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CHIGNIK SOCKEYE STUDIES

Annual Report - Anadromous Fish Project

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CHIGNIK SOCKEYE STUDIES

(Annual Report for Period July 1, 1975 through June 30, 1976)

PREFACE

The annual run of sockeye salmon (*Oncorhynchus nerka* (Walbaum)) to the Chignik lakes is the largest on the south side of the Alaska Peninsula. Biologists of the Fisheries Research Institute (FRI), University of Washington, in conjunction with State of Alaska and Federal investigators, have been developing and perfecting a rational scheme for managing this valuable resource since 1955.

Analysis efforts in fiscal year 1976 were concentrated primarily on the analysis of freshwater scale patterns of Chignik sockeye to determine the relationship between various scale patterns and age. This problem of age determination is part of a larger study to resolve the discrepancy in the age composition of the major stocks of adult sockeye returning to Chignik when calculated by alternative methods.

This report presents the results of the aging study completed to date, a summary evaluation of the status of Chignik sockeye runs, and a preliminary report of field activities in 1976.

ACKNOWLEDGMENTS

As in previous years our research effort was coordinated with biologists of the Alaska Department of Fish and Game (ADF&G). In particular we would like to acknowledge the assistance with data collection provided by Mr. Arnold Shaul, the Chignik Area Management Biologist, Mr. Philip Rigby, the Assistant Area Management Biologist in 1975 and Mr. Larry Nicholson, the Assistant Area Management Biologist in 1976.

Personnel on Project

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PART I. PRELIMINARY REPORT ON AGE DETERMINATION STUDY

INTRODUCTION

Description of Study Area

The Chignik watershed is located on the Alaska Peninsula about 400 km southwest of King Salmon (Fig. 1) and covers an area of approximately 1,520 km^2.

Black Lake has a surface area of 41.1 km^2 and is very shallow with a mean depth ($\bar{Z}$) of only 3 m. Alec River and Fan Creek provide the majority of the spawning area for sockeye salmon which utilize Black Lake as a nursery area. Black River (12 km long) connects Black Lake to Chignik Lake. Two major spawning streams, West Fork and Chiaktuak, flow into Black River.

Chignik Lake has a surface area of 22.7 km^2 and contains over six times the volume (0.64 km^3 versus 0.10 km^3) of Black Lake due to its greater depth ($\bar{Z}$ = 29 m). The majority of the sockeye spawning activity occurs along Hatchery Beach and in Clark's River. The Chignik River (7.2 km long) connects Chignik Lake with Chignik Lagoon.

Chignik Lagoon covers an area of 41.8 km^2 at high tide and about 20 km^2 at low tide. Salinities range for 17°/oo to 32°/oo at high tide from the upper lagoon to the sand spit. At low tide the range is 10°/oo to 30°/oo. The lagoon is an important secondary rearing area for postsmolt sockeye (Phinney 1968).

When compared with 24 other sockeye salmon nursery lakes in western Alaska, Burgner et al. (1969) reported that the Chignik system ranked second in the number of spawners per unit of surface area, first in the rate of photosynthetic activity (by area and volume), first in chlorophyll _a_ per unit volume and second in total dissolved solids. The system ranked first in standing crop of phytoplankton.

Stocks of Sockeye within the Chignik Lakes

The identification of spawning groups of sockeye salmon within the Chignik lakes system was reported by Narver (1963*a*). Eight major and three minor groups were described based upon lacustrine scale pattern and age, time-of-entry of the returning adults, and time and location of spawning. These groups and their characters are summarized in Table 1.

From Table 1, returning sockeye bound for the tributaries of Black Lake, the upper reaches of Chiaktuak, West Fork, and Bearskin Creek enter the system from early June through early July, while sockeye bound for the tributaries of Chignik Lake, the lower reaches of Chiaktuak, West Fork, and Bearskin enter the system from late June through late September. Studies by Narver (1963*b*; 1966), Dahlberg and Phinney

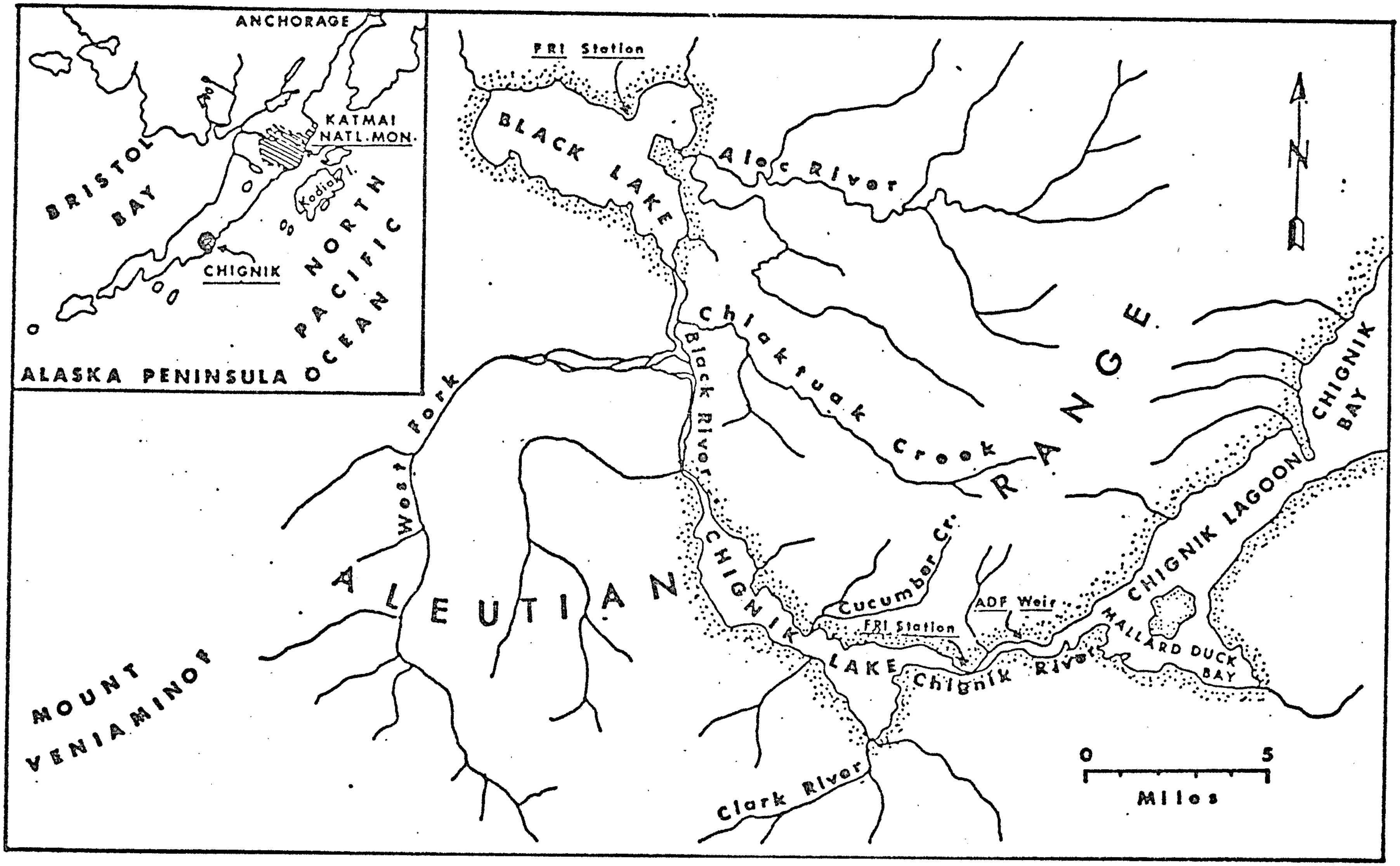

Fig. 1. Chignik watershed with inset of western Alaska.

Table 1. Characteristics of the spawning groups of Chignik sockeye (adapted from Narver, 1963)

Group	Lacustrine age	Time of entry	Spawning characteristics		Rearing area	Lacustrine scale	Importance
			Time	Location			
Black Lake (early)	I	6/10-7/6	7/25-8/20	Alex River system, Fan Creek	Black Lake	F_1 radius large	Major
Black River (early)	I	6/10-7/6	7/25-8/20	Upstream areas of West Fork, Chiaktuak, Bearskin Creek	Chignik Lake	F_1 radius small	Major
Black River (late)	I	6/20-8/10	8/20-9/20	Lower areas of Chiaktuak, Bearskin Creek	Chignik Lake	F_1 radius small	Minor
Black Lake (early)	II	6/10-7/6	7/25-8/20	Alec River system, Fan Creek	Black Lake and Chignik Lake	$F_1 + F_2$ count large	Major
Black River (early)	II	6/10-7/6	7/25-8/20	Upstream areas of West Fork, Chiaktuak, Bearskin Creek	Chignik Lake	$F_1 + F_2$ count small	Minor
Black River (late)	II	6/20-8/10	8/20-9/20	Lower areas of Chiaktuak and Bearskin Creek	Chignik Lake	$F_1 + F_2$ count small	Minor
Chignik Lake	I	6/20-9/20	8/20-11/15	Cucumber, Home, Clark Hatchery Beach	Chignik Lake	F_1 radius small	Major
Chignik Lake	II	6/20-9/20	8/20-11/15	Cucumber, Home, Clark Hatchery Beach	Chignik Lake	$F_1 + F_2$ count small	Major

(1967), Dahlberg (1968), Phinney and Lechner (1969), and Parr and Pedersen (1969) have shown through tagging studies that reasonably good separation of the major stocks, Black Lake and Black River (early) and Chignik Lake and Black River (late), can be made on time-of-entry alone. Considerable yearly variation was apparent, however.

Management Concepts

Studies by Narver (1966), Dahlberg (1968), Burgner et al. (1969), and Parr (1972) have indicated that the production of sockeye in this system is probably not related to the availability of spawning area. Rather, they all point to the carrying capacity of the nursery areas as the primary limiting factor. They emphasized that optimization of the lakes' nursery capabilities is accomplished by precisely regulating the size of the spawning populations of each major stock to prevent excessive density-dependent interactions from reducing growth and survival. This hypothesis has led the management agency, ADF&G, to set escapement goals of 375,000 for Black Lake tributaries and 275,000 for Black River and Chignik Lake tributaries.

Management Methods

Methods employed to determine the magnitude and age composition of the annual return and to apportion it into component stocks are presented in detail by Dahlberg (1968). A summary is herein provided as an aid to those who are unfamiliar with the details of the data collection and analysis procedures.

Estimation of Run Magnitude

Regulation requires that the run size on a given day be estimated. This is accomplished by combining catches in different areas with the escapement on a given day by compensating for migration times from the fishing grounds to the weir. The contribution of the two main stocks (Black Lake - early, and Chignik Lake - late) to the adjusted daily run is estimated by an average time-of-entry curve (Fig. 2). This curve was calculated by combining tagging data collected in the years 1962-1969. The proportion of Black River spawners is estimated by aerial surveys of the spawning grounds.

Age Composition by Stock of Returning Adults

The age composition of the adjusted daily run is estimated by extrapolation of age composition data obtained by reading scale and otolith samples collected from fish captured in the commercial fishery or by beach seining above the weir. Age composition data are not collected on a daily basis. Linear interpolation is used to estimate the age composition for intervening periods.

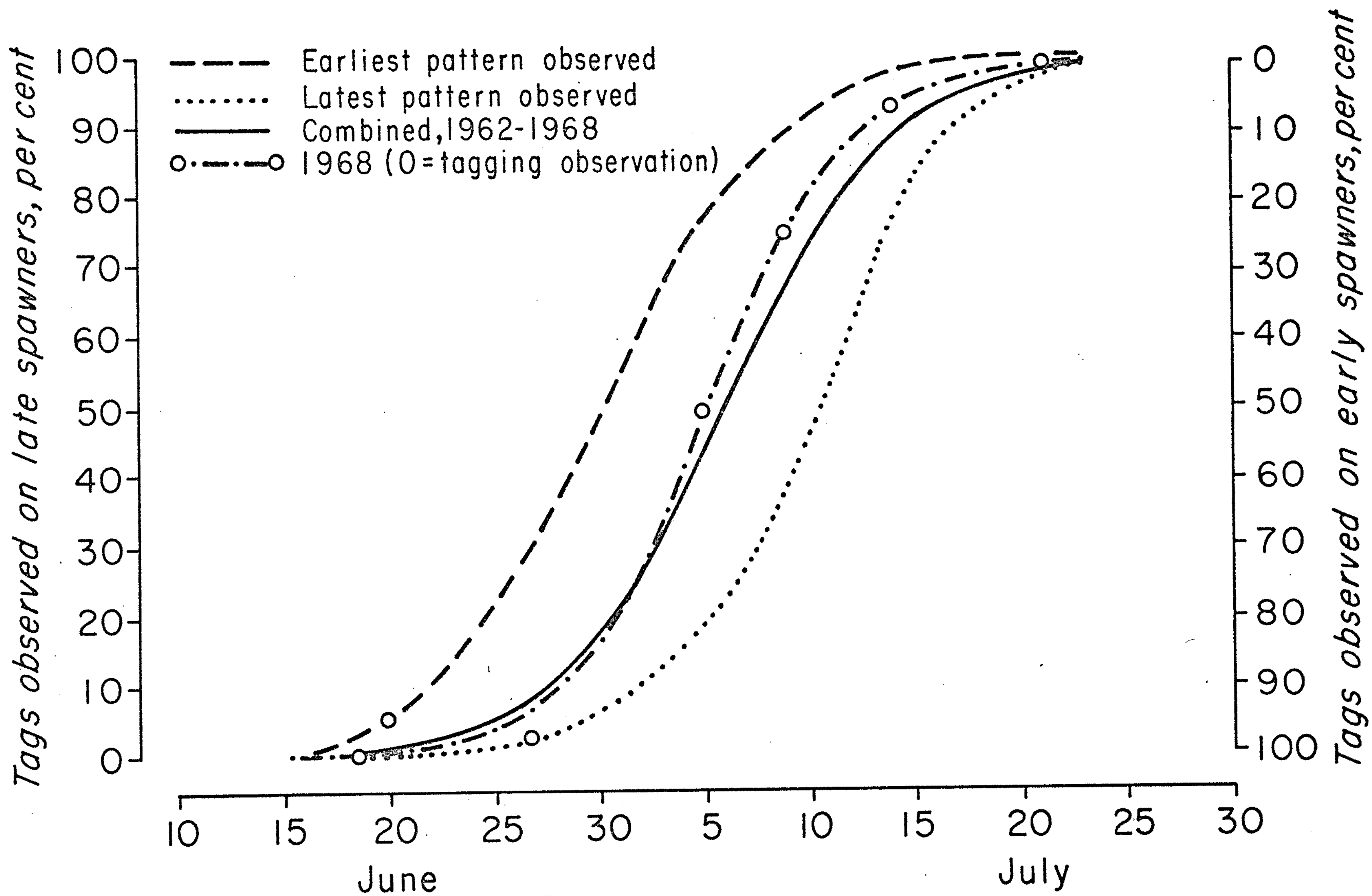

Fig. 2. Pattern of time of entry for Black Lake (early) and Chignik Lake (late) stocks, 1962-1968.

Assignment of an age composition to each stock on a daily basis is made by applying the proportion of each stock estimated to be passing the weir on a given day to the estimated number of fish in each age class on that day. No attempt is made to adjust for differences in the age composition of the two stocks during the period of overlap (late-June through mid-July).

A second set of statistics for the age composition of each stock is calculated by extrapolating age readings of otoliths collected from spent and live fish in each spawning area. In earlier years, extrapolation accounted for the relative abundance by sex in each area; in recent years, it has not. For Black Lake tributaries weighting was discontinued due to an apparent homogeneity of age composition data between areas. For Chiginik Lake it was discontinued due to the abundance of beach spawners, which prevented accurate assessment of relative abundance by area. The heterogeneity of the age composition by area in Chignik Lake in most years precludes an accurate extrapolation to the entire stock without good estimates of abundance.

For the sake of brevity, these two methods will be referred to as the fishery/scale and spawning ground/otolith methods.

Management Problems

In past years, considerable discrepancy has been noted between the calculated age composition for the Chignik and Black Lake stocks based on age reading of scale samples collected in the commercial fishery and of otolith samples collected on the spawning grounds. Data in Table 2 illustrate this discrepancy in the statistics for the Black Lake stock by periods corresponding to years when tagging studies were conducted to separate the run (1964-1969) and for years when the average time-of-entry curve was used (1970-1975). Deviations in a year were calculated as the percentage difference between the two methods relative to spawning ground samples. Mean deviations by age class were calculated as the unweighted sum of the yearly deviations divided by the number of years in which the percentage of the run for that age class was greater than 0.1.

Data for the Chignik Lake stock are not presented because, as previously mentioned, substantial problems exist in accurately extrapolating spawning ground age data due to the large number of beach spawners.

The Black Lake data show a consistent trend for the spawning ground/otolith method to produce a higher estimate for the percentage of 1-freshwater-age fish and a lower estimate of 2- and 3-freshwater-age fish of each ocean age than does the fishery/scale method. Further, these deviations are largest in 3-ocean-age fish which generally comprise the majority of the run (Dahlberg 1968; Burgner et al. 1969; Shaul and Nicholson 1976). Large differences are also evident for 2-ocean-age fish in some years.

Table 2. Mean deviations, relative to spawning ground samples, in the percentage of each age class for the Black Lake run as determined by alternative techniques, 1964-1975

Years	Age class	N[1]	Mean	Range
1964-1969	1.2	6	+0.6	-16.2 to 6.1
	2.2	6	-2.2	- 5.9 to 2.9
	3.2	5	-1.0	- 0.3 to 0.2
	1.3	6	+11.8	-32.0 to 26.4
	2.3	6	-9.5	-23.5 to 33.2
	3.3	4	-0.2	- 0.9 to 0.3
	1.4	5	+0.9	- 0.3 to 2.7
	2.4	3	-0.1	- 0.2 to 0.0
1970-1975	1.2	6	+2.9	- 0.3 to 12.7
	2.2	6	-2.4	- 3.1 to 0.8
	3.2	3	-0.3	- 0.4 to -0.1
	1.3	6	+12.6	+ 5.9 to 19.6
	2.3	6	-9.9	-22.6 to -2.4
	3.3	3	-2.6	- 7.2 to 0.2
	1.4	6	+0.4	- 1.1 to 3.7
	2.4	1		+0.1

[1] When an age class comprised < 0.1% of the run, the data were omitted.

The need for reliable data to regulate the two stocks, to evaluate the effects of regulation, and to perfect forecasting techniques, requires that one set of accurate statistics be compiled.

Objectives of Age Determination Study

The goal of this study is to identify and to develop methodology to correct factors contributing to discrepancies in the annual run statistics. This is being accomplished by systematically evaluating each step in the data collection and analysis scheme for the two methods - fishery/scale and spawning ground/otolith. Factors currently thought to contribute to the discrepancies and methods which will or may be used to rectify the problem are:

I. Fishery/scale method.

A. Estimation of age composition

1. Frequency of sampling. In some years small returns have precluded a commercial fishery and therefore an adequate scale sampling program. We believe that either a trap should be constructed at the weir or beach seining conducted at the weir to supplement commercial fishery sampling when needed.

2. Age readings from scales. Analysis is currently underway to help resolve this problem. Progress to date is reported herein.

B. Stock apportionment.

1. Numbers. The errors introduced by using an average time-of-entry curve are currently being evaluated by comparing weir count data with acoustic estimates of adults migrating through Black River.

2. Age class apportionment. During the period of overlap in time-of-entry of the two principal stocks, we should account for differences in age composition. Sampling the escapement in Black Lake is designed to alleviate this problem in future years. The magnitude of errors introduced into the historic statistics due to not accounting for this difference and method for correcting the data, if required, need to be investigated.

II. Spawning ground/otolith method.

A. Representativeness of samples.

In some systems it has been shown that sex and length affect recoveries of spent fish. The role this may play in sample collection in Black Lake tributaries is being evaluated.

B. Age readings from otoliths.

Studies are needed to verify age readings of Chignik sockeye otoliths. Recent studies by Pannella (1971, 1974) which show that otoliths grow in diurnal cycles resulting in the formation of daily growth rings may provide a means to verify age readings. A proposal to investigate this possibility is in preparation.

METHODS AND MATERIALS

Field Procedures

Sample Collection

Samples of juvenile sockeye were collected with a townet and fyke net as described below.

Townet sampling was conducted during the hours of darkness due to increased availability of fish at this time (Narver 1966; Marshall et al. 1974). The net used has a 2 m^2 opening and was pulled on the surface behind two skiffs equipped with 40 hp outboard motors. Towing speed approximated 1.5 m/sec. A diagram of the net and procedures for setting and retrieving it may be found in Narver (1966), or Burgner and Marshall (1974).

Samples were collected in Black River with a fyke net. The net has a 1.2 m^2 opening supported by a steel frame with two wings each 3.1 m long. The wings and net bag are constructed of 20 mm cotton webbing. The cod-end is constructed of 0.64 mm knotless nylon webbing. The net was supported by driving two steel bars into the river bottom approximately 2.5 m apart and perpendicular to the current. Rope loops on the leading edge of the wings were then slid over the bars.

Sample Processing

Random subsamples were taken when exceptionally large catches were made (>300-400 fish). Excess fish were returned to the water with as little handling as possible. Samples retained were isolated in perforated plastic bags, and transferred to a 10 percent formalin solution. Tip of snout-fork of tail (ts-ft) was recorded to the nearest millimeter after length had stabilized (24 hours) (Burgner 1962; Rogers 1964).

Scale samples were collected by scraping the lateral surface of the body just behind the posterior insertion of the dorsal fin above and/or below the lateral line and mounted on glass slides. This is the area where scales first form on sockeye salmon (Koo 1955; Clutter and Whitesel 1956).

Laboratory Procedures

Scale Collection and Image Recording

Two methods of collecting scales were used in this study. In 1974, unweighted stratified random sampling was used. In this scheme, three and occasionally four fish of each length interval (1 millimeter) were sampled from the length frequency distribution. This was done to insure adequate sampling of the tail ends of the length frequency distribution. In 1975 a purely random scheme was adapted as preferred.

Scale images were magnified 226 times and projected onto a working surface using a microprojector (Dahlberg and Phinney 1968). Measurements and morphological codes from this image were recorded directly onto a form (Fig.3). The radius along which measurements were made approximates 17.5° from the primary axis of the scale (Narver 1963*a*), hereafter termed the preferred axis.

One scale for each smear was chosen for analysis by the following criteria:

1. The scale which had the largest number of circuli was located. (This scale was taken to represent the one formed earliest in the life of the fish.)

2. The view of the anterior field must be unobstructed by another scale or dirt.

3. The focus could not be round nor could its primary axis be perpendicular to the primary scale axis.

4. The scale could not be round or grossly distorted. (Criteria 3 and 4 are necessary in order to properly align the measurement form and determine along which axis measurements would be recorded.)

Circuli were classified by type according to the following scheme which was adapted and modified from Mosher (1968):

1) Complete - a circulus which was more than one-half the length of the arc in the sculptured field in which it was found and which showed no breaks in continuity; 2) broken - a circulus which was more than one-half the length of the arc in the sculptured field in which it was found and which showed breaks in continuity; 3) annulus - a complete or broken circulus which was preceded by circuli which formed a presumed annular growth check; 4) incomplete - a circulus which was less than one-half but more than one-fourth the length of the arc in the sculptured field in which it was found and which had no breaks in continuity; 5) fragmented - a circulus which was less than one-half but more than one-fourth the length of the arc in the sculptured field in which it was found and which showed breaks in continuity; 6) crossover - any circulus (except

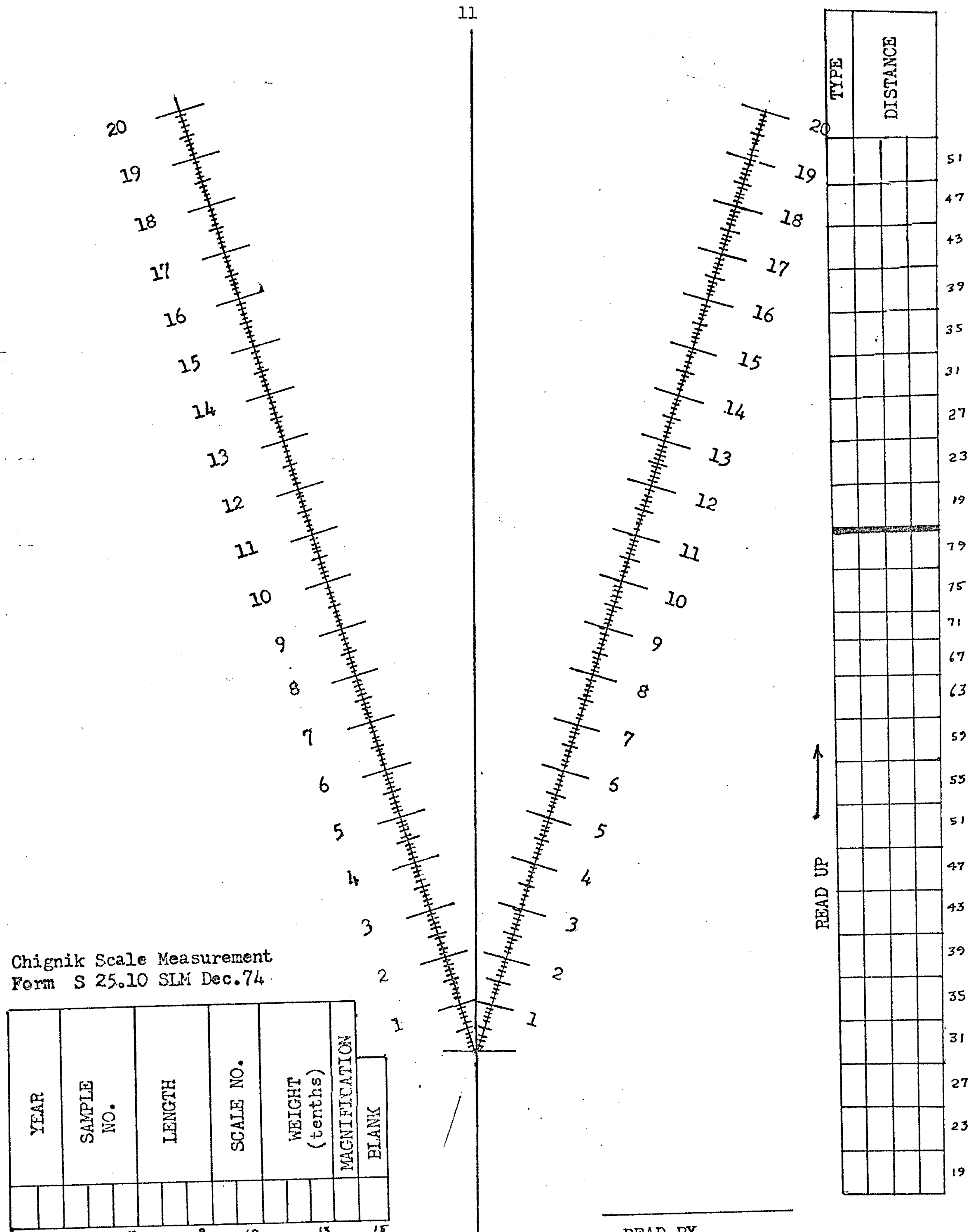

Fig. 3. Scale measurement form.

one which was interpreted as an annulus) which in its lateral margins appeared to cross over into the field of an adjoining circulus. "Loops" and "islands" were ignored unless they occurred along the measuring axis.

Other considerations were: 1) Any irregular or partial circuli within the focus were ignored; and 2) if the focus was spiraled, each turn was counted where it crossed the measuring axis.

Reference Point Adjustment of Data

As previously mentioned, data on the types of circuli and distance between adjoining circuli were recorded along the preferred axis working outward from the focus to the scale margin. In this scheme termed focus-adjusted, the first circulus was coded as +1, the second as +2, etc. The distance between the focus and the first circulus was coded as (F/+1), between the first and second as (+1/+2), etc.

For the purpose of analyzing patterns which occurred in proximity to other points of reference on scales (e.g., near the margin or annulus), it was necessary to appropriately adjust the reference point. In the analysis of patterns occurring near the margin, the data were "margin-adjusted." Under this scheme circulus number and distance interval codes were reassigned as follows: Working along the preferred axis inward from the margin toward the focus, the first circulus encountered was designated as (-1), the second as (-2), etc. The interval between the margin and the first circulus was designated as (-1/m), between the first and second as (-2/-1), etc.

To facilitate analysis of patterns occurring near an annulus, the data were "annulus-adjusted." Under this scheme circulus number and distance interval codes were reassigned as follows: Working away from the focus along the preferred axis the first circulus encountered past the annulus was denoted as (+1), the interval between the annulus and circulus (+1) was denoted as (A/+1). Working toward the focus from the annulus along the preferred axis the first circulus encountered was denoted as (-1) and the interval between the annulus and circulus (-1) was denoted as (-1/A).

The Process of Age Determination

An Approach to the Problem

The process of age determination we used was adapted from Sych (1974). The process of age determination is presented in an abridged and modified form below.

In Sych's (1974) view, the true age of a fish is naturally coded in the structure of the scales which serves as a transmitting medium. The investigator decodes and processes this information to determine age

(Fig. 4). The physiological pathways which produce various patterns are determined by the interaction of genetic and environmental factors and of time, i.e., the effect of time causing a breakdown of the physiological pathways. Our limited understanding of the calcification process (Simkis 1974) precludes the ability to directly interpret the meaning of the various patterns. Sych (1974) argues, however, that we are able to establish relationships between scale structures and age by studying the patterns formed on scales of fish of a known age, established by tagging, from a specific population reared in a known environment.

In our view separation of environmental from genetic influences can be made by observing patterns formed on the scales of fish from the same stock reared under different conditions. Separation of genetic from environmental influences can be made by observing patterns formed on the scales of fish from different stocks reared under the same conditions. The effects of time may be analyzed by repeating such experiments at intervals throughout the life cycle of the species in question. Furthermore, the requirement for tagging is unnecessary when age can be determined by methods independent of hard tissue analysis. For example, the Petersen method is quite reliable for aging juvenile sockeye in Black Lake due to the presence of only a single major stock, a relatively homogeneous environment and a growth rate which results in pronounced bimodality of age classes with little if any overlap.

Reception of Information

Reception of information involves observation and identification of scale patterns with master images fixed in the investigator's mind. Errors in the reception process can be due to either poor image reception or improper identification. Discarding the smears from which a clear scale image could not be obtained was designed to reduce errors of the first kind. Obtaining permanent records of the scale images was designed to reduce errors of the second kind.

Processing of Information

The application of decision rules to the available decision information produces an age determination. This process is presented diagrammatically in Fig. 5. Decision information includes that set of data associated with the fish being aged and may be classified into three categories:

1. Scale information - naturally coded information on the scale.

2. Growth information - length and/or weight of the fish.

3. Complementary information, e.g., date and location of sampling.

The data base required to formulate decision rules includes:

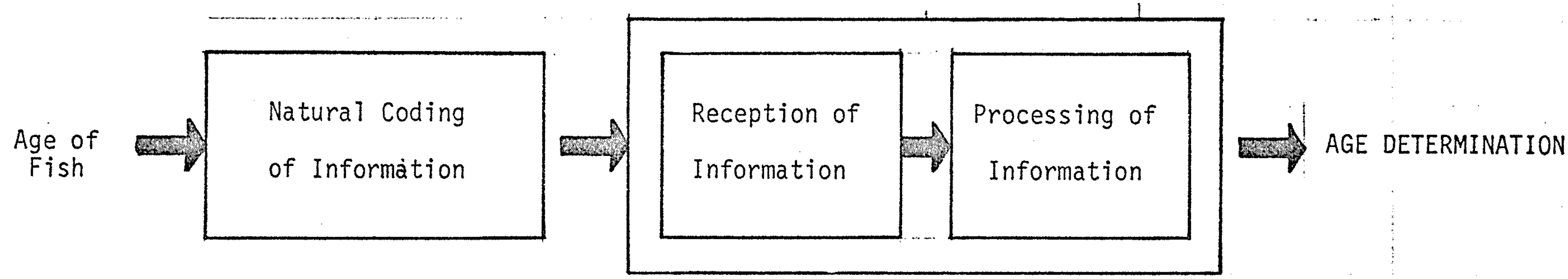

Fig. 4. The process of age determination of fish.

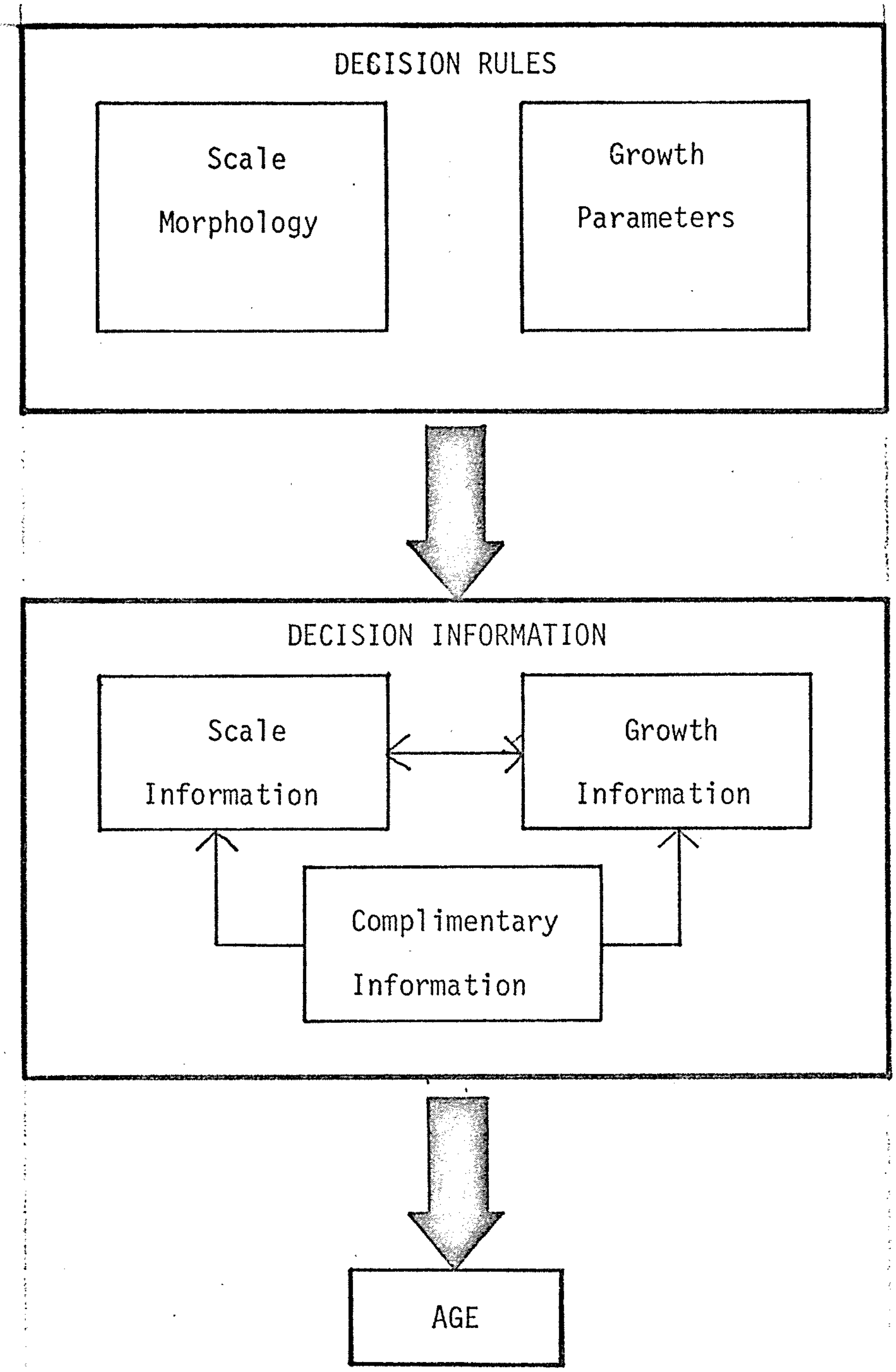

Fig. 5. Information pathways used in the aging.

1. Scale morphology:

   a. Size of fish at time scales form.

   b. Concept of regeneration.

   c. Concept of resorption.

   d. Season when annular marks form.

   e. Morphology of an annular mark.

   f. Morphology of an accessory mark and probability of occurrence.

2. Growth parameters:

   a. Time of emergence.

   b. Size at emergence.

   c. Growth rate.

SCALE PATTERNS OF CHIGNIK SOCKEYE - A SUMMARY OF THE LITERATURE

The first reference to the scale patterns of Chignik sockeye was that of Holmes[1] who reported that scales of juvenile sockeye collected in Black River during June showed considerably more growth of the year than scale samples collected in Chignik River. Similarly, Kelez (cited by Roos[2]) characterized age I smolt scales as having "large bold" circuli in the first year's zone. Scales from age II smolts were characterized as having a small first year's zone with a fine-ringed inner check.

Higgins (1930) was the first to allude to the problem of interpreting age from scales of Chignik sockeye. He reported:

> "The problems relating to red salmon of this system are proving to be of unusual complexity. The scales present irregularities that cannot be interpreted with certainty until a detailed study has been made of the growth of the fingerlings and the development of their scales."

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[1]Letter from Harlan Holmes to Dr. Willis H. Rich. July 26, 1928. In Univ. Wash. Fish. Res. Inst. Archives.

[2]Roos, John F. 1960. Life history of red salmon *Oncorhynchus nerka* (Walbaum) at Chignik, Alaska. Univ. Wash. Fish. Res. Inst. 56 pp. [unpublished manuscript]

In 1929, a study of the growth of the juvenile sockeye was begun in an effort to resolve this problem. Higgins (1932) reported that length frequency analysis of samples collected in Chignik Lake and Chignik River provided no relief because the fish were "distributed in such an array that practically defies age analysis..." During this period, extensive fin clipping of juveniles began in an effort to resolve this problem.

Juveniles which were marked in 1929 returned to Chignik as adult sockeye in 1932 and 1933. Higgins (1934*a*, 1934*b*) reported that these returns proved extremely valuable in interpreting the scales of smolts captured by fykenetting in Chignik River. Unfortunately, no data were published on the scale patterns of these fish. The fin clipping program was expanded to include fingerlings in Black Lake during 1932.

Budget constraints forced the discontinuation of juvenile salmon studies at Chignik (Higgins 1936) and as a result a substantial amount of data was apparently never published.

In 1955 studies of juvenile sockeye were reinitiated and the problem of properly interpreting age from scales still needed to be resolved. Roos[3] concurred with Kelez's earlier characterization of smolt scales and with Higgin's (1930) statement regarding the need to follow the growth and development of juvenile sockeye in order to properly interpret age. As a guide to future researchers, Roos[4] provided a set of photographs of "typical" scales along with his interpretation of age. He analyzed the lacustrine portion of scales taken from adults on the spawning grounds and reported that the mean number of circuli and size of the lacustrine zone was larger for Black Lake spawners of age I and age II than for Chignik Lake spawners of these ages. He attributed these differences to more favorable growing conditions in Black Lake than in Chignik Lake.

Narver (1963) also recognized the need to consistently identify growth checks and to verify that such checks were annuli. Criteria he used to identify growth checks were: 1) A narrowing of the circuli and/or space between circuli; 2) a "cutting over" of the first circulus of the new year's growth into the field of the previous circuli; 3) the continuation into the posterior field of the first circulus of the new year's growth. Photographs of these scale patterns were presented. Validation of age readings in this study was accomplished by following the scale development of juvenile sockeye of each age class from emergence through outmigration. The limited number of samples made validation "admittedly circumstantial" in some cases, however.

[3,4] Roos, John F. 1960. Life history of red salmon *Oncorhynchus nerka* (Walbaum) at Chignik, Alaska. Univ. Wash. Fish. Res. Inst. 56 pp. [unpublished manuscript]

A significant outcome of Narver's (1963*a*) work was the development of a consistent and objective method for measuring adult and juvenile scales. In three reader tests, he showed that experienced biologists could consistently measure and count circuli along a chosen axis as shown by their own readings over time and with each other's.

Significant problems arose, however, in the visual identification of lacustrine growth checks. For two separate readings of adult scales two months apart by three experienced readers, the following results were obtained: 1) Individual readers aged some scales differently on the two occasions. The percent disagreement for the three readers was 10, 10, and 40 percent; 2) on the two occasions complete agreement between readers on age was reached for any 80 and 65 percent of all scales; 3) only 50 percent of all scales were aged consistently by all three readers on both occasions. These results re-emphasized the serious problems which still existed in identifying growth checks on scales of Chignik sockeye.

Narver (1963*b*) reported that the scales from adults of both lakes often show an extensive zone of "plus growth." He characterized circuli in this zone as being intermediate in spacing between circuli formed in the lacustrine versus marine environments. Comparisons of the mean number of circuli on late migrating smolts and on surviving adults of the 1954-1956 year classes indicated considerably more plus circuli on the adult scales. This increase was attributed to growth achieved in Chignik Lagoon. Additional studies of scales collected from postsmolt in Chignik Lagoon and from late migrating smolts in Chignik River also indicated that substantial growth was being realized in the Lagoon. Phinney (1968) also described this zone as being "intermediate between the lacustrine and marine growth portions with respect to heaviness of and distance between circuli." He concluded that the zone was easily identified on most scales due to the abrupt transition from lagoon to marine growth patterns. Neither Narver (1963*b*) or Phinney (1968) presented criteria for distinguishing between plus growth realized in the lacustrine versus estuarine environment, however.

RESULTS

Length Frequency Analysis - Black Lake Stock

Age Determinations

The length frequency distributions of juvenile sockeye collected by townetting in Black Lake during 1974 and of smolts collected by fykenetting in Black River during 1975 are plotted in Fig. 6. Mean lengths are summarized in Table 3, part A. The presence of a single mode in all samples and the small size of these fish in late June (mean length = 41.3 mm) indicate that they were from the 1973 brood year. The significantly larger size of some fish in the samples of July 31 and September 2 led us to assign them to the 1972 brood year.

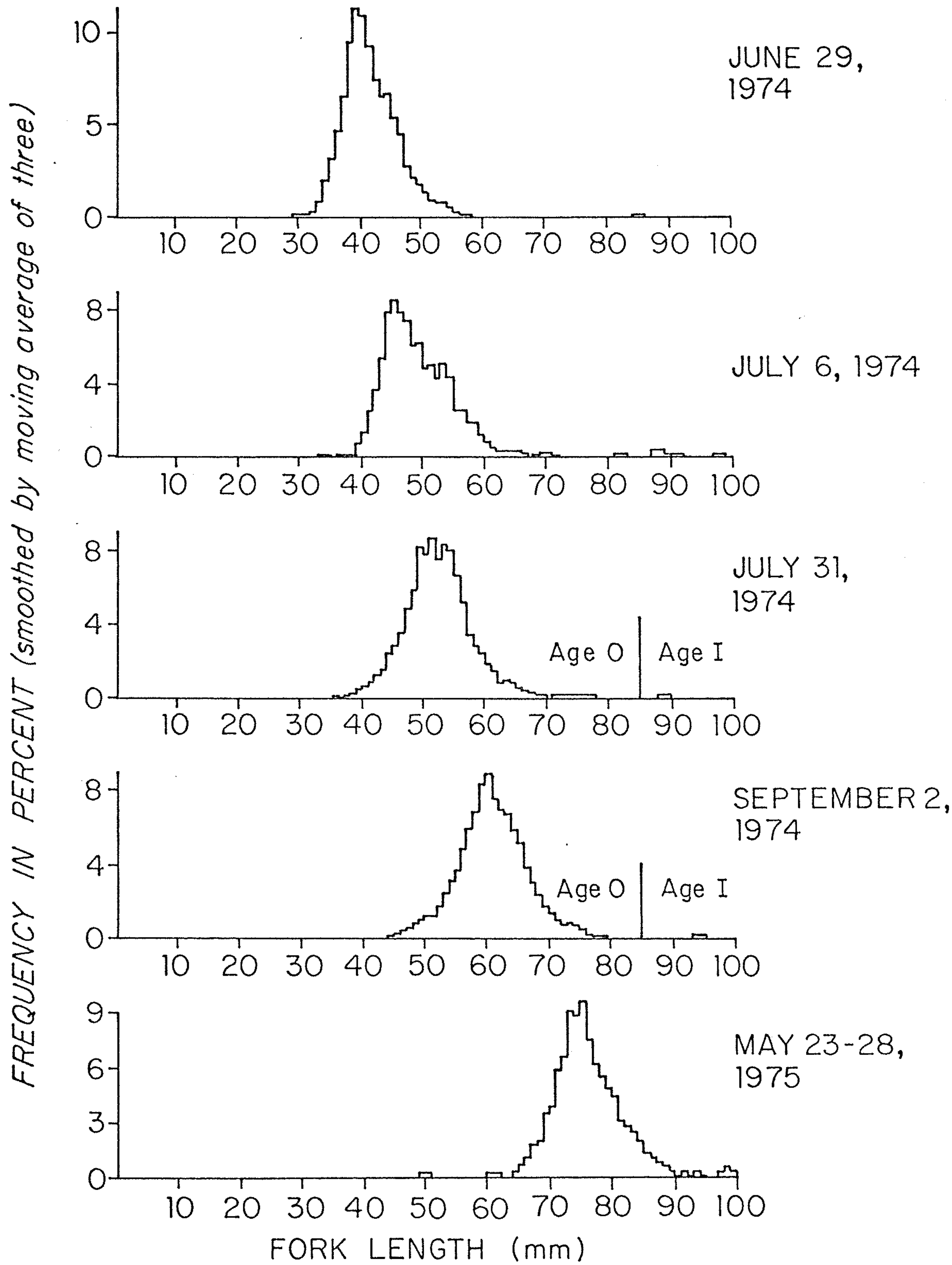

Fig. 6. Length frequency histograms for juvenile sockeye sampled by townetting in Black Lake, 1974, and by fyke-netting in Black River, 1975.

Table 3. Mean lengths for the 1973 year class of juvenile and smolt Black Lake sockeye. Part A fish captured in and smolting from Black Lake; Part B, pre-smolt emigrants

Location	Gear	Date	Age	Sample size	Mean length	95% confidence interval (±)
Part A						
Black Lake	Tow net	6/29/74	0	445	41.3	0.4
"	"	7/6/74	0	400	49.1	0.6
"	"	7/31/74	0	1,552	52.0	0.3
"	"	9/2/74	0	886	61.4	0.4
Black River	Fyke net	5/23-28/75	I	239	75.2	0.7
Part B						
Black River	Fyke net	6/25-29/74	0	98	49.2	1.2
"	"	7/5-9/74	0	1,032	53.8	0.3
"	"	7/19-20/74	0	311	50.9	0.7
"	"	7/27-8/2/74	0	1,458	51.3	0.3
"	"	8/15-16/74	0	565	56.6	0.4
"	"	8/21-22/74	0	108	56.3	1.4
"	"	9/1-2/74	0	11	-	-

The length frequency distributions of juvenile sockeye emigrating from Black Lake during the summer of 1974 are plotted in Fig. 7. Mean lengths are summarized in Table 3, part B. The presence of a single mode, and the small size of the fish in late June (mean length = 44.6 mm) indicated that they were from the 1973 brood year. The significantly larger size of some fish captured on July 5-9 and from July 17-20 led us to assign them to the 1972 brood year.

Comparison of Size Between Emigrating and Nonemigrating Fish

From inspection of length frequency data (Figs. 6 and 7 and Table 3) samples collected by townetting in Black Lake indicate a seasonal growth progression; the fyke-net samples do not.

A comparison of size between emigrating and nonemigrating sockeye was therefore made by testing for differences in mean length on dates when both townet and fyke net sampling was conducted. T-tests indicated that emigrating sockeye were larger than those remaining in the Black Lake on June 29 ($t = 17.5^{**}$ (510 df)) and on July 6 ($t = 11.3^{**}$ (734 df)); by July 30 mean lengths for the two populations were the same ($t = 1.2$ N.S. (1956 df)).

Growth Rate

Narver (1966) and Parr (1972) concluded that growth of age 0 Black Lake sockeye was essentially linear during the summer. Both used the slope of the linear regression equation of mean length (as determined by townet sampling) on time to estimate growth rate. Parr (1972) cited the lack of any significant difference in size between fish captured in different areas of the lake, and high correlation coefficients (approximately 0.98) for the linear model as justification for its use. Based on these arguments and a visual inspection of the data we also concluded that a linear model would adequately describe summer size progression in Black Lake.

The calculation of a growth rate for the 1973 year class was complicated, however, by differences in size between emigrating and nonemigrating fish from late June until mid-July and by inability to estimate the proportion of the total population each group represented. No study was specifically undertaken to estimate the magnitude of the emigration. The average fyke net catch per hour was useful, however, in determining the timing of emigration and did shed light on possible bias introduced by using length data obtained by townetting alone. The average catch per hour data are plotted in Fig. 8. These data indicate the migration was at a low level until early July. The majority of the fish seem to have emigrated from early July through early August. Small catches occurred during the period mid-August - early September. If emigration of significantly larger fish was substantial during early July, it would tend to reduce the mean length of fish remaining in Black Lake in late June and early July, thereby tending to increase the slope of regression of mean length on time.

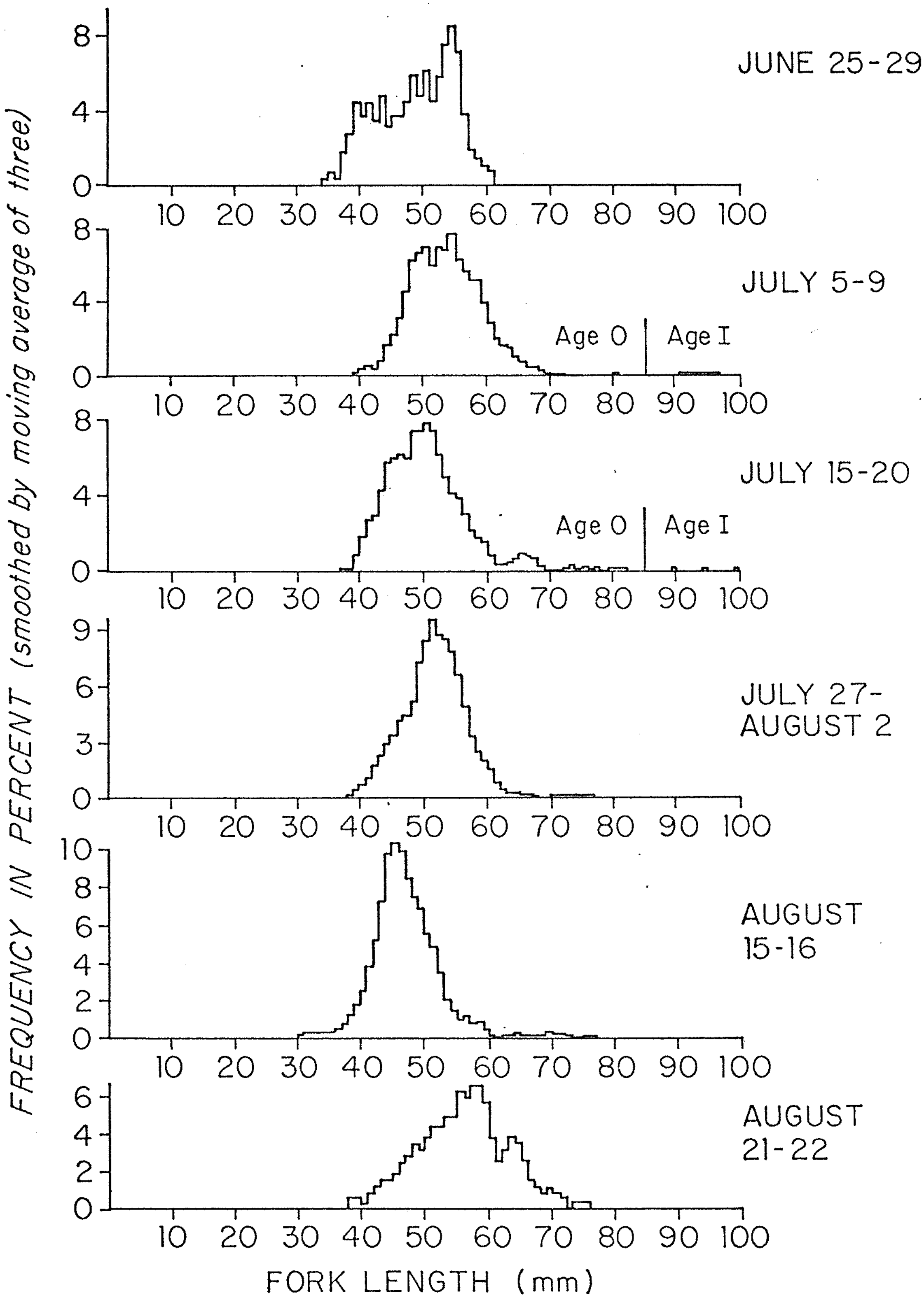

Fig. 7. Length frequency histograms for juvenile sockeye sampled by fyke-netting in Black River, 1974.

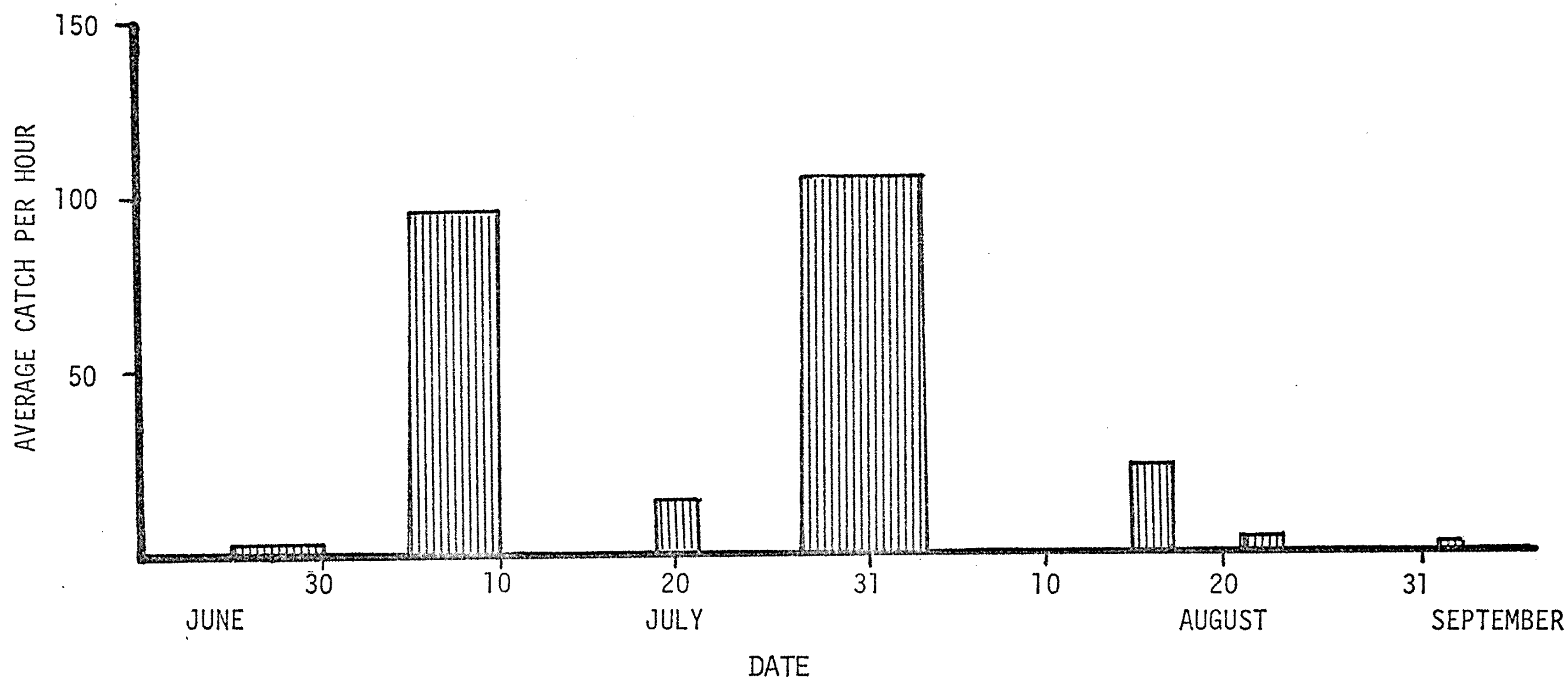

Fig. 8. Mean fyke-net catch per hour, grouped by period, Black River, 1974.

For the age 0 fish remaining in Black Lake, the regression of mean length as determined by townet sampling on days from June 1 yielded the equation: (mean length) = 36.1 + 0.27 (days from June 1). This is plotted as a solid line in Fig. 9. The trajectory of apparent growth of these fish during the fall of 1974 was estimated by plotting the mean length of smolts migrating from Black Lake in the spring of 1975 and by assuming that growth was insignificant during the period when ice covered the lake. This trajectory, plotted as a dashed line, indicates that fish remaining in Black Lake continued to grow well into the fall. That this growth was obtained during the fall months, and not the following spring is corroborated by the close proximity of sampling in the spring to ice breakup and by the lack of plus growth on the scales in that spring (see scale patterns section).

Identification of Black Lake Presmolt Emigrants in Chignik Lake

Narver (1966) and Parr (1972) reported that in some years differentiation of age 0 Black Lake presmolt emigrants and Chignik Lake resident fry captured with townets in Chignik Lake was possible utilizing length frequency data. The method relied upon the compound effects of an earlier emergence and faster growth rate for the Black Lake stock to produce a bimodal length frequence distribution of age 0 fry in Chignik Lake. While this method may in some years facilitate the identification of presmolt emigrants it does not allow for inferences to be made concerning the growth rates realized by these fish while in Chignik Lake nor could it provide any insight into resulting scale patterns. The constraints of this method led us to develop a simple model to predict the mean length of presmolt emigrants rearing in Chignik Lake on the dates when townet sampling was conducted therein.

The equation developed to predict the mean length of presmolt emigrants in Chignik Lake is:

$$\bar{L}_t = \frac{\sum_{i=1}^{n} [(\bar{L}_i) + (g \cdot T_i)]\,[w_i]}{\sum_{i=1}^{n} w_i} \qquad (1)$$

where:

$\bar{L}_t$ = Estimated mean length of presmolt emigrants at time t in Chignik Lake.

$\bar{L}_i$ = Mean length (by period) of fish emigrating from Black Lake.

g = Growth rate in mm/day as determined from townet sampling in Black Lake.

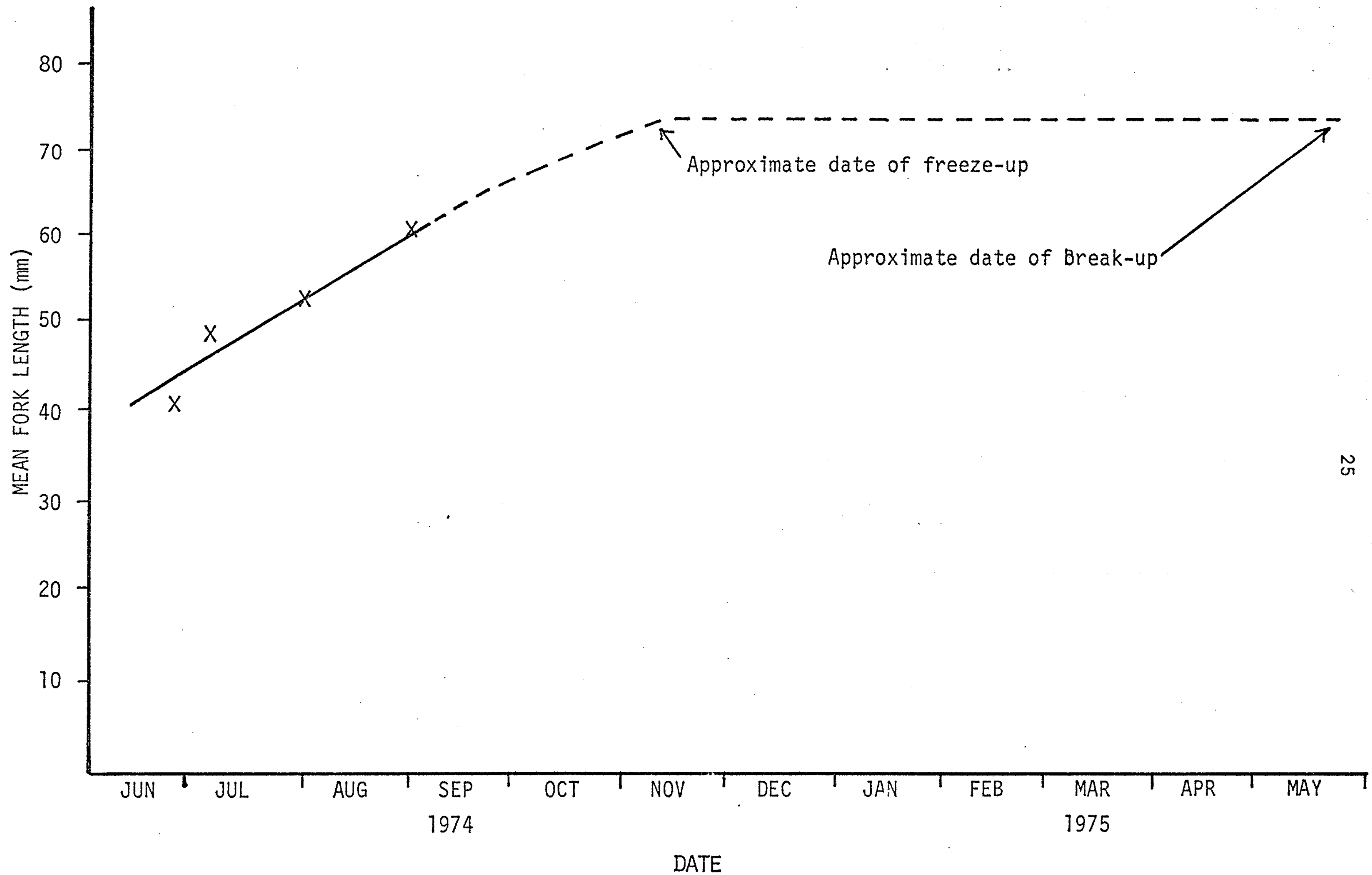

Fig. 9. Growth trajectory for the 1973 year class of Black Lake sockeye.

T_i = Number of days group i reared in Chignik Lake.

w_i = Weight factor, average catch per hour during period i. The application of the growth calculated for those fish rearing in Black Lake to those which emigrated and reared in Chignik Lake carries with it the explicit assumption that the emigrants continued to grow at the same rate as those which remained in Black Lake. Departures from this assumption were found and are discussed in the following section.

Results of solving this equation for the dates on which townet sampling was conducted in Chignik Lake are summarized in Table 4.

Length Frequency Analysis - Chignik Lake Samples

Age Determinations

Length frequency histograms for juvenile sockeye collected by townet sampling in Chignik Lake during 1974 are plotted in Figs. 10 to 14. The upper graph (a) of each figure represents the entire catch. The lower graphs (b, c and d) plot the distribution by age group. All data were reduced to a percentage basis and smoothed by a moving average of three (mean and modal lengths for the raw data are summarized in Table 5).

Age determinations were made by: 1) Visual inspection of the scales using the criteria of Roos[5] and Narver (1963*a* 1966); and 2) the graphical analysis of Koo (1955). Infrequently, discrepancies between the two methods were encountered; they were resolved by accepting the results obtained by method 2.

Length frequency data for the entire catch on June 16, 1974 (Fig. 10a), indicated the presence of 5 modes, 35.5, 56, 64, 69 and 91 mm's. Fish represented by the mode at 35.5 were assigned to the 1973 year class of the Chignik Lake stock because fish in this size range were not captured emigrating from Black Lake.

Age I fish ranged from 48 to 96 mm. The larger of these fish represented by the mode at 91 mm are clearly distinct from those represented by the modes at 56, 64 and 69 mm's. The large size of these fish at age I strongly suggests that they are from the 1972 year class of the Black Lake stock. This large size is consistent with the size of age I smolts generally found emigrating from Black Lake in the spring (Fisheries Research Institute, unpublished data). For age I fish represented by the modes at 56, 64 and 69 mm no data existed on which to distinguish

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[5]Roos, John F. 1960. Life history of red salmon *Oncorhynchus nerka* (Walbaum) at Chignik, Alaska. Univ. Wash. Fish. Res. Inst. 56 pp. [unpublished manuscript]

Table 4. Predicted mean lengths of age 0 Black Lake presmolt emigrants rearing in Chignik Lake on dates when townet sampling was conducted, 1974

	Date			
	7/12	8/6	9/9	11/7
Estimated mean length (mm)	55.4	57.3	66.8	83.1

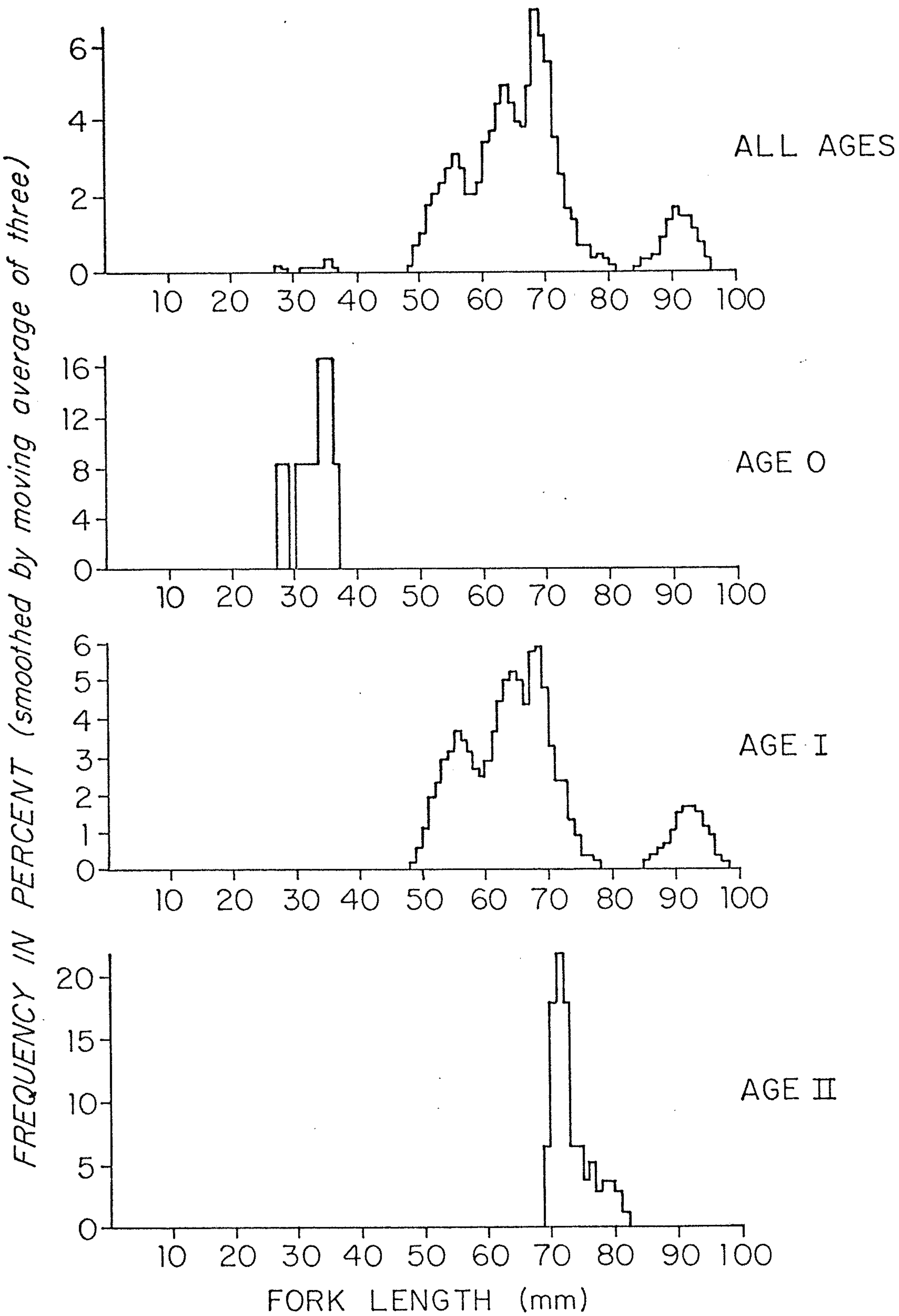

Fig. 10. Length frequency histograms of juvenile sockeye captured by townetting, Chignik Lake, June 16, 1974.

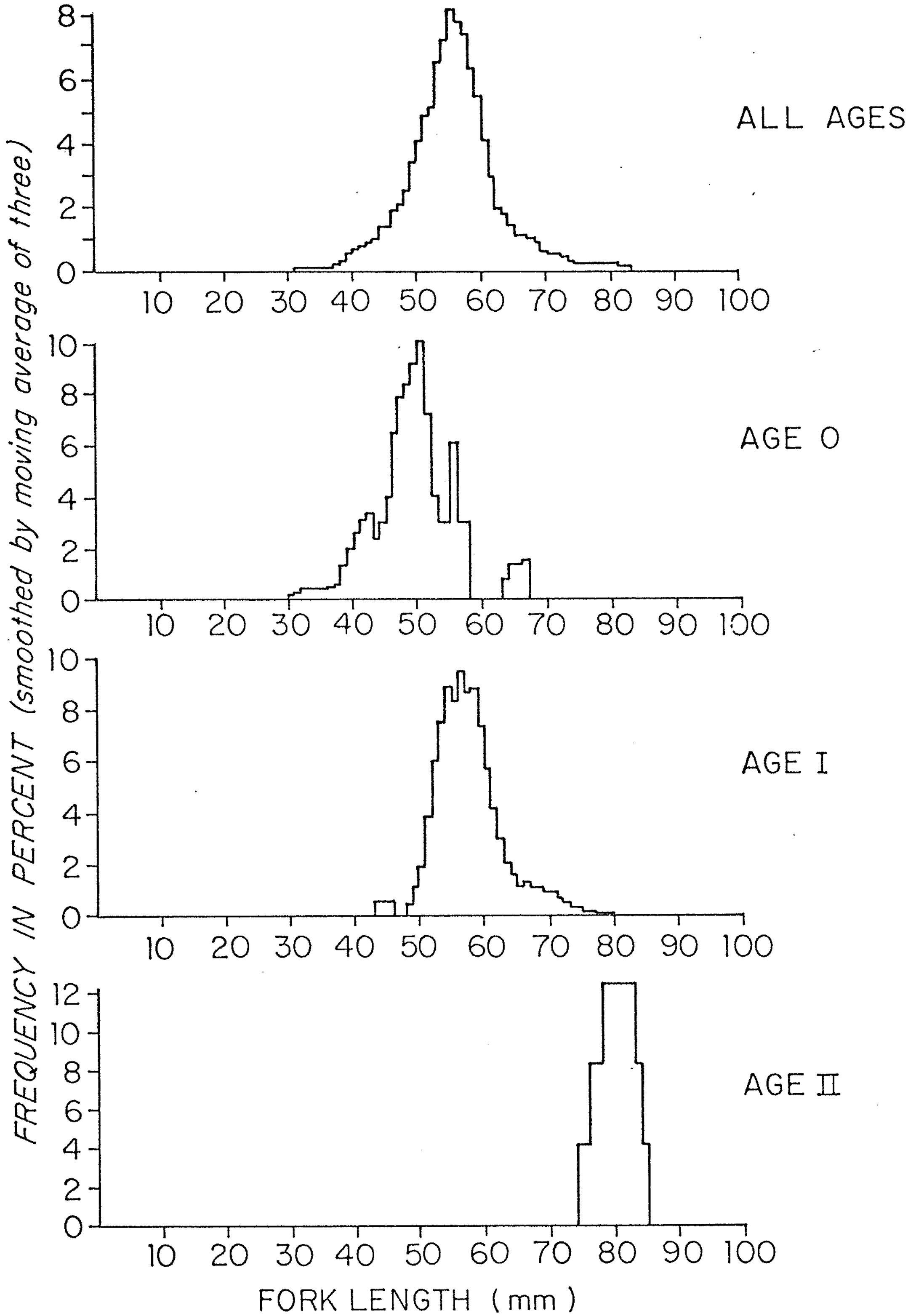

Fig. 11. Length frequency histograms of juvenile sockeye captured by townetting, Chignik Lake, July 12, 1974.

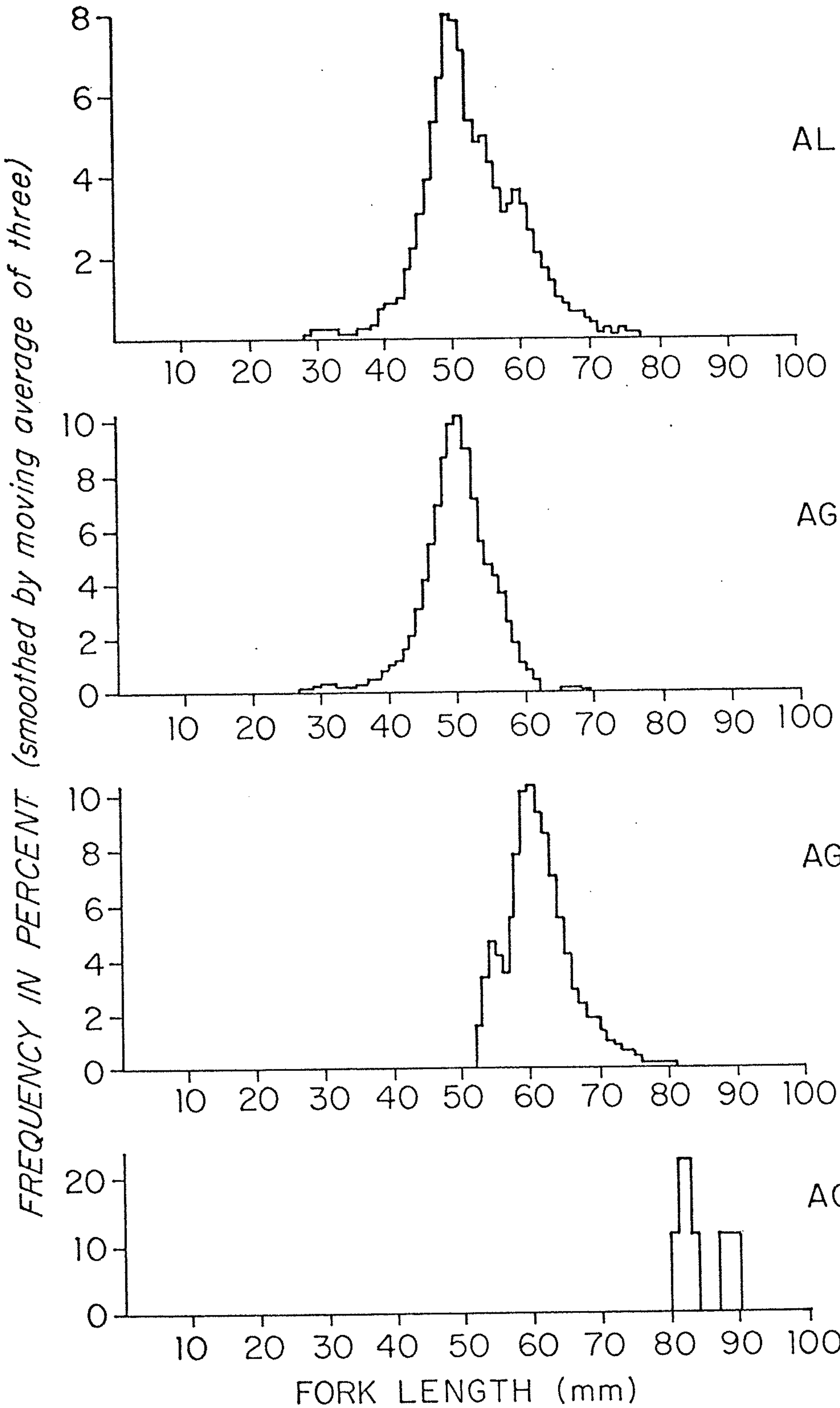

Fig. 12. Length frequency histograms of juvenile sockeye captured by townetting, Chignik Lake, August 8, 1974.

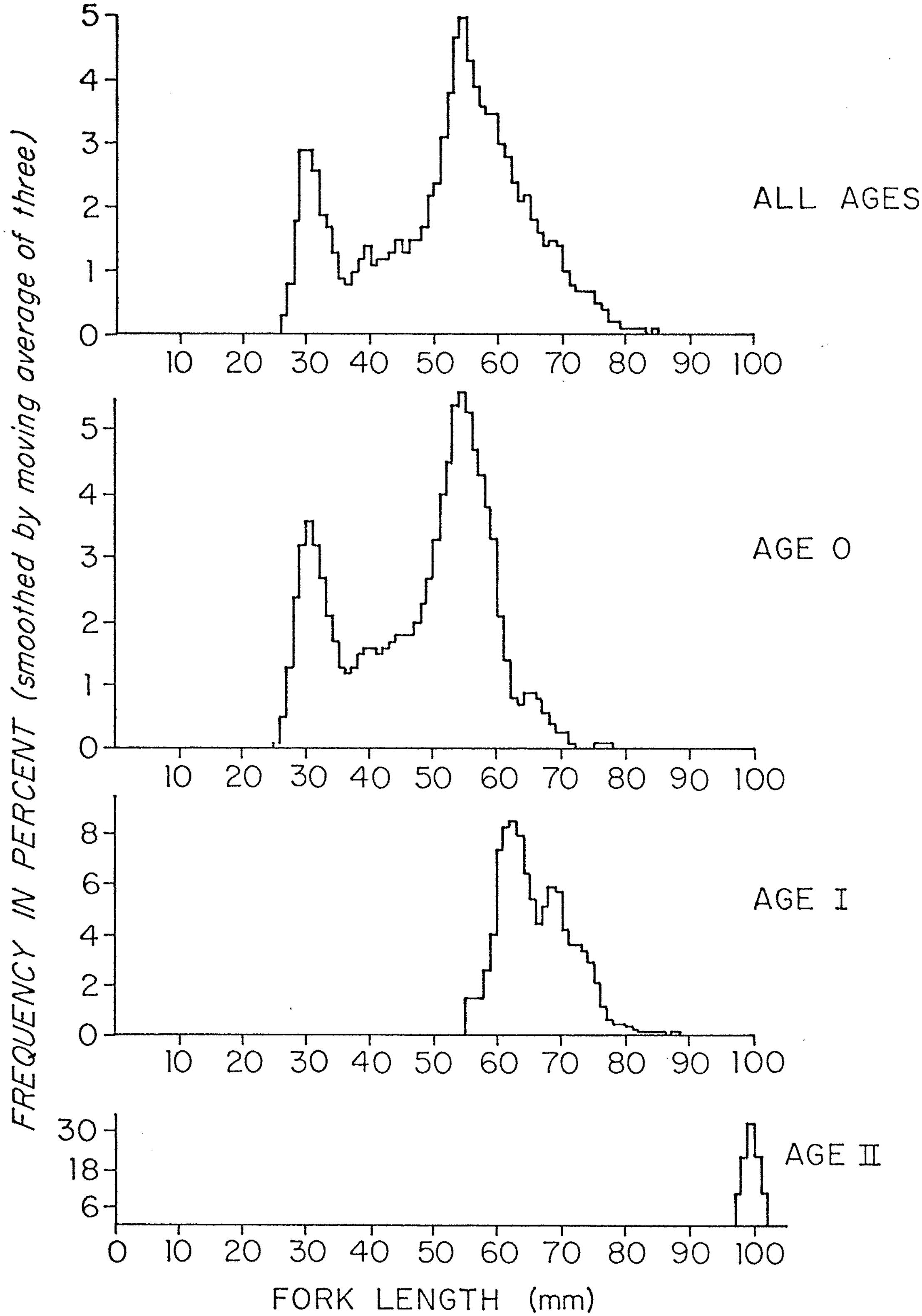

Fig. 13. Length frequency histograms of juvenile sockeye captured by townetting, Chignik Lake, September 9, 1974.

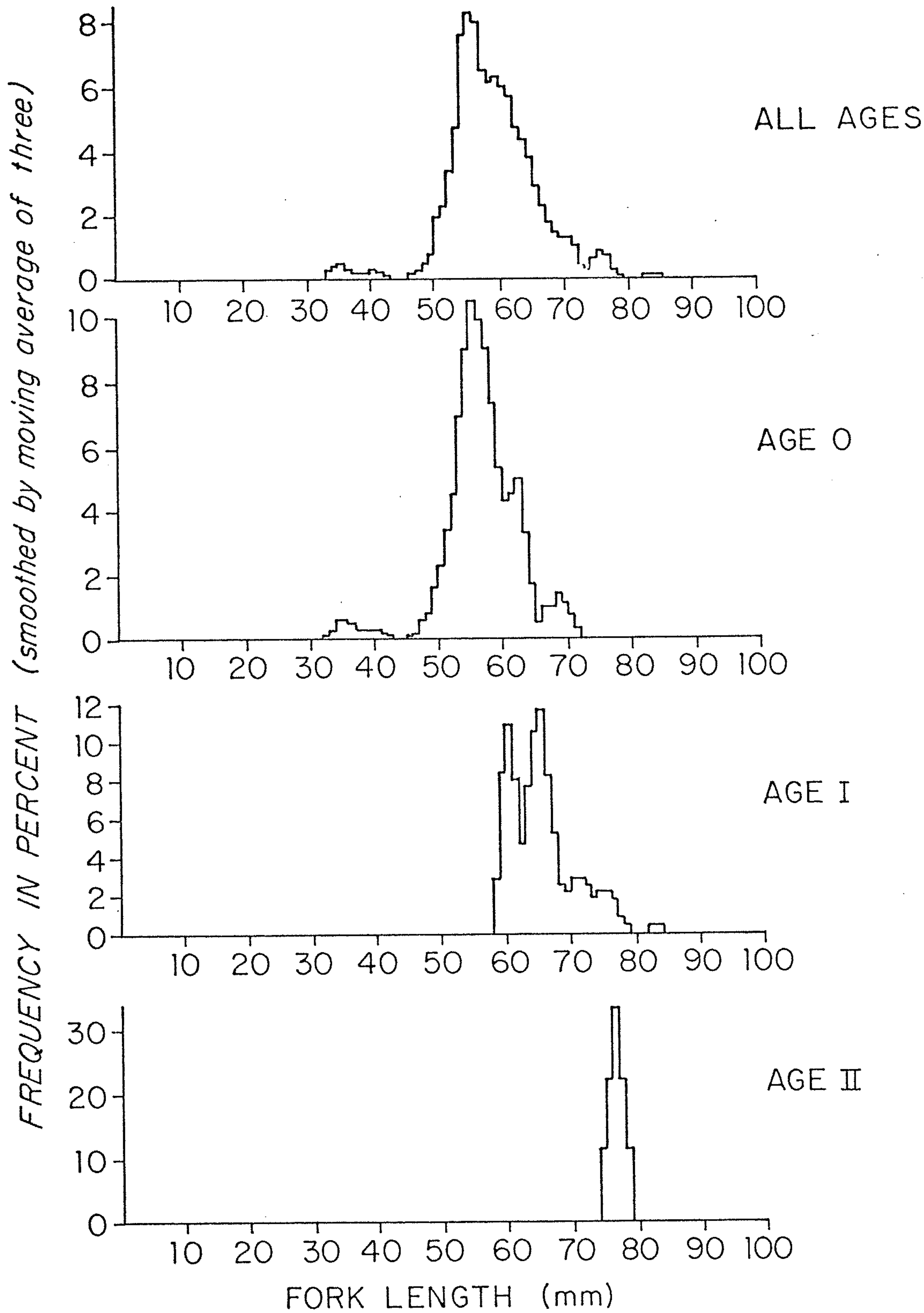

Fig. 14. Length frequency histograms of juvenile sockeye captured by townetting, Chignik Lake, November 7, 1974.

Table 5. Mean and modal lengths for juvenile sockeye sampled by townet in Chignik Lake, 1974

Date	Age	Stock	N	$\bar{X}$	Confidence interval ± 95%	Modal lengths		
6/16	0	C.L.	4	32.9	4.3	35.5		
	I	-	184	63.0	0.9	56.0	64.0	69.0
	I	B.L.	23	91.4	1.1	91.0		
	II	-	25	72.6	1.2	71.0		
7/12	0	Mixed	278	48.7	0.7	51.0		
	I	-	744	57.2	0.4	55.0		
	II	-	8	79.4	1.8	81.0		
8/6	0	Mixed	1411	49.5	0.3	49.0		
	I	-	472	60.8	0.4	59.0		
	II	-	3	83.7	4.2	80.5		
9/9	0	C.L.	693	34.8	0.8	29.5		
	0	Mixed	905	54.4	0.3	54.0		
	I	-	441	65.6	0.5	62.0		
	II	-	1			99.0		
11/7	0	C.L.	11	36.5	1.6	35.0		
	0	Mixed	284	57.0	0.5	56.0		
	I	-	92	65.0	1.0	59.0		
	II	-	1			76.0		

C.L. = Chignik Lake.
B.L. = Black Lake.
Mixed = Chignik Lake and Black Lake.

between Black and Chignik Lake origin since Black Lake stock migrated as age 0 into Chignik Lake the previous summer. Similarly, no stock of origin could be assigned to the age II fish represented by a modal length of 71 mm.

Length frequency data for the entire catch on July 12, 1974 (Fig. 11a), showed a single mode at 55 mm. However, age determinations revealed the presence of three year classes; 1973, 1972 and 1971.

Fish from the 1973 year class had a mean length of 48.7 mm. The length frequency distribution for this year class was negatively skewed. From equation 1, the predicted mean length for presmolt emigrants from Black Lake was 55.4 mm. The discrepancy in predicted and observed mean length, the skewed distribution and the presence of small age 0 fish in Chignik Lake on June 16 combine to indicate that the catch was composed of fish from both stocks.

Fish of the 1972 and 1971 year classes had mean lengths of 57.2 and 79.4 mm, respectively. No data existed to assign a stock of origin to these fish.

Length frequency data for the entire catch on August 6, 1974 (Fig. 12a), indicated the presence of one mode at 49 mm. Age readings revealed the presence of three age classes 1973, 1972 and 1971.

Fish of the 1973 year class had a mean length of 49.5 mm. From equation (1) the predicted mean length for Black Lake presmolt emigrants on this data was 57.3 mm. This size is only slightly larger than that observed on July 12 (i.e., 0.8 mm). These facts again suggested the presence of both stocks in the sample.

Fish from the 1972 and 1971 year classes had mean lengths of 60.8 and 83.7 mm, respectively. No data existed to assign a stock of origin to these fish.

Length frequency data for the entire catch on September 9, 1974 (Fig. 13a) showed two modes; one at 30 mm and one at 54 mm. Age determinations revealed the presence of three year classes; 1973, 1972 and 1971.

Fish of the 1973 year class exhibited a bimodal distribution (modes at 30.5 and 54 mm). Fish represented by the smaller mode were clearly of Chignik Lake origin as fish of this size were not found to be emigrating from Black Lake. Separation of the two populations was accomplished using probability paper (Harding 1949 and Cassie 1954). Means for the two groups were estimated at 34.8 and 54.4 mm, respectively.

The predicted size for presmolt emigrants in Chignik Lake on the date was 66.8 mm. It would appear from these data that the larger group probably includes fish from both stocks.

Fish from the 1972 class had a mean length of 65.0 mm. Only one fish representing the 1971 year class was captured. No data existed to assign a stock of origin to this fish.

Length frequency data for the catch on November 11, 1974 (Fig. 14a), showed a single mode at 55 mm. Age determinations revealed the presence of three year classes; 1973, 1972 and 1971.

While not distinctly bimodal, the 1973 year class appeared to be composed of two groups. Fish between 33 and 42 mm (mean = 36.5) were probably recent recruits to the pelagic area. These fish were most likely members of the Chignik Lake stock.

The majority of the 1973 year class ranged in size from 46 to 71 mm (mean length = 57.0). A prediction of the size of Black Lake presmolt emigrants on this date was 83.1 mm. The lack of any fish within 12 mm of this size strongly suggests that the growth rate realized in Black Lake of 0.27 mm per day was not sustained in Chignik Lake.

Fish from the 1972 year class had a mean length of 65.0 mm. The distribution of lengths for this year class was positively skewed. Only one fish of the 1971 year class was identified in the sample. As with previous samples, no data existed on which to identify stock of origin for these fish.

Growth Rate

1973 Year Class. Narver (1966) and Parr (1972) both emphasized that growth rate data for age 0 sockeye in Chignik Lake may be unreliable due to late emergence and recruitment of fry to the pelagic area and due to fry emigrations from Black Lake. Late emergence and emigration were shown to occur during the summer of 1974. We felt, therefore, that calculation of a growth rate would be inappropriate for the 1973 year class of sockeye reared in Chignik Lake. Fig. 15 summarizes the mean lengths of the 1973 year class by probable stock of origin. The predicted mean lengths of Black Lake presmolt emigrants are also shown.

1972 Year Class. Mean lengths for the 1972 year class of sockeye (excluding those larger than 84 mm on June 16 (which were assigned to the Black Lake stock) rearing in Chignik Lake are also plotted in Fig. 15. The decrease in mean length from June 16 to July 12 was probably due to smoltification of the larger of these fish. On June 23 and 24, fyke net catches in Chignik River showed a mean size for sockeye of 60.7 mm (Rigby, unpublished data).

Growth of the 1972 year class rearing in Chignik Lake appears to have been curvilinear over the period July 12-November 7 (Fig. 15). We therefore calculated two growth rates for these fish. The slope of the

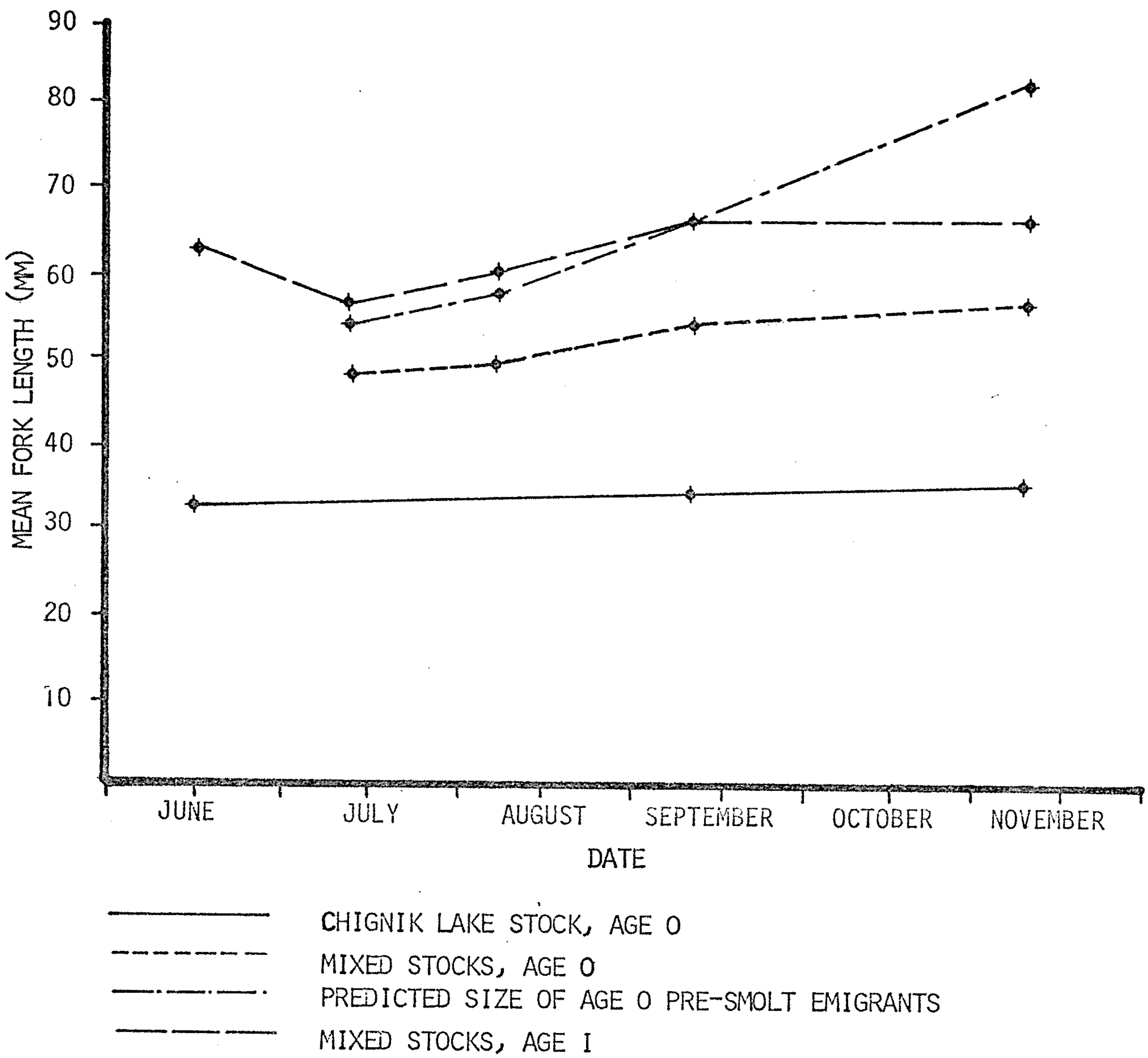

Fig. 15. Mean lengths by age group for juvenile sockeye rearing in Chignik Lake, 1974.

linear regression of mean length on days from June 1[6] for the period July 12-September yielded a growth rate of 0.142 mm/day. For the period September 9-November 7 the mean length declined though not significantly ($t = 0.95$ NS (531 df)), indicating that no growth was realized during the fall months.

Scale Patterns

In this section the baseline "scale" data required to formulate decision rules is presented. As we discussed in the methods sections, the potential for genetic and environmental factors to influence scale patterns requires that patterns formed be attributed, when possible, to specific stocks reared in specific environments. The problems of identifying stock of origin for fish rearing in Chignik Lake precluded our ability to separate genetic and environmental influences. Our approach therefore was to analyze observed patterns with reference to brood year and environment only, where stock identification was not possible.

Scale Regeneration - Black and Chignik Lake Stocks

Regeneration of lost scales is typical of Pacific salmon. Lost scales (first generation) are replaced in about one month. Circuli are not laid down on the new scale (second generation) until it approximates the size of the lost scale (Mosher 1968). It follows that second generation scales can be identified on a quantitative basis if the distance from the focus to the first circulus (F/+1) on such a scale is significantly larger than (F/+1) values of first generation scales. This approach cannot, however, identify second generation scales formed at such an early point in the life of the fish that its F/+1 value falls within the range of F/+1 values typical of first generation scales. This problem is insignificant, however, since the amount of information lost is undetectable.

We identified scales (which we had previously selected for study based upon the criteria presented previously) suspected of being regenerated using the criteria of Mosher (1968) and by inspection of (F/+1) values classified by age and environment. If either criteria identified a probable second generation scale, the frequency distribution of (F/+1) values for that group of fish was plotted. Rejection of data points was based on Anscombe and Tukey's method for the identification of outliers from a normally distributed population (Snedecor and Cochran 1967). The method rejects observations whose residual ($y - \bar{y}$) is larger than a constant (c) calculated from the following:

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[6]Days from June 1 is an arbitrary starting point. Any date prior to the commencement of sampling may be used since in this analysis we were interested in estimating a daily rate.

$$C = [K (1 - \frac{K^2-2}{4f}) \sqrt{\frac{f}{N}}] s$$

where

$K = 1.4 + 0.85 Z$

Z = The one-tailed normal deviate corresponding to a probability fp/100 N where P is expressed as a percentage.

f = The number of degrees of freedom = N-1.

N = number of observations.

s = The standard deviation of the population.

Inspection of scales collected from the 1973 year class of Black Lake sockeye indicated two of 287 were probably regenerated (Fig. 16).

Results of Anscombe and Tukey's test (Table 6 at the p = 2 1/2 percent level indicated that a data point with a residual > 9.2 should be rejected. This corresponds to an upper limit of 29 mm (226 times). Three data points were therefore rejected, the two larger of which were visually identified as probable second generation scales.

Inspection of scales collected on September 9, 1974, from juvenile sockeye in Chignik Lake indicated three of 152 were probably regenerated scales (Fig. 16). Since individual fish could not be assigned a stock of origin, nor an age with certainty, all data were combined in the calculation of "C." Results of the test at p = 2 1/2 percent (Table 6) indicated that a data point with a residual $\geq$ 20.2 should be rejected. This corresponded to an upper limit of 39.2 mm (226 times). Three data points were therefore rejected, all of which had been previously identified as probable second generation scales.

Size at Time of Scale Formation - Black and Chignik Lake Stocks

Gilbert (1914), Koo (1955) and Clutter and Whitesel (1956) reported that scales first appeared on juvenile sockeye when they reached 36-40 mm. These findings disagreed with those of Fraser (1920) and Dunlop (1924), who reported sizes of 30.5 and 29 mm, respectively. Clutter and Whitesel (1956) concluded that this discrepancy was related to fish reared under hatchery versus natural conditions with scales forming earlier on hatchery fish. Because environmental and/or genetic factors appeared to influence scale development, we determined this parameter for fish reared in Black and Chignik Lakes.

One hundred seven (107) samples were collected on July 27, 1975, from fish ranging in size from 31 to 40 mm in Black Lake and 144 samples were collected from fish 28 to 41 mm on May 11, June 6, and June 28,

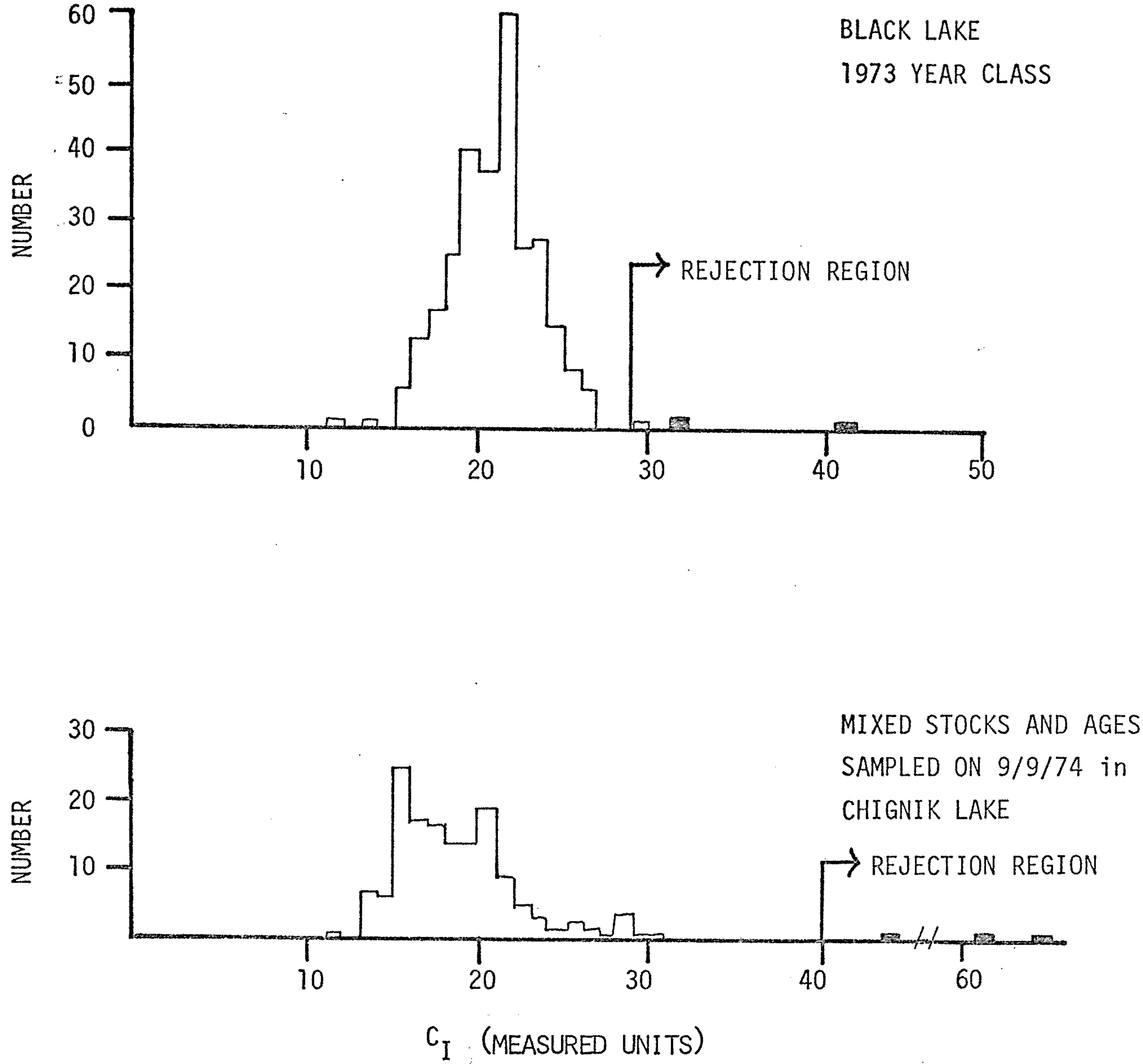

Fig. 16. Relative frequency histogram of F/+1 values for the 1973 year class of Black Lake sockeye and for fish rearing in Chignik Lake on September 9, 1974, regardless of stock

Table 6. Results of Ancombe and Tukey's test for the identification of second generation scales based on F/+1 values classified by stock and year class

Stock	Year class	N	$\bar{x}$	σ	P, (%)	C	Critical value ≥ (mm 226x)
Black Lake	1973	287	19.5	3.0	2.5	3.1	29.0
Mixed	1972-73	152	19.0	6.6	2.5	3.1	39.2

1975, in Chignik Lake. The numbers and percent of fish with and without scales are summarized by length interval in Table 7. Data for the Chignik Lake stock were combined due to the limited number of samples available for the individual sessions. Regardless of stock, scales first appeared on some fish 33 mm long and all fish 37 mm or larger had scales. Slight differences in the percent of fish with scales over the range of 33 to 35 mm was evident for the two stocks. These data are presented graphically in Figs. 17a and 17b. The similarities in size at which scales first appeared and at which all fish had formed scales for the two stocks, suggested that the data may be combined. These combined data are plotted in Fig. 17c and indicates a linear relationship between size of fish and scale formation over the size range of 32 to 37 mm. The linear equation for this relationship is (percent of fish with scales) = (-594.8) + 18.8 (length).

Identification of Annular Marks - Black Lake Stock

The development of decision rules for interpreting scale data in the aging process may be accomplished by following the formation of the circuli pattern on the scales of the population in question. In this way, the time of formation and location on the scale of characteristic patterns may be determined and catalogued. Our approach has been to present the initial pattern observed in spring and then to present the patterns which occurred near the margin of the scales on subsequent sampling sessions which correspond to the growth realized during the intervening time. The patterns are defined in terms of spacing between adjoining circuli and the proportions of circular types observed.

Dynamics of Circuli Formation. The presentation of scale patterns formed between sampling periods requires that the portion of the scale field attributable to growth realized during the period in question be isolated. For samples collected from the 1973 year class of Black Lake sockeye this was accomplished by:

1. Calculating the linear regression for the number of circuli on length (all samples were combined); and solving the equation for the mean length on each sampling session;

2. The average number of new circuli was then determined by subtracting the mean number of circuli on a session from that on the following session;

3. As a guard against loss of information, decimal values for the mean number of new circuli formed between periods were rounded up to the next integer.

The equation for the regression of number of circuli on length is (number of circuli) = (-6.50) + (0.23) (length). The regression was found to be highly significant (F = 1674.9** (df = 1,372)). Solutions

Table 7. The numbers and percentage of sockeye with and without scales by length interval for the Chignik and Black Lake stocks, 1975

	Black Lake				Chignik Lake										Combined stocks	
	July 27, 1975				May 11, 1975		June 6, 1975		June 28, 1975		Combined Dates					
	Number		Percent		Number						Number		Percent		Percent	
Length	w/o	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o	w
28							7		1		8		100		100	
29							10		4		14		100		100	
30							7		4		11		100		100	
31	1		100				4		5		9		100		100	
32	2		100	0	2				4		6		100	0	100	0
33	2	4	33	66	6	1	3				9	1	90	10	69	31
34	4	6	40	60	5	2	2	3	1		8	5	62	38	52	48
35	3	10	23	77	9	6	1	2			10	8	56	44	42	58
36	3	11	21	79	3	9		3		1	3	13	19	81	20	80
37		10	0	100		5		2				7	0	100	0	100
38		21		100		4		5				9		100		100
39		15		100		4		5				9		100		100
40		15		100		5		1		2		8		100		100
41						2		1		3		6		100		100

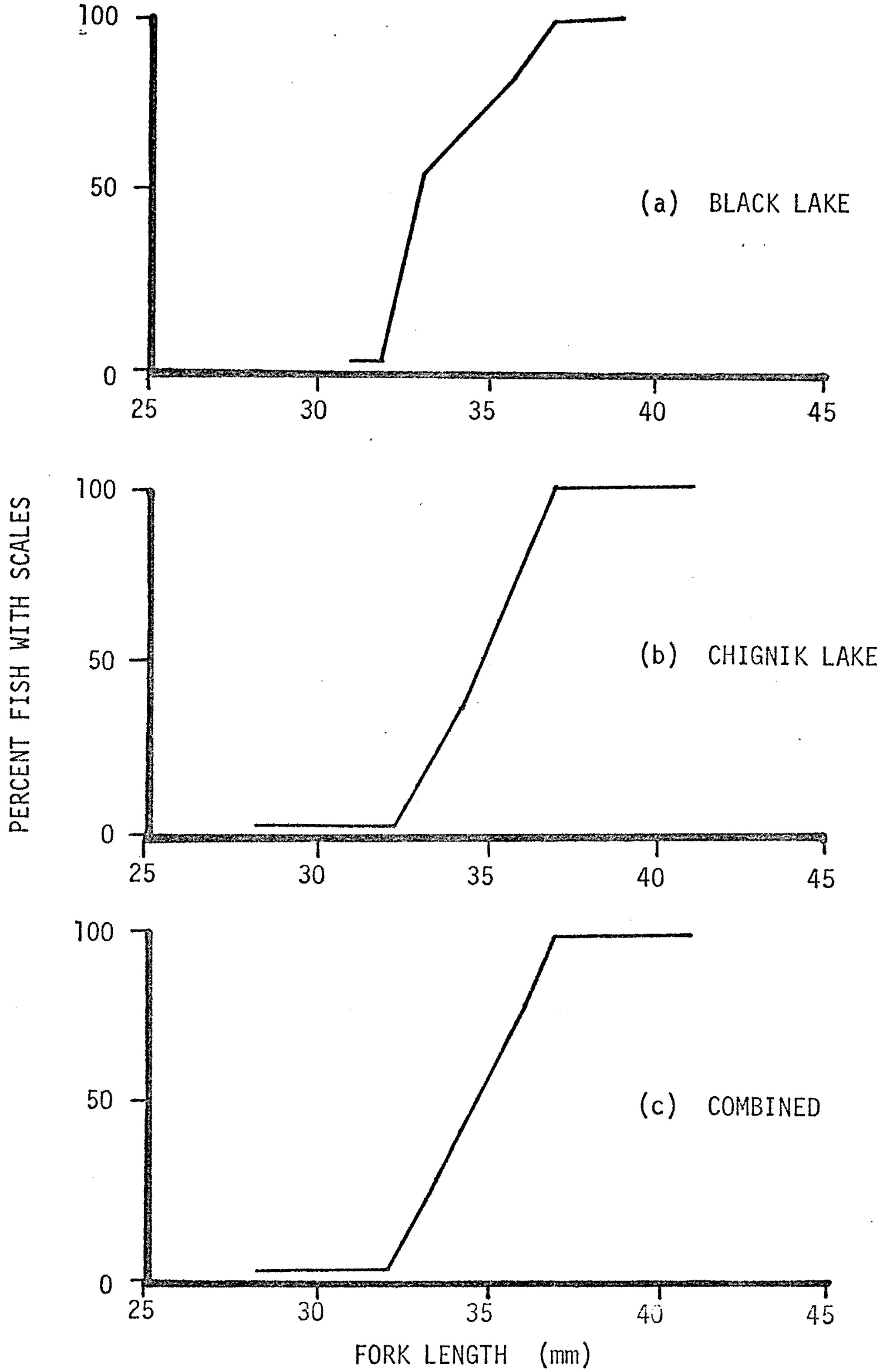

Fig. 17. The relationship between size of fish and the formation of scales for the Black Lake and Chignik Lake stocks and for the combined data, 1975

for this equation when mean lengths were entered, changes in mean number of circuli between sampling sessions, and rates of circuli formation are summarized in Table 8.

Spacing Between Adjoining Circuli. The average distances between marginally-adjusted, adjoining circuli are presented in Appendix Table 1. In Fig. 18 these data are summarized and arrows delimiting that portion of the pattern corresponding to the time interval in question are included. Means connected by a solid line indicate established patterns. The dashed lines, since they connect the points corresponding to the intervals (-2/-1) and (-1/m), define the minimum value for the spacing between the last circulus formed and the next circulus to form.

The relationship between the spacing of adjoining circuli on June 29 is for the average distance between interval (n-1/n) to be greater than the average distance between interval (n/n+1) where n is a margin adjusted circulus number equal to -2 or -3. This pattern of circuli being laid down closer and closer to each other as subsequent circuli were formed was also evident for circuli laid down between June 29-July 31 and July 31-September 2.

The pattern formed between September 2, 1974, and May 23-25, 1975, indicates a minimum in the spacing between adjoining circuli, occurred at interval (-2/-1) in May 1975. This minimum was defined by the increase (though not significant) in the spacing between intervals (-2/-1) and (-1/m). The similarity between these two intervals precludes the possibility for the next circulus to be laid down closer to the one preceding it (-1) than the preceding one (-1) was to the one (-2) before it. This is necessarily true because measurements are made to the outer edge of a circulus and a circulus has a width which is a component of the interval measurement.

The outer circulus defining this minimum interval at (-2/-1) was (-1). On the average, this corresponds to circulus (+10.3) on a focus-adjusted basis. This circulus was on the average 65.7 mm (226 times) from the focus. Table 9 summarizes data pertinent to locating this circulus on a focus-adjusted basis.

The tendency for the spacing between adjoining circuli to decrease as one approached the relative minimum was summarized with the following linear question:

$$y = 3.06 - 0.31\,x$$

where:

y = Mean distance between adjoining circuli,

x = Inner circulus defining interval of interest-marginally adjusted.

The regression was found to be highly significant ($F = 303.12^{**}$ (df = 1,11)).

Table 8. Dynamics of circuli formation for the 1973 year class of Black Lake sockeye

	DATE			
	6/29/74	7/31/74	9/2/74	5/23-25/75
Mean length	41.3	52.0	61.4	75.2
Mean number of circuli	3.0	5.46	7.62	10.80
Change in the mean number of circuli from previous period		2.46	2.16	3.18
Rate of formation during previous period (circuli/day)		0.769	0.655	0.041

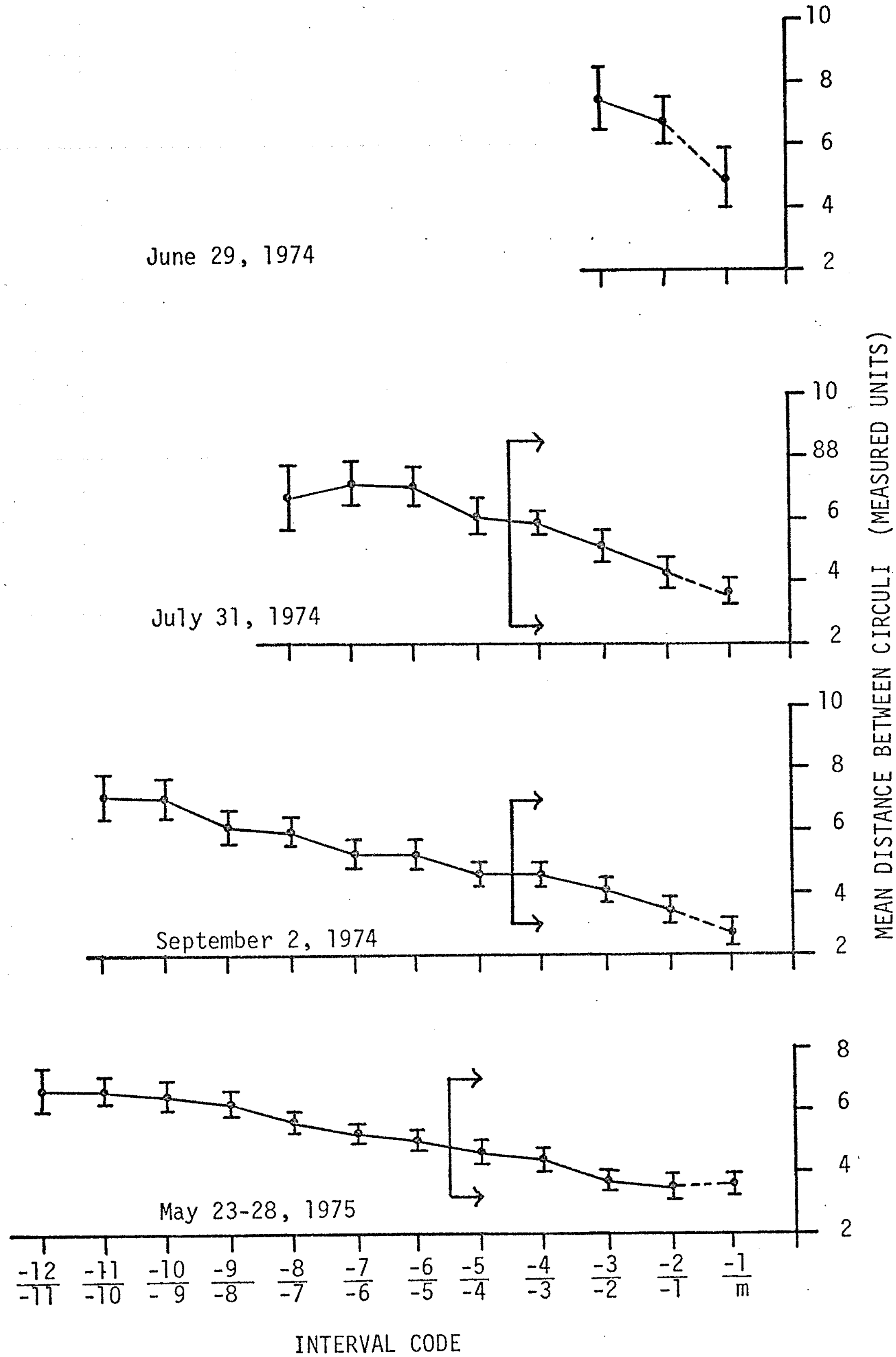

Fig. 18. Mean distance between adjoining circuli on the scales of the 1973 year class of Black Lake sockeye which reared in Black Lake

Table 9. Location of the relative minimum in the spacing between adjoining circuli on the scales of juvenile sockeye smolting from Black Lake, May 23-25, 1975

Method	Mean	Confidence Interval ± 95%	Range of values
Distance from focus (mm x 226)	65.7	± 1.7	50-88
Number of circuli	10.3	± 0.3	7-14

Type of Circuli Observed. The occurrence of a minimum in the spacing between circuli near the margin on the scales of sockeye smolting from Black Lake during late May suggested that an annular mark, in the sense of Koo (1955), was forming. It was of interest to determine if a change in the types of circuli found characteristically accompanied this narrowing. Data regarding the proportion of types of circuli found are summarized in Appendix Table 2 and are presented in Fig. 19.

We found that a very high proportion of the circuli closest to the margin (-1) was broken, incomplete and fragmented regardless of sampling date. Furthermore these types were not found at such high levels in the interior field on subsequent sampling sessions. This was observed because a new circulus does not appear spontaneously on the margin, rather it forms gradually appearing first at one or more points along the margin. Subsequently, these pieces are "spliced" together until the final pattern is formed. It is probable, therefore, that when sampling a population of fish that one will find circuli on the margin which are in various stages of formation. This process makes it impossible to make predictions regarding the final pattern which will develop.

Data collected on June 29 indicated that the majority of the circuli laid down early in the life of these fish was complete, but that the occurrence of broken circuli in the interior of the field could be expected. By July 31, incomplete, fragmented, and cross-over circuli were also evident in the interior field. Broken circuli were being formed near the margin at low levels. By September 2, the proportion of broken circuli being formed appeared to be increasing. This was coupled with a decrease in the proportion of complete circuli. The proportion of incomplete, fragmented, and cross-over circuli continued at a low level of about 10 percent. The pattern observed on May 23-25, 1975, showed a continued trend in the increase of broken and decrease in complete circuli as one approaches the margin. The continued presence of incomplete, fragmented, and cross-over circuli was again noted.

These data showed that as the relative minimum in the spacing between circuli is approached, broken circuli are more likely to be encountered than are complete circuli. A graph of the percent of broken and complete circuli as a function of the marginally-adjusted circulus number for data collected from smolt in May 1975 is presented in Fig. 20. Polynomial regression was used to fit a curve to the observed data. In both cases a quadric term was found to be significant (Tables 10 and 11).

The equations were:

(percent complete circuli) -35.95 - 21.13 (number of circuli) - 0.91 (number of circuli)^2

(percent broken circuli) = 130.33 + 20.23 (number of circuli) + 0.87 (number of circuli)^2

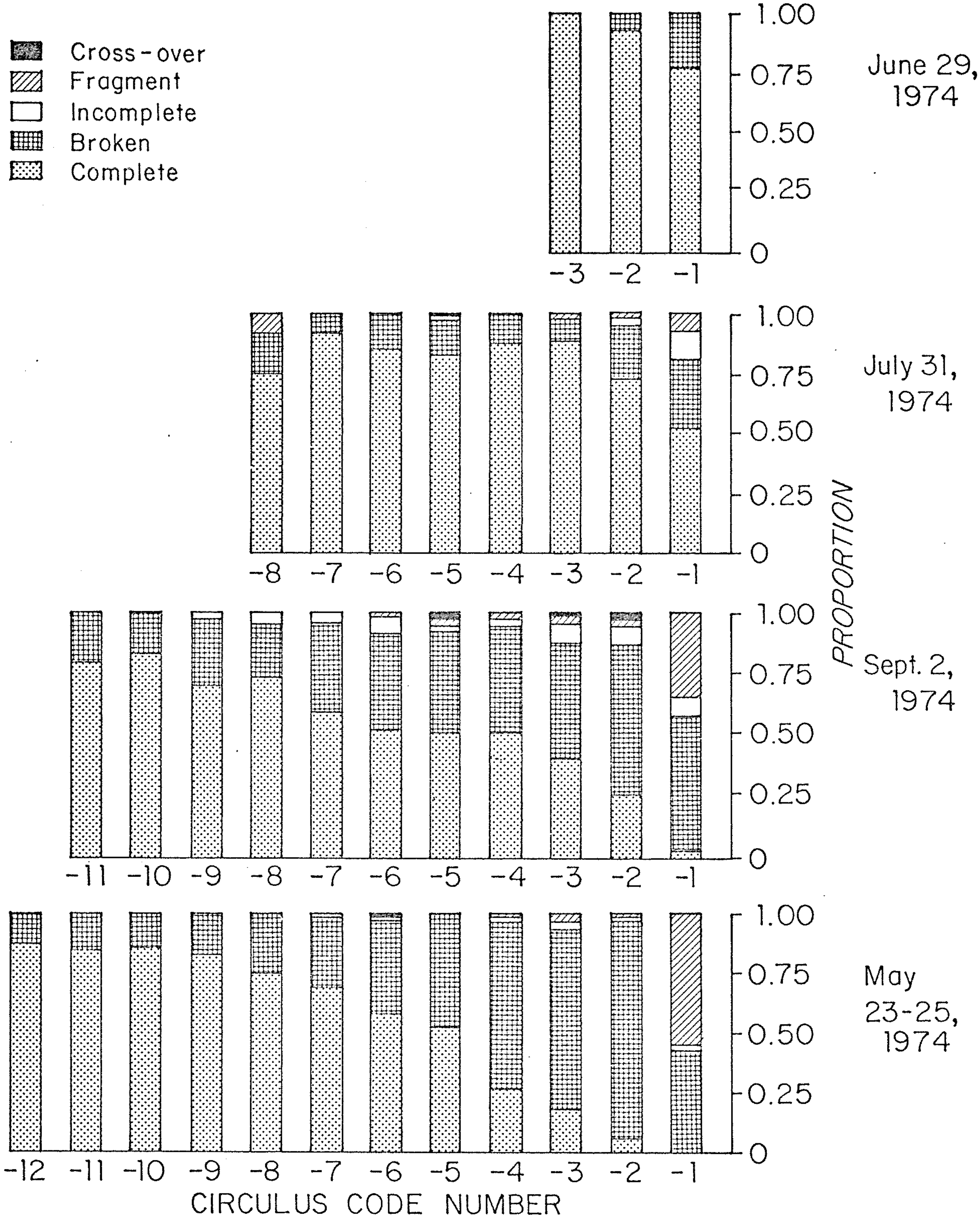

Fig. 19. The proportion of circuli types (margin-adjusted) ocurring on the scales of the 1973 brood year of Black Lake sockeye

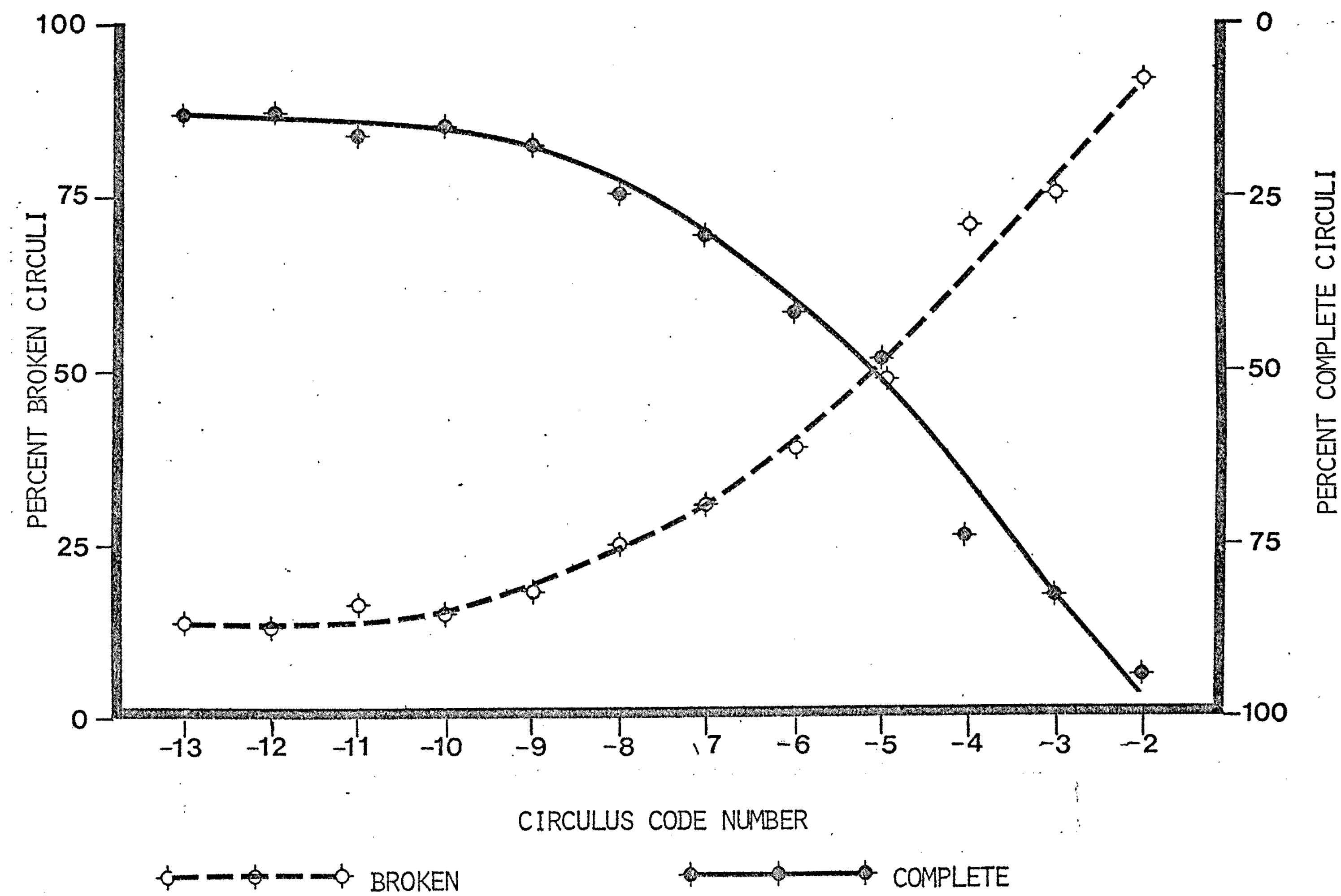

Fig. 20. The percent of broken and complete circuli as a function of the margin-adjusted circulus number. 1973 brood year of Black Lake sockeye sampled by fyke-netting in Black Lake, May 1975.

Table 10. Analysis of variance test for the significance of departure from linearity. Proportion of broken circuli on the margin-adjusted circlus number. 1973 brood year of Black Lake sockeye captured by fyke-net sampling in Black River, May 1975

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Deviations from linear term	10	1,100		
Deviations from quadric term	9	84.2	9.4	
Reduction in sum of squares	1	1,015.8	1,015.8	108.1**

Table 11. Analysis of variance test for the significance of departure from linearity. Proportion of complete circuli on the margin-adjusted circulus number. 1973 brood year of Black Lake sockeye captured by fyke-net sampling in Black River, May 1975

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Deviations from linear term	10	1,213.4		
Deviations from quadric term	9	114.0	12.67	
Reduction in sum of squares	1	1,099.4	1,099.4	86.77**

Identification, Validation, and Characterization of Annular Marks - 1972 Brood Year Rearing in Chignik Lake

The problem of validating growth checks as annular marks on fish from the 1972 brood year was complicated by a paucity of information on their scale patterns prior to commencement of this study. Our approach therefore was to test our consistency in interpretation of checks and then to infer, from the available data, the probability that these checks represent annular marks.

Identification

The problem of consistency in interpretation of checks may be stated as follows: Is there any significant difference in either the spacings between adjoining circuli or the types of circuli observed (for annulus-adjusted data) between sampling sessions for those fish identified as members of the 1972 brood year? Acceptance of the null hypothesis would indicate we consistently identified checks. The presence of significant difference would suggest two alternative hypotheses: 1) We did not consistently identify checks; or 2) the population sampled was not the same between dates. Acceptance of the second alternative could indicate that age 0 Black Lake emigrants formed a false check upon entering Chignik Lake which was different from checks on the scales of fish from the combined Chignik Lake-Black Lake 1972 brood year currently resident in Chignik Lake.

To determine if difference in the spacing between adjoining circuli were present between dates we plotted the mean values obtained on each session. These data are presented in Fig. 21 and Appendix Table 3. These data showed that no differences were present in this parameter for circuli in close proximity to the presumed annulus.

To determine if differences in the types of circuli observed were present between dates, we graphed to proportion of circuli types found on either side of the annulus Figs. 22a-d (Appendix Table 4) and performed Chi-square tests on the raw count data. Both analyses indicated that no significant differences were present for two circuli on either side of the annulus. We therefore concluded that we consistently identified these checks.

The preceding analysis demonstrated that Black Lake presmolt emigrants probably did not form a false check upon entering Chignik Lake which was different from the checks on scales of fish resident in the lake. It is possible however that they formed false checks which were the same as those on the scales of fish resident in the lake. Prior to validating these checks as true annuli, it is necessary to show that this was not the case. Our approach was the same as that used to identify annular marks on smolts emigrating from Black Lake, i.e., we isolated that portion of the pattern formed between sampling sessions and looked to see if checks were present near the margin.

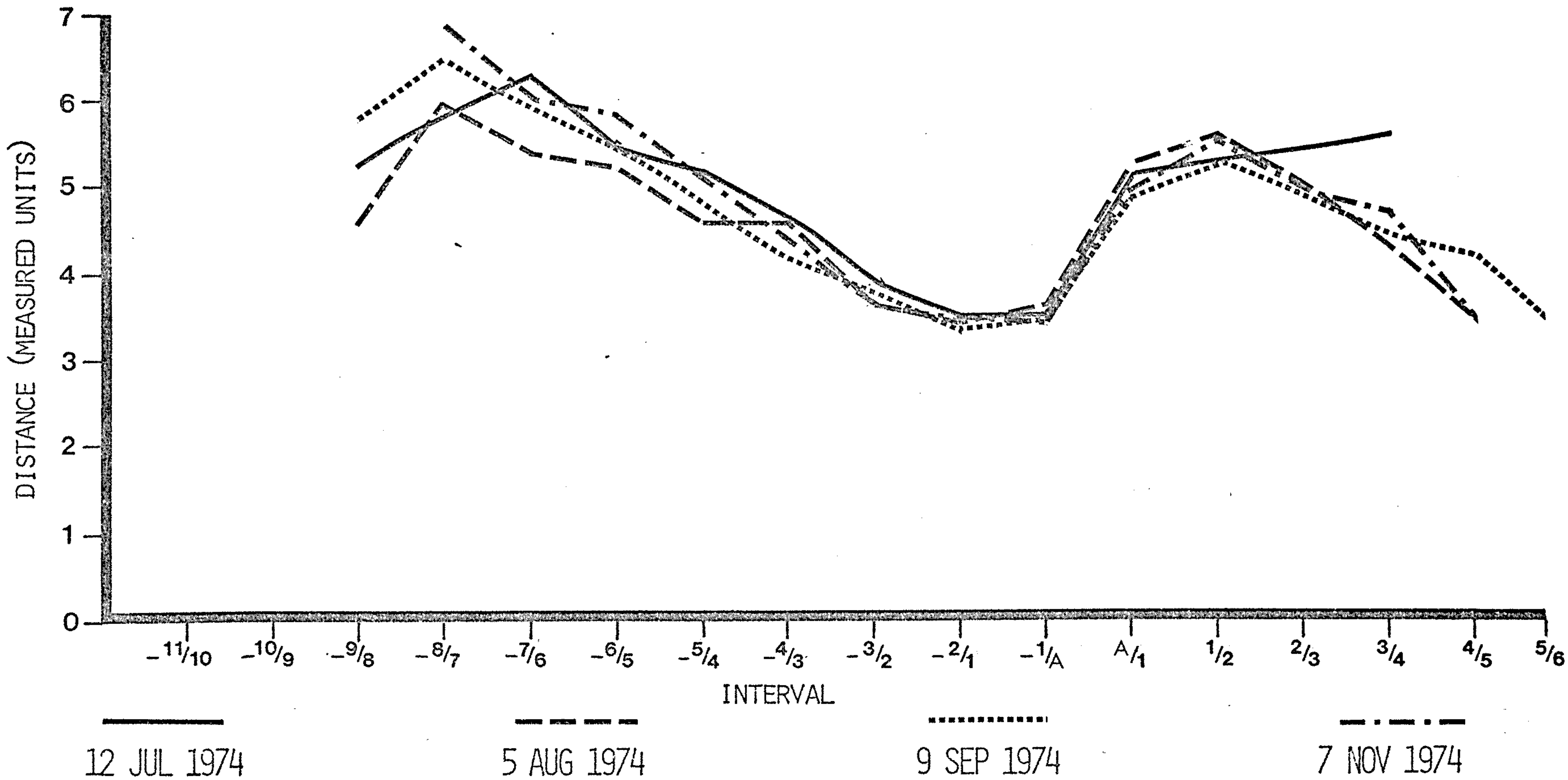

Fig. 21. Mean distance between adjoining circuli (annulus-adjusted) on the scales of the 1972 brood year of sockeye rearing in Chignik Lake, by period, 1974.

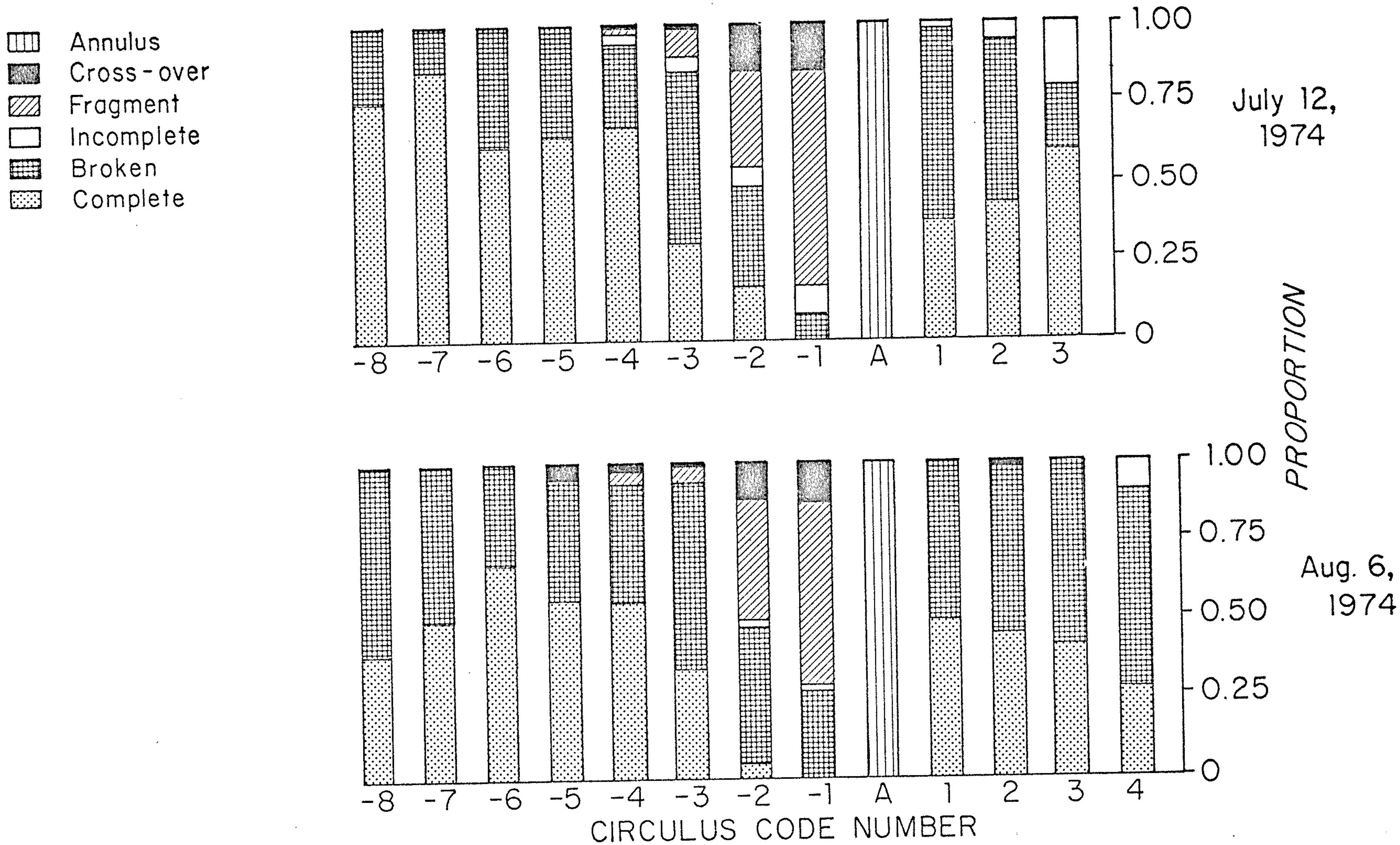

Fig. 22. The proportion of circuli types (annulus-adjusted) on the scales of the 1972 brood year of sockeye salmon rearing in Chignik Lake, by period, 1974.

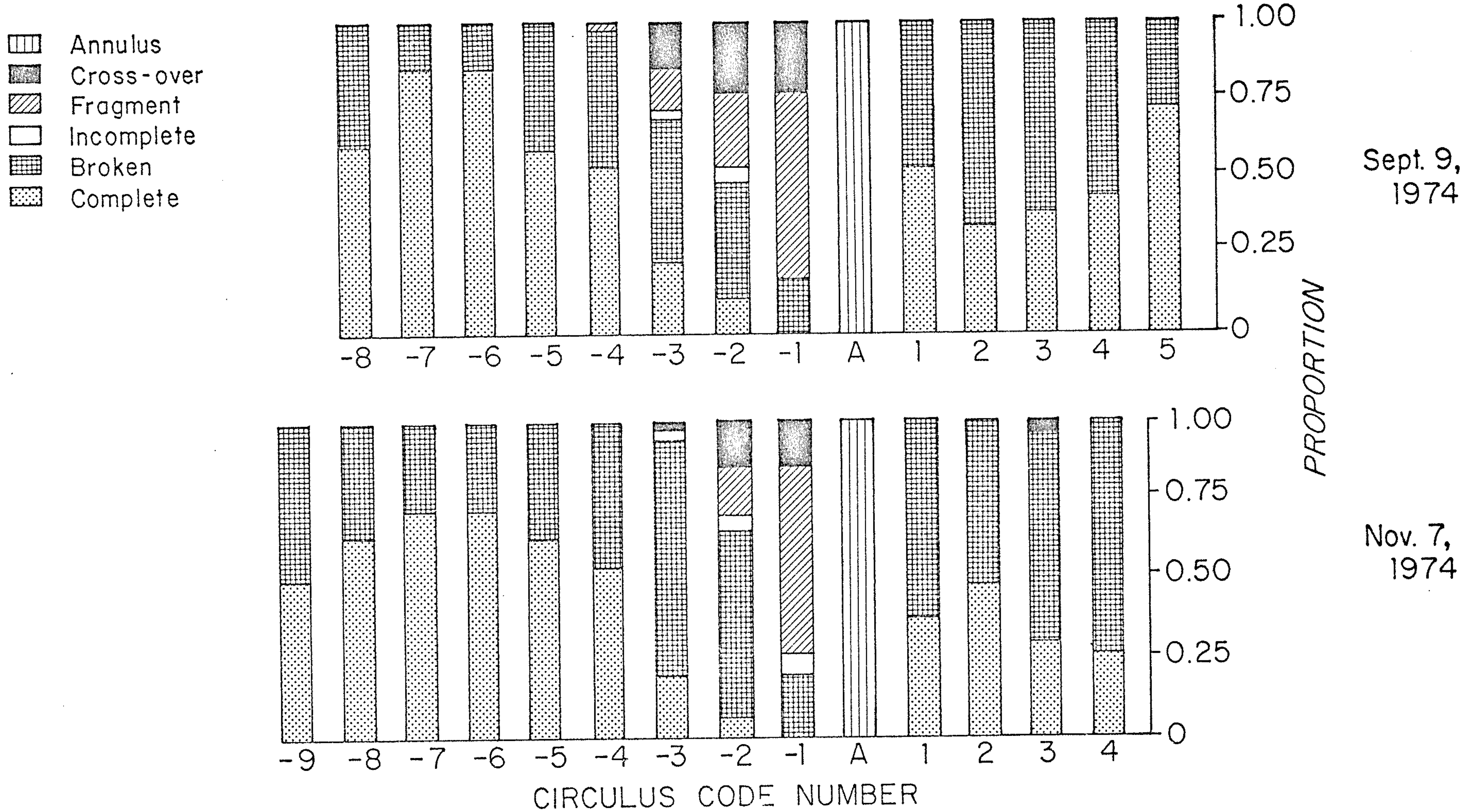

Fig. 22. The proportion of circuli types (annulus-adjusted) on the scales of the 1972 brood year of sockeye salmon rearing in Chignik Lake, by period, 1974. (Continued)

Isolation of that portion of the pattern formed between sampling sessions required that the dynamics of circuli formation be determined. The equation for the regression of number of circuli on length for all fish showing one growth check on all sampling sessions was:

$$(\text{number of circuli}) = -2.35 + 0.206\ (\text{length})$$

Solutions for this equation when mean lengths were entered for each sampling date, the change in the mean number of circuli between dates, and the rates of circuli formation are summarized in Table 12. From these data, arrows delimiting that portion of the scale pattern formed between sampling sessions were drawn. Decimal values were rounded up.

The average distance between marginally-adjusted circuli are presented in Fig. 23 (Appendix Table 5). These data showed no indication of a relative minimum in that portion of the pattern formed between sampling sessions. The proportion of circuli types observed for margin-adjusted data is presented in Fig. 24 (Appendix Table 6). These data concurred in showing no checks in that portion of the field formed between sampling sessions. We therefore concluded that no detectable proportion of the 1973 brood year of Black Lake presmolt emigrants formed an accessory check upon entering Chignik Lake.

Validation

The dearth of information regarding the scale patterns of the 1972 brood year at age 0 precludes an absolute validation of these checks as annular marks. A comparison between the size of age 0 sockeye in Chignik Lake in 1973 with the size of age I fish in 1974 is presented in Fig. 25. The reasonable increase in length over the winter and early spring of 2.5 mm and the published reports of time of annulus formation (Koo 1955) led us to accept these checks as true annuli.

Characterization

Spacing Between Circuli. The mean distance between annulus-adjusted circuli for the combined data are presented in Fig. 26 and summarized in Table 13. In the first year's zone the progressive decrease in spacing between circuli approaching the annulus was apparent. Low values ranging from 3.47 $\pm$ 0.15 to 3.77 $\pm$ 0.15 were found at the last three intervals in the zone. Spacing increased for the first two intervals following the annulus after which a renewed decline was observed. The average maximum value in the first year's zone was larger than in the second year's zone, 6.34 $\pm$ 0.47 versus 5.47 $\pm$ 0.17, respectively. The most abrupt change in the pattern occurred on either side of the annulus where average spacing increased form 3.65 $\pm$ 0.16 to 5.13 $\pm$ 0.15.

Types of Circuli. The best estimate of the proportion of each type of circuli found at each annulus-adjusted circulus number is found by pooling the data collected each session. This method does not provide

Table 12. Dynamics of circuli formation for the 1972 brood year of sockeye rearing in Chignik Lake during 1974

Date	Mean length	Mean number of circuli and 95% C.I.	Increase from previous period	Rate (circuli/ day)
July 12	57.2	9.4 ± 0.2		
August 6	60.8	10.2 ± 0.2	0.8	0.024
September 9	65.6	11.1 ± 0.1	0.4	0.013
November 7	65.0	11.0 ± 0.1	-0.1	---

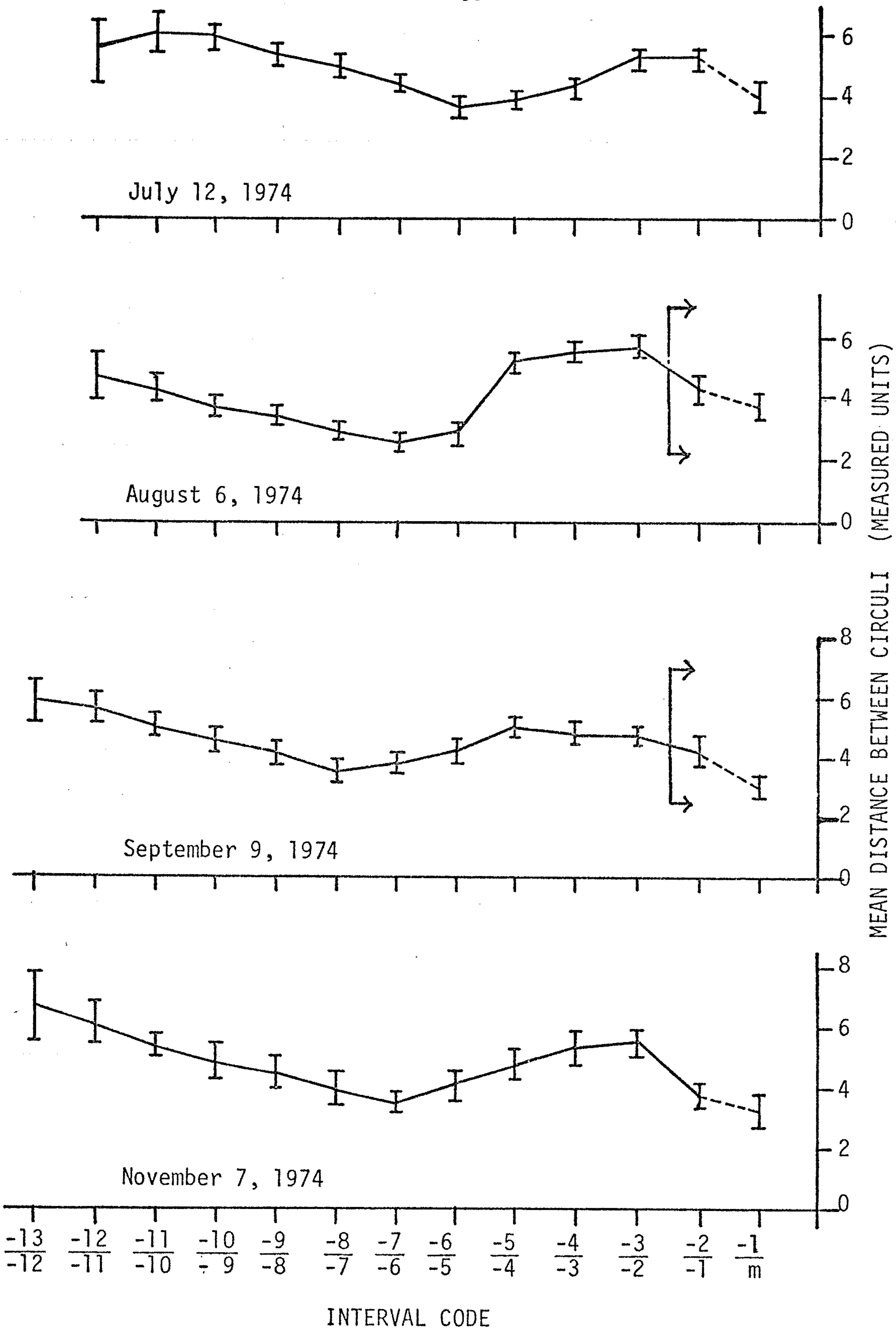

Fig. 23. Mean distance between adjoining circuli (margin-adjusted) on the scales of the 1972 brood year of sockeye salmon rearing in Chignik Lake, by period, 1974.

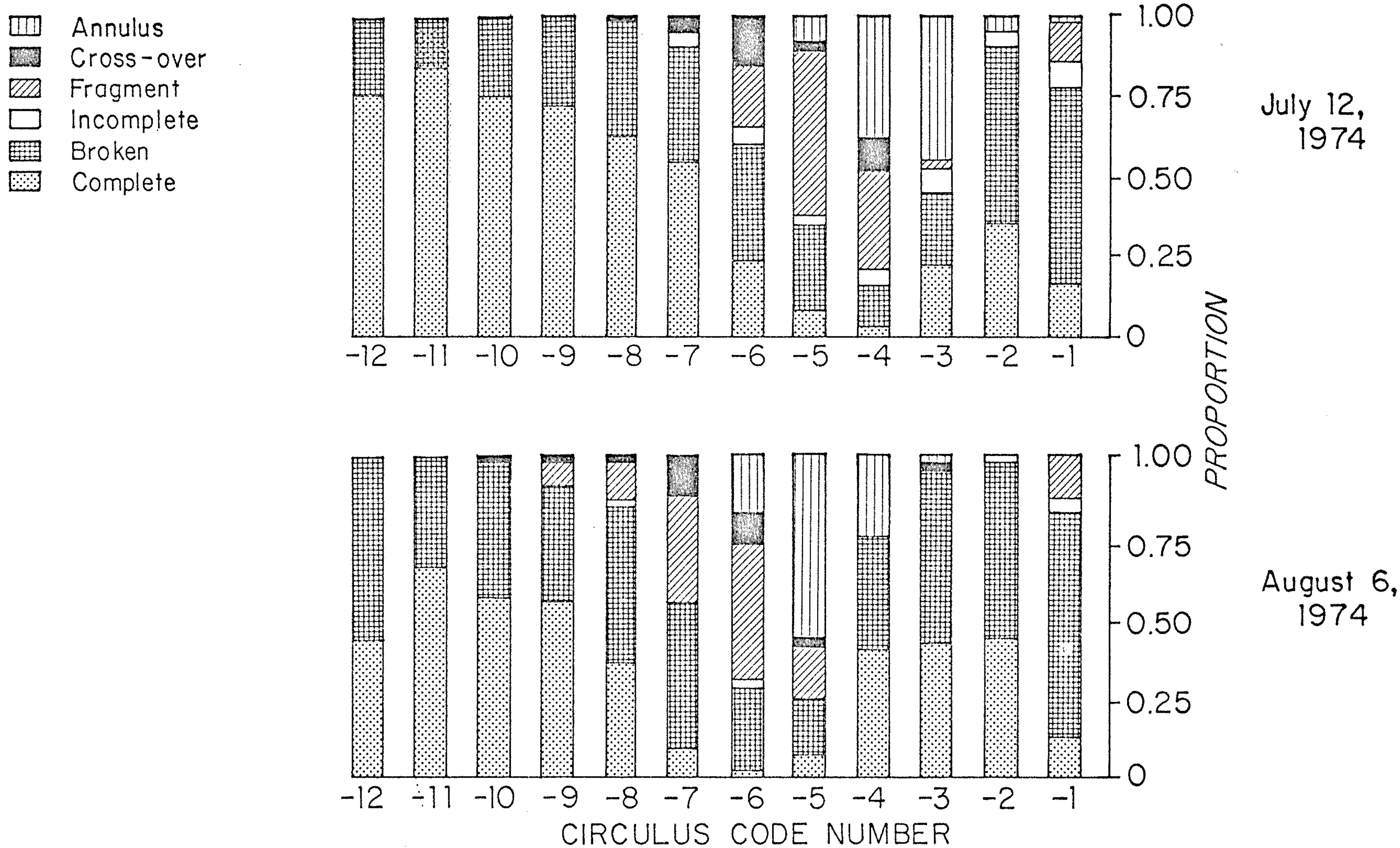

Fig. 24. The proportion of circuli types (margin-adjusted) on the scales of the 1972 brood year of sockeye salmon rearing in Chignik Lake, by period, 1974.

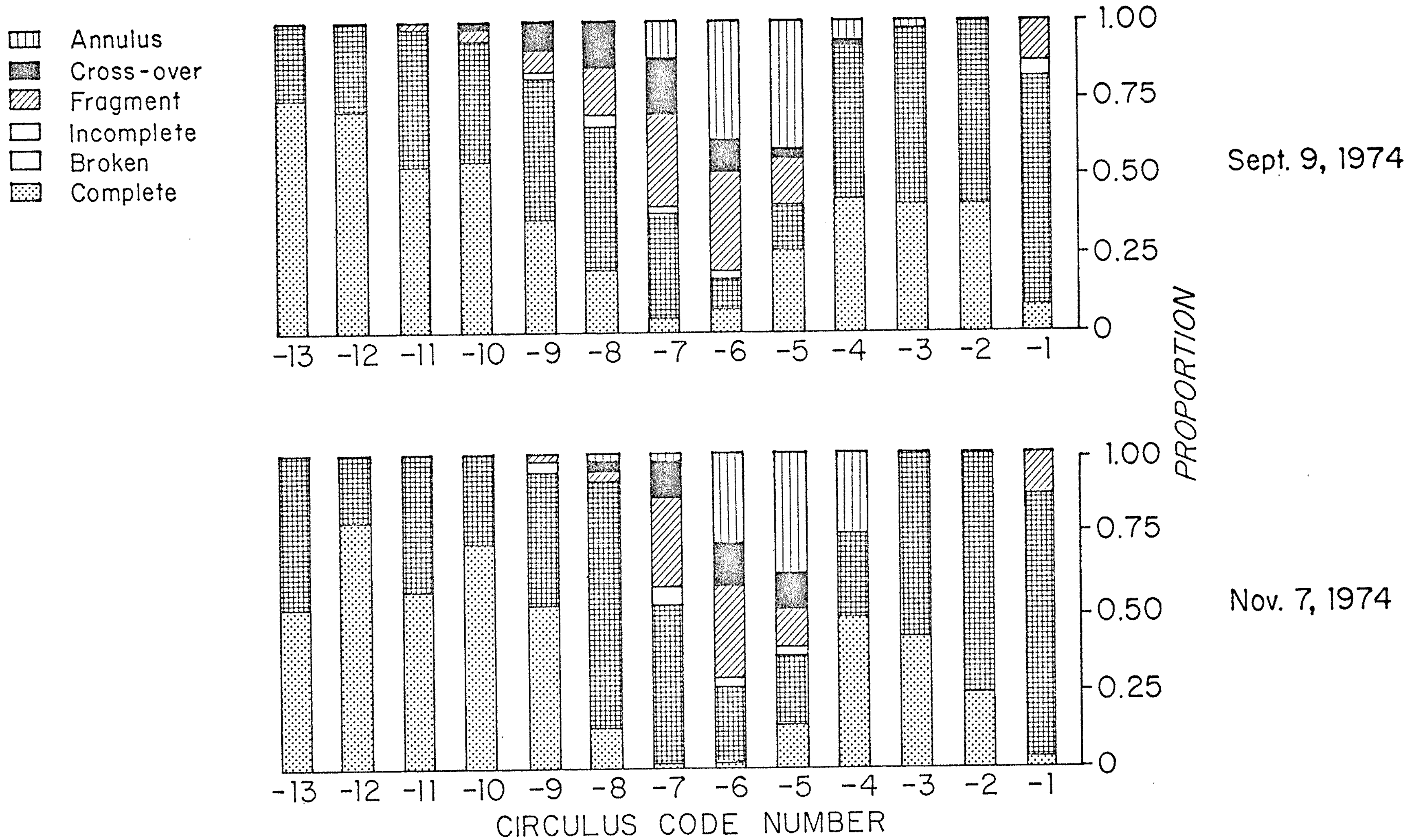

Fig. 24. The proportion of circuli types (margin-adjusted) on the scales of the 1972 brood year of sockeye salmon rearing in Chignik Lake, by period, 1974. (Continued)

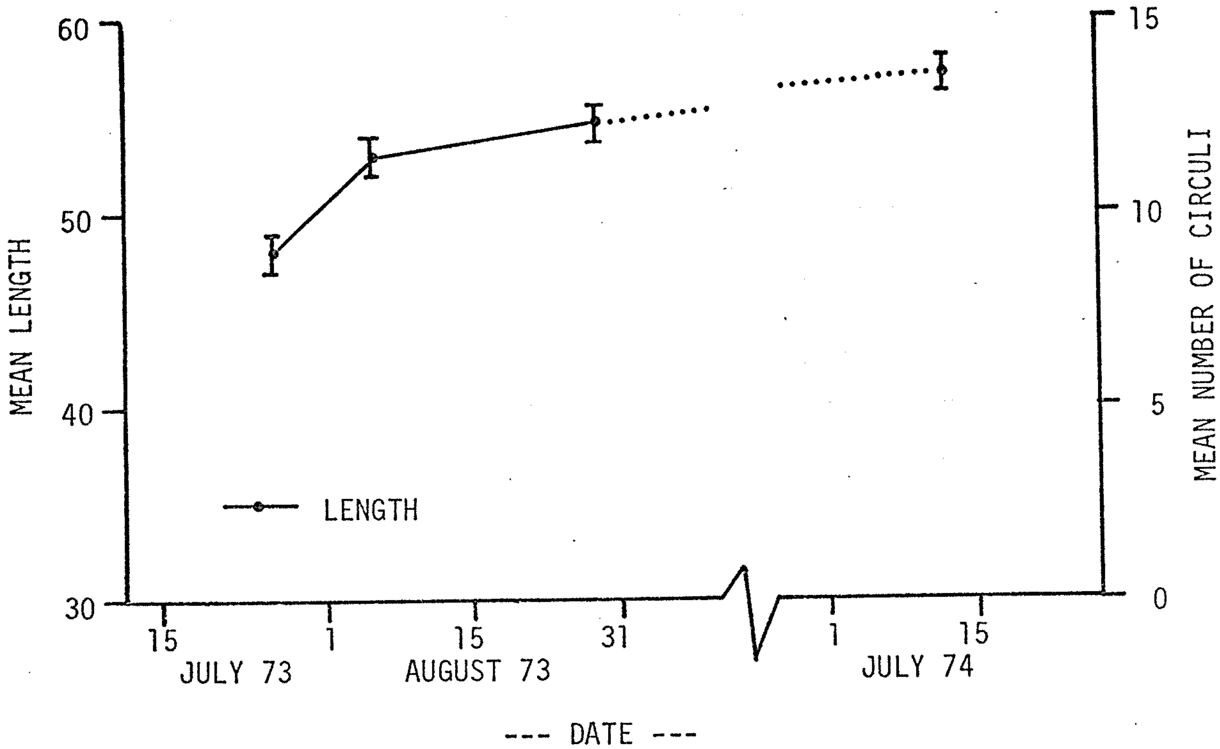

Fig. 25. Mean lengths of the 1972 brood year of sockeye salmon rearing in Chignik Lake, July 1973-July 1974.

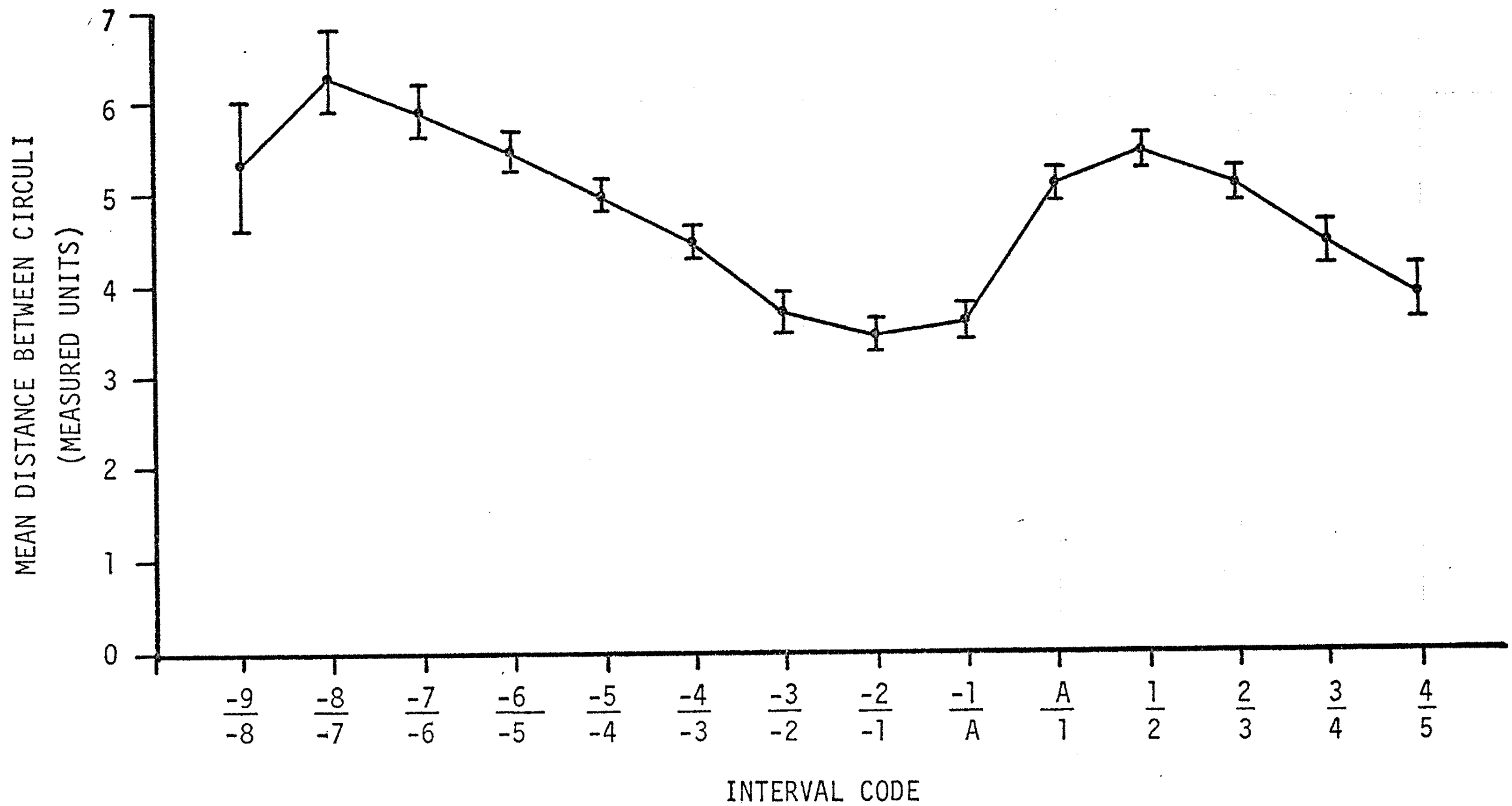

Fig. 26. Mean distance between adjoining circuli (annulus-adjusted) on the scales of the 1972 brood year of sockeye salmon rearing in Chignik Lake, combined periods, 1974.

Table 13. Mean distance between adjoining circuli (annulus-adjusted) on the scales of the 1972 brood year of sockeye salmon rearing in Chignik Lake, combined periods, 1974

	Measured units													
	Interval													
Parameter	-9/-8	-8/-7	-7/-6	-6/-5	-5/-4	-4/-3	-3/-2	-2/-1	-1/A	A/1	1/2	2/3	3/4	4/5
Sample size (N)	17	47	94	145	183	201	203	203	203	202	199	166	117	47
Mean ($\bar{x}$)	5.29	6.34	5.90	5.50	4.97	4.49	3.77	3.47	3.65	5.13	5.47	5.13	4.53	3.91
95% Confidence Interval $\pm$	0.70	0.47	0.27	0.21	0.18	0.16	0.15	0.15	0.16	0.15	0.17	0.17	0.20	0.33

an estimate of the variance and therefore precludes an estimation of confidence intervals. For these reasons we treated the proportions derived each session as individual observations and calculated their means and corresponding confidence intervals. These data are summarized in Table 14 and are plotted in Fig. 27.

The following observations were made from these data:

1. For scales with a large first year's zone, broken and complete circuli were found exclusively in the first half of the first year's zone. Furthermore, complete circuli predominated.

2. Approaching the annulus, the proportion of complete circuli declined rapidly reading 0.00 at circulus (-1).

3. The proportion of broken circuli was unstable, reaching a maximum value at circulus (-3) and then declined rapidly to a minimum value at circulus (-1).

4. Incomplete circuli were found on both sides of the annulus at low levels.

5. Fragmented circuli were found only in the first year's zone within four circuli of the annulus. Furthermore, there was a rapid increase in the proportion of these circuli approaching the annulus. On 60 ± 8 percent of all fish the last circulus of the first year's zone was fragmented.

6. Cross-over circuli were found on either side of the annulus. Significant proportions were found only within two circuli of the annulus in the first year's zone, however.

7. Seventy-eight percent of all fish exhibited either as fragmented or cross-over circuli as the last circulus of the first year's zone. Of the remaining 22 percent, 40 percent (9 percent of the total) exhibited one of these types in either the -2 or -3 position. The remaining 60 percent (13.4 percent of the total) showed neither of these types of circuli in these positions.

Scale Patterns of the 1973 Brood Year Rearing in Chignik Lake During 1974

Dynamics of Circuli Formation

The dynamics of circuli formation for the 1973 brood year were calculated for both known Chignik Lake stock fish and for those fish which no stock of origin could be positively deduced. Separate rates were calculated to prevent biasing the results due to differences in size and varying contributions in each group represented in the catches. These data are summarized in Table 15. Generally, less than 1 circulus was laid down between sampling dates.

Table 14. Means and 95 percent confidence intervals for the proportion of circuli types observed on the scales of the 1972 brood year of sockeye salmon rearing in Chignik Lake, combined periods, 1974

Type	Annulus-adjusted circulus number							
	-10	-9	-8	-7	-6	-5	-4	-3
Annulus								
Cross-over						.02 ± .05	.02 ± .03	.05 ± .10
Fragment						<.01	.02 ± .03	.05 ± .08
Incomplete							<.01	.03 ± .03
Broken	.50 ± .50	.50 ± .40	.34 ± .32	.27 ± .27	.35 ± .10	.40 ± .10	.39 ± .16	.58 ± .18
Complete	.50 ± .50	.51 ± .40	.67 ± .32	.73 ± .27	.65 ± .10	.58 ± .11	.58 ± .13	.27 ± .11

Type	Annulus-adjusted circulus number							
	-2	-1	A	+1	+2	+3	+4	+5
Annulus			1.00					
Cross-over	.16 ± .06	.17 ± .06			<.01	.01 ± .02		
Fragment	.26 ± .16	.60 ± .08						
Incomplete	.05 ± .03	.04 ± .06		<.01	.02 ± .06	.05 ± .16		
Broken	.43 ± .18	.19 ± .13		.54 ± .11	.55 ± .11	.51 ± .33	.65 ± .18	.34 ± .52
Complete	.10 ± .10			.45 ± .13	.43 ± .10	.43 ± .19	.32 ± .18	.67 ± .52

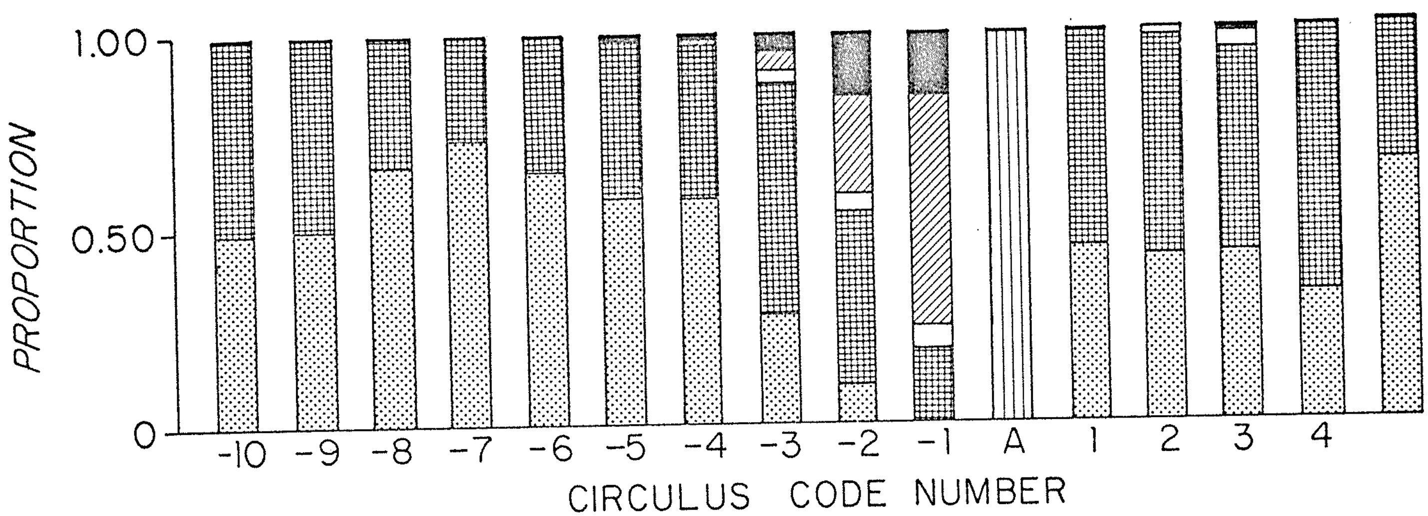

Fig. 27. The mean proportion of circuli types observed on the scales of the 1972 brood year of sockeye salmon rearing in Chignik Lake, combined periods, 1974.

Table 15. Dynamics of circuli formation for the 1973 brood year of sockeye rearing in Chignik Lake in 1974 by probable stock of origin

Date	Chignik Lake Age 0's				Mixed stocks Age 0's			
	Mean length	Mean number of circuli, 95% C.I.	Increase from previous period	Rate (circuli/day)	Mean length	Mean number of circuli, 95% C.I.	Increase from previous period	Rate (circuli/day)
July 12	32.9	(No scales collected due to small size)			48.7	5.15 ± 0.14		
August 6	(No fish of this age from this stock were captured)				49.5	5.29 ± 0.13	0.14	0.004
September 9	34.8	2.4 ± .60			54.4	6.17 ± 0.11	0.88	0.026
November 7	36.5	2.8 ± .49	0.4	0.007	57.0	6.64 ± 0.13	0.47	0.008

Spacing Between Circuli

Inspection of the data revealed no significant differences in the spacing between margin-adjusted circuli for these two groups of fish and the data were therefore combined. These data are presented in Fig. 28 and Appendix Table 7. These data illustrate that the distance between circuli near the focus is very similar but after 3 to 4 circuli a tendency for the spacing between circuli to decrease becomes pronounced. When the distances between circuli (-2/-1) are plotted for each sampling date this temporal pattern is more precisely defined, Fig. 29.

Types of Circuli

The proportion of types of circuli observed by sampling date are plotted in Fig. 30 and summarized in Appendix Table 8.

On July 12, the majority of the circuli observed on the focal side of circulus (-1) was complete. Broken circuli were observed frequently and incomplete or fragmented circuli observed occasionally. On August 6, interval (-2) showed a higher proportion of broken than complete circuli. On the focal side of this circulus, the pattern was similar to that observed previously. By September 9, a trend for circuli other than complete ones to dominate the pattern near the margin becomes apparent. This pattern was repeated in samples collected on November 7.

DISCUSSION AND CONCLUSIONS

The primary objective of this study was to provide the information required to resolve the discrepancies in freshwater age determination of Chignik sockeye which exist between readers and within readers over time. For the Black Lake stock we hypothesized that fry emigrating from Black Lake into Chignik Lake form a weak growth check due to differences in the limnological conditions between lakes and the faint nature of this accessory check led to reader indecision and inconsistency.

The results of this study show that no such accessory check was formed on the scales of the 1973 brood year. It is impossible to prove from these data that such a pattern was not formed in previous years. We believe, however, that if this was the source of error, then the chances of a false check not being formed are unlikely since the discrepancy has been found in every year where between reader tests have been conducted.

The presence of variation in the interpretation of age from a single scale read by a biologist at different times (*see* Narver 1963*a* or Burgner and Marshall 1974) illustrates that a single set of purely objective criteria (decision rules) was not consistently employed to determine the age. The magnitude of this variation is directly related to: 1) The individual consistency in applying his decision rules; and 2) the number of scales for which his decision rules produce no positive

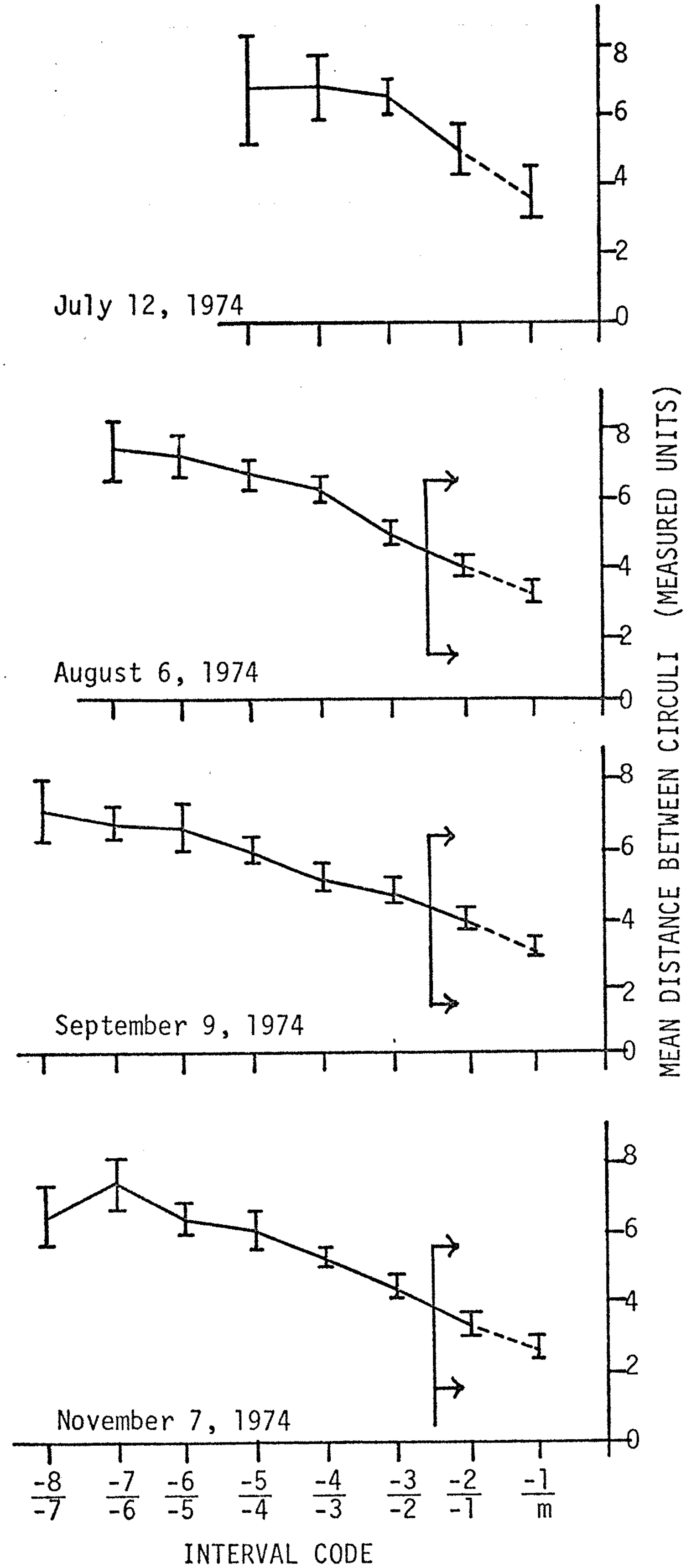

Fig. 28. Mean distance between adjoining circuli (margin-adjusted) on the scales of the 1973 brood year of sockeye salmon rearing in Chignik Lake, 1974.

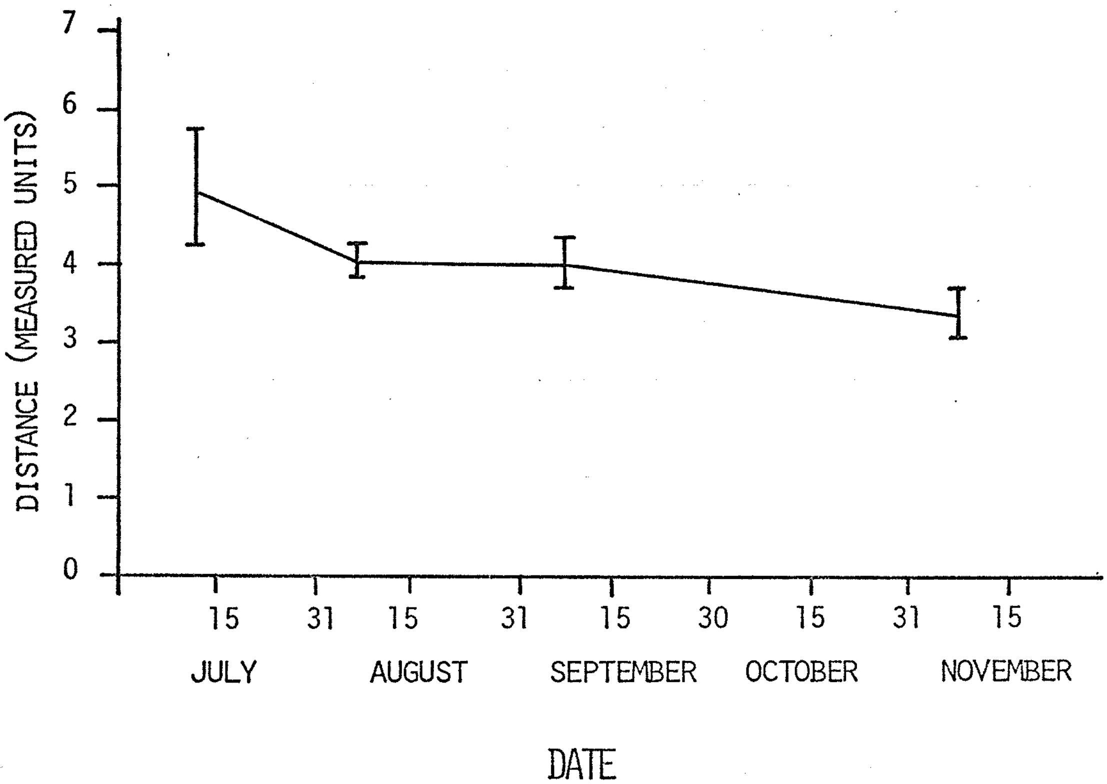

Fig. 29. The mean distances and 95 percent confidence intervals for the spacing between circuli (-2/-1) by date. 1973 brood year of sockeye salmon rearing in Chignik Lake, 1974.

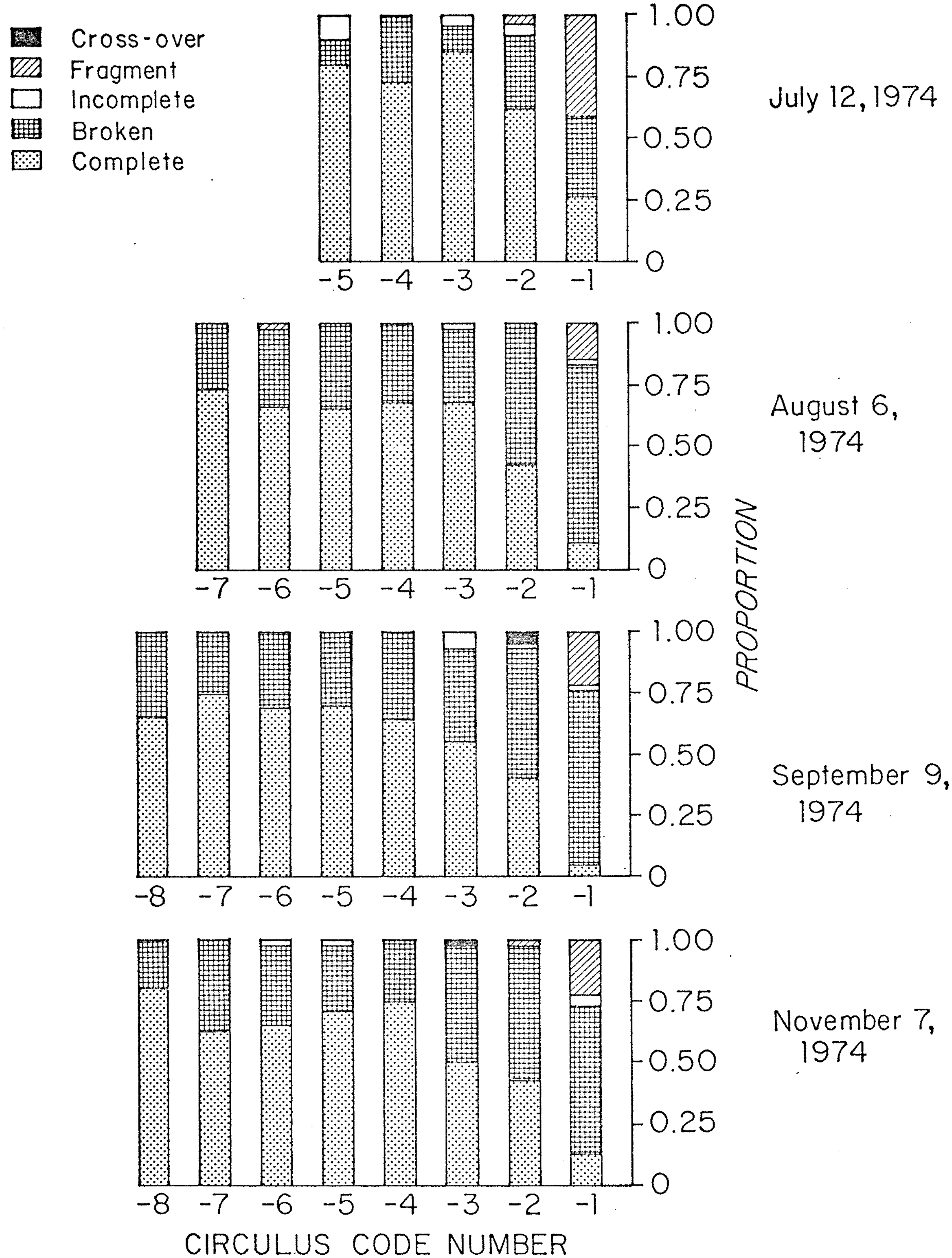

Fig. 30. The proportion of circuli types (margin-adjusted) occurring on the scales of the 1973 brood year of sockeye salmon rearing in Chignik Lake, 1974.

age determination and are, therefore, left open to the variability of subjective interpretation, i.e., the completeness of his set of decision rules. The presence of between reader variation demonstrates that either one, some, or all of the readers did not utilize a single set of purely objective decision rules in a consistent fashion or that each individual was using a purely objective set of decision rules, but the rules used varied between individuals. The magnitude of the discrepancy between readers is a complex interaction of all these sources of variation.

At the present time, it appears that the best method for eliminating variation in age readings is to plot scale curves for all fish which do not show distinct, clearly identifiable growth checks. The major problems associated with such a proposal are the time required to measure the scales, calculate the curve, and plot the result. We have however, as mentioned in the Methods and Materials section, developed a computer program[7] which accepts as input distance measurements made from the center of the focus to each circulus and outputs a completed graph along with the accompanying identification data. Since calculation and plotting account for the majority of the time in producing scale curves, we feel that the extra time spent in measuring ambiguous scales is well worth the effort.

While we cannot claim that such a procedure will produce accurate age determinations for all fish, it will eliminate reader variation and therefore allow the concerned agencies to agree upon and accept, at least on a tentative basis, one set of age readings. As a further step, we have proposed to determine the validity of age determinations made by this method utilizing daily growth patterns of otoliths[8].

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[7]Gales, L. 1975. Scale analysis (Fortran IV). Fisheries Analysis Center Computer Program No. FRG749. Fish. Res. Inst., Univ. Washington, Seattle, Washington. 12 pp. [Processed]

[8]Burgner, R. L. Chignik Lakes Research, Proposal to U.S. Dep. Commerce, NOAA, NMFS, dated April 1977.

PART II. PRELIMINARY REPORT OF FIELD ACTIVITIES IN 1976

Field activities in 1976 emphasized a cooperative study with ADF&G to evaluate alternative methods of apportioning returning adult sockeye into component stocks. This was accomplished by enumerating the Black Lake escapement as they migrated up Black River. The ADF&G provided a Bendix acoustic counter for this purpose. Except for brief periods when our weir washed out, counting was conducted continuously from June 7 through July 23.

Scales for use in aging and lengths were collected from 1,156 adults captured by beach seining at the outlet of Black Lake during the period June 19-June 30.

Spawning ground surveys were conducted in Black Lake and Black River tributaries during July and August to provide additional age composition data. In Black River tributaries 350 otoliths were collected. In Black Lake tributaries we collected otoliths from 467 adults and a scale and on otoliths from an additional 493 adults.

Results of our analysis of these data will be reported at the end of FY 1977.

PART III. SUMMARY EVALUATION OF CHIGNIK SOCKEYE RUNS

INTRODUCTION

This section of our report includes: 1) A brief summary of the available knowledge regarding the decline in abundance of Chignik sockeye; 2) an evaluation of the role that reallocating escapement has played in rebuilding the run; and 3) recommendations of further steps which could prove useful to rehabilitate these stocks.

Commercial exploitation of sockeye salmon at Chignik began in 1888. The trend in the catch is presented in Fig. 31. The annual harvest slowly increased until about 1907, then leveled off through the early 1920's. A drastic decline in the early 1920's was followed by about a 25-year period at an intermediate level of abundance. In the late 1940's a second decline in yield occurred and was followed by almost 20 years of extremely low yields. Since the late 1960's, yields have approximated those during the period 1925-1949.

Factors Relating to The Decline in Abundance

Changes in Size of Fish

A decrease in the average size of females escaping to spawn could have a pronounced effect upon potential egg deposition. This could occur through either a decrease in total ocean growth of females within an age class; a decrease in the average ocean age of returning females; or through selective removal by the fishery of the larger females.

Dahlberg (1968) has shown that for the years 1955-1966 there was no decrease in the average size of either male or female sockeye within each major ocean age class. Analysis of the number of fish per case also showed no decrease in the average weight through time. He also showed that there was no significant decrease in the average ocean age among the returning fish during the periods 1922-1933 and 1949-1966.

Roos[9] demonstrated that the purse-seine fishery which began operating in 1932 does not selectively harvest fish. Dalhberg (1968) concluded that the trap fishery which operated from 1895 until 1955 was nonselective.

A gillnet fishery operated at Chignik sporadically from 1932 to 1954. Mathisen (1967) has shown such fisheries to be selective in the Nushagak District of Bristol Bay. During this period, the gillnet

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[9] Roos, John F. 1960. Life history of red salmon *Oncorhynchus nerka* (Walbaum) at Chignik, Alaska. Univ. Wash. Fish. Res. Inst. 56 pp. [unpublished manuscript]

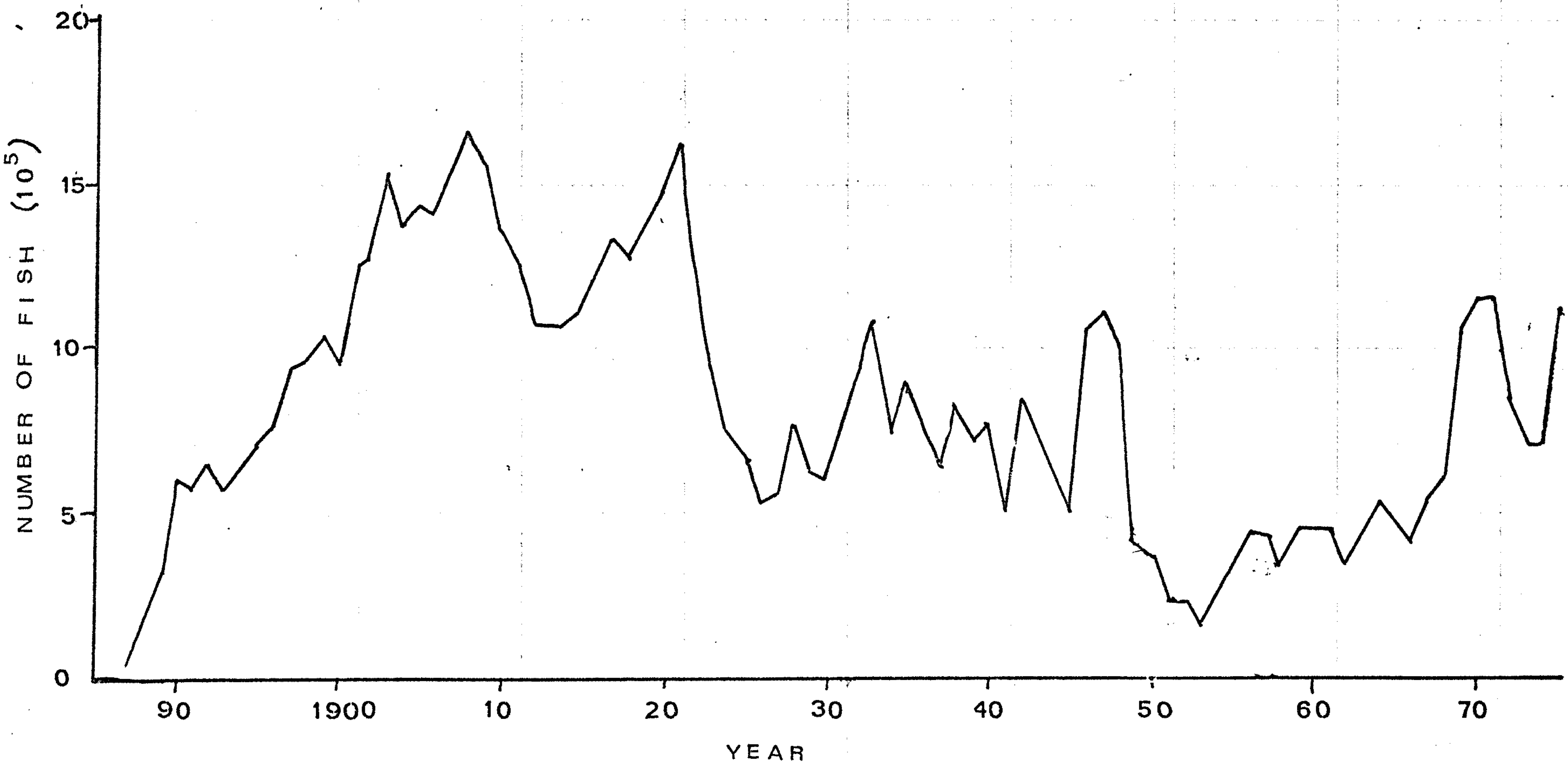

Fig. 31. Commercial catches of Chignik sockeye salmon, 1895-1976. Data were smoothed by a moving average of three.

fishery took an average of 1.7 percent of the catch and in any year it never took more than 5.2 percent of the catch. We believe that due to its limited nature, this fishery was insignificant in producing any long-term changes in production.

All available information suggests that changes in the average size of females escaping to spawn has not been contributory to the decline in abundance of these stocks.

Loss of Races

No direct evidence is available to determine whether or not races of sockeye within the system have disappeared. If races did disappear, it would be difficult to determine what role, if any, this factor played in the decline. Narver (1963*a*) identified eight major and five minor spawning groups within the system based in part upon time and location of spawning. Recent estimates of the relative density of spawners in Chiaktuak, Bearskin, West Fork, Cucumber Creek, and others, suggests that these areas are underutilized in many years. Whether or not they supported large numbers of spawners historically is unknown.

The current importance of potentially "lost" races to the production of the system is best evaluated in the current ability of the nursery lakes to support fry if they had not been "lost." The carrying capacity of the nursery lakes is discussed in detail in other sections.

Loss of Spawning Areas

A loss of spawning habitat could result in high densities of spawners and cause superimposition of eggs and excessive compensatory mortality. There is no evidence to suggest that such a loss of habitat occurred during or since the decline. Dahlberg (1968) postulated that minor losses may have occurred but that the current spawning area is adequate. This conclusion is supported by Phinney's (1970) compilation of available spawning area.

Weather

Dahlberg (1968) believed that the disproportionate decline between stocks together with the small size of the watershed indicated that climatic conditions did not cause the decline. Mathisen (1967) and Rogers (personal communication) dismissed the notion that climatic conditions caused the decline in abundance of the Nushagak stocks. Rogers believes, however, that the abnormally cold winters of the early 1940's may have contributed to the failure of the five successive brood years which preceded the decline. While no extensive studies have been conducted on the role climatic conditions played in the decline of sockeye stocks at Chignik, current evidence suggests that climatic conditions probably did not cause, but may have contributed to, the declines.

Predation

Three species of fish, Dolly Varden char (*Salvelinus malma*), coho salmon (*O. kisutch*), and sculpins (*Cottus* sp.), have been shown to be predators on juvenile sockeye in the Chignik system. The paucity of information regarding both the abundance of and feeding rate by these species prior to and during the decline precludes a definitive study regarding the role predation may have played in the decline.

An understanding of the current role predation is playing in controlling production would be useful, however, in evaluating alternative rehabilitation schemes.

Roos (1959) reported on the feeding habits of Dolly Varden in Chignik Lake and Chignik River during the summers of 1955 and 1956. He found that 9 percent of those fish which had been feeding contained young sockeye. This was equivalent to 0.1 sockeye fry per stomach examined. Insects, primarily caddis and Diptera larvae, were found most commonly. Sculpin, smelt, blackfish, and stickleback were found occasionally. The incidence of feeding on young sockeye was highest in swift waters where the movement of the young sockeye was restricted, e.g., below the outlet of Chignik Lake. He concluded that the Dolly Varden was not a serious predator on sockeye at Chignik.

Roos (1959) and Narver and Dahlberg (1965) reported on the feeding habits of the Dolly Varden in Chignik Lagoon during the late spring of 1959 and the summer of 1963. Roos (1959) found no sockeye in the stomachs he examined. Sampling was conducted one week prior to the peak smolt emigration and he believed that there were few sockeye in the area where sampling was conducted. Narver and Dahlberg (1965) reported that juvenile sockeye represented only 0.3 percent of all food items found. Amphipoda (46.1 percent), Pacific sand lance (20.2 percent), and whitespotted greenling (10.6 percent) were the most numerous. Juvenile sockeye were estimated to be more abundant in the lagoon during sampling than the fish which were eaten more frequently. They felt the high mortality of sockeye in relation to the other fish species captured may explain this selection. Both studies concur that predation by Dolly Varden on sockeye in Chignik Lagoon during the period when it is being utilized as a secondary nursery area (Phinney 1968) is insignificant.

Burgner and Marshall (1974) reported on the feeding habits of Dolly Varden captured in Black Lake and Black River, and Chignik Lake and Chignik River during the summers of 1970 and 1971. Significant differences were present between this study and Roos (1959); among them:

1. Dolly Varden were found to feed upon juvenile sockeye in Chignik Lake (9.3 percent of fish containing food). Roos found no such feeding.

2. A higher incidence of feeding on sockeye by Dolly Varden in the 10-50 cm length group was noted.

3. Predation on age 0 sockeye in Chignik River was higher, but predation was lower on ages I and II.

4. On a volumetric basis, without regard for fish size, stomach fullness, sample location, or date of capture, juvenile sockeye accounted for about 41 percent of the stomach contents, followed by insects (30 percent) and miscellaneous items (13 percent).

Some notable similarities were:

1. The incidence of feeding on juvenile sockeye was highest in Chignik River.

2. Cottids were the most important nonsockeye fish food item.

New information on the feeding habits of Dolly Varden in Black Lake and Black River indicated:

1. Insects were the most frequently found item (93 percent of feeding fish) followed by algae (82 percent of feeding fish).

2. Sockeye were found infrequently (4.5 percent of feeding fish).

3. While Black Lake supports large populations of pond smelt, stickleback, and sculpin, only one fish of these species was found.

Burgner and Marshall (1974) concluded that overall, predation by Dolly Varden on juvenile sockeye within the Chignik lakes appeared to be higher than reported by Roos (1959). However, since both of these studies were conducted in the late spring and summer when population levels are lowest (Roos 1959) and the size of the population of Dolly Varden was unknown, conclusions regarding the importance of Dolly Varden as a predator could not be made.

Chignik coho migrate to sea at ages I, II, and III (Israel 1933). In recent years most have migrated at age II (Shaul and Rigby 1975). Estimates of numbers of fish spawning by year are incomplete because returning fish generally enter the system in August and September after the ADF&G weir is removed. Catch of cohos for the years 1960-1975 has ranged from about 1,200 to 53,000 and averaged about 13,000, but since this fishery is sporadic, catch data are a poor indicator of abundance.

Roos (1960) reported on the stomach contents of juvenile coho collected from May through July in the years 1956, 1957, and 1959. For those fish which had been feeding, 30 percent contained sockeye, averaging

2.3 sockeye per stomach. This was equivalent to 0.7 sockeye per coho stomach for all juvenile coho sampled. Eighty-seven percent of all stomachs examined contained insects. Sockeye salmon were the only fish species eaten.

Burgner and Marshall (1974) reported on the food habits of coho collected throughout the lake system in 1970 and 1971. Sockeye were found in 18.9 percent of coho with food in stomachs for an average of 0.21 sockeye per all fish examined. (The incidence of feeding on other fish species was very low. Insects were the most common item found.)

In general, Roos (1959) found a higher incidence of feeding on sockeye by larger coho than did Burgner and Marshall (1974).

As with Dolly Varden, estimates of feeding rates during other seasons of the year and the population size and distribution is needed in order to assess the role coho predation plays in the Chignik system.

Sculpin are abundant within the watershed. Roos (1959) reported observations of sculpin feeding on sockeye fry in Chignik River. No quantitative studies have been made on the food habits of this species; however, Roos hypothesized that sculpin act as a predation buffer for sockeye against Dolly Varden.

In summary, the role predation may have played in the decline of Chignik sockeye is unknown. It is reasonable to hypothesize, however, that as the abundance of fry in the lakes decreased, predation may have become more important if predators took a fixed number, rather than a proportion of the population (Dahlberg 1968).

Compensatory Mortality

Dahlberg (1968) showed significant decreases in the $\log_e$ return per spawner (Ln (R/S)) at fixed densities of spawners between the periods 1922-1933 and 1949-1960 for each major stock (Figs. 32 and 33).[10] He interpreted the decrease to mean that the population had lost some of its potential for increase. The hypotheses which have been formulated to explain the decreased productive potential are outlined below.

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[10]Narver (1963*a*) identified eight major and five minor spawning stocks within the Chignik system based on lacustrine scale patterns and age, time-of-entry, and time and location of spawning. Further studies (Narver 1966) showed, however, that nursery lake rearing area of the stocks was the most important criterion governing production. Based upon this character, there are two major stocks, Chignik Lake and Black Lake.

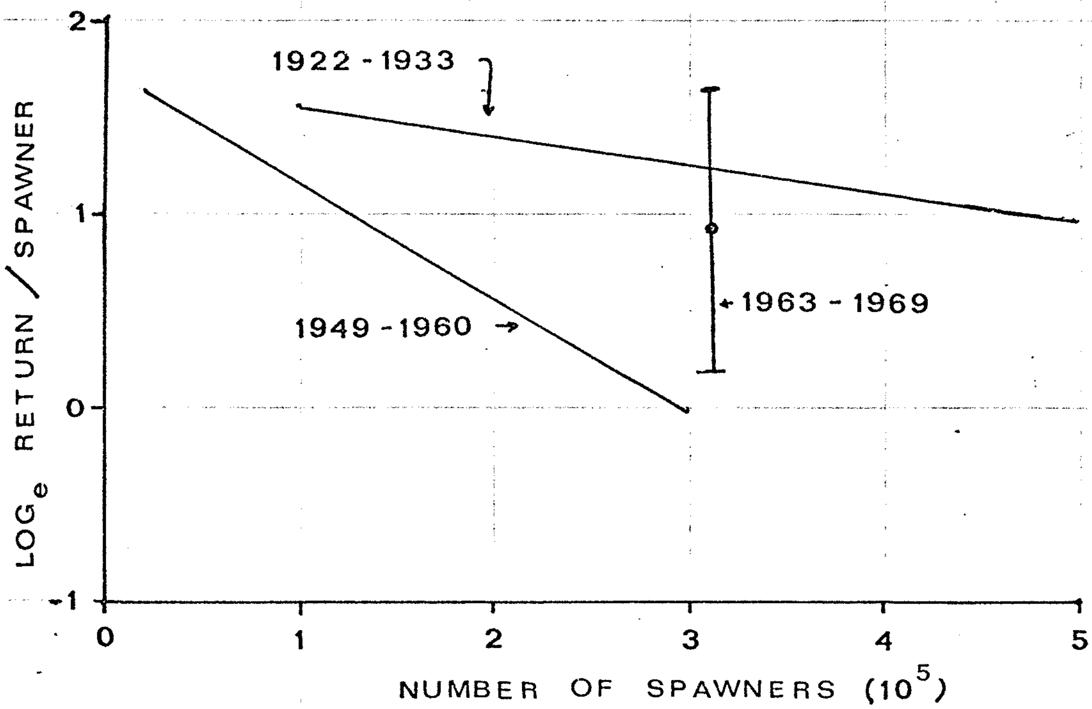

Fig. 32. The relationship between the natural logarithm of the return per spawner and the abundance of spawners, Black Lake stock.

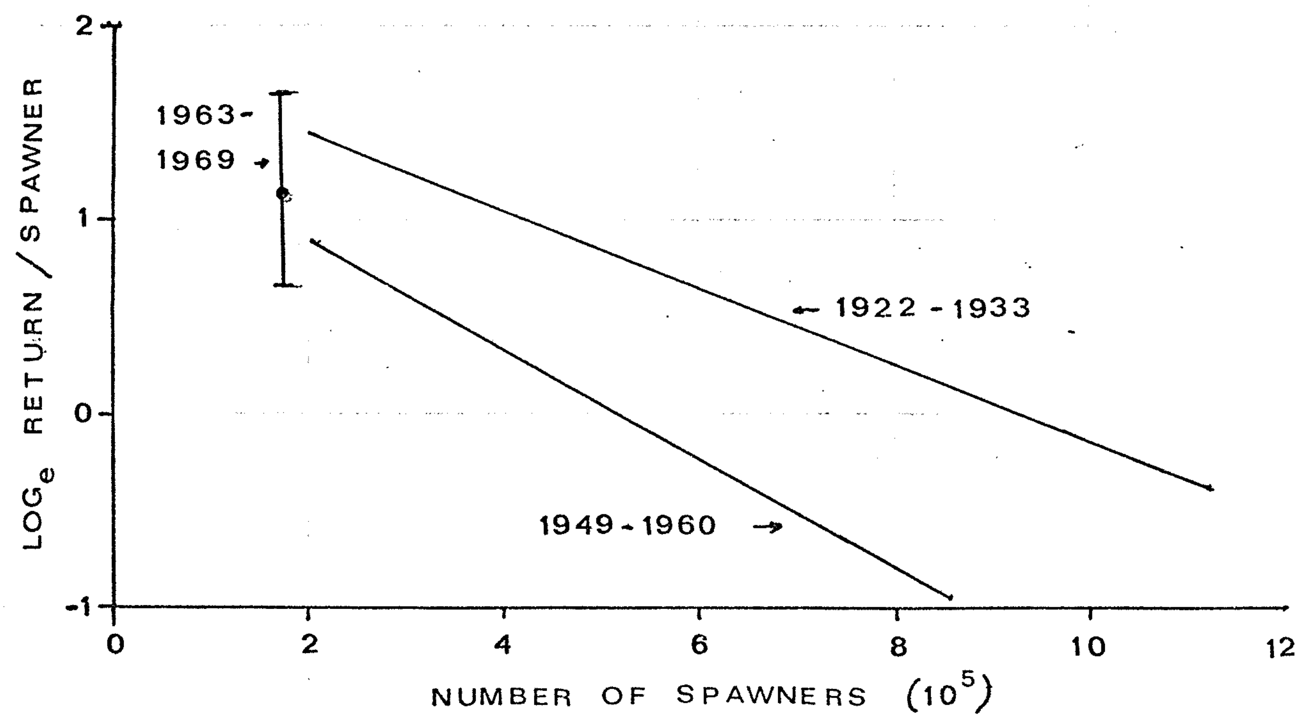

Fig. 33. The relationship between the natural logarithm of the return per spawner and the abundance of spawners, Chignik Lake stock.

Dahlberg (1968) showed that escapements were significantly lower during the period 1949-1960 than during 1922-1933. Black Lake stocks received 40 percent and Chignik Lake stocks 58 percent of their former average escapements.

In Black Lake, Narver (1966) and Dahlberg (1968) believed that consistent underescapements provided an opportunity for competitor species (threespine stickleback, *Gasterosteus aculeatus*; ninespine stickleback, *Pungitius pungitius*; and pond smelt, *Hypomesus olidus*) to increase in abundance. This reduced the carrying capacity for sockeye in Black Lake.

When the carrying capacity for sockeye is exceeded, a midsummer fry emigration occurs. In some years small numbers of lake resident fish also emigrate. The emigration, along with reduced growth rates in years of high abundances of all fish, acts as population regulating mechanisms (Narver 1963*a*, 1966; Parr 1972; Burgner and Marshall 1974).

Typically, upon entering Chignik Lake, emigrant fry do not continue to grow at the same rate as their cohorts which remained in Black Lake (Narver 1966; Marshall, this report). The decreased growth rate is apparently due to intraspecific competition (Narver 1966; Parr 1972).

Narver (1966) has shown that Black Lake fry which reach about 70 mm at the end of their first year's lacustrine residence smolt at age I. This size is achieved in every year by virtually all fish which remain in Black Lake. Emigrant fish typically do not reach this threshold for smoltification. The result is that emigrant fry usually spend a second year in Chignik Lake prior to smolting.

The hypothesized tendency for a larger proportion of the fry of each brood year to emigrate during the period 1949-1960 than during the period 1922-1933 because of greater interspecific competition concurs with Dahlberg's (1968) observation that the percentage of age 2.3 spawners has increased from 19 percent to 38 percent between these periods.

Narver (1966) and Dahlberg (1968) disagreed somewhat on factors contributing to an increase in compensatory mortality for the Chignik Lake stock. Narver (1966) identified intraspecific competition among juvenile sockeye rearing in Chignik Lake as the significant density-dependent force. He pointed out that fry emigrations from Black Lake intensified the competition. Roos (1958) and Narver (1966) reported that severe intraspecific competition apparently caused mass starvation in the springs of 1958 and again in 1960. Narver (1966) believed, however, that Chignik Lake was currently capable of supporting as many fry as it did prior to the first decline.

Dahlberg (1968) acknowledged findings of Burgner et al. (1969) that Chignik Lake was one of the most productive sockeye salmon nursery lakes which has been studied in southwest Alaska. He noted, however, that during the period 1949-1960 the escapements to the entire system averaged 5.61×10^5. This is less than the average number (6.35×10^5) of spawners which the Chignik Lake stock supported during the period 1922-1933. Dahlberg felt the reduced escapement (and presumably therefore fewer fry rearing in the lake) coupled with an increase in the average freshwater age during the two periods suggested that a change in the productivity of the lake may have occurred. Dahlberg believed that a decrease in the abundance of spawning salmon might lead to a decrease in the overall productivity of the nursery lakes. This could occur if the contribution of nutrients (especially phosphorus and nitrogen) which decomposing salmon carcasses supply represent a significant contribution to the system. He felt, however, that only by observing the effects of reallocating the escapements by monitoring the ecological conditions within the system could final judgment be made regarding this point.

THE CONTROLLED ESCAPEMENT PLAN

The results of two major studies (Narver 1966; Dahlberg 1968) strongly suggested that a major factor contributing to the decline in abundance of Chignik sockeye during the late 1940's was consistent underescapement, poorly allocated between the major stocks. Independent estimates of optimum escapements from these studies were made (Table 16). From these data the ADF&G set escapement goals of 375,000 for Black Lake tributaries and 275,000 for Chignik Lake and Black River spawning areas. Escapements were held below the 1922-1933 optimum of 340,000 in Chignik Lake to allow for the emigration of fry from Black Lake. Beginning in 1963, these goals were met or exceeded in most years. We now have the returns through the 1969 brood year to evaluate the effectiveness of this strategy in rebuilding the Chignik runs.

The relationships between the Ln R/S[11] and number of spawners for the Black Lake stocks during three time periods--1922-1933, 1949-1960, and 1963-1969--are plotted in Fig. 31. The lack of any significant linear relationship during the period 1963-1969 is due to the high variation in the Ln R/S and the limited range of spawning stock sizes observed during this period. Plotted, therefore, is the mean Ln R/S and the 95 percent confidence interval at the mean spawning stock size. The best estimate of the Ln R/S during the period 1963-1969 is 0.81 (which corresponds to an arithmetic mean - (AM) R/S of 3.36).[12] Based on these data, increased escapements to Black Lake, coupled with decreased escapement to Chignik Lake have decreased compensatory mortality for this stock in relation to the period 1949-1960. The mean Ln R/S during 1963-1969 of 0.81 is lower, but not significantly so, that the predicted Ln R/S of 1.18 (AM = 6.23) at the same density of spawners during the period 1922-1933. Return per spawner relationships for the Chignik stock is presented in Fig. 33. A linear relationship was not found

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[11]Ln R/S = Natural logarithm of number of returning adults produced per spawner.

[12]Arithmetic means were calculated from the relationship $\log_{10}(AM/GM) = 0.2172\, s^2\, (N-1)/N$ (Ricker, 1975).

Table 16. Optimum escapements for the Chignik lakes

Nursery lake	Time period	Narver (1966)	Dahlberg (1968)
Black	1922-33		383,000
	1960s	411,000	383,000
Chignik[1]	1922-33		395,000
	1960s	256,000	256,000

[1]Includes Black River spawners.

during the period 1963-1969. The reasons for this are the same as previously discussed. During the period 1922-1933 a predicted Ln R/S at the average density of 1.82×10^5 spawners was 1.50 (AM = 4.8); during 1949-1960 the value fell to 0.95 (AM = 2.75). Production in recent years has averaged 1.17 (AM = 3.81). While the mean Ln R/S in recent years falls between the predicted Ln R/S during the other time periods, they are not statistically different.

By combining the stocks we can look at changes in the compensatory mortality for the system as a whole. These data are presented in Fig 34. Once again, no significant linear relationship was present for the period 1963-1969. The mean Ln R/S for this period was 0.96 (AM = 3.05). This is lower than the expected mean Ln R/S during 1922-1933 of 1.24 (AM = 3.94) but higher than 0.64 which occurred during the period 1949-1960 (AM = 1.94).

Because the reduced yields in the 1950's and early 1960's were associated with an increase in the average lacustrine age, it is germane to determine what the age composition trend has been in recent years. Fig. 35 summarizes the percentage of age 2.- fish in the returns by stock for the years 1922-1937 and 1955-1975.[13] For the Black Lake stock the increase in the Ln R/S during recent years has been accompanied by a decrease in the proportion of age 2.- fish. For the Chignik Lake stock, the proportion of age 2.- spawners has remained relatively constant--an increase during 1974-1975 is evident, however.

Factors Relating to Variable R/S in Recent Years

The regression of the percentage of age 1.- fish in the returns on the Ln R/S for the 1963, 1965-1969 brood years of Black Lake sockeye is represented in Fig. 36.[14] These data demonstrate that in recent years when the optimum escapement has been approximated, the variation in year class survival is related to the freshwater age structure of the smolt population. In previous sections, we have demonstrated that only those fry which emigrate into Chignik Lake will spend two years in the lacustrine environment. The most plausible hypothesis to explain this variable reproduction based upon these factors is that emigrant fry experience excessive mortality during their residence in Chignik Lake. An important corollary of this hypothesis is that this mortality is not offset by increased estuarine survival of age II smolts due to any larger size which they may achieve.

For the Chignik Lake stock, variation in the Ln R/S during the period 1963-1969 is inversely related to abundance of yearlings in Chignik Lake during the year when fry of these brood years were present

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[13]Fish which reared two years in freshwater before smoltifying.

[14]The 1964 brood year data were omitted because the escapement was only 1.37×10^5 and this represents only 39 percent of the optimum.

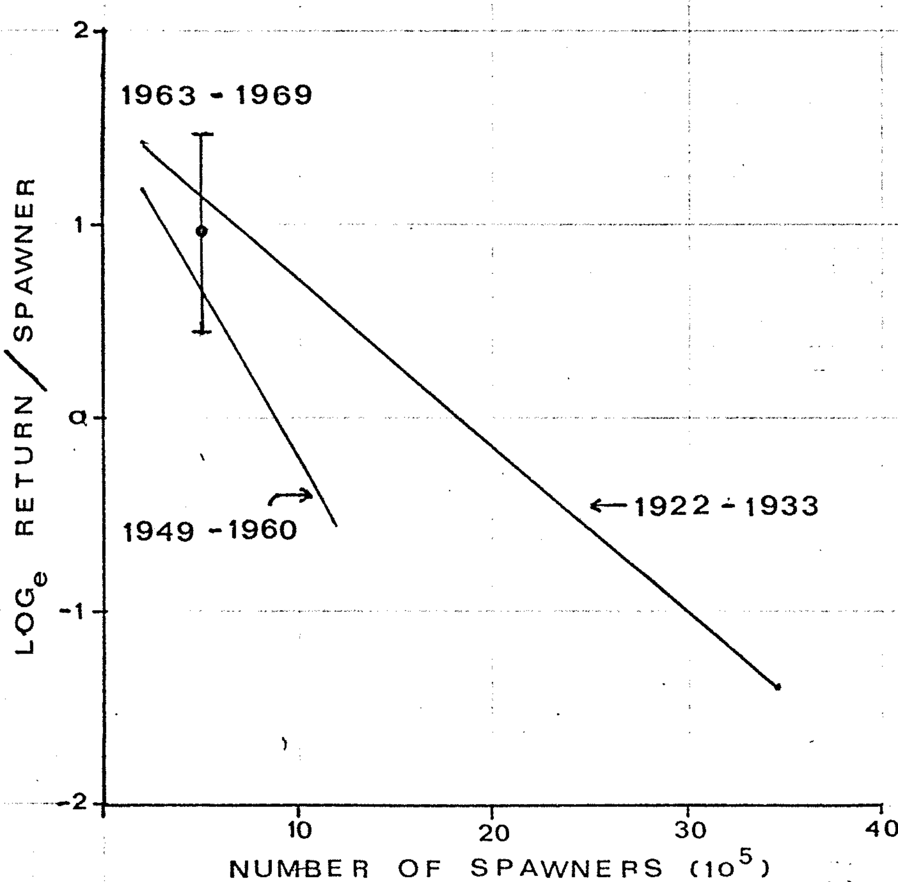

Fig. 34. The relationship between the natural logarithm of the return per spawner and the abundance of spawners, combined stocks.

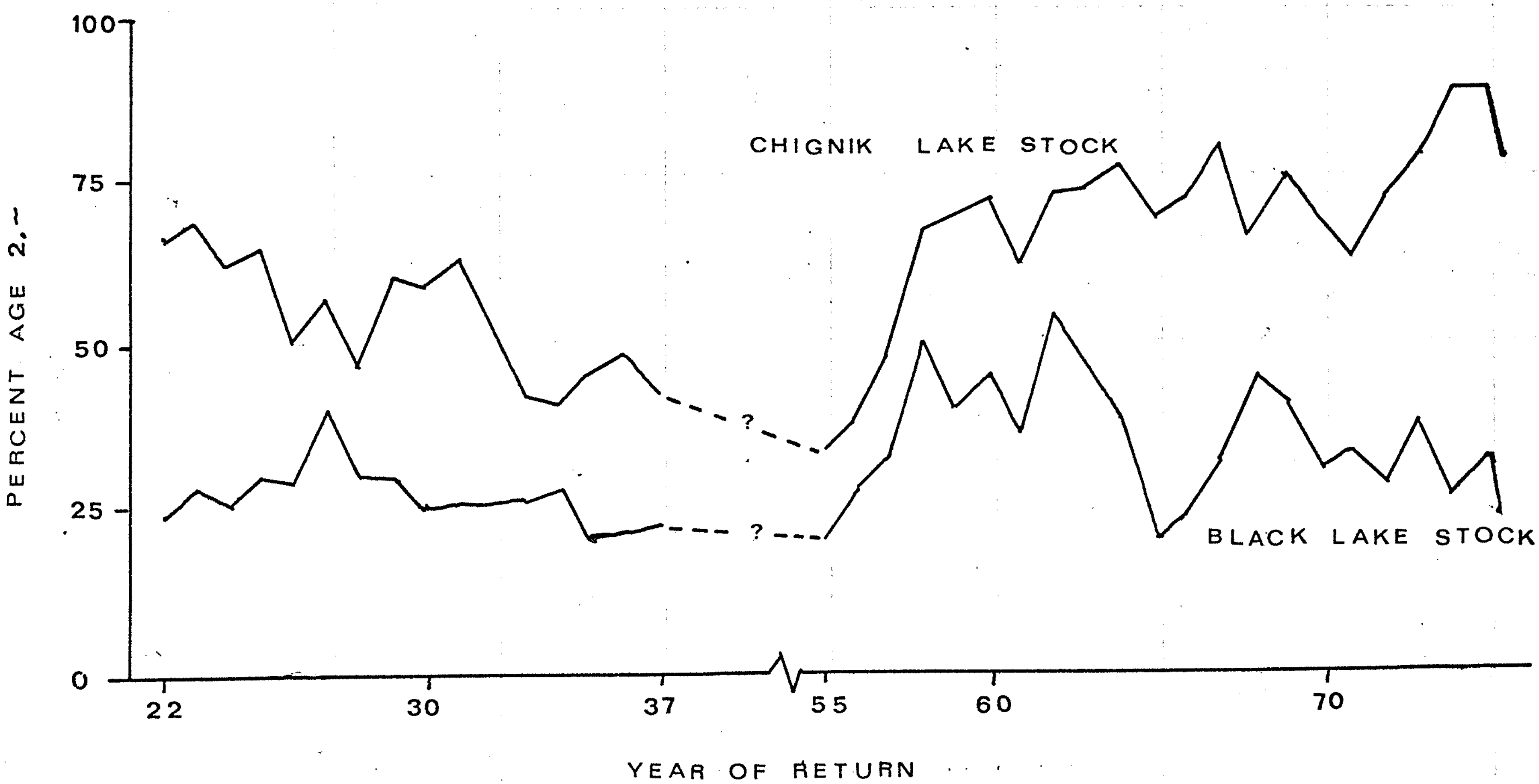

Fig. 35. The percent of age 2.- fish in the yearly returns to the Chignik lakes, by stock, 1922-1937 and 1955-1976. The data were smoothed by a moving average of three.

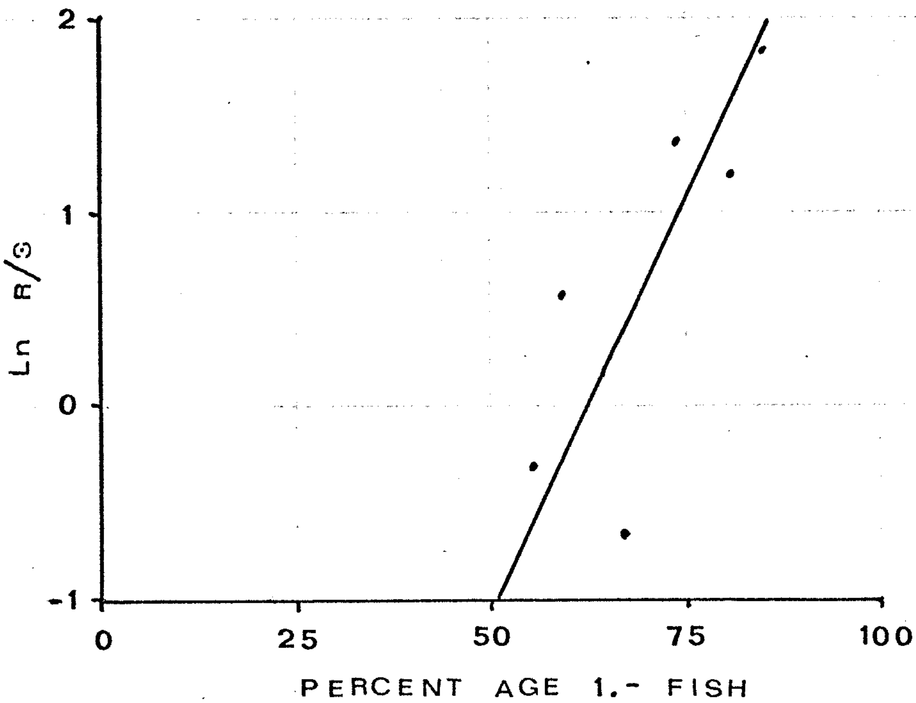

Fig. 36. The relationship between the natural logarithm of the return per spawner and the percent og age 1.- fish in the returns by brood year, Black Lake stock, 1963, 1965-1969.

in the lake (Fig. 37). These data tend to support Dahlberg's (1968) hypothesis that high abundances of larger age I fingerlings adversely affect the survival of late emerging fry. He speculated that severe intraspecific competition, in which larger juveniles have a competitive advantage, could account for the decrease in abundance of the late entering Chignik Lake stocks that has been observed since the 1920's.

High abundances of age I fingerlings in Chignik Lake in a year are the result of: 1) Fry emigrations from Black Lake during the preceding year; 2) the abundance of Chignik spawners two years previous; and 3) growing conditions within the lake the preceding year which determines what proportion of the fry (age 0's) of both stocks which will reach the threshold size for smoltification at age I. These data strongly suggest that the productive potential for Chignik Lake is high but that on the average, given the current ecological conditions, we cannot expect Chignik Lake to produce at the 1920's level due to the severe intraspecific competition which occurs in many years.

CONCLUSIONS

The decrease in compensatory mortality for the Black Lake stock in recent years suggests that Narver's (1966) hypothesis that increased abundances of fry in Black Lake achieved through increased escapements has been instrumental in increasing the carrying capacity for sockeye in the lake. Other supporting evidence includes: Reduced growth rates and abundances of sticklebacks in years of high abundances of sockeye (Parr 1972); a general decrease in the abundance of competitor species in Black Lake since the early 1960's (Burgner and Marshall 1974); a decrease in the average lacustrine age for the stock since the early 1960's.

We believe, however, that, since the level of compensatory mortality has not returned to its former level (which is apparently related to fry emigrations and excessive mortality associated with a second year's lacustrine residence), to date the experiment has been only partially successful. We feel that further long-term increases in the production from this stock must be dependent on further reductions in the level of interspecific competition in Black Lake and intraspecific competition in Chignik Lake.

The present management strategy for Chignik stock which allows the fry from 275,000 spawners plus emigrants from Black Lake to rear in Chignik Lake appears to be severely taxing the lake's carrying capacity in many years. This conclusion is based upon evidence of: 1) Reduced growth rates of fingerlings in years of high abundances of all sockeye (Parr 1972); 2) the apparent causal relationship between high abundances of fingerlings and poor returns of the fry in the lake during the same time period; and 3) a continued high proportion of age 2.- adults.

We believe that basic changes in the carrying capacity of Chignik Lake have occurred because: 1) The total number of juveniles which Chignik Lake currently supports is apparently less than the total number

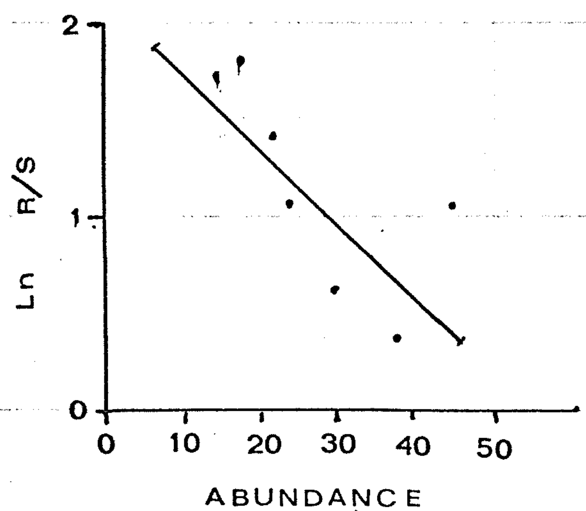

Fig. 37. The relationship between the natural logarithm of the return per spawner (for brood year i) and the abundance of age I juveniles in Chignik Lake in year i+1, Chignik Lake stock, 1963-1969.

it supported during the period 1922-1933; 2) interspecific competition is insignificant; 3) we have evidence of mass starvation in some years; and 4) increased predation (if it occurred) would not account for increased average freshwater age. The most probable explanation for the reduction in lake carrying capacity is a reduction in the forage base.

Reductions in the forage base within sockeye nursery lakes have been hypothesized to be related to a decrease in the input of inorganic nutrients as a result of decreased escapements (Nelson and Edmonson 1955; Nelson 1959; Donaldson 1967; Parsons 1972; Rogers 1976). For the Chignik system an average annual harvest for the years 1888-1975, of 828,700 fish has resulted in an estimated average yearly loss of 9.76 tons of phosphorus and 101.5 tons of nitrogen. If these quantities represent a significant contribution to the nutrient pools on which primary production and in turn secondary production depend, then increased compensatory mortality, acting through increased intraspecific competition for food, may help explain the decreased production from these stocks.

We believe that efforts to rebuild the Chignik stock should be directed toward evaluating the role of increasing the inorganic nutrient supply to the lake through artificial fertilization.

All the available evidence strongly suggests that escapements to the Chignik stock should not be increased to the 1920's optimum of 395,000.

LITERATURE CITED

Burgner, R. L. 1962. Studies of red salmon smolts from the Wood River lakes, Alaska. Univ. Washington, Publ. in Fish., New Ser. 1:247-314.

Burgner, R. L., C. J. DiCostanzo, R. J. Ellis, G. Y. Harry, Jr., W. L. Hartman, O. E. Kerns, Jr., O. A. Mathisen, and W. F. Royce. 1969. Biological studies and estimates of optimum escapements of sockeye salmon in the major river systems in southwestern Alaska. U.S. Fish Wildl. Serv., Fish. Bull. 67(2):405-459.

Burgner, R. L., and S. L. Marshall. 1974. Optimum escapement studies of Chignik sockeye salmon. Univ. Washington, Fish. Res. Inst. Final Rep. (July 1, 1972-June 30, 1973) FRI-UW-7401. 91 pp.

Cassie, R. M. 1954. Some uses of probability papers in the analysis of size frequency distributions. Aust. J. Mar. Freshwater Res. 5:513-522.

Clutter, R. I., and L. E. Whitesel. 1956. Collection and interpretation of sockeye salmon stocks. Int. Pac. Salmon Fish. Comm., Bull. 9. 159 pp.

Dahlberg, M. L. 1968. Analysis of the dynamics of sockeye salmon returns to the Chignik lakes, Alaska. Ph.D. Dissertation, Univ. Washington, Seattle. 337 pp.

Dahlberg, M. L., and D. E. Phinney. 1967. Studies of mature sockeye salmon at Chignik, 1966. Univ. Washington, Fish. Res. Inst. Circ. 67-7. 41 pp.

Dahlberg, M. L., and D. E. Phinney. 1968. A microprojector for use in scale studies. The Progr. Fish-Cult. 30(2):118-119.

Donaldson, J. R. 1967. The phosphorus budget of Iliamna Lake, Alaska, as related to the cyclic abundance of sockeye salmon. Ph.D. Dissertation, Univ. Washington, Seattle. 153 pp.

Dunlop, H. A. 1924. The growth rate of the scales in the sockeye salmon, *Oncorhynchus nerka*. Contrib. to Canad. Biol.; studies from Biol. Sta. Can., New Ser. 2(10):151-159.

Fraser, C. M. 1920. Growth rate in the Pacific salmon. Trans. Roy. Soc. Can., Ser. 3, 13:163-226.

Gilbert, C. H. 1914. Age at maturity of the Pacific Coast salmon of the genus *Oncorhynchus*. U.S. Fish. Bull. 32:3-22.

Harding, J. P. 1949. The use of probability paper for the graphical analysis of polymodal frequency distributions. J. Mar. Biol. Assoc. U.K. 28:141-153.

Higgins, E. 1930. *In* Progress in biological inquiries, 1928. U.S. Bur. Fish., Rep. Comm. Fish. for 1929. Append. X:645.

Higgins E. 1932. *In* Progress in biological inquiries, 1930. U.S. Bur. Fish., Rep. Comm. Fish. for 1931. Append. III:558.

Higgins, E. 1934*a*. *In* Progress in biological inquiries, 1932. U.S. Bur. Fish., Rep. Comm. Fish. for 1933. Append. II:106-107.

Higgins, E. 1934*b*. *In* Progress in biological inquiries, 1933. U.S. Bur. Fish., Rep. Comm. Fish. for 1933. Append. III:342-343.

Higgins, E. 1936. *In* Progress in biological inquiries, 1934. U.S. Bur. Fish., Rep. Comm. Fish. for 1934. App. III:364.

Israel, H. R. 1933. On the life history of the silver salmon, *Oncorhynchus kisutch* (Walbaum), of Chignik River, Alaska. M.A. Thesis, Stanford Univ., Palo Alto, California. 58 pp.

Koo, T. S. Y. 1955. Biology of the red salmon, *Oncorhynchus nerka* (Walbaum), of Bristol Bay, Alaska as revealed by a study of their scales. Ph.D. Dissertation, Univ. Washington, Seattle. 164 pp.

Marshall, S. L., R. L. Burgner, and J. J. Dawson. 1974. Chignik sockeye studies, Anadromous Fish Project Final Report for period ending June 30, 1974. AFC-48 Segment 1. Univ. Washington, Fish. Res. Inst., FRI-UW-7405. 27 pp.

Mathisen, O. A. 1967. Past and present escapement levels in the Nushagak system. Pages 8-14 *in* Fisheries Research Institute presentation at the Twenty-Ninth Annual Canned Salmon Cutting Demonstration and Technical Conference. Held at the Olympic Hotel, Seattle, March 7, 1967. Univ. Washington, Fish. Res. Inst. Circ. 67-12.

Mosher, K. H. 1968. Photographic atlas of sockeye salmon scales. U.S. Fish Wildl. Serv., Fish. Bull. 67(2):243-280.

Narver, D. W. 1963*a*. Identification of adult red salmon groups by lacustrine scale measurements, time of entry, and spawning characteristics. M.S. Thesis, Univ. Washington, Seattle. 96 pp.

Narver D. W. 1963*b*. Chignik red salmon studies. Pages 19-21 *in* T. S. Y. Koo, ed. Research in Fisheries, 1962. Univ. Washington, Coll. Fish. Contrib. 147.

Narver, D. W. 1966. Pelagial ecology and carrying capacity of sockeye salmon in the Chignik lakes, Alaska. Ph.D. Dissertation, Univ. Washington, Seattle. 348 pp.

Narver, D. W., and M. L. Dahlberg. 1965. Estuarine food of Dolly Varden at Chignik, Alaska. Trans. Amer. Fish. Soc. 94(4):405-408.

Nelson, P. R. 1959. Effects of fertilizing Bare Lake, Alaska, on growth and production of red salmon. U.S. Fish Wildl. Serv., Fish. Bull. 60(159):59-86.

Nelson, P. R., and W. T. Edmondson. 1955. Limnological effects on fertilizing Bare Lake, Alaska. U.S. Fish Wildl. Serv., Fish. Bull. 56(102): 415-436.

Pannella, G. 1971. Fish otoliths : daily growth layers and periodical patterns. Science 173:1124.

Pannella, G. 1974. Otolith growth patterns: an aid in age determination in temperate and tropical fishes. Pages 28-39 *in* T. B. Bagenal, ed. Aging of fish. Unwin Bros.

Parr, W. H., Jr. 1972. Interactions between sockeye salmon and alke resident fish in the Chignik lakes, Alaska. M.S. Thesis, Univ. Washington, Seattle. 103 pp.

Parr, W. H., and P. C. Pedersen. 1969. Studies of adult sockeye salmon at Chignik in 1968. Univ. Washington, Fish. Res. Inst. Circ. 69-16. 40 pp.

Parsons, T. R., K. Stephens, and M. Takahashi. 1972. The fertilization of Great Central Lake. I. Effect of primary production. NOAA Fish. Bull. 70(1):13-23.

Phinney, D. E. 1968. Distribution, abundance, and growth of postsmolt sockeye in Chignik Lagoon, Alaska. M.S. Thesis, Univ. Washington, Seattle. 159 pp.

Phinney, D. E. 1970. Spawning ground catalog of the Chignik River system, Alaska. U.S. Fish Wildl. Serv., Data Rep. 41. 147 pp. on 3 microfiche.

Phinney, D. E., and J. Lechner. 1969. Studies of adult Chignik sockeye salmon in 1967. Alaska Dep. Fish Game Inform. Leafl. 130. 43 pp.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Canad. Dep. Environ., Fish and Mar. Serv. Bull. 191. 382 pp.

Rogers, D. E. 1964. Variability in measurement of length and weight of juvenile sockeye salmon and threespine stickleback. Univ. Washington, Fish. Res. Inst. Circ. 224. 34 pp.

Rogers, D. E. 1976. Fertilization of Little Togiak Lake. Part B of Final Report for period May 1, 1976-March 1, 1977, ADF&G. Univ. Washington, Fish. Res. Inst. FRI-UW-7617-B. 40 pp.

Roos, J. F. 1958. Red salmon smolt studies at Chignik in 1958. Univ. Washington, Fish. Res. Inst. 17 pp. [Unpublished manuscript.]

Roos, J. F. 1959. Feeding habits of the Dolly Varden, *Salvelinus malma* (Walbaum), at Chignik, Alaska. Trans. Amer. Fish. Soc. 88:253-260.

Roos, J. F. 1960. Predation of young coho salmon on sockeye salmon fry at Chignik, Alaska. Trans. Amer. Fish. Soc. 89(4):377-378.

Shaul, A. R., and L. Nicholson. 1976. Chignik area finfish annual report, 1976. Alaska Dep. Fish Game. 123 pp.

Shaul, A. R., and P. W. Rigby. 1975. Chignik area finfish annual report, 1975. Alaska Dep. Fish Game. 95 pp.

Simkis, K. 1974. Calcium metabolism of fish in relation to aging. Pages 1-12 *in* T. B. Bagenal, ed. Aging of fish. Unwin Bros.

Snedecor, G. W., and W. G. Cochran. 1967. Statistical methods. Iowa State Univ. Press., Ames, Iowa. 593 pp.

Sych, R. 1974. The sources of errors in aging fish and considerations of the proofs of reliability. Pages 78-86 *in* T. B. Bagenal, ed. Aging of fish. Unwin. Bros.

APPENDICES

Appendix Table 1. The proportion of types of circuli observed (margin-adjusted) on the scales of the 1973 brood year of Black Lake sockeye salmon by period, 1974-1975

		Circulus code													
Date	Type	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1
June 28, 1974	Cross-over														
	Fragment														
	Incomplete														
	Broken													0.07	0.23
	Complete										1.00	1.00	1.00	0.93	0.77
	Sample size										1	7	18	28	30
July 31, 1974	Cross-over										0.01				
	Fragment							0.08					0.01	0.01	0.07
	Incomplete										0.01			0.04	0.12
	Broken					0.33	0.20	0.17	0.08	0.15	0.15	0.13	0.12	0.22	0.29
	Complete					0.67	0.80	0.75	0.92	0.85	0.83	0.87	0.87	0.73	0.52
	Sample size					3	5	12	26	41	55	61	67	68	68
Sept. 2, 1974	Cross-over										0.01		0.01	0.03	
	Fragment									0.01	0.04	0.03	0.03	0.03	0.35
	Incomplete						0.02	0.05	0.03	0.07	0.03	0.02	0.08	0.05	0.08
	Broken			0.25	0.21	0.18	0.29	0.22	0.39	0.41	0.42	0.44	0.51	0.65	0.55
	Complete		1.00	0.75	0.79	0.82	0.69	0.73	0.58	0.51	0.50	0.50	0.37	0.24	0.02
	Sample size		1	4	19	34	40	60	67	74	79	86	86	86	86
May 23-25, 1975	Cross-over									0.01					
	Fragment											0.01	0.03	0.01	0.55
	Incomplete								0.01	0.02		0.02	0.03	0.01	0.02
	Broken		0.14	0.13	0.16	0.15	0.18	0.25	0.30	0.39	0.48	0.71	0.76	0.92	0.43
	Complete	1.00	0.86	0.87	0.84	0.85	0.82	0.75	0.69	0.58	0.52	0.26	0.18	0.06	
	Sample size	1	7	16	43	72	87	95	97	97	97	97	97	97	97

Appendix Table 2. Mean distance between adjoining circuli (margin-adjusted) on the scale of the 1973 brood year of Black Lake sockeye, by period, 1974-1975

		Measured units													
		Interval code													
Date	Parameter	-14/ -13	-13/ -12	-12/ -11	-11/ -10	-10/ -9	-9/ -8	-8/ -7	-7/ -6	-6/ -5	-5/ -4	-4/ -3	-3/ -2	-2/ -1	-1/ m
June 29, 1974	Sample size										1	7	18	28	30
	Mean											8.6	7.7	7.0	5.2
	95% C.I.±											1.8	1.0	0.6	0.8
July 31, 1974	Sample size					3	5	12	26	41	55	61	67	68	68
	Mean					9.0	7.0	6.9	7.4	7.1	6.3	6.0	5.3	4.4	3.8
	95% C.I.±					2.5	2.0	1.0	0.5	0.6	0.4	0.3	0.3	0.3	0.4
Sept. 2, 1974	Sample size		1	4	19	34	48	60	67	74	79	86	86	86	86
	Mean			7.0	7.3	7.2	6.4	6.1	5.5	5.3	4.8	4.9	4.4	3.6	3.0
	95% C.I.±			2.2	0.6	0.7	0.5	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3
May 23-28, 1975	Sample size	1	7	16	43	72	87	95	97	97	97	97	97	97	97
	Mean		6.7	6.7	6.7	6.5	6.2	5.7	5.2	5.0	4.6	4.3	3.7	3.5	3.6
	95% C.I.±		0.9	0.7	0.5	0.4	0.3	0.3	0.3	0.2	0.2	0.3	0.2	0.2	0.3

Appendix Table 3. Mean distance between adjoining circuli (annulus-adjusted) on the scales of the 1972 brood year of sockeye salmon rearing in Chignik Lake, by period, 1974

Date	Parameter	-11/ -10	-10/ -9	-9/ -8	-8/ -7	-7/ -6	-6/ -5	-5/ -4	-4/ -3	-3/ -2	-2/ -1	-1/ A	A/ 1	1/ 2	2/ 3	3/ 4	4/ 5	5/ 6	6/ 7
		Measured units																	
		Interval code																	
July 12	Sample size			4	13	28	39	55	65	65	65	65	64	61	30	6			
	Mean			5.3	5.9	6.3	5.5	5.2	4.7	4.0	3.5	3.6	5.2	5.4	5.5	5.7			
	95% C.I. ±			0.8	1.0	0.5	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.5	1.7			
August 6	Sample size		2	6	10	22	37	54	57	58	58	58	58	58	57	43	10		
	Mean		3.0	4.2	6.0	5.4	5.2	4.6	4.6	3.6	3.5	3.7	5.3	5.6	5.1	4.4	3.5		
	95% C.I. ±		12.7	2.1	0.8	0.6	0.5	0.3	0.4	0.3	0.2	0.3	0.3	0.4	0.3	0.3	0.7		
Sept. 9	Sample size	1	2	5	13	27	44	47	49	49	49	49	49	49	48	45	25	6	
	Mean		6.0	5.8	6.5	6.0	5.5	4.9	4.2	3.8	3.4	3.6	4.9	5.4	4.9	4.5	4.3	3.5	
	95% C.I. ±		0.0	1.0	1.0	0.5	0.3	0.4	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.3	0.5	0.6	
Nov. 7	Sample size			2	11	17	25	27	30	31	31	31	31	31	31	23	12	2	1
	Mean			6.0	7.0	6.0	5.8	5.2	4.5	3.6	3.5	3.7	4.9	5.7	5.1	4.7	3.5	4.6	
	95% C.I. ±			0.0	1.2	0.6	0.6	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.4	0.5	0.6	12.7	

Appendix Table 4. The proportion of types of circuli observed (annulus-adjusted) on the scales of the 1972 brood year of sockeye salmon rearing in Chignik Lake, by period, 1974

		Annulus adjusted																	
		Circulus code number																	
Date	Type	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	A	1	2	3	4	5	6
July 12, 1974	Annulus												1.00						
	Cross-over								0.02	0.02	0.15	0.15							
	Fragment								0.02	0.08	0.29	0.68							
	Incomplete								0.03	0.05	0.06	0.08		0.03	0.07	0.20			
	Broken			0.25	0.23	0.14	0.38	0.35	0.25	0.54	0.32	0.09		0.59	0.50	0.20			
	Complete			0.75	0.77	0.86	0.62	0.65	0.69	0.31	0.17			0.38	0.43	0.60			
	Sample size			4	13	28	39	55	65	65	65	65	65	64	30	5			
Aug. 6, 1974	Annulus												1.00						
	Cross-over							0.06	0.04	0.02	0.12	0.14			0.02				
	Fragment								0.04	0.07	0.38	0.56							
	Incomplete										0.02	0.02					0.09		
	Broken		1.00	0.83	0.60	0.50	0.32	0.39	0.37	0.57	0.43	0.28		0.50	0.52	0.58	0.63		
	Complete			0.17	0.40	0.50	0.68	0.56	0.56	0.34	0.05			0.50	0.46	0.42	0.27		
	Sample size		2	6	10	22	37	54	57	58	58	58	58	58	57	43	11		
Sept. 9, 1974	Annulus												1.00						
	Cross-over								0.02	0.14	0.22	0.22							
	Fragment							0.02		0.12	0.24	0.59							
	Incomplete									0.04	0.04								
	Broken			0.40	0.15	0.15	0.41	0.49	0.45	0.47	0.37	0.18		0.47	0.65	0.60	0.56	0.17	
	Complete	1.00	1.00	0.60	0.85	0.85	0.59	0.49	0.53	0.22	0.12			0.53	0.35	0.40	0.44	0.83	
	Sample size	1	2	5	13	27	44	47	49	49	49	49	49	49	48	45	27	6	
Nov. 7, 1974	Annulus												1.00						
	Cross-over									0.03	0.16	0.16				0.04			
	Fragment										0.13	0.58							
	Incomplete									0.03	0.06	0.06							
	Broken			0.50	0.36	0.29	0.28	0.37	0.47	0.74	0.58	0.19		0.61	0.52	0.65	0.75	0.50	
	Complete			0.50	0.64	0.71	0.72	0.63	0.53	0.19	0.06			0.39	0.48	0.30	0.25	0.50	1.00
	Sample size			2	11	17	25	27	30	31	31	31	31	31	31	23	12	2	1

Appendix Table 5. Mean distance between adjoining circuli (margin-adjusted) on the scales of the 1972 brood year of sockeye salmon rearing in Chignik, by period, 1974

		Measured units																
		Interval code																
Date	Parameter	-17/ -16	-16/ -15	-15/ -14	-14/ -13	-13/ -12	-12/ -11	-11/ -10	-10/ -9	-9/ -8	-8/ -7	-7/ -6	-6/ -5	-5/ -4	-4/ -3	-3/ -2	-2/ -1	-1/ m
July 12, 1974	Sample size					2	12	18	32	46	61	64	64	65	65	65	65	65
	Mean					5.5	5.6	6.1	6.0	5.4	5.0	4.4	3.6	3.9	4.3	5.3	5.3	4.1
	95% C.I. ±					6.4	0.9	0.7	0.4	0.4	0.4	0.3	0.3	0.3	0.4	0.3	0.3	0.4
Aug. 6, 1974	Sample size			2	4	9	21	39	51	55	58	58	58	58	58	58	58	58
	Mean			3.0	4.5	5.7	5.7	5.3	4.7	4.4	3.9	3.5	3.8	5.2	5.5	5.7	4.3	3.7
	95% C.I. ±			12.7	3.3	1.0	0.8	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4
Sept. 9, 1974	Sample size	2	2	2	8	20	38	44	47	49	49	49	49	49	49	49	49	49
	Mean	5.5	6.0	4.5	6.0	5.9	5.7	5.1	4.6	4.2	3.6	3.8	4.2	5.1	4.9	4.8	4.3	3.1
	95% C.I. ±	6.4	0.0	6.4	1.1	0.7	0.5	0.4	0.4	0.4	0.3	0.3	0.4	0.3	0.3	0.3	0.4	0.3
Nov. 7, 1974	Sample size				4	10	18	25	31	31	31	31	31	31	31	31	31	31
	Mean				6.8	6.7	6.2	5.4	4.9	4.5	4.0	3.6	4.1	4.8	5.4	5.5	3.8	3.2
	95% C.I. ±				2.4	1.1	0.7	0.4	0.6	0.5	0.5	0.3	0.5	0.5	0.5	0.4	0.3	0.5

Appendix Table 6. The proportion of types of circuli observed (margin-adjusted) on the scales of the 1972 brood year of sockeye salmon rearing in Chignik Lake, by period, 1974

		Margin adjusted data																
		Circulus code number																
Date	Type	-17	-16	-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1
July 12, 1974	Annulus													0.08	0.39	0.47	0.05	0.02
	Cross-over										0.01	0.05	0.16	0.03	0.09			
	Fragment												0.19	0.53	0.32	0.02		0.12
	Incomplete										0.01	0.03	0.05	0.03	0.06	0.06	0.05	0.09
	Broken						0.25	0.17	0.25	0.28	0.36	0.36	0.37	0.27	0.11	0.23	0.55	0.62
	Complete					1.00	0.75	0.83	0.75	0.72	0.62	0.54	0.23	0.08	0.03	0.22	0.35	0.15
	Sample size					2	12	18	32	46	61	64	64	65	65	65	65	65
Aug. 6, 1974	Annulus												0.17	0.57	0.24	0.02		
	Cross-over								0.02	0.07	0.02	0.12	0.10	0.03		0.02		
	Fragment									0.02	0.12	0.33	0.43	0.16				0.12
	Incomplete										0.02		0.02				0.02	0.05
	Broken			1.00	0.75	0.67	0.57	0.33	0.41	0.35	0.48	0.46	0.26	0.17	0.36	0.55	0.55	0.71
	Complete				0.25	0.33	0.43	0.67	0.57	0.56	0.36	0.09	0.02	0.07	0.40	0.41	0.43	0.12
	Sample size			2	4	9	21	39	51	55	58	58	58	58	58	58	58	58
Sept. 9, 1974	Annulus											0.12	0.39	0.41	0.06	0.02		
	Cross-over								0.04	0.08	0.14	0.18	0.12	0.04				
	Fragment							0.02	0.02	0.08	0.14	0.29	0.33	0.04	0.02			0.18
	Incomplete									0.02	0.04	0.02						
	Broken			0.50	0.25	0.25	0.29	0.45	0.40	0.45	0.47	0.33	0.08	0.24	0.49	0.57	0.59	0.74
	Complete	1.00	1.00	0.50	0.75	0.75	0.71	0.53	0.54	0.37	0.20	0.06	0.08	0.27	0.43	0.41	0.41	0.08
	Sample size	2	2	2	8	20	38	44	47	49	49	49	49	49	49	49	49	49
Nov. 7, 1974	Annulus										0.03	0.03	0.29	0.38	0.26			
	Cross-over										0.03	0.13	0.13	0.10				
	Fragment									0.03	0.03	0.26	0.29	0.13				0.13
	Incomplete									0.03		0.06	0.03	0.03				
	Broken				0.25	0.50	0.22	0.44	0.29	0.42	0.78	0.49	0.23	0.23	0.26	0.58	0.77	0.84
	Complete				0.75	0.50	0.78	0.56	0.71	0.52	0.13	0.03	0.03	0.13	0.48	0.42	0.23	0.03
	Sample size				4	10	18	25	31	31	31	31	31	31	31	31	31	31

Appendix Table 7. Mean distance between circuli (margin-adjusted) on the scales of the 1973 brood year of sockeye salmon rearing in Chignik Lake, by period, 1974

		Measured units									
		Interval code									
Date	Parameter	-10/-9	-9/-8	-8/-7	-7/-6	-6/-5	-5/-4	-4/-3	-3/-2	-2/-1	-1/m
July 12	Sample size				2	4	10	19	27	27	27
	Mean				7.0	6.0	6.7	6.8	6.5	5.0	3.7
	95% C.I. ±				3.8	3.4	1.5	0.9	0.4	0.7	0.7
Aug. 6	Sample size		2	4	15	29	51	58	61	61	61
	Mean		8.0	7.3	7.4	7.2	6.7	6.3	5.0	4.1	3.3
	95% C.I. ±		0.0	1.0	0.8	0.6	0.4	0.3	0.3	0.3	0.3
Sept. 9	Sample size	3	3	17	31	63	77	87	91	91	91
	Mean	6.7	5.7	7.1	6.8	6.6	6.0	5.2	4.8	4.0	3.2
	95% C.I. ±	6.3	3.8	0.9	0.5	0.7	0.3	0.3	0.3	0.3	0.2
Nov. 7	Sample size		4	16	30	48	51	53	58	60	60
	Mean		7.0	6.5	7.4	6.4	6.1	5.3	4.5	3.4	2.7
	95% C.I. ±		2.9	0.8	0.7	0.4	0.5	0.3	0.3	0.3	0.3

Appendix Table 8. The proportion of types of circuli observed (margin-adjusted) on the scales of the 1973 brood year sockeye salmon rearing in Chignik Lake, by period, 1974

Date	Type	Circulus code number										
		-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1
July 12	Cross-over											
	Fragment							0.10			0.04	0.41
	Incomplete									0.04	0.04	
	Broken			1.00			0.50	0.10	0.27	0.11	0.30	0.33
	Complete				1.00	1.00	0.50	0.80	0.73	0.85	0.62	0.26
	Sample size			1	1	2	4	10	19	27	27	27
Aug. 6	Cross-over									0.02		
	Fragment						0.03					0.16
	Incomplete									0.02		0.02
	Broken					0.27	0.31	0.35	0.31	0.28	0.57	0.71
	Complete			1.00	1.00	0.73	0.66	0.65	0.69	0.68	0.43	0.11
	Sample size			2	4	15	29	51	58	61	61	61
Sept. 9	Cross-over										0.04	
	Fragment											0.20
	Incomplete									0.07	0.01	0.01
	Broken		0.33	0.33	0.35	0.26	0.32	0.31	0.36	0.38	0.54	0.71
	Complete	1.00	0.67	0.67	0.65	0.74	0.68	0.69	0.64	0.55	0.41	0.05
	Sample size	1	3	3	17	31	63	77	87	91	91	91
Nov. 7	Cross-over									0.02		
	Fragment										0.02	0.22
	Incomplete						0.02	0.02				0.05
	Broken			0.25	0.19	0.37	0.31	0.27	0.25	0.48	0.56	0.60
	Complete		1.00	0.75	0.81	0.63	0.67	0.71	0.75	0.50	0.42	0.13
	Sample size		1	4	16	30	48	51	53	58	60	60