

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

ARCTIC CHAR IN THE WOOD RIVER LAKES

by

Dan Moriarity

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ARCTIC CHAR IN THE WOOD RIVER LAKES

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INTRODUCTION

Predation by resident fish on Pacific salmon has been observed in numerous locations. Because of their relatively lengthy residence in freshwater, sockeye salmon (*Oncorhynchus nerka*) losses to predators during their early life history are especially noteworthy. In the Wood River lakes, southwestern Alaska, sockeye fry and smolts begin feeding and migration activities in the spring, normally coinciding with ice breakup. Depending on their incubation and rearing area, smolts must swim down up to four clear, shallow rivers to reach the system outlet (Fig. 1). Concurrently, arctic char (*Salvelinus alpinus*) populations congregate at river mouths and become recognizably predaceous. This feeding pattern continues 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 minor salmon predators with respect to char (Nelson 1966).¹

The various freshwater phases of sockeye life history have been dealt with quite extensively. Hartman and Burgner (1972) discuss factors related to production in nursery lakes, including predation by resident fish. Dynamics, biology, and abundance of young salmon from several of the Wood River lakes are analyzed by Burgner (1958); fluctuations in smolt abundance and growth between years and lakes are shown. Rogers (1968) found similarity between the diets of sockeye fry and threespine stickleback, and evaluates the interactions of juvenile salmon with other species in littoral habitats of Lake Aleknagik (1973).

Several papers have dealt specifically with arctic char ecology. Nelson (1966) studied feeding and distribution in Lake Aleknagik for one summer and concludes that char are nonselective feeders. Food items in stomachs analyzed varied with time of season and availability. 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. Burgner (MS 1959) 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 Weaver (MS 1964) analyzed char biology and predation in Lakes Nerka and Aleknagik in the mid-1950's, and emphasized differences between prey concentration and non-concentration areas.

¹Nelson's paper dealt with Lake Aleknagik only.

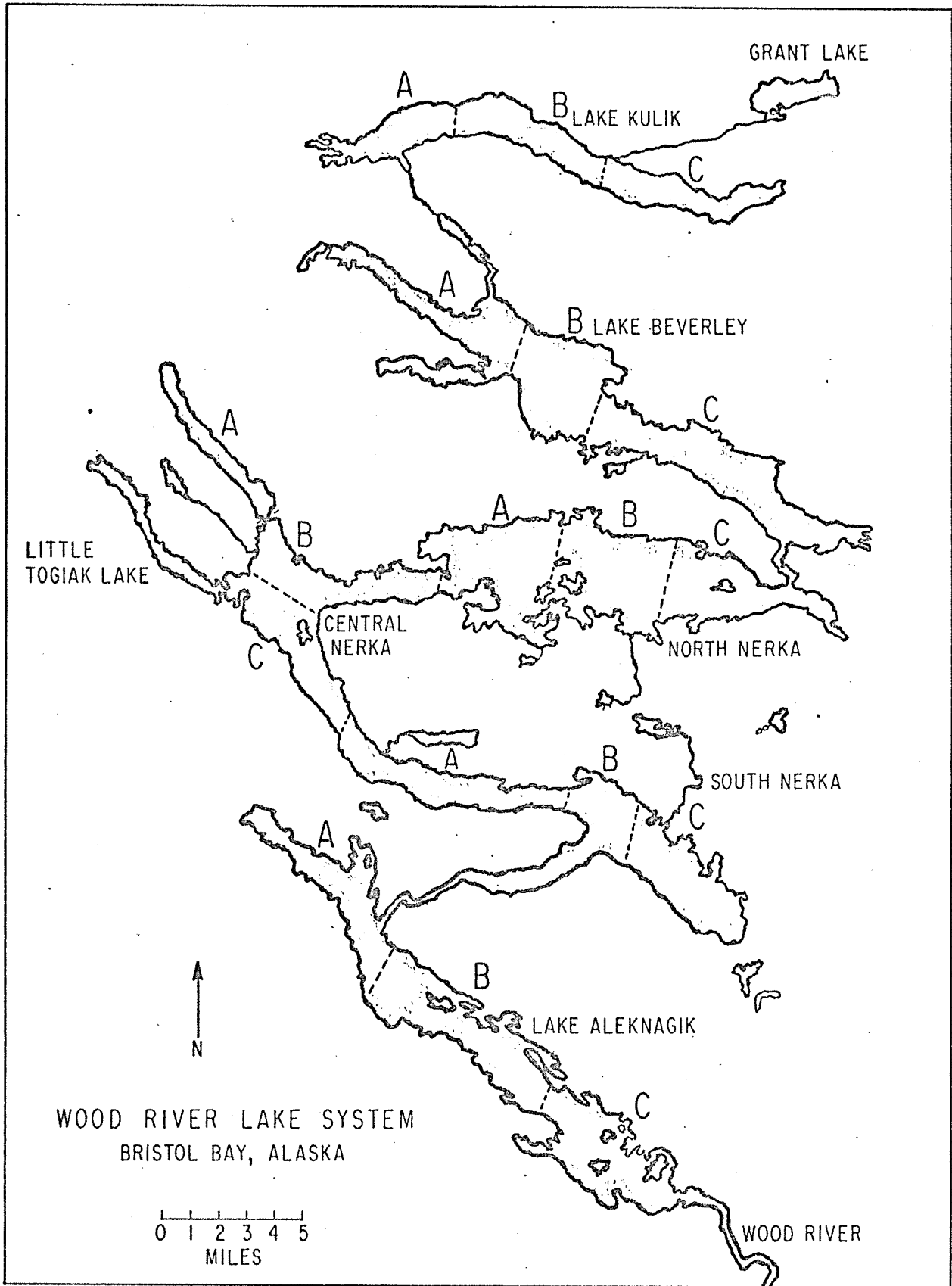


Fig. 1. Map of the Wood River lake system, showing sampling areas (A,B,C).

Their findings included:

1. Char predation was heaviest in areas of smolt concentrations; its intensity was 3.5 times higher at river mouths than in open lake areas.
2. Sticklebacks replaced sockeye fingerlings in stomachs as the former's availability decreased.
3. All char collected over 100 mm in length showed capabilities of consuming juvenile sockeye.
4. Occurrences of juvenile sockeye and stickleback showed seasonal patterns; all other food items did not. Insects occurred in char stomachs only during periods of warmer lake water.

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 U.S.S.R. 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). Geographical, hydrological, and biological characteristics of the Wood River lakes, in addition to the region's relative lack of development yet commercial importance, singularize the system ecologically. Char production in the lakes has evolved around unique conditions, and the understanding of the char's role in salmon production is necessary for sound management.

Although F.R.I.'s research efforts 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 the 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 is to further define and elaborate upon the role of the arctic char as a predator on young sockeye of the Wood River lakes. This analysis will summarize the extent of Fisheries Research Institute data through the 1976 field season. Specific objectives are:

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 the 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 on 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 gross migration information as determined through tag recoveries during periods subsequent to population estimates.
7. To summarize existing analyzed data on juvenile char from beach seine catches.
8. To include catch per unit effort data where such information is available in fulfilling the above specific objectives.

On reviewing the specific objectives and considering the information available for analysis, the following question can be 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, in relation to sockeye population?

The scope of this analysis will be that of a summary. The raw data results from efforts of different investigators employing varied techniques over a 26-year period. Major error sources will undoubtedly be the lack of consistent sampling techniques since 1950 as well as missing data from certain periods, especially September through May. However, due to the diversity of sampling, it is felt that a sufficient descriptive summary is possible.

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 are most likely to be found in Lake Aleknagik and its tributaries only (D. E. Rogers, personal communication). For practical purposes, 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 relatively long-lived fish as char involves grinding off opaque deposits and reading 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 gill nets) showed a range of ages from one to 13 years, mean of 6, and mode of 7. No otolith data are available for this study.

METHODS

The most effective method of accomplishing the objectives as stated was to first standardize all available data. Fisheries Research Institute form S 9.2.3. (Revised Field Examination Form - Resident Freshwater Form, Fig. 2) was suitable because of its capability to store the entirety of information. After transcription of all material onto these forms, the data base was 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" describes habitats; char samples are classified by station as being collected from (1) within river-creek, (2) river-creek mouth, or (3) open lake.

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		Tenhs	Sex	Gill net mesh size	Fullness of Gut	Occurrence										Numbers of fish										Total						
		Grams						Zooplankton	Insects	Centropedon	Algae	Plant	Fish eggs	Fish	Other	Red Age 0	Red Age I, II	Coho	King	Pink	Char	Rainbow	Unident.	Crayling	Round	Humpback	Pigmy		Unident.	Garra	Fungius	Sculpin	Blackfish	Ford smelt
31	35	37	40	41	43	44	46	47	48	50	52	54	56	58	60	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.

"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
February	
March	(244 Samples)
April	
May	
June	2 - During juvenile migrations
July	(5,899 samples)
August	3 - Summer lake residence
September	(804 Samples)

Hence, comparisons from both time and space perspectives are 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 present.

All lengths were expressed 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, occurrences have been estimated on scales of zero to ten by different biologists. As a result of these inconsistencies, and 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. 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 accurate measurements of char feeding behavior are not available; nevertheless, changes in diet preference over time and by location can be detected and described. In addition to absence/presence of food types in each fish, the numbers of fish items by species in the stomachs have been recorded.

Catch per unit effort data, broken down by gear type, provided a rough index of relative abundance of char throughout the system. Additionally, population size estimates have been performed in various locations, and a summary of these helped to delineate 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 original sex categories mentioned.

Length-Weight Analysis

Appendix Table 1 presents char lengths and weights by year and sex, all lakes combined. In several cases, sample size deviated from totals described in Table 1 due to small percentages of missing length and weight values.

In order to detect further trends, 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 assuming fixed effects. A slight weakness of this model is that "year" tends more toward randomness because of discontinuities in its range. 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 regression analyses controlling for all categories of each of the five variables were chosen as an alternative to ANOVA. Results are shown in Figs. 3 through 7. Means are represented by circles, and ranges indicated by lengths of the lines.

From visual examination, the effect of sex appears insignificant. Both male and female form approximately equal sized categories with

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

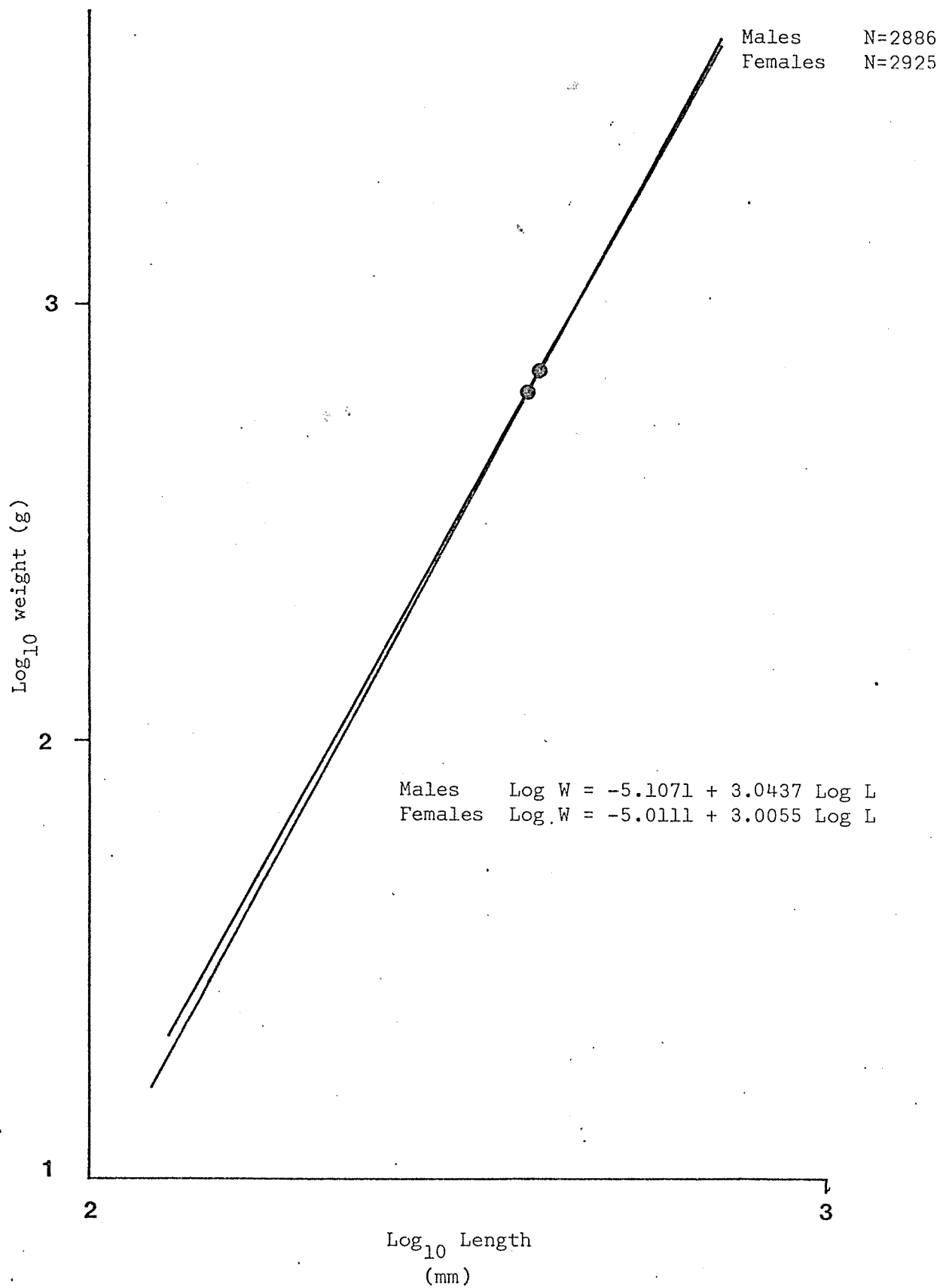


Fig. 3. Regressions of log₁₀ weight on log₁₀ length by sex.

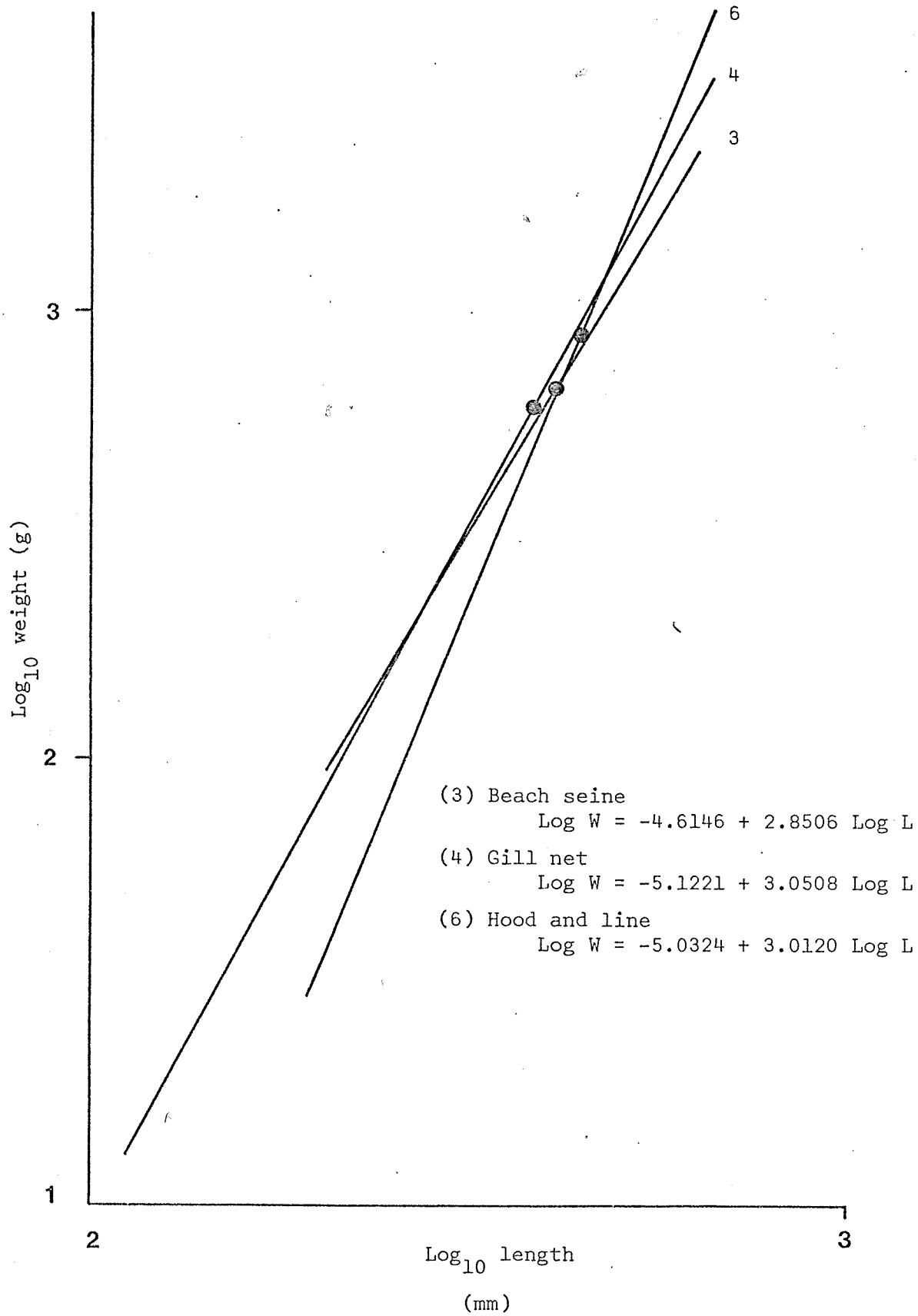


Fig. 4. Regressions of \log_{10} weight on \log_{10} length by gear type.

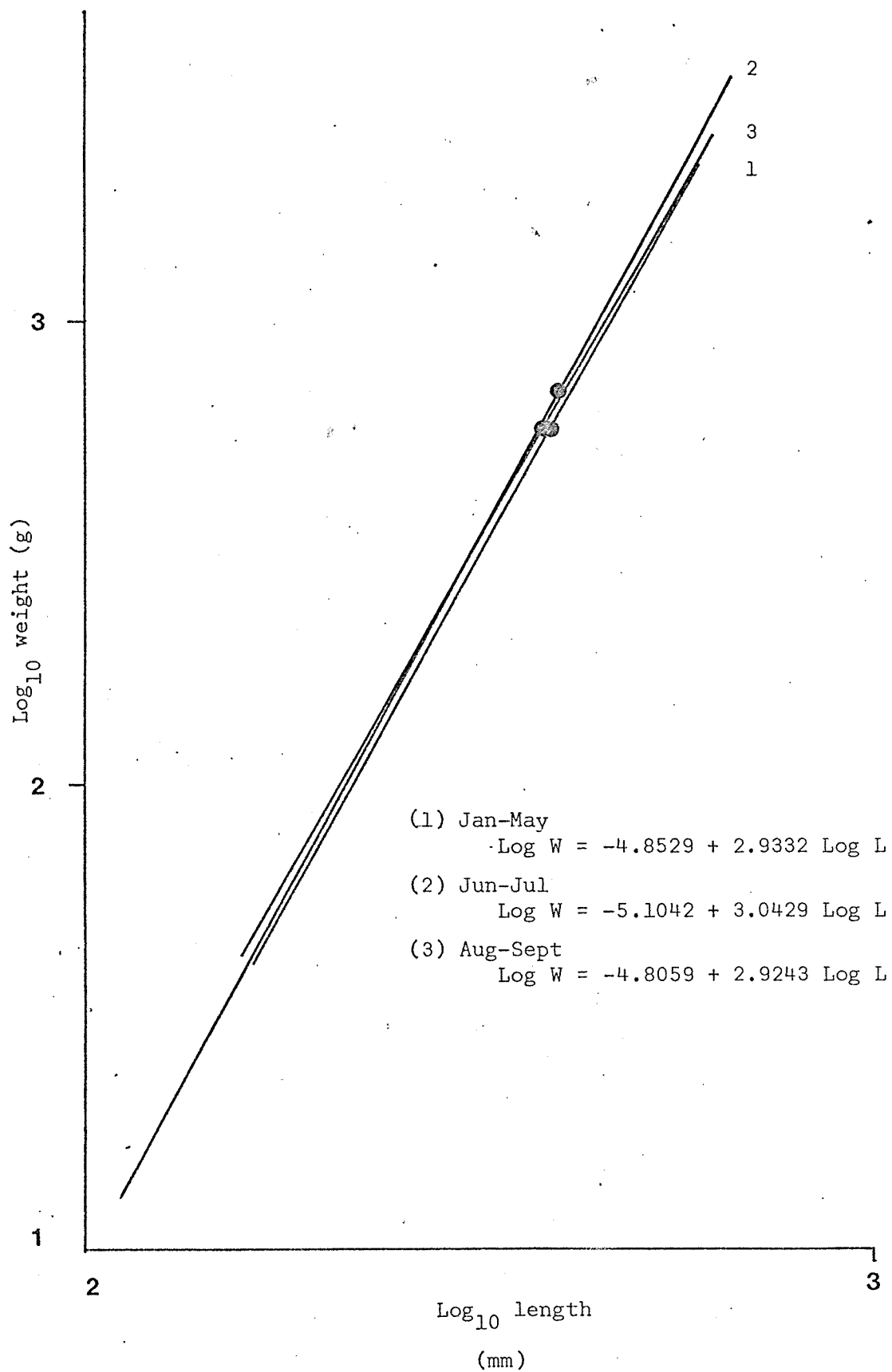


Fig. 5. Regressions of \log_{10} weight on \log_{10} length by period (season).

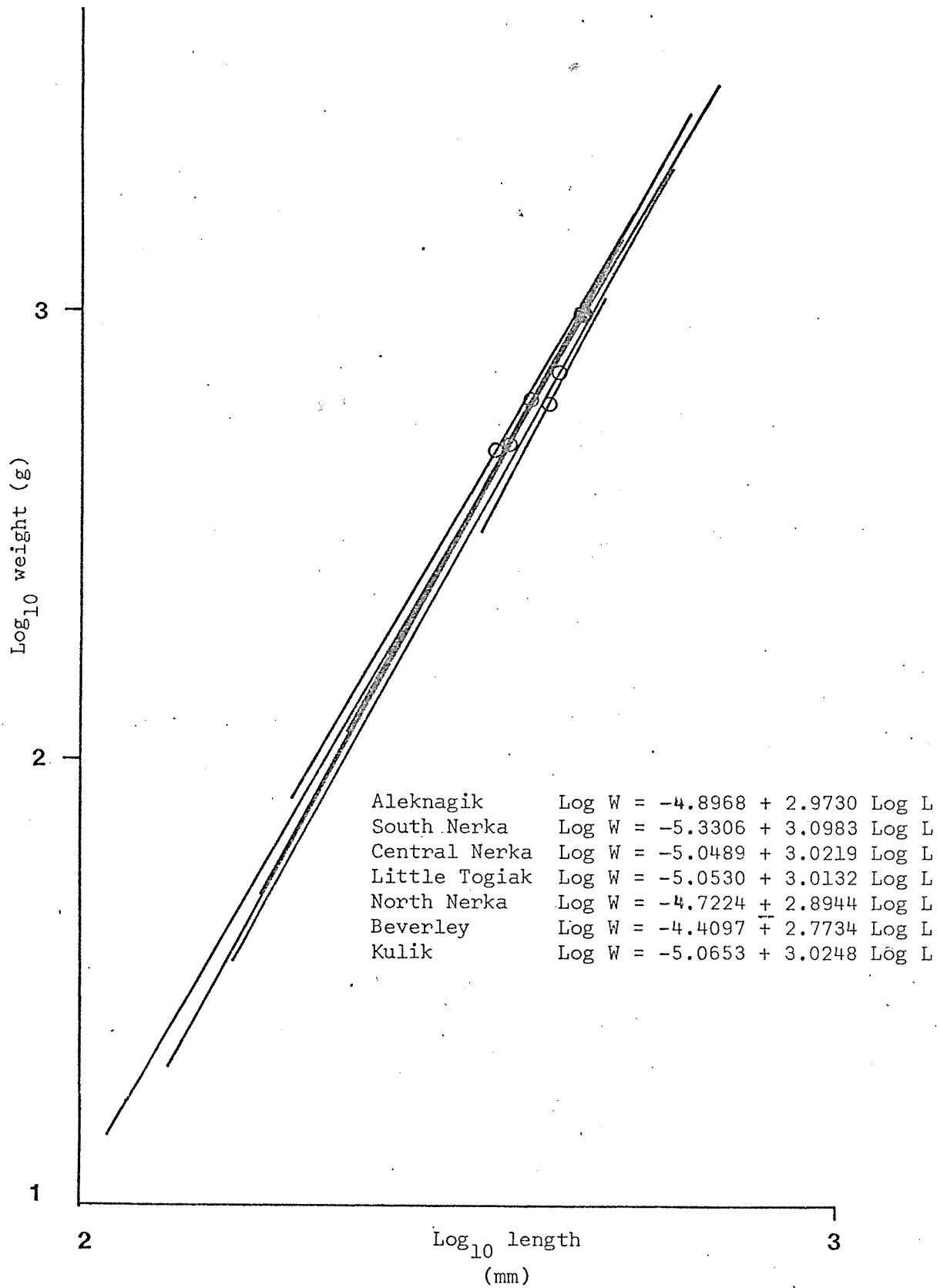


Fig. 6. Regressions of \log_{10} weight on \log_{10} length by lake.

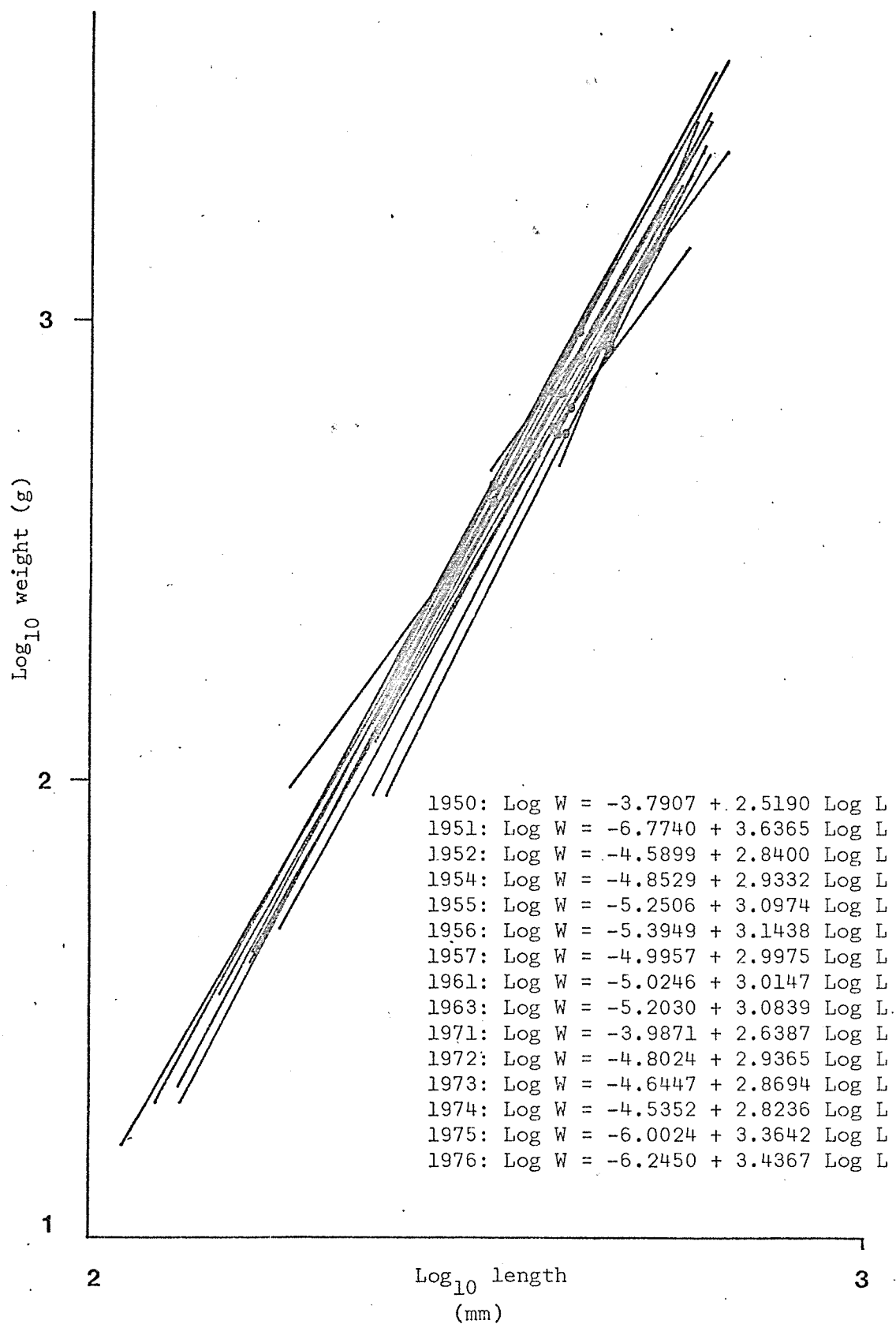


Fig. 7. Regressions of \log_{10} weight on \log_{10} length by year.

similar slopes and only slightly differing means. Gear types seem to select different size groups. Hook and line fishing yielded heavier fish at greater lengths and lighter fish at smaller lengths. Gill nets 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.

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

Mean weights in individual lakes varied considerably. The logarithmic spread of mean weights by lake was roughly 2.66 to 3.00, or 455 to 1000 grams; mean lengths varied from 2.55 to 2.65, or 355-450 millimeters. Comparative ranges of length and weight fluctuated but between lakes, 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 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 are 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 in the system along with relatively small abundances of both threespine stickleback and sockeye fry (D. E. Rogers, personal communication), the relativity of its low weight value may be valid despite the sample size. The absence of a major river mouth on South Nerka may also correlate.

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 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:

- (1) Adult escapement to the Wood River lakes two years previous.
- (2) Average fyke net catch of outmigrating 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.

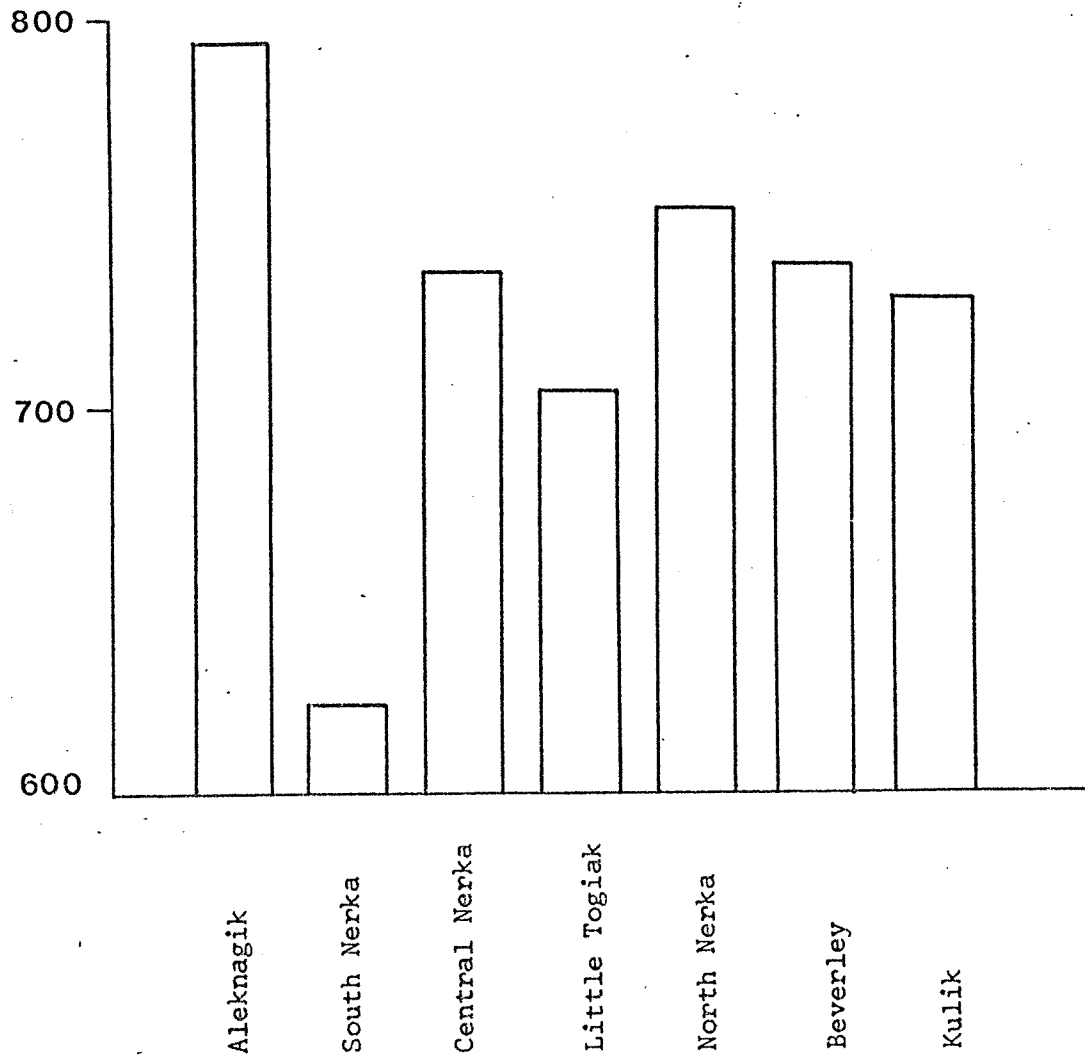


Fig. 8. Weights of char at 420 mm by lake.

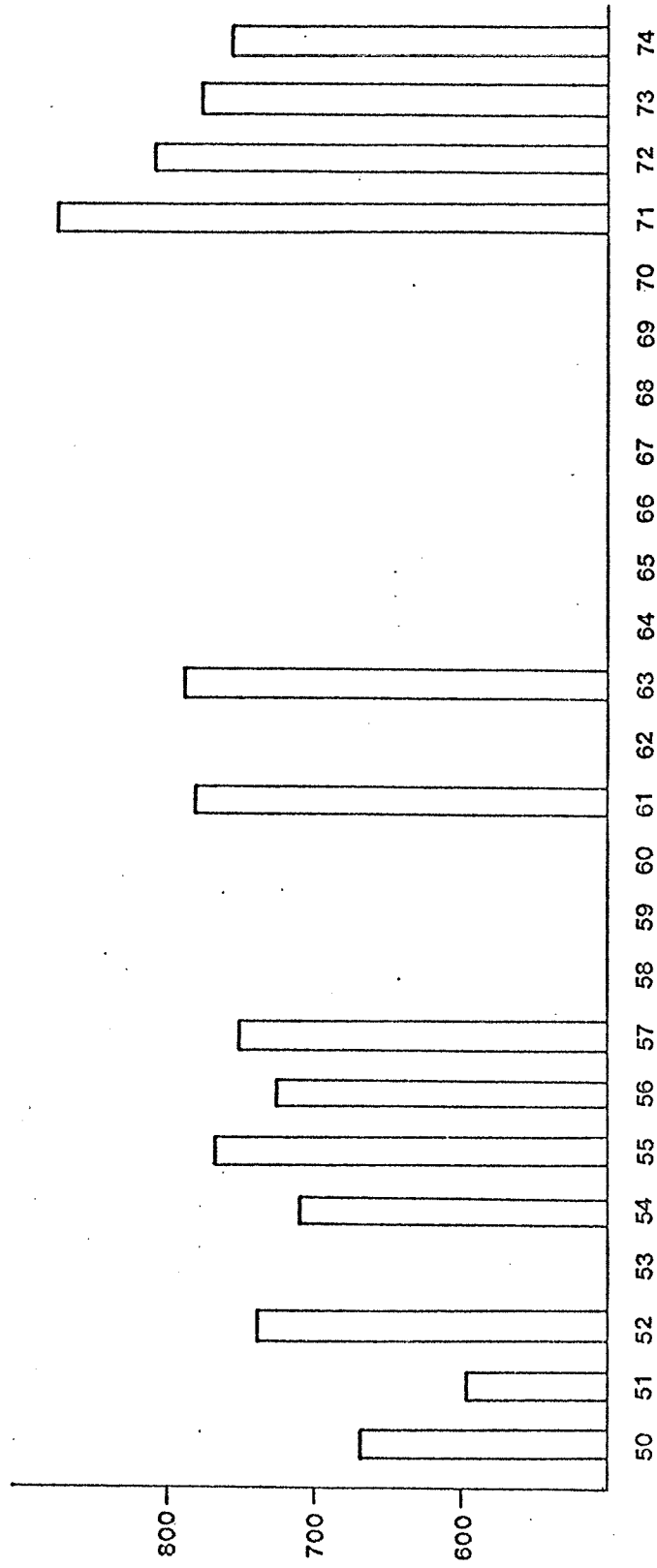


Fig. 9. Weight of char at 420 mm by year.

Resulting scattergrams displayed variation much in excess of any expected relationship; in each case, there was no correlation evident.

From Table 1, sufficient data are available to permit size comparisons of char in five lakes during 1952 and 1972 (Table 2). Condition factor ($\text{weight}/\text{length}^3$) 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 consistently are of greater length and weight than females. In Lakes Aleknagik, Beverly, and Kulik, size of fish is noticeably greater in 1972. However, with the possible exception of Lake Aleknagik, fish condition remained relatively unchanged.

Table 3 presents annual changes 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 behavior 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 report, 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 confide in the mean values measured here as being truly reflective of actual gross changes in populations, especially with respect to feeding habits. Yet, from the length-weight changes within a given year, the bearing of feeding habits on size becomes more apparent.

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 enough to base any generalizations upon, the information is nonetheless valuable and represents tedious efforts on the part of Church (1952). Mean length of char decreased from January through April of 1952 and sharply increased in May, and this correlates 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

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

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

	MEAN LENGTH						MEAN WEIGHT (gm)						MEAN CONDITION FACTOR					
	Agulovak River	Lower Aleknagik	Central Nerka	Little Togiak R.	Agulovak River	Lower Aleknagik	Central Nerka	Little Togiak R.	Agulovak River	Lower Aleknagik	Central Nerka	Little Togiak R.	Agulovak River	Lower Aleknagik	Central Nerka	Little Togiak R.		
	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F		
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	1239	1155	1207	981	1027	810	1.15	1.12	1.19	1.13	1.07	1.01		
1973	497	475	455	443	1376	1155	1170	1009	1003	745	1.08	1.06	1.15	1.15	0.96	0.97		
1974	443	411	392	410	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		

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)

Togiak River and Mosquito Point were heavier than those in Central Nerka. Fish in upper Little Togiak Lake (area B) were of substantially smaller size in June 1973 than fish in 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, the data were examined to detect bases for comparisons. Similar to availability of length-weight data, relatively little information existed for January through May, and August-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 ratios in samples have consistently approximated 1. Burgner (MS 1959) 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 and understood, in the Wood River lakes and elsewhere (Nelson 1966; Thompson and Weaver, MS 1964; Savvaitova and Resetnikov 1962; Hunter MS 1970; Grainger 1963). 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 significantly 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 plants and eggs were insignificant during any period (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 stickleback² were the principal diet items. Fry and smolt were utilized heaviest in river areas, and sticklebacks in lake areas. Sticklebacks and blackfish were fed upon equally in lake areas 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. Predation was also noticeably greater at the mouth of the Agulowak than within Lake Aleknagik itself, in agreement with Nelson (1966).

Keeping in mind that char population sizes vary at respective river mouths, average losses of fry and smolt varied with location in 1972 (Table 7). Smolt losses were greater within Little Togiak and Agulukpak

²Numbers 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."

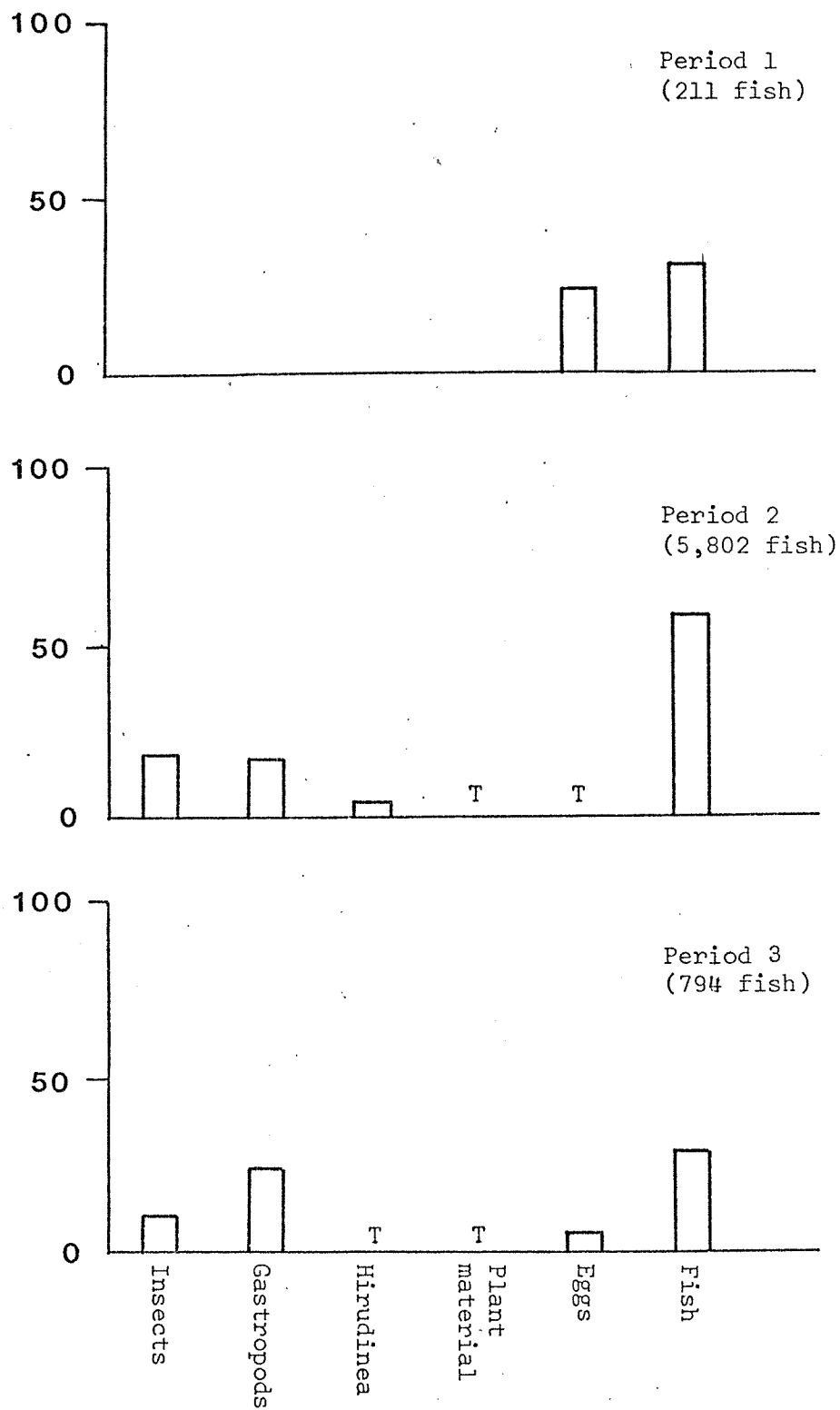


Fig. 10. Occurrences of food types by period, expressed in percentages; years and sexes combined.
T = trace.

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												
	Fry	Smolt	3-Spine	9-Spine	Sculpin	Blackfin	% Empty Stomachs	Fry	Smolt	3-Spine	9-Spine	Sculpin	Blackfin	% Empty Stomachs	Fry	Smolt	3-Spine	9-Spine	Sculpin	Blackfin	% Empty Stomachs
January - May	-	-	-	-	-	-	-	.02	.21	.57	0	.01	0	70.4	-	-	-	-	-	-	66.7 ¹
PERIOD 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.

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

Location	Year	Station 1		Station 2		Station 3	
		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 station in five locations, June and July, 1972

Location	Lake Aleknagik		Little Togiak River		Agulukpak River		Peace River		Wind River	
	Fry	Smolts	Fry	Smolts	Fry	Smolts	Fry	Smolts	Fry	Smolts
<u>Station 1</u>										
Within River-Creek	--	--	2.83	4.49	0.01	10.36	0.54	2.37	0.50	2.85
<u>Station 2</u>										
River-Creek Mouth	0.42	2.01	0.19	1.64	0.26	6.33	--	--	--	--
<u>Station 3</u>										
Within Lake	0.32	0.59	--	--	--	--	--	--	--	--

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; however, losses of fry and smolt at the Peace and Wind Rivers were about equal.

Burgner (MS *op. cit.*) and Nelson (1966) found differences in char feeding with respect to size in specific locations. Table 8 summarizes feeding habits with respect to size and verifies their results on the system level.

Population Estimates

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 Weaver, MS 1964). 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 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.

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 at each of five river mouths roughly within the same time period provide an indication of adult abundance throughout the lakes (Rogers 1973). 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,³ the sizes of smolt migrations should have been substantially different in these two years.

Char distribution throughout the system in 1972 further confirms the hypothesis of feeding at prey concentration points. All juvenile salmon from the upper lakes are funneled into Lake Aleknagik, where the highest char density exists.

³1969 escapement = 440,000; 1970 escapement = 860,000.

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

PERIOD	<u>CHAR LENGTH</u>									
	200 mm or less Fry	or less Smolt	200-300 mm Fry	300 mm Smolt	300-400 mm Fry	400 mm Smolt	400-500 mm Fry	500 mm Smolt	500 mm or more Fry	or more 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

Catch Per Unit Effort

Most adult char captured were taken in gill nets, although angling was also used consistently (Table 10). Beach-seined adults were insignificant in quantity. Hook and line gear consisted of a red and white spoon with single barbless hook attached to 15 pound test monofilament. Types of gill nets used in Wood River lakes sampling have varied considerably (Table 11). It is not the purpose of this report to analyze differences in gill net selectivities or related catch curves, but Reeves (1969) fitted a Holt-normal model to selectivity of gill nets for char in several Nushagak lakes, including Aleknagik.

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 catch of a selected unit of effort). Aside from changes in fishing power resulting from the different gill nets, variation in "q" for char fishing seems minimal due to relatively low levels of effort through the years, constant vulnerability of adult char to the gear, and generally constant stock abundance. Therefore, catch per unit effort measurements will be examined as indices of char abundance.

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. "Hours fished" is the measure of effort for both gill net and hook and line sampling. Because (1) similarities in population estimates between years exist, (2) negligible fishing mortality of char occurs, and (3) similar seasonal behavior has been observed on a year-to-year basis, CPUE has been averaged over years by location to establish a rough index of abundance (Table 12).

Char are present in all locations to some degree. Catches per unit effort from open-lake sites are all less than 1, with the exception of Lake Aleknagik (1.4). In contrast, values at river mouths are much higher. As expected, char are less numerous at river mouths in the upper lakes where abundance of smolts is low.

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

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

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 SIZES (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	
1953, 54	6	125			x		x			x			x	x	x	Linen
1954	8	180			x		x			x			x	x		Nylon
1954	15	270			x		x			x			x	x	x	Linen
1962	9	200	x	x			x			x			x	x	x	Nylon
1965, 66	9	220	x	x	x		x			x			x	x		Nylon
1971, 74	12.5	160					x			x			x	x	x	Nylon

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	--

A description of species caught incidentally in char sampling is presented in Appendix Table 2, and a breakdown of species composition of gill net catches by lake from the 1950's is given in Table 13.

Juvenile Char Abundances

Beach seine catches of age 0 char are summarized in Table 14 as an index of their relative abundance. Variations occur between lakes, between areas of lakes, and between the two time periods involved. Fry are present in all areas, but not at all locations within Lake Aleknagik.

During the first time interval (June 20 - July 19), littoral abundances are relatively high, but decrease notably after mid-July. In areas near major rivers (Aleknagik, A; Little Togiak, C; North Nerka, C; Beverley, A), mean numbers of fry in catches are large.

These fry distributions indicate that a substantial amount of char spawning takes place in the upper lakes; yet, adult abundances are greatest in Lake Aleknagik. Fry distribution does not correlate with adult distribution. The individual lakes do not support their own char populations, as there appears to be movement for spawning purposes. Interlake migration for other purposes such as feeding remains in question.

Char Observations Made in Conjunction with Sockeye Spawning Surveys

No quantitative data were available, but char have been commonly observed in streams utilized by sockeye spawners, and off the mouth of Sunshine Creek in Lake Aleknagik.

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. After briefly summarizing these data, a discussion of char predation in relation to salmon production will follow.

Char size and relative abundance appear to be closely related. Individual as well as population size has 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 towards the upper lakes with decreasing salmon abundance. Annual and monthly variation in length and weight occurs by location, but to a relatively minor extent. The abundance of adult char was related to that of outmigrating smolts, yet because of a disjoint distribution of adults and juveniles, char migrations seem likely.

Table 13. 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

Table 14. Geometric means of the catches of age 0 char in beach seine hauls by lake, year, area, and date

Lake	Year	SAMPLING AREA					
		A (June 20-July 19)	B	C	A (July 21-Aug. 5)	B	C
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 14. 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

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. More knowledge could be gained if numbers of char within rivers during the same period (June and July) were known.

Feeding habits have been shown to vary seasonally and by location with food availability throughout the system. Again, the data were weak in allowing comparisons between years, but sockeye smolts are without question the arctic char's primary food source in Period 2.

The role of char as predators on young salmon is but one controlling factor in sockeye production. Nelson (1966) concludes:

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 stable in relation to varying abundances of sockeye; similar numbers and behavior of char are noted annually despite significant differences in sockeye levels. Char feeding behavior in the Wood River lakes has 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 pose a threat to incubating eggs, but their significance has not been evaluated. Large flocks of birds (Arctic tern, *Sterna paradisaea*; glaucous-winged gull, *Larus glaucescens*; and Bonaparte's gull, *Larus philadelphia*) can be observed circling above rivers, actively feeding on migrating smolts simultaneously with char. Consumption rates of smolt by these birds remains unmeasured, but in all likelihood is substantial. Predation by belugas on seaward migrants has been noted and measured (Alaska Dept. Fish., 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 fishing.

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 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 (U.S. Bur. Fish., 1912-1942). 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 certainly 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 act as a positive control on this competition, in favor of salmon; however, the rates of predation 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.

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APPENDICES

Appendix Table 1. 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 1. Descriptions of char lengths and weights
by year and sex, all fish combined - Continued

Year	Sex	Mean		Standard Deviation		Minimum		Maximum		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 2. 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)
								46
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 2. 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