

FRI-UW-7705

March 1977

FISHERIES RESEARCH INSTITUTE
College of Fisheries
University of Washington
Seattle, Washington 98195

ARCTIC CHAR IN THE WOOD RIVER LAKES

by

Daniel Stephen Moriarity

FINAL REPORT

For the Period November 1, 1975 to October 31, 1976
Alaska Department of Fish and Game

Approved

Submitted March 21, 1977

Ray E. Nakatani
for Director

CONTENTS

	<u>Page</u>
INTRODUCTION	1
METHODS	9
RESULTS	14
Length-Weight Analysis	14
Stomach Contents	27
Population Estimates and Distributions	32
Catch Per Unit Effort	38
Juvenile Char Abundances	43
Migration Information	46
SUMMARY AND DISCUSSION	48
LITERATURE CITED	53
APPENDICES	55

LIST OF TABLES

<u>Table No.</u>		<u>Page</u>
1	Annual composition of char samples by lake	13
2	Mean lengths, weights, and condition factors by sex for 5 lakes, 1952 and 1972	24
3	Annual mean lengths, weights, and condition factors by sex; lower Lake Aleknagik (area C) and Agulowak River (1971-74), Lake Central Nerka (1955-57), and Little Togiak River (1972-76)	26
4	Monthly mean lengths and weights of arctic char by sex, year, and location	28
5	Averages of annual mean numbers of fish in char stomachs, by period, station, and species, and percentages of empty stomachs (no food material in gut) by period and station	31
6	Mean number of sockeye salmon fry and smolts in char stomachs during June and July of consecutive years, by location	33
7	Mean number of sockeye salmon fry and smolts in char stomachs by location, June and July, 1972	34
8	Mean number of sockeye salmon fry and smolts in stomachs of char by length groups and period. Years, lakes and char sexes combined	35
9	Population estimates of arctic char by year, location, and date	36
10	Compositions of annual samples in percent by gear type	39
11	Description of gill nets used in char sampling, Wood River lakes	40
12	Mean catch per unit effort for different locations, June and July, 1950-1976	42
13	Geometric means of the catches of age 0 char in beach-seine hauls by lake, year, area, and date	44

LIST OF FIGURES

<u>Figure No.</u>		<u>Page</u>
1	Map of the Wood River lake system, showing sampling areas (A,B,C)	2
2	Coding form used in data standardization	10
3	Regressions of weight on length by sex	15
4	Regressions of weight on length by gear type	16
5	Regressions of weight on length by period	17
6	Regressions of weight on length by lake	18
7	Regressions of weight on length by year	19
8	Weight of char at 420 mm by lake	21
9	Weight of char at 420 mm by year	22
10	Occurrences of food types in char stomachs by period, expressed as percentages of total fish (in parentheses) containing given item; years, lakes, and sexes combined	30

ACKNOWLEDGMENTS

Drs. Donald E. Rogers, Robert L. Burgner, and Richard B. Thompson contributed valuable guidance and constructive criticism as my Supervisory Committee. Their knowledge of the biology of the Wood River lakes area provided depth and perspective, and I thank them for instruction of distinguished quality.

I wish to thank the Fisheries Research Institute for facilities used in this study, and the Alaska Department of Fish and Game for financial support.

The following persons were highly inspirational toward the completion of this thesis: Frank Bunk, Jr., Dr. Gary Fowler, George Frayne, Marvin Gardens, Dr. Karl F. Lagler, Lael Saulsman, and "Dr. Sax."

Gratitude is expressed to Helen Bailey, Dr. Larry Gales, and Katie Swanson for their aid in data processing setups; and to Dorothy Beall, Linda Haglund, and Virginia Mills for patience and cooperation in their preparation of the manuscript.

Final thanks to Buck's Pike Palace, and to everyone else who helped.

This thesis is dedicated to the life, spirit, and aspirations of the late Stanley B. Nielsen.

INTRODUCTION

Predation by resident fish on Pacific salmon has been observed in numerous locations. Sockeye salmon (*Oncorhynchus nerka*) are particularly vulnerable to predators during their early life history because of their relatively lengthy residence in freshwater and slow growth. In the Wood River lakes, southwestern Alaska, sockeye fry (age 0) and smolts (age I and II) begin feeding and migration activities in the spring, normally coinciding with ice breakup in late May to early June. Depending on their incubation and rearing area, smolts must swim down from one to four clear, shallow rivers to reach the system outlet (Fig. 1). Concurrently, arctic char (*Salvelinus alpinus*) congregate at river mouths and become recognizably predaceous on the migrating smolts well into July.

During the remainder of the year, Wood River char opportunistically consume a variety of other food items, including resident fish (*Gasterosteus*, *Pungitius*, *Cottus*, *Dallia*), gastropods, Hirudinea, and insects. Their predation on salmon is, therefore, quite temporally and spatially isolated. Other large resident fish (*Salmo gairdneri*, *Thymallus arcticus*, *Esox lucius*, *Coregonus* sp., and *Prosopium* sp.) are relatively minor predators on salmon (Nelson 1966).¹

The various freshwater phases of sockeye life history have been dealt with quite extensively. Hartman and Burgner (1972) discussed factors related to production in nursery lakes, including predation by

¹Nelson's paper dealt with Lake Aleknagik only.

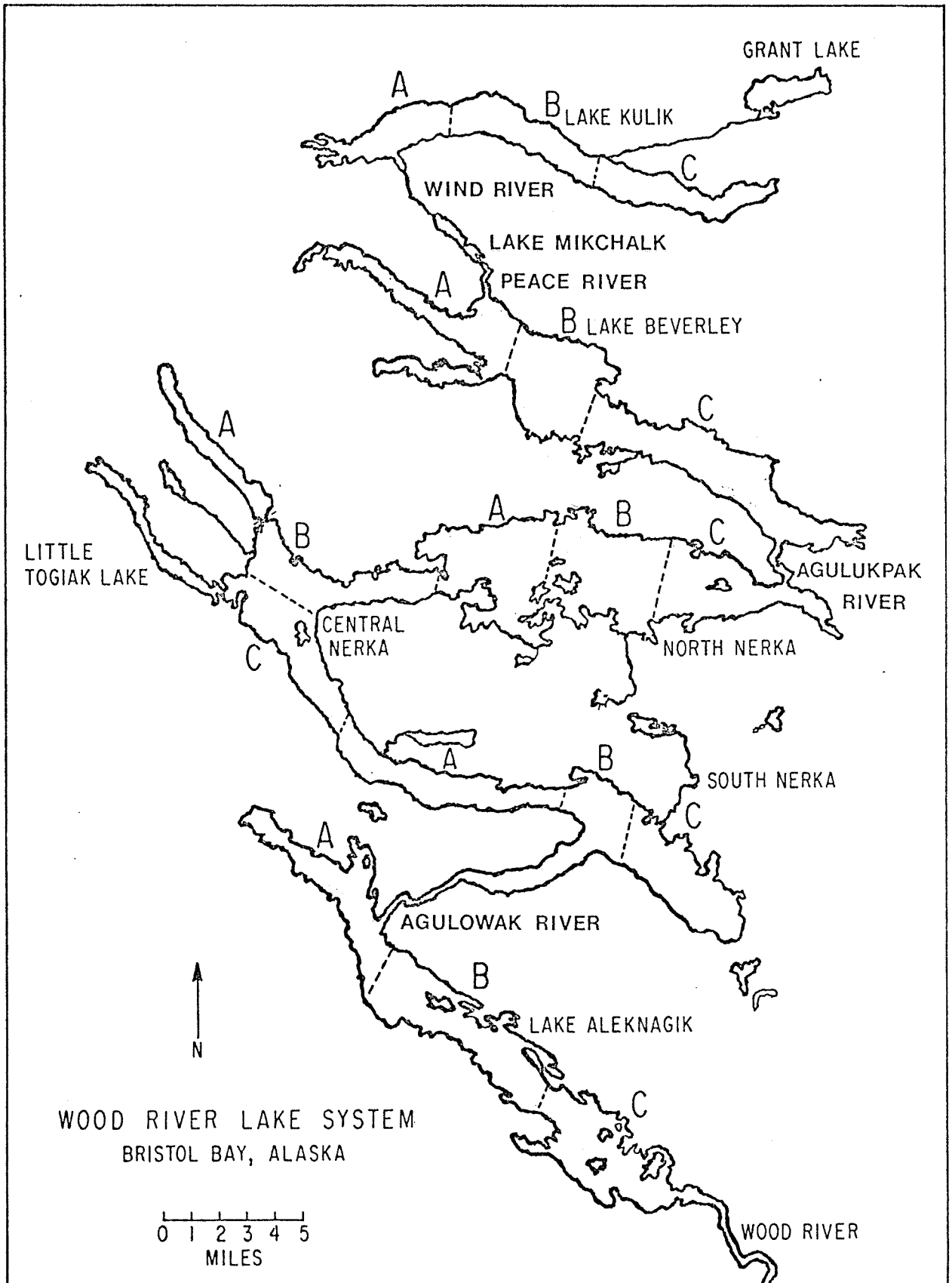


Fig. 1. Map of the Wood River lake system, showing sampling areas (A,B,C).

resident fish. Burgner (1958) studied the fluctuations in smolt abundance and growth between years and among the Wood River lakes. Rogers (1968) found similarity between the diets of sockeye fry and threespine stickleback, and Rogers (1973a) evaluated the interactions of juvenile salmon with other species in littoral habitats of Lake Aleknagik.

Several papers have dealt specifically with the ecology of arctic char in the Wood River lakes. Nelson (1966) studied feeding and distribution in Lake Aleknagik for one summer and concluded that char are nonselective feeders. Food items in the stomachs varied with time of season and availability of prey. Reeves (1969) reviewed char life history and compared char populations in four Nushagak District lakes, including Aleknagik. He related char production to general lake productivities. Burgner² described results of extensive char sampling by gillnet in Lake Nerka during 1955-57. He showed a shift in food preference by char size; smaller fish ate more insects and sockeye fry, and larger fish ate relatively more smolts and *Gasterosteus*. Thompson and Weaver³ studied the biology of char and their predation on salmon in Lakes Nerka and Aleknagik in the mid-1950's. They emphasized differences between prey concentration and non-concentration areas.

Their findings included:

²Burgner, R. L., 1959, Observations on distribution and feeding habits of arctic char (*Salvelinus alpinus*) in Lake Nerka, Alaska. Univ. Wash., Fish. Res. Inst., unpublished manuscript.

³Thompson, R. B., and C. R. Weaver, 1964, A study of the freshwater predators of young sockeye salmon (*Oncorhynchus nerka*) in the Wood River lakes, Alaska, with particular reference to the arctic char (*Salvelinus alpinus*). Nat. Mar. Fish. Serv., N.W. Reg. Off., unpublished manuscript.

1. Char predation was heaviest in areas of smolt concentrations; its intensity was 3.5 times higher per char at river mouths than in open lake areas. Heaviest consumption of smolt occurred between June 11 and 30, but neither char nor sockeye in char stomachs were as abundant in the open area of Lake Nerka as in the restricted area near the mouth of the Agulowak River (Aleknagik).
2. Sticklebacks replaced sockeye fingerlings in stomachs as the former's availability decreased.
3. All char over 100 mm in length were capable of consuming juvenile sockeye.
4. Occurrences of juvenile sockeye and stickleback in char stomachs showed seasonal patterns, and insects occurred in char stomachs only during the summer.

It is evident that *Salvelinus alpinus* is flexible in adapting to different environments throughout its circumpolar distribution. These adaptations include a potential role as predators of economically important fish; char are known to consume juvenile salmon in the USSR as well as Alaska (Savvaitova and Reshetnikov 1962). Other resident freshwater fish have also adapted roles as salmon predators, for example, burbot (*Lota lota*) in Sweden (Larsson and Larsson 1974). However, arctic char are the major predator on salmon in the Wood River lakes and Rogers et al. (1972) demonstrated that they were capable of significantly reducing the production of sockeye salmon in the lake system. Char populations in the lakes have evolved around unique conditions, and the understanding of the char's role in salmon production is necessary for developing sound management strategies.

Although research efforts by Fisheries Research Institute (F.R.I.) have been primarily targeted at sockeye biology, periodic data and analysis dealing with char have been accumulating since 1950. The following is a description of this information:

- Sampling locations by lake, area, station, date, and time collected.
- Type of fishing gear employed, time fished, and resulting catches.
- Lengths, weights, and sexes.
- Occurrences of eight major food types:
 - Zooplankton
 - Gastropods
 - Plant material
 - Insects
 - Hirudinea
 - Fish eggs
 - Fish
 - Other
- Numbers of individual fish items in the stomachs.

The purpose of this study was to define further and elaborate upon the role of the arctic char as a predator on young sockeye of the Wood River lakes. This analysis summarizes the extent F.R.I. data through the 1976 field season. This study was conducted for the Alaska Department of Fish and Game. Their specific objectives were:

1. To determine with respect to date of collection and location the (a) mean length and weight by sex, (b) sex ratio, and (c) composition of stomach contents and the number of juvenile salmon in the stomachs.
2. To estimate the populations of arctic char at each of the major rivers in the lake system from a 1972 tagging program.
3. To compare the distribution of arctic char in the lake system with distribution of juvenile sockeye salmon.
4. To provide information from char observations made in conjunction with salmon spawning ground surveys for years when data are available.
5. To determine species composition for other species caught in conjunction with char sampling.
6. To provide information on movements of char from tag recoveries during periods subsequent to population estimates.
7. To summarize data on the relative abundance of juvenile char from beach-seine catches.
8. To include catch per unit effort data where such information was available in fulfilling the above specific objectives.

On reviewing the specific objectives and considering the information available for analysis, the following question was posed as a basis for this study: How do size, food habits, and relative abundance of arctic char vary with respect to season, year, location, and sex in the Wood River lakes, and in relation to the sockeye population?

The scope of this analysis will be that of a summary. The raw data resulted from efforts of different investigators employing varied techniques over a 26-year period. The lack of consistent sampling techniques since 1950 as well as the unavailability of data from certain periods, especially September through May, were major sources of error. However, a sufficiently descriptive summary was possible from the diversity of the sampling.

Several aspects of char biology remain outside the scope.

1. Taxonomical considerations. Two distinct species of *Salvelinus* reside in the Wood River lakes. *S. alpinus* can be distinguished from *S. malma* (Dolly Varden) (McPhail 1961). Dolly Varden, however, constitute a minor portion of the *Salvelinus* complex in the lakes, and the few that are present are most likely to be found in Lake Aleknagik and its tributaries (D. E. Rogers, personal communication). For practical purposes within this summary, the two species will collectively be referred to as "arctic char."
2. Reproduction. No reliable records of char reproductive activity are available, except for Thompson's study (1959) on fecundity. Char assume external coloration changes associated with spawning in late summer, usually September. Actual spawning has not been observed; however, char fry are found in significant quantities with red salmon fry in beach-seine

hauls in the spring. Fisheries Research Institute field studies are normally concluded during late September; as a result, data descriptive of this life history phase remain unrecorded.

3. Age. Presently, the only practical method of aging the relatively long-lived and slow-growing char involves grinding off opaque deposits and reading the lateral surfaces of otoliths (Nordeng 1961). Reeves (1969) modified this technique and applied it to Lake Aleknagik char. His results (samples were from variable mesh gillnets) showed a range of ages from one to 13 years, mean of 6, and mode of 7. No additional otolith data were available for my study; however, growth of entirely freshwater populations of arctic char is typically very slow (McPhail and Lindsey, 1970).

METHODS

The most effective method of accomplishing the objectives was to first standardize all available data. Fisheries Research Institute form S 9.2.3. (Revised Field Examination Form - Resident Freshwater Fish, Fig. 2) was suitable because of its capability to store the entirety of information. After transcription of all observations onto these forms, the data were converted into an S.P.S.S. system file and stored on magnetic tape. S.P.S.S. allows processing, selection from, and recombinations of large numbers of cases.

Each lake was numerically coded and divided into three sections (A, B, and C) of approximately equal surface area (Fig. 1). The variable "station" described habitats; char samples were classified by station according to (1) within river-creek, (2) river-creek mouth, or (3) open lake.

"Month" was recoded into "period", or season, for the purpose of simplifying most of the analysis. Although monthly changes in feeding habits, length-weight relationships, etc., may be evident, it was felt that time segments more descriptive of the seasonal life history of char were appropriate. Therefore, the following classifications were used.

<u>Month</u>	<u>Period</u>
January	1 - Ice Cover (244 Samples)
February	
March	
April	
May	
June	2 - During juvenile migrations (5,899 samples)
July	
August	3 - Summer lake residence (804 Samples)
September	

Sample No.	Species	Location			Date caught			Time collected	Gear	Hours fished in 1/10 hrs.	Number caught
		Lake	Arec	Sta.	Mo.	Day	Year				

FISHERIES RESEARCH INSTITUTE
 S9. 2.3 Revised Field Examination Form
 - Resident Freshwater Fish
 Species _____
 Sample No. _____
 Page _____ of _____
 Location _____

No.	Length in mm	Weight		Tenths	Sex	Gill net mesh size	Fullness of Gut	Occurrence										Numbers of fish										Total														
		Grams																																								
								Zooplankton	Insects	Gastropods	Blindworm	Plant	Fish eggs	Fish	Other	Red Age 0	Red Age I, II	Coho	King	Pink	Char	Rainbow	Unident.	Grayling	Round	Humpback	Pumpkin		Unident.	Caracass	Pungitius	Sculpin	Blackfish	Pond smelt	Unident. fish	Other sp.						
31	35	31	40	41	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

Examined by _____ Date _____ Specimens preserved _____
 Remarks _____

Fig. 2. Coding form used in data standardization.

Hence, comparisons from both time and space perspectives were possible. Potential trends between periods in a given year, as well as trends between years were investigated; however, no data representing the months of October through December were available.

Lengths were measured from tip of snout to tail fork in millimeters, and weights in grams. "Sex" was initially given four categories--male, female, missing, and undetermined. However, because of numerical insignificance of the latter two in the samples, only males and females were considered.

Descriptions of sampling gear and processing procedures used in F.R.I. Wood River char studies are provided by Nelson (1966) and Reeves (1969). The variety of gear types utilized in these studies will be discussed.

Categories of stomach contents (e.g., insects, gastropods) were by necessity treated by the frequency of occurrence method. Throughout the 26-year timespan involved, varying degrees of subjectivity in interpretation of stomach contents have been introduced. For example, in past individual studies, occurrences have been estimated on scales of zero to ten by different biologists. Consequently, despite the importance of each study, inconsistencies have resulted; to minimize potential error, the most suitable analysis approach was simply to treat food categories as being either present or absent in a given fish. Although this method is a relatively weak tool for the purpose of describing foraging strategies, it appears to be the only alternative in this case. Quantitative information on char feeding in the Wood River lakes is given by Nelson

(1966), Reeves (1969), and Thompson and Weaver.⁴ A method proposed by Pinkas et al. (1971) would greatly increase the usefulness of a study designed to describe feeding habits and behavior using stomach content analysis. Their index of relative importance of stomach contents (IRI) provides information on occurrence, numerical, as well as bulk (volumetric) rankings.

Data which would permit descriptions of char feeding behavior were not available; nevertheless, changes in diet preference or prey availability over time and by location could be detected and described. In addition to absence/presence of food types in each fish, the numbers of fish items in the stomachs have been recorded by species.

Catches per unit effort of both gillnets and angling provided a rough index of relative abundance of char throughout the system. Additionally, population size estimates were made in various locations, and a summary of these helped to measure char abundances.

Numbers of char available for analysis by lake and year are shown in Table 1. The total of 6,947 fish includes all four sex categories originally mentioned.

A description of species caught incidentally in char sampling is presented in Appendix Table A-1, and a breakdown of species composition of gillnet catches by lake from the 1950's is given in Appendix Table A-4. No data on char were available from stream spawning surveys, other than their presence or absence from visual observations.

⁴See footnote 3, p. 3.

Table 1. Annual composition of char samples by lake [each parenthesized value represents the percentage of that year's total sample from a given lake]

Year	Aleknagik	S. Nerka	C. Nerka	L. Togiak	N. Nerka	Beverley	Kulik	Total
1950	88 (45.8)	12 (6.3)	44 (22.9)			10 (5.2)	38 (19.8)	192
1951	26 (68.4)	6 (15.8)		6 (15.8)				38
1952	75 (10.0)	5 (0.7)	276 (36.7)	180 (23.9)	16 (2.1)	68 (9.0)	132 (17.6)	752
1954	120 (100)							120
1955			479 (68.1)	96 (13.7)	128 (18.2)			703
1956			419 (91.1)	41 (8.9)				460
1957			746 (100)					746
1961			559 (81.4)	62 (9.0)	33 (4.8)		33 (4.8)	687
1963	119 (100)							119
1971	403 (100)							403
1972	1,051 (62.8)			180 (10.8)	240 (14.3)	108 (6.5)	95 (5.7)	1,674
1973	282 (46.2)			220 (36.0)	91 (14.9)	15 (2.5)	3 (0.5)	611
1974	61 (22.2)			214 (77.8)				275
1975				72 (100)				72
1976				95 (100)				95
Total	2,225	23	2,523	1,166	508	201	301	6,947

RESULTS

Length-Weight Analysis

Appendix Table A-2 presents char lengths and weights by year and sex, all lakes combined. In several cases, sample size deviated from totals described in Table 1 from small percentages of missing length and weight values. Five variables were selected whose effects were judged as being possibly significant. The influences of "sex," "gear type," "period," "lake," and "year" on length-weight relationships were incorporated into an analysis of variance model which assumed fixed effects. However, S.P.S.S. failed to invert the input matrix; inconsistencies in the data probably caused matrix singularity. Therefore, no ANOVA was performed.

Lengths and weights were then transformed to their \log_{10} values, and linear regressions were calculated for all categories of each of the five variables as an alternative to ANOVA. Results of the regressions are shown in Figs. 3 through 7 on arithmetic scales. Means are represented by circles, and ranges in length are indicated by lengths of the curves.

From visual examination, the effect of sex appears insignificant. Both male and female form approximately equal-sized categories with similar slopes on a log-log scale, and only slightly differing means. Gear types seem to select different size groups. Hook and line fishing yielded heavier fish at longer lengths and lighter fish at shorter lengths. Gillnets caught the largest size range, and beach seines the lowest. However, beach seines were used for only a small minority of total adult sampling effort.

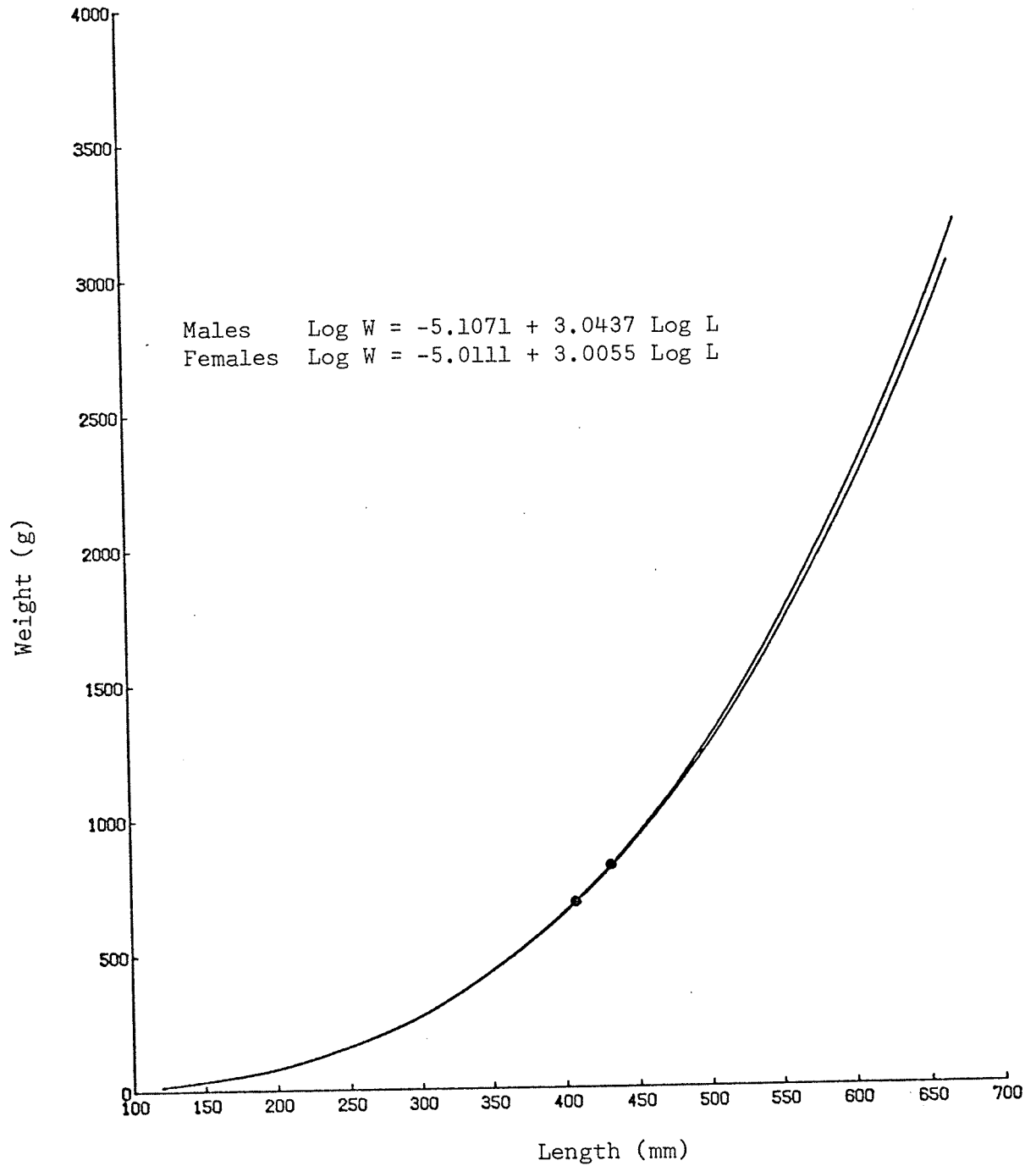


Fig. 3. Regressions of weight on length by sex.

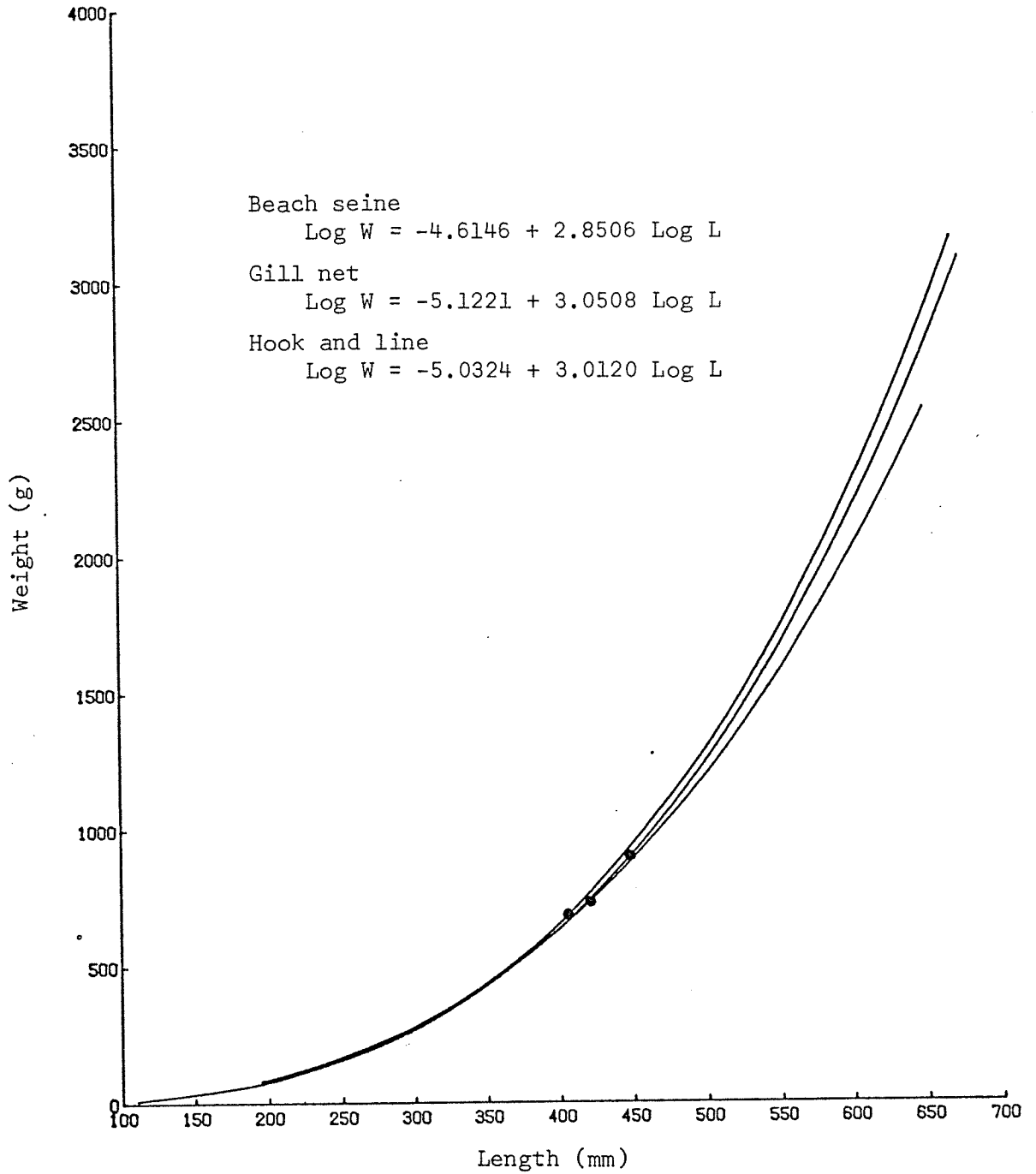


Fig. 4. Regressions of weight on length by gear type.

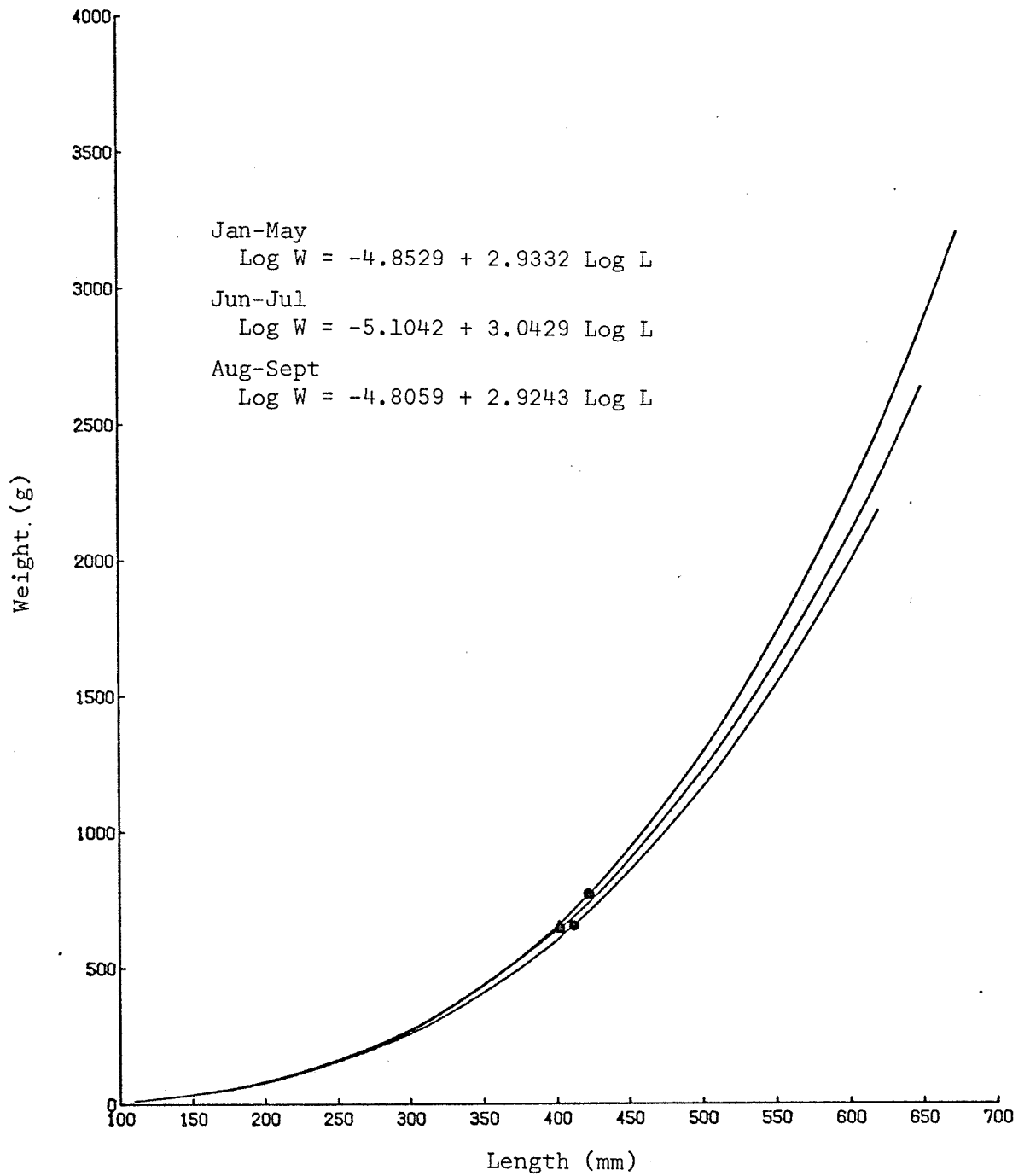


Fig. 5. Regressions of weight on length by period (season).

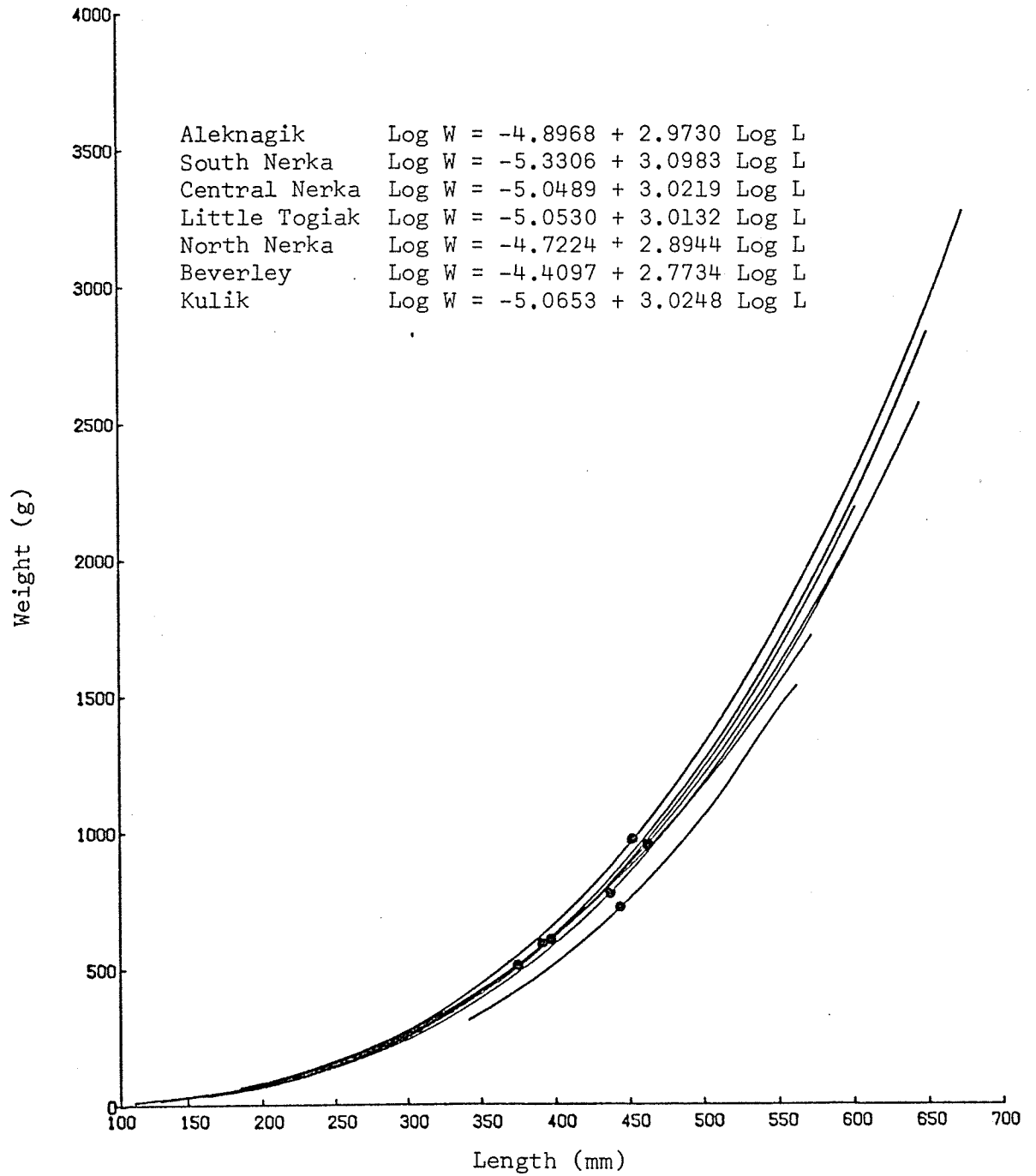


Fig. 6. Regressions of weight on length by lake.

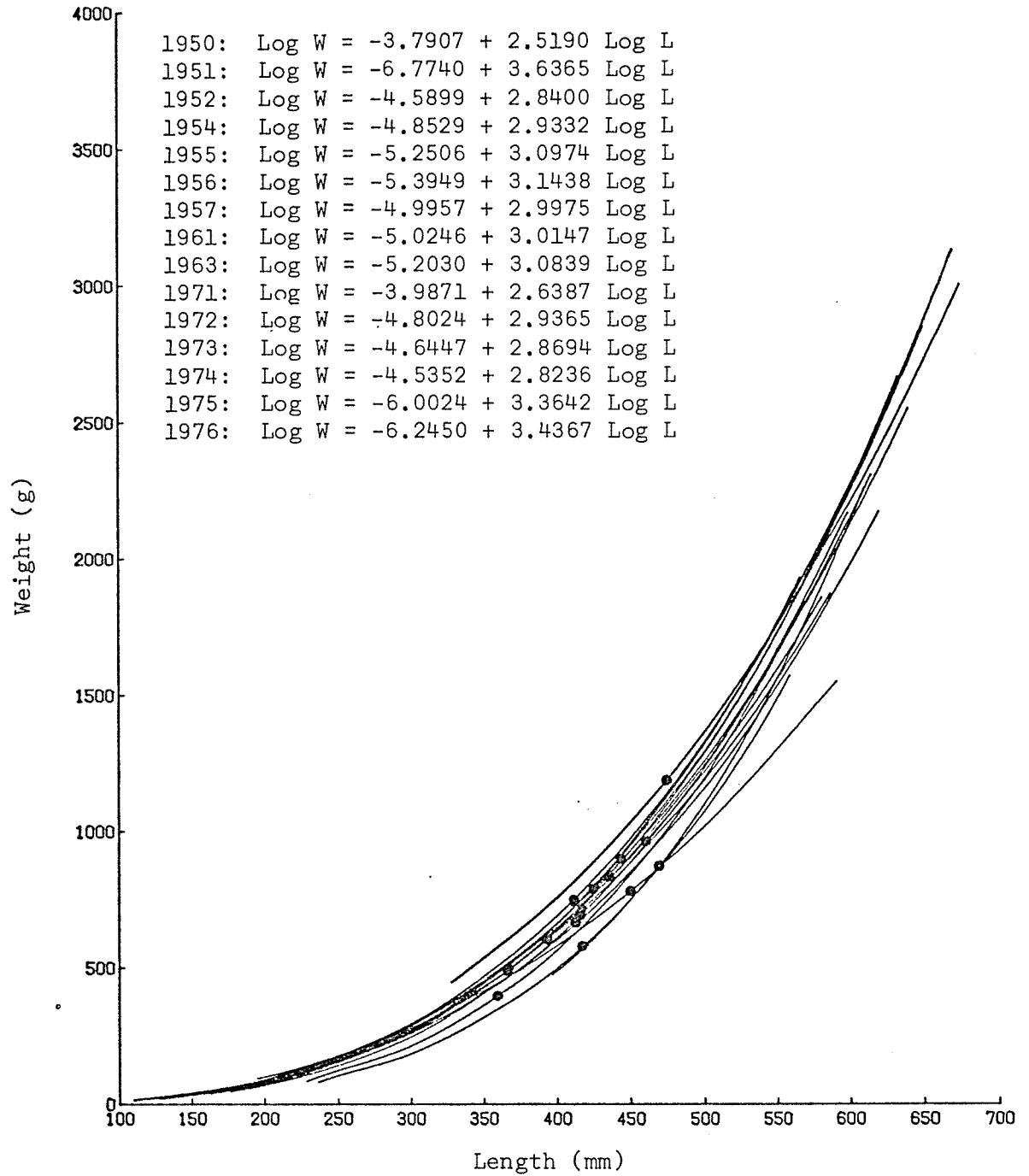


Fig. 7. Regressions of weight on length by year.

Fish of slightly heavier mean weight at a given length were caught during juvenile sockeye migrations (Period 2, Fig. 5). In addition, a considerably greater size range, weighted with young char, occurred during this season, but all regression slopes were nearly identical.

Mean weights in individual lakes varied considerably. The spread of mean weights by lake was roughly 500 to 1000 g; mean lengths varied from 350 to 450 mm. Comparative ranges of length and weight fluctuated between lakes, but length and weight values showed highest variation between years (Fig. 7).

Further analysis of trends among lakes and years was desired; thus, a predictive mechanism was constructed, whereby the overall average of mean lengths (420 mm) was held constant for all categories of "lake" and "year," and corresponding weights were calculated using the appropriate regression estimators.

At a length of 420 mm, char in Lake Aleknagik were heavier than in any other lake (Fig. 8). The lower weight of South Nerka's fish is based on a total sample of only 23 fish; therefore, its accuracy is in doubt. However, since South Nerka has consistently supported among the lowest spawning densities of sockeye in the system along with relatively small abundances of both threespine stickleback and sockeye fry (D. E. Rogers, personal communication), the relatively low weight may be valid despite the sample size. The absence of a major river mouth on South Nerka may also be a factor.

Figure 9 illustrates changes in mean weight at 420 mm since 1950. Missing years are included on the scale to provide better perspective. Values for 1975 and 1976 are not included due to limited scope of those

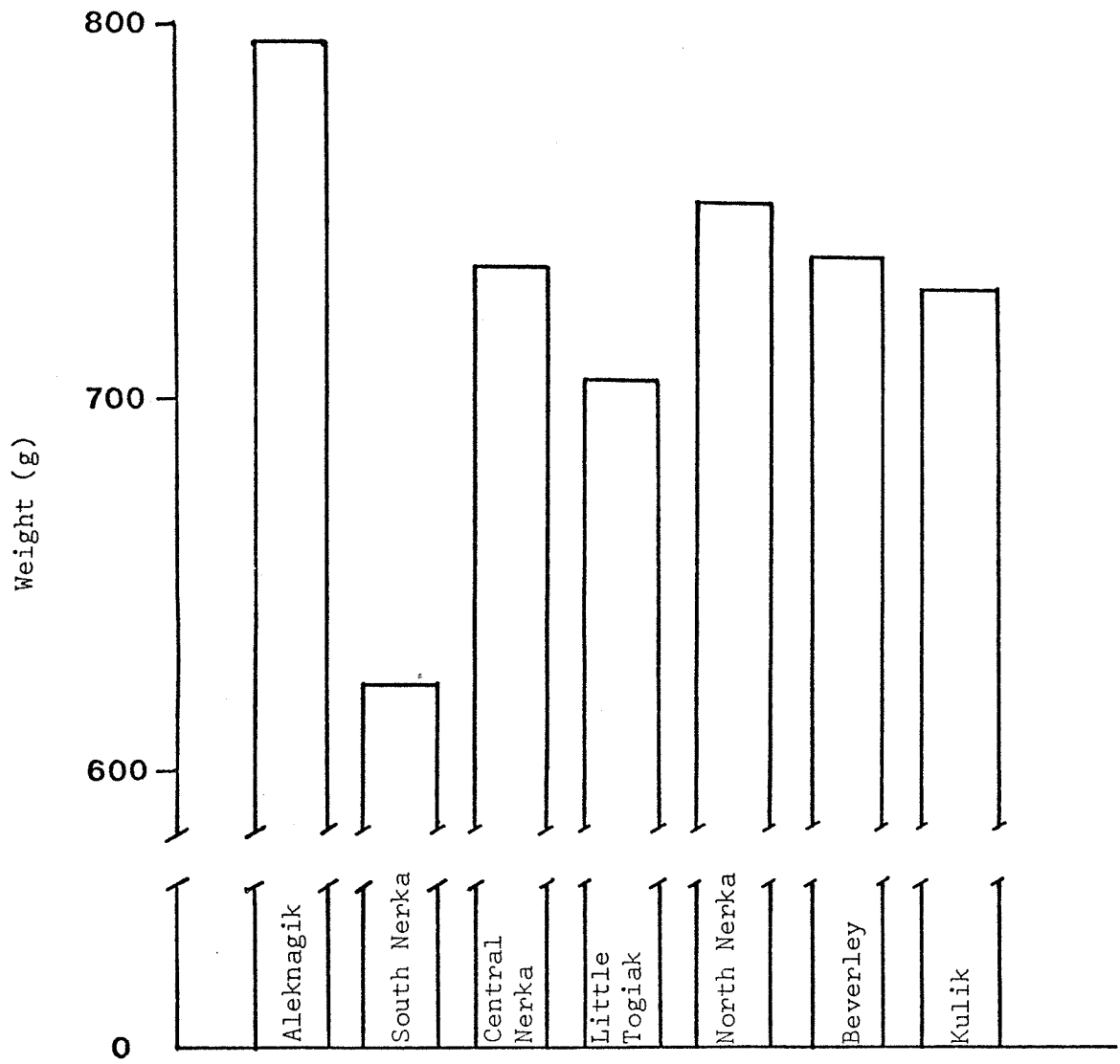


Fig. 8. Weight of char at 420 mm by lake.

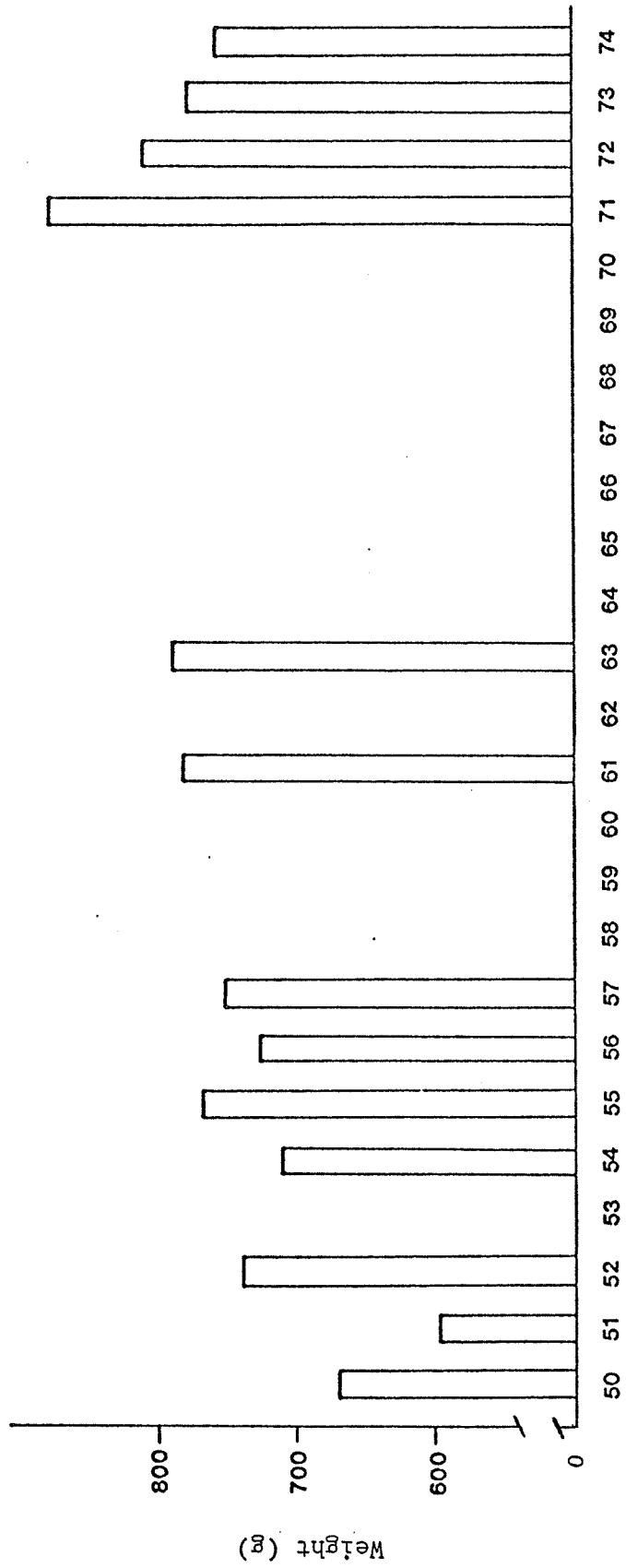


Fig. 9. Weight of char at 420 mm by year.

data (Little Togiak River only; sample sizes of 72 and 95 fish, respectively). An upward trend of weights through the years is evident. Weights in 1971-1974 and 1961, 1963 are higher than those in 1954-1957, which, in turn, are higher than in 1950-1952. Explanations for this apparent increase were sought through attempts to correlate char weights in a given year with the following factors (source: Rogers et al. 1972):

- (1) Adult sockeye escapement to the Wood River lakes two years previous.
- (2) Average fyke-net catch of outmigrating sockeye smolts per two-hour index period (2100-2300), June 1 - July 20 annually, Mosquito Point, Lake Aleknagik.
- (3) Estimated escapement of sockeye per surface square mile of system lake rearing area two years previous.

The data were plotted, but in each case, there was no correlation evident.

Sufficient data are available to permit size comparisons of char in five lakes during 1952 and 1972 (Table 2). Condition factor (weight/length³) was calculated for each fish to complement mean lengths and weights. This measurement is "... suitable for comparing different individual fish of the same species; it will also indicate differences related to sex, season, or place of capture" (Ricker 1975). Males were consistently longer and heavier than females. In Lakes Aleknagik, Beverley, and Kulik, size of fish is noticeably greater in 1972. However, with the possible exception of Lake Aleknagik, fish condition remained relatively unchanged. The 1972 figures may be greater because all fish sampled then were from river mouth areas. Some fish in 1952 were caught

Table 2. Mean lengths, weights, and condition factors by sex for 5 lakes, 1952 and 1972

Lake	Mean length (mm)		Mean weight (g)		Mean condition factor	
	1952	1972	1952	1972	1952	1972
Aleknagik						
Male	416	450	875	1213	1.01	1.18
Female	418	432	801	1010	1.03	1.13
Little Togiak						
Male	457	447	(Missing)	1027		1.07
Female	421	424		810		1.01
N. Nerka						
Male	507	503	1,139	1,407	1.00	1.07
Female	490	469	1,189	1,081	0.96	1.05
Beverley						
Male	361	428	577	837	1.04	1.01
Female	352	400	509	678	1.03	1.02
Kulik						
Male	350	401	517	727	1.09	1.04
Female	342	363	440	528	1.05	1.03

in the western ends of Lakes Beverley and Kulik. Thus, some differences could be due to larger size of char at river mouths. The effect of different sampling gear on the data in Table 2 is probably relatively minor compared to the effect of different locations.

Table 3 presents annual differences in lengths, weights, and condition factors for the Agulowak River, area C of Lake Aleknagik, area C of Lake Central Nerka, and Little Togiak River during series of consecutive years. Conceptually, sequential length-weight measurements on a yearly basis are of great value in attempts to detect and analyze long-term condition of Wood River char populations. In this case, however, the lack of standardized sampling as well as age data may mask any actual trends, if indeed they are present. In Central Nerka, length and weight decreased from 1955 to 1957, yet condition remained constant. At the Agulowak and Little Togiak Rivers, both weight and condition decreased over the sampling periods. Fish age, while not a parameter considered in this study, seems very relevant. Because of the following:

- (1) char grow slowly with respect to length,
- (2) condition of char does not vary linearly with age,
- (3) distinct feeding patterns will be shown between char of different length ranges,

it may be unwise to accept the mean values measured here as being truly reflective of actual gross changes in populations, especially with respect to feeding habits. Yet, considering length-weight changes within a given year, the bearing of feeding habits on size becomes more apparent.

Table 3. Annual mean lengths, weights, and condition factors by sex; lower Lake Aleknagik (area C) and Agulowak River (1971-74), Lake Central Nerka (1955-57), and Little Togiak River (1972-76)

	MEAN LENGTH (mm)						MEAN WEIGHT (gm)						MEAN CONDITION FACTOR					
	Lower Aleknagik F M	Central Togiak R. F M	Little Togiak R. F M	Agulowak River M	Lower Aleknagik F M	Central Nerka F M	Little Togiak R. F M	Agulowak River M	Lower Aleknagik F M	Central Nerka F M	Little Togiak R. F M	Agulowak River M	Lower Aleknagik F M	Central Nerka F M	Little Togiak R. F M			
1955																		
		425	409				939	751							1.03 1.02			
1956																		
			414	406			869	705							0.97 0.98			
1957																		
			361	358			607	539							1.00 1.00			
1971	490	465 (missing)																
							1446	1121 (missing)							1.20 1.10 (missing)			
1972	441	427	455	434	447	424	1239	1155	1207	981	1027	810	1.15	1.12	1.19	1.13	1.07	1.01
1973	497	475	455	443	461	422	1376	1155	1170	1009	1003	745	1.08	1.06	1.15	1.15	0.96	0.97
1974	443	411	392	410	447	428	1041	721 (missing)			950	801	1.09	1.01 (missing)			1.02	1.00
1975					418	410					767	654					0.92	0.89
1976					430	410					751	566					0.84	0.78

Emphasis will now be directed toward monthly mean changes. In Table 4, all available winter data (ice cover, Period 1, 1952 and 1954) are included. Although scarcely adequate on which to base any generalizations, the information is nonetheless valuable and represents tedious efforts under difficult winter conditions on the part of Church.⁵ Mean length of char decreased from January through April of 1952 and then sharply increased in May. Apparently, larger fish moved into the area, coinciding with increasing water temperature and probably greater food availability. During successive summer months in area C, Central Nerka, 1961, lengths and weights increased, while somewhat of an opposite trend was evident at Mosquito Point in summer, 1972. Fish at Little Togiak River and Mosquito Point were heavier than those in Central Nerka. Fish in upper Little Togiak Lake (area B) were substantially smaller in June 1973 than fish at the lake's outlet during the same period.

Stomach Contents

To assess the effects of season, year, and location on the feeding by char in the Wood River lakes, I first examined the data to detect bases for comparisons. As with length-weight data, relatively little information existed for January through May, August and September, annually. Examination of feeding habits by sex was felt unnecessary. It has been shown that gear does not select for char sex, and male/female

⁵Church, W., 1952, Winter log. Univ. Wash., Fish. Res. Inst., unpublished Bristol Bay data.

Table 4. Monthly mean lengths and weights of arctic char by sex, year, and location. [Sample sizes parenthesized]

	\bar{L} (mm)		\bar{W} (gm)	
	M	F	M	F
1952				
Little Togiak River mouth				
Jan	481 (1)	385 (6)		
Feb		382 (7)		
Mar	414 (20)	379 (25)	(Missing)	
Apr	402 (10)	366 (11)		
May	465 (7)	437 (13)		
1954				
Agulowak				
Mar	409 (66)	451 (29)	733 (65)	871 (29)
1961				
Central Nerka				
Jun	330 (15)	335 (21)	378 (15)	424 (21)
Jul	349 (43)	341 (74)	582 (43)	510 (74)
Aug	413 (118)	353 (144)	845 (118)	549 (144)
1972				
Mosquito Point				
Jun	481 (86)	451 (60)	1451 (60)	1114 (41)
Jul	448 (126)	432 (250)	1153 (31)	961 (55)
Aug	426 (49)	429 (83)	943 (49)	929 (83)
1973				
Little Togiak Lake				
Area B				
Jun	347 (5)	330 (7)	460 (5)	444 (7)
LTR.				
Jun	470 (57)	429 (37)	1056 (57)	786 (37)
Jul	447 (35)	420 (44)	900 (35)	732 (44)
Sept	461 (23)	409 (12)	1032 (23)	670 (12)

ratios in samples have consistently approximated unity. Burgner⁶ found "no significant differences between sexes in consumption of any of the food items" from extensive sampling in Lake Nerka.

The ability of arctic char to utilize food other than fish is well-documented in the Wood River lakes and elsewhere (Nelson 1966; Thompson and Weaver;⁷ Savvaitova and Reshetnikov 1962; Hunter;⁸ Grainger (1953). Although fish were the predominant food item in terms of occurrence in this study, char ate insects, gastropods and Hirudinea in significant quantities in June and July. Occurrences of Hirudinea were noticeably less than the first two categories, and no Hirudinea were found in stomachs during August and September. Insects and gastropods also decreased in importance after July. Occurrences of plant materials were insignificant during any period, and occurrences of eggs were restricted. Less than 100 fish in each of Periods 1 and 3 had eggs in their stomachs, and it is doubtful whether the eggs in Period 1 were sockeye eggs (Fig. 10).

Heaviest feeding occurs in June and July, based on the percentages of empty stomachs by period (Table 5). Average numbers of principal fishes in stomachs of char provide an index of their importance; sockeye fry and smolt, and threespine stickleback⁹ were the principal diet

⁶See footnote 2, p. 3.

⁷See footnote 3, p. 3.

⁸Hunter, J. G., manuscript. 1970. Production of arctic char in a small arctic lake. Fish. Res. Board Can. Tech. Rep. 231. 190 pp.

⁹Numbers of stickleback, sculpin, and blackfish are slightly low in relation to sockeye fry and smolt, because of a one-digit column on form S 9.2.3. Two-digit numbers were necessarily recorded as "9."

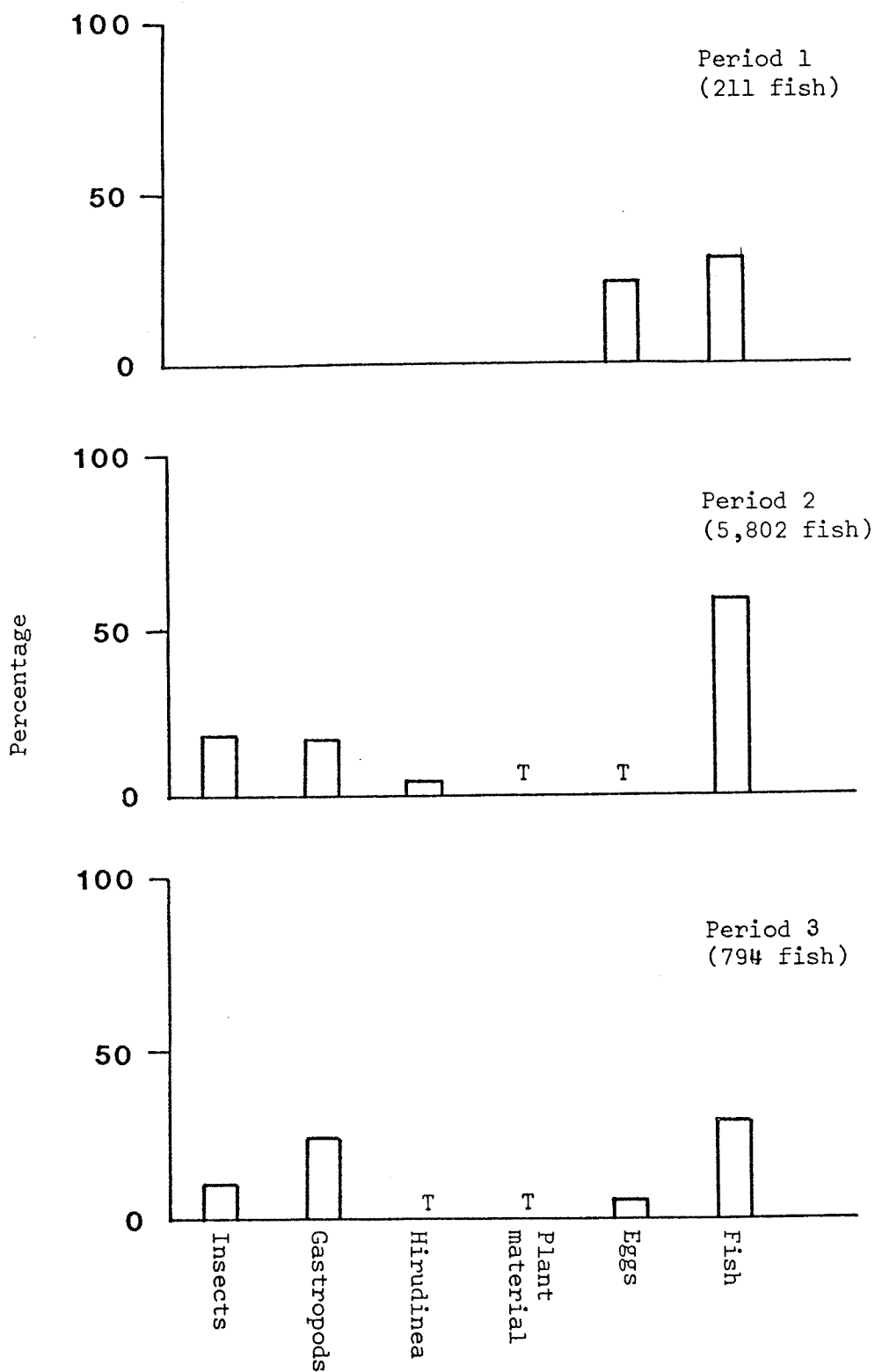


Fig. 10. Occurrences of food types in char stomachs by period, expressed as percentages of total fish (in parentheses) containing given item; years, lakes, and sexes combined.

Table 5. Averages of annual mean numbers of fish in char stomachs, by period, station, and species, and percentages of empty stomachs (no food material in gut) by period and station. T = Trace

PERIOD	STATION															% Empty Stomachs						
	1. Within River-Creek					2. River-Creek Mouth					3. Within Lake											
	Fly	Smolt	3-Spine	9-Spine	Sculpin	Blackfin	% Empty Stomachs	Fly	Smolt	3-Spine	9-Spine	Sculpin	Blackfish	% Empty Stomachs	Fly	Smolt	3-Spine	9-Spine	Sculpin	Blackfish	% Empty Stomachs	
January - May	-	-	-	-	-	-	-	.02	.21	.57	0	.01	0	0	70.4	-	-	-	-	-	-	66.7 ¹
June - July	.78	2.42	.11	.01	T	.01	39.7	.08	3.21	.08	T	T	.04	37.0	.65	.91	.52	.08	.04	.14	48.9	
August - September	0	0	.31	0	0	0	91.4	0	.10	.09	.04	.07	0	86.2	.12	.15	.56	.02	.03	.13	61.9	

¹All stomachs contained food other than fish.

items. Fry and smolt were utilized heaviest in river areas, and sticklebacks in lake areas. Numbers of sticklebacks and blackfish in char stomachs from lake areas were similar during Periods 2 and 3.

Consumption of fry and smolt during consecutive years is shown in Table 6. Conspicuous differences between years are evident. At Little Togiak River, predation on smolts was heavier within the river than off the mouth of the river. The heaviest predation within Lake Aleknagik occurred at the mouth of the Agulowak River just as Nelson (1966) found in his 1962 study.

Given that char population sizes vary at respective river mouths, consumption of fry and smolt varied with location in 1972 (Table 7). Predation rates on smolt were greater within Little Togiak and Agulukpak Rivers than at their mouths. Consumption of fry appears minor in relation to smolts, and the data indicate that char pose more of a detriment to smolt survival than fry survival.

Burgner¹⁰ and Nelson (1966) found differences in char feeding with respect to size in specific locations. Table 8 presents sockeye fry and smolt consumption by char size and verifies these differences for the entire lake system.

Population Estimates and Distributions

Table 9 summarizes char population estimates in the Wood River lakes. In 1954, the population at the mouth of the Agulowak was assessed in each of nine 10-day intervals using Schnabel's method (Thompson and

¹⁰See footnote 2, p. 3.

Table 6. Mean number of sockeye salmon fry and smolts in char stomachs during June and July of consecutive years, by location

Location	Year	Within River-Creek		River-Creek Mouth		Within Lake	
		Fry	Smolt	Fry	Smolt	Fry	Smolt
C. Nerka	1955	--	--	0	1.31	0	2.05
	1956	--	--	--	--	0.44	0.68
	1957	--	--	--	--	1.31	0.51
Little Togiak R.	1972	2.83	4.49	0.19	1.64	--	--
	1973	1.27	2.40	--	--	--	--
	1974	0.85	1.55	0.36	3.19	--	--
	1975	0.12	1.84	--	--	--	--
	1976	0.40	2.35	--	--	--	--
Aleknagik	1971	--	--	0.05	9.13	--	--
	1972	--	--	0.41	2.01	0.32	0.59
	1973	--	--	0.13	7.15	0.21	0.84
	1974	--	--	--	--	4.40	0.43

Table 7. Mean number of sockeye salmon fry and smolts in char stomachs by location, June and July, 1972

Location	Lake Aleknagik		Little Togiak River		Agulupak River		Peace River		Wind River	
	<u>Fry</u>	<u>Smolts</u>	<u>Fry</u>	<u>Smolts</u>	<u>Fry</u>	<u>Smolts</u>	<u>Fry</u>	<u>Smolts</u>	<u>Fry</u>	<u>Smolts</u>
Within River-Creek	---	---	2.83	4.49	0.01	10.36	0.54	2.37	0.50	2.85
River-Creek Mouth	0.42	2.01	0.19	1.64	0.26	6.33	---	---	---	---
Within Lake	0.32	0.59	---	---	---	---	---	---	---	---

Table 8. Mean number of sockeye salmon fry and smolts in stomachs of char by length groups and period. Years, lakes and char sexes combined. T = Trace

CHAR LENGTH

<u>PERIOD</u>	200 mm or less		200-300 mm		300-400 mm		400-500 mm		500 mm or more	
	Fry	Smolt	Fry	Smolt	Fry	Smolt	Fry	Smolt	Fry	Smolt
January - May	--	--	--	--	0	.2	T	.3	0	.1
June-July	.8	.1	.4	.3	1.0	1.5	.2	2.2	.2	3.5
August - September	--	--	.1	0	.1	.3	.1	.2	T	T

Table 9. Population estimates of arctic char by year, location, and date.

Year	Location	Dates	Average Number Smolts Consumed Per Char (Daily)	Population Estimate	95% Confidence Interval
1954	Agulowak River Mouth (R.M.)	6/11-6/20	6.63	9,278	
		6/21-6/30	2.23	9,667	
		7/1 - 7/10	0.65	10,593	
		7/11-7/20	0.42	12,557	
		7/21-7/30	0	11,518	
		7/31-8/9	0	12,386	
		8/10-8/19	0	11,911	
		8/20-8/29	0	12,658	
		8/30-9/8	0	11,101	
					mean = 11,297
1971	Lake Nerka, Cabin Bay	6/11-6/20	1.91	7,653	
		6/21-6/30	0.35	4,815	
		7/1-7/10	0.17	--	
		7/11-7/20	0	--	
1971	Agulowak R.M.	6/17-7/18	9.22	13,400	11,400-15,600
1972	Agulowak R.M.	6/22-7/2	--	12,402	6,932-24,850
		6/19-7/25		7,262	5,847-9,628
	Little Togiak R.M.	6/26-7/26		3,524	2,438-5,303
		6/29-7/15		3,590	1,649-9,792
	Wind R.M.	7/8-7/18		3,012	1,638-6,274
1972 Totals				29,790	18,504-55,847

Weaver).¹¹ They assumed a closed population; that is, negligible immigration and emigration. The lower abundance of char with fewer smolts in their stomachs at Cabin Bay indicates that heaviest predation occurs at prey concentration points, and it appears from available data and past observation that these points are rivers and their mouths. Stomachs were devoid of smolts after July 20, yet the population remained relatively high at the mouth into September. Nelson (1966) found decreasing char abundances at this location in August 1962. The calculated loss of sockeye to char during the season in both 1954 estimate areas was between one and one and a half million, based on stomach content analysis and population estimates.

Rogers et al. (1972) allowed for an open population in their 1971 estimate at the Agulowak, and calculated a loss of over four million smolts to char. Char were larger at the Agulowak than other areas in Lake Aleknagik, and those sampled in surface waters were larger than those from greater depths (in agreement with Nelson 1966). The average number of smolts consumed was directly related to char size, as was the maximum number of smolts.

In 1972, estimates were made at each of five river mouths roughly within the same time period (Rogers, 1973b). The estimate at the Agulowak did not differ significantly from that of 1971, yet from adult escapements into lakes above the Agulowak two years previous,¹² the sizes of smolt

¹¹See footnote 3, p. 3.

¹²1969 escapement = 440,000; 1970 escapement = 860,000.

migrations should have been substantially different in these two years. Fluctuations in juvenile salmon abundance do not seem to affect char abundance at this location on a year-to-year basis.

The distribution of char during the summer of 1972 corresponded directly with concentration locations of sockeye smolts, the predominant food item at this time of year. The greatest number of char was found at the Agulowak River, with progressively smaller populations at upriver locations. The hypothesis of heavy and concentrated char feeding at prey concentration points is confirmed by observations on distribution as well as stomach content data.

Catch Per Unit Effort

Most adult char captured were taken in gillnets, although angling was also used consistently (Table 10). Insignificant numbers of adults were taken by beach seines. Hook and line gear usually consisted of a red and white spoon or similar lure with a single barbless hook attached to 15-pound test monofilament. Types of gillnets used in Wood River lakes sampling have varied considerably (Table 11). It is not the purpose of this study to analyze differences in gillnet selectivities or related catch curves. However, Reeves (1969) fitted a Holt-normal model to selectivity of gillnets for char in several Nushagak lakes, including Aleknagik, and concluded that despite only an approximate fit, the results indicated selection by gear negligibly affected estimates of growth.

Gulland's (1964) discussion of catch per unit effort as a measure of abundance lists factors which may induce variation in the coefficient "q" (probability of a randomly selected individual appearing in the

Table 10. Compositions of annual samples in percent by gear type

Year	Beach seine	Gill net	Hook and line
1950	14.6		84.4
1951			100.0
1952	8.8	9.2	82.0
1954		100.0	
1955		78.2	21.8
1956		91.1	8.9
1957		100.0	
1961	26.5	65.6	7.9
1963		100.0	
1971		53.1	46.9
1972		65.7	34.3
1973		28.8	71.2
1974		67.3	32.7
1975			100.0
1976			100.0

Table 11. Description of gill nets used in char sampling, Wood River lakes

Year	Depth (feet)	Length (feet)	Mesh size (inches)										Material				
			1	1 1/4	1 1/2	1 5/8	1 3/4	2	2 1/4	2 1/2	2 3/4	3		4	5		
1951	15	90						x						x			Linen
1952, 54	15	270			x			x						x			Linen
1953-54	6	125			x									x			Linen
1954	8	180			x									x			Nylon
1955-57	9	150			x									x			Nylon
1962	9	200			x									x			Nylon
1965-66	9	220			x									x			Nylon
1971-74	12 1/2	160												x			Nylon

catch of a selected unit of effort). Aside from changes in fishing power resulting from the different kinds of gillnets, variation in "q" for char fishing is probably low due to relatively low levels of effort through the years, relatively constant vulnerability of adult char to the gear, and generally constant stock abundance as indicated by population estimates.

Differences in nets are substantial, but Reeves (1969) and Nelson (1966) both caught over 70 percent of total gill-netted char in meshes of 2, 2-1/2, and 3 inches, and these meshes have been fishing in F.R.I. gear since 1950 (Table 11). Therefore, in spite of known differences in nets, for the purposes of this comparison both gillnet and hook and line catches per effort will be used to approximate char abundances. Measures of effort are net-hour and angler-hour, respectively.

The data for June and July (Period 2) were pooled by location and gear. Insufficient information from Periods 1 and 3 prevented analysis from winter and late summer. Because (1) similarities in population estimates between years exist, (2) negligible fishing mortality of char occurs, and (3) similar seasonal distributions have been observed on a year-to-year basis, I averaged CPUE over years by location to establish a rough index of abundance (Table 12).

Char were present in all locations to some degree. Catches per unit effort from open-lake gillnets were all less than 1, with the exception of Lake Aleknagik (1.4). In contrast, values at river mouths were much higher. As expected from estimates of char populations, the hook and line catches of char were lower at the river mouths in the upper lakes of the system than at those in Aleknagik and Nerka.

Table 12. Mean catch per unit effort for different locations,
June and July, 1950-1976

LOCATION	<u>CPUE</u>	
	Gillnet	Hook and line
Aleknagik Area C	1.40	--
Agulowak River Mouth	11.16	9.21
Little Togiak River	--	7.74
Little Togiak River mouth	2.78	--
Central Nerka Area C	0.65	--
North Nerka Area A	0.65	--
Agulukpak River Mouth	2.58	15.16
Beverley Area A	0.44	--
Area C	0.71	--
Peace River Mouth	--	6.00
Wind River Mouth	--	5.88
Kulik Area A	0.78	--

Gillnet catches per effort are nearly identical at the mouths of Little Togiak and Agulukpak Rivers (2.78 and 2.58), yet the latter's estimated population size in 1972 (7.262) was twice that of the former's (3.524). This discrepancy can be resolved when the area of each location is considered; gillnets at the Agulukpak sampled a smaller percentage of that population because of the larger area involved. Char seemed to be equally abundant at the mouths of 4th and 5th Rivers.

Nelson (1966) noted large decreases in char catches at his primary stations in Lake Aleknagik after mid-July, and suggested a general migration to deeper water correlated with rising temperatures and changing food availability (particularly the disappearance of sockeye smolts). Apparently char spend the late summer months at lower depths.

Juvenile Char Abundances

Beach-seine catches of age 0 char are summarized in Table 13 as an index of their relative abundance. Variation occurs between lakes, between areas of lakes, and between the two time periods involved. Fry are present in all areas, and at most sampling locations within Lake Aleknagik. However, only three char fry have been caught at one of the ten stations in Lake Aleknagik where six hauls have been made each year since 1962, and catches have been consistently larger in the upper end of the lake (Rogers, 1973a).

During the first time interval (June 20 - July 19), littoral abundances are relatively high, but decrease notably after mid-July. Catches tend to be larger in areas near major rivers (Aleknagik, A; Little Togiak, C; North Nerka, C; Beverley, B).

Table 13. Geometric means of the catches of age 0 char in beach-seine hauls by lake, year, area, and date

Lake	Year	SAMPLING AREA					
		A	B	C	A	B	C
		(June 20-July 19)			(July 21-Aug. 5)		
Aleknagik	1962	18	4	2	9	9	2
	1963	--	--	--	12	7	8
	1964	26	2	1	21	2	3
	1965	9	1	1	16	2	3
	1966	25	4	2	2	1	1
	1967	35	3	1	15	2	0
	1968	22	2	2	1	0	0
	1969	6	0	1	10	2	1
	1970	14	2	3	8	5	3
	1971	4	1	1	4	2	2
	1972	14	3	1	9	4	2
	1973	19	3	1	18	8	3
	1974	34	5	6	7	2	1
	1975	4	1	1	6	2	1
1976	9	2	1	8	2	1	
Little Togiak	1973	11	23	26	1	8	13
	1974	14	5	22	1	2	4
	1975	28	65	32	3	8	5
	1976	10	14	28	10	3	16
North Nerka	1969	6	3	5	--	--	--
	1970	25	2	272	3	--	--
	1971	19	2	0	--	--	--
	1972	20	0	32	--	--	--
Beverley	1968	59	212	0	--	--	--
	1969	39	4	1	--	--	--
	1970	41	214	0	--	--	--
	1971	25	17	2	--	--	--
	1972	9	18	4	--	--	--

Table 13. Geometric means of the catches of age 0 char in beach-seine hauls by lake, year, area, and date - Continued

Lake	Year	SAMPLING AREA					
		A	B	C	A	B	C
		June 20-July 19)			(July 21-Aug. 5)		
Mikchalk	1968	80	--	--	--	--	--
	1969	22	--	--	--	--	--
	1970	2	--	--	--	--	--
	1971	1	--	--	--	--	--
	1972	0	--	--	--	--	--
Kulik	1968	27	28	86	--	--	--
	1969	8	3	3	16	5	7
	1970	14	82	31	15	47	21
	1971	28	10	2	5	4	2
	1972	13	19	5	--	--	--
<u>MEANS:</u>							
Aleknagik		14	2	1	7	3	2
Little Togiak		14	18	27	2	4	8
North Nerka		15	2	14	3	--	--
Beverley		29	35	2	--	--	--
Mikchalk		15	--	--	--	--	--
Kulik		16	17	10	11	10	7

Migration Information

During the period 1950-1954, 517 char throughout the lakes were caught, marked with numbered tags, and released. Seventy-seven were later recovered. Tagging locations included Wind River mouth, Golden Horn, Little Togiak River, Cabin Bay, and Lynx Creek on South Nerka. Most fish were recovered in the same location and year, with the following notable exceptions: A char that had been tagged four years previously at Wind River was recovered at the mouth of the Agulowak; a fish marked in Golden Horn was caught two years later in Cabin Bay; a fish marked at Pick Creek was recovered at Mosquito Point, Lake Aleknagik one year later; finally, one fish tagged at Cabin Bay in 1953 was caught at the same location in 1954, and again in 1957.

Char were marked during population estimates at the mouth of the Agulowak in 1971, and at the mouths of all major rivers in 1972. As in the 1950's, recoveries have occurred both out of area and in subsequent years (Appendix Table A-3).

Movements involving relatively long distances within the system are apparent from recoveries; the longest movement observed was from Wind River to the Agulowak. Both downriver and upriver movements occurred. For example, a fish tagged at the Wind River was later caught at the Peace, and a char marked at the Agulowak was encountered at the outlet of Little Togiak. A scattering or dispersal of individuals from river mouths is suggested by recovery data, yet individual char have been found at the same location in consecutive years. One char marked by F.R.I. at the Agulowak in 1971 was recovered at the same location by Alaska Department of Fish and Game in 1976.

The observations show that char are involved in interlake migration to an unknown extent. Char movements during June and July are most likely due to feeding activities, but movements in autumn for spawning purposes are also probable. Migrations, that is, periodic movements of a predictable nature, are not evident from these data. However, such movements may occur because of periodicities in food availability and spawning behavior.

SUMMARY AND DISCUSSION

The life history of the arctic char in the Wood River lakes has been examined with respect to season, year, location, and sex. A length-weight analysis was performed, and char stomach contents were analyzed; special emphasis was given to the consumption of sockeye salmon. Population estimates were summarized, and distributions of arctic char and juvenile sockeye salmon prey were discussed. Beach-seine catches of juvenile char were utilized as an index of their relative abundance, and the concept of catch per unit effort as a measure of relative adult abundance was applied. Very little information on char has been recorded from stream spawning surveys. Recoveries of char marked in 1971 and 1972 tagging programs are summarized and interlake movements discussed. Additionally, char marks and recaptures in the 1950's are reviewed.

Sizes of char individuals as well as populations have consistently been greater in Lake Aleknagik, where a larger population consumes more salmon at the mouth of the Agulowak than in any other single location. The density and size of char are highest in river areas during June and July, and decrease toward the upper lakes with decreasing abundance of salmon prey. Annual and monthly variation in length and weight occurs by location, but to a relatively minor extent. Localized abundances of adult char were related to outmigrating sockeye smolts. Sampling inconsistencies between years may have masked actual variations in size and abundance; however, population estimates at the Agulowak River in 1954, 1971, and 1972 were quite similar.

Char feeding habits were shown to vary by season and with changing food availability. Again, the data were weak in allowing comparisons between years, but sockeye smolts are the primary food source for large char during June and July. Heaviest feeding on smolts occurs at the interconnecting rivers where smolts are concentrated.

The role of char as predators on young salmon is but one factor influencing sockeye production, but perhaps a very important one.¹³ In regard to the effects of sockeye on char, Nelson (1966) concluded:

When one considers the char's capacity to use other foods, one can deduce that the condition of the char population as a whole is probably little, if at all, affected by fluctuations in the availability of sockeye salmon, even though the salmon may be the most abundant and readily utilized source of food early in the summer. Char populations appear more stable than sockeye; similar numbers and behavior of char are noted annually despite significant differences in sockeye levels. Char feeding activities in the Wood River lakes have evolved around sockeye as a primary food source, and this pattern was present long before commercial exploitation of the stocks and subsequent declining catches.

Sockeye production is also influenced by predation from other known sources, and possibly some undiscovered marine sources. Resident rainbow trout may pose a threat to incubating eggs, but their significance has not been evaluated. Large flocks of arctic terns (*Sterna paradisaea*)

¹³Appendix B summarizes the history of predator control in Bristol Bay.

and Bonaparte's gulls (*Larus philadelphia*) can be observed circling above rivers, actively feeding on migrating smolts, usually driven near the surface by char. Consumption rates of smolt by these birds remains unmeasured, but in all likelihood is substantial. Predation by belugas in tidewaters on seaward migrants has been noted and measured (Alaska Dep. Fish Game, 1955). Over 1,000 fingerlings were found in stomachs of individual belugas from Nushagak Bay in 1954 and 1955. Predation by man occurs in commercial and subsistence fishing.

The impact of the area's sport fishery on rainbow trout is, in all likelihood, heavy. Such an impact could conceivably allow arctic char to capture the niche of rainbows in the rivers and streams. The ecological relationship between char and rainbow needs better definition; are there less rainbow trout in the Wood River lakes due to proportionately more char there than in other neighboring lakes?

Freshwater mortality of young sockeye is generally heavy, and critical to survival of year classes. Behavioral adaptations to minimize this mortality have been discussed (Hartman et al. 1967; Ginetz and Larkin 1976; Hoar 1954; and Hoar 1958). Primary adaptations of sockeye against predators, in addition to individual avoidance flight, include travel at night through critical areas, schooling, and an overall rapid exodus from freshwater; however, the period of smolt migration in the Wood River lakes is generally longer than at other locations in Bristol Bay.

Efforts at char removal in the Wood River lakes and Bristol Bay area from 1920-1940 through expeditions and a bounty system proved inconclusive in determining effects on adult returns.¹⁴ No adequate records were kept; however, the abundance of salmon remained stable during this period and did not decline in the Nushagak District until the early 1950's. Fishing pressure, especially that of traps, was intense during the early twentieth century, and overexploitation probably occurred. The termination of bounties on char coincided with Hubbs' (1940) critique of the program, which emphasized unestimated biological as well as economic considerations in the design of predator removal.

Although compensatory mortality of salmon stocks is known to take place through time, its exact role in production of Wood River sockeye is not known. Conceptually, less predation at an early stage could later be offset by more intense predation. However, increasing freshwater survival would theoretically afford a basis for significantly better returns, other factors being constant.

In addition to their obvious role as salmon predators, char appear in another respect to perform a role that complements salmon production. The diet overlap between threespine stickleback and salmon fry noted by Rogers (1968) sets the stage for food competition between the two species, especially in limnetic zones after mid-July in localities where an unfavorable abundance ratio of fish to food exists. Char, in feeding upon stickleback, may dampen this competition in favor of salmon; however,

¹⁴Predator Control Briefs, 1912-1942. Univ. Wash., Fish. Res. Inst., 1956, unpublished Bristol Bay manuscript.

the rates of predation by char on the two species may be independent and variation in the abundance of one species may not affect the rate of predation by char on the other species.

Arctic char are capable of utilizing a wide range of food items. Their size, distribution, and feeding habits have been examined and found to be generally stable and consistent with respect to location and time of year over a 26-year period, despite decreasing catches of adult sockeye since the turn of the century. The arctic char in the Wood River Lakes appear to have a greater potential to affect the production of sockeye salmon than the variation in salmon abundance has to affect the production of char.

LITERATURE CITED

- Alaska Dep. Fish. 1955. Annu. Rep. 95-106.
- Burgner, R. L. 1958. A study of fluctuations in abundance, growth, and survival in the early life stages of the red salmon (*Oncorhynchus nerka*) of the Wood River lakes, Bristol Bay, Alaska. Ph.D. dissertation, Univ. Wash. 200 pp.
- Ginetz, R. M. and P. A. Larkin. 1976. Factors affecting rainbow trout (*Salmo gairdneri*) predation on migrant fry of sockeye salmon (*Oncorhynchus nerka*). J. Fish. Res. Board Can. 33(1):19-24.
- Grainger, E. H. 1953. On the age, growth, migration, reproductive potential and feeding habits of the arctic char (*Salvelinus alpinus*) of Frobisher Bay, Baffin Island. J. Fish. Res. Board Can. 10(6): 326-370.
- Gulland, J. A. 1964. Catch per unit effort as a measure of abundance. Symp. on measurement of abundance of fish stocks. Cons. Perma. Int. Explor. Mer, Rapp. et Proc. - Verb. Reun. 155:8-14.
- Hartman, W. L., W. R. Heard, and B. Drucker. 1967. Migratory behavior of sockeye salmon fry and smolts. J. Fish. Res. Board Can. 24(10): 2069-2099.
- Hartman, W. L. and R. L. Burgner. 1972. Limnology and fish ecology of sockeye salmon nursery lakes of the world. J. Fish. Res. Board Can. 29(6):699-715.
- Hoar, W. S. 1954. The behavior of juvenile pacific salmon, with particular reference to the sockeye (*Oncorhynchus nerka*). J. Fish. Res. Board Can. 11(1):69-97.
- Hoar, W. S. 1958. The evolution of migratory behavior among juvenile salmon of the genus *Oncorhynchus*. J. Fish. Res. Board Can. 15(3): 391-428.
- Hubbs, C. L. 1940. Predator control in relation to fish management in Alaska. Trans. Fifth N. Amer. Wildlife Conf., 153-162.
- Larsson, H-O. and P-O. Larsson. 1974. Predation on hatchery reared smolts after release in the River Lule, 1974. [In Swedish, English abstract] Laxforskningsinstitutet Meddelande 9/1975.
- McPhail, J. D. 1961. A systematic study of the *Salvelinus alpinus* complex in North America. J. Fish. Res. Board Can. 18(5):793-816.
- McPhail, J. D. and C. C. Lindsey. 1970. Freshwater fishes of North-western Canada and Alaska. Bull. Fish. Res. Board Can. 173, 381 pp.

- Nelson, M. O. 1966. Food and distribution of arctic char in Lake Aleknagik, Alaska, during the summer of 1962. M.S. thesis, Univ. Wash., 164 pp.
- Nordeng, H. 1961. On the biology of char (*Salmo alpinus* L.) in Salangen, North Norway. I. Age and spawning frequency determined from scales and otoliths. *Nytt. Magasin for Zoologi* 10:67-123.
- Pinkas, L., M. S. Oliphant, and I. L. K. Iverson. 1971. Food habits of albacore, bluefin tuna, and bonito in California water. *Calif. Fish and Game, Fish. Bull.* (152):1-105.
- Reeves, J. E. 1969. A comparative analysis of arctic char populations in sockeye salmon lakes of the Nushagak District, Alaska. Ph.D. dissertation, Univ. Wash., 218 pp.
- Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. *Bull. Fish. Res. Board Can.* 191, 382 pp.
- Rogers, D. E. 1968. A comparison of the food of sockeye salmon fry and threespine sticklebacks in the Wood River lakes. Reprinted from: *Univ. Wash. Publ. in Fish., New Ser., Vol. III, Further Studies of Alaska Sockeye Salmon.*
- Rogers, D. E. 1973a. Abundance and size of juvenile sockeye salmon and associated species in Lake Aleknagik, Alaska, in relation to their physical environment. *NOAA Fish. Bull.* 71(4):1061-1075.
- Rogers, D. E. 1973b. Alaskan salmon studies. Part A. Study of red salmon in the Nushagak District. Periodic Contract Rep. 2, U.S. Dept. Commerce, NOAA, Jan. 30, 1973, 13 pp.
- Rogers, D. E., L. Gilbertson, and D. Eggers. 1972. Predator-prey relationship between arctic char and sockeye salmon smolts at the Agulowak River, Lake Aleknagik, in 1971. *Fish. Res. Inst., Univ. Wash., Circ.* 72-7, 40 pp.
- Savvaitova, K. A. and I. S. Reshetnikov. 1962. The food of different biological forms of the Dolly Varden char, *Salvelinus malma* (Walb.), in certain Kamchatka waters. *Vopr. Ikhtiol.* 10:127-135. (*Fish. Res. Board Can., Transl. Ser.* 373.)
- Thompson, R. B. 1959. Fecundity of the arctic char *Salvelinus alpinus* of the Wood River lakes, Bristol Bay, Alaska. *Copeia* 4:345-46.

APPENDICES

Appendix Table A-1. Description of species caught in conjunction with Arctic char

Species	Date	Location	Catch	Mean Length (mm)	Length Range (mm)	Mean Weight (g)	Weight Range (g)	No. stomachs containing food items
Arctic Grayling (<u>Thymallus arcticus</u>)	Jul, Aug 61	Central Nerka, Elva Creek	16 (10 F, 6 M)	372	311-442	610	340-936	(Predominantly insects)
	Jul, Aug 61	South Nerka, Lynx Creek	204 (60 F, 62 M, 82 missing)	305	115-417	369	28-936	Insects 121 Fish 52 Empty 3 (Remainder missing)
Rainbow Trout (<u>Salmo gairdneri</u>)	Jul, Aug 61	Central Nerka Area	70 (29 F, 37 M, 4 missing)	373	187-481	567	85-1134	Insects 46 Fish 5 Eggs 2 Plant 14 Gastropods 7 Empty 10
	Jul, Aug 50	Kulik	38 (16 F, 13 M, 9 missing)	358	205-484	442	100-1075	Insects 25 Gastropods 3 Fish 1 Empty 2
	Jun, Jul 50	Aleknagik, Whitefish Cr.	20	211	160-285	--	--	Insects 20 Fish 2 Empty 0

Appendix Table A-1. Description of species caught in conjunction with Arctic char -
Continued

Species	Date	Location	Catch	Mean Length (mm)	Length Range (mm)	Mean Weight (g)	Weight Range (g)	No. stomachs containing food items
Northern Pike (<u>Esox lucius</u>)	Jul 50	Aleknagik, Agulowak R.	21 9 F, 12 M	368	160-415	--	--	Insects 21 Gastropods 1
	Jul 61	Little Togiak Lake	45 (21 F, 24 M)	692	514-966	2332	1162-6124	Insects 1 Gastropods 3 Empty 22 Fish 152
	Jul 61	Central Nerka	75 (39 F, 36 M)	547	429-673	1325	680-2693	Hirudinea 2 Empty 37 Fish 333
	Jul 61	North Nerka East End Bay	69 (35 F, 34 M)	525	393-641	1164	454-2268	Insects 2 Fish 22 Gastropods 3 Hirudinea 1 Empty 42
	Jul, Aug 61	Kulik, Grant R.	8 (4 F, 4 M)	756	615-860	3423	1816-4540	Fish 4 Empty 4

¹In a sample of 63 grayling on 8/2, 44 had fish in stomachs; of these, the average number of red salmon fry was 17.4.

²Blackfish, stickleback

³Blackfish, stickleback, sculpin

Appendix Table A-2. Descriptions of char lengths and weights by year and sex, all fish combined

Year	Sex	Mean		Standard Deviation		Minimum		Maximum		Sample Size	
		L	W	L	W	L	W	L	W	L	W
1950	M	458	720	66	334	253	265	590	1740	97	29
	F	442	630	37	168	330	360	540	880	83	12
1951	M	482	1041	51	454	420	600	610	2050	23	23
	F	454	785	33	294	400	500	525	1550	15	15
1952	M	408	742	90	468	157	25	586	2384	358	286
	F	380	573	70	308	167	75	579	2050	371	283
1954	M	411	762	94	471	180	54	620	1928	76	75
	F	444	843	54	271	285	227	530	1418	32	32
1955	M	431	964	102	500	163	50	633	2200	413	413
	F	415	768	65	310	194	50	528	1650	290	290
1956	M	420	898	115	562	177	50	598	2550	257	257
	F	409	711	68	298	187	50	540	1350	203	203
1957	M	361	607	109	516	151	25	615	2850	369	369
	F	358	539	87	347	151	50	516	1550	377	377
1961	M	385	731	109	543	171	57	650	2438	298	298
	F	352	547	89	371	128	28	562	1899	377	377
1963	M	405	821	107	573	165	60	565	2400	46	46
	F	411	813	71	379	130	10	535	1810	73	73
1971	M	490	1447	67	560	330	440	675	3100	158	158
	F	465	1121	44	330	345	420	600	2400	245	245
1972	M	454	1144	88	572	120	45	665	3200	690	440
	F	431	921	62	397	165	50	670	3970	870	503
1973	M	475	1171	72	512	230	120	640	2500	295	295
	F	448	970	53	345	210	150	560	2000	310	309

Appendix Table A-2. Descriptions of char lengths and weights
by year and sex, all fish combined - Continued

Year	Sex	Mean		Standard Deviation		Minimum		Maximum		Sample Size	
		L	W	L	W	L	W	L	W	L	W
1974	M	442	957	65	383	270	240	580	2110	128	116
	F	423	790	47	255	275	200	540	1760	147	124
1975	M	418	767	77	472	230	70	567	2230	32	32
	F	410	654	57	261	231	95	475	1300	36	36
1976	M	427	735	73	399	238	90	558	1780	49	49
	F	411	570	50	249	250	90	540	1310	46	46
All Years Combined	M	428	926	100	565	120	25	675	3220	3289	2886
	F	410	762	76	391	128	10	670	3970	3475	2925

Appendix Table A-3. Recaptures of char marked by Fisheries Research Institute, Wood River lakes

Type of mark	When applied	Where applied	Recaptures at later time, or out of area
Dorsal punch	June, 1971	Agulowak River	Little Togiak River, July, 1972 Agulowak River, June-July, 1972 Agulukpak River, June, 1972
Red Dennison	June, 1971	Agulowak River	Agulowak River, June-July, 1972 and 1973
Brown Dennison/ anal punch	June, 1971	Agulowak River	Agulowak River, June-July, 1972 Agulukpak River, June, 1972
Green Dennison	June, 1972	Agulowak River	Little Togiak River, July, 1972 Mosquito Point, July, 1972 Agulowak River, June, 1973
Blue Dennison	June, 1972	Little Togiak River	Little Togiak River, June, 1973, and July, 1974 Lake Aleknagik, Area A, June, 1973
Yellow Dennison	June, 1972	Agulukpak River	Little Togiak River, July, 1972
Pink Dennison	July, 1972	Wind River	Peace River, July, 1972

Appendix Table A-4. Percentage composition of gill-net catches of resident fishes in the Wood River lakes, 1952-54 and 1955-57

Species	1952-54					1955-57
	Lake Aleknagik	Lake Nerka	Little Togiak Lake	Lake Beverley	Lake Kulik	Lake Nerka
Humpback whitefish	1.6					
Round whitefish	4.9	0.4	0.1	13.9	23.5	0.7
Rainbow trout	1.0	0.7	0.1	0.7	1.8	0.3
Arctic char	90.7	95.8	99.1	83.6	70.1	98.4
Dolly Varden	0.5	0.3	0.1			
Arctic grayling	0.6	0.7	0.1	1.6	1.9	0.2
Northern pike	0.6	2.1	0.5	0.1	2.7	0.4
Burbot	0.1			0.1		
Total number caught	2,820	3,555	876	447	776	1,779
Total net hours	3,647	3,867	731	506	596	2,832
Catch/net hour	0.77	0.92	1.12	0.88	1.30	0.63

APPENDIX B

SUMMARY OF PREDATOR CONTROL

The role of arctic char as fish predator in the Wood River lakes has been apparent since pre-1900 exploratory fishing efforts and subsequent inception of commercial sockeye fishing. The information in this section is taken from a series of predator control briefs, compiled by the Fisheries Research Institute and drawn from field notes and annual reports of the U.S. Bureau of Fisheries and Territory of Alaska in the early 1900's.¹⁵

Published accounts in 1912 reflect outcries against char feeding on sockeye: "On account of its voracious habits the Dolly Varden is undoubtedly the most destructive natural enemy that young salmon have in fresh-water. The suggestion is frequently heard that the government ought to place a bounty on trout to aid in preserving the salmon industry." Understandably, the economics of this developing industry were a paramount concern to both the Territory and cannery personnel. Any obstructions to maximum utilization of the sockeye resource were undesirable; char predation rapidly gained relevant notoriety, and was soon to be the target for the first attempts at managing Bristol Bay runs.

For the duration of years prior to 1920, several noteworthy developments warrant mention. The feeding activities of other salmon predators were observed, and similar vociferations arose regarding control of gulls, terns, eagles, hair seals, and bears. Responses centered upon

¹⁵See footnote 14, p. 51.

the establishment of brief bounty periods on predatory birds and hair seals periodically during the following 20 years. Perhaps the most effort was directed at predatory birds. In 1915, power to destroy birds was delegated to Bureau of Fisheries personnel by the Department of Agriculture; "officials may take such action as is necessary to protect salmon and their eggs on the spawning grounds."

Concurrently, several canneries began experimentation on marketing trout products, including char and steelhead. The Midnight Sun Packing Company, Kotzebue Sound, successfully sold increasing quantities of char annually until 1919. In 1918, the value of Midnight Sun's char pack exceeded that of all other Alaskan trout products. At this point, canneries in southeastern Alaska, namely Petersburg and Ketchikan, became more successful at marketing trout products (including steelhead); in any case, a viable market to the United States had been established.

In 1920, an association of Bristol Bay packers joined monetarily with the Territorial Fish Commission to fund efforts "for the purpose of making a survey of the salmon spawning streams, providing for their improvement where necessary and for the extermination of predatory fishes and birds." Dennis Winn, a Seattle-based agent of the U.S. Bureau of Fisheries, was appointed as supervisor of field operations. Base camps for predator control crews were established on Upper Naknek River, Lake Iliamna, and Lake Aleknagik. Arriving in May, expeditions awaited iceout annually through 1925, and throughout the summers concentrated their efforts at destroying as many char as possible. Gear employed included set and drift gillnets, seines, traps, and troll and setlines. Statistics for char removal in Wood River lakes, as well as

the Bristol Bay area, are shown in Appendix Table B-1. These figures are from Winn's annual reports. Most Wood River char were taken from Lake Aleknagik, near the outlets of both the Agulowak and the lake itself." "There are more Dolly Varden trout in the upper part of Wood River and in Lake Aleknagik than in all the other lakes combined." Attempts at char removal were also made through the ice during at least one season in this period, but with extremely poor results.

Winn's observations and comments in his annual reports to the Territorial Fish Commission reflect his pursuance toward predator eradication. However, the scientific basis of the crews' efforts remains questionable at best. In reference to stomach contents of char, "Their consumption of eggs is enormous, estimated to be many hundred each day for every individual during the spawning season... Specimens of stomachs examined showed from 20 to 60 fingerlings, and up to 200 fry have been found in others." After the first field season Winn concluded:

"We are thoroughly convinced that the predatory fishes, together with the terns mentioned heretofore, constitute one of the most serious menaces facing the salmon industry... The only hope of curtailing this loss is by waging a constant, aggressive and extensive campaign against these marauders."

Quoting from the same report,

"So well pleased were the packers with the results of these investigations and the extermination operations and so thoroughly were they aroused to the gravity of the situation pointing to an early extermination of the salmon (sic) in that greatest of sockeye districts, that they are planning to continue the work in those sections upon a much larger scale and to extend the same to the Ugashik, Egegik, Herendeen Bay and Port Moller... The situation out there is alarming and the packers are at least mildly scared. The close gleaning for years without the least attempt at replenishment has rendered futile the attempts of Nature to maintain the red salmon in that district. If it had not been for an occasional storm or other natural cause occurring during the fishing season the runs would have been annihilated before this."

Appendix Table B-1. Summary of predatory fish control efforts, Bristol Bay, 1912-1941

Year	Western Alaska Commercial trout pack		Wood River		Bristol Bay		Bounties paid Bristol Bay Area	
	Cases	Value	Lakes expeditions Char destroyed	Pounds destroyed	Area expeditions Char destroyed	Pounds destroyed	Total fish	Funds expended
1912	1,326	\$ 3,315						
1913	775	2,788						
1914		5,758						
1915	176	704						
1916	504	3,024						
1917	1,112	8,800						
1918	2,587	24,105						
1919	91	600						
1920	43	258		40,000	50,000			
1921			12,702	44,457	34,758	122,762		
1922			7,410	18,525	33,542	131,496		
1923			7,519	18,797	45,872	161,941		
1924			5,551	13,877	#1			
1925			4,384	8,768	*			
1926					19,687			
1927 ²							38,894	\$ 1,944
1928							*	
1929							251,000	12,500
1930							339,748	16,987
1931							*	
1932							*	
1933							*	
1934							*	
1935							*	
1936							800,000	20,000
1937							680,000	17,000
1938							630,000	15,820
1939							460,000	11,540
1940								
1941 ³								

¹*Indicates missing data.
²No predatory work in 1927.
³Predatory control discontinued.

It was reported in 1925 that average weight of char collected in Lake Aleknagik dropped from five to two pounds since the work was begun. Total numbers of char killed in this lake steadily declined; however, no corresponding description of effort expended is available. In 1926, approximately 20,000 char were taken from the Ugashik District only; in 1927, no attempts were made in any area of Bristol Bay.

Coincident with the discontinuation of the expedition approach and the commencement of the bounty system in 1928, two observations made in 1927 are singularly interesting. Here it is noted that the adult escapement of sockeye passing up the Agulowak was the lowest in many years, and that "Trips to Lake Aleknagik indicated that Dolly Varden were nearly as numerous and active as in former years before the canners and Bureau began their cooperative work of extermination."

As with Winn's expeditions, local canners and the Territorial legislature assumed responsibility for funding the bounties; processors mutually agreed to contribute a flat amount for each case packed. These pledges were in turn matched by public funds. Similar to funding of earlier expeditions, this money included apportionments for stream improvement and fishing regulation enforcement, as well as bounties.

"The natives catch the trout, dry the tails, and assemble them by the hundred on strings, and deliver them to a representative of the Bureau, who prepares an affidavit on the form provided by the Territorial Government. Arrangements have been made whereby the owners of various trading posts will accept these trout tails as cash for purchases made by the natives."

Initially, each tail was valued at five cents; in 1934, the exchange was lowered to 2.5 cents. No limits were placed on numbers of fish residents could exchange. One Mrs. M. J. Baas received \$812.30 for

submitting 32,492 fish during 1937-39. Mean number of fish destroyed from 1937 through 1940 was over one-half million. The bounty system inherently provided for larger quantities of fish to be removed than previously.

During its 1940 session, the legislature did not issue any appropriations for salmon management; the bounty operation came to an abrupt halt, and has never been reinstated.

In a paper submitted to the Fifth North American Wildlife Conference, concomitant with the legislature's decision to cut management funds, Hubbs (1940) objectively reviewed the Bristol Bay predator control efforts. In general, he emphasized the economic as well as biological considerations that, in fact, should have been researched and defined beforehand. He additionally uncovered a series of abuses associated with implementation of the programs. The following points of Hubbs are most relevant:

1. "With few exceptions, the destruction of salmon enemies has been allowed, financed and prosecuted in the honest belief that the prosperity of the great salmon industry and hence of the Territory demanded such action."

2. "The natives (and some who are concerned with native welfare) are coming to regard the right to kill and collect bounties as a vested right, and are calling for an extension of the bounty to other animals... which feed on salmon."

3. He refuted the idea that predation on salmon eggs is detrimental to production.

4. Tails of rainbow trout and salmon had been offered and accepted as bounty in unrecorded quantities.

5. "The value of some predators as fur, food, game, Territorial economy and recreation may more than balance any harm they may do in destroying salmon. For each species and each region it remains to be determined, by sound research, to what degree the kill of salmon predators is justified."

6. "The biological consequences of the depletion of Dolly Varden are not simple to determine."

7. "Administrative decision should therefore rest on a full understanding of all points of view, and on all facts which can be determined by impartial and penetrating research."