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Arctic Char Predation Control Project
in the Wood River System, Alaska
Final Report 1975 - 1980

by
Jack Miller
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Alaska Department of Fish & Game
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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

From 1976 to 1980 the Alaska Department of Fish and Game impounded Arctic char, *Salvelinus alpinus*, during the mass emigration of sockeye salmon, *Oncorhynchus nerka*, smolts. Following the peak of smolt emigration, the Arctic char were released so that local sport fishermen and subsistence users could utilize the resource. During the 5 years of this project, over 3.5 million smolts were "saved" from predators. The returning adults generated an estimated ex-vessel value of $879,000 for the common-property fishery, resulting in a benefit-cost ratio for the project of 5.8:1.

Arctic char confined at the mouth of the Agulowak River survived captivity well; those confined at the mouth of the Agulukpak River showed reduced growth, increased fat depletion, and reduced survival.

KEY WORDS: Predator control, Arctic char, *Salvelinus alpinus*, sockeye salmon smolts, *Oncorhynchus nerka*.

INTRODUCTION

From the early 1900s to the mid-1970s, a long decline was observed in the Wood River sockeye salmon, *Oncorhynchus nerka*, population (Meacham 1977a). During the 1974/1975 legislative session, $600,000 was appropriated to determine the reasons for this reduced production and to promote the rehabilitation of sockeye salmon populations in Bristol Bay. Because the Wood River system sustained the most serious decline of sockeye salmon, a majority of the appropriation was spent investigating this system. As part of this rehabilitation project, lake fertilization studies were conducted in the upper end of Little Togiak Lake (Rogers

1977). Also, investigations into controlling the sockeye salmon parasite, *Triaenophorus crassus*, (Burke 1978) and its intermediate host the northern pike, *Esox lucius*, were initiated by the University of Washington and Alaska Department of Fish and Game (ADF&G). Finally, investigations were made into the role that Arctic char, *Salvelinus alpinus*, play in the predation of sockeye salmon smolts as well as the methods for controlling this predation. This report focuses on the Arctic char control portion of the project.

The Wood River system drains into the upper end of Nushagak Bay, which is located in the northern portion of Bristol Bay. The Wood River lakes lie between 59° and 60° north latitude and 158° 20' and 159° 20' west longitude (Figure 1). These lakes lie in a general southeast-northwest direction and are connected by short, swift rivers. The total surface area of the system covers 456 km² (176 mi²). The lake basins are of glacial origin and are characterized by shallow and weedy areas in their eastern end and by deep fjords (exceeding 150 m) in the western ends. The lakes are usually covered by ice from December through May (Nelson 1966).

Nelson (1966) estimated that Arctic char represented 75% of the resident fish population of the Wood River lakes; Reeves' (1969) estimate was 83% Arctic char. Moriarity (1976) estimated the Arctic char component of the resident fish population in Little Togiak Lake and Lake Kulik to be 99% and 70%, respectively.

The predation of sockeye salmon smolts by Arctic char was recognized early in the twentieth century. Attempts were made by federal agents to control Arctic char populations through the annual destruction of 3,000 to 12,000 fish from 1920 to 1925. Starting in 1928, a bounty was paid for each "trout" tail that was turned over to authorities; this program continued through 1940. During this period, several hundred thousand char were removed from the Wood River system. Following the termination of this program,

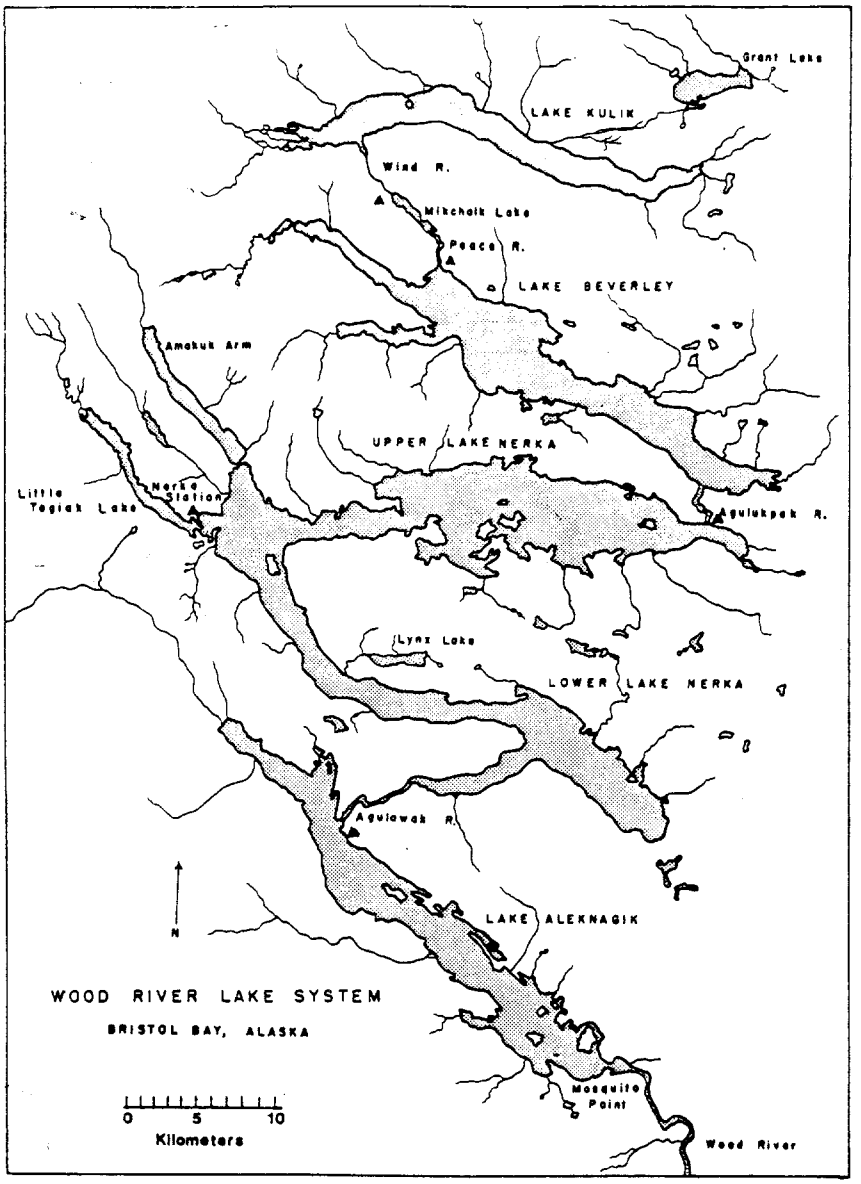

Figure 1. Map of the Wood River lakes system.

the catch level of Nushagak district sockeye salmon declined (Figure 2) from about 3 million to 1 million (Meacham 1977a).

The most serious predation upon young sockeye salmon occurs during June and July when sockeye salmon smolts concentrate for their seaward migration. In the Wood River system, most of this predation occurs in river mouths where smolts are at their highest density. In addition to this short period of smolt predation, Arctic char are known to feed on the eggs, fry, and fingerlings of sockeye salmon. Predation on eggs is probably inconsequential, because they are only available to char on the surface of the stream bed and would probably die. The magnitude of predation on fry is generally unknown, although the seasonal movement of Arctic char into areas of fry abundance (i.e., creeks flowing into the system) has been documented (McBride 1979). Meacham (1977a) noted that one Arctic char taken in the Agulukpak River had 142 fry in its stomach. Sockeye salmon fry probably play a more important role in the diet of young Arctic char than the larger sockeye salmon juveniles found in the river mouths during smolt emigration. Predation upon resident sockeye salmon fingerlings occurs throughout the year. From January through May 1976 the mean number of fingerlings per Arctic char stomach was 0.2 (Meacham 1977a). An overview of this situation is presented by Meacham and Clark (1979).

While the effects of Arctic char predation has been clearly demonstrated over the years, the Arctic char is valuable as a regional sport and subsistence fish. At the time of this study, there were three active fishing lodges on the Wood River system; a fourth was located nearby. In 1976 there were 3,185 angler days of sport fishing effort; most of it took place in June, July, and August (Meacham 1977a). About 25% of the fishing effort occurred at the mouth of the Agulowak River. The Agulukpak River mouth received only 5% of the effort. Few data have been collected on the subsistence use of Arctic char; however, observations (Meacham 1977a) indicate that subsistence fishing

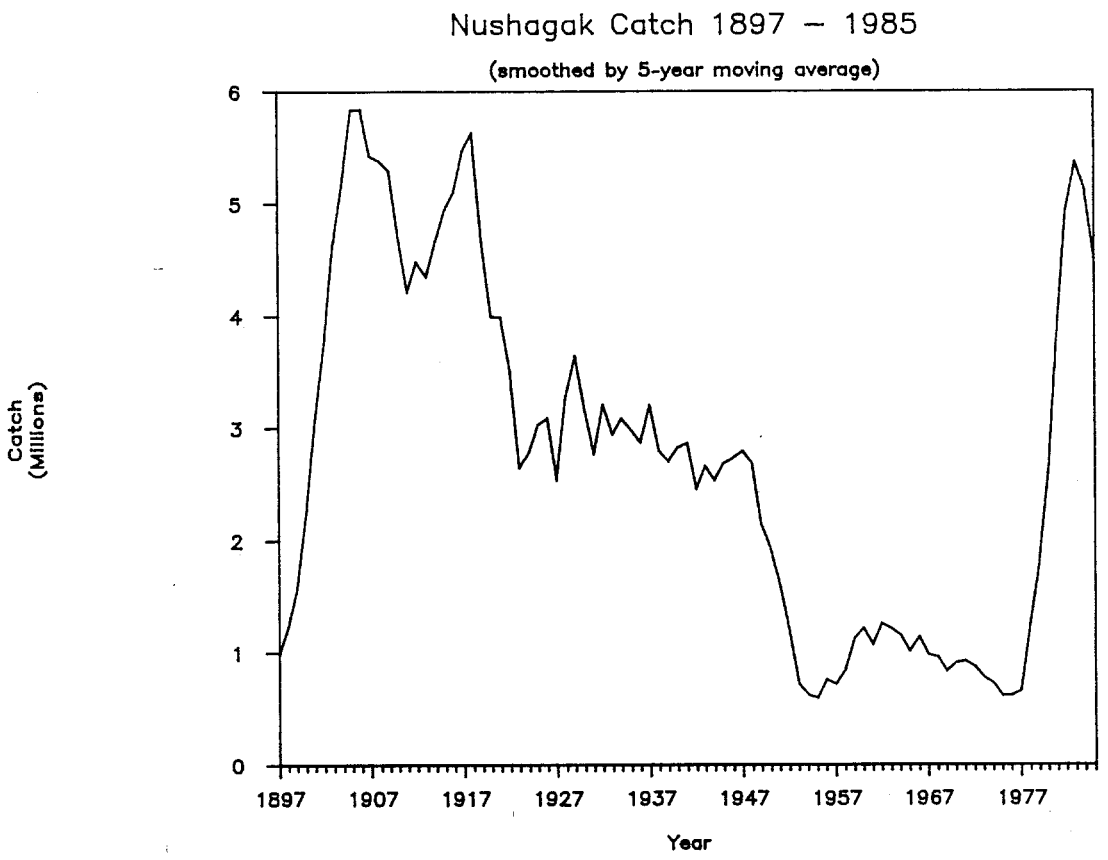

Figure 2. Nushagak catches (1897-1985) (adapted from Meacham 1977b).

occurs during much of the year, except June through August when many of the locals are involved in commercial fishing operations.

In response to the needs of the commercial, sport, and subsistence fisheries, a program was conducted from 1975 to 1980 in which Arctic char were impounded during smolt emigration periods. During the periods of low smolt aggregation, sport fishermen were allowed open access to the resource.

This project was broadly divided into two areas of study: (1) to assess the impact that the removal of predators would have on the Wood River sockeye salmon populations; and (2) to study the effect that long-term impoundment would have on Arctic char. During the early years (1975-1978), the project was under the direction of the Commercial Fisheries Division. In later years (1979-1980), the project was conducted by the Fisheries Rehabilitation, Enhancement and Development (FRED) Division. Annual budgets averaged between $30,000 and $40,000.

RESULTS OF STUDIES AND PROJECTS

Arctic Char Population Estimates

During 1975 approximately 4,500 Arctic char were captured, measured, and tagged (internal-anchor tags). The project was conducted by the Commercial and Sport Fisheries Divisions. During 1976, 8,900 Arctic char were captured and tagged in various areas of the Wood River system. Using Petersen and Schnabel methods, population estimates of Arctic char were made in 1976 (Table 1). In general, these estimates agree with those made by other agencies in previous years. In 1954 the Fisheries Research Institute (FRI) reported 11,297 Arctic char in the Agulowak River and 6,234 Arctic char in the Little Togiak River (Meacham 1977a); these population estimates were made on congregations that were found

Table 1. Estimates of the natural Arctic char populations found in the Wood River system (Meacham 1977a).

Subsystem name	Char population
Wind River	3,000
Peace River	3,500
Agulukpak River	7,500
Little Togiak River	5,000
Agulowak River	12,000
Wood River System Total	31,000

in river mouths; those not found in the river mouths were excluded from the estimates. In the fall of 1976, Lakes Aleknagik, Nerka, and Beverly were sampled for prespawning concentrations of Arctic char. In the course of this 2-week survey, 84 Arctic char previously tagged in the river mouths were recovered. Meacham (1977a) reported, "Although neither the assumption of random fishing effort nor random mixing of tagged fish required for a valid Petersen population estimate were met, the recapture of 84 Arctic char previously tagged during the summer of 1976, was used to 'estimate' 165,863 (95% C.I. 136,781 to 209,032) Arctic char present in the system."

Arctic Char Migratory Patterns

McBride (1979) traced the movements of tagged Arctic char from the river mouths, where they aggregated to prey on emigrating sockeye salmon smolts, to their spawning areas in creeks draining into the Wood River lakes. What emerged was a pattern of feeding and spawning in the same locations by the same individuals with little mixing of the stocks. After analyzing 80,000 tagging records, McBride (1979) concluded that there were probably in excess of 20 discrete Arctic char populations, or stocks, in the Wood River system. The Arctic char at the feeding sites accounted for only 40% of the estimated 160,000 fish present in the system, and those at the mouth of the Agulowak River had little or no migratory interaction with the other discrete subpopulations or the population at large in the lake system. McBride (1979) found that 89% of the estimated 10,000 to 15,000 Arctic char that aggregated in the mouth of the Agulowak River returned to that feeding site the following year. Meacham's (1977a) data also suggest that no immigration of fish to the tagging area from other parts of the system occurred. McBride (1979) also identified nine other feeding locations in the Wood River lakes that were revisited by at least 75% of the individuals feeding in each location during previous years.

Arctic Char Impoundment

In the summer of 1975, the feasibility of impounding Arctic char was examined. A total of 235 fish were captured and impounded (Meacham 1977a); about half were captured with gill nets and half were captured by hook and line. During subsequent years, the impoundment project was expanded; from 1976 to 1980, they were captured by purse seine and hook and line. Table 2 shows the number of Arctic char captured during the project.

Table 3 shows population estimates of Arctic char in pens and in the river mouths. Of the 165,000 Arctic char estimated by Meacham (1977a) to be in the Wood River system, only 31,000 could be accounted for in the mouths of the rivers (*see* Table 1). Meacham (1977a) found that, while Arctic char were steadily being removed from the Agulowak River mouth, the estimate of fish there increased by 61 per day, compared to the increase of 99 fish per day in 1976 when there was no impoundment.

While the increasing number of fish in the river mouths seems inconsistent with McBride's (1979) findings, it is not; the increasing numbers with each successive population estimation reflect the arrival of those Arctic char that have traditionally fed in this location, not smaller fish arriving to fill the void left by captured ones. During the years of impoundment, the population was relatively stable, since the number of impounded Arctic char added to the number of fish in the river mouths did not exceed the population estimates from the preimpoundment years. The Agulukpak River showed similar trends.

The question of how many smolts were actually "saved" by the impounding of Arctic char is a difficult one. Several authors have documented the number of smolts that an Arctic char can consume; their findings are summarized in Table 4. The actual number depends on water temperatures, smolt size, and the size of the Arctic char. The number of smolts saved was calculated by

Table 2. Numbers of Arctic char confined during the project[a/].

Location	1976	1977	1978	1979	1980
Agulukpak	3,300	1,800	1,800		
Agulowak		5,300	5,900	3,300	4,300
Totals	3,300	7,100	7,700	3,300	4,300

[a/] From Buklis et al. (1979) and Fried and Laner (1980).

Table 3. Population estimates for Arctic char in the Agulowak and Agulukpak River mouths from 1976 to 1980[a/].

Date	River	Penned	Unpenned	Total	Penned as % of total
July '76	Agulowak	3,493	10,560	14,053	25%
27-Jun-77	Agulowak	3,080	2,525	5,605	55%
05-Jul-77	Agulowak	4,147	2,924	7,071	59%
14-Jul-77	Agulowak	4,893	3,587	8,480	58%
05-Jun-78	Agulowak	183	5,163	5,346	3%
26-Jun-78	Agulowak	3,213	8,609	11,822	27%
10-Jul-78	Agulowak	5,771	4,009	9,780	59%
03-Jun-79	Agulowak	219	12,310	12,529	2%
23-Jun-79	Agulowak	1,980	13,689	15,669	13%
05-Jun-80	Agulowak	547	7,547	8,094	7%
23-Jun-80	Agulowak	1,977	3,133	5,110	39%
06-Jul-80	Agulowak	3,280	1,956	5,236	63%
Average		2,663	5,950	8,613	35%
27-Jun-77	Agulukpak	1,532	2,603	4,135	37%
10-Jul-77	Agulukpak	2,187	3,649	5,836	37%
08-Jun-78	Agulukpak	49	1,963	2,012	2%
24-Jun-78	Agulukpak	1,271	3,086	4,357	29%
Average		1,260	2,825	4,085	27%

[a/] From Meacham (1977a), Clark (1978), and Fried and Laner (1980).

Table 4. Arctic char consumption of sockeye salmon smolts.

Average consumption	Temperature (°C)	Author
0.8 / 24 Hr.		Ruggerone and Rogers (1984)
4.2 / 24 Hr.	5.5 - 9.5°C	Howe (1981)
3.3 / 24 Hr.	3.5 - 9.5°C	Meacham (1977a,b)
2.0 / 24 Hr.		Thompson et al. (1971)

multiplying the daily smolt consumption at a given water temperature by the number of impounded Arctic char. Table 5 shows the number of smolts that were saved by the impoundment of Arctic char.

Effects of the Impoundment on the Arctic Char

As most of the Arctic char were held for several weeks without feeding, studies were undertaken to determine the effects of prolonged confinement on their general health (Buklis et al. 1979). A control group was established by measuring and then releasing some of the captured fish; the remaining ones were impounded in floating pens. Population estimates were made of unconfined Arctic char, and data were collected from the control group upon their recapture.

Unsuccessful attempts were made to feed impounded fish an artificial diet (Rangens pelletized fish food). Recent advances in artificial diets might prove more successful if additional feeding attempts were made.

Effects of Confinement on the Agulukpak River Arctic Char

Capture and confinement mortalities averaged 9.8% from 1976 to 1978 for the Agulukpak River (Buklis et al. 1979; Fried and Laner 1981). This average could be expected to drop if the project were reinstated; mortalities tended to decrease as the project developed from its pilot phase to its production phase. Postconfinement tag recovery showed that as the number of days of confinement increased, the recapture rate of tagged fish decreased. Using 1976 data, Buklis et al. (1979) predicted that confinement of Arctic char for 26 days would reduce tag recovery by 50% in one year, and confinement of 21 days would reduce tag recovery by 50% over a 2-year period.

Table 5. Smolts "saved" through the impoundment of adult Arctic char.

River	Year	Number of smolts saved	Author
Agulukpak	1976	341,573	Meacham (1977a,b)
Agulowak	1977	906,933	Meacham (1980)
Agulukpak	1977	225,833	Meacham (1980)
Agulukpak	1978	56,809	Clark (1983)
Agulowak	1978	1,111,715	Clark (1983)
Agulowak	1979	291,535	Fried and Laner (1981)
Agulowak	1980	615,225	Fried and Laner (1981)
	Total	3,549,623	

Data collected after 2 seasons (1976-1977) of confinement showed that growth was reduced by 30% in fish confined during each of two seasons, when compared with fish confined for one season. The number of tags that were recovered over 2 years was so small that no statistical analysis could be made.

Both the Agulukpak and Agulowak River Arctic char tended to recover lost fat reserves after confinement, although studies (Buklis et al. 1979) indicated that fish confined at the Agulukpak River mouth during 1975 and 1976 did not regain normal condition factors and fat reserves by the summer of 1977.

Effects of Confinement on the Agulowak River Arctic Char

Confinement and capture mortalities averaged 3.7% for the years 1977 to 1980 for the Agulowak River (Buklis et al. 1979; Fried and Laner 1981). Buklis et al. (1979) found that during the fall of 1977, roughly equal numbers (5%) of the confined and control groups were later recaptured after their release; the following year (summer of 1978), 32% of the unconfined fish and 46% of the confined fish were recaptured after over 1 year at large. Buklis et al. (1979) concluded that confinement in the Agulowak River mouth did not affect the overwinter survival of confined fish.

While the long-term mortality resulting from confinement did not appear to be great, there was a reduction in growth. Data collected from the Agulowak River in 1977 showed a reduction from the 29-mm growth of fish never confined to 14-mm per year for Arctic char confined for 51 days.

During confinement, the Arctic char resorted to metabolizing fat reserves. Buklis et al. (1979) concluded that after 1 year, Agulowak River Arctic char did not differ significantly in condition factor or percent body fat from those that had never been confined; those fish that had been released after confinement were found to have regained their depleted reserves in 2 months.

Moreover, fish confined during two consecutive summers did not draw more heavily upon available energy reserves than those confined the first time.

Effects of Arctic Char Impoundment on the Sport and Subsistence Fisheries

As mentioned previously, the principal reason for impounding Arctic char was to prevent them from eating sockeye salmon smolts. They were penned rather than killed because they were important for sport and subsistence fisheries. From 1976 to 1980, aerial surveys of the Wood River system were conducted to determine the sport fishing effort. In addition, a creel census of local anglers was conducted to determine angler success. Independently, departmental employees angled for Arctic char and recorded their catches and effort.

During the project, indices of abundance and fishing effort fluctuated greatly. Clark and Meacham (1977) concluded that in 1977

(1) sport fishing effort decreased; however, the values from 1977 were well within the range of preimpoundment values;
(2) CPUE did not differ from the preimpoundment studies; and
(3) the results of departmental hook-and-line sampling did not change significantly from 1976 to 1977.

However, multiple linear-regression analysis indicated that the number of Arctic char impounded significantly (alpha = .15) affected the sport fishing CPUE.

Results of the 1978 field season were not analyzed. Fried and Laner (1981) reported that 76 anglers caught 343 Arctic char in 1979 (4.5 char/angler), and 114 anglers caught 239 Arctic char in 1980 (2.1 char/angler). Unfortunately, the results were not

expressed in the same units as Meacham (1977a), so no comparisons can be made to other project years or preimpoundment studies.

DISCUSSION

The purpose of this project was to increase the number of sockeye salmon in the commercial fishery by increasing the survival of smolts in the Wood River system. When this project was conceived, salmon harvests in the state were at all-time lows; however, when this project was evaluated, the salmon harvests were at all-time highs. Unfortunately, there is no method for evaluating survival of adult returns of "additional" sockeye salmon resulting from this project. Prior to the return of adults resulting from the first smolts that had been "saved" as a result of the Arctic char project, the production levels of most river systems in Bristol Bay soared as a result of mild winters and favorable ocean conditions.

It seems logical that the "saved" smolts would contribute to stronger returns during subsequent years. Although relative effect of "saved" smolts on an unusually abundant population was slight, the effects of reduced predation through Arctic char impoundment would contribute significantly toward maintaining spawning populations in times of extremely low smolt emigration.

Ricker (1952) gives a good account of the three basic types of predation and how they numerically relate to predator control. Of these, type 'A' best describes the Arctic char of the Wood River system: the predators take a fixed number of prey because they can only feed until satiated. Once the predator is satiated, the remainder of the prey escape. If the number of predators are reduced, a greater number of prey will escape. When estimating the benefits of predator reduction, it becomes apparent that the maximal benefit comes when population sizes of

emigrant smolts are small. The Arctic char impoundment project was conducted at a time when it was least effective because of relatively large smolt emigrations (Table 6).

While the number of "saved" smolts was extremely small when compared with the total emigration, it is possible that they produced a considerable amount of money for the commercial fishery. Table 7 outlines the estimated possible contributions that the "saved" smolts made to the fishery.

The Wood River Arctic char impoundment project appeared to be a cost-effective method of augmenting the production of the Wood River system. While this project produced a good benefit-cost ratio, it only augmented the production of smolts and did not reverse any long-term trends. As Table 6 illustrates, the project did not make a significant contribution toward restoring the river system to its former levels of production -- nature seems to have done that. If conditions of poor smolt production return to the Wood River system, a project of this nature would be effective in minimizing natural losses.

Confined Arctic char showed reduced growth, compared to fish not confined. This loss of growth would reduce the value of Arctic char as a sport fish resource and may have other, less obvious negative effects. Other negative effects of the impoundment were probably negligible in the Agulowak River, as studies demonstrated the ability of impounded fish to replace lost fat reserves and return to their previous condition. Studies of the Agulukpak River Arctic char indicated that long-term captivity and repeated capture could adversely affect them.

Disruption of the sport fishery in the mouth of the Agulowak River was well documented (Meacham 1977b). The reduction in sport fishing effort was apparently due to the presence of an ADF&G camp, which reduced the quality of the lodge guest's "Wilderness Experience" rather than a reduced CPUE. This did not

Table 6. Number of smolts "saved" and their contribution to total production.

Year	Smolts saved	Smolt emigration	% of emigrants saved
1976	341,573	106,200,000	0.3%
1977	1,132,766	73,300,000	1.5%
1978	1,168,524	55,000,000	2.1%
1979	291,535	65,900,000	0.4%
1980	615,225	48,300,000	1.3%

Table 7. Numbers of returning adults and the estimated income generated by the "saved" smolts.

River name	Year	Number of smolts "saved"	% Ocean surv.	Catch portion of returning adults	Average weight (kg)	Total poundage	Average price	Ex-vessel income generated	Project budget	Benefit cost
Agulukpak	1976	342,000	3.6%	12,000	2.9	76,000	$0.72	$ 55,000	$23,000	2.4 :1
Agulowak	1977	907,000	5.1%	46,000	2.7	276,000	$0.66	$182,000	$10,200	17.8 :1
Agulukpak	1977	226,000	5.1%	12,000	2.7	72,000	$0.66	$ 48,000	$10,200	4.7 :1
Agulukpak	1978	57,000	8.0%	5,000	3.0	34,000	$0.66	$ 22,000	$15,000	1.5 :1
Agulowak	1978	1,112,000	8.0%	89,000	3.0	596,000	$0.66	$393,000	$22,000	17.9 :1
Agulowak	1979	292,000	4.8%	14,000	2.9	90,000	$0.72	$ 65,000	$32,400	2.0 :1
Agulowak	1980	615,000	4.5%	28,000	2.9	176,000	$0.65	$114,000	$39,600	2.9 :1
Total/Averages		3,551,000	5.6%	206,000	2.9	1,320,000	$0.68	$879,000	$152,000	5.8 :1

significantly affect the income of local lodge owners, because they could have easily relocated sport fishermen to other parts of the lake system.

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REFERENCES

Burke, J.A. 1978. Occurrence and effects of the parasite *Triaenophorus crassus* in sockeye salmon, *Oncorhynchus nerka*, of the Wood River Lake System, Bristol Bay, Alaska. M.S. Thesis, University of Washington, Seattle. 73 p.

Buklis, L.S., J.H. Clark, and C.P. Meacham. 1979. Effects of confinement on Arctic char in the Wood River Lake system, Alaska. Alaska Department of Fish and Game Informational Leaflet Number 182. 61 p.

Clark, J.H. 1983. Arctic char studies in the Agulowak and Agulukpak Rivers of the Wood River Lakes system, 1978. Bristol Bay Data Report 137. Alaska Department of Fish and Game Commercial Fisheries Division. Anchorage. 29 p.

Clark, J.H. and C.P. Meacham. 1977. Arctic char predation suppression projects. Report to the board of fisheries. Alaska Department of Fish and Game Commercial Fisheries Division. Anchorage. December 1977.

Fried, S.M. and J.J. Laner. 1981. 1979 and 1980 Wood River system char impoundment studies. FRED Division File Reports. Alaska Department of Fish and Game FRED Division. Anchorage.

Howe, A.L. 1981. Wood River char digestion analysis. State of Alaska Memorandum. June 19, 1981. FRED Division File Reports. Alaska Department of Fish and Game FRED Division. Anchorage.

McBride, D.N. 1979. Homing of the arctic char, *Salvelinus alpinus* (Linnaeus), to feeding and spawning sites in the

Wood River Lake System, Alaska. M.S. Thesis, University of Alaska, Juneau. 29 p.

Meacham, C.P. 1983. Wood River Arctic char predation investigation (Legislative Reports for 1975, 76, and 77). Bristol Bay Data Report Number 113. Alaska Department of Fish and Game Commercial Fisheries Division. Anchorage. 32 p.

Meacham, C.P. 1977a. Arctic char predation assessment and control investigations within the Wood River system, Alaska, 1975 and 1976. Bristol Bay Data Report Number 75. Alaska Department of Fish and Game Commercial Fisheries Division. Anchorage. 79 p.

Meacham, C.P. 1977b. Agulowak River Arctic Char Studies - 1977. State of Alaska Memorandum. November 4, 1977. Alaska Department of Fish and Game Commercial Fisheries Division. Anchorage.

Meacham, C.P. 1980. Arctic char predation assessment and control projects at the Agulowak and Agulukpak Rivers, Wood River system, Alaska, 1977. Bristol Bay Data Report Number 76. Alaska Department of Fish and Game Commercial Fisheries Division. Anchorage. 30 p.

Meacham, C. and J.H. Clark. 1979. Management to Increase Anadromous Salmon Production. In Predator-Prey Systems in Fisheries Management. R. Strond and M. Klepper, Ed. Sport Fisheries Institute, Washington, D.C. 377-386.

Moriarity, D. 1976. Arctic char in the Wood River Lakes. Preliminary draft report for Alaska Department of Fish and Game. Fisheries Research Institute, University of Washington. 47 p.

Nelson, M.D. 1966. Food and distribution of Arctic char in Lake Aleknagik Alaska, during the summer of 1962. M.S. Thesis, University of Washington, Seattle. 164 p. as seen in Bristol Bay Data Report Number 75. Alaska Department of Fish and Game Commercial Fisheries Division. Anchorage. 79 p.

Reeves, J.E. 1969. A comparative analysis of Arctic char populations in sockeye salmon lakes of the Nushagak District, Alaska. Ph.D. Thesis, University of Washington. 219 p.

Ricker, W.E. 1952. Numerical relations between abundance of predators and survival of prey. The Canadian Fish Culturist, 13(12):5-9.

Rogers, D.E. 1977. Collection and analysis of biological data from the Wood River Lake System, Nushagak District, Bristol Bay, Alaska. Fertilization of Little Togiak Lake. Fisheries Research Institute, University of Washington, Report FRI-UW-7802. 41 p.

Ruggerone, G.T. and D.E. Rogers. 1984. Arctic char predation on sockeye salmon smolt at Little Togiak River, Alaska. Fishery Bulletin 82(2):401-410.

Thompson, B.T., C.R. Weaver, W.D. Gronlund. 1971. A study of the role of the Arctic char, *Salvelinus alpinus*, as a salmon predator in the Wood River Lakes, Alaska. Manuscript. MR-F No. 96. NOAA National Marine Fisheries, Auke Bay Laboratory, Auke Bay, Alaska. 39 p.