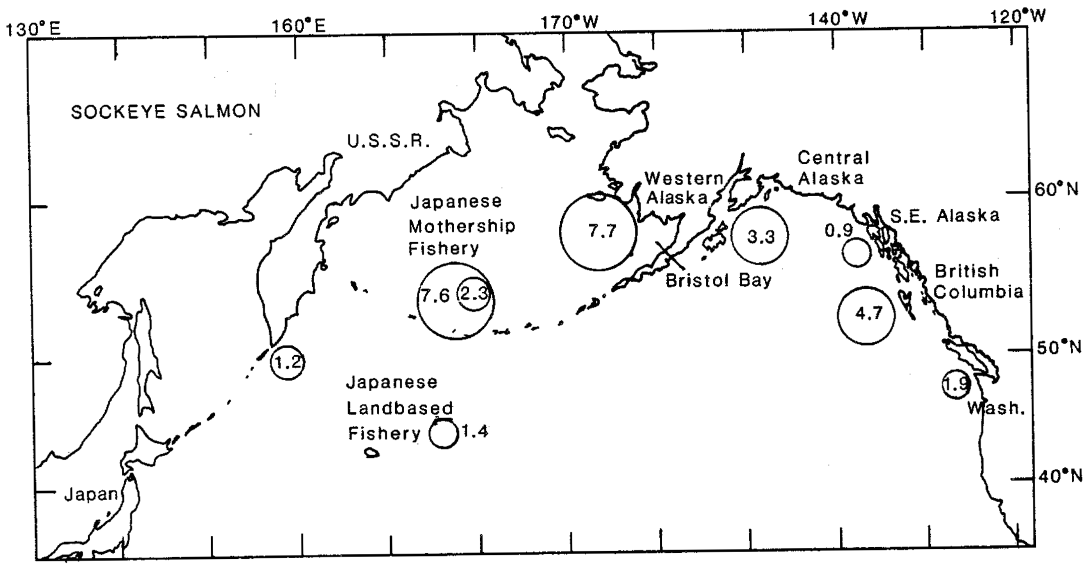

Figure 2. Commercial catches of sockeye salmon in North America, Asia, and on the high seas. Averages (millions of fish) are based on years 1952-1975 except for the number of western Alaska sockeye that are intercepted by the Japanese mothership fishery (circle within a circle), which is based on years 1956 - 1975.

Table 1. Inshore domestic and Japanese mothership high seas commercial catch of sockeye salmon of Bristol Bay origin, 1963-82.

	Number Fish in Thousands						
	Bristol Bay Catch			Bristol Bay		Percent Japanese Catch of:	
Year	Inshore	Japanese[a/]	Total	Escapement	Total Return[b/]	Total Catch	Total Bay Run
1963	2,871	1,001	3,872	4,033	7,905	26	13
64	5,596	314	5,910	5,341	11,251	5	3
65	24,255	6,943	31,198	28,873	60,071	22	12
66	9,314	1,935	11,249	8,239	19,488	17	10
67	4,331	922	5,253	6,022	11,275	18	8
1968	2,793	885	3,678	5,217	8,895	24	10
69	6,622	2,031	8,653	12,421	21,074	24	10
70	20,721	3,968	24,689	18,679	43,368	16	9
71	9,584	2,049	11,633	6,241	17,874	18	12
72	2,416	1,302	3,718	2,984	6,702	35	19
1973	761	839	1,600	1,683	3,283	52	26
74	1,362	510	1,872	9,603	11,475	27	4
75	4,899	1,353	6,252	19,333	25,585	23	5
76	5,619	1,001	6,620	5,920	12,540	15	8
77	4,878	768	5,646	4,844	10,490	14	7
1978	9,928	452	10,380	9,996	20,376	4	2
79	21,429	304	21,733	18,475	40,208	1	1
80	23,762	590	24,352	38,727	63,079	2	1
81	25,713[c/]	818	26,531	8,872	35,403	3	2
82	15,146[c/]	443[c/]	15,589	7,104	22,693	3	2
20-Yr. Tot.	202,001	28,428	230,428	222,607	453,035		
1963-72 Tot.	88,503	21,350	109,853	98,050	207,903		
1973-82 Tot.	113,498	7,078	120,575	124,557	245,132		
20-Yr. Ave.	10,100	1,421	11,521	11,130	22,652	12	7
1963-72 Ave.	8,850	2,135	10,985	9,805	20,790	19	11
1973-82 Ave.	11,350	708	12,058	12,456	24,513	6	3

a/ Includes immature fish caught in previous year.
b/ Includes Bristol Bay catch and escapement and Japanese catch.
c/ Preliminary.

From ADF&G 1983

HISTORY OF SOCKEYE SALMON REHABILITATION IN BRISTOL BAY

From 1972 through 1977, Bristol Bay sockeye salmon runs reached alarmingly low levels (Table 1). The Alaska State Legislature appropriated 1.5 million dollars of disaster funds to ADF&G to use toward rehabilitation and enhancement of these runs. Initially, this money was spent on collection of background information on several lake systems. Of the systems examined two lake systems in particular were identified as having high potential for rehabilitation and enhancement: the Egegik River/Becharof Lake system and the Snake River/Lake Nunavaugaluk system. The disaster fund program has continued to focus on these two lake systems.

The Egegik River/Becharof Lake system is located on the western side of the Alaska Peninsula (Fig. 1). It is the second largest salmon producing system in the area. However, compared to production of other systems (fish/unit of rearing area) in Bristol Bay, the Egegik system produces few fish (Clark 1980). So the goals were to determine potential options for rehabilitation and/or enhancement in this system. Clark (1980) suggested that the main basin of Becharof Lake could provide extensive rearing habitat for juvenile sockeye salmon, but is underutilized as such. Artificially propagated juvenile sockeye salmon could be placed in this main basin, where there is an adequate food supply for rearing fry.

The Lake Nunavaugaluk/Snake River system (Fig. 1) also showed high potential for rehabilitation and enhancement opportunities. Lake Nunavaugaluk is a relatively deep, single basin lake (area 78.76 km^2; mean depth = 57m, max. depth = 162m) which has historically shown poor salmon production rates. It is located between the Igushik and Wood Rivers. A study conducted from 1962 to 1965 showed that Lake Nunavaugaluk was lower in standing crops of phytoplankton and zooplankton and higher in transparency than the Igushik lakes and Lake Aleknagik of the Wood River system (Fisheries Research Institute 1965). They also found low densities of young salmon and resident species, except for threespine stickleback (*Gasterosteous aculeatus*) which was extremely abundant. In comparison to Nushagak District lakes, Lake Nunavaugaluk was found to have an adequate oxygen supply, but low levels of silicon and total dissolved solids and high water transparency (Gadau 1966). Overall, Lake Nunavaugaluk was evaluated as a poor producing system. There were indications that interspecific competition and lack of available nutrients for rearing sockeye salmon fry were potentially limiting factors.

Relationships between nutrient cycling, predation/competition and recruitment for Lake Nunavaugaluk sockeye salmon populations are not simple. Local lore suggests that Lake Nunavaugaluk had once been a high producing system. If this is true, the limiting factor could be a short supply of adult spawners into the system;without the nutrient input to the system, low fertility and competition by stickleback could then result. A similar hypothesis has been proposed to explain the decline of Karluk Lake sockeye salmon production (McIntyre 1980).

From these baseline data, as well as from the logistical factors involved, it was determined that the Lake Nunavaugaluk system was the most feasible site for artificial propagation of sockeye salmon fry in the Bristol Bay area. From 1974 through 1978, a pilot program using instream incubators was conducted at East Creek on Lake Nunavaugaluk (Fig. 3). In 1978, a

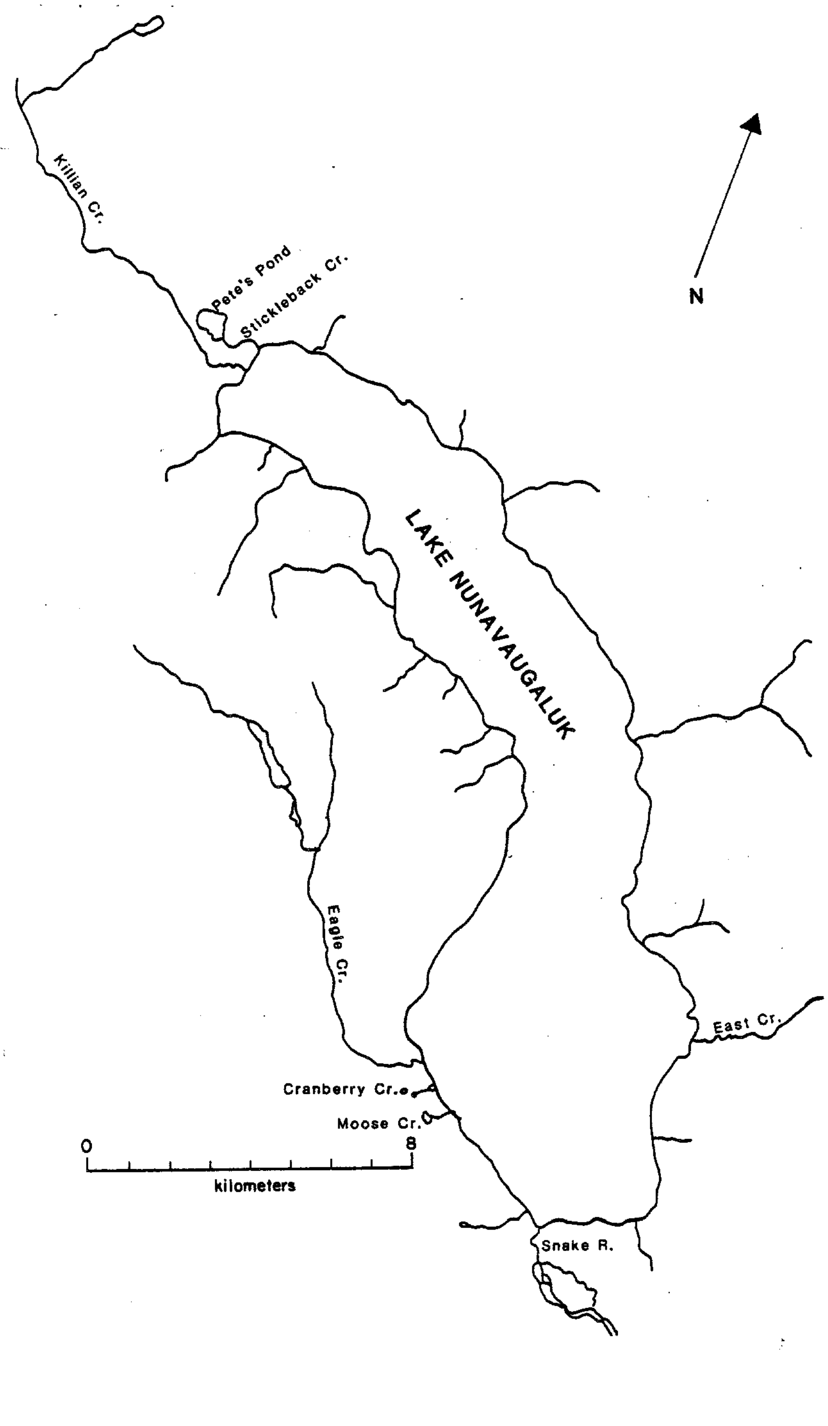

Figure 3. Lake Nunavaugaluk, near Bristol Bay, Alaska.

permanent indoor hatchery facility was completed with an ultimate objective to produce 15 million sockeye salmon fry. Production at East Creek Hatchery has ranged from 6,100 fry released in 1975 to 5.6 million fry released in 1982 (Table 2).

In conjunction with the hatchery incubation project in the mid-1970's, NMFS, in cooperation with ADF&G, F.R.E.D. Division, conducted extensive biological studies on the Lake Nunavaugaluk/Snake River system (Jaenicke and Kirchhoffer 1976; Jaenicke and Olsen 1975; Jaenicke, et al. 1978; Jaenicke et al. 1980; Hoffman 1978, 1979; Dahlberg 1974, 1976; Dahlberg and Thomason 1976; Dahlberg and Sheng 1977; Brown 1981; Thomason 1979; Lemberg et al. 1974). The main objective of these studies was to estimate the carrying capacity of the lake so that releases of hatchery sockeye would not result in excessive intraspecific competition and thus decreased survival of sockeye fry.

Results of the NMFS studies identify the location and extent of shallow water rearing areas which are important for early fry survival (Jaenicke et al. 1978), but no estimate of carrying capacity of the lake was ever made. Determination of number and age of sockeye salmon smolts migrating from the lake was also investigated as a method to evaluate freshwater survival and production of sockeye salmon juveniles. Thomason and Jaenicke (1979) postulated that two significant periods of smolt migration occur at Snake River: (1) most age 2.0 smolts and many age 1.0 smolts outmigrate before and during ice breakup, with the age 2.0 smolts leaving before the age 1.0 smolts; and, (2) most age 1.0 smolts leave the lake after ice breakup. They concluded that efforts to obtain an estimate of total smolt migration after ice breakup were not valid since only a portion of the actual smolt migration was included (Thomason and Jaenicke 1979).

Lake Fertilization

Artificial lake fertilization has been investigated as a tool for enhancement and rehabilitation in Bristol Bay. Little Togiak Lake, in the Wood River Lake system (Fig. 4), was used as an experimental site for lake fertilization studies conducted by UW-FRI. Diammonium phosphate was added to the upper end of the lake in late August of 1974 and 1975 and, subsequently over most of the lake in mid-July of 1976, 1977 and 1978. Rogers (1979) reported increases in chlorophyll, zooplankton and emergent chironomid production late in the season (September). Sockeye salmon fry growth did not increase significantly in early summer, but the size of migrating age 1.0 smolts the next spring showed a significant increase (Rogers 1979). In 1979, Rogers did not add fertilizer to Little Togiak Lake, but the lake was monitored. He found that zooplankton abundance and standing crop of phytoplankton had returned to normal (i.e. levels of prefertilization).

Interest in the rehabilitation of Lake Nunavaugaluk was continued in 1981, when a 2 year prefertilization program was begun. Limnological sampling was conducted periodically throughout the winter months and approximately every 3 weeks during the ice-free months (May - November). Analysis of these data is in progress (Koenings, in prep.).

Table 2. Historical production record, East Creek Hatchery.[a]

Species	Brood Year	Donor Source	Number of Eggs	Number Released	Date	Returns to Hatchery	Year	Estimated Harvest	Total Returns By Brood Year
Sockeye	1974	East Cr.	67,000						
		Killian Cr.	73,000	6,000	1975				
		Outlet							
	1975	East Cr.	88,000	252	1980	126			
		Killian Cr.	392,274	346,529	1976				819
		Outlet	141,660	128	1981	313			
		Beach	210,069						
	1976	East Cr.	339,000	2,548	1980	774			
		Killian Cr.	1,800,000	1,990,895	1977	250	1981	612	3,000[b]
		Beach	1,040,000						
	1977	East Cr.	150,730						
		Killian Cr.	379,919	1,663,417	1978	178	1981	436	614[b]
		Beach	1,549,919						
	1978	East Cr.	240,000						
		Beach	2,400,000	2,687,511	1979				
	1979	East Cr.	272,882						
		Francis Cr.	6,327,338	1,000,000	1980[c]				
	1980	East Cr.	2,978,724						
		Killian Cr.	29,516	4,361,433	1981				
		Francis Cr.	1,956,229						
	1981	East Cr.	524,980						
		Francis Cr.	6,165,272	5,564,002	1982				

a/ From ADF&G, 1982

b/ *Does not include possible returns in 1982 and 1983.*

c/ IHNV outbreak at hatchery caused high mortality and consequently annihilation of those that survived, excluding the 1,000,000 that appeared healthy enough to be released.

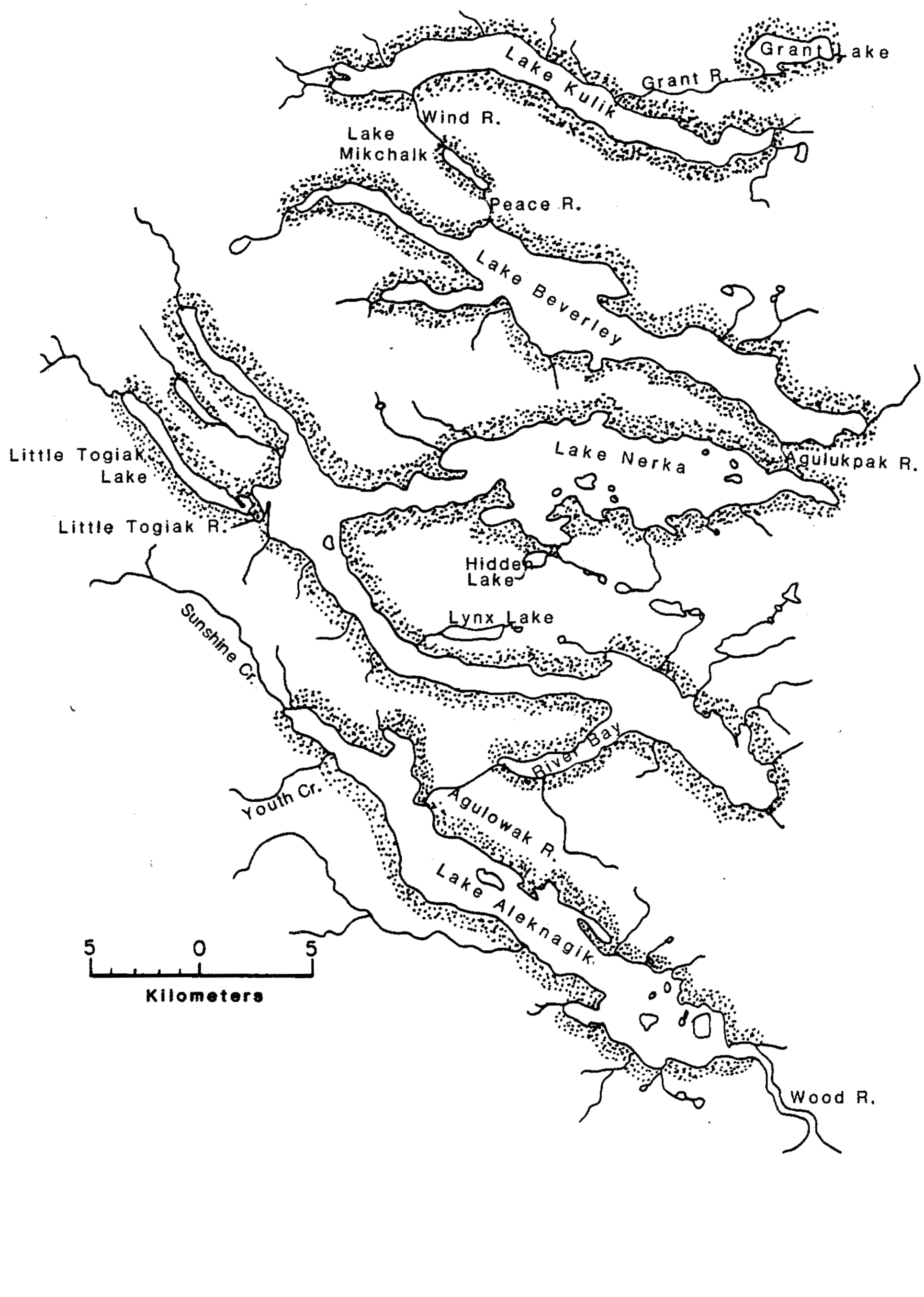

Figure 4. Wood River Lake system, near Bristol Bay, Alaska.

In conjunction with prefertilization studies, baseline data were collected in 1981 on food habits, migration and relative abundance of sockeye salmon fry in Lake Nunavaugaluk. Analysis of these data was delayed until a second year of data could be obtained in 1982. However, funding restrictions in the 1982 season have prevented collection of additional data. The 1981 data are reported by Laner (1982a).

Hatchery Evaluation

Recovery of marked, hatchery produced fry is a means of evaluating enhancement results. A fry marking program was planned for FY82 at East Creek Hatchery, but it was cancelled because of a concern for stress-related factors and the threat of infectious hematopoietic necrosis virus (IHNV) on emergent sockeye fry.

Predator/Competitor Studies

ADF&G has historically been involved with research and development of techniques to control predators and competitors of salmon. Predatory species of major concern are Beluga whale (*Delphinapterus leucas*) and Arctic char (*Salvelinus alpinus*). Threespine stickleback (*Gasterosteous aculeatus*) and ninespine stickleback (*Pungitius pungitius*) are also known competitors of salmon.

Beluga Whale Predation:

Since 1954, biologists as well as local fishermen have documented that beluga whales move into the various river systems in Bristol Bay and feed extensively on outmigrating sockeye salmon smolts. Brooks (1954a, 1954b, 1955) and Vania (1966) conducted food habit studies on beluga whales that inhabit Bristol Bay in spring and summer. They showed that beluga whales feed primarily on sockeye salmon smolts in the narrow confines of river mouths during spring and early summer when smolt are migrating from freshwater to saltwater. Examination of stomach contents of 37 beluga whales taken in the spring of 1954 and 1955 indicated an average of 685 juvenile salmon per stomach (Brooks, 1954b, 1955). The total annual predation on juvenile salmon at the Kvichak River was estimated to be around 3 million (Brooks, 1955). In the summers of 1954 and 1955, 78 beluga whales were collected. Examination showed an average of 6 adult salmon per stomach. All five species of Pacific salmon were represented. An estimated 196,000 adult salmon were consumed in 1954, and an estimated 99,225 adult salmon were consumed in 1955 by beluga whales (Brooks, 1954b, 1955).

Between 1956 and 1959, harassment experiments were conducted by ADF&G personnel in an effort to chase belugas out of the rivers with outboard powered skiffs. In 1960 small explosive charges were fired near belugas. These primitive methods were abandoned because skiffs were operable only during calm weather and daylight hours. Also, explosives could not be used in areas of high densities of smolts (Brooks 1956, 1957, 1958).

Between 1965 and 1970, Fish and Vania (1971) conducted studies of beluga whale reactions to the underwater transmissions of killer whale sounds. They concluded that beluga whales were repelled from the river channels when killer whale sounds were transmitted across the width of the river. Some problems were encountered in keeping the sound transmission at effective levels of strength. This was resolved when a second transmitter was placed on the opposite side of the river. Fish and Vania (1971) then judged the method to be both practical and effective.

In 1975 and 1976, ADF&G acquired several 'beluga spookers' and placed them at sites on the Naknek, Kvichak and Nushagak Rivers. They were successful in keeping beluga whales out of the rivers, but there were extensive mechanical and logistical problems (Skrade pers. comm.). Evaluation of the efficacy of this phase of the control technique was not done.

In 1979, ADF&G, F.R.E.D. Division explored possible approaches to the beluga whale predation problem. Goals were: (1) to develop acoustical repelling units for routine use on fisheries enhancement; (2) to investigate abundance and distribution of beluga whales in the Nushagak Bay river systems; and 3) to design a field experiment for evaluation of repelling unit effectiveness (Fried et al. 1980). Because of budget restraints, only an abundance and distribution study in the Nushagak Bay river systems was completed in the 1979 field season. Fried et al. (1980) listed several recommendations for further work concerning beluga whale predation on salmon in Bristol Bay.

Other relevant beluga whale studies are: Calderon and Wenz 1967; Cornelius 1965; Cumming and Thompson 1971; Fish and Mowbray 1962; Klinkhart 1966; Lensink 1961; Pitcher 1974; Randall 1975; Schevill and Lawrence 1949; Seaman and Burns 1981; Seaman et al. 1982; Seargeant 1973; Seargeant and Fisher 1957; Skrade 1976; Vania 1971; Vania and Klinkhart 1966; Vania et al. 1968, 1969.

During the 1982 field season, the Game Division of ADF&G cooperating with NMFS, conducted research on beluga whales in Snake River. Efforts were made to capture and radio tag individual whales to monitor their movement. One whale was captured but not tagged. Improvements in capture and tagging techniques were found to be necessary and research is expected to be continued in 1983 (K. Taylor pers. comm.).

Stickleback Competition:

During certain phases of their life histories, threespine and ninespine stickleback and juvenile sockeye salmon have been shown to have similar food habits and local migratory movements in the Wood River Lakes and Lake Nunavaugaluk (Rogers 1968, 1973, 1977; Hoffman 1979). However, the effect of stickleback abundance on growth and survival of juvenile sockeye salmon in these systems is undetermined. Between 1958 and 1977, UW-FRI made many observations on life history and on relative abundance and growth of threespine stickleback. Rogers (1977) discusses these data with emphasis on factors which likely influence stickleback abundance and relationship to juvenile sockeye salmon. He states that stickleback in their first year are more similar in diet and habitat distribution to sockeye salmon fry ("zero age") than are the 2 year old or 3 year old stickleback. Hoffman (1979) also states that the diet of all age classes of both sockeye salmon and stickleback is significantly associated with habitat in the littoral zone of the lake, i.e., physical characteristics, such as bottom type and vegetation, determine what food items will be available at any given time.

In the limnetic zone of Lake Nunavaugaluk, Hoffman (1978) compared diets of sockeye salmon fry and stickleback (ranging in age from first year of life to third year of life) in relation to timing and abundance of zooplankton species. There was an overlap in diet between the two fish species. Since sample sizes in this study were limited, further efforts would be needed to confirm the results of the study (Hoffman 1978).

From 1974 through 1976, Johnson (1976) conducted a stickleback control program on Lake Nunavaugaluk. Traps were placed in Moose Creek, Cranberry Creek, and Stickleback Creek (Fig. 3) prior to stickleback spawning. Migrating spawners were caught while moving upstream, then the traps were reversed so downstream migrating fry and spent adults were captured. Objectives of this program were to: (1) remove spawning populations of threespine and ninespine stickleback; (2) assess spawning populations of stickleback; and (3) collect samples of stickleback for age, sex, fecundity, and food habits information.

The results of Johnson's (1976) stickleback program show a total of 122,000 adult and 4.5 million juvenile threespine stickleback, as well as 5,600 adult and 50,800 juvenile ninespine stickleback that were trapped at all locations in 1974. Despite these efforts, stickleback remained the most abundant fish species in the lake.

Rogers (1977) concluded that quantitative estimates of the effects of stickleback abundance on the growth of juvenile sockeye salmon were not possible. Growth of sockeye salmon fry, growth of stickleback in their first year, relative abundance of each species, and abundance of zooplankton were all interrelated. In the Wood River system, competition for food and habitat does occur between stickleback and sockeye salmon juveniles, but the extent of this competition is still undetermined (Rogers 1977).

Arctic Char Predation:

Arctic char are predators of juvenile salmon. They have been a primary concern throughout the history of the commercial sockeye salmon industry in Bristol Bay. In the Wood River lake system (Fig. 4) Arctic char predation on sockeye salmon smolts has been studied intensively. Char often congregate at the mouths of rivers and prey on sockeye salmon smolts. During the spring migration, smolts pass through these areas in large concentrations. Meacham (1977) estimated that 1.5 to 1.9 million sockeye salmon smolts were consumed each year by Arctic char at the mouth of the Agulowak River, in the Wood River system, in 1975 and 1976. Concern for this source of sockeye salmon smolt mortality has resulted in several projects, which have been conducted periodically since 1920.

Early predator control projects were carried out with enthusiasm but were never adequately evaluated. Two approaches of control were employed. First, between 1920 and 1927, federal agents (Bureau of Fisheries) conducted an eradication program by capturing and destroying Arctic char in Bristol Bay salmon spawning and nursery waters. A total of 3000 to 12,000 char were destroyed annually at the mouth of the Agulowak River in Lake Aleknagik (Rogers et al. 1972). The second approach, from 1928 to 1940, used a bounty system. Bristol Bay residents were paid 2.5 to 5 cents per char tail. This soon became an important cash resource for the area, involving hundreds of thousands of dollars. The program was poorly designed and conducted. Many tails brought in for payment were never properly identified, and even included other species, including young salmon (Hubbs, 1940).

The first assessments of Arctic char as a salmon predator in the Wood River system was conducted in 1953 (Thompson et al. 1971). They sampled a total of 5900 char stomachs (collected from the five major lakes during various seasons) and concluded that incidence of predation was 3.5 times higher in areas of high smolt concentration (i.e. river mouths during migration) than in open lake areas. A total of 1.3 million sockeye salmon smolts were estimated to have been consumed at the mouth of the Agulowak River between 11 June and 20 July 1954.

Moriarity (1976) compiled and analyzed data on Arctic char abundance and distribution that was collected by UW-FRI personnel from 1956 through 1976. He included baseline data on life history of Arctic char with respect to season, year, location and sex. Feeding habits were shown to vary seasonally and by location throughout the system. Feeding habits changed with food availability, suggesting an opportunistic feeding pattern. Sockeye salmon smolts were found to be the primary food source during June and July (Moriarity 1976). Thompson et al. (1971) reported that threespine sticklebacks replaced sockeye salmon fingerlings in char diets as the salmon dispersed into deep water areas in late summer. Observations made during September sampling showed that char stomachs were packed only with snails (M. Kaill pers. obs.). Although sockeye salmon juvenile population levels vary from year to year, char populations have remained stable.

Ricker (1952) discusses the different relationship that can occur between predator and prey. He defines "type A" as follows:

> "Predators of any given abundance take a fixed number of the prey species during the time that they are in contact, enough to satiate them. The surplus prey escapes".

The result is "depensatory mortality" (Neave, 1952). In times of low sockeye salmon smolt abundance, the char predator population will take about the same number of prey as in other years, but the percentage of mortality in times of low abundance will be higher than at any other level of abundance. The result is that the emigrating sockeye salmon smolts are hit hardest when they are at their lowest population levels.

When the Bristol Bay disaster funds were appropriated in 1974-75 by the state legislature, ADF&G directed major efforts toward the Nushagak district, including the Wood River system. Meacham (1977) conducted an Arctic char predation assessment and control investigation within the Wood River system. He estimated that Arctic char consumed 1.5 million sockeye salmon smolts at the Agulowak River in 1975 and 1976. Experiments were conducted to design a control method for Arctic char during the spring-summer smolt migration periods. A nonlethal control method was sought, because Arctic char is a valuable resource to sport and subsistence fishermen and occupy an important ecological niche in the lake system.

An impoundment program, where char were confined in pens during the smolt migration period, was found to be the most feasible approach, considering the concerns of the various user groups of the area. The char impoundment program was initiated in 1975 at Little Togiak Lake and was continued on a larger scale between 1976 and 1980 at the mouths of the Agulukpak and Agulowak Rivers. Char were captured with hand operated purse seines that were set and retrieved from two skiffs. All char captured were measured for fork length and tagged with individually numbered tags. This allowed monitoring of escape rate, migration behavior, and biological effects of confinement on char relative to mortality, condition factor, body fat content, growth, and fecundity (Meacham & Clark 1979).

McBride (1980) reported on the homing and migration behavior of Arctic char to feeding and spawning sites in the Wood River lake system. As a result of tagging studies, he concluded that char which were found at the Agulowak River feeding site, represent one subpopulation out of twenty or more subpopulations of char in the Wood River lake system. About 98% of the char found feeding at the Agulowak River returned to the same site the following summer. In the fall, char from the Agulowak River migrate to spawning sites at Sunshine and Youth Creeks (Fig. 4). Similar migration patterns have been documented for subpopulations of Arctic char in other sections of the Wood River lake system (McBride 1980).

Studies of confinement mortality and growth rates of impounded char were reported by Buklis et al. (1979). In 1977, high mortality rates of confined char were experienced at the Agulukpak River site because of warm water temperatures in the shallow water (shore based) confinement pen (Buklis et al. 1979). A deep water (15 m) floating net pen was used at the Agulowak River from 1977 through 1980, and mortalities of confined char were less than 5 percent of all fish caught (Buklis et al. 1979). During confinement, char did not feed, resulting in a loss of fat reserves proportional to the length of confinement. Confinement had a significant negative effect on growth rate of Arctic char during the year following release, and repeated confinement further reduced growth rate (Buklis et al. 1979). However, following their release from the pens, the survival rate was not significantly affected. Confinement had no effect on fecundity, egg size, or spawning frequency (Buklis et al. 1979).

Concurrent with the confinement projects, creel census catch and effort data were collected from 1975 through 1977 by Clark and Meacham (1977). They compared: (1) Agulowak River mouth creel census information from two pre-impoundment years (1975-1976) to that of an impoundment year (1977), and (2) creel census information from an impoundment area to surrounding areas. Clark and Meacham (1977) concluded that catches of Arctic char per man day of fishing did not change significantly because of impoundment. For 1979, aerial surveys were flown over the Wood River system to determine sport fish use and a partial creel census was conducted on the Agulowak River (Newcome 1980). Collection of these data was never finished nor was analysis of the data conducted, with respect to impoundment effects.

Benefits of the impoundment program were reported as "number of smolts saved" and "benefit-to-cost ratio." To determine the number of smolts saved, weekly smolt consumption levels by unconfined char were multiplied by the number of char removed from the river mouth feeding area (Meacham and Clark 1979). This estimate assumes that confined char would have consumed the same number of smolts that unconfined char consumed. A benefit-to-cost ratio was obtained by multiplying the number of smolts saved by a 10% ocean survival rate to obtain the estimated number of returning adults available to the commercial fishery. The value of the commercial catch is then related to the cost of the impoundment project. Benefit-to-cost ratios at the Agulowak River in 1977 were 10:1, and in 1978 were 16:1. At the Agulukpak River benefit-to-cost ratios were 2.2:1 in 1977 and 1:1 in 1978 (Clark 1978).

In 1979 and 1980, the F.R.E.D. Division continued the char project at the Agulowak River mouth. Based on the past successful years of the project, a commercial purse seine operated from a 10m chartered vessel was utilized to capture char. Benefit-to-cost ratios on the char project in 1979 and 1980 at the Agulowak River were calculated to be 1.3:1 and 2.7:1 respectively. The ratio showed greater success in 1980 because of larger numbers of char that were impounded and increased consumption of smolts by char (Fried and Laner 1980a). Other studies on arctic char predation and impoundment are reported by Meacham (1978, 1980); Nelson (1966); and Rogers and Ruggerone (1980).

GOALS OF F.R.E.D. DIVISION IN BRISTOL BAY

The work addressed in this report was directed at a set of goals. The overall goal as stated in the Area Plan for Bristol Bay (Kaill et al. 1980), has been the development of rehabilitation and enhancement techniques that could be used to: (1) moderate cyclic fluctuations in the Pacific salmon abundance, and (2) provide optimal populations of other fishery resources for the benefit of all user groups.

The area program is defined as follows (Kaill et al. 1980):

1. Lake Nunavaugaluk Sockeye Salmon Production Evaluation Goal - to monitor the fate of hatchery produced sockeye salmon in the natural environment and develop methods to maximize their survival in order to assist East Creek Hatchery in meeting its production goals.

2. East Creek Hatchery Production and Maintenance Goal - to develop techniques and maintain facilities necessary for production of 15 million sockeye salmon fry for release into Lake Nunavaugaluk by 1980 and for maintenance of a run of 200 thousand sockeye salmon by 1984.

3. Sockeye Salmon Predator/Competitor Investigations Goal - to manipulate predator and competitor populations (e.g. Arctic char, beluga whale, threespine stickleback) to favor sockeye salmon survival.

4. Bristol Bay Lake Fertilization Investigations Goal - to increase rearing capacities of oligotrophic lakes for juvenile sockeye salmon through controlled additions of chemical fertilizers.

5. Bristol Bay Project Development and Control Goal - to identify, evaluate, and develop opportunities for increasing fishery production throughout Bristol Bay through use of suitable rehabilitation and enhancement techniques.

Hatchery production was considered to be the best way to address the goal of minimizing fluctuations in sockeye salmon production for Bristol Bay. This resulted in an emphasis on facility evaluation for the biology program.

Lake Nunavaugaluk Sockeye Salmon Smolt Studies

Sockeye salmon studies have been conducted at Lake Nunavaugaluk (Fig. 3) since 1973, in conjunction with East Creek Hatchery. In 1981, intensive studies of each sockeye salmon life stage (fry, smolt, and adult), were conducted (Laner 1982a). In 1982, budget restraints allowed only continuation of sockeye salmon smolt studies. Objectives of these studies were:

1) to determine whether large numbers of smolts leave the lake prior to or during ice breakup;

2) to sample the smolt migration and obtain information on the total production of Lake Nunavaugaluk hatchery and wild stocks;

3) to estimate age, weight and length composition of smolts leaving the lake;

4) to continue to develop and improve techniques for enumerating total smolt migration.

Methods and Materials:

Prior to and during ice breakup in 1982, smolt sampling was conducted at two sites near the outlet of Lake Nunavaugaluk (Fig. 5). Outlet width was approximately 1000 m, and water depth ranged from 0.6 to 3.6 m. After ice breakup, smolt sampling was conducted within Snake River, about 50 m below the outlet. River width at the sample site was 57 m and depth ranged from 0.3 to 1.5 m. Water velocity varied from 0.8 to 1.3 mps throughout the season. This sample site was upstream from the site used in previous years; it was chosen because high water level and high rates of flow made sampling difficult at the downstream site.

Prior to and during ice breakup, gill net sampling of sockeye salmon smolts was conducted. Two gill nets with variable square mesh (3.8, 3.2, 2.5, 1.9, 1.3 cm) were used. Nets were fished continuously from 2000 h on 8 May until 1000 h on 26 May and were checked daily at 1000 h. Sampling was discontinued on 26 May after floating ice destroyed both nets.

Fyke nets [fitted with floating live boxes as described by Thomason and Jaenicke (1979)] were used to sample smolts from 25 May through 19 June. Two stationary sample sites were used throughout the sample season. These sites were located in the middle and near the east shore of the river (Fig. 5). Two different sample designs were used in the smolt enumeration.

Index Sampling Method. During and immediately after ice breakup (25 May - 6 June) index sampling [similar to that described by Fried and Laner (1980b)] was conducted. During the early part of the migration (25 May to 6 June), ice and water conditions made it impossible to obtain samples consistently during each hour of each sample night, so one fyke net was fished at one

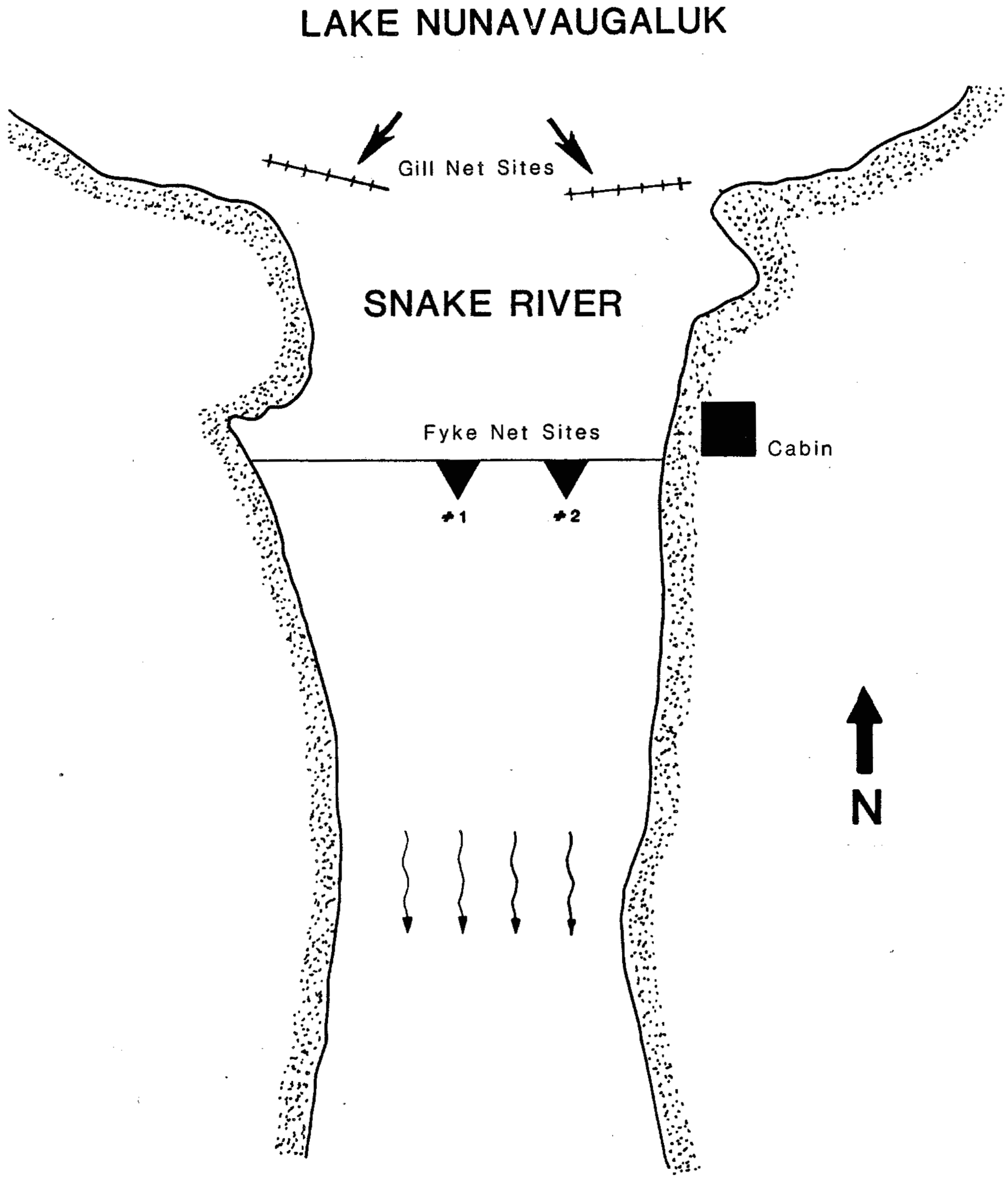

Figure 5. Area where Lake Nunavaugaluk drains into Snake River, showing location of gill net and fyke net sampling sites for sockeye salmon smolts.

site during a sample night. From 7 June to 19 June, 2 nets were operated. A sample night was defined as the 5-hour period from 2300 h through 0300 h. Thomason and Jaenicke (1979) reported that an average of 94% of all smolts (trapped at Snake river from 1974-1978) were caught between 0000 h and 0300 h.

From 25 May to 6 June, the smolts caught in the net(s) during a predetermined 6 minute sample period each hour were counted. These index counts were then expanded to estimate the total hourly smolt migration, using the following formulas:

$$\hat{Y}_{st} = \sum_{f=1}^{2} C_f \hat{Y}_f = \sum_{f=1}^{2} C_f \left(N \sum_{h=1}^{L} \frac{N_h}{N} \bar{y}_h\right)$$

$$V(\hat{Y}_{st}) = \sum_{f=1}^{2} C_f^2 V(\hat{Y}_f) = \sum_{f=1}^{2} C_f^2 \left(\sum_{h=1}^{L} \frac{N_h\,(N_h - n_h)}{n_h} s_h^2\right)$$

Where;

$\hat{Y}_{st}$ = estimated total smolts migrating during period when fyke nets were fished,

$\hat{Y}_f$ = estimated total smolts migrating through f fyke net(s),

C_f = expansion factor = (river width)/(net width),

N_h = total number of units (minutes) in h^{th} stratum,

$N = \sum_{h=1}^{L} N_h$,

s_h^2 = sample variance in stratum h,

$\bar{y}_h$ = sample mean for sockeye salmon smolts in stratum h,

V = variance,

f = number of nets fishing

h = stratum h

L = total number of strata

n_h = total number of units (minutes) in sample from h^{th} stratum.

Mark - Recapture Method. The second estimation procedure was a mark-recapture method which was conducted between 7 June and 19 June. Sockeye salmon smolts were dye-marked by immersion in a solution of Bismark Brown-Y stain and water (12.5g/380 liters). Smolts to be dye-marked were captured between

2300 h and 0200 h and held in a net pen near the shore until the dye process was complete (0330 h - 0600 h). A 750-liter fiberglass tub was used to contain the dye solution.

In 1981, use of the dye-mark technique overstressed the smolts because of:

1) immersion in the dye solution for more than 45 minutes;
2) rising water temperatures in shallow water where smolts were held during the day prior to being dye-marked, and
3) overcrowding in the tub and stress from resultant depleted oxygen supply.

These problems caused smolt mortalities (Rowse pers. obs.). In 1982, the dye-mark process was conducted in the early morning and smolts were released immediately along the lake shoreline about 500 m above the outlet. Also, immersion time in the dye solution was reduced to 30 minutes, and only 300-350 smolts were immersed at one time. Smolt mortality was reduced.

The proportion of dye-marked smolts recaptured in the fyke nets (2 nets were operated 7 June - 19 June) was used to estimate the proportion of the run that was sampled. Smolts captured during the 6-minute counts were pooled in a net pen and checked for dye-marks the next day. After 10 June, when fewer smolts were migrating, subsampling (6-min counts) was discontinued. The total number of smolts captured during a sample night and the total number of dye-marked smolts captured were recorded.

The following formula (Rawson 1982) was used to obtain an estimate of total smolts migrating between 7 June and 19 June:

$$\hat{N} = n \frac{D}{d} \left[1 + \frac{D-d}{Dd}\right]$$

Where;

$\hat{N}$ = estimated total number of smolts leaving lake between 7 June and 19 June,

D = number of dyed smolts released,

d = number of dyed smolts recaptured,

n = number of smolts caught in fyke nets during period of interest.

The estimated variance of the population estimate is as follows (Rawson 1982):

$$\text{Var}(\hat{N}) = \frac{n(n+d)D(D-d)}{d^3},$$

Assuming that N follows a normal distribution, we have:

$$95\%\ \text{C.I.} = N - 1.96\sqrt{\text{Var}(\hat{N})} \quad \text{to} \quad \hat{N} + 1.96\sqrt{\text{Var}(\hat{N})}$$

Age-Weight-Length Analysis. A random sample of 20 smolts was collected from the catch each sample night for age-weight-length analysis (AWL). These smolts were anesthetized with tricaine methanesulfonate (MS-222), measured for fork length, weighed (after blotting dry), and a scale smear taken. All smolts were returned to Snake River, 50 m below the fyke net site, after dark during the next sample night.

Smolt scales were mounted between glass microscope slides in the field and later viewed under a microfiche reader. Scale patterns were interpreted using criteria developed by Thomason (1979) for Snake River sockeye salmon smolts. Estimates for mean length and weight for age 1.0 smolts were weighted by the estimated smolt migration during each dye-mark period; 6/7 to 6/9, 6/10 to 6/12, and 6/13 to 6/19. Only three age 2.0 smolts were captured, so mean weights and lengths were not estimated for this age group.

Coded Wire Tagging. Sockeye salmon smolts were coded wire tagged (CWT) between 3 June and 17 June at Snake River. Smolts were collected using fyke nets with attached live boxes. They were transferred from the live boxes into 190-liter tubs, transported to shore, and transferred into net pens for holding. The following day, smolts were anesthetized with MS-222, their adipose fins were clipped, and they were tagged with full length coded wire. After dark each evening, all but 100 tagged smolts were released downstream of the fyke net site. The 100 fish were retained for 24 hours, anesthetized, and passed through a quality control device to determine short term percent tag retention.

Results:

Climatological Data. Daily air and surface water temperatures were recorded from Snake River near the outlet of Lake Nunavaugaluk (Table 3). Maximum and minimum water temperatures for the sampling period were 9.0°C and 2.0°C respectively, with a mean of 4.5°C. Maximum and minimum air temperatures were 14°C and 1°C respectively, with a mean of 6.3°C. All temperatures were recorded between 2200 h and 2300 h.

Outmigration Estimates. Index gill net sampling during the period 8 May to 26 May showed little Arctic char activity near the Lake Nunavaugaluk outlet. Eight char were examined for stomach contents. Food items included stickleback and insects.

Twenty-six salmon smolts (23 sockeye, 2 coho, 1 chinook) were caught in gill nets during the period 8 May to 26 May. Scales of the sockeye salmon smolts were not readable for age determination. Catches on 24 May (15 smolts) indicated that smolts began migrating on that date. This coincided with the beginning of ice breakup near the outlet and with a slight increase in daily water temperature.

Fyke net index sampling was initiated on 25 May at 2200 h (Table 4). No sampling was conducted between 2400 h 26 May and 2300 h 2 June because of hazardous ice conditions. Char feeding behavior and the "boiling" activity of migrating schools of smolts were noted in the evening hours during this time span, suggesting passage of smolts. On 31 May, four char were caught with hook and line. Standard length and stomach contents were as follows:

Table 3. Daily air and surface water temperatures (°C) recorded at Snake River, near Lake Nunavaugaluk outlet, during fyke net sampling for sockeye salmon smolts in 1982. Dashes represent missing data.

Date	Air	Water	Date	Air	Water
5/7	3.3	3.5	6/1	5.5	4.5
5/8	5.0	3.5	6/2	6.0	3.5
5/9	4.0	3.0	6/3	8.0	5.5
5/10	1.5	2.0	6/4	6.0	5.0
5/11	1.0	2.8	6/5	4.7	4.5
5/12	4.5	2.5	6/6	4.0	5.0
5/13	3.7	2.3	6/7	9.0	6.0
5/14	3.5	2.5	6/8	9.0	6.0
5/15	8.0	2.5	6/9	8.5	5.0
5/16	6.0	2.8	6/10	8.0	5.7
5/17	6.5	3.0	6/11	7.2	5.9
5/18	3.0	2.5	6/12	3.0	5.0
5/19	6.0	3.0	6/13	6.0	5.0
5/20	4.8	2.9	6/14	8.2	6.0
5/21	--	--	6/15	9.0	6.0
5/22	2.0	2.8	6/16	6.0	6.0
5/23	7.0	3.0	6/17	6.0	8.5
5/24	4.5	3.5	6/18	11.0	9.0
5/25	5.5	3.0	6/19	14.0	7.5
5/26	7.0	3.0	6/20	9.5	6.8
5/27	5.5	3.5	6/21	9.2	6.5
5/28	--	--	6/22	9.0	6.5
5/29	6.0	4.0	6/23	9.5	7.2
5/30	9.8	5.0			
5/31	7.0	5.5			

Table 4. Fyke net catches of sockeye salmon smolts, Snake River, 1982.

Date	Six minute subsamples Net #1	Net #2	Total Nightly Counts
5/25[a/]	301	---[c/]	
5/26	24	---	
6/3	2054	---	
6/4		128	
6/5	1862	128	
6/6	85	156	
6/7	416	1229	
6/8	532	879	
6/9	34	83	
6/10	311	105	
6/11[b/]			1094
6/12			1371
6/13			3853
6/14			728
6/15			574
6/16			1270
6/17			667
6/18			77
6/19			94

a/ 6 min. hourly counts conducted 5/25 through 6/10.
b/ total # smolt caught in both nets per sample night.
c/ no data collected.

540mm - 18 smolts,
550 mm - snails and small stones,
493 mm - 2 smolts and other fish remains,
410 mm - 1 smolt and other fish remains.

Fyke net sampling resumed at 2300 h 2 June. Releases of dyed smolts occurred on 7 June, 10 June and 13 June with 1079, 1347, and 1123 smolts released, respectively (Table 5). The total number of marked fish recaptured was 75. Estimates of migrating smolt populations by period are presented in Table 6. Population estimates were separated into six sample periods. Estimates for periods one and three were calculated using the index sample method. No sampling was conducted during period two. Estimates for periods four, five, and six were calculated using the dye mark-recapture sample method. Delineation of sample periods was necessary to take into account varying trap efficiencies throughout the sample season. A chi-square test shows a significant difference in trap efficiency between sample periods (χ^2=29.39, d.f.=2). Thus, it is not valid to lump all releases of dye-marked fish and analyze the data as a single sample period (Rawson 1982). A total of 3.2 million smolts were estimated to have migrated from Lake Nunavaugaluk during the sample periods. This is considered a very rough estimate. Due to logistical problems with sample gear and ice conditions, 7 days of sampling were missed. During this period, large numbers of smolt were observed migrating downriver. The heaviest migration occurred during sample period two. Water temperatures during this period ranged from 4.5°C to 5.5°C, with a mean of 5.0°C. Most smolts migrated out of the lake before surface water temperatures rose above 6.0°C.

Age-Weight-Length. A total of 403 sockeye salmon smolts were sampled (from gill nets and fyke nets) to determine mean weight, length, and age composition. Of the fyke net catches (n=379) (24 May-19 June) less than 1% were age 2.0 smolts.

Mean lengths and mean weights for age 1.0 smolts were 96.6 mm and 7.7 g, respectively (Table 7). Insufficient data were obtained on age 2.0 smolts (n=3) to determine weighted mean length and weight. The data for age 1.0 smolts are similar to a 9-year mean length of 96.5mm and mean weight of 8.0 g. Annual mean lengths and weights by age class from 1973 through 1982 are presented in Table 8.

Coded Wire Tagging. A total of 28,800 sockeye salmon smolts were tagged and released at Snake River between 3 June and 17 June 1982. Daily tagging mortality averaged 1.2%. Total tagging mortality (throughout the season) accounted for 353 dead smolts. Tag retention ranged from 88% to 98%, with a mean of 95%. Total valid tagged sockeye salmon smolts released in Snake River was 27,100, after daily mortalities and tag retention rates were applied.

Discussion:

Seasonal and diel timing of the sockeye salmon smolt migration from Lake Nunavaugaluk during 1982 was similar to patterns reported for this system in past years (Thomason and Jaenicke 1979; Fried and Laner 1980b, 1981; and Laner 1982b). There has been some uncertainty in the past as to the timing of the start of the run and the age composition of the early migrating smolts. In 1982, weather patterns during spring breakup were indicative of

Table 5. Summary of sockeye salmon smolt dye-mark release/recaptures between 7 June and 19 June, 1982.

Date Released	Total # Marked Fish Released	Date Recaptured	Total # Fish Recaptured	Total # Fish Caught
6/7	1079			
		6/8	9	5716
		6/9	1	460
		6/10	9	3296
6/10	1347			
		6/11	6	1094
		6/12	5	1371
		6/13	11	3853
6/13	1123			
		6/14	10	728
		6/15	6	574
		6/16	14	1279
		6/17	3	667
		6/18	1	77
TOTALS	3549		75	19,115

Table 6. Age 1.0 sockeye salmon smolt migration estimates grouped by sample periods, Snake River, 1982.

Sample Period	Date	$\hat{N}$	SD ($\hat{N}$)
1[a/]	5/25-5/26	96,000	48,000
2	5/27-6/2	--	--
3[a/]	6/3-6/6	1,499,000	878,000
4[b/]	6/7-6/9	732,400	210,000
5[b/]	6/10-6/12	683,200	196,000
6[b/]	6/13-6/19	185,100	27,000
TOTAL		3,196,100	925,300[c/]

a/ index sample method
b/ dye mark-recapture method
c/ calculated by taking the square root of the sum of the variances

Table 7. Mean length, mean weight, standard deviation(s), variance (s^2) and sample size (n) for sockeye salmon smolts grouped by sample periods and age class from Snake River, 1982.

Date	Mean Length (mm)	s	s^2	Mean Weight (g)	s	s^2	n
Age 1.0							
1. 5/12-24[a/]	108.9	7.4	54.9	12.0	2.9	8.2	21
2. 5/25-6/5[c/]	102.3	6.2	38.1	9.2	1.7	2.9	99
3. 6/6-6/10	94.6	6.7	45.2	7.0	1.5	2.4	100
4. 6/11-6/12	89.8	4.3	18.2	5.9	1.0	.9	40
5. 6/13-6/19	89.5	5.3	28.5	6.0	1.1	1.1	140
Mean[b/]	96.6	0.4		7.65	0.1		
Age 2.0							
1. 5/12-24[a/]	130	11.3	64	19.8	4.9	12	2
2. 5/25-6/5	104			9.5			1

a/ represents smolts caught in gill nets prior to ice breakup.
b/ weighted by estimated number of Age 1.0 smolts migrating during each sample period.
c/ no samples collected 5/27-6/2.

Table 8. Mean lengths and weights of sockeye salmon smolts from Snake River, 1973-1982[a/].

Year	Age 1.0 Fork Length (mm)	Age 1.0 Weight (g)	Age 2.0 Fork Length (mm)	Age 2.0 Weight (g)
1973	92	6.7	122	11.8
1974	92	7.3	---[b/]	---
1975	94	8.0	105	10.1
1976	91	6.3	---	---
1977	96	8.0	---	---
1978	93	6.8	104	9.4
1979	101	9.0	131	14.5
1980	105	10.1	129	18.0
1981	104	9.7	132	20.3
1982	97	7.7	---	---

a/ Data for 1973-1981 from Laner (1982b).
b/ No data collected.

an average over the past 20 years (M. Nelson pers. comm.) but were 2 to 3 weeks later than the average over the past 5 years (Table 9). Gill net sampling indicated that smolts began leaving the lake about 24 May. Ice still covered the entire lake until 3 June when the south tip of the lake became ice-free. Southerly and easterly winds shifted the ice for several days. On 3 June fyke net index sampling indicated the peak of smolt migration was occurring or had occurred shortly before. Fyke net catches on 4 and 5 June dropped drastically (Table 4). Similar results were observed in 1973, 1975, 1976, and 1977 at Snake River (Thomason and Jaenicke 1979). Past smolt studies at Snake River show that migration quickly builds to a peak soon after ice breakup and then declines within a week or two (Fried & Laner 1980b, 1981; and Laner 1982b). Given this pattern of migration, it is possible that a large percentage of the smolt population may have migrated prior to the time when weather and ice conditions would have permitted sampling in 1982.

Age-Weight-Length. Thomason and Jaenicke (1979) concluded that most age 2.0 and many age 1.0 smolts outmigrate before and during ice breakup. In 1982, efforts were made to confirm or deny the presence of a significant population of age 2.0 smolts in the emigration. Large numbers of smolts were observed migrating, but no estimates of number or age composition could be made. Subsamples collected from fyke net catches on 25 and 26 May indicated 100% age 1.0 smolts outmigrating at that time. Other data from char predation suggest a small age 2.0 component in the 1982 emigration. However, these would be important factors to monitor if salmon production in Lake Nunavaugaluk was greatly increased. Snake River system sockeye salmon smolts are consistently larger than smolt from the adjacent Wood River system. For the Snake River system sockeye salmon smolts, the 9-year mean weight is 8.0 g and the mean length is 96.5 mm. For the Wood River system sockeye salmon smolts, the 4-year mean weight is 5.4 g and 9-year mean length is 81.8 mm (Meacham 1981).

The lack of evidence of a large age 2.0 smolt population and the relatively large size of age 1.0 smolts in Lake Nunavaugaluk suggest that the lake provides adequate nutrients and that stickleback competition is not a limiting factor for rearing juvenile salmon. These characteristics of the smolt population also support the hypothesis that the growth of the Lake Nunavaugaluk sockeye salmon stock is not limited by in-system factors. This is further supported by data from sampling of the plankton populations (J. Koenings, pers. com.). The preferred food organisms were not cropped down during the growing season as they would be if the available food supply were stressed by food-limited rearing sockeye salmon populations. However, Jaenicke (pers. comm.) did find that numbers of preferred food organisms decreased in abundance as a function of increased escapement in the shoal areas of the upper lake, where rearing sockeye salmon were concentrated. The cropping, though detectable, was not limiting.

With adequate recruitment to the system, production could reach levels where the food supplies would be cropped to levels that would limit sockeye salmon production. Under these conditions, lake fertilization would be an appropriate strategy to continue enhancement of the system.

Table 9. Dates of ice breakup at Snake River/Lake Nunavaugaluk from 1977 through 1982.

Year	Date Ice-Out
1977	31 May
1978	19 May
1979	1 May
1980	16 May
1981	10 May
1982	3 June

The fraction of returning adults contributed by the 2.2 and 2.3 age classes (age 2.0 migrants) is typically 25% to 35%, as back-calculated from adult return. This is an apparent inconsistency with the reported 5% or less age 2.0 component of the smolt emigrants (Laner, 1982a). We do not have a ready explanation for this disparity.

Possible explanations are:

1. Differential survival. Age 1.0 and Age 2.0 smolts leaving the system do not have equivalent survival. Therefore, more Age 2.0 fish could be expected to reach adulthood than Age 1.0 fish. As a rule of thumb, this factor is a two-fold difference in survival, in favor of the Age 2.0 fish.

2. Sampling error. It is known that Age 2.0 sockeye salmon smolts leave earlier than Age 1.0 fish. What is not known is how much of the Age 2.0 migration leaves at ice-out. As we found in this year's field activities, sampling gear is difficult to maintain and operate in breakup conditions. This creates sampling bias. Under some circumstances, smolts have been observed swimming in, then out, of the throat of a fyke net (Rowse, Laner pers. obs.). Age 2.0 fish would be expected to be more powerful swimmers than age 1.0 fish.

3. The sample sizes used to determine age composition of returning adults are highly variable.

Smolt Population Estimate. Smolt sampling to determine a population estimate was greatly hampered by weather conditions in 1982. The sampling design was originally set up to use the incline plane traps that were used in the 1981 field season (Laner 1982b). However, continuous rain prior to and during ice breakup caused high discharge rates, which prevented setting the traps in place. Fyke nets were utilized as soon as ice conditions permitted. However, a 7 day period after the beginning of migration, was not sampled because ice still covered more than 75% of the lake.

Smolt dye-marking experiments were aimed at obtaining better population estimates. This technique, using Bismarck Brown-Y stain, showed success after several changes were made from the 1981 procedure. For 1981, smolts were dye-marked in the evening hours and released at the lake outlet just prior to the beginning of the smolt migration for that evening. Instead of moving downstream immediately, smolts were observed moving back into the lake, to migrate downstream within the next 3 days. In 1982, the dye process was conducted from 0330 to 0600 h. Smolts were released immediately into the lake along the shoreline. These changes avoided the excessive mortalities observed in 1981 that were due to: (1) stress from holding smolts throughout the day, and (2) rising temperatures in the shallow water where smolts were held throughout the day in 1981.

One assumption in the dye mark method is that smolts caught while migrating down-river and then released in the early morning hours back into the lake would regroup and migrate down-river again within 1 to 3 days. The dye-marking process was repeated every third day throughout the migration. However, it was observed that marked smolts stayed in the lake for up to 5 days after release. Thus, smolts from each dye-mark sample period overlapped to some extent in dates of recapture. It would be desirable to discriminate between releases (e.g. use different colored marks) so that smolts from each sample period could be identified.

A second assumption critical to the dye mark-recapture technique is that each fish is caught in the traps with the same probability (Rawson 1982). From the coded wire tagging studies, which were conducted in conjunction with the smolt enumeration program, it was observed that a proportion of tagged smolts moved back into the lake after release, even though they were released below the fyke net sample site and during the heaviest period of migration (i.e. 2400-0100 h) daily. Daily percent recaptures ranged from less than 1% to 7% with a mean of 0.8%. This violation of assumption was observed in the 1981 sample season, but did not appear significant. It was much more pronounced during the 1982 sample season, for unknown reasons. Smolts were observed to swim in and out of fyke nets, which would result in a biased sample (Laner and Rowse pers. obs.). These problems greatly comprise the validity of the population estimate.

Further research should address the following:

1) Do all sockeye salmon smolts move back and forth in the river, or do only tagged fish move back into calm lake areas to reorient themselves after being held and tagged?

2) Would this problem be alleviated if sampling and/or releases were conducted further downstream away from the lake?

Rawson (1982) discusses examples of F.R.E.D. Division projects where this dye-mark/recapture method has been used successfully. In the Snake River sockeye salmon smolt enumeration project, marking and tagging studies should not continue unless the above problems are resolved.

Coded Wire Tagging. In 1982, the coded wire tagging program at Snake River produced marginal results. Original objectives were to tag 50,000 sockeye salmon smolts. However, inclement weather and problems with sample gear prevented obtaining enough smolts for the tagging program. Since only 27,000 smolts were tagged, a large number of returning adult sockeye salmon will have to be examined to determine the contribution of Snake River sockeye to the Nushagak Bay commercial catch. Laner (1982b) proposed that if 50,000 smolts were tagged in 1982, 117,400 adult sockeye salmon from the 1984 Nushagak catch would have to be examined. With only 27,000 smolts tagged in 1982, evaluation of the Snake River system's contribution to Nushagak Bay commercial catch must include examination of 230,000 adults in 1984.

The CWT program was greatly aided in 1982 by an experienced tagging crew. Setup and operation of the tagging process was conducted efficiently with a minimal number of smolt mortalities caused by stress related problems. In 1981, sunshine and warm air temperatures caused mortalities of smolts held in shallow water net pens. In 1982, cooler weather alleviated these problems. Percent tag retention ranged from 88% to 98% in 1982. Operator error caused most of the tag loss. In a field operation of this sort, emphasis must be placed on quality of tagged fish and not necessarily on quantity of tagged fish.

Summary of 1982 Field Operations:

1. We operated under the assumption that age 2.0 smolts migrate first, possibly at breakup. Since physical conditions prevented sampling, an unknown percentage of the total smolt population migrated prior to fyke net sampling.

2. No age composition of early migrating smolt was obtained. Gill net samples suggested a small number of age 2.0 smolts were present, but no quantitative sampling was conducted. Fyke net catches showed 100% age 1.0 smolts outmigrating on 25 and 26 May, and from 3 June throughout the migration period.

3. Although the dye-marking went well and healthy smolt were marked and released, the population estimate of 3,196,000 sockeye salmon smolts (derived from dye-mark and index sampling methods) is suspect because of violation of assumptions in the dye-mark method. Lack of data from the first part of the migration before ice-out on the lake tends to make the population estimate conservative.

4. From a tagging objective of 50,000, only 27,000 were tagged.

Lake Nunavaugaluk Sockeye Salmon Adult Studies

Adult sockeye salmon runs on record have historically been low in Lake Nunavaugaluk. Sockeye salmon spawning escapement and distribution studies at Snake River/Lake Nunavaugaluk have been conducted by ADF&G since 1946. A weir has been operated during the field seasons from 1972 through 1978, and from 1980 through 1981. Table 10 shows catch and escapement data for the past 20 years. The Snake River section is a minor component of the Nushagak District, in terms of management of Bristol Bay sockeye salmon runs. Since 1969, the Snake River section has been closed to fishing until 15 July each year. However, weir counts in past years indicate that sockeye salmon runs peak on or near 15 July. F.R.E.D. Division has recommended that the Snake river section remain closed to fishing until 31 July to allow Lake Nunavaugaluk sockeye salmon stocks to increase.

This issue was of particular interest to us, because the reasons for Lake Nunavaugaluk's low productivity have never been adequately explored. The question can be divided into in-system and out-of-system concerns. Based on the following evidence, we feel that the lack of productivity for Lake Nunavaugaluk is not due to in-system consideration.

a. Surveys of plankton show preferred food organisms not fully cropped by populations of rearing fish.

b. The emigrant smolts are large and robust (e.g., typical length of 98 mm, compared to a typical length of 88 mm at the neighboring Wood River system).

c. Emigrant populations are primarily age 1.0 (i.e. there are few age 2.0 holdovers).

Table 10. Commercial catch and escapement of sockeye salmon returning to the Snake River system, Nushagak district, Bristol Bay, 1961-81.

YEAR	CATCH	SOCKEYE SALMON ESCAPEMENT	TOTAL RUN
1962	2,600	1,760	4,400
1963	23,200	38,000	61,200
1964	14,600	12,400	27,000
1965	8,100	12,000	20,100
1966	2,800	4,500	7,300
1967	0 a/	11,000	11,000
1968	0 a/	4,100	4,100
1969	0 a/	9,300	9,300
1970	0 a/	23,800	23,800
1971	0 a/	8,500	8,500
1972	900	2,000	2,900
1973	300	900	1,200
1974	3,300	15,300	18,600
1975	7,200	9,500	16,700
1976	11,000	12,700	23,800
1977	3,900	9,300	13,200
1978	16,700 b/	18,100	34,800
1979	8,900 b/	8.400	17,400
1980	17,800 b/	36,500	54,300
1981	35,200 b/	14,600	49,800
1982	0 a/	11,600	22,200
20-year Average	10,400	12,600	21,000

a/ Catch not pro-rated to Snake river system
b/ Preliminary inshore catch

A more likely explanation of Nunavaugaluk's sustained low production level is the continued low levels of escapement. From 1969 until present, the Finfish Regulations of the Alaska Board of Fisheries have required that the Snake River section of the Nushagak District remain closed from 15 June to 15 July. After 15 July, the waters within the Snake River section were open to fishing unless closed by emergency order.

From available data (1960-64 and 1973-81) concerning timing of Snake River escapements, the peak of escapement occurs between 12 July and 15 July. This compares to peak escapement dates for Wood River and Igushik River of 4-10 July and 7-11 July, respectively.

Data do not exist on travel time of Snake River fish from the Snake section to Lake Nunavaugaluk. But, by assuming a travel time of 2-3 days, the bulk of the system's escapement would appear to be in the Snake River section between 9-12 July.

If the above assumption is correct, the present regulation probably protects the major part of the Snake River's escapement. However, conversations with local fishermen reveal that fishing can be quite good after 15 July in the Snake River. While the fish taken there are probably of mixed stock, we felt, during a period of good returns, it would be a valuable and instructive experiment to continue protection for the fish in the Snake River section past 15 July. If there was an obvious increase in escapement for the time period in question, natural (regulatory) rehabilitation could be considered for restoration of the Snake system stock.

In 1982, aerial spawning surveys at Lake Nunavaugaluk were conducted by ADF&G, Commercial Fisheries Division, on 9, 20, and 27 August. Survey flights were made from an altitude of 61-77 m in a Cessna 185. Details regarding survey methods and procedures are described by Nelson (1979).

The 1982 spawning ground surveys estimated 11,600 sockeye salmon escaping into the system. Table 11 shows distribution of sockeye salmon on beaches and major creeks at Lake Nunavaugaluk. The 1982 sockeye salmon escapement is close to a 20-year mean of 10,400 fish.

East Creek Hatchery Production and Maintenance

Much of the effort of F.R.E.D. Biologists based in Dillingham was directed at evaluation and research in support of the East Creek hatchery. The Snake River smolt project, the Lake Nunavaugaluk fry investigations, and contract work involving studies of productivity of the Lake Nunavaugaluk/Snake River system are cases in point (Laner 1982a, 1982b).

Predator/Competitor Studies

Control of Arctic char and beluga whale have shown high potential for rehabilitation and enhancement of sockeye salmon in Bristol Bay (Fried et al., 1980; Fried and Laner, 1980a; Meacham and Clark 1979). There is continued potential here for cooperative work with the Commercial Fish Division, e.g.:

Table 11. Peak aerial live counts and total population estimates of sockeye salmon in Lake Nunavaugaluk, 1982.[a/]

Area	Aerial Counts Date	Aerial Counts Number	Expansion Factor[b/]	Total Pop. Estimate
Snake River	8/20	300	2	600
Snake R. to Eagle Cr. Beaches	8/27	1,220	2	2,440
Eagle Creek	8/9	150	2	300
Eagle Creek Lake Beaches	8/9	500	2	1,000
Eastshore Beaches	8/27	1,165	2	2,330
Killiam Creek	8/9	900	2	2,930
East Creek	8/27	100	2	200
Southshore Beaches	8/27	10	2	20
Total		5,810		11,620

[a/] All counts rounded to nearest 10 fish.
[b/] Derived by expanding peak live count to reflect fish not counted because variables such as schooled and dead fish, late or poor survey conditions, etc.

"...recent escapement levels far above those levels previously identified as "optimum" will probably be producing massive numbers of juvenile salmon rearing in the lakes. A serious question arises in that fresh water predators may also show a massive increase in abundance which could have disastrous conse quences when conditions of "normal" escapements and juvenile salmon production return. The Wood River system would be ideal to follow the relationship between adult and juvenile salmon pro duction and abundance of predators since population estimates of predatory Arctic char have been made for a number of past years by F.R.E.D., Comm. Fish., and the Fisheries Research Institute." (C. Meacham, Com. Fish. File Material, Anchorage, 1982).

Threespine Stickleback: Past studies concerning the extent of competition for food items and habitat between sockeye salmon fry and threespine stickleback indicate this is not currently a serious factor affecting sockeye salmon fry survival in the Wood River Lakes and Lake Nunavaugaluk. It has been suggested that stickleback in their first year and age 0.0 sockeye have overlapping requirements for prey items in relation to the habitat type occupied by each fish species (Hoffman 1979). There is evidence that juvenile sockeye salmon have the advantage in the competition between the species, because the growth of both species was more closely related to the abundance of the sockeye than to the abundance of the sticklebacks (Rogers 1977). Results from the stickleback eradication program, conducted by Johnson (1976), suggests that a program of this type is not effective. It appears that insufficient numbers of sticklebacks were taken out of the Lake Nunavaugaluk system to allow much reduced competition for food with sockeye fry.

Arctic Char Predation: The Arctic char impoundment program has proved to be a practical and cost effective means of reducing predation on sockeye smolts (Fried and Laner 1980a). Perhaps the greatest promise of this technique is reducing the effect of "depensatory mortality" of char on emigrant sockeye salmon smolts. (Ricker 1952; Meacham and Clark 1979).

The char impoundment project might be most valuable if it were held in inactive status until fry sampling and other indicators suggest that production from the major Bristol Bay lake systems is down (i.e. a poor production "valley" in the Bristol Bay cycle). When this occurs, the char control project could be activated. Since predator populations tend to take a relatively constant number of smolts at a given site, the result of controlling those predators could well mean saving a substantial percentage of a system's production during off years.

BRISTOL BAY PROJECT POTENTIALS FOR REHABILITATION AND ENHANCEMENT

Newhalen River Velocity Barriers

The Newhalen River is the outlet river of Lake Clark, flowing into Lake Iliamna (Fig. 6). North of Lake Iliamna, a velocity barrier is found in the Newhalen River rapids during years of high water levels. Depending on flows, salmon are partially or completely blocked during their migration into Lake Clark. In 1980 an estimated 2.1 million adult sockeye were prevented from reaching the spawning grounds. Of the 1.5 million that did

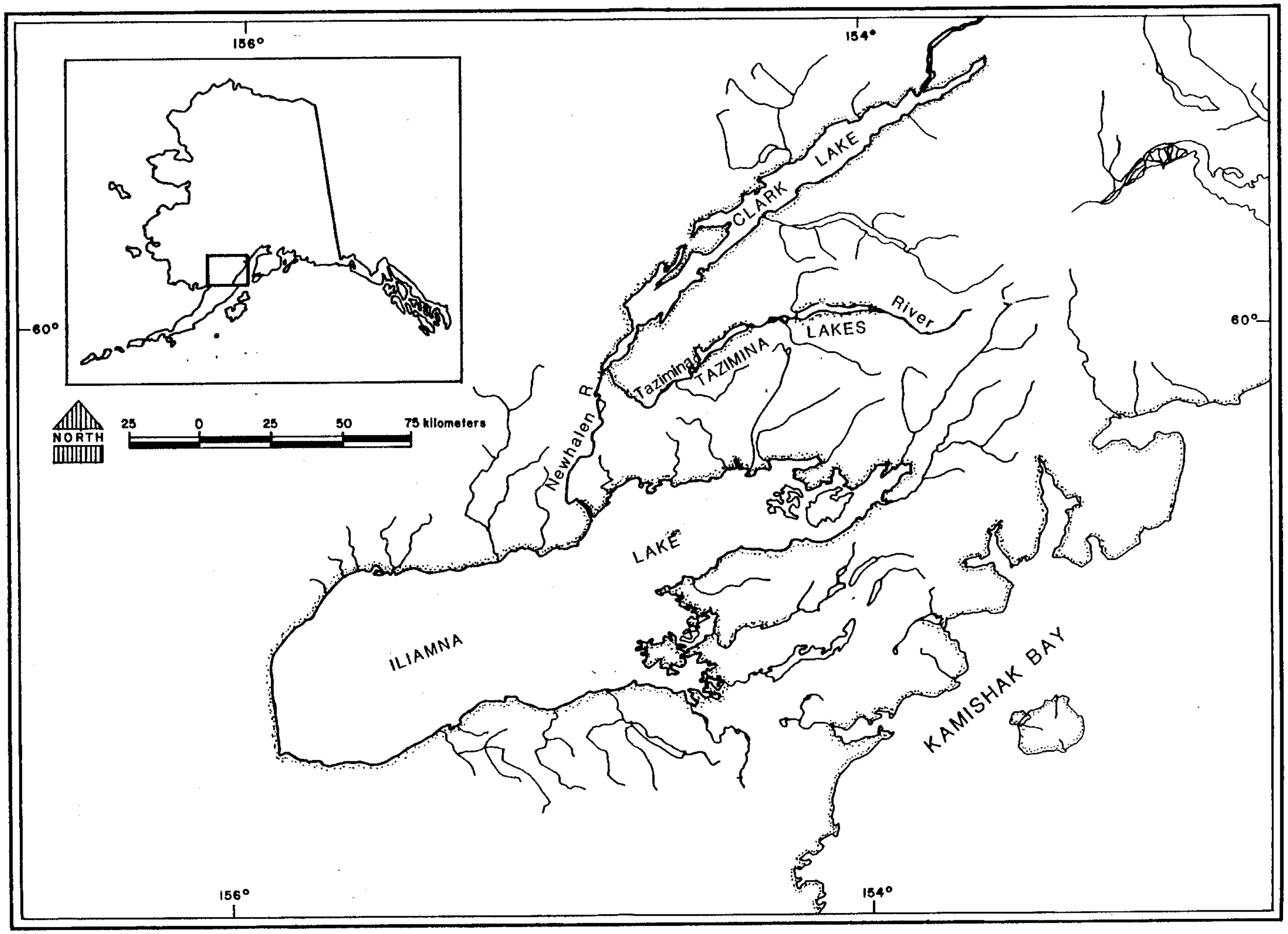

Figure 6. Lake Clark and Lake Iliamna drainages, near Bristol Bay, Alaska.

reach the grounds, only an estimated 0.8 million spawned successfully (Mathisen and Poe 1969; Poe and Mathisen 1980). A fish pass would allow sockeye to enter Lake Clark in years of high water. UW-FRI, Alaska Power Authority, and other agencies are continuing work on this project, both as a fisheries problem and as possible mitigation for hydro power development.

Nuyakuk River Fish Pass

The Nuyakuk River system (Fig. 1) is the third largest producer of sockeye salmon in Nushagak Bay. During years of high water, a partial blockage and delay of returning salmon occurs in the rapids area. We recommend a work feasibility study to detail effects of the blockage, and to determine the potential benefits of a fish pass.

Wood River System Beaver Dam Removal

The department gets requests each year (particularly in times of low water) to open salmon spawning streams blocked by beaver dams. Although dramatic in appearance, such blockages probably look much more serious than they really are. Another, probably more detrimental way in which beavers dam impact salmon production is through increased siltation of stream beds caused by reduced velocity of the stream. Beavers must periodically move their colonies to new locations when the available food supply near their lodge is exhausted. Often colonies move no more than a few hundred yards up or downstream. After several years, a succession of dams and houses is noticeable along the stream. Not all abandoned dams are washed away by spring floods, and those that survive may take many years to decompose. A stream that was once a free running stream with a clean gravel bed thus becomes a slow moving, almost stagnant, body of water with a thick layer of silt covering the gravel. Water temperatures as well as turbidity may be increased. (pers. comm. K. Taylor, 1982.) It is difficult to generalize on the benefits of beaver dam removal, though potential benefits to salmon populations make this strategy worth further study.

Becharof Lake Supplemental Fry Production

The main basin of Becharof Lake (Fig. 7) has shown potential for increased rearing of sockeye salmon fry. The first steps in the realization of this potential are to continue baseline investigations, and to identify the most effective approach. Possibilities are a hatchery, or to provide fry or eggs for planting in under utilized spawning habitat (Kaill et al. 1980).

Featherly Creek Fish Pass

Featherly Creek is one of the main sockeye spawning streams of Becharof Lake (Fig. 7). The creek contains a fish blockage that prevents sockeye salmon from using several kilometers of prime spawning habitat. We propose that a study be implemented to gather baseline data and determine the feasibility of a fish pass structure.

Tazimina River Fish Pass

The Tazimina River falls are located north of Lake Iliamna, about 10 kilometers upstream from Six Mile Lake (Fig. 6). The falls act as a complete block for migrating adult salmon. A fish pass facility to allow

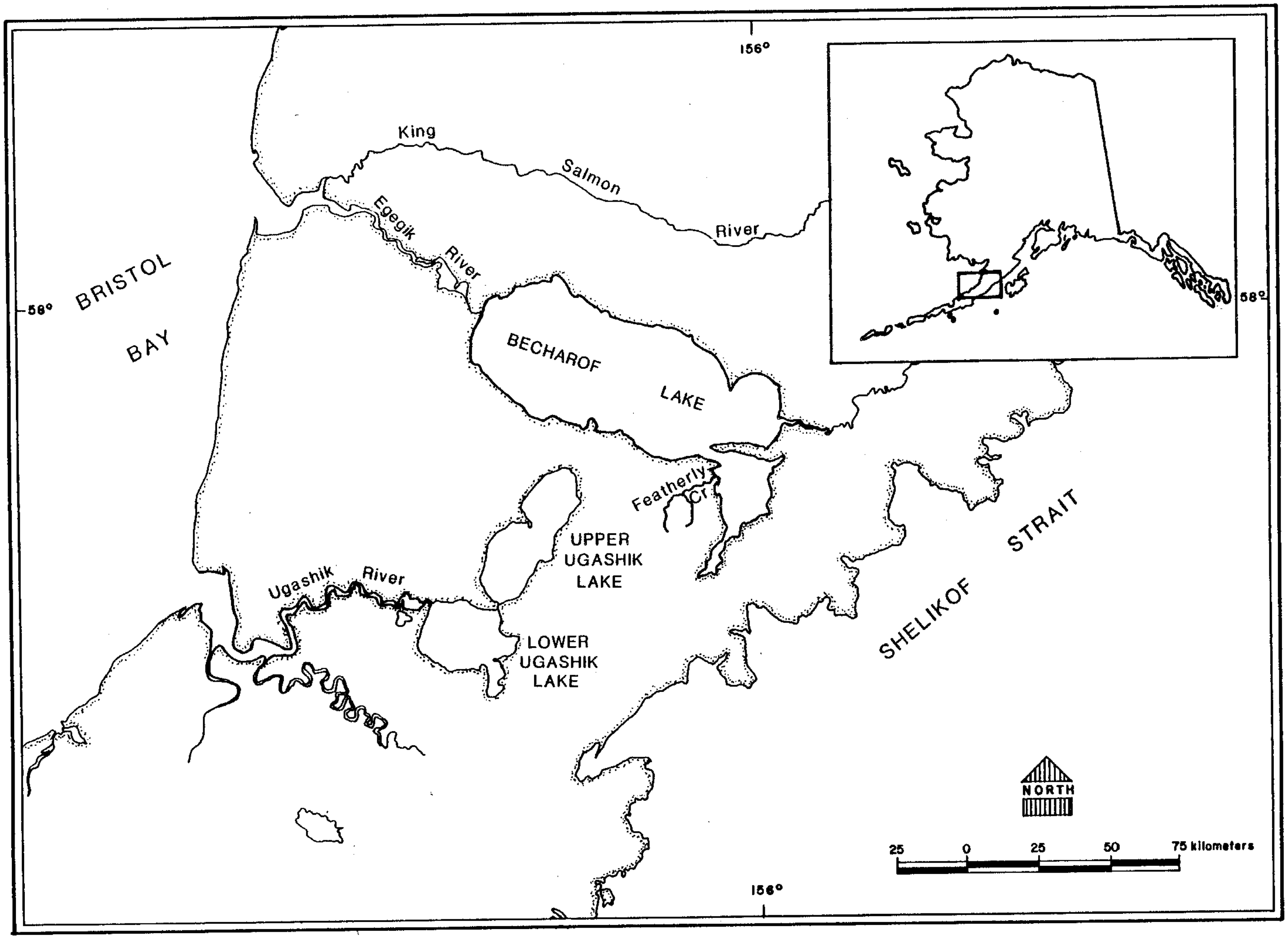

Figure 7. Becharof Lake drainage, near Bristol Bay, Alaska.

spawning adult salmon to reach upriver has been proposed. Moreover, the Alaska Power Authority is currently engaged in a feasibility study for a hydro electric project on the river.

Nuyakuk River System Enhancement

This study would include the Tikchik Lakes/Nuyakuk River system (Fig 1). The objective would be to develop and assess enhancement opportunities to increase the sockeye and pink salmon production of the Nuyakuk River system. Limited data on this system indicates that production of salmon could be increased. There is potential for sockeye salmon fry plants to increase production of adults.

Bay of Island Creek

Bay of Island Creek flows from Idavain Lake south to Naknek Lake, in Katmai National Park on the Alaska Peninsula (Fig. 1). Enhancement techniques, such as an eyed egg plant and fish passes, have the potential to improve production of the Naknek River system. Eyed egg plants could increase the sockeye salmon fry population by as much as 782,000. Fish passes would allow additional production of 21.6 million sockeye salmon fry, by increasing utilization of available nursery areas of North Arm. The passes would also open up 13 km of potential salmon spawning grounds that are presently blocked by falls.

Lake Inventory

In a cooperative effort with the Commercial Fish Division, limnological and juvenile fish studies on lake systems in Bristol Bay would be useful to determine the effects of increased natural production of salmon fry. Effects on ecosystem productivity, salmon growth, age at smoltification, disease and parasite infection rates, and survival could be assessed and be helpful management of the systems. Many systems in Bristol Bay offer the potential for lake fertilization. A process for screening and prioritization of potential projects is needed.

Sport Fish

Bristol Bay has drawn the attention of national and international sport fishermen over the past 25 years. Anglers are attracted primarily to the salmon and rainbow trout fisheries in the Naknek, Kvichak and Wood-Tikchik River drainages although recent years have seen rapid development of salmon sport fisheries as well. Studies concerning sport fish in Bristol Bay have been very limited in the past. Some creel census data and scattered migration and distribution data have been collected over past years, but there is much that is unknown.

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