INTERNATIONAL PACIFIC SALMON
FISHERIES COMMISSION

APPOINTED UNDER A CONVENTION
BETWEEN CANADA AND THE UNITED STATES FOR THE
PROTECTION, PRESERVATION AND EXTENSION OF
THE SOCKEYE SALMON FISHERIES IN
THE FRASER RIVER SYSTEM

BULLETIN IX

COLLECTION AND INTERPRETATION OF SOCKEYE SALMON SCALES

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NEW WESTMINSTER, B. C., CANADA, 1956

ABSTRACT

This study establishes the methodological basis for the use of scales in the development and implementation of fundamental concepts in the scientific management of Fraser River sockeye salmon. Techniques of scale collection, mounting, and examination are described in detail. A fundamental analysis of scales is made regarding interpretation of life history, including fresh water growth rates and age at maturity. It is shown that sampling procedures for fresh water growth study and age composition study must take into account many variable factors, including: unequal growth among the scales of any given individual sockeye, differences in age composition between sexes, variability of age composition by time during runs, differences in growth and age composition between stocks, changes in growth and age composition from year to year, effects of net selectivity, and variability in availability of size groups among dead fish on spawning grounds. Length frequency and otolith analyses are shown to be useful supplementary methods of determining age composition.

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INTRODUCTION

The life histories and habits of fishes are largely obscured from the view of man because of their inaccessibility, thus knowledge of the ways of fishes is partly a matter of inference. Fish, unlike terrestrial animals, cannot be observed continuously throughout their lives under natural conditions, therefore their life histories must be studied in retrospect through indirect means. Many fishes record their own biographies in bodily structures such as fin rays, bones, or scales. Scales provide the most useful record in many species; this is especially true of the sockeye salmon *(Oncorhynchus nerka)*.

The contribution of sockeye scale studies to knowledge is of long standing and proved importance. During the period 1913-1924 C. H. Gilbert (1914-1925) studied the scales of Fraser River sockeye. His scale studies led him to enunciate the home stream theory and the concept of races. Complete proof of the validity of Gilbert's assumptions is not available in his writing, but subsequent investigations by other scientists have substantiated his basic concept. Primarily on the strength of Gilbert's findings the International Pacific Salmon Fisheries Commission has inaugurated a comprehensive investigation to ascertain the full value of scale analysis in the management of the Fraser River sockeye.

As Gilbert indicated, the Fraser River runs are made up of many unit-stocks, commonly called "races", each of which is largely or wholly self-perpetuating. Data on the abundance and times of migration and spawning of these unit-stocks form the basis for the Commission's management policies. These policies, as explained by Royal (1953), can be summarized as follows:

1. Treatment of each "race" or spawning population as a separate management problem.

2. Maintenance of approximately natural time-abundance relationship in the escapement, or, where possible, the obtaining of the escapement from the peak of the run of each population.

3. Maintenance of the same relative fishing intensity from year to year, regardless of the size of the unit run, unless that particular run has been reduced in size by temporary abnormal reproductive environment or unless production has been unusually good and there is a danger of the potential escapement exceeding the requirements of the reproducing area.

The identification of the unit-stock in the commercial catches at all times and in all fishing areas is necessary for the successful implementation of these policies. On the basis of such identification it is possible to determine the character of the curve of abundance of each race as it enters the fishery, to measure accurately the catch of each race in each fishing area, and to determine the change in character of the population abundance curve of each race as the fish pass through the extensive and intensive fishery influenced by the fishery regulations in respect to weekly closed periods. The sum of the number of fish of a unit-stock in the commercial catch and the number of fish of this stock taken by Indians or reaching the spawning grounds is the total production.

Scales of sockeye salmon commence development early in the fry stage and continue to grow throughout the growing life of the fish. It has been well established that the growth of the scale corresponds with the growth of the fish as a whole, and it is therefore possible to arrive at an understanding of much of the life history of the fish, especially the rate of growth, from an interpretation of the characteristics of the scale. The central or nuclear area of the scale is formed during the fresh water or lacustrine life of the fish, and may therefore be formed under varying environmental conditions. These differences in lacustrine growth provide a means of segregating unit-stocks in commercial fishery catches through scale analysis. Study of the nuclear areas of adult scales may also lead to an understanding of the relationship between lacustrine growth and adult survival. Age determination from the examination of scales allows the segregation of age groups and the calculation of total production from given spawnings. All the information contributes to an understanding of the dynamics of populations.

The purpose of the present study is to establish the methodological basis for the use of scales in the further development of fundamental concepts in the management of the sockeye salmon in the Fraser River.

COLLECTION AND MOUNTING OF SCALES

Sources of Scale Samples

There are three periods during the life cycle of Fraser River sockeye when scales can be taken conveniently, namely from *(1)* seaward migrants or smolts, *(2)* jacks (grilse) and adults when caught in the sea or rivers along their spawning migration route, and *(3)* jacks and adults on the spawning grounds.

Smolts are captured with fyke nets, trawls, traps, or seines as they leave the nursery lakes on their way to the sea and samples are preserved for subsequent laboratory examination and scale-taking. Maturing sockeye of ages three, four, or five years are first available for observation when taken in the commercial fishery. Here scales are usually taken at canneries but they have also been taken from fish captured by commercial fishing methods and used in tagging operations. Sometimes scales are taken along the migration path, as at Hell's Gate, Bridge River Rapids, Farwell Canyon, or at other upriver points from fish captured with Indian dipnets. Spawning grounds scale samples are sometimes taken from live fish during tagging conducted for routine population enumeration, and sometimes from live fish as they pass through counting weirs. Most often part or all of spawning grounds scale samples are taken from fresh-dead spawned fish.

Procedure for Collecting and Mounting Scales

Scale collection has two facets. The first of these, collecting technique, comprises the acquisition of scales quickly and efficiently and forwarding them to the laboratory in a form whereby they can be kept separate and easily identified with any concurrent recorded data. Design of sampling procedures is a second and very important aspect; this governs the adequacy and representativeness of samples. Consideration of design of sampling procedures requires an extensive background of the methods and validity of scale interpretation, and for this reason this extensive subject will follow the discussion of scale interpretation.

COLLECTING TECHNIQUE

Adult sockeye scale specimens are taken in the field and placed in scale books about 4 inches by 7 inches in size, specially designed with spaces for recording corresponding length and sex data. Scales have been removed from the fish in two slightly different ways in the past. Prior to 1952 samples were taken with a small knife by scraping a small patch of scales, ten to fifteen in number, from a restricted area above the lateral line and below the space between the dorsal and adipose fins. Each scrape sample was transferred from the scale knife to a space on the page of a scale book. After five such samples were placed on each page the page was folded over, covering the damp scales and forming a light bond. This process was repeated on the twenty-four pages of each book. Since 1952 one scale only has been taken from each fish. Each scale is placed in one of the 115 small pockets which are formed between the leaves of each conventional scale book by affixing staples between each scale space about one-half inch out from the binding. The single scales are removed from the body of the fish with four-inch, fine-tipped, curved forceps. Comparison of the results and respective merits of the scrape and single scale methods appears in a following section.

Each scale book is labelled as to date of sampling and place of sampling and, in the case of commercial samples, the place and date of capture and the name of the fishing gear with which the fish are caught. The scale books are forwarded to the laboratory where they are immediately numbered and cataloged for subsequent mounting.

As stated previously, smolts are captured in the field and transferred to the laboratory. There three or four scales are removed from each fish and the length and weight data are recorded concurrently.

MOUNTING TECHNIQUE

Originally scales were mounted in glycerine jelly on glass slides. This procedure was time consuming, required much space for storage, and the mounts deteriorated with time. The method was subsequently replaced by that of making plastic impressions, which has proved to be more efficient. The plastic impression method used is an adaptation of the procedure developed by Dr. S. Y. Koo of the Fisheries Institute of the University of Washington.

When each single scale is removed from the scale book the sample space is numbered to correspond with the number of the scale, in this way the length and sex data corresponding to the particular scale are identified. Forty scales are removed from the scale book in repeated operations. Each scale is immersed in water in one of forty separate Syracuse watch glasses; placing the watch glasses on a large sheet of black paper improves the visibility of the scales. The scales are allowed to soften for one or two minutes, then each softened scale is cleaned by rubbing it between the thumb and first finger or by wiping it on a folded paper towel. While the scale is still damp it is placed, with forefinger or forceps, sculptured side out on a piece of mucilage-coated kraft paper. The mucilage holds the scale firmly in place with no curl on the edges. The kraft paper has dimensions 2½ inches by 5 inches and is stamped with crossed lines to facilitate mounting. Forty scales are placed on each piece of mucilage paper. When the scales have been affixed the mucilage paper is faced with a 0.020 inch-thick sheet of clear plastic (cellulose acetate) of equal size. The mucilage paper and plastic are held together by two small strips of transparent adhesive tape. Notations of source and scale numbers are made on the non-adhesive side of the mucilage paper. An experienced technician can mount as many as two hundred individual scales per hour by this method, depending on the condition of the scales.

Smolt scales are taken from the fish and placed directly on mucilage paper. Fine-grained kraft paper with small fibres and no striations is essential for mounting such very small scales because coarser paper leaves extraneous impressions on the plastic. Three or four scales are taken from a very limited area on the body of each smolt. In mounting smolt scales much care is necessary to be certain that the sculptured side is uppermost and not folded because these small scales are very thin.

After the kraft paper with affixed adult or smolt scales and the plastic plate have been taped together they are ready for the press. Both pressure and heat are used to form scale impressions in the plastic. The mucilage paper and attached plastic are placed in an electrically-heated, hand-operated hydraulic press (FIGURE 1). The upper platen of the press is bolted to two upright steel posts and remains in a fixed position whereas the lower platen is moveable with guides around the upright posts. Each of the platens has a 10 inch by 12 inch surface dimension and consists of two layers; the outer layer is cast iron and the inner layer is cast aluminum to facilitate heat conduction. Each platen is heated by two 500 watt thermostatically-controlled strip heating elements located between the cast iron and aluminum layers. An orifice of diameter sufficient to admit a standard centigrade thermometer has been drilled in each of the aluminum blocks to facilitate adjustment of the thermostats. Pressure is applied to the lower, moveable platen by a 20-ton hydraulic jack to which a pressure gauge has been attached. The lower platen is drawn away from the upper platen by two heavy coil springs.

The platens accommodate six plastic cards; two hundred and forty individual scale impressions can be made in one pressing operation. To facilitate placement in the press and removal therefrom the plastic cards are placed between two standard 10 inch by 14 inch ferro-type plates of the type commonly used in photographic work. A sheet of ⅛ inch thick gasket rubber is placed on the outside of each ferro-type plate to compensate for any unevenness in the platen surface. A thin sheet of asbestos paper is placed on the outside of each rubber pad to allow the operator to quickly remove the assembly without discomfort from the heat. The plastic sheet is faced toward the upper platen and the mucilage paper toward the lower. The entire assembly is subjected to heat and pressure for five minutes before removal. The upper platen temperature is 110 degrees centigrade and the lower platen 100 degrees centigrade. The gauge pressure is 3000 pounds. The pressure on the platen surfaces is about 100 pounds per square inch and on the plastic sheets 160 pounds per square inch. This time-pressure-temperature formula was chosen after numerous trial samples were pressed and observed under the projection microscope.

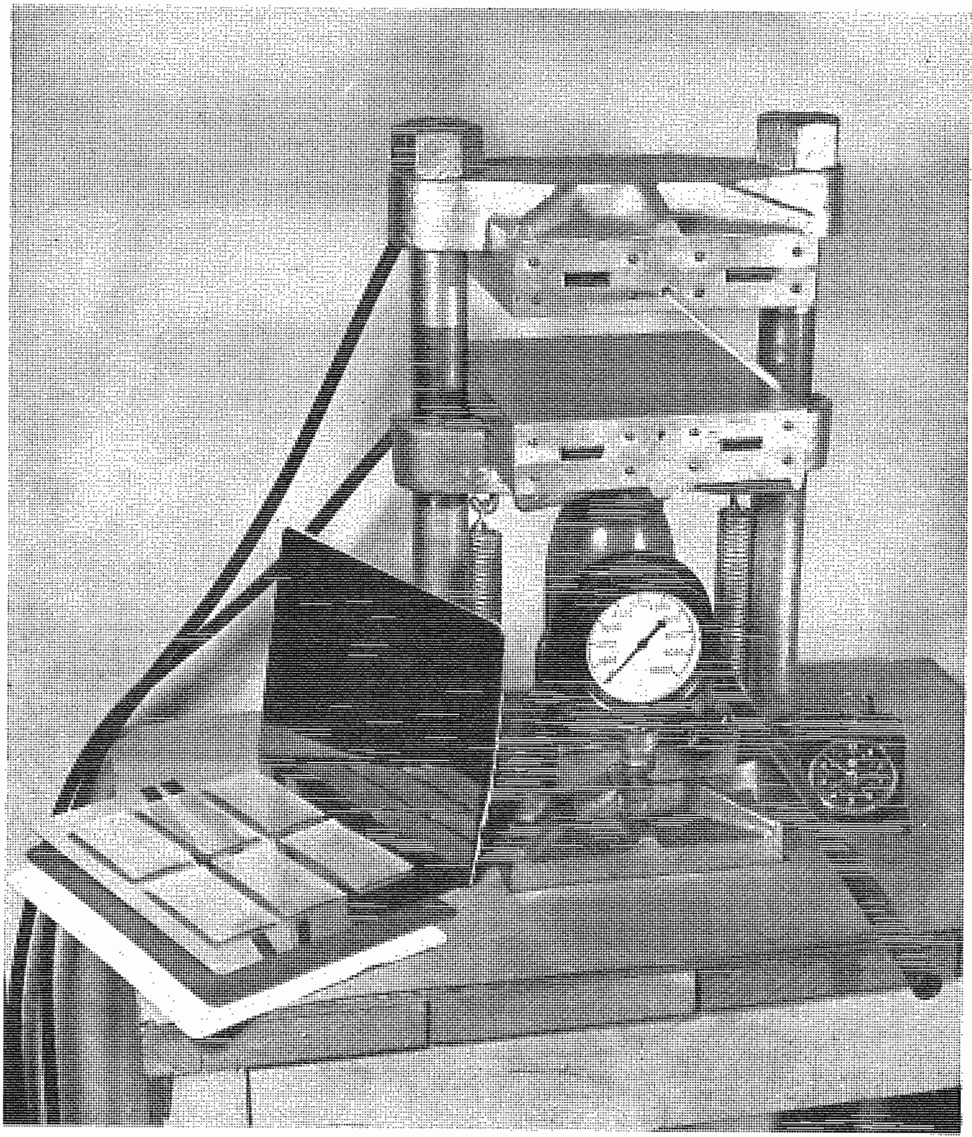

FIGURE 1—Hydraulic press, hand-operated and electrically heated, developed for making plastic scale impressions.

When the entire assembly is removed from the press the top sheets of asbestos and rubber are removed, and the top ferro-type plate with the plastic cards adhering to it is leaned against a convenient upright. The ferro-type plate is allowed to cool at room temperature for about two minutes, during which time the plastic sheets peel away from it. Two minutes is sufficient time for the plastic to harden and thus permanently fix the scale impressions. The plastic card and mucilage paper adhere closely to each other after being pressed; the bond is broken by sliding them between the thumb and first finger while exerting a slight bending pressure. Two complete sets of pads and plates are used so that one assembly can be prepared while the other is in the press. Sixty cards or 2400 individual scales can be pressed per hour by this method.

After the pressing operation is completed a small adhesive label is placed on the upper left corner of each plastic card identifying the scales as to origin, collection date, and scale sample numbers. Mucilage paper and plastic card are kept attached together for filing purposes; the identifying information appearing on the back of the mucilage paper is usually more complete than that appearing on the plastic card. The mucilage paper and affixed scales are unchanged by pressing, and duplicate plastic impressions can be made with little effort or expense. Plastic impressions are conveniently stored. Fifteen thousand individual scale impressions can be stored in a standard 3 inch by 5 inch filing card drawer where they are readily accessible for subsequent examination.

EXAMINATION AND DESCRIPTION OF SCALES

Method of Examination

The need for rapid and detailed examination has led to the use of *Promar* projection microscopes (FIGURE 2). These microscope assemblies have built-in 6 volt, 5 ampere light sources behind the stages. Transformer-resistor assemblies are used to exactly adjust the voltage and thereby provide long service from the low voltage bulbs. Each microscope is mounted about 22 inches above the desk surface on a stand. The impression image is reflected at a 90 degree angle downward onto the desk surface by a mirror mounted on the ocular. Each microscope assembly is shielded from excess outside light by being placed in a plywood hood. These instruments have precision optical systems with high quality condenser and microscope lenses and are equipped with three objective lenses. The objectives of lowest and highest magnification are used most extensively. The lowest magnification (50 diameters at desk surface) is used primarily for aging the scales while the highest (200 diameters) is used for detailed examination of the individual circuli, especially in the fresh water growth area and the zone of transition between lacustrine and marine areas.

In the Commission's laboratory, scale "reading" is usually limited to a period of four hours per day per observer to avoid excessive eye fatigue and possible resultant inaccuracy. An experienced observer can age and measure the lacustrine growth zone of 150 to 200 adult scales per hour, depending on the condition of the scales.

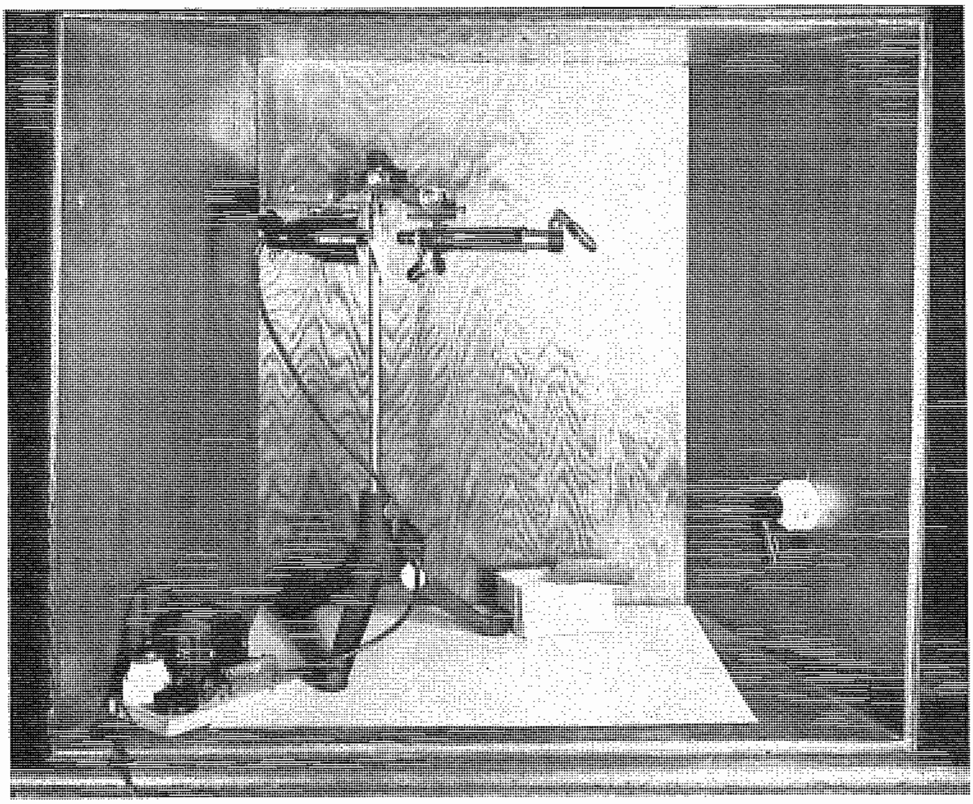

FIGURE 2—*Promar* projection microscope in plywood light shield.

Description of Sockeye Scales and Definition of Terms

The scales of sockeye salmon are flat, calcified structures which lie in pockets in the skin. They are normally regularly arranged in diagonal rows and are overlapping, or imbricated, like shingles on a roof. Each diagonal row represents a line of outgrowing tissue from one of the primary scale-forming papillae of the lateral line (Neave, 1936). The scales increase in area and thickness with the growth of the fish. In form adult sockeye scales are slightly elliptical, with their anterior-posterior axes longer than the dorsal-ventral axes. They are marked by the formation of more or less concentric series of ridges, the circuli, which are present on the anterior portion but absent from the posterior field (FIGURE 3). These two zones of the scale meet along a somewhat irregular line which forms a slight angle with the dorsal-ventral axis. The circuli of the anterior field are subdivided into an inner zone formed in fresh water and an outer zone formed in the sea. When growth is rapid the circuli are heavy and far apart, when growth is slow they are fine and close together. Ridges formed in freshwater are finer in structure, of lesser height, and closer together than seawater ridges. When growth is relatively slow, as in winter conditions, the circuli are closely grouped, forming what may be called winter "checks". This designation of "checks" as groups of closely associated circuli rather than single circuli follows the example

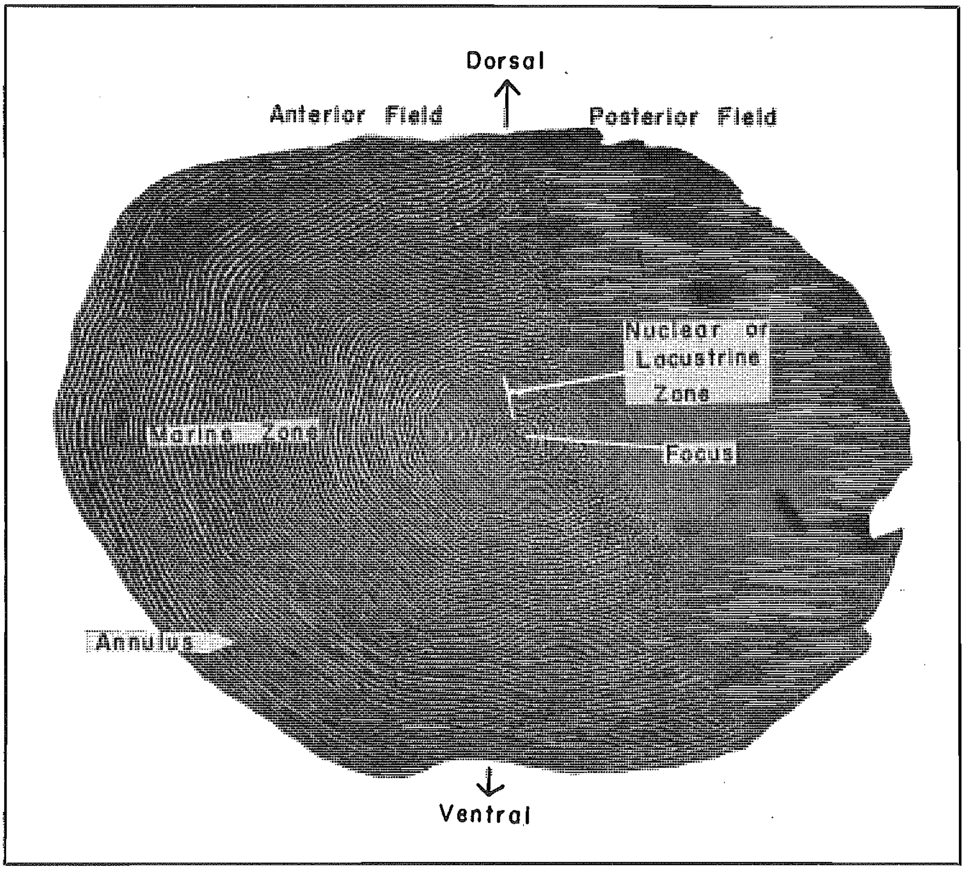

FIGURE 3—Adult 4_2 sockeye scale with descriptive notations.

of C. H. Gilbert and of Van Oosten (1929). This is most practical for sockeye salmon because it is rarely possible to confidently designate a single circulus, as has been the practice of Beckman (1943), and others regarding the scales of certain freshwater fishes. Bands of small, crowded circuli may occur occassionally during times other than the restricted winter growth periods. This may be due to any of several causes; Blair (1942) states that normal scales adjacent to an area containing a large number of regenerating scales form a check at the time of most rapid growth of the regenerating scales. Also these accessory checks may be formed at times when growth is restricted by temporary reduction of food supply or disease. Lateral line scales have circuli and form winter bands just as other scales do, however they have distorted centers and are, in general, unsuitable for examination.

The scale consists of two virtually flat layers — an outer calcified layer with circuli and an inner fibrous plate. The calcified layer is formed first. During scale growth the margin of the scale consists solely of bone or of the osteoid tissue which precedes calcification. The bony substance is deposited only at the periphery, whereas the fibrillary plate is built up as a series of successively larger lamellae beneath the calcified layer. The first circuli form at any early stage in scale development; circuli are continuous and homogeneous with the general calcified layer. Development of the circuli begins on the calcified layer near but not directly at the extreme margin of the scale. (Neave, 1936; Welander, 1940).

The process of scale formation seems to be reversed when sockeye undergo the extensive series of physiological changes which accompany the approach of spawning time. The margins of the scales suffer disintegration, being gradually broken down and absorbed. This absorption is especially extensive in the males, which develop greatly elongated jaws with large teeth, and the dorsal hump in addition to the growth and maturation of sex products. Absorption occurs on the concealed anterior portions of the scales as well as on the posterior portions which have been exposed by loss of the epidermal covering. This eliminates mere mechanical abrasion as the cause of the loss of scale material at the periphery.

Atypical scales are formed on sockeye to replace scales which have been lost through mechanical abrasion. In these regenerated scales the focus is replaced by an expanded central area devoid of circuli, rough or granular in appearance and irregular in outline. According to Blair (1942) the initial growth of regenerating scales is very rapid, and during this time circuli are not formed. As the rate of growth decreases, circulus formation begins, the circuli first formed being widely separated. The forming circuli are progressively closer together as the scale approaches normal size, and a check is often formed when it fills the pocket and commences normal growth. Neave (1940) states that where laceration of the skin or excoriation takes place three processes contribute to rescaling. First, the scales left in position at the margin of the wound area tend to enlarge on the side toward the wound, in some cases forming a definite mark. Second, and most important, new scales may develop from the partly destroyed scale pockets at the margin of the excoriated area. Third, new scales may arise within the wound area from osteogenic cells which have migrated from the lacerated or intact scale pockets at the margin of the wound area. He interprets the early absence of circuli as due to the utilization of all available scale forming material at the growing margin.

Infrequently a large scale appears to have a smaller scale inset with the main axes at different angles. This phenomenon is described by Van Oosten (1929) as possibly the result of a young scale having been dislocated and rotated in its scale pocket with the result that the later growth pattern does not coincide with the earlier.

Certain terms which are used in the sections to follow are defined below and some of their equivalents are listed; sources are noted for two ambiguous usages.

Focus—the small, well-defined area near the center of the scale which lies within the first circular ridge. Equivalents: centrum, nucleus (Dunlop, 1924), platelet, placode.

Circuli—circular bony ridges, concentric around the focus, appearing primarily on the anterior part of the sockeye scale. Equivalents: annuli (Esdaile, 1912), circular ridges, rings, ridges, sclerites.

Annuli[1]—zones of crowded, thin or incomplete circuli which indicate a sudden decrease in growth rate and are interpreted as indicating the period of winter growth. Equivalents: annual rings, periodic rings, winter bands, winter checks.

Accessory checks—zones of crowded, thin or incomplete circuli which resemble annuli but are not formed during the restricted winter growth period. Equivalents: accessory marks, false annuli, false checks.

Nuclear area—the portion of the sockeye scale which is formed in fresh water, principally or wholly during the period of lake residence, exhibiting finely-etched, closely-associated circuli. Equivalents: fresh-water zone, lacustrine zone.

Transition zone—the area where lacustrine growth ends and sea growth begins, sometimes composed of circuli which are intermediate in character.

For convenience of reference sockeye may be divided into four general age groups on the basis of size and length of residence in fresh water and in the sea. The components of these general groups, their life history patterns and age nomenclature are more fully described in a following age classification section (page 82).

Fry—young male and female sockeye from the time they have emerged from the gravel until they have assumed the body shape characteristic of fingerlings.

Smolts—one and two year old male and female seaward migrants which have not yet reached the sea.

Jacks—3_2 and 4_3 sockeye, sometimes called grilse, which have spent about fifteen months in the sea and are mostly male precocious spawners notably smaller in size than other maturing age groups.

Adults—4_2, 5_3, and 5_2 sockeye which have spent about twenty-seven or thirty-nine months in the sea and exhibit more even sex ratios than jacks as well as being much larger. The 4_2 group is the most common among Fraser River sockeye.

LACUSTRINE GROWTH STUDY

Fraser River sockeye spend an important part of their lives in fresh water; during this period the various unit-stock populations are usually living under differing ecological conditions. Some of these conditions produce differences in growth and survival. Lacustrine scale study provides a measure of growth during the year or two of lake residence and a means of separating unit-stocks in the commercial catches by the scales of adults on their return. Because of its possible great importance in contributing to an understanding of the dynamics of populations lacustrine growth study is worthy of careful fundamental analysis regarding both interpretation and design of sampling procedures.

[1] Defined as single circuli, Beckman (1943), and others.

Interpretation of Nuclear Area of Scales

The growth and early life history encompassed by the lacustrine residence period can be correctly interpreted from scales only when the relationship between growth of scale and growth of fish is known. To determine this relationship early scale development must be understood, extent of fresh water scale growth must be defined, and a reliable technique must be developed for measuring scale growth. All scales used in these interpretational studies were taken from particular parts of the bodies of the fish for reasons to be explained in a subsequent section. Also, unless otherwise stated, all scale circulus counts have been made along a particular axis of the scales (ventral 20° radial line); the reason for this will be explained subsequently.

EARLY SCALE DEVELOPMENT

Fraser River sockeye fry emerge from the gravel of the spawning area during the spring of their first year of life. These emergent fry then enter a lake where they usually remain for one year and occassionally two years. The one-year-olds migrate to sea in the spring of their second year and the two-year-olds in the spring of their third year. This pattern of habitation and migration was observed by early workers, and has been corroborated by intensive life history studies undertaken by the Commission in fry and smolt enumeration programs. The long-standing belief that the nuclear areas of sockeye scales are formed in fresh water during the period from shortly after fry emergence until entry into sea water is easily substantiated.

Scale Formation

Newly-emergent sockeye fry are about 27 millimeters in length from tip of jaw to fork of tail, and have no scales. Wild fry develop rudimentary scales when about 38 millimeters long. Forty-one wild fry of selected sizes have been examined for scales by removing and observing the skin of each under the microscope. These fry were taken from three widely separated areas: twenty-seven from Stellako River, nine from Thompson River, and five from Harrison River. There was no observable difference in size of scale formation among the fry of these three areas. The fry in the sample ranged in fork length from 30 millimeters and 48 millimeters. Twenty fry had no scales. Scales had just begun to form on ten fry between 36 millimeters and 40 millimeters fork length and eleven had formed one or more circuli on the most developed scales. The smallest fry with scales was 36 millimeters and the largest fry without scales was 40 millimeters. These findings are similar to those of Gilbert (1913), who found that of a sample of fry taken from the Fraser River at Lytton only the largest, 39 millimeters to 41 millimeters fork length, had developed scales. Foerster (1929) used a length at scale formation of 1.5 inches (38 millimeters) for Cultus Lake fry in his calculations.

These conclusions are somewhat at variance with those of Fraser (1920) and Dunlop (1924). Fraser took 1.2 inches (30.5 millimeters) as the average length of the fry when the first ring is formed around the nucleus of the scale. Dunlop stated that the sockeye fry less than 28 millimeters long which he examined showed no indication of scales; however there was at least some trace of scales at lengths greater than this. His scales were taken from hatchery fry, and this is apparently the reason that the fry which he examined developed scales at smaller size. To check Dunlop's findings thirty-four hatchery fry of selected sizes from Adams River stock have been examined which were taken at the Quesnel Field Station in 1952. These hatchery fry developed rudimentary scales when about 31 millimeters fork length. The fry in the sample ranged from 28 millimeters to 52 millimeters. Scales had begun to form on one fry of 31 millimeters, and the

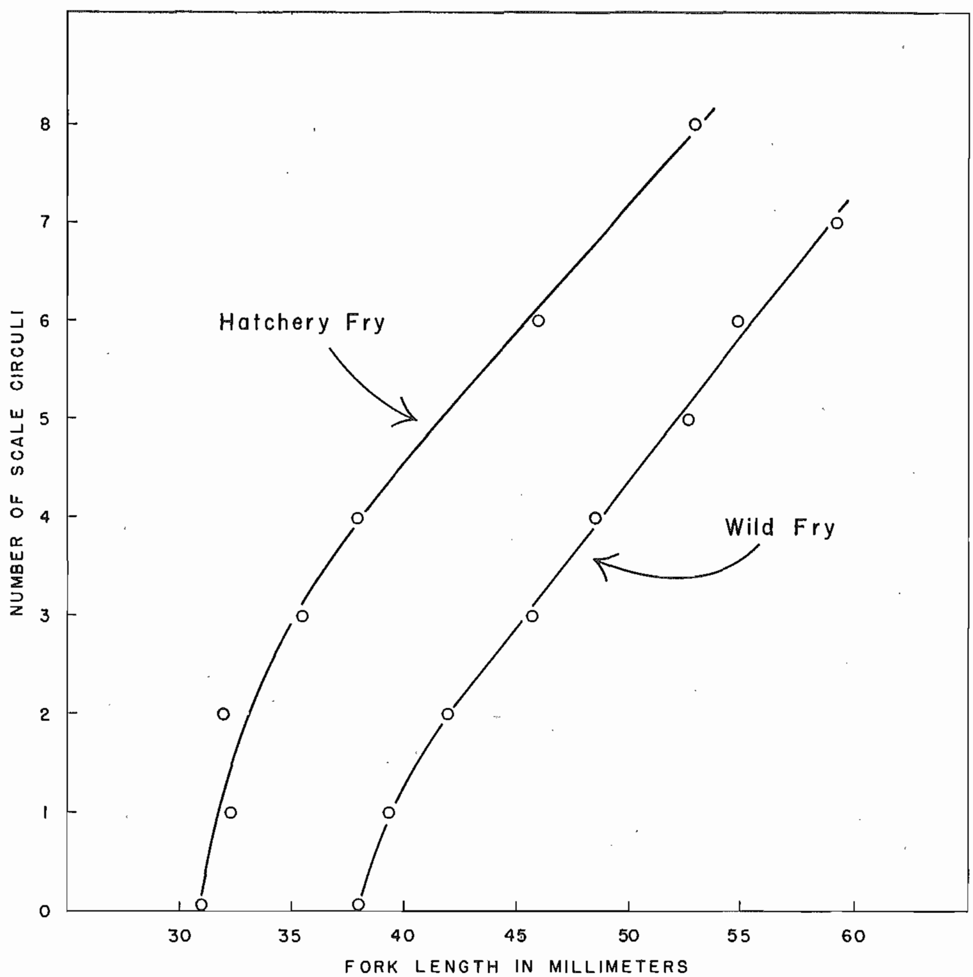

FIGURE 4—Comparison between hatchery fry and wild fry of relationship between length and scale development.

largest without scales was 32 millimeters. Eleven fry had no scales and twenty-two had formed one or more circuli on the most developed scales. The difference in length at scale formation between wild fry and hatchery fry is apparently not attributable to a possible difference between stocks. The hatchery fry of Dunlop (1924) came partly from the Harrison River system, and the more recent hatchery fry sample came from the Thompson River system. Both of these systems were represented in the wild fry sample. The difference in the relationship between size of fish and number of scale circuli persists after scale development is advanced, as illustrated in FIGURE 4. The points of this figure are average fork lengths corresponding to given numbers of scale circuli, which were taken from the wild and hatchery fry data presented above, and supplemented with advanced wild fry data from 1955 Little River sampling.

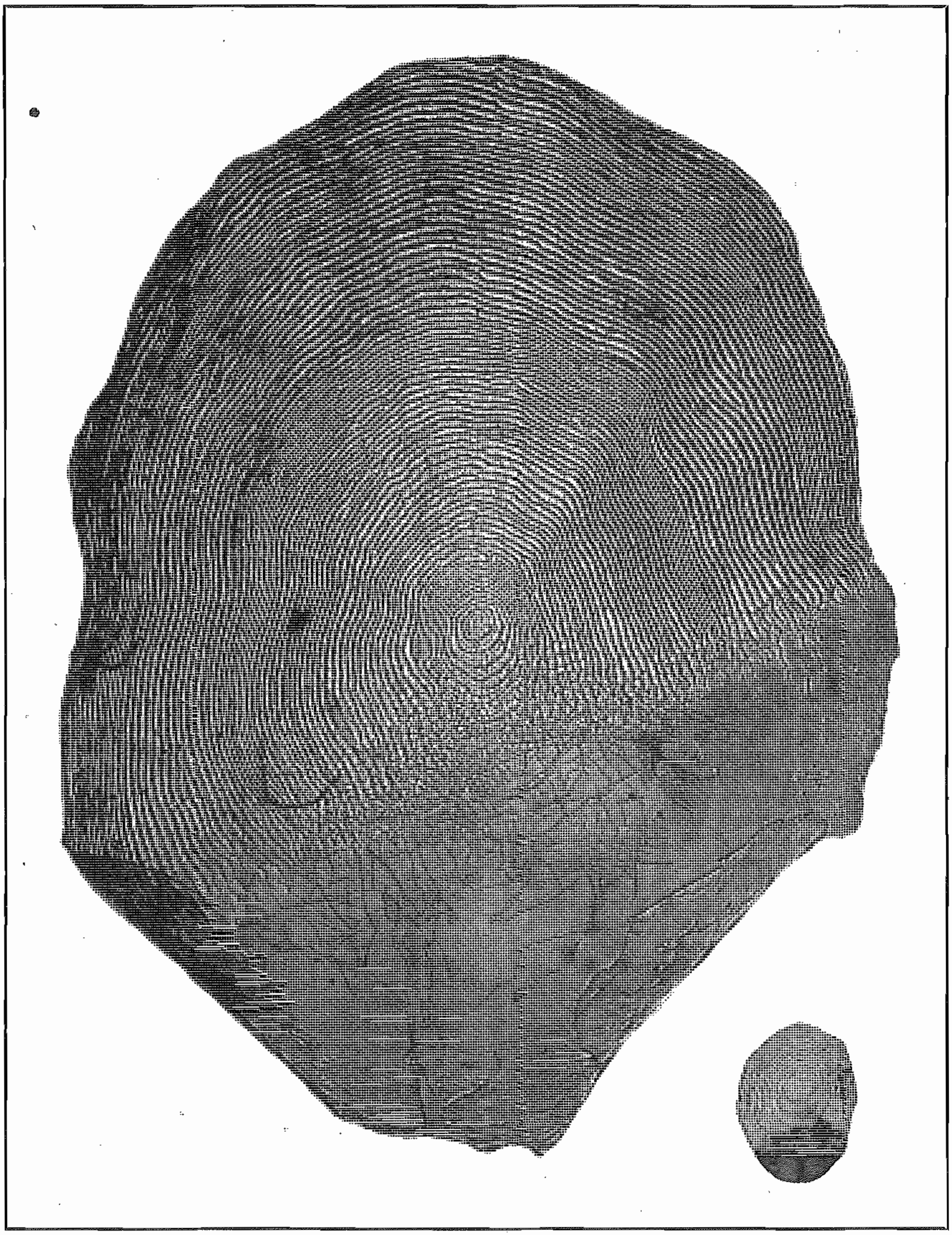

FIGURE 5—1951 Chilko River yearling smolt scale and 1953 Chilko River adult 4_2 scale, showing similarity in lacustrine growth due to concurrent lake residence.

Lacustrine Growth

The growth pattern of wild fry scales apparently does not change much throughout the summer and autumn months. During the first winter of the juvenile sockeye's life scale growth usually becomes retarded. The circuli formed tend to be thinner, more closely spaced and sometimes broken in structure. This is presumably the result of retarded growth of the fish because of limited food

FIGURE 6—1953 Shuswap Lake yearling smolt scale and detail of 1955 Adams River adult 4_2 scale, showing "spring growth" scale types.

supply or low temperature or both. The yearling sockeye usually migrate to sea shortly after the period of retarded scale growth. The scales of downstream migrating smolts are clearly similar to the nuclei of the scales of the subsequently returning adults of concurrent lake residence (FIGURE 5). The average sizes of the nuclear areas of the adult scales are similar to the average sizes of the smolt scales.

Occasionally additional and larger circuli are formed on the outside of the winter check of smolt scales, this is often referred to as "spring growth" (FIGURE 6), although the term may not be fitting in all cases. The occurrence of this new, vigorous growth after the period of retarded growth is not common to all populations of Fraser River sockeye. It does not appear every year in those unit-stocks which exhibit it and not among all fish of the run of a particular year. The Adams River run is one of the few which sometimes have a significant proportion of this scale type. TABLE 1 shows that in sixteen years of sampling at Adams River the percentage of spring growth scales varied from 3.4 per cent to 67.1 per cent,

TABLE 1—Relative occurrence of "spring growth" type scales in Adams River populations of adult 4_2.

Sampling Year	Number Scales Examined	Percent of Scales Exhibiting "Spring Growth"
1938	193	3.6
1939	151	7.9
1940	109	39.4
1941[1]	71	31.0
1942	221	32.6
1943	131	6.1
1944	95	7.4
1946	95	4.2
1947	146	8.2
1948	187	5.3
1950	207	67.1
1951	162	8.6
1952	186	4.8
1953	197	5.6
1954	211	8.1
1955	489	32.9

[1]1940 3_2 jacks.

with an average of 40.6 per cent for the five years of high occurence and an average of 6.3 per cent for the remaining eleven years.

Among the scales of offspring from the 1951 Adams River spawning the 1953 Shuswap Lake one year smolts exhibited 73/184 or 39.7 per cent spring growth and the subsequently returning 1954 3_2 jacks 68/192 or 35.4 per cent and the 1955 4_2 adults 161/495 or 32.5 per cent.

Sockeye with and without lacustrine spring growth appear concurrently in some populations; this occurs in both seaward migrating smolts and spawning ground adults, eliminating time of downstream migration as sole cause of the extra growth. In TABLE 2 a comparison of the scale growth of common type and spring growth type is made using scales from three age groups of offspring from the 1951 Adams River spawning. The spring growth scales had less growth through the presumed winter check period than scales without extra growth; yet they were larger at the time of downstream migration than the common type. Gilbert (1916) suggested that the phenomenon of spring growth is evidence of compensatory growth whereby all smolts tend to attain approximately the same size at migration regardless of the amount of growth attained up to the end of the winter period. This possibility cannot be denied on the strength of the 1951 brood Shuswap Lake data, however Shuswap Lake smolts data gathered in 1956 indicate higher percentage spring growth in sectors of the lake having slightly larger smolts; this is not compatible with Gilbert's theory. Also Foerster (1929) showed that Cultus Lake downstream migrants with spring growth had a normal range of growth in the period before the extra growth occurred and that the extra growth merely increased their size at time of migration.

Gilbert (1916) stated that the extra growth past the first winter check was not included in his studies of lacustrine growth from adult scales. In studying the

TABLE 2—Comparison of "spring growth" and "common" type lacustrine growth sockeye of concurrent residence in Shuswap Lake.

SAMPLING AREA	Sampling Year	Age	Number Scales in Sample	Mean Number Lacustrine Scale Circuli			
				"Spring Growth" Type			"Common" Type
				Growth Through Winter	Extra Growth	Total	Total
Shuswap Lake	1953	1 Yr. Smolt	184	11.6	2.7	14.3	13.2
Adams River	1954	3_2	192	11.5	3.9	15.4	13.0
Adams River	1955	4_2	495	11.6	3.8	15.4	13.5

possible relationship between lacustrine growth and survival to returning adults it is necessary to include this extra growth because without it the mean size of the downstream migrants is not indicated. Study of the growth through the end of the scale winter check period only may nevertheless have value in determining relative survival of the juveniles over the critical winter period.

TRANSITION FROM LACUSTRINE GROWTH TO MARINE GROWTH

The growth of young sockeye apparently accelerates when they enter the sea, and this produces a change in the growth pattern of the scales. The existence of discernable differences in appearance between lacustrine circuli and marine circuli is prerequisite to assessing the nuclear growth of adult sockeye scales. Search has been made for information pertaining to the possibility of dyeing scales so that the nuclear area is delineated from the sea growth, but no success was experienced. Also the United States Federal Bureau of Investigation was communicated with regarding the possible use of fingerprint identification methods in recognizing scales from particular unit populations, but the criteria used in fingerprint identification are not adaptable to scale analysis. Nevertheless, ordinary careful observation shows that differences exist between lacustrine and marine circuli, although a certain amount of judgment must be used in interpreting them. A seawater rearing experiment has been conducted to test whether there are observable differences between known lacustrine circuli and know marine circuli in young sockeye scales. Also scale "reader" tests have been made to study the consistency of interpretation of lacustrine growth in adult sockeye scales among different observers.

Seawater Rearing Experiment

In the spring of 1952 yearling seaward migrants were captured as they left Cultus Lake. Through the co-operation of the Washington State Department of Fisheries these smolts were placed in a rearing pond at the Deception Pass Research Station. After a ten day acclimation period two hundred of the fish were removed and preserved in formalin. Subsequently another group of two hundred was retained in 100 per cent sea water for fifty-five days and then preserved in formalin. Scales were subsequently taken from both samples in the laboratory.

There were 189 readable scales in the first sample; these had formed no circuli of the heavier appearance which was thought to be characteristic of circuli formed in sea water. There were 191 readable scales in the second sample; these

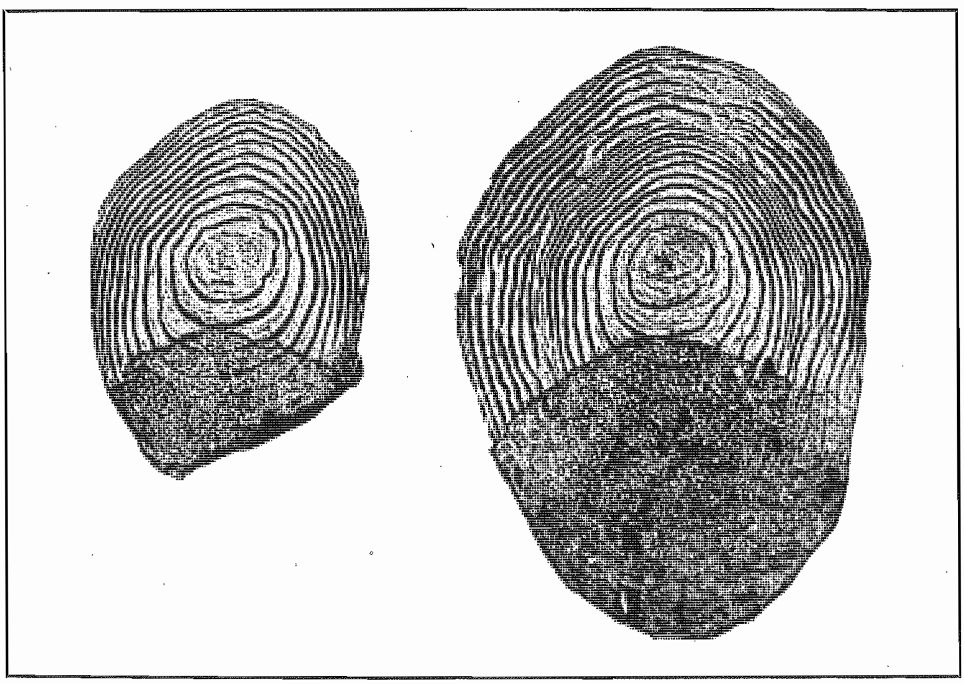

FIGURE 7—Scales of sockeye smolts: *A*. Prior to introduction into sea water; *B*. After fifty-five days residence in sea water, note heavier appearance of extra-nuclear circuli.

smolts of fifty-five day sea water residence had formed an average of 6.2 circuli of heavier appearance. (A representative individual scale from each of these two samples in shown in FIGURE 7.) The circuli having the appearance assumed to be characteristic of fresh water growth were enumerated in each of the samples and the means of the two series of counts were compared. Two observers made independent counts of the two series of scales producing the results shown in TABLE 3. Neither observer viewed his own results nor those of the other observer until after completion of the experiment. The similarity between the means of the two samples indicates that the change in character of circulus deposition after introduction into seawater is abrupt and discernable.

TABLE 3—Comparative interpretation of mean number lacustrine scale circuli of sockeye smolts prior to introduction into sea water and after fifty-five days sea water residence. Independent interpretation by two observers.

OBSERVER	MEAN NUMBER LACUSTRINE CIRCULI		
	Prior to Introduction	After 55 Days	Difference
a	12.6	12.7	0.1
b	12.8	12.8	0.0
Average of *a* and *b*	12.70	12.75	0.05

There is a difference between observers of 0.2 circulus in interpreting the scales of the pre-introduction sample and 0.1 circulus in the fifty-five days sea water sample. This is attributable to slight differences in the inclusion or rejection of branched circuli or partially-formed peripheral circuli, resulting partly from lack of experience of the observers. Criteria for rejection or inclusion of circuli is discussed further in a following section.

Scale Reader Tests

Variability in selection of lacustrine circuli is not uncommon in interpreting nuclear growth of adult scales. The degree of variation depends on the characteristics of the particular scales being examined. Observers may disagree only slightly concerning the collective lacustrine growth of a series of adult scales and yet differ to a greater degree in the interpretation of the individual scales. The problem of conformity of interpretation among different observers and consistency of interpretation by given observers has been studied through scale reader tests.

The observers had only brief experience in scale reading, therefore the variability in these interpretations is greater than that which would result from similar tests made with selected, well-indoctrinated and experienced observers. A sample of one hundred adult 4_2 scales was read an aggregate of twenty-one times, producing a total of 2100 nuclear circulus counts. The scales were read by eight observers; four of these observers read them three to five times each. Examinations by the same observer were at least ten days apart and often at a much longer interval. At no time during the course of these tests were the several readers informed of their own results or the results of others. The scales were taken from a commercial fishery catch of mixed runs, and the scales chosen are at least as difficult to interpret as the average sample taken from either the commercial fishery or the spawning grounds.

The mean nuclear circulus count is chosen to illustrate the variability in interpretation of the collective nuclear growth of the one hundred scales. The results are summarized in TABLE 4. The standard deviation of means is a measure of the variation in the mean circulus count. The total twenty-one means had a standard deviation of 0.46 circulus. The standard deviation of the means

TABLE 4—Variations in interpretation of mean number nuclear circuli of one hundred test scales by untrained observers.

	Number of Readings	Mean of Means	Standard Deviation of Means
Total readings by 8 observers	21	17.62	0.46
Initial readings by 8 observers	8	17.83	0.49
Observer *a*	4	17.67	0.79
Observer *b*	5	17.39	0.56
Observer *c*	3	17.48	0.37
Observer *d*	5	17.80	0.16
Average of observers *a, b, c, d,* weighted by number readings	17	17.59	0.46

of the first readings of each of the eight observers is 0.49 circulus; this is the measure of the variation between observers. The average standard deviation of the four observers who made multiple observations is 0.46 circulus; in this case the variation *within* the readings of each particular observer is calculated and a weighted mean deviation for all four is taken, yielding the expected variation from reading to reading for any given observer. The variation between observers is only slightly more than the expected variation for any given observer. The low standard deviation (0.16 circulus) of Observer *d* indicates that certain observers can interpret the nuclear growth with considerably better than average consistency.

The variation in mean circulus count is a function of the variation in interpreting individual scales. Analysis of the test scale readings shows that this individual variation is apparently random.

Since personal judgment is used in determining the nuclear circulus count it is not possible to assign an undeniable absolute value to the nucleus of any given adult which has not been sampled and marked prior to its entry into the sea. The circulus count most often chosen for each scale, i.e. the modal value, is considered to be the best estimate of the true value. The mean number of circuli, as computed from several readings of a single scale, is not a useable parameter because the circulus count is discrete. A distribution of the twenty-one readings is compiled for each scale of the one hundred scale series. These distributions are coded, that is, the mode is assigned a value of zero and deviations therefrom are given graded positive or negative values depending upon whether they are greater or less than the mode. There are one hundred scales in the test sample, and, there-

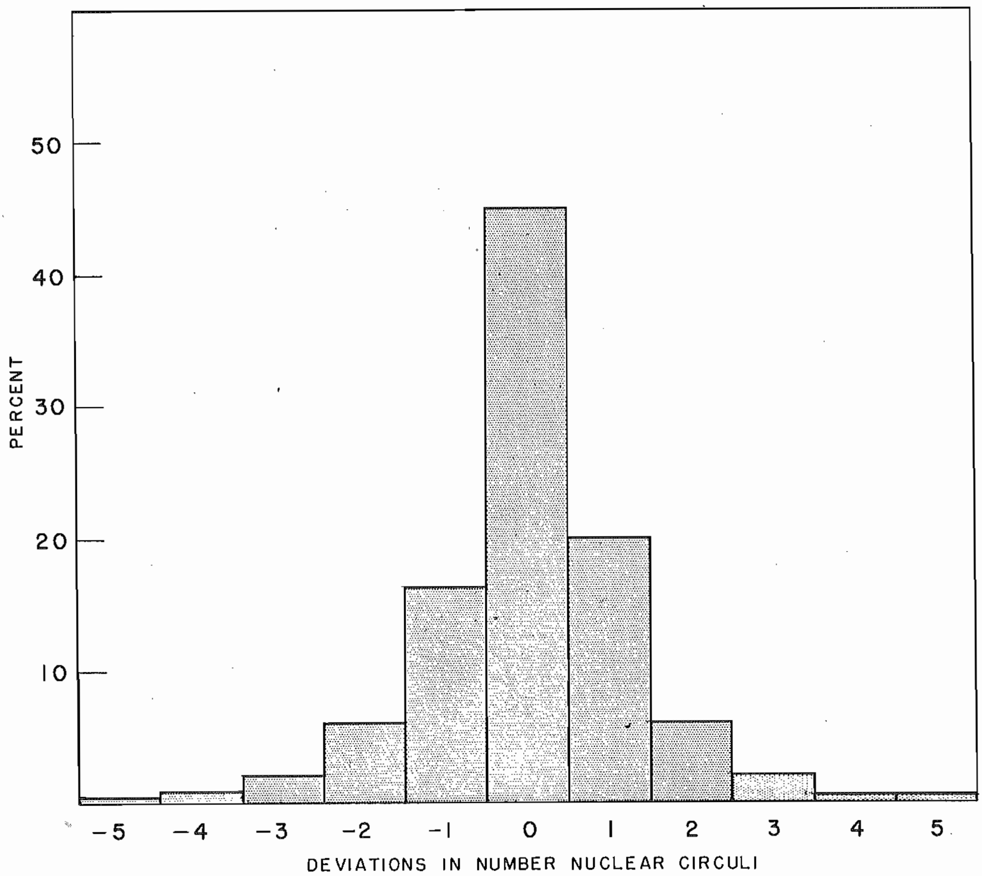

FIGURE 8—Variations in lacustrine growth scale reading interpretations of untrained observers. Composite of twenty-one interpretations of each of one hundred 1951 commercial adult 4_2 scales. Expressed in deviations from the modal nuclear circulus count.

fore, there are one hundred such coded distributions which are combined to produce the composite distribution of deviations shown in FIGURE 8.

The deviations from the mode are almost symmetrical; 46.2 per cent of the scale readings fall on the mode, 83.1 per cent are within one circulus from the mode, and 94.7 per cent are within two circuli. Of the initial readings of all eight observers 83.3 per cent are within one circulus from the mode, and an average of 86.7 per cent of the readings of the observers who made multiple observations are within one circulus from the mode.

As stated before, the scale reader tests just described were conducted with eight different observers of whom none was experienced. Much more consistent results are obtained from well-indoctrinated and experienced observers. This is exemplified by the results of a scale reading test using one hundred 1952 commercial fishery adult 4_2 scales chosen from the same seasoned period as the above 1951 test scales. These scales were read three different times by the same observer, who allowed an interval of a week or more between readings and had no recourse to the previous readings until after the test was completed. These three readings yielded the following mean nuclear circulus counts: first reading, 18.62; second reading, 18.63; third reading, 18.64. There were 64 of the 100 scales which were interpreted exactly the same all three times, and 99 which were interpreted the same two of three times.

Deviations which are greater than three circuli are considered to be gross deviations. These can be attributed to clerical errors or to misinterpretation of the transition zones on the few scales which present uncommon difficulties in this respect. The accuracy of the nuclear circulus count depends on the degree of difference in appearance between fresh water and sea water circuli. The circuli in the transition zone are sometimes intermediate between clear-cut lacustrine and marine types, and occasionally a circulus will have lacustrine appearance at one extremity and marine appearance at the other. This intergradation is probably a result of the characteristic pattern of circulus formation. A ridge is not built-up simultaneously in all its parts. According to Creaser (1926) various detached portions may be under construction at the same time, the detached fragments increasing in length until they merge with one another. The ridges at the margin of the scale are at all times incomplete. Because of this a circulus may be influenced by both lacustrine and marine growth conditions.

A minor portion of Fraser River sockeye form scales which are difficult to interpret. The difficulty usually results from a lack of distinctness between fresh water and sea water circuli. This lack of distinctness occurs primarily when the last-formed fresh water circuli are large and approach the size of small sea water circuli. This may be the result of particularly vigorous growth during the spring prior to seaward migration. In some cases the nuclear area will not show the characteristic first year winter check. The absence of this check, coupled with large and intergrading transitional fresh water circuli, can make interpretation of the nuclear areas of certain scales questionable. These uncommonly difficult scale growth patterns originate in particular populations primarily; the great majority of Fraser River sockeye scales are much easier to interpret.

A system has been devised which reduces the possible error in mean circulus count which might arise from inconsistent interpretation. Each series of scales for which a mean is sought is read independently by two observers. The readings are compared scale for scale. Where the count differs by more than three circuli the particular scale is rejected as unreadable. The number rejected because of disagreement varies from 1 per cent to 10 per cent of the sample and is usually less than 5 per cent. Means are calculated for the remaining scales and the means of the two samples are compared. If there is not more than about 0.5 circulus difference the means are accepted, and the average of the two is taken as the mean for the population. If, as only occasionally occurs, there is more than 0.5 circulus difference between the means the scale series is read again by one of the observers after a lapse of several days. If his mean does not change appreciably the series is read again by the other observer. Agreement is usually effected by this time. The results of the readings are made known to the observers only after the means have been accepted.

MEASUREMENT OF LACUSTRINE GROWTH

In the tests just described lacustrine scale growth was measured by enumerating the circuli in the nuclear area, but this is only one possible method of

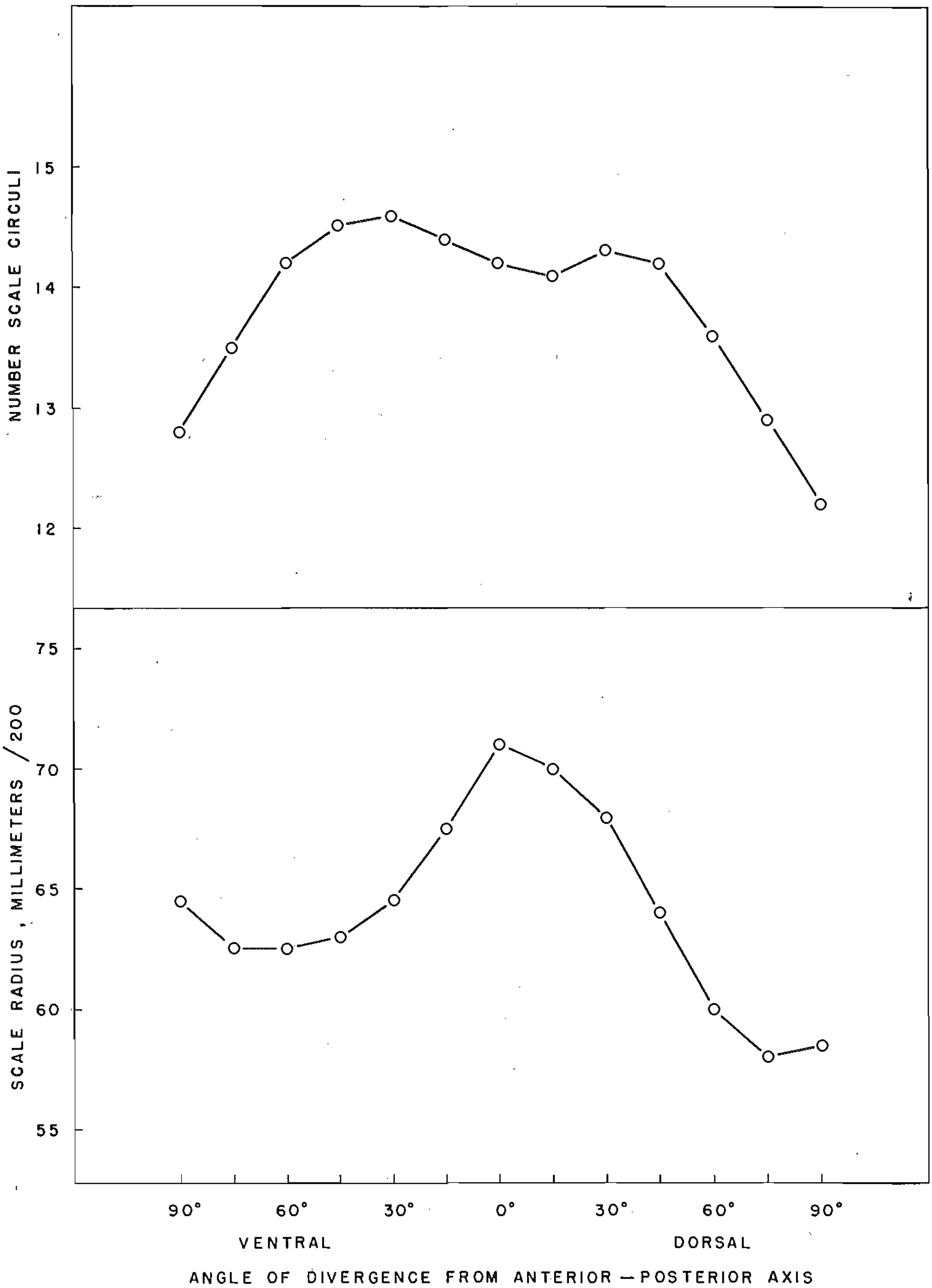

FIGURE 9—Variation in mean number circuli and mean radius measurement on sockeye smolt scales with change in position of radial observation line through scale focus. Ninety-five scales in sample.

measurement. Circuli must always be examined to determine where the lacustrine growth ends, but the zone included in the nuclear area can be assessed by linear radius or diameter measurement or measurement of the plane area in square units.

Since the sockeye scale is approximately round and grows outward from a common focus it is possible to measure the growth in almost any direction in the anterior field along lines radiating from the focus. There are, however, differences in the rate of addition of scale material along these different directional lines which result in differences in radius measurement and number of circuli as well. FIGURE 9, representing an analysis of ninety-five Lillooet Lake yearling scales of the 1952 migration, shows that both the mean number of circuli and the mean radius vary with change in the position of the radial observation line and, further, that the circulus counts and radius measurements vary in divergent patterns. The mean circulus count is greatest about 30 degrees ventral to the anterior-posterior axis, whereas the mean radius is greatest along the anterior-posterior axis itself. The number of circuli along the anterior-posterior axis is not a maximum because of the broken and discontinuous character of the circuli in this zone. For angles of 45° and less the radius is greater on the dorsal side than on the ventral side, whereas the number of circuli is greatest on the ventral side. Measurements or counts on different radial lines clearly differ. Their efficacy in accurately indicating the lacustrine growth of the fish must be determined separately, and conversion factors are necessary if the various measurements are to be related with each other.

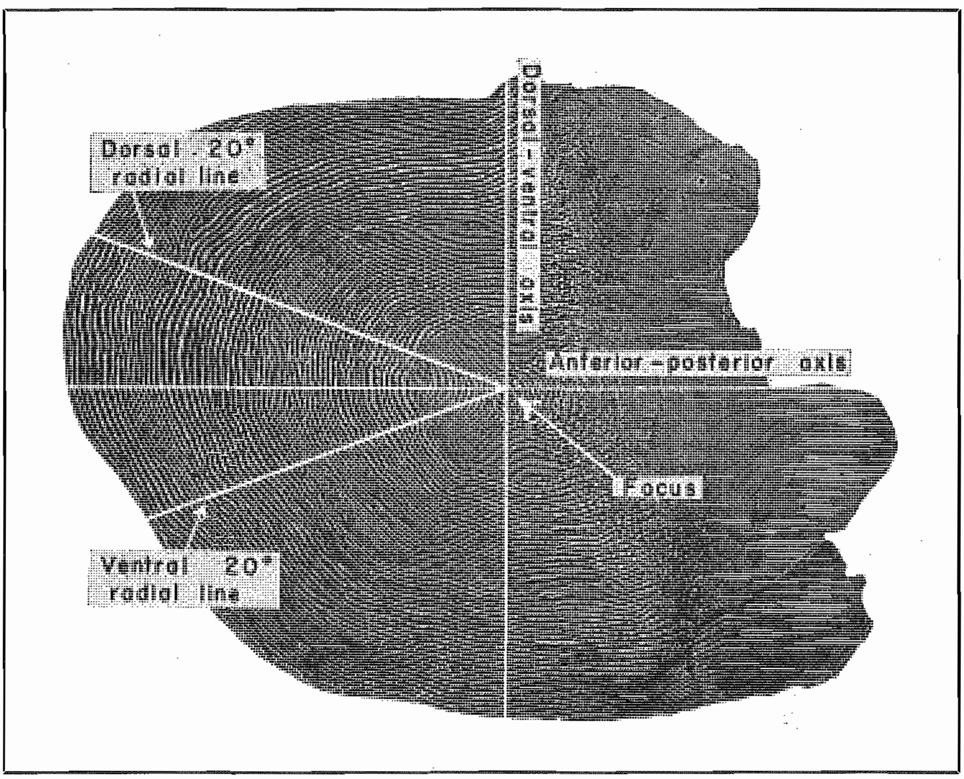

FIGURE 10—Scale of adult (4_2) sockeye with superimposed radial reference lines.

TABLE 5—Comparison of mean size of juvenile sockeye with mean number of scale circuli and scale measurements on variously-positioned radial observation lines. Samples from various areas; all seaward migrant smolts except Shuswap Lake 1955 (advanced fry) and Horsefly Lake 1955 (yearling kokanee).

LAKE	YEAR	AGE OF FISH	NUMBER IN SAMPLE	MEAN FORK LENGTH mm.	MEAN WEIGHT gm.	MEAN NUMBER CIRCULI		MEAN RADIUS mm./200		Mean Maximum Radius mm./200	Mean Dorsal-Ventral Diameter mm./200
						Ventral 20° Radial Line	Dorsal 20° Radial Line	Ventral 20° Radial Line	Dorsal 20° Radial Line		
Chilko	1951	1	117	72.0	3.72	11.5	11.4	54.1	56.6	57.6	111.1
	1952	1	159	82.4	5.08	13.3	13.2	69.0	72.6	74.5	130.8
	1952	2	108	113.3	12.41	22.2		102.2		112.4	191.2
	1953	1	144	77.1	4.29	12.5	12.3	62.6	66.8	67.9	125.1
	1953	2	60	107.9	10.70	20.4		98.2		108.0	186.2
	1954	1	358	77.1		12.2		59.1			
	1954	2	169	107.5	11.52	20.5		98.8			
	1955	1	300	69.9	3.30						
	1955	2	100	101.1	9.08						
Cultus	1944	2	36	147.6	28.36	32.0	32.4	148.8	154.4	159.7	252.4
	1952	1+	221	109.9	12.33	20.2		99.1		107.7	193.8
Francois	1951	1	116	104.8	12.02	19.3	18.8	99.0	104.0	108.3	177.4
Harrison	1950	1	32	105.8		20.7	20.5	108.8	112.3	116.8	182.5
	1953	1	47	94.9	9.15						
Horsefly	1955	1	60	125.6	19.51	24.6	24.5	129.0	133.2	138.9	217.8
Lillooet	1953	1	117	76.9	4.48	12.1		62.2			
Shuswap	1948	1	133	63.0	2.58	8.7					
	1952	1	126	63.9	2.02						
	1953	1	184	84.8		14.0					
	1955	0+	64	52.5	1.58	5.6	5.5	37.1	39.5	40.0	79.0
Stuart	1951	1	190	95.1	8.38	16.8	17.3	85.3	88.6	90.5	150.9

Further evidence of this divergence appears in the following sections where comparisons are made between mean scale circulus counts and measurements from various samples of smolts. These counts and measurements are made along particular radial lines on the scale, as illustrated in FIGURE 10.

The principal considerations in measuring lacustrine growth are the mechanics of the method and the representativeness of the results. Since the measurement of the nuclear area of the scale for growth studies is made in lieu of measurement of juvenile sockeye it is necessary to know how closely the growth of the scale reflects the growth of the young fish. Both the efficiency and accuracy of the possible methods of measuring the nuclear area must be evaluated.

The relationships between mean length, mean weight and mean number scale circuli, mean scale radius, mean scale diameter, and, to a limited extent, scale area, are discussed in the subsections which follow. Analysis of the relationship between the means rather than the values for individual fish is preferred because means are used in the analytic comparison of most growth data. In all, 2,841 fish were examined. As shown in TABLE 5 the total sample is composed of twenty-one subsamples originating from eight different river systems and including both one and two year smolts, and one sample from Horsefly Lake that is apparently composed of yearling kokanee. For brevity, all of the samples included in this scale measurement analysis are referred to as smolts, even though they include the Shuswap Lake advanced fry and the Horsefly Lake kokanee. The subsamples range in magnitude from 32 to 358 fish, with fifteen of the subsamples greater than 100 fish. Not all subsamples are analysed for all of the attributes studied, but a representative number of samples covering the entire range of lengths are analysed in each case.

The smolts were weighed and measured at the time the scales were taken. Four scales were taken from each smolt from the body area immediately posterior to the insertion (posterior) of the dorsal fin and in the first two rows above the lateral line. The scales were carefully removed with very light weight curved forceps which had been filed to fine points, and thereafter placed individually on mucilage paper with the sculptured sides exposed. Scale impressions were made as described in a prior section. All four scales from each fish were examined but only the most clearly-impressed and regular scale from each fish was measured and circuli counted for subsequent analysis.

Length and Weight of Smolts

All of the smolts used in these tests had been preserved in formalin of about 10 per cent concentration for periods ranging from six months to ten years, most having been in preservation from one to three years. Fork length measurements, from the tip of the snout to the tips of the central caudal fin rays, were taken to the nearest millimeter on a plane measuring board with headpiece. Balance scale weight of each fish was taken to one-tenth gram accuracy after removal of excess liquid by blotting the body with paper towelling. The relationship of the mean length and mean weight data appearing in TABLE 5 is illustrated in FIGURE 11. The two points nearest the origin on the curve represent fry; newly-emerged

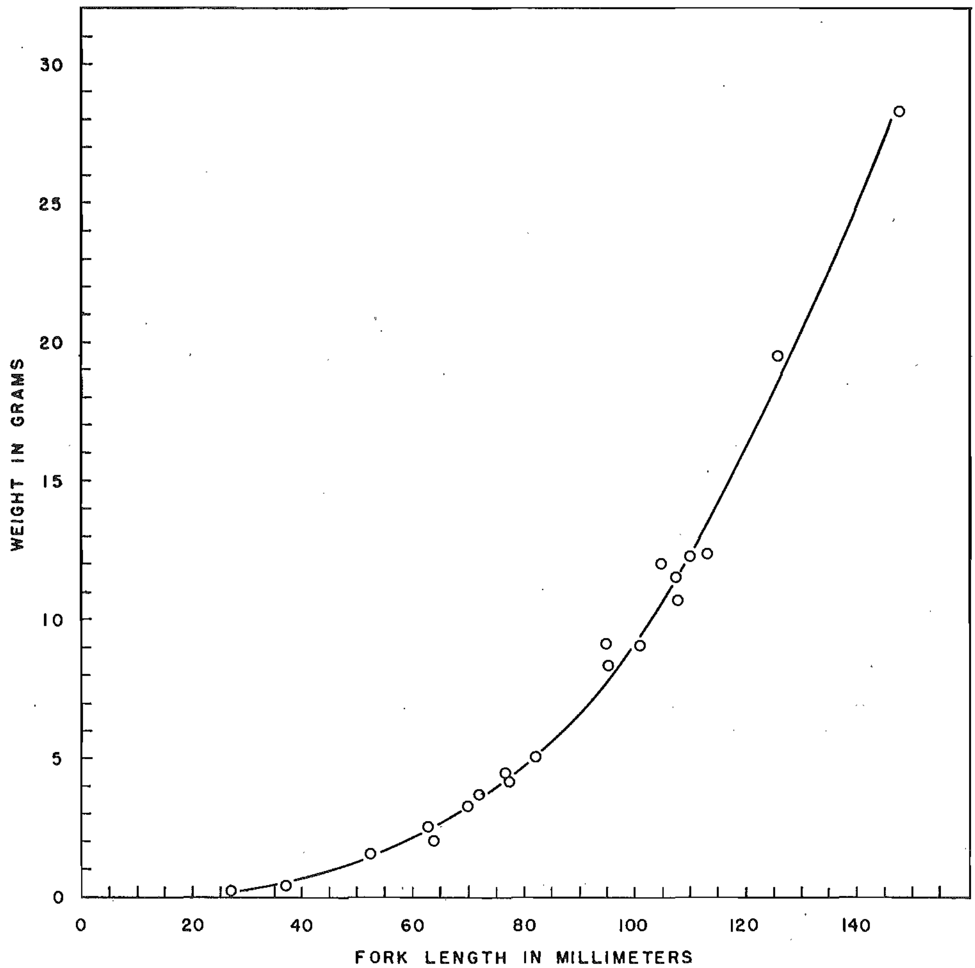

FIGURE 11—Relationship between mean weight and mean fork length of sockeye fry and smolts; 2,267 smolts in samples.

fry are about 27 millimeters fork length and 0.14 gram weight; fry at scale formation are about 38 millimeters fork length and 0.55 gram weight.

Tests of the effect of formalin of various concentration on weight and length were made to determine whether there is an effect, and, if so, whether the change is of sufficient degree to require a correction factor. Smolts of ages one and two years were taken at Chilko River during the 1955 downstream migration. Four 100-fish samples of fresh-killed smolts were weighed and measured before being preserved; thereupon 100 of the one-year smolts were placed in a 10 per cent formalin, 100 in 15 per cent formalin and 100 in 25 per cent formalin, and 100 two-year smolts were placed in 10 per cent formalin. The individual fish of each sample were again weighed and measured after 25 days of preservation, and weighed and measured for the third time after 180 days of preservation. Each sample was kept separate for each analysis. TABLE 6 shows that the average lengths did not change appreciably in the 25 day interim, but there was a

TABLE 6—Effect of formalin preservation on fork length of sockeye smolts. One hundred smolts in each of four groups.

FORMALIN CONCENTRATION, PER CENT	AGE OF SMOLTS	RELATIVE DECREASE IN LENGTH FROM FRESH CONDITION	
		25 Days Preservation	180 Days Preservation
10	1	0.015	0.047
10	2	0.000	0.026
15	1	0.001	0.031
25	1	0.016	0.049

general decrease in size. However, during the six month preservation period there was a decrease in body length of from 2.6 per cent to 4.9 per cent from the fresh condition. There was no difference in effect among the different concentrations of formalin. Unfortunately, the fresh weights of the samples were nullified due to technical difficulties and no comparison of change from fresh weight can be made; however there was a decrease in weight of about 2 per cent in the interim between the 25 day and 180 day weighings. No adjustment has been made in the comparisons of length, weight, and scale measurements to follow, the relationships are valid because all fish in the samples were similarly preserved, however if greatest accuracy is desired the fork lengths need merely be increased by a factor of 4 per cent.

Enumeration of Scale Circuli

Enumeration of circuli has been the most-used method of measuring lacustrine scale growth of sockeye. This method was employed by Gilbert (1914-1925) in his scale studies and has been the principal method used by the Commission up to the present time. The irregularities of scale growth are such that it has been necessary to establish criteria for interpretation, and routine scale reading is conducted in accordance with a simple set of basic rules. Circulus counts are made along a particular radial line for consistency of results. The radial line chosen for all routine analyses extends ventro-anteriorly from the focus of the scale, forming an angle of 20° with the horizontal or longitudinal axis of the scale (FIGURE 10). This ventral 20° radial line is almost perpendicular to the anterior edge of the unsculptured posterior field. The chosen radial line is disclosed by overlaying the transmitted scale image with a clear plastic guide onto which a longitudinal axis and two 20° radial lines have been etched. The common focus of the angles is placed on the focus of the scale and the longitudinal axis of the guide is aligned with the longitudinal axis of the scale. The circulus count is then made along the ventral 20° radial line.

The ventral 20° radial line was chosen for past routine analyses after critical examination of the nuclear circuli indicated that consistent and representative results were obtainable there. This choice is justified by the detailed analyses to be discussed in this and following subsections. In past routine analyses the dorsal 20° radial line was used alternatively when the circuli on the ventral

20° radial line were effaced or obliterated. As shown in FIGURE 9, and as will be reaffirmed in following sub-sections, the circulus count on the dorsal 20° radial line is slightly lower, but not sufficiently so that its occasional use is unwarranted.

The circuli in the proximity of the longitudinal axis of the scale are often discontinuous or broken, especially in the zone of transition between lacustrine and marine growth. The fresh water circuli are thickest where they meet the posterior field of the scale and sometimes simulate salt water circuli in this region. The anterior-posterior and dorsal-ventral axes present obvious difficulties in defining the transition from lacustrine to marine growth and enumerating the nuclear circuli. Because of this only the 20° radial lines were used in routine analyses.

Irregular circuli are sometimes encountered when nuclear circulus counts are being made. Certain simple rules have been applied to the counting or rejection of such circuli in both routine and test analyses. Where a single circulus branches, and the two branches extend across both the ventral 20° radial line and the dorsal 20° radial line, the two branches are counted as distinct circuli. Where two circuli cross both 20° radial lines but fuse between them they are counted as two distinct circuli. Short branches of nuclear circuli are not enumerated. Where a circulus appears to be discontinuous for some distance across the anterior section of the nuclear area but appears on both sides near the 20° radial lines it is counted as a complete circulus.

Regenerated scales are rejected. About 10 per cent of adult Fraser River sockeye scales examined are regenerated. Scales with rotated centres are rejected if they are not clearly interpretable. Occasionally the innermost circulus of a scale is incomplete and continuous with succeeding circuli, forming a spiral. When circulus counts are made of such scales, only the circuli crossing the ventral radial line are enumerated.

Cursory observation shows that larger fish tend to have larger scales and that larger scales tend to have more circuli; therefore a relationship between size of smolt and number of scale circuli exists. It is necessary to determine the closeness of this relationship and whether number of circuli can be used to express the amount of lacustrine growth, and whether this method of scale measurement is as accurate in depicting growth as other methods. The relationship between size of fish and number of scale circuli was studied for two observational positions on the smolts scales: the ventral 20° radial line and the dorsal 20° radial line (FIGURE 10). FIGURE 12 graphically illustrates the relationship between the mean number of scale circuli on the ventral 20° radial line and mean fork length. The data are taken from TABLE 5. The comparison of these two attributes from an aggregate of seventeen samples shows a high positive correlation with a correlation coefficient (r) of 0.998 and a standard deviation of circulus count on length ($S_{c.l}$) of 0.45 circulus. The equation for the regression line is:

$$\text{number circuli} = 0.269 \text{ fork length} - 8.51$$

In the statistical treatment of these data each of the individual seventeen samples was given equal importance regardless of sample size. This was desirable because

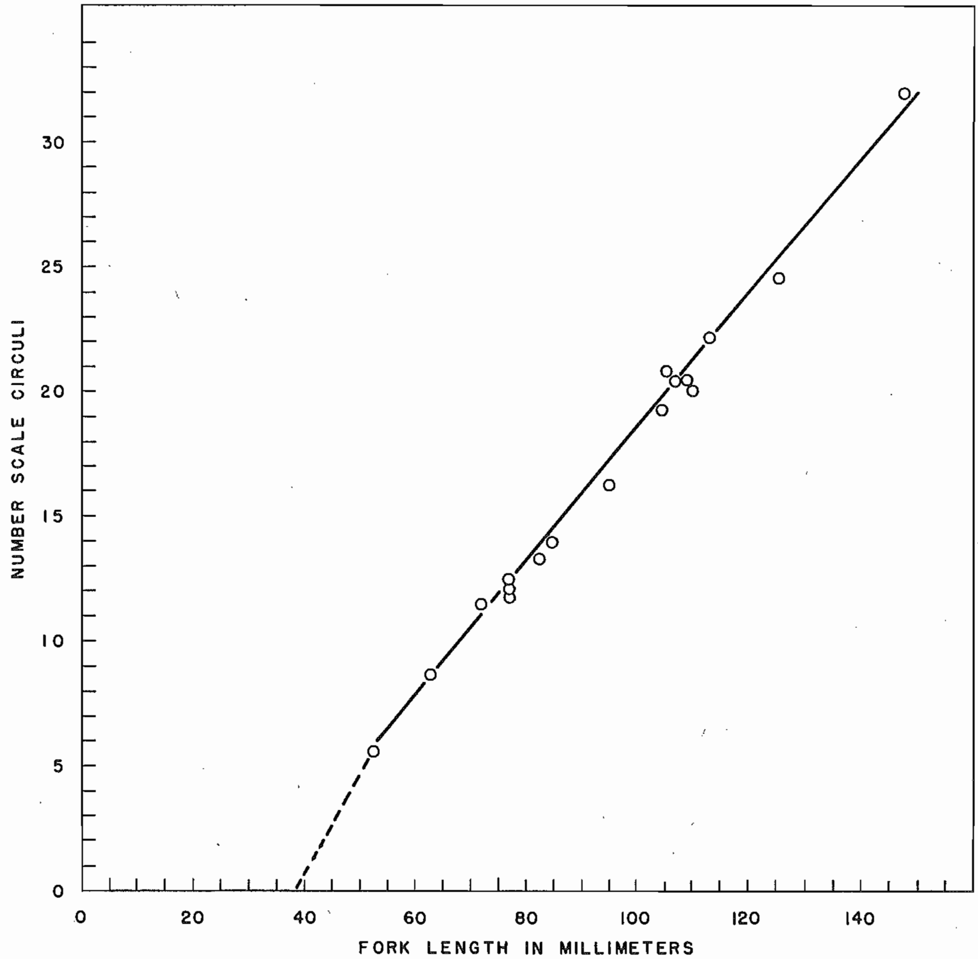

FIGURE 12—Relationship between mean number scale circuli on ventral 20° radial line and mean fork length of juvenile sockeye; 2,268 smolts in samples.

the variability of the relationship is largely a function of natural variations within the samples, not attributable to size of sample. For example, as will be shown, the points representing the two samples of greatest mean length and mean weight fall on opposite sides of the fitted lines in the comparison with mean circulus count, but their positions with relation to the fitted lines are interchanged in the comparison with mean radius measurement. The straight line relationship does not extend below 50 millimeters; as was shown in FIGURE 4 the relationship for fry is curvilinear, the scales being formed at a length of 38 millimeters.

The relationship between mean number of circuli on the ventral 20° radial line and mean weight is curvilinear as shown in FIGURE 13. The curve was fitted to the sixteen points by inspection. The points are slightly more dispersed, and the relationship not quite as exact as the relationship between number of circuli and length. The lower two points on the weight-circulus count curve

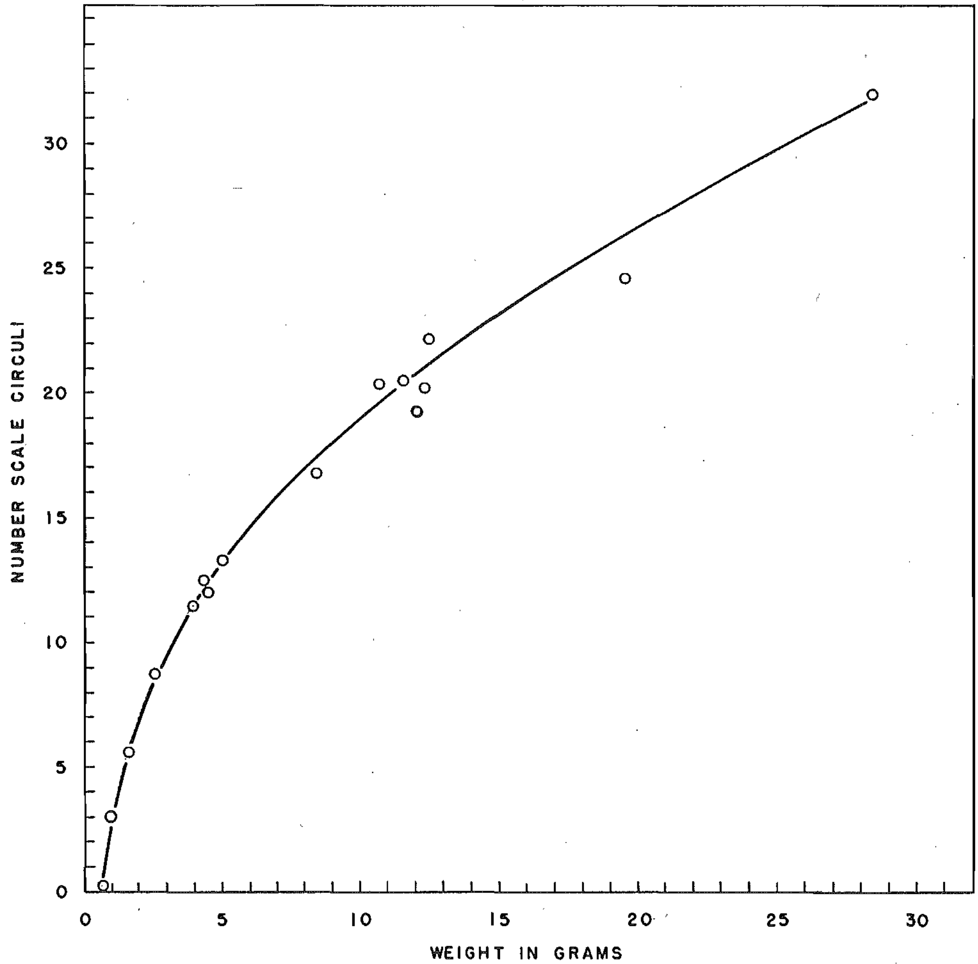

FIGURE 13—Relationship between mean number scale circuli on ventral 20° radial line and mean weight of sockeye fry and smolts; 1,694 smolts in samples.

represent fry; scale formation takes place when fry are about 0.55 gram in weight and at 0.9 gram weight fry have approximately three scale circuli.

The relationship between mean number of scale circuli on the dorsal 20° radial line and mean fork length was tested for nine samples covering the entire range of fork lengths (FIGURE 14). There is a high positive correlation with a correlation coefficient of 0.997 and a standard deviation of circulus count on length of 0.73 circulus. Here again the straight line relationship does not extend below 50 millimeters. The equation for the regression line is:

$$\text{number circuli} = 0.274 \text{ fork length} - 8.95$$

Measurement of Scale Radius

Measurement of radius or diameter in linear units is a second method of measuring lacustrine scale growth. This may be done by divider or caliper measurements or by projecting the scale image on an appropriately calibrated graduated rule such as a millimeter rule, on the desk surface or projection plane,

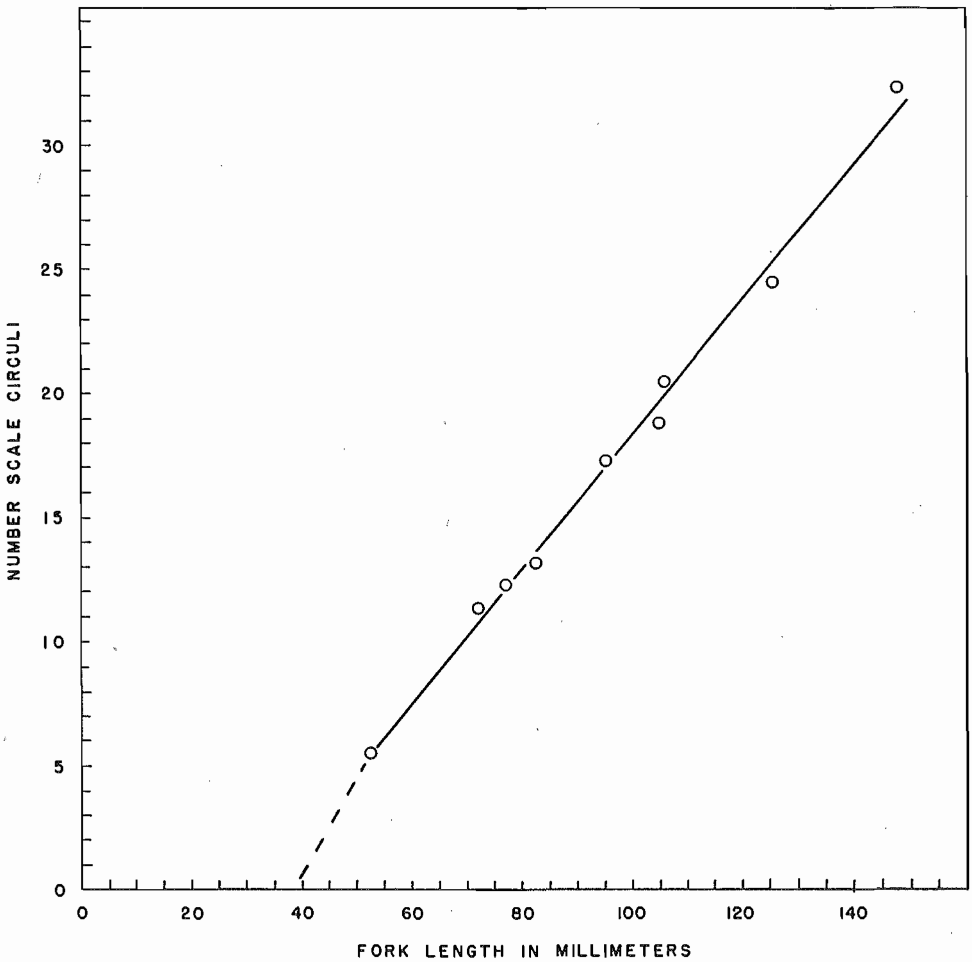

FIGURE 14—Relationship between mean number scale circuli on dorsal 20° radial line and mean fork length of sockeye smolts; 918 smolts in samples.

where the measurement can be read directly. As with enumeration of circuli, regenerated or otherwise irregular scales are rejected. Smolt scale radius measurements have been made along both the ventral and dorsal 20° lines, and diameter measurements have been made across the dorsal-ventral axis.

The relationship between the mean radius on the ventral 20° radial line and mean fork length appear in TABLE 5 and are illustrated graphically in FIGURE 15. The comparison of these two attributes from an aggregate of fifteen samples shows a high positive correlation with a correlation coefficient of 0.991 and a standard deviation of radius on length of 4.11 millimeters/200. The equation for the regression line is:

$$\text{radius} = 1.238 \text{ fork length} - 32.60$$

The unit of all radius and diameter measurements used here is two hundredths millimeters.

The comparison of mean radius on the ventral 20° radial line and mean

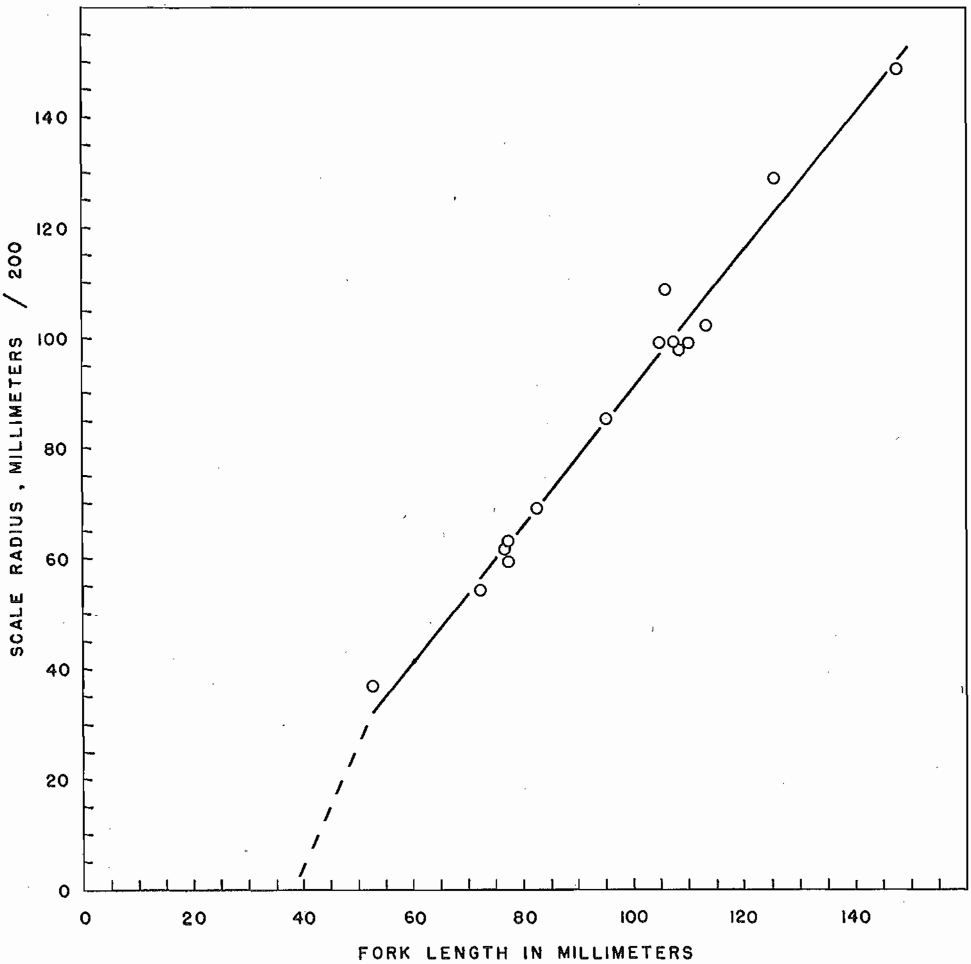

FIGURE 15—Relationship between mean scale radius on ventral 20° radial line and mean fork length of sockeye smolts; 1,951 smolts in samples.

weight is curvilinear. The curve fitted by inspection to the fourteen points appearing in FIGURE 16 shows that a closer relationship exists between radius and weight than between number of circuli and weight, whereas the opposite was the case in the relationship with length. Note that the two upper points (1955 Horsefly, 1944 Cultus) are interchanged in position with respect to the line in FIGURES 15 and 16 (number circuli) as compared with FIGURES 12 and 13 (radius). This is the result of difference in life history of the two groups of fish. The smaller fish of the two groups were Horsefly Lake yearlings which had experienced fast growth in their first year and had spent only one winter in the lake; whereas the fish of larger size were Cultus Lake two-year smolts which had spent two winters in the lake. During winter growth more circuli are laid down in relation to the increase in radius than are laid down during fast growing periods.

Mean scale radius on the dorsal 20° radial line and mean fork length were compared using nine samples covering the entire range of fork lengths (FIGURE

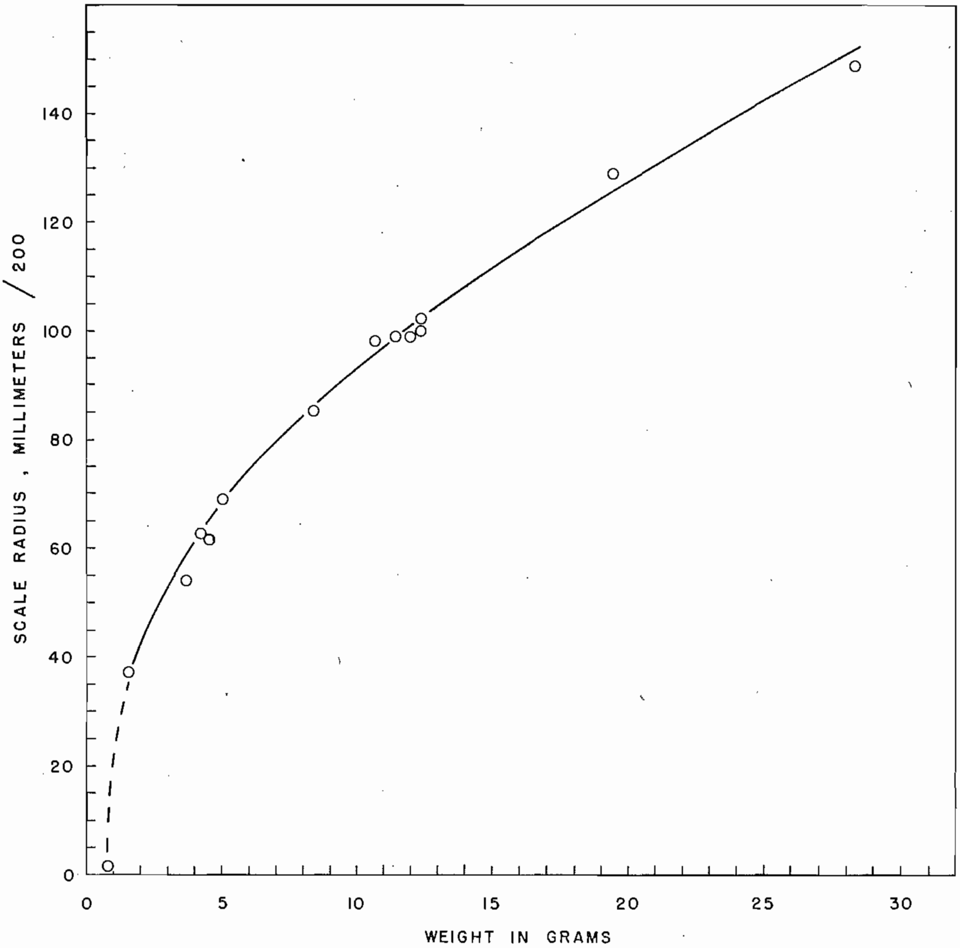

FIGURE 16—Relationship between mean scale radius on ventral 20° radial line and mean weight of sockeye smolts; 1,561 smolts in samples.

17). There is a high positive correlation with a correlation coefficient of 0.994 and a standard deviation of radius on fork length of 4.28 millimeters/200. The relationship would become curvilinear below 50 millimeters fork length. The equation for the regression line is:

$$\text{radius} = 1.282 \text{ fork length} - 30.92$$

As was shown in FIGURE 9 the scale radius varies considerably with change in the position of the radial line along which the measurement is made. The maximum radius does not lie along either the dorsal or ventral 20° radial lines but approximately along the anterior-posterior axis, and its position may vary slightly from scale to scale. The mean maximum radius is another possible criterion of lacustrine growth. FIGURE 18 shows the relationship between mean maximum radius and mean fork length as established by twelve samples. There is a high positive correlation with a correlation coefficient of 0.991 and a standard devi-

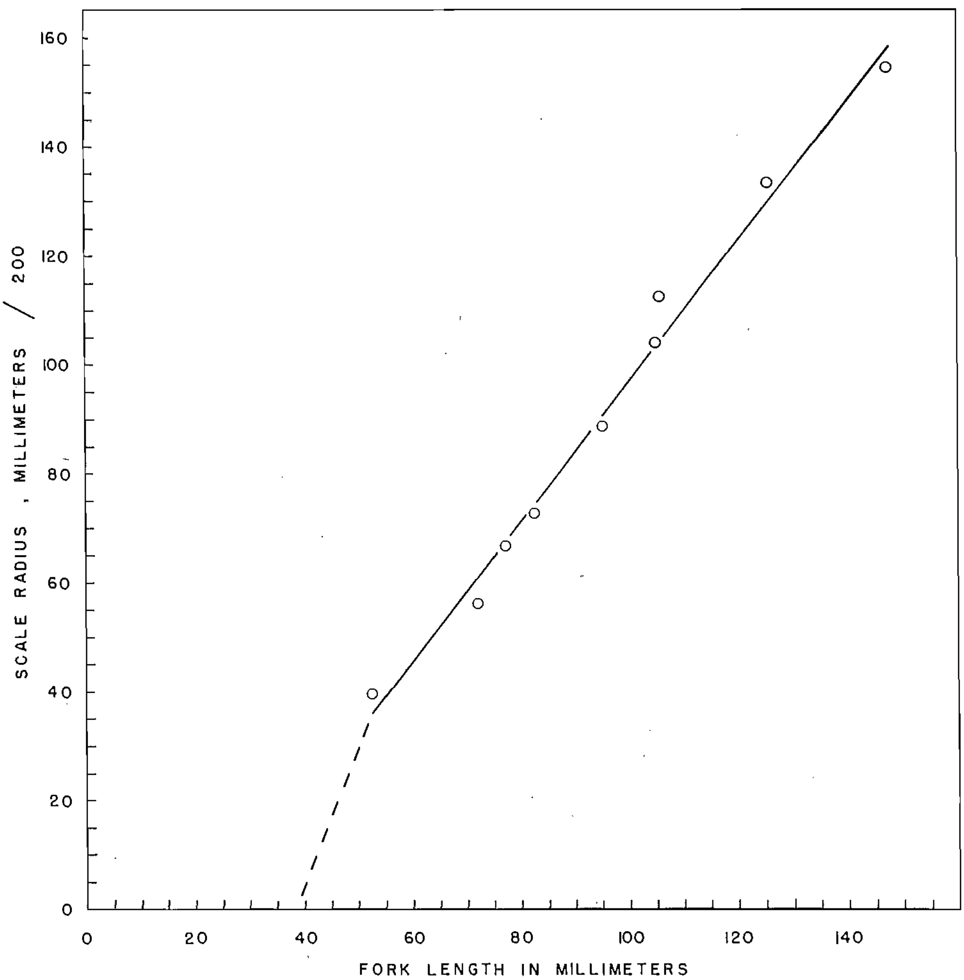

FIGURE 17—Relationship between mean scale radius on dorsal 20° radial line and mean fork length of sockeye smolts; 918 smolts in samples.

ation of radius on fork length of 4.75 millimeters/200. The equation for the regression line is:

$$\text{radius} = 1.323 \text{ fork length} - 33.11$$

Measurement of Scale Diameter

The possibility of measuring the diameter of the lacustrine growth zone of the scale has also been considered. It is not possible to do this along the anterior-posterior axis or along most radial lines diverging therefrom on adult scales because the circuli do not extend over the posterior fields of the scales, and it is therefore impossible to delimit the lacustrine zone in the posterior fields. However circuli are present both on the dorsal and ventral sides of the scale focus, and it is possible to measure the scale diameter across the dorsal-ventral axis. This scale diameter is closely related to the fork length as illustrated in FIGURE 19. Comparison of twelve samples shows a high positive correlation with a correl-

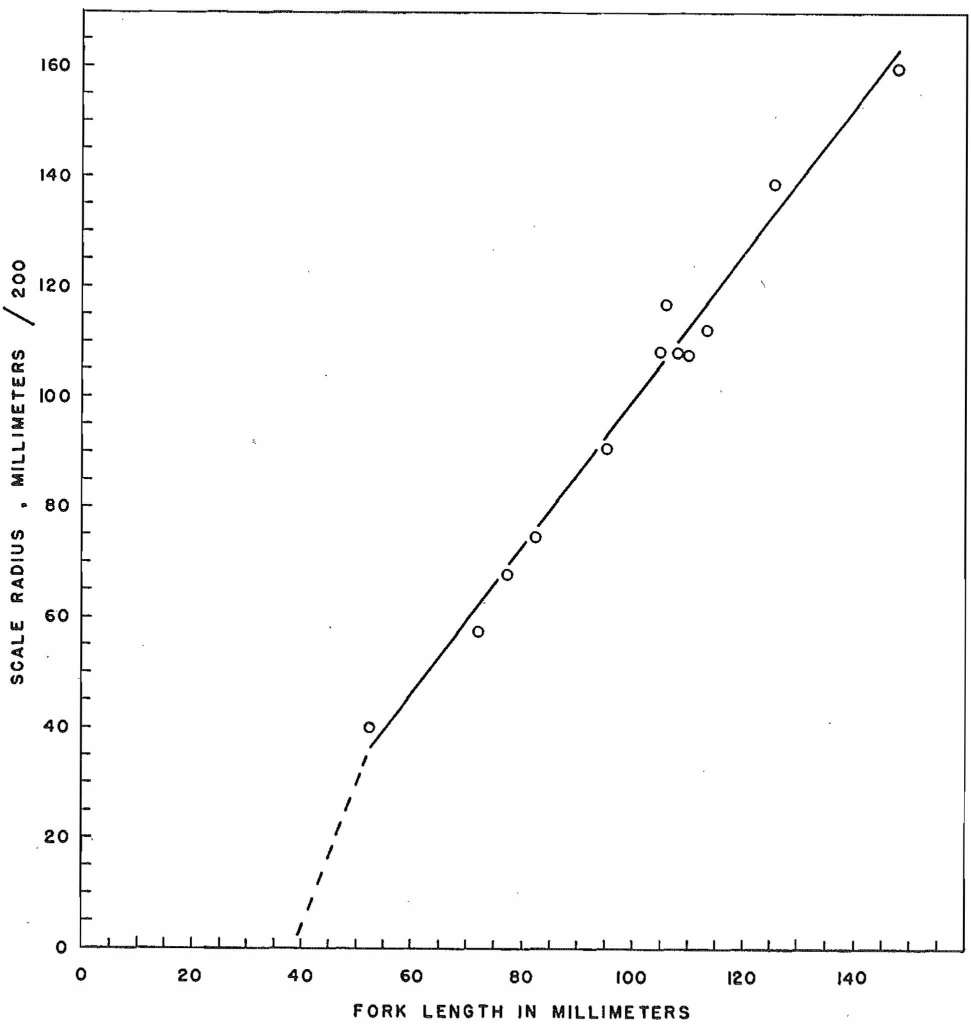

FIGURE 18—Relationship between mean maximum scale radius and mean fork length of sockeye smolts; 1,307 smolts in samples.

ation coefficient of 0.996 and a standard deviation of diameter on fork length of 4.40 millimeters/200. The equation for the regression line is:

$$\text{diameter} = 1.895 \text{ fork length} - 22.03$$

Measurement of Scale Area

Since both radius and diameter scale measurements have been shown to closely reflect the size of smolts the plane area of the scale must also. One hundred 1954 Chilko River smolt scales were analysed in this manner. The reflected images of the smolt scales magnified 200 times were traced around the anterior periphery and across the dorsal-ventral axis with a polar planimeter to measure the enclosed area in square units. The results showed a favorable comparison with other methods for the same sample, however no further experimen-

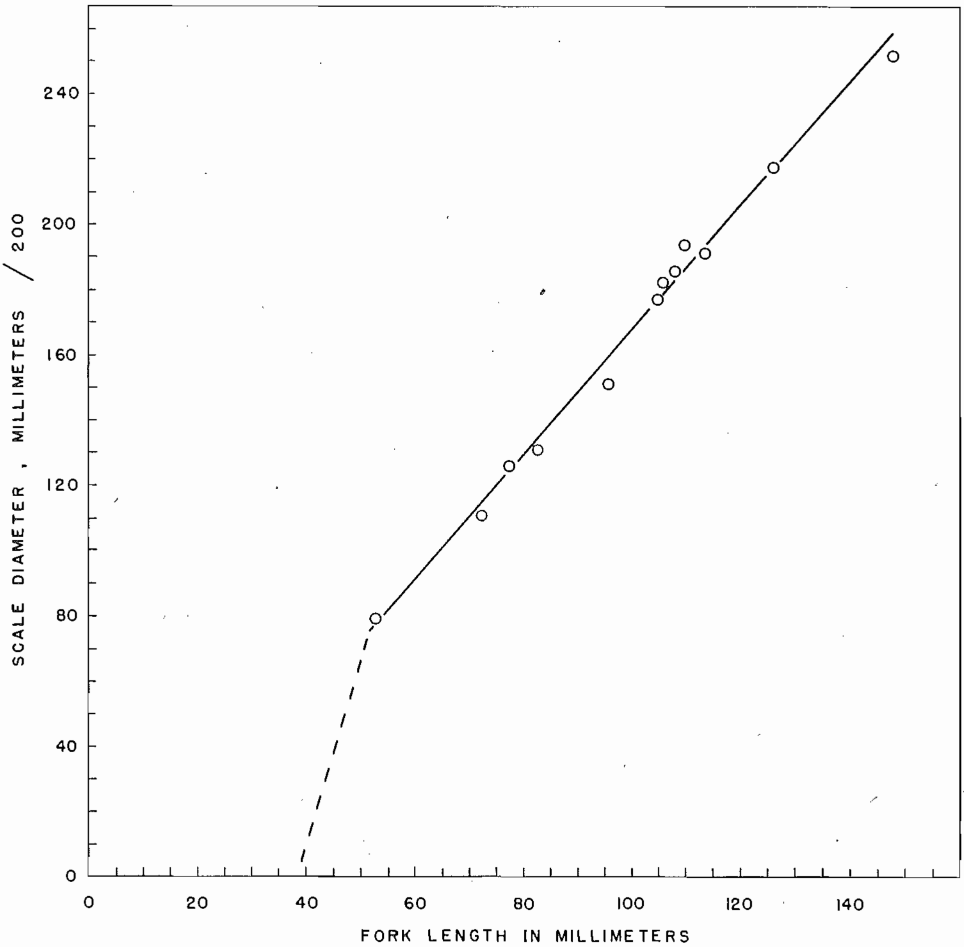

FIGURE 19—Relationship between mean scale diameter on dorsal-ventral axis and mean fork length of sockeye smolts; 1,307 smolts in samples.

tation was done because the method proved to be too laborious and technically difficult to be considered further.

Comparison and Evaluation of Methods

The number of scale circuli and scale radii vary somewhat independently with change in position of the radial line along which the count or measurement is made, as illustrated in FIGURE 9. For this reason the relationship between the methods may vary by position. FIGURE 9 shows that the average number of circuli on the equivalent positions ventral and dorsal of the anterior-posterior axis are roughly comparable, with the ventral side having the highest count. This relationship is confirmed by a comparison between the two 20° radial lines of mean number of circuli from the smolt samples from various areas (TABLE 5). The nine sample points lie very close to the 45° line; in seven of nine cases the mean number of circuli on the ventral 20° radial line is higher (FIGURE 20).

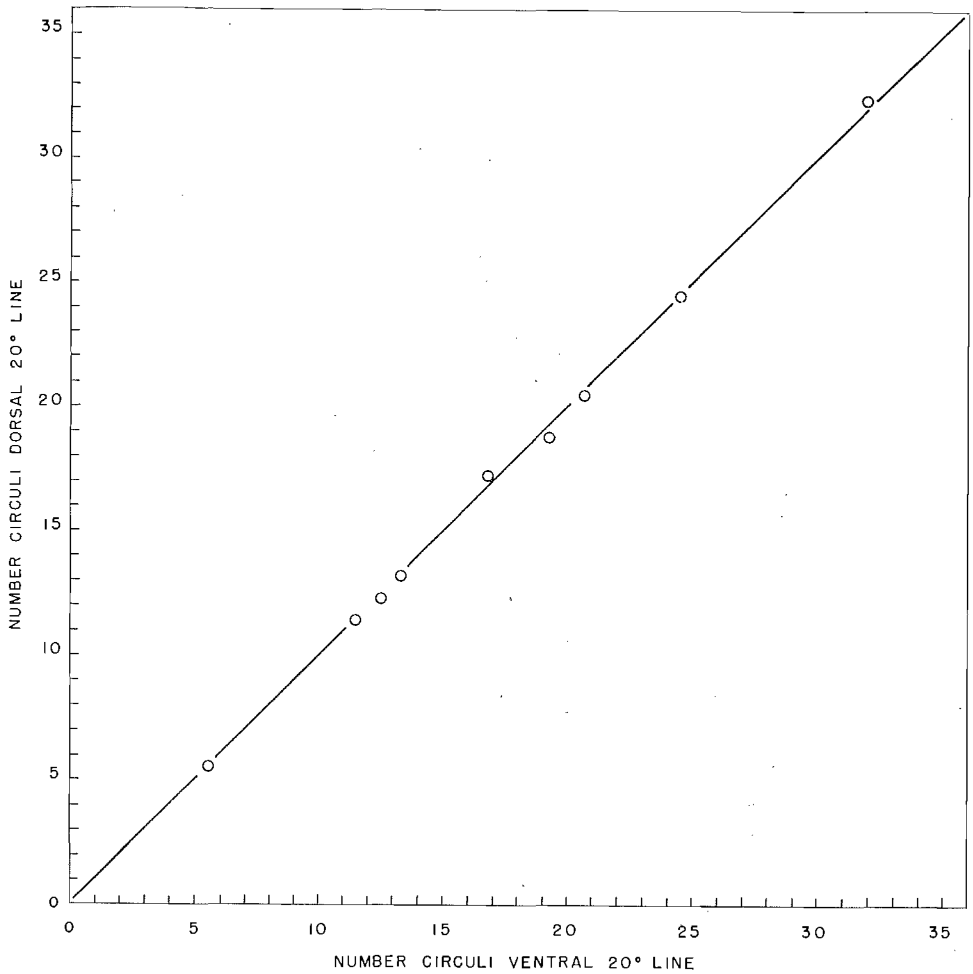

FIGURE 20—Relationship between mean number scale circuli on ventral and dorsal 20° radial lines of sockeye smolt scales; 918 smolts in samples.

FIGURE 9 shows that the radius measurement also varies with the position of the radial line along which the measurement is made. In this case however there is less bilateral symmetry around the anterior-posterior axis; the radius is larger on the dorsal side than the comparable position on the ventral side from 0° to 45° and smaller from 60° to 90.° This relationship is confirmed by a comparison of mean radius on the ventral 20° radial line with that on the dorsal 20° radial line of the smolt samples from various areas (FIGURE 21). Here there is an almost constant difference of 5 millimeters/200 in favor of the dorsal 20° radial line, with a slight but consistent tendency for the difference to increase with increase in size of the scales.

Calculation of conversion formulae or lines is desirable when comparing two methods of measurement because of the possibility of changing the method of measurement in the future. The relationship between mean number of circuli and

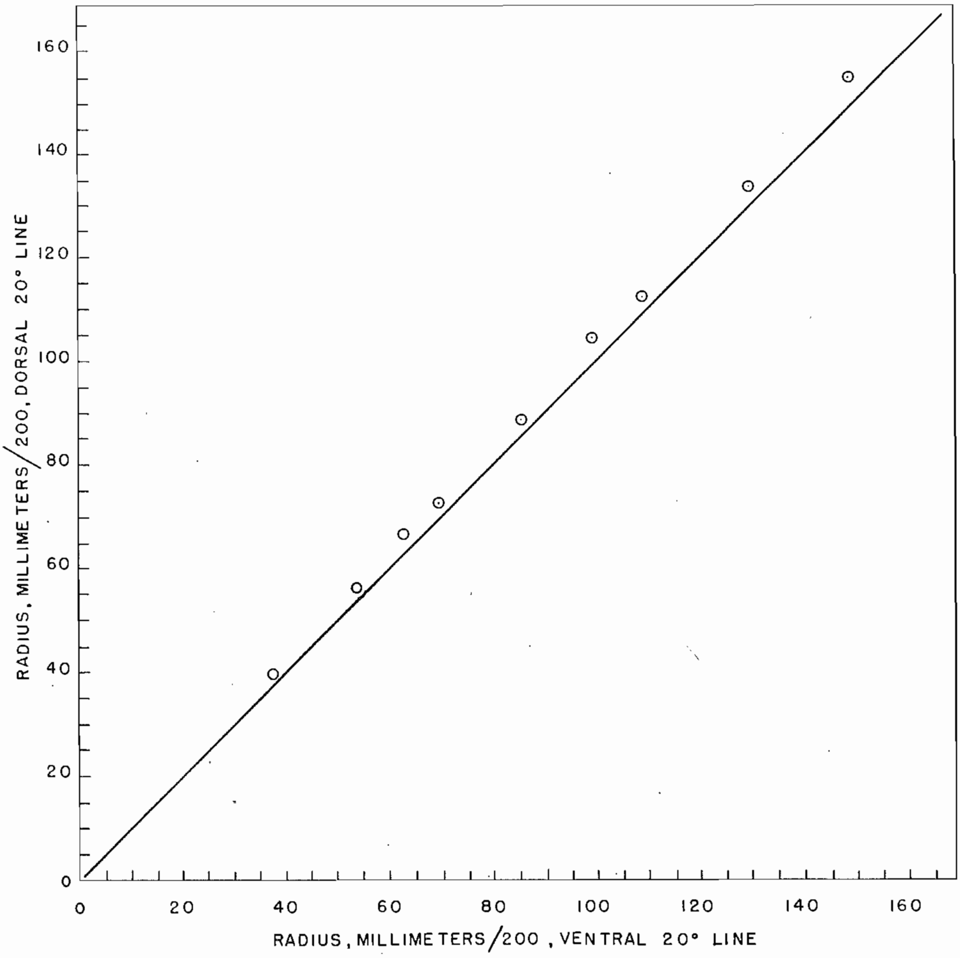

FIGURE 21—Relationship between mean radius on ventral and dorsal 20° radial lines of sockeye smolt scales; 918 smolts in samples.

mean radius on the ventral 20° radial line, and between the mean number of circuli and mean radius on the dorsal 20° radial line are shown in FIGURES 22 and 23. The relationships between mean number of circuli and mean radius are not as exact as those existing between mean circulus counts on the two 20° radial lines or mean radii on the two 20° radial lines. However the mean number of circuli and mean radius measurements are closely related; the mean relationship for the ventral 20° radial line is indicated by the calculated straight line fitted to the points in FIGURE 22. The equation for the regression line is:

$$\text{radius} = 4.558 \text{ number circuli} + 7.37$$

The mean relationship for the dorsal 20° radial line is indicated in FIGURE 23. The equation for the regression line is:

$$\text{radius} = 4.636 \text{ number circuli} + 11.70$$

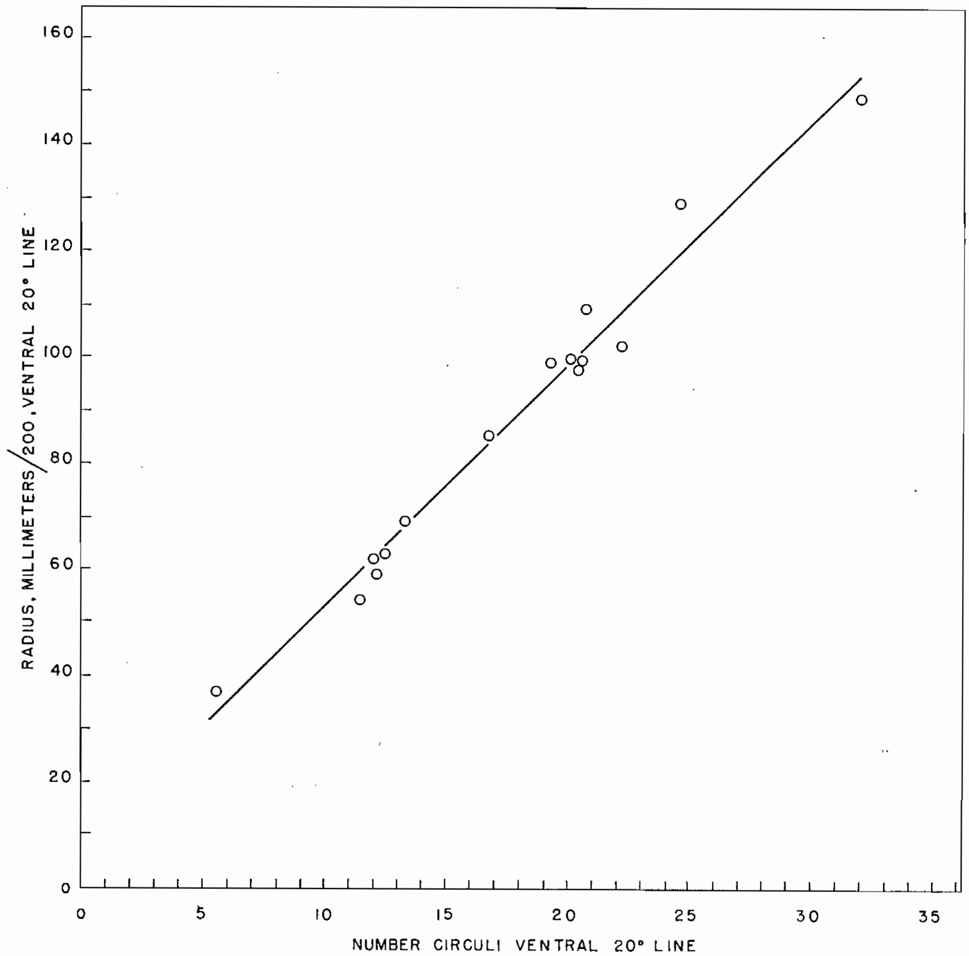

FIGURE 22—Relationship between mean number circuli and mean radius on ventral 20° radial line of sockeye smolt scales; 1,951 smolts in samples.

The remaining methods of measurement, i.e. the maximum radius and the diameter along the dorsal-ventral axis, are compared with circulus count on the ventral 20° radial line in FIGURES 24 and 25. The equation for the regression line in FIGURE 24 is:

$$\text{radius} = 4.886 \text{ number circuli} + 9.31$$

and for FIGURE 25:

$$\text{diameter} = 6.977 \text{ number circuli} + 39.12$$

The ventral 20° circulus count is chosen as the standard for comparison because of its extensive prior use in routine scale analysis, and so that any possible future change in the method can be directly related to the data already collected and

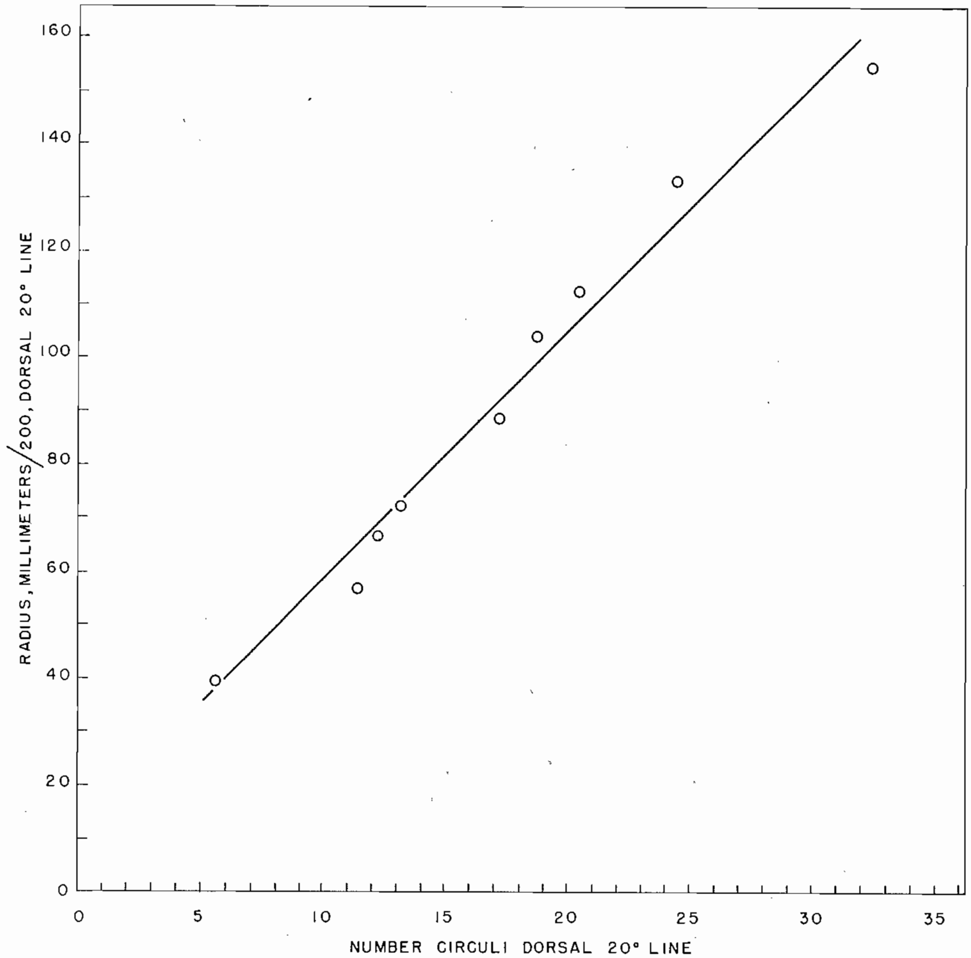

FIGURE 23—Relationship between mean number circuli and mean radius on dorsal 20° radial line of sockeye smolt scales; 918 smolts in samples.

analysed. All of the relationships between the various methods of scale measurement appear to be linear and all are closely inter-related.

There are some differences in the accuracy of the various methods in depicting the size of the smolts, although all show a high degree of accuracy. Comparison of the standard deviations of the various attributes on fork length is one way of determining the relative degree of variability, however such a direct comparison of standard deviations is not possible because the units of measurement are not comparable between number of circuli and radius or diameter measurements, these unit levels being determined by the universal mean of all samples. It is possible however to adjust the standard deviations to a common comparative level by dividing them by the universal mean in each case. The resultant statistic is the coefficient of variation $(S_x/\bar{x})$. The coefficient of variation of each attribute on fork length are listed by increasing degree of variation,

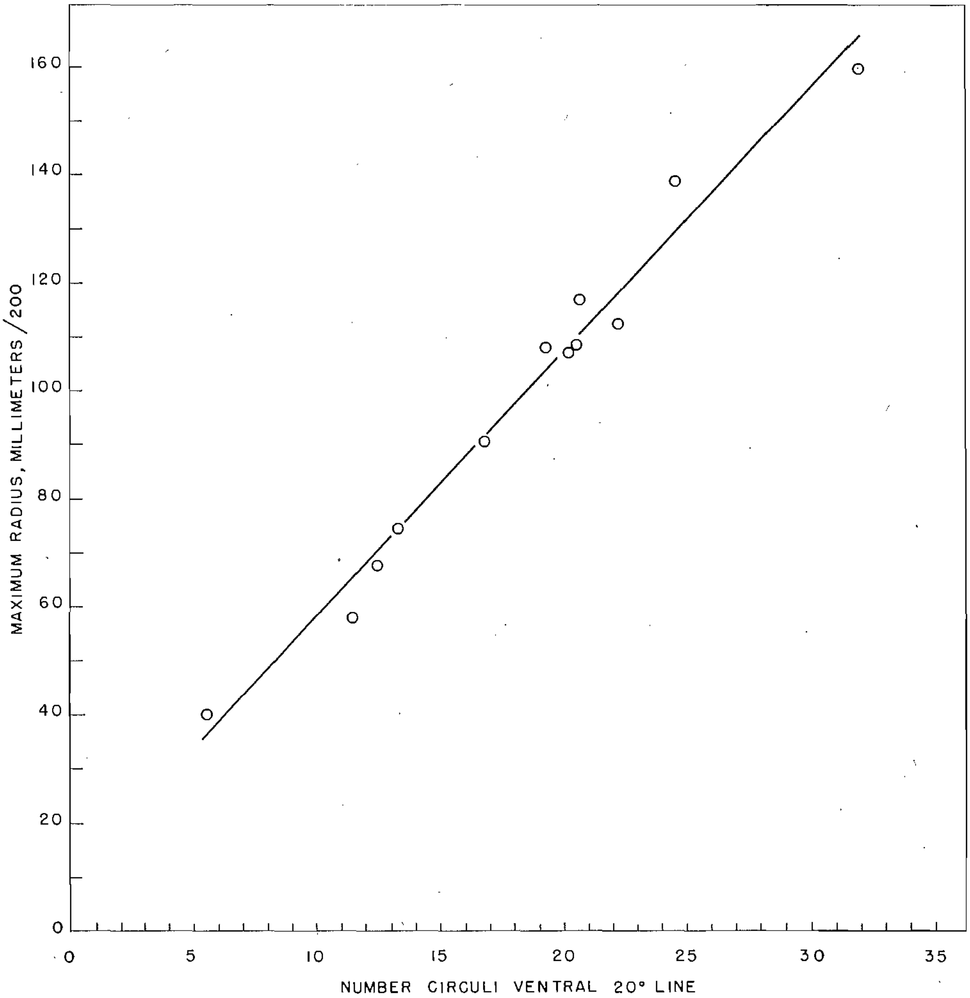

FIGURE 24—Relationship between mean number circuli on ventral 20° radial line and maximum radius of sockeye smolts scales; 1,307 smolts in samples.

thus comparing the accuracy of the various methods of measuring lacustrine scale growth in depicting fork length of smolts, as follows:

mean number circuli ventral 20° radial line	0.026
mean diameter dorsal-ventral axis	0.026
mean number circuli dorsal 20° radial line	0.042
mean radius ventral 20° radial line	0.047
mean radius dorsal 20° radial line	0.047
mean maximum radius	0.048

Mean ventral 20° circulus count and mean dorsal-ventral diameter are equally accurate in representing fork length. Circulus count on either dorsal or ventral 20° radial line is better than radius on either dorsal or ventral 20° radial line,

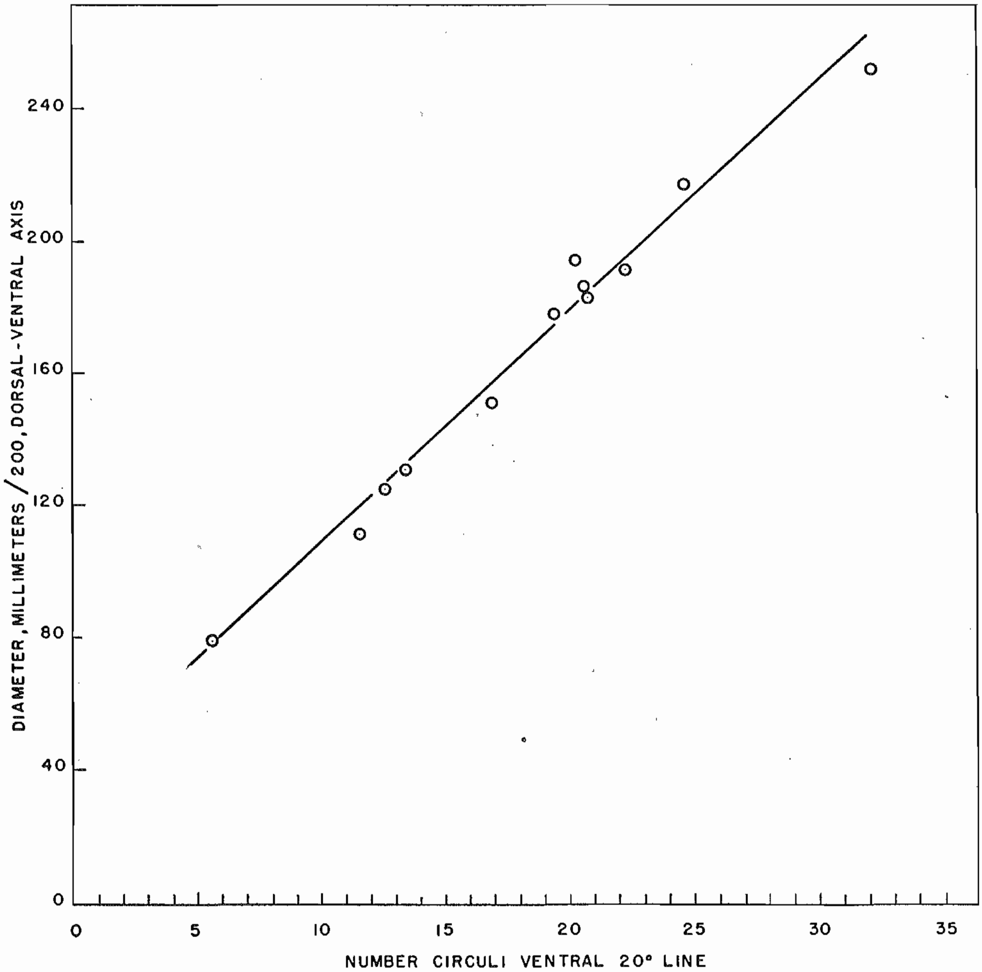

FIGURE 25—Relationship between mean number circuli on ventral 20° radial line and diameter on dorsal-ventral axis of sockeye smolt scales; 1,307 smolts in samples.

and the dorsal and ventral 20° radius measurements are slightly more accurate than the maximum radius. It must be remembered that a comparison of FIGURES 13 and 16 shows radius measurement to be more accurate than circulus count in depicting mean weight of smolts.

Application of Methods to Adult Scales

The method of measuring lacustrine growth must not only accurately depict smolt lengths from smolt scales but must also be accurate and efficient in determining lacustrine growth from adult scales. Enumeration of circuli on the ventral 20° radial line is shown to be accurate in representing fork length at the smolt stage and has been applied in routine analysis of adult scales. Diameter measurement across the dorsal-ventral axis is one of the two best methods of analysing smolt scales; but the phenomenon of progressive thickening of rings as they curve toward the posterior field on both dorsal and ventral sides of the focus renders this method less accurate than the other methods in routine adult scale analysis. This lessened accuracy results from the difficulty of distinguishing the exact periphery of the lacustrine growth zone because along the dorsal-ventral axis the thickened fresh water circuli in the transition zone sometimes closely resemble sea circuli. The measurement of radius on the ventral 20° radial line is somewhat less accurate than circulus enumeration in representing mean length of smolts but more accurate in representing mean weight. This method has the advantage of not requiring the counting of individual circuli and, therefore, not requiring adherence to the citeria for acceptance or rejection of individual circuli based on the completeness of formation or degree of branching. The technical requirements of this method are rigid however; it is essential that the same measurement magnification be used for all samples to be compared. Also a system of grouping units must be devised and strictly adhered to. Such a unit system should have about ten class intervals for the average sample of lacustrine growth scale measurements from any given unit-stock population. Speed tests have shown radius measurement of lacustrine growth to be slightly slower than circulus counting. Where study of sea growth for purposes other than age determination—e.g. sea growth by season related to sea survival — is undertaken the radius measurement technique is best because circulus enumeration is in this case a very laborious method.

Design of Sampling Procedure for Lacustrine Growth Study

In collecting and analysing scales for the study of growth and racial population dynamics it is necessary to design sampling procedures which will supply adequate and representative samples. It is first necessary to determine whether the attributes sought for are distributed randomly through the population in question or whether they are unevenly concentrated at certain levels in time or space, i.e. whether there is stratification. Secondly, it is necessary to take samples large enough to minimize the possibility of misleading or inconclusive results within desired limits.

Measurement of lacustrine growth is a quantitative process; therefore great care must be taken to delimit all factors which might affect the representativeness of that measurement. The several possible influencing factors are considered by subsection in the following order: Selection of scale sampling location on the bodies of individual sockeye. Effect of possible size selectivity on lacustrine growth analyses. Comparison of lacustrine growth between sexes in temporally and spacially restricted samples, i.e. given year and given unit-stock population. Comparison of lacustrine growth by time during the run within given populations. Comparison of lacustrine growth between different age groups of concurrent lake residence. Comparison of lacustrine growth by years and stocks. Determination of sample size.

SELECTION OF SCALE SAMPLING LOCATION ON BODY OF FISH

Unequal nuclear growth exists among the scales of any individual sockeye. This can be demonstrated from studying formation and growth pattern of scales on young sockeye and by studying the variability of nuclear growth exhibited by scales taken from different parts of the bodies of adult sockeye.

Formation and Growth Pattern of Scales on Young Sockeye

Scales form on wild sockeye fry at approximately 38 millimeters fork length as shown on page 11. The skins of seventy-five fry from various stocks, thirty-four hatchery-reared and forty-one wild, and four smolts from three areas were removed and examined for pattern of scale formation and development. Thirty-one of the fry had developed scale papillae but had not yet developed rudimentary scales. The formation of scale papillae first begins near the lateral line and between the dorsal and adipose fins, and tends to proceed radially from

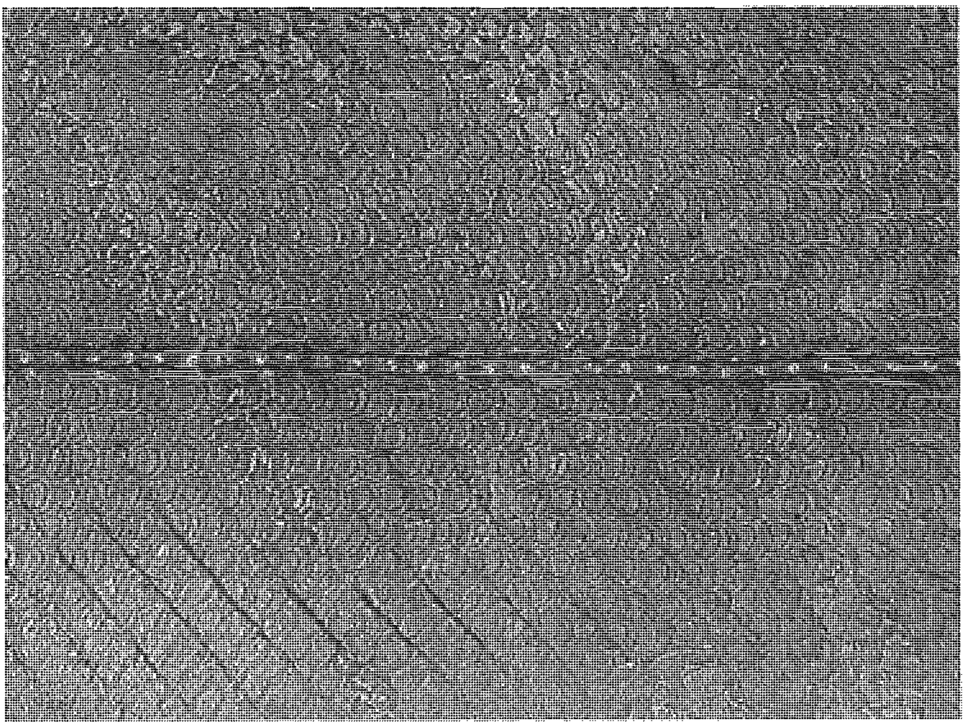

FIGURE 26—Photomicrograph of skin of sockeye fry 45 millimeters fork length—scales in situ, stained with alizarin red dye—showing decreasing scale development away from lateral line.

this area, proceeding most rapidly along the lateral line. Forty-four of the fry had developed scales, these ranged from the plate stage to a maximum of eight circuli. Scales are first formed in a thin band on each side of and including the lateral line, with first development and greatest expansion in the area between the dorsal and adipose fins (FIGURE 26). On the four smolts examined the largest scales with the greatest number of circuli were found in the area of first development. This is illustrated by FIGURE 27, which is a diagram of the pattern of scale development on a seaward migrant sockeye smolt of 81 millimeters fork length. The skin with scales intact had been removed from the fish and stained with alizarin red dye, allowing the scales to be observed in situ. The

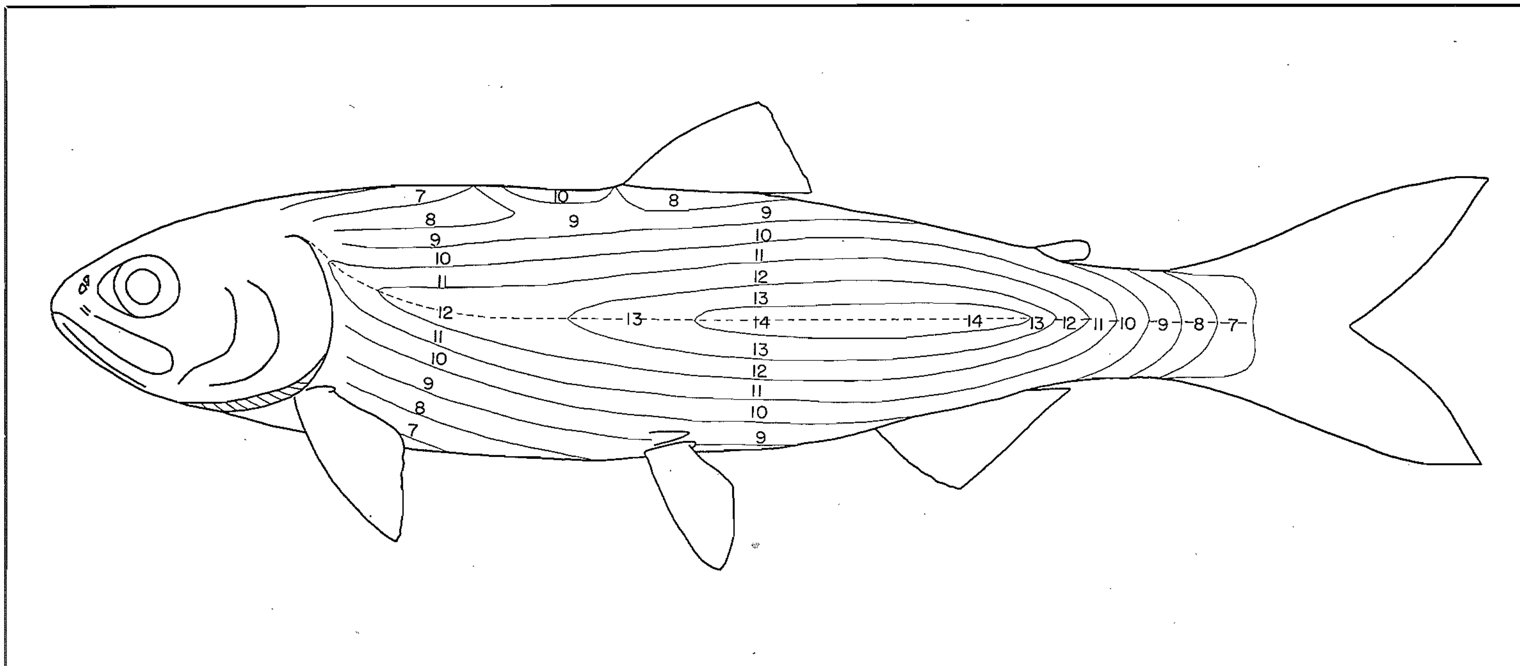

FIGURE 27—Pattern of divergence in size of scales on body of sockeye smolt as illustrated by gradation in number of circuli.

scales in the zone of rapid development are not merely formed first but continue to develop somewhat more rapidly than those farther removed from the lateral line and dorsal fin to adipose fin area. The scales of larger yearling sockeye tend to exhibit greater absolute differences between locations on the body than smaller yearlings, and two-year smolt scales exhibit differences between locations on the body in both first year and second year nuclear growth zones. This phenomenon is further corroborated by observations of the scales of forty adult sockeye which showed that the scales of adult sockeye decrease in size in proportion to the distance from the lateral line and the dorsal fin-adipose fin region of first development. This observation was also made by Kelez (1932).

The sockeye pattern of scale formation is similar to that of brown trout (cf. Parrott, 1934) but unlike that of certain species such as smallmouth bass (cf. Everhart, 1949).

In routine operational scale sampling it would be advantageous to take scales from either side of the fish, therefore it is important to know whether either side can be sampled in the same relative position with equal results. Scales were taken from the routine sampling position, i.e. on the diagonal scale column extending downward and tailward from the insertion of the dorsal fin and on the second scale row above the lateral line, from both the left side, which is the standard sampling position, and also the right side of 273 Chilko Lake yearling smolts from the 1954 downstream migration. The mean number of circuli of the left side scales was 12.22 and of the right side scales 12.23, showing no difference between comparable scales taken on either side of the fish. Thus a scale may be taken from the right side if the scales are missing or there is undue regeneration about the normal left side sampling position. Naturally, in scales from the opposite side of the fish the dorsal and ventral radial lines are interchanged in position.

Evidence of Scale Variability from Adult Samples

Since the nuclear growth of smolt scales apparently remains unchanged on the scales of adults it appeared to be probable that differences in nuclear growth on different parts of the body would be exhibited by adult scales. To test this possible divergence by position of sampling, scales were taken and examined from thirty-six different positions (FIGURE 28) on the bodies of each of forty adult sockeye. The sample of forty fish was taken from three different 1952 spawning stocks: ten fish were from Adams River, ten from Chilko River, and twenty from Cultus Lake. Since each individual fish had lacustrine growth which was not necessarily the same as that of any other fish in the sample it is necessary to derive a representative circulus count for each fish from which to test the variation due to change in sampling position on the body. This was done by finding the average circulus count for the scales from all thirty-six positions on each fish and coding the individual circulus counts from the specific areas on the fish according to their deviation, positive or negative, from this average. In this way comparable average values in terms of deviation according to position are established for the entire forty fish in the sample. The results in terms of deviation from the coded mean (0) are shown in FIGURE 29. The curves of deviations are slightly irregular because the circulus counts were made on scales of adult

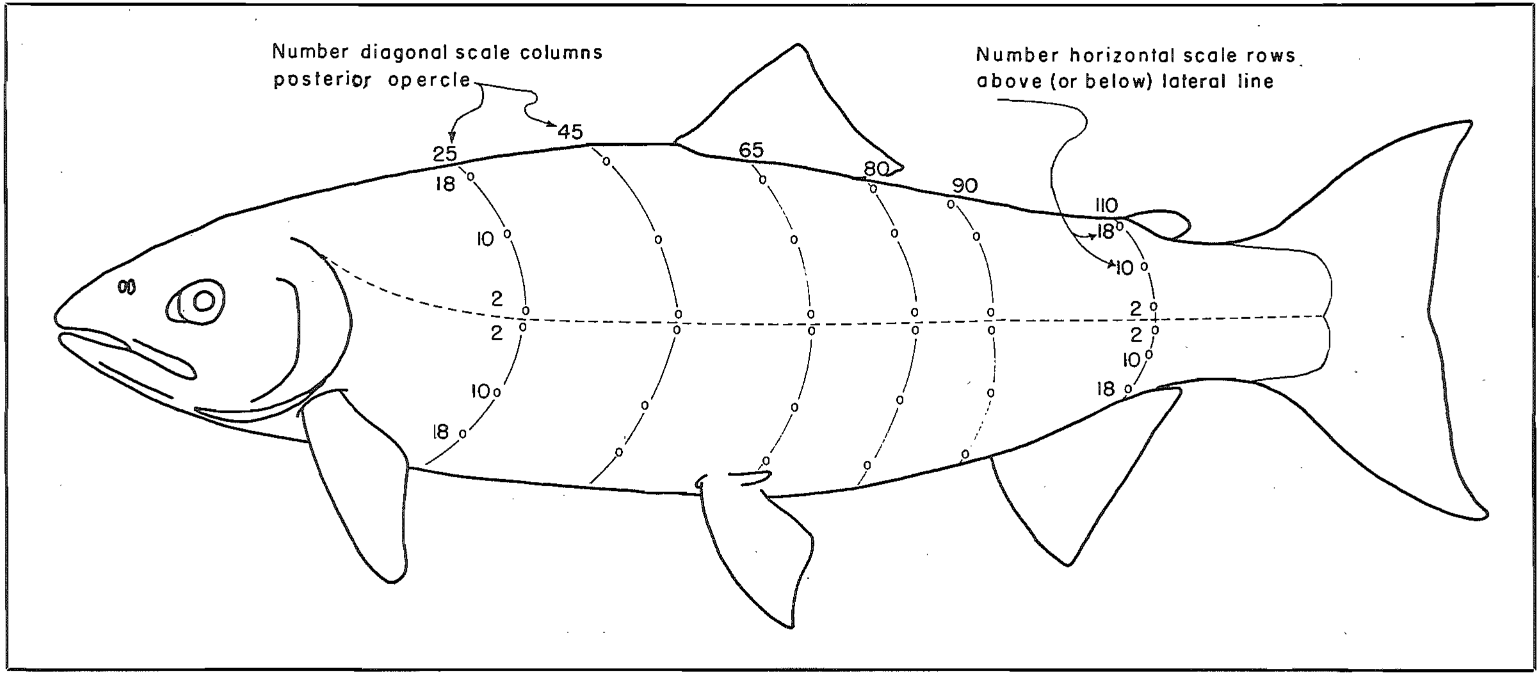

FIGURE 28—Sampling locations used in study of divergence in lacustrine growth of adult of sockeye scales on different parts of the body.

fish where there is possibility of some variation in interpretation of individual scales. The scales were read without knowledge, at the time, of where they were taken from the body of the fish; this was done to obviate bias in interpretation.

The scales were taken from specific positions at intersections of diagonal scale columns and horizontal scale rows. The diagonal columns are identified with respect to the distance in number of columns from the opercle and the horizontal rows are identified with respect to the distance in number of rows from the lateral line. The sampling positions may be referred to by number, thus "25-2 above" is the sample taken from the 25th diagonal column and the 2nd horizontal row above the lateral line.

The greatest positive deviation from the mean, indicating the scales with largest number of circuli, occurs in the second horizontal rows from the lateral line and in the region between the dorsal and adipose fins in sampling locations 65-2, 80-2 and 90-2. This corroborates the findings of the study of scale formation and development on juvenile sockeye. Both above and below the lateral line the ring count decreases as the head and tail regions are approached and as the distance from the lateral line increases. The most notable deviation from a regular pattern occurs at the position 65-18 above, where there is a decided dip in the curve. This dip occurred in each of the samples from the three areas and can not therefore be attributed to error in selecting or mounting the scales or tabulating the resultant data. Also the scales were read independently by two different observers and the results were the same. As also observed on the smolts examined there appears to be an area of somewhat retarded scale growth immediately under the dorsal fin. This, apparently, was also observed by Elson (1939) on the brown trout. He states (page 307) that "development [of scale papillae] is . . . slowest below the dorsal fin."

The need for careful scale selection is very real in scale sampling for growth and racial identification studies. In an actual recorded instance an untrained observer took two hundred adult sockeye scales from a certain Fraser River spawning ground population which resulted in a badly-skewed bimodal lacustrine growth circulus-count curve with a mean of 14.5 circuli, whereas a trained observer concurrently sampled the same population and produced scales with a smooth uni-modal curve with a mean circulus count of 16.8.

COMPARISON OF SINGLE SCALE AND SCRAPE SCALE SAMPLES

The scales from adult fish making up the Commission's extensive collection have been taken in two different ways in the past. Prior to 1952 scale samples were taken by scraping a small patch of scales, ten to fifteen in number, from a restricted area above the lateral line about midway between the dorsal and adipose fins; only one scale per fish from these multiple-scale samples was mounted for examination. Beginning in 1952 one scale only has been taken from each fish sampled. This scale is selected from the diagonal scale column which extends backward and downward from the insertion (posterior) of the dorsal fin and on the second horizontal row above the lateral line. Since the past and current data are to be related, comparisons of lacustrine scale growth are herein made between samples selected in the two different ways, and the necessary correction factor is established. This relationship is determined by taking scales from the same fish by both sampling methods. The samples used in the comparison, totalling 4401 fish, were taken from twelve different populations. Duplicate readings of each of the two series of scales were made independently by two observers and the means compared are composite means of the duplicate readings. To avoid possible bias in interpretation, the results of the comparisons were not revealed

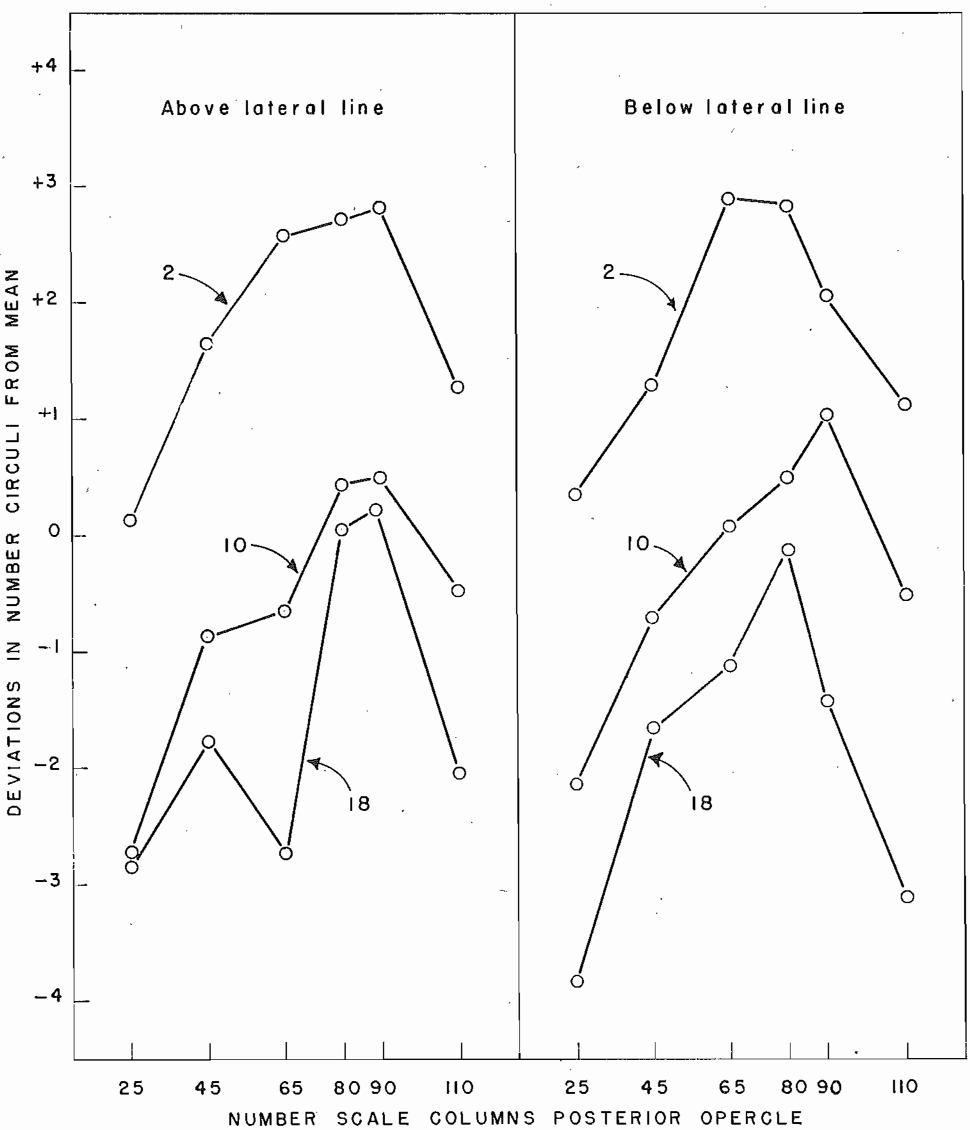

FIGURE 29—Divergence in lacustrine growth of adult sockeye scales selected from different locations on body of fish above and below lateral line. Expressed in deviations from mean number of circuli. Encircled numerals indicate number horizontal scale rows above or below lateral line; 1,440 scales in samples.

to the observers until after the completion of the study. The composite means for the two series appear in TABLE 7.

In every case the single scale samples have greater mean number of circuli than the scrape samples, with an average difference among the twelve population means of 0.95 circulus. The degree of difference varies between samples and may be attributed to inconsistent selection of scrape sampling location among the several field observers who took the scrape samples. There is a tendency toward increased absolute difference in mean number of circuli between the two methods as the mean number of circuli in the sample increases.

Further evidence of the difference between the results from the use of single scales and scrape samples is afforded by smolt scales. A group of nineteen down-

TABLE 7—Comparison of mean number nuclear scale circuli between scrape samples and single scale samples of jack and adult sockeye from various areas, 1952.[1]

SAMPLING AREA	AGE	SCRAPE SAMPLE		SINGLE SCALE		DIFFERENCE IN MEANS
		Mean No. Circuli	No. in Sample	Mean No. Circuli	No. in Sample	
Adams River	4_2	10.6	180	11.0	191	0.4
Gates Creek	4_2	18.6	148	19.7	149	1.1
Horsefly River	3_2	17.4	273	18.2	444	0.8
Nadina River	3_2	18.7	57	20.1	57	1.4
Seymour River	4_2	14.1	196	14.7	200	0.6
Silver Creek	4_2	22.8	51	25.5	60	2.7
Stellako River	4_2	17.9	89	18.3	370	0.4
Chilko River	4_2	11.6	161	11.8	310	0.2
Forfar Creek	3_2	18.0	88	19.1	313	1.1
Kynoch Creek	4_2	17.9	169	18.5	195	0.6
Raft River	4_2	17.6	99	18.5	184	0.9
Fraser River Gillnets	4_2	16.8	202	18.0	215	1.2

[1]Adams River sampled in 1954.

stream smolts was captured alive, measured, and sampled for scales by the scrape method. The mean fork length of the fish was 101.4 millimeters and the mean number of scale circuli 16.9. By consulting the expected linear relationship between fork length and number of circuli appearing in FIGURE 12 it is found that the scales are 2.1 circuli smaller than would be expected for a comparable single scale sample.

The single scale method is the better of the two primarily because the location of sampling is better defined; also larger scales of earlier development are taken at that location, which cover more of the early life history period of the fish.

Single scale selection with forceps is mechanically more efficient in taking spawning ground samples because the absorbed scales of adult spawners, especially males, are much easier to extract by this method.

EFFECT OF POSSIBLE SIZE SELECTIVITY

Adult sockeye scales may be taken for lacustrine growth analysis from mixed-run commercial fishery catches and from spawning populations. The commercial samples may be used in segregating unit-stocks and calculating their respective fishing mortalities. The spawning grounds scale samples may be used to identify the various stocks in the commercial fishery samples and the average lacustrine growth values for each population may be used in studies of the relationship between lacustrine growth and adult survival.

Spawning grounds samples are collected by netting live fish and by recovery of carcasses. As will be demonstrated in a subsequent section, it is possible that certain sizes of fish are selected in disproportion to their actual relative abundance; because of this it is necessary to determine whether size selectivity within any given age group of a given population would affect the estimation of mean lacustrine scale growth for that age group. If the size at time of downstream migration were correlated with the final adult size, then selection of adults by size would produce non-representative lacustrine growth estimates for the adult population of the given age group. If there were no correlation the possible selectivity for certain sizes of fish within given age groups would have no detrimental effect on the calculation of lacustrine growth from scales.

A comparison between standard length at adulthood and lacustrine scale growth has been made for 3_2 jacks and 4_2 adults from four spawning populations. Both low and high lacustrine growth populations are included, and males and females are considered separately because of the natural sexual dimorphism in length at maturity. Low lacustrine growth populations are represented by Adams River 3_2 and Bowron River 4_2, and high lacustrine growth populations by Stuart River 3_2 and Stellako River 4_2. Males only are included in the 3_2 samples because very few females are present in this age group. The results of correlation analyses of these data appear in TABLE 8. None of the correlation coefficients is significant at the 1 per cent level, showing that there is no relationship between lacustrine growth and length at maturity of 3_2 and 4_2.

In commercial sampling the situation is different from that of spawning ground sampling because, as will be shown in a subsequent section, the commercial catch is often composed of mixed stocks. Since there has been size selectivity by the linen gill nets operating in the Fraser River fishery (Peterson, 1954) the racial composition of the gill net catch may have been dependent upon the variations in size between the fish of different stocks. TABLE 9 shows that there are differences in the mean size at adulthood among different individual populations. The populations are listed in order of their general time of appearance in the commercial fishery showing that size at adulthood is not necessarily a function of

TABLE 8—Correlation between lacustrine scale growth and standard length at maturity of certain unit-stock spawning populations, ages 3_2 and 4_2.

Area	Year	Age	Sex	Correlation Coefficient (r)	Number in Sample
Lower Adams River	1953	3_2	♂	0.031	205
Stuart River	1951	3_2	♂	–0.026	167
Bowron River	1953	4_2	♂	0.007	102
		4_2	♀	0.210	100
Stellako River	1952	4_2	♂	0.057	171
		4_2	♀	0.150	199

TABLE 9—Comparison of mean standard length of adult 4_2 by sex for certain 1954 populations.

	MALES		FEMALES	
POPULATION	Number in Sample	Mean Standard Length	Number in Sample	Mean Standard Length
Bowron River	115	60.5	114	55.7
Nadina River	86	52.6	134	50.7
Seymour River	115	62.1	110	57.0
Middle River	76	54.5	105	53.3
Weaver Creek	162	63.8	174	57.5

the time of such appearance. These populations overlap one another in pattern of migration and several stocks may therefore be present in the catch of a single day. Selectivity has no effect on the calculation of racial fishing mortality from the catch as long as the sample is representative of the catch for the particular gear in question. However when both gill nets and presumably non-selective gear such as purse seines and reef nets are engaged in the same fishery it may sometimes be necessary to analyse the catch of each type of gear separately. If only one sample can be taken from a fishing area on a single day it should be from that type of gear which takes the greatest number of fish. If gill net samples are taken they should be from the catches of several boats having a representative distribution of net mesh sizes.

UNIFORMITY OF LACUSTRINE GROWTH BETWEEN SEXES

Both males and females are sampled for analysis of lacustrine growth. Because of sample size limitations and for efficiency of analysis it is desirable to combine the data for the sexes, but before this may be done it is necessary to determine whether the lacustrine growth differs between sexes. Also commercial fishery scale sampling for racial population segregation can be considerably expedited when sex data are not required. The comparison of lacustrine growth between sexes is made directly through smolt length analysis and indirectly through analysis of the nuclear growth zones of adult scales.

Smolts

Smolts display no external or secondary sexual dimorphism. The sex of smolts has been determined by opening the body cavity and observing whether ova are present. Specimens without ova are assumed to be males. This method has been used by Gilbert (1915) and Foerster (1937).

A comparison of mean fork lengths of smolts by sex appears in TABLE 10. Ten samples of one year smolts from the Fraser River watershed are presented; in six of the ten samples males were larger, with an average difference for the ten samples of 0.45 millimeter in favor of males. In two samples of two-year-olds the males were larger, the average difference being 1.60 millimeters. Six samples of smolts from areas other than the Fraser River showed males to be larger in four instances, with equality existing in one sample and females slightly larger in one sample. The mean difference for the non-Fraser River samples is 0.72 millimeter in favor of males. The combined results of all eighteen samples show males to be larger in twelve of the samples with an average difference for eighteen samples of 0.67 millimeter. This length difference of 0.67 millimeter is equivalent to a difference of 0.18 scale circulus, as calculated from the length-scale size relationship of FIGURE 12.

It will be shown in a subsequent section that there is no appreciable difference between sexes in size of smolts by time period during a run so this difference in

TABLE 10—Comparison of mean fork length of sockeye smolts between sexes. Data for years 1914-1919 from Gilbert (1915-1920).

SAMPLING AREA AND AGE	SAMPLING YEAR	MALES		FEMALES		MALE LESS FEMALE DIFFERENCE
		Number in Sample	Mean Fork Length, mm.	Number in Sample	Mean Fork Length, mm.	
Fraser River—1 year						
Chilko River	1954	236	77.0	228	77.5	−0.5
Harrison River	1953	24	93.9	31	91.9	+2.0
Horsefly Lake	1955	29	126.3	32	125.2	+1.1
Lillooet Lake	1953	62	77.1	67	78.7	−1.0
	1954	260	70.8	275	70.4	+0.4
Quesnel Lake	1915	50	89.5	50	87.7	+1.8
	1919	122	87.0	130	87.4	−0.4
Seton Lake	1914	136	86.7	164	86.4	+0.3
Shuswap Lake	1953	72	85.7	87	84.1	+1.6
Stuart River	1953	207	99.2	168	100.0	−0.8
Fraser River—2 year						
Chilko River	1954	84	108.8	90	106.5	+2.3
	1955	62	102.7	38	101.8	+0.9
Non-Fraser River—1 year						
Babine Lake	1914	126	85.2	112	83.5	+1.7
	1915	171	86.2	218	85.5	+0.7
Rivers Inlet	1914	ca. 500	60	ca. 500	60	0
	1916	1299	60.1	1161	60.2	−0.1
Smith Inlet	1914	87	67.2	106	66.0	+1.2
	1915	132	72.1	118	71.3	+0.8

length of smolts is not the result of that possible factor; also the samples were selected from different periods in the migration patterns of the various runs.

Jacks and Adults

While the sex of jacks and adults can usually be determined from external characteristics such as snout development, body shape and coloration as they approach spawning time unmistakable identification is ensured in commercial sampling by making a small incision in the abdominal wall and identifying the gonads by sight or touch.

Females are so rare among jacks that the problem of possible difference between sexes is inconsequential; therefore no comparison is here made between sexes of jacks.

Adult scales are analysed without knowledge of the sex corresponding to each scale at the time of scale examination, thus ensuring no bias in interpreting the scales. To determine whether the lacustrine growth is the same between sexes of the same age group of adults nuclear circulus counts are compared between sexes from a given single stock for several years and for several populations. TABLE 11 shows the mean number of nuclear scale circuli by sex for the Chilko River population for fifteen years. Males had a larger nuclear growth in seven of the samples, females were larger in five of the samples, and there

TABLE 11—Comparison of mean number lacustrine scale circuli of adult 4_2 sockeye between sexes. Chilko River, 1938-1953.

YEAR	MALES		FEMALES		Males Less Females, Difference
	Mean Number Circuli	Number in Sample	Mean Number Circuli	Number in Sample	
1938	12.5	19	13.3	27	—0.8
1939	13.3	22	12.9	46	+0.4
1940	13.5	38	13.1	102	+0.4
1941	12.6	100	12.4	80	+0.2
1942	13.2	58	13.6	104	—0.4
1944	12.7	85	12.2	124	+0.5
1945	13.3	56	13.3	91	0.0
1946	13.4	43	13.3	75	+0.1
1947	14.5	15	15.1	50	—0.6
1948	12.1	29	11.6	31	+0.5
1949	11.9	51	11.5	48	+0.4
1950	11.7	117	11.8	48	—0.1
1951	12.8	88	13.1	97	—0.3
1952	11.6	101	11.6	206	0.0
1953	12.3	160	12.3	309	0.0

was no difference in three of the samples. The average difference for the sixteen samples was 0.02 circulus in favor of males. The larger individual differences occur where samples are small.

TABLE 12 shows the mean number of scale circuli by sex for twelve samples, each from a different population. In only one of these samples did males show larger lacustrine growth; in seven samples females were larger, and in four samples there was no difference. The average difference for the twelve samples was 0.15 circulus in favor of females.

The comparisons of lacustrine growth between sexes have shown the male smolts to be slightly larger on the average, and showed no consistent difference between sexes of adults. None of the average differences is significant to lacustrine growth study, and, therefore, lacustrine growth data of males and females may be combined for both smolts and adults for any practical application.

VARIABILITY OF LACUSTRINE GROWTH BY TIME DURING RUN

Sockeye may be sampled at time of downstream migration and upon their return to spawn as adults. Both smolts and adults have been sampled by time periods to determine the extent of variation through the course of migration.

TABLE 12—Comparison of mean number lacustrine scale circuli of adult 4_2 sockeye between sexes. Spawning populations from various areas.

AREA	YEAR	MALES		FEMALES		Males Less Females, Difference
		Mean Number Circuli	Number in Sample	Mean Number Circuli	Number in Sample	
Adams River	1953	15.4	59	15.4	114	0.0
Bowron River	1953	13.1	102	13.4	100	—0.3
Chilko River	1953	12.3	160	12.3	309	0.0
Cultus Lake	1953	15.2	64	15.9	117	—0.7
Gates Creek	1952	19.5	64	19.6	86	—0.1
Horsefly River	1953	17.7	101	17.7	97	0.0
Nadina River	1953	18.8	66	18.7	121	+0.1
Raft River	1953	17.7	86	18.2	114	—0.5
Seymour River	1953	15.0	93	15.1	103	—0.1
Stellako River	1952	18.2	171	18.3	199	—0.1
Stuart River	1952	18.5	85	18.5	105	0.0
Middle River	1953	18.0	100	18.1	79	—0.1

Smolts

A review of the findings of a number of investigators on the seasonal change in smolt size is presented together with data examined by the present authors.

Chamberlain (1907) presented evidence of daily variation in mean fork length of Naha River yearling sockeye smolts; his data are summarized in

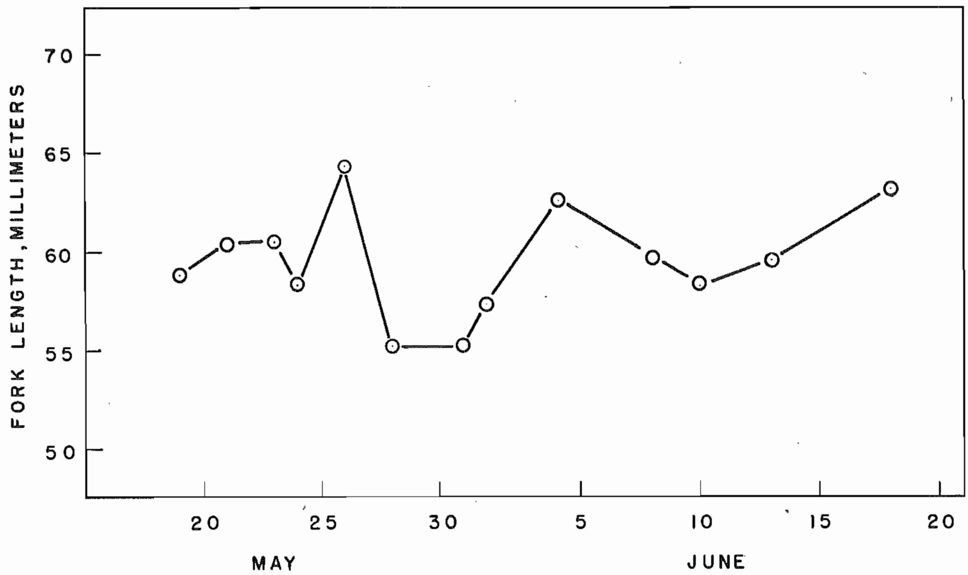

FIGURE 30—Comparison of mean fork length among periods of run. Naha River yearling seaward migrant sockeye, 1904. From Chamberlain (1907) ; 2,665 smolts in samples.

FIGURE 30. Chamberlain's daily samples ranged in magnitude from 17 to 422 smolts. Two of the daily samples, the first and the last, numbering 22 and 17 smolts, are omitted from the graph as being too limited in number to be representative. These first and last samples were probably taken during periods of light daily migration. The mean lengths of the Naha River smolts fluctuated from 55.3 millimeters to 64.4 millimeters and exhibited no consistent trend. Gilbert (1916) points out that these Naha River smolts were not distinguished as one-year-olds and

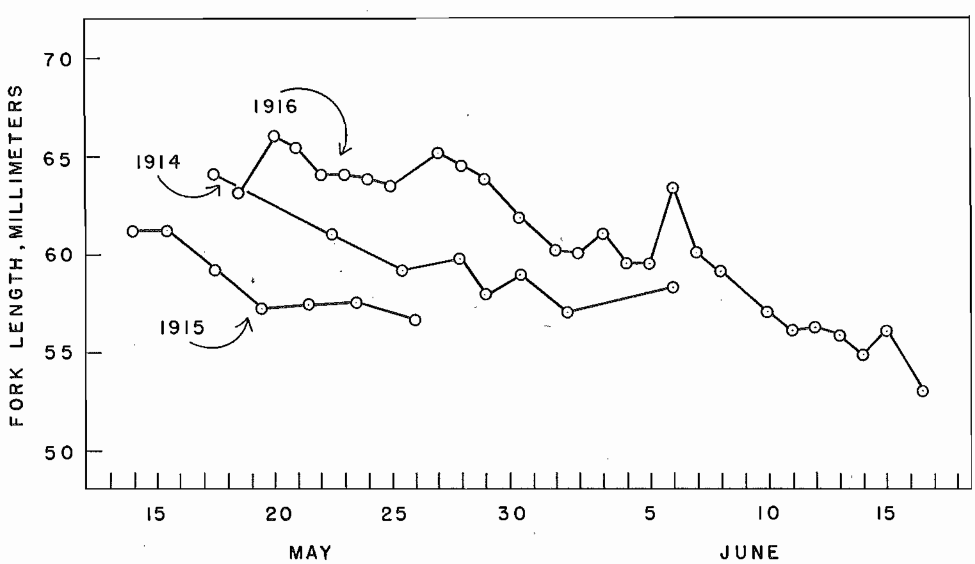

FIGURE 31—Comparison of mean fork length among periods of run. Rivers Inlet yearling seaward migrant sockeye, 1914-1916. From Gilbert (1916, 1918) ; 4,040 smolts in samples.

two-year-olds and that the individual length range was very great for a single age population.

Gilbert (1916, 1918) determined the periodic mean length of yearling sockeye smolts during their course of migration at Rivers Inlet for three successive years, 1914-1916. These data appear in FIGURE 31. Each of his daily samples in 1914 included 100 smolts. In 1915 two of the seven daily samples included 75 smolts and the remaining five numbered 150. Of the twenty-six daily samples taken in 1916 ten were more than 100 in number, sixteen were less than 100 in number and five of these were less than 50 in number; the samples ranged in magnitude from 22 to 257. In each of these three years the average length decreased fairly regularly from the beginning to the end of the migration. The daily samples were sexed in 1916, and males and females exhibited almost exactly the same daily

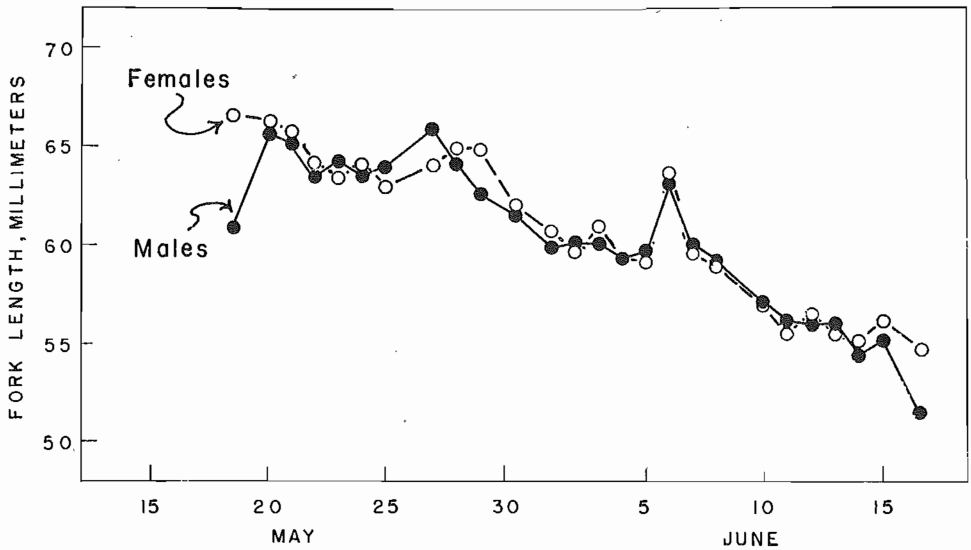

FIGURE 32—Comparison between sexes of mean fork length among periods of run. Rivers Inlet yearling seaward migrant sockeye, 1916. From Gilbert (1918) ; 2,340 smolts in samples.

variation, as shown in FIGURE 32. The only appreciable divergence between sexes occurred in the first and the last samples, both of which included few fish.

Foerster (1929, 1936) presents data on the average length of Cultus Lake yearling smolts by time during the downstream migrations of 1927 and 1928. In 1927 six daily samples were taken ranging in number from 14 to 45. In 1928 fourteen daily samples were taken, the first of these was 53 in number and the remainder varied between 126 and 191 in number. The 1927 sampling (FIGURE 33) showed an increase in mean fork length of 7 millimeters between the earliest and the latest sample, with a fairly regular trend; however the first sample was only 14 in number and may therefore have been of small mean fork length as a result of natural sampling variation only. The results of the 1927 sampling, insofar as they go, tend to contradict Gilbert's findings for Rivers Inlet, wherein there had been regular decrease in fork length as the run progressed. The 1928 sampling,

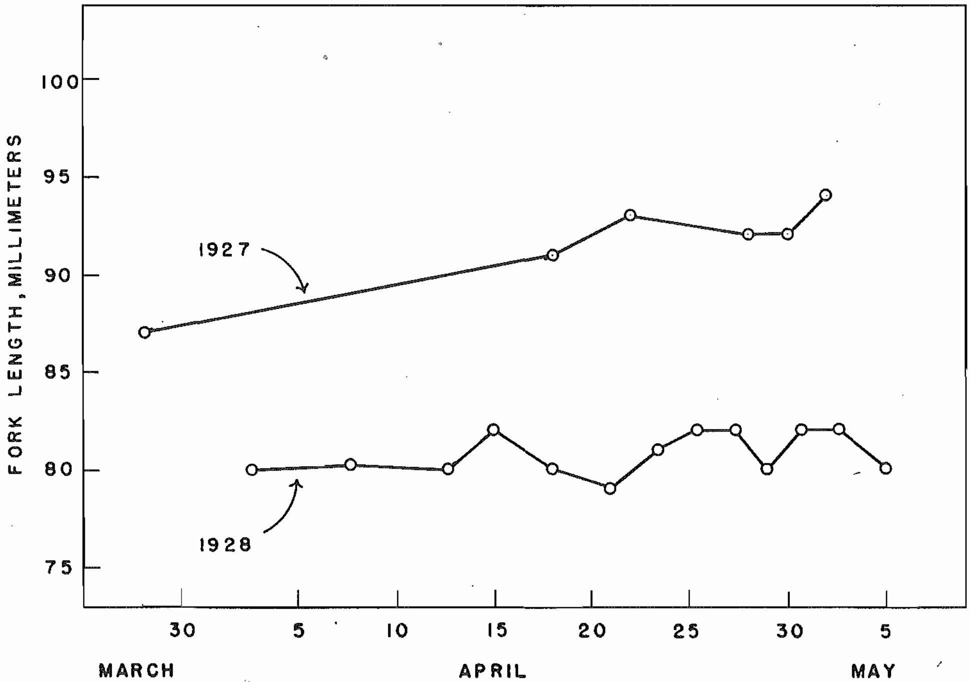

FIGURE 33—Comparison of mean fork length among periods of run. Cultus Lake yearling seaward migrant sockeye, 1927 and 1928. From Foerster (1929, 1936) ; 2,035 smolts in samples.

consisting of regularly sizeable samples, showed little change in average length throughout the period sampled.

More recent data for Cultus Lake are available in the form of daily average weight calculated for the purpose of volumetric enumeration of the seaward migrants of the years 1941 to 1944. The average weight data are calculated from the daily average counted number of smolts per six pound weighing. The more such counted six pound weighings there are the more accurate the calculated average weight, however only one such counted weighing is necessary to provide an estimate of the mean weight. Each of the mean weight points appearing in FIGURE 34 was calculated by combining the results of two adjacent sampling days. The two-day combined number of counted six pound weighings varied from 2 to 64 during the four years of sampling. Of the total of 86 two-day sample mean weights 63 included more than 15 counted weighings. (In 1941: 15 of 17 samples included more than 15 counted weighings, in 1942: 14/20, in 1943: 18/23, in 1944: 16/26.) The two day samples of less than 15 counted weighings were taken at the beginnings and endings of the runs when migration was light.

Apparently the average weights of Cultus Lake yearling smolts varied according to no fixed pattern during the four years in which sampling was conducted. The fish of the 1941 seaward migration decreased in weight from the beginning of the sampling period and then increased in weight regularly throughout the greater part of the sampling period. In all of the 1941 samples the number of counted 6 pound weighings was ten or more. The migrants of 1942 increased

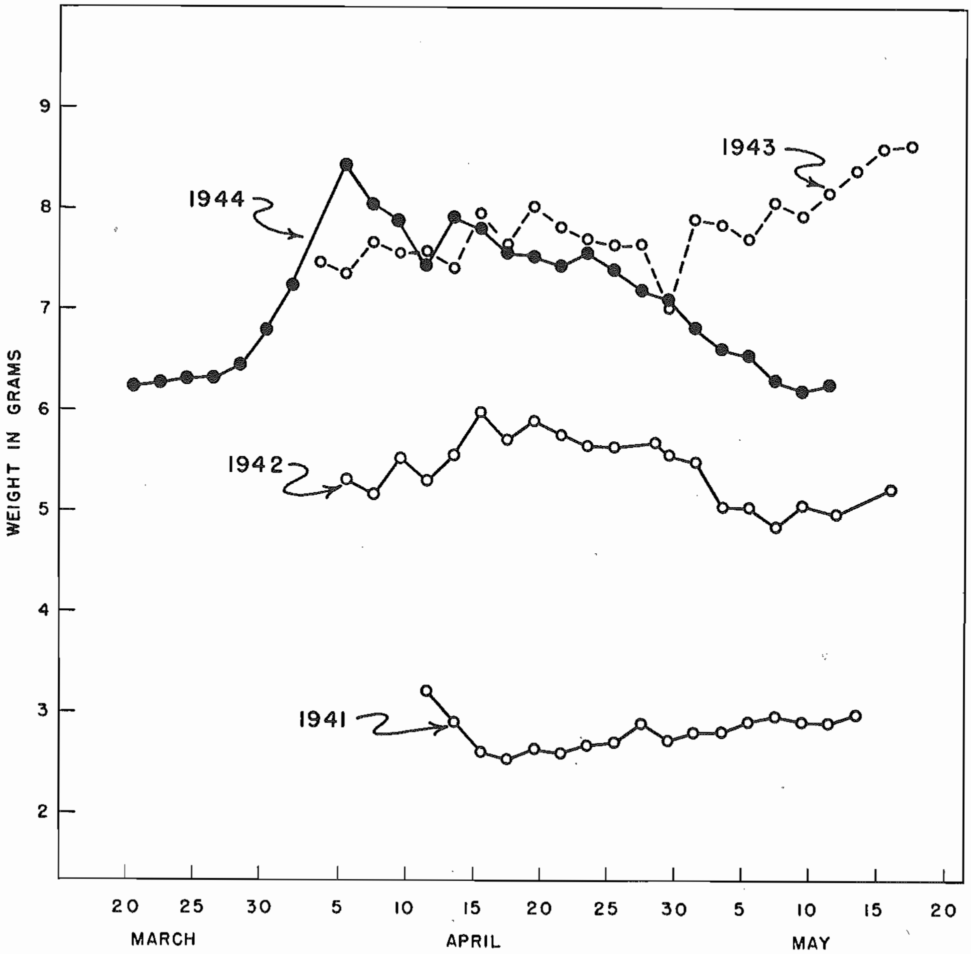

FIGURE 34—Comparison of mean weight among periods of run. Cultus Lake yearling seaward migrant sockeye, 1941-44. Calculated from total of 2,087 counted 6 pound weighings.

in weight erratically during slightly more than the first one-third of the sampling period and then regularly decreased in average weight to level off toward the end of the run. The trend of the 1943 sampling was toward increasing weight throughout the migration period. The 1944 run increased in average weight for the first one-third of the season and progressively decreased thereafter.

In addition to the average weight data presented in FIGURE 34, daily mean fork length data were collected at Cultus Lake in 1944 from the yearling downstream migrants. The daily mean length pattern (FIGURE 35) corroborates the average weight variation and extends the period of sampling by twenty days. When grouped into two-day samples by combining the length frequencies of adjacent days, the samples range in number from 30 to 364, with only three samples less than 50 in number and 19 samples more than 100 in number, the remaining 17 being between 50 and 100. During the extended sampling period encompassed by the average length data the average size of these 1944 smolts

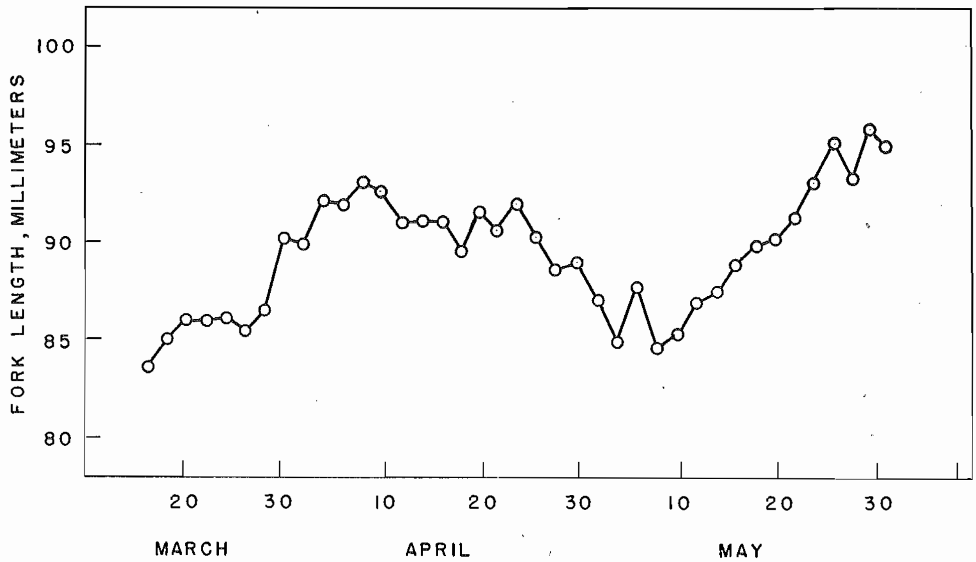

FIGURE 35—Comparison of mean fork length among periods of run. Cultus Lake yearling seaward migrant sockeye, 1944; 4,879 smolts in samples.

increased markedly in the last twenty days of sampling, a period not covered by the weight sampling.

The average size by time during the seaward migrations of certain upper Fraser River stocks has also been studied. Periodic sampling of the 1951 Francois Lake downstream migrating smolts yielded the results shown in FIGURE 36. The thirteen samples of the series ranged in number from 41 to 195 smolts, with six of the samples numbering more than 100 smolts. The mean fork length of the smolts was greater during the first half of the run than during the last half.

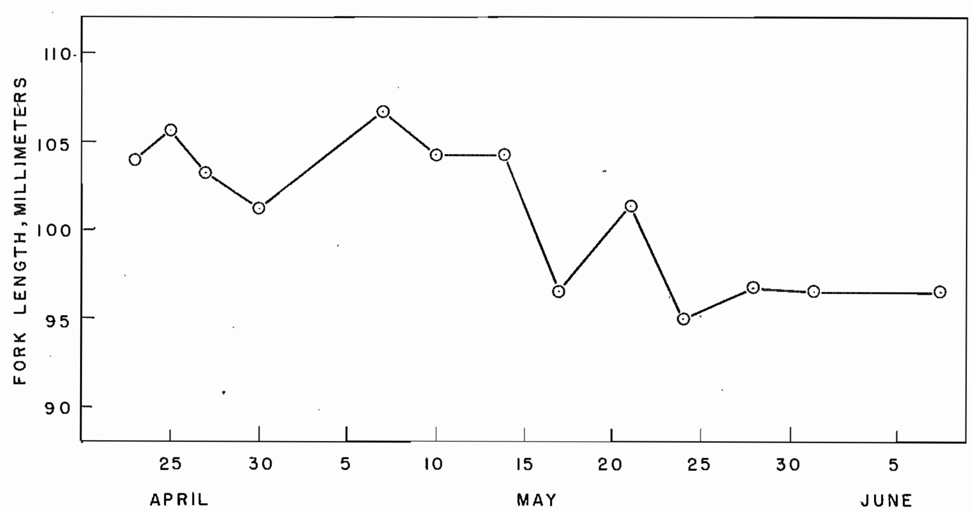

FIGURE 36—Comparison of mean fork length among periods of run. Francois Lake yearling downstream migrant sockeye, 1951; 1,279 smolts in samples.

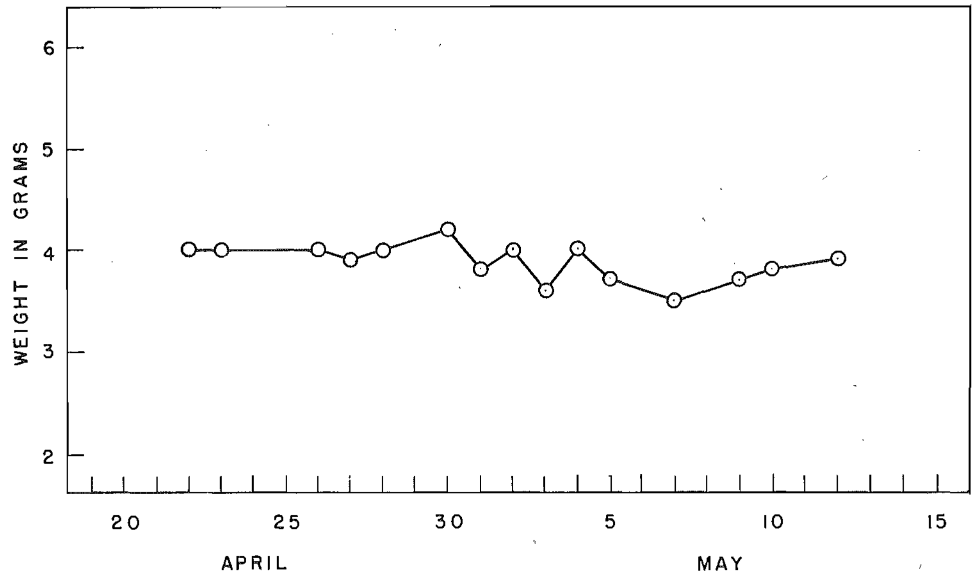

FIGURE 37—Comparison of mean weight among periods of run. Chilko River yearling seaward migrant sockeye, 1953; 6,504 smolts in samples.

Mean weight by time was calculated for the 1953 Chilko River yearling smolts from weighings of live fish. The fifteen samples ranged in number of smolts from 251 to 913, with six of the samples greater than 500. The results shown in FIGURE 37 indicate a very slight downward trend in mean weight with only a small degree of daily variation.

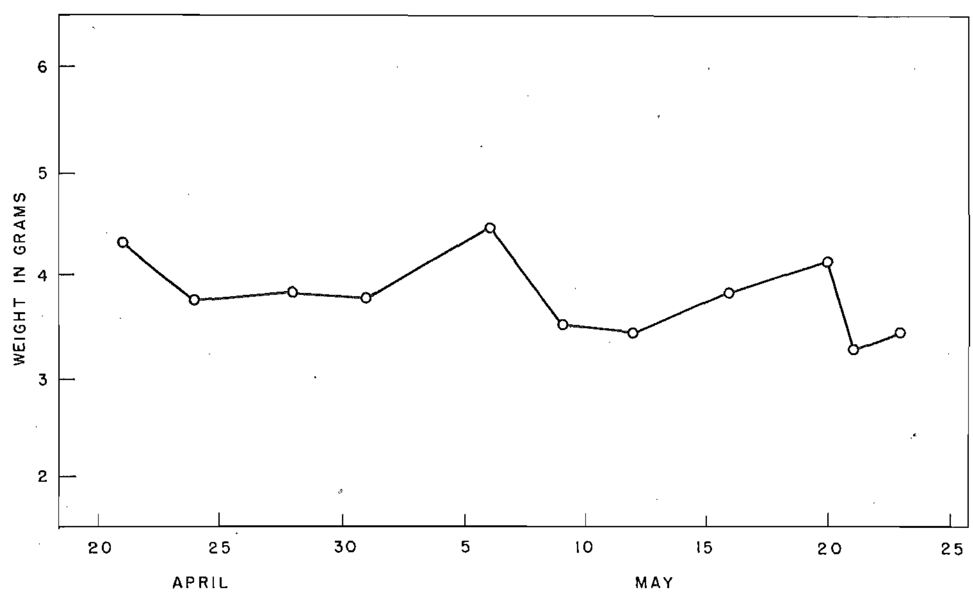

FIGURE 38—Comparison of mean weight among periods of run. Chilko River yearling seaward migrant sockeye, 1954; 1,372 smolts in samples.

The 1954 Chilko smolt migration was sampled for weight over a longer period of time. The results were obtained from eleven periodic samples ranging in number of smolts from 91 to 176, with only one sample less than 100 in number. The 1954 samples were preserved and individual weights were taken in the laboratory to 0.1 gram accuracy. The results (FIGURE 38) were slightly more variable than those of 1953 but showed essentially the same feature, namely that the fish of the second half of the run were of slightly lesser weight than those of the first half.

The 1954 Chilko Lake periodic samples were measured as well as weighed. The average fork lengths illustrated the same relative variation as the average weights, as shown in FIGURE 39. These preserved samples were supplemented by the measurement of live fish in the field, and, although the trend of slightly decreasing length is exhibited by both sampling techniques, the live measurements were on the average slightly higher than the preserved samples. In one instance the

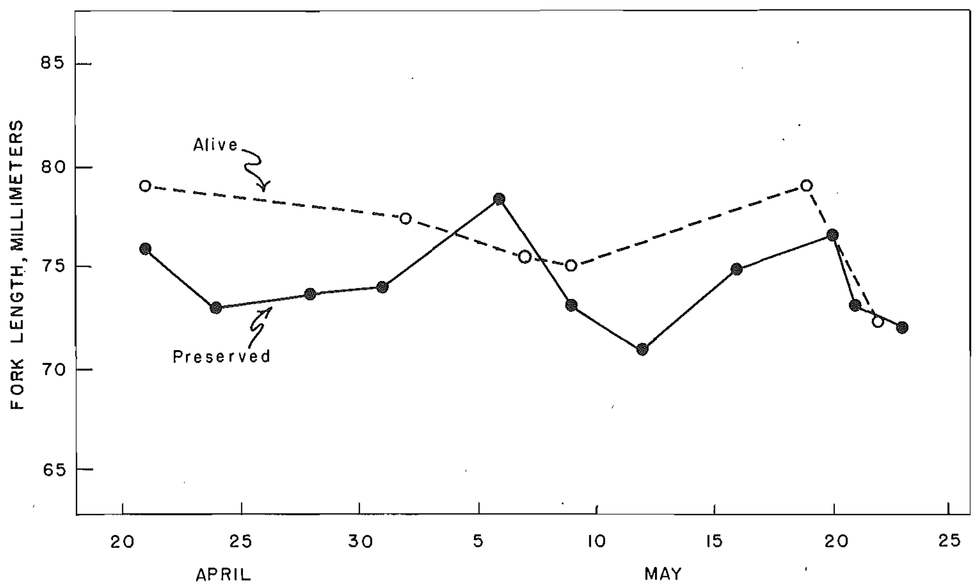

FIGURE 39—Comparison of mean fork length among periods of run. Chilko River yearling seaward migrant sockeye, 1954. Separate samples measured alive and measured preserved; 2,427 smolts in samples.

preserved sample was larger than the adjacent live samples and in one case a live sample was equal to the adjacent preserved samples, but in all other cases the live measurements yielded larger size. As was shown in TABLE 6 preservation decreases the size of sockeye smolts.

The preserved samples of 1954 Chilko River yearling smolts have been analysed for possible variation in fork length by time between sexes (TABLE 13). Slight variations in mean length occur among the samples, but male and female lengths vary in the same way. This corroborates the more extensive evidence of Gilbert (FIGURE 32) that males and females are not divergent in mean length during the period of downstream migration.

TABLE 13—Comparison of mean fork length between sexes by time during run. Preserved 1954 Chilko River yearling sockeye smolts.

SAMPLING DATE	MALES		FEMALES	
	Number Smolts	Mean Fork Length, mm.	Number Smolts	Mean Fork Length, mm.
April 21	48	75.7	49	76.1
May 6	65	78.3	53	78.7
May 20	68	75.8	75	77.7

More-limited samples of Chilko Lake two-year-old smolts were taken in 1954 on the dates shown in TABLE 14. These samples were of insufficient magnitude to be analysed sexes separate, therefore the grouped data only are presented. The data show more variation than those of the 1954 yearlings as well as a slight progressive decline in mean length by time and a more pronounced decline in mean weight.

The data for smolts in regard to lacustrine growth and period of migration during the run show considerable inconsistencies between areas and populations, and inconsistency for one area, Cultus Lake, among years. In the Fraser River areas other than Cultus Lake the smolts are of fairly consistent size during the runs with frequently a trend toward seasonal decrease in size. Among the periodic Cultus Lake samples the greatest variations in trend of lacustrine growth occurred during the period of light migration. During the period of major migration in 1941, April 12-30, there was a slight regular increase in size with little day to day variation. In 1942 the peak migration period occurred between April 19 and May 3; the daily mean size of smolts was very regular and decreased very slightly during this period. In 1943 the main migration occurred from April 20-27; there was a slight progressive decrease in size during this period. In 1944 during the major migration, occurring between April 10 and April 29, there was a fairly regular decrease in size of smolts. All four yearly migrations exhibited regularity in daily mean size and very little overall change through the period of main migration, indicating that practically the same results may be obtained from samples taken at any time during the main period of migration.

TABLE 14—Comparison of mean fork length and mean weight by time during run. Preserved 1954 Chilko River two-year sockeye smolts.

Sampling Date	Number Smolts	Mean Fork Length, mm.	Mean Weight, gm.
May 4	77	109.9	123.6
May 9	69	106.3	111.1
May 23	31	104.5	103.5

Jacks and Adults

The migration of individual unit-stocks of jack and adult sockeye are about one month in duration. Since scale samples for lacustrine growth study may be taken at any time during the run it is necessary to know whether within given age groups the lacustrine scale growth of these fish differs through the period of migration. Average lacustrine growth in relation to time of sampling during migration, spawning ground arrival and period of dying, as estimated from the nuclear areas of scales of jacks and adults, has been studied for three of the important age groups of Fraser River sockeye, namely 3_2, 4_2, and 5_3. These age groups will be reviewed in that order.

3_2—Three groups of 3_2 scales were analysed from the 1951 Chilko River spawning run. The first two collections, September 4 to September 8 and September 10 to September 13, were made during the period of tagging for population enumeration prior to the main period of spawning. The third collection was made during the recovery of dead spawned fish. The scale samples were read by one observer only and not checked by duplicate reading, but all three samples were analysed concurrently and the interpretation should be comparable between periods. TABLE 15 shows that there was a very slight decline in mean number of nuclear circuli between the first and second tagging samples. The mean number of nuclear circuli for the third period (dead recovery sample) was about the same as the second period sample.

TABLE 15—Comparison of mean number lacustrine scale circuli among periods of run. Chilko River spawning ground 3_2, 1951.

Sampling Date	Number Scales	Mean Number Nuclear Circuli
September 4-8	172	12.0
September 10-13	220	11.6
October 9-15	109	11.5

In 1938, scales were taken from live Cultus Lake 3_2 as they passed through a counting weir. These scales were analysed by two observers in the manner described on page 21; the combined means by period appear in TABLE 16. The first group sampled exhibited significantly less lacustrine growth than the following two groups, which were similar in amount of growth. The peak of migration past the Cultus Lake weir was about November 15 in 1938.

TABLE 16—Comparison of mean number lacustrine scale circuli among periods of run. Cultus Lake spawning ground 3_2 at counting weir, 1938.

Sampling Date	Number Scales	Mean Number Nuclear Circuli
October 6-14	179	14.3
October 28-November 15	165	15.6
November 17-December 1	128	15.4

A third sampling of 3_2 by time during a spawning run is available for 1952 Horsefly River sockeye. The samples were taken from fresh dead fish on the spawning ground. The mean number of nuclear circuli progressively increased in the three periods (TABLE 17), the increase was most marked between the second and third periods. These data were derived from the combined means of two observers and the change was apparent in the interpretation of each observer. The peak of dying for 3_2 was about September 7 at Horsefly River in 1952.

TABLE 17—Comparison of mean number lacustrine scale circuli among periods of run. Horsefly River spawning ground 3_2, 1952.

Sampling Date	Number Scales	Mean Number Nuclear Circuli
August 22-30	95	17.4
September 3-5	149	17.8
September 7-11	200	18.8

4_2—Determination of the mean number of nuclear circuli were made on several runs of the 4_2 age group to establish the extent of variablility. A series of three samples of fresh dead spawned fish from Adams River spawning ground in 1955 were analysed by one observer only. TABLE 18 shows for Adams River a moderate progressive increase in mean number of nuclear circuli by sampling period.

TABLE 18—Comparison of mean number lacustrine scale circuli among periods of run. Adams River spawning ground 4_2, 1955.

Sampling Date	Number Scales	Mean Number Nuclear Circuli
October 19	164	13.8
October 27	165	14.2
November 4	160	14.5

The migration of the Chilko River run past Farwell Canyon on the Chilcotin River 118 miles below the Chilko River spawning grounds has been sampled during progressive periods in the years 1944, 1946, and 1948. The results, as shown in TABLES 19, 20, and 21, indicate no regular pattern of variation for all three years and all of the variations are of minor degree. In the 1944 samples (TABLE 19) the lowest mean occurred in the central period. In the 1946 samples (TABLE 20) the first period had the lowest mean, and there was a progressive increase

TABLE 19—Comparison of mean number lacustrine scale circuli among periods of run. Chilko River 4_2 at Farwell Canyon, 1944.

Sampling Date	Number Scales	Mean Number Nuclear Circuli
August 8-23	96	13.1
August 29-30	98	12.6
September 8-10	96	12.8

TABLE 20—Comparison of mean number lacustrine scale circuli among periods of run. Chilko River 4_2 at Farwell Canyon, 1946.

Sampling Date	Number Scales	Mean Number Nuclear Circuli
August 3-16	87	13.2
August 18-22	86	13.4
September 1-7	72	13.5

thereafter. In the 1948 samples the mean was highest in the central period (TABLE 21). All of the Farwell Canyon scales of the 1944, 1946, and 1948 samplings were checked-read by two observers and the means shown in the tables are combined means of those duplicate readings.

TABLE 21—Comparison of mean number lacustrine scale circuli among periods of run. Chilko River 4_2 at Farwell Canyon, 1948.

Sampling Date	Number Scales	Mean Number Nuclear Circuli
July 30-August 16	184	11.8
August 19-27	155	12.0
August 28-September 8	167	11.8

An extensive sampling from 1953 Chilko River spawning ground fish recovered as fresh dead after spawning shows (TABLE 22) no regular change in mean number of nuclear circuli by time and no significant variation among samples. The period of peak dying was about September 23 in 1953. These samples were all analysed by two observers.

TABLE 22—Comparison of mean number lacustrine scale circuli among periods of run. Chilko River spawning ground 4_2, 1953.

Sampling Date	Number Scales	Mean Number Nuclear Circuli
September 10-15	100	12.5
September 17-19	100	12.5
September 21-24	100	12.2
September 25-28	100	12.5
September 29-October 1	100	12.2
October 2-October 6	55	12.4

Three periodic scale samples were analysed from 1955 Chilko River fresh dead spawners. The means were calculated from the readings of one observer only. Very little variation occurred between successive samples but a regular decrease in mean numbers of nuclear circuli is apparent (TABLE 23).

TABLE 23—Comparison of mean number lacustrine scale circuli among periods of run. Chilko River spawning ground 4_2, 1955.

Sampling Date	Number Scales	Mean Number Nuclear Circuli
September 13	184	13.3
September 23	178	13.2
October 3	180	12.9

Three samples of 4_2 from Cultus Lake, 1938, were analysed from different periods of the run as the fish were passed through a counting weir at the outlet of the lake. Duplicate readings of the series were made. TABLE 24 shows a decidedly lower nuclear circulus count in the first sample, the last two samples being similar. The peak of migration was about November 15 in 1938.

TABLE 24—Comparison of mean number lacustrine scale circuli among periods of run. Cultus Lake spawning ground 4_2 at counting weir, 1938.

Sampling Date	Number Scales	Mean Number Nuclear Circuli
October 6-14	166	16.6
October 28-November 4	155	17.9
November 17-30	133	17.8

The Kynoch Creek population, one of the early migrating northern spawning runs to the Stuart River system, was analysed for possible variation in lacustrine growth by time period in 1951. One sample was taken from live fish on July 27-29, prior to spawning, and two were taken from dead spawned fish in two sampling periods, August 3-13 and August 18-27. The scales were analysed by one observer only. No variation in nuclear circulus count by time of sampling was found (TABLE 25). The peak of dying at Kynoch Creek was about August 13 in 1951.

TABLE 25—Comparison of mean number lacustrine scale circuli among periods of run. Kynoch Creek spawning ground 4_2, 1951.

Sampling Date	Number Scales	Mean Number Nuclear Circuli
July 27-29	257	18.2
August 3-13	190	18.2
August 18-27	93	18.2

A later migrating northern run to the Stellako River has been sampled by time period in 1952 from fresh dead spawners. The scales were analysed by two observers. A slightly lesser circulus count at the beginning of the period of dying for this population is evident from TABLE 26. The peak of dying was October 8 at Stellako River in 1952.

TABLE 26—Comparison of mean number lacustrine scale circuli among periods of run. Stellako River spawning ground 4_2, 1952.

Sampling Date	Number Scales	Mean Number Nuclear Circuli
September 22	113	18.1
October 3	171	18.4
October 12-13	87	18.3

5_3—The analysis of 5_3 lacustrine growth by time involves a two year period of growth, and variation could occur in the ring counts of either year separately or in both years combined. Three seasonal series of samples from the Chilko River run are available wherein the numbers of 5_3 are sufficient for representative results to be obtained.

TABLE 27—Comparison of mean number lacustrine scale circuli among periods of run. Chilko River spawning ground 5_3, 1953.

SAMPLING DATE	NUMBER SCALES	MEAN NUMBER NUCLEAR CIRCULI		
		First Year	Second Year	Both Years
September 10-11	35	7.9	12.3	20.2
September 15-18	28	7.8	12.4	20.2
September 19-22	38	7.5	12.5	20.0
September 24-26	32	7.5	12.6	20.1
September 28	89	7.9	12.1	20.0
Sept. 29-Oct. 1	62	7.8	12.0	19.8
October 2-5	62	8.2	12.0	20.2

A series of Chilko River 5_3 scale samples were taken from fresh dead spawners in 1953. The samples were check-read by two observers. No significant or progressive change in either first or second year growth, or in total lacustrine growth, was exhibited (TABLE 27). In 1954 progressive samples were taken from the Chilko run at two locations. The first scale collection was made from live migrating fish at Siwash Bridge, 52 miles below the spawning ground. The results of the analysis of this collection are presented in TABLE 28. A slight progressive increase in nuclear circulus count is evident throughout the sampling period, most of which apparently resulted from the regular seasonal increase in first year growth exhibited by the scales.

TABLE 28—Comparison of mean number lacustrine scale circuli among periods of run. Chilko River 5_3 at Siwash Bridge, 1954.

SAMPLING DATE	NUMBER SCALES	MEAN NUMBER NUCLEAR CIRCULI		
		First Year	Second Year	Both Years
August 4-8	7	7.8	12.4	20.2
August 10-14	12	7.3	13.3	20.6
August 15-18	25	8.6	13.0	21.6
August 19-22	27	8.3	13.3	21.6
August 23-26	46	8.7	13.0	21.7
August 27-28	48	9.7	13.1	22.8
August 29-31	49	9.4	13.4	22.8
September 1-3	57	9.3	13.3	22.6

The 1954 spawning ground sample, taken from fresh-dead spawned fish and analysed by two observers, did not show this variation (TABLE 29). The absence of variation may have been the result of mixing at death caused by varying duration of life after spawning, which is shown to be possible by Killick (1955).

TABLE 29—Comparison of mean number lacustrine scale circuli among periods of run. Chilko River spawning ground 5_3, 1954.

SAMPLING DATE	NUMBER SCALES	MEAN NUMBER NUCLEAR CIRCULI		
		First Year	Second Year	Both Years
September 20-23	29	9.5	12.8	22.3
September 24-27	28	9.3	12.6	22.9
September 28-29	32	9.3	13.2	22.5
September 30-Oct. 1	31	9.1	13.0	22.1
October 2-4	35	9.5	13.2	22.7
October 6-7	37	9.3	13.1	22.4
October 9-11	41	9.3	13.1	22.4
October 12-15	39	9.4	12.9	22.3

To recapitulate, jack and adult scales exhibit some variation in lacustrine growth by time during migration and spawning. The trend of variation is not consistent among areas nor between years for the same area. A slight tendency toward increasing number of nuclear circuli by time appears among six of the fifteen jack and adult samples, but the opposite condition occurs in two samples. Four of the six samples with increasing means were taken from migrating fish which had not yet reached their spawning ground. No trend was exhibited by seven of the fifteen samples, including two samples of migrating fish. The trend of increasing lacustrine circuli of the 1954 Chilko River 5_3 population at Siwash Bridge was not evident in the subsequent dead spawned fish of the same run.

This may be attributable to varying length of life span after spawning; the trend toward increasing lacustrine growth which was apparent in four of the six migration path samples could have been obscured in dead fish samples in the same way.

Smolts and adults both exhibit little variation in lacustrine growth during the periods of peak abundance occurring in the central portions of the migrations. Since the variation in amount of lacustrine growth is slight throughout the period of the run it is advisable to sample during the period of peak abundance, that is, when the greatest numbers of fish are present. For a single sampling this will produce the most representative results. Somewhat more representative sampling for average lacustrine growth of the population may be acquired by sampling periodically and weighting the values so obtained by the relative abundance of the fish present during each particular period of the run, but the additional effort involved is not warranted for routine sampling.

COMPARISON OF LACUSTRINE GROWTH OF AGE GROUPS OF CONCURRENT LAKE RESIDENCE

Sockeye of any given stock and brood year may be sampled as one year and two year smolts, and as three, four, or five year adults. If the lacustrine growth of a given age group is to be extrapolated from that of a younger age group appearing in a prior year, the relationship between the groups must be established. It may also be important to population dynamics and relative survival studies to determine the differences in lake growth between age groups of concurrent lake residence.

Lacustrine growth of one year smolts and returning 4_2 are compared for five lakes in TABLE 30. The sockeye of a given lake residence year have been sampled as seaward migrant smolts in the year following, and the adult 4_2 have been sampled in the autumn about twenty-eight months later than the smolts. For example, the fish of 1947 lake residence were sampled as smolts in 1948

TABLE 30—Comparison of mean number lacustrine scale circuli between one-year smolts and returning 4_2 adults of concurrent lake residence.

RESIDENCE LAKE	Lake Residence Year	SMOLTS		4_2 ADULTS		DIFFERENCE No. CIRCULI ADULTS LESS SMOLTS
		No. in Sample	Mean No. Circuli	No. in Sample	Mean No. Circuli	
Chilko	1949	1239	10.6[1]	310	11.8	1.2
	1950	117	11.5	187	12.5	1.0
	1951	159	13.3	762	14.0	0.7
	1952	144	12.5	184	13.3	0.8
	1953	358	12.2	181	13.1	0.9
Cultus	1951	189	12.7	216	12.6	—0.1
Francois	1950	116	19.3	187	19.0	—0.3
Shuswap	1952	184	14.0	164	14.2	0.2
Stuart	1950	190	16.8	100	18.0	1.2

[1]Calculated from mean fork length.

and as 4_2 adults in 1950. Chilko River provides a comparison of five consecutive years; in each of these years the returning 4_2 had a larger mean number of nuclear circuli than the downstream migrants of which they had been part, the difference being about one circulus in each case. In the nine samples including various areas there were six instances where the numbers of circuli of 4_2 fish were significantly larger than those of the smolts and one instance where they were only slightly larger. In two instances the numbers of circuli in the smolt scales were larger, but only slightly so in both cases. The average difference of the nine samples was 0.62 circulus in favor of 4_2.

Lacustrine growth of 3_2 jacks and 4_2 adults of concurrent lake residence is compared in TABLE 31. The 3_2 were sampled in the year prior to the 4_2 sampling. In nineteen of twenty-three examples the 3_2 had a greater mean number of nuclear scale circuli, in two cases 3_2 and 4_2 are equal and in two cases 4_2 are greater. The average difference for all twenty-three examples is 0.6 circulus in favor of 3_2. Among the seven comparisons from Shuswap Lake, 3_2 were greater in only four, with a mean difference of 0.3 circulus in favor of 3_2. Among

TABLE 31 — Comparison of mean number lacustrine scale circuli between 3_2 jacks and 4_2 adults of concurrent lake residence.

SAMPLING AREA	Lake Residence Year	3_2 JACKS		4_2 ADULTS		Difference No. Circuli 4_2 Less 3_2
		No. in Sample	Mean No. Circuli	No. in Sample	Mean No. Circuli	
Adams River	1936	54	12.1	122	12.5	0.4
	1939	213	10.2	214	9.9	—0.3
	1943	155	11.9	89	10.8	—1.1
	1948	72	12.1	189	12.1	0.0
	1949	177	17.1	175	17.1	0.0
	1950	92	16.6	173	15.5	—1.1
	1951	202	11.3	191	11.0	—0.3
Bowron River	1951	92	14.4	192	14.2	—0.2
Chilko River	1937	51	13.3	140	13.2	—0.1
	1948	198	12.7	186	13.0	0.3
	1949	203	12.7	310	11.8	—0.9
	1950	59	12.7	187	12.5	—0.2
	1951	95	14.1	762	14.0	—0.1
Cultus Lake	1936	165	15.6	190	14.2	—1.4
	1937	73	15.4	164	14.1	—1.3
	1943	35	17.1	156	16.6	—0.5
	1951	205	13.5	216	12.6	—0.9
Horsefly River	1950	444	18.2	199	17.8	—0.4
Kynoch Creek	1938	43	18.1	206	16.8	—1.3
Middle River	1950	83	18.8	181	17.9	—0.9
Nadina River	1950	65	20.2	187	19.0	—1.2
Stellako River	1951	175	19.3	162	17.7	—1.6
Weaver Creek	1951	136	22.3	259	21.7	—0.6

five samples from Chilko Lake four had 3_2 with the greater number of circuli, and there was an average difference of only 0.2 circulus in favor of 3_2. In four cases from Cultus Lake the 3_2 were on the average 1.0 circulus greater than the 4_2. In the seven samples from areas other than Adams, Chilko, or Cultus there was a mean difference of 0.9 circulus in favor of 3_2. Based on this series of 23 samples, differences apparently exist between areas or stocks. The differences seem to be related to the amount of lacustrine growth in that greater difference tends to occur when lacustrine growth is greater. In the absence of specific information for particular stocks an adjustment of 0.6 circulus would seem to be best if a substitution of values is to be made.

During any one year Fraser River sockeye residence lakes contain what may be classed as three groups of resident sockeye, excluding residual or so-called land-locked varieties. The most common and most abundant are those which are in their first year of life and will migrate to sea as yearlings. The second group, which are brethren of the first, are in their first year of life but will for some reason remain in the lake for one additional year to migrate as two year olds. The third group, which are representatives of the prior brood year, are concurrently resident during their second year of life. Circulus counts indicating growth for a given residence year, for example 1950, are made from (1) the yearling smolt scales of the 1951 seaward migration, (2) the second year scale zone of the two year smolts of the 1951 seaward migration, and (3) the first year scale zone of the two year smolts migrating seaward in 1952. Comparison through scale analysis of smolts of the respective growth of these three types during concurrent residence in Chilko Lake is presented in TABLE 32. In four of five cases the one year smolts had larger growth during the year than either the first year of the potential two-year smolts or the second year of the immediate two-year smolts. In four of five years the second year growth of the immediate two-year smolts was greater than the first year of the potential two-year smolts. There was one instance of greater growth in the first year rather than the second year of two-year-olds; this unusual relationship of greater growth in the first year than in the second was not common among the same groups of

TABLE 32—Comparison of mean number lacustrine scale circuli among one-year and two-year smolts of concurrent residence in Chilko Lake.

LAKE RESIDENCE YEAR	ONE YEAR SMOLTS		TWO YEAR SMOLTS			
			First Year		Second Year	
	No. in Sample	Mean No. Circuli	No. in Sample	Mean No. Circuli	No. in Sample	Mean No. Circuli
1950	117	11.5	108	8.9	86	11.8
1951	159	13.3	60	11.3	108	12.9
1952	144	12.5	169	9.2	60	9.1
1953	358	12.2	99	8.7	169	11.3
1954	274	10.0	304	7.4	99	9.4

fish returning as 4_3 and 5_3 in 1954 and 1955 although the scales of a few of these jacks and adults exhibited it.

A similar comparison between one and two-year-olds of concurrent lake residence can be made through scales of adults of one and two year lake residence. Comparisons of the three above-mentioned concurrent residence types appear in TABLE 33. In all comparisons the first year growth of the one-year-lake-type is greater than the second year growth of concurrent two-year-lake-type. In all

TABLE 33—Comparison of mean number lacustrine scale circuli among 4_2 and 5_3 adults of concurrent residence in Chilko Lake.

LAKE RESIDENCE YEAR	4_2		5_3			
	First Year		First Year		Second Year	
	No. in Sample	Mean No. Circuli	No. in Sample	Mean No. Circuli	No. in Sample	Mean No. Circuli
1948	186	13.0	69[1]	9.7	13	10.3
1949	310	11.8	346	7.9	69[1]	10.2
1950	187	12.5	543	9.2	346	12.2
1951	762	14.0	36[2]	8.7	543	13.1
1952	178	13.1	29	9.8	36[2]	10.2

[1]1951 4_3 and 1952 5_3 combined to increase sample.

[2]1954 4_3 and 1955 5_3 combined to increase sample.

comparisons the concurrent second year growth of two-year-lake-type is greater than the first year growth of the potential two-year-lake-type.

The relationship between growth of one-year and two-year smolts, as exhibited by both smolt and adult scales, is constant in trend but variable in degree. The relationship is doubtless affected by population pressure and other environmental factors. Extrapolation of growth values between these types cannot be accomplished without use of correction factors.

VARIABILITY OF LACUSTRINE GROWTH BY YEARS AND STOCKS

The lacustrine growth of any unit-stock of Fraser River sockeye is not necessarily constant from year to year, nor is it necessarily the same among different stocks in the same year. Evidence of this variability appears in TABLES 34 and 35; the mean values in these tables were derived from scale readings of two observers. This diversity is to be expected among populations which fluctuate widely in numbers from year to year and reside in lakes as much as 700 miles apart which vary in size from 1,500 to 90,000 acres and have great differences in plankton production. The wide differences in number of lacustrine scale circuli, representing wide differences in size of smolts, appear to be primarily functions of environment rather than of racial heritage. The fluctuation in mean smolt size of more than 50 per cent which is exhibited by the Adams River

TABLE 34—Comparison of mean number lacustrine scale circuli among years. Lower Adams River spawning ground 4_2 adults.

Year	Number Scales in Sample	Mean Number Nuclear Circuli
1950	189	11.1
1951	189	12.1
1952	175	17.1
1953	173	15.5

populations (1950 vs. 1952) indicates strong environmental influence. The effect of environment is also illustrated by certain runs of sockeye which have been transplanted from their original spawning and rearing areas to new locations. These transplanted fish experienced different growth rates from those members of the same genetical populations which were allowed to remain in their native areas. Comparisons between the transplanted and native control groups appear in TABLE 36.

TABLE 35—Comparison of mean number lacustrine scale circuli among various spawning populations of adult 4_2, 1954.

Population	Number Scales in Sample	Mean Number Nuclear Circuli
Adams River	191	11.0
Bowron River	192	14.2
Stellako River	162	17.7
Portage Creek	157	20.7

TABLE 36—Comparison of mean number lacustrine scale circuli between (1) control and (2) transplanted sockeye of the same brood.

Area	Year	Age	Number Scales in Sample	Mean Number Nuclear Circuli
(1) Horsefly River	1952	3_2	444	18.2
(2) Quesnel Field Station	1952	3_2	10	13.9
(1) Horsefly River	1953	4_2	199	17.8
(2) Quesnel Field Station	1953	4_2	27	12.8
(1) Lower Adams River	1954	4_2	191	11.0
(2) Portage Creek	1954	4_2	157	20.7
(1) Seymour River	1954	4_2	168	11.4
(2) Upper Adams River	1954	4_2	5	16.4

The sockeye reared at Quesnel Field Station were hatched from Horsefly River eggs. The resultant fingerlings were marked by fin excision and planted in Quesnel Lake, the natural rearing area of the Horsefly River fish, in November of the year of hatching. They returned as 3_2 jacks and 4_2 adults in 1952 and 1953, as did the naturally-spawned run. The nuclear scale growth of the hatchery fish was four to five circuli less than that of the nature-reared fish, apparently as a result of the seven months artificial rearing. The Portage Creek fish emanated from eyed-eggs of Lower Adams River stock. A few of the Portage Creek sockeye may have come from the natural spawning of a few pairs of fish which were observed spawning in 1950, but the bulk were undoubtedly from the transplanted eggs. The increase in lacustrine growth of the transplanted Portage Creek fish over that of their Adams River brethren was almost ten circuli, or almost 100 per cent. The Upper Adams River sample, which hatched from transplanted Seymour River eyed-eggs exhibited 43 per cent more lacustrine growth than the fish of the donor stock. The results of these comparisons indicate that any heritable lacustrine growth patterns among Fraser River sockeye populations are strongly overshadowed by ecological effects.

DETERMINATION OF SAMPLE SIZE

Measurement of lacustrine growth may be conducted on spawning grounds samples of individual runs and commercial fishery or migration route samples of complex mixed-run populations. Spawning grounds samples divulge the mean lacustrine growth of the individual populations for growth studies and also for the identification of these populations as they appear in the commercial catch samples. Commercial fishery or migration route samples may be used to separate unit-stock populations and thereby calculate the unit-stock fishing mortalities and establish the times and characteristics of their migrations.

Individual spawning ground samples must be large enough to ensure a reasonably accurate assessment of the mean lacustrine growth of each population through scale analysis. Mixed-population samples must be large enough to reflect the complex unit-stock composition of the catch. A different principle of sampling theory is involved in each case, although both principles are involved in commercial sampling, as will be shown.

Sample sizes may be determined in two ways. First through application of formulae based on the theory of sampling, and, second, through calculation of the limits of accuracy of empirical values. The theoretical treatment of the sample size question assumes that the scales are analysed by one observer only, whereas the discussion of empirical data includes duplicate readings and combined means. Both of these approaches will be discussed for spawning grounds and commercial sampling separately.

Spawning Grounds Sampling

If all factors tending to produce non-representative sampling have been properly accounted for and it may be assumed that virtually pure samples of randomly-distributed scales are being analysed, then — and only then — sampling theory can be applied.

Theoretical—Statistical tests of nuclear circulus counts have shown that most are approximately normally-distributed, thereby validating the use of an approximation of the normal distribution in determining minimum sample sizes.

It is desired to find the sample size necessary to determine mean circulus count within a given fraction of the true value with a high degree of confidence. If the standard deviation of the population is not known exactly it is impossible to guarantee that the confidence interval will be no longer than a specified amount, but it can be guaranteed with a given probability.

The general relationship which determines n, as set down by Harris Horvitz and Mood (1948), is:

$$\left(\frac{d}{S_1}\right)^2 = \frac{t_{1-\alpha}^2 (n-1) \cdot F_{1-\beta} (n-1, m-1)}{n} \tag{1}$$

Where: S_1 is a previously acquired estimate of the population standard deviation
d is ½ the length of the confidence interval
α is the confidence coefficient of the confidence interval
β is the probability the specified length will not be exceeded
$t_{1-\alpha}(n-1)$ is the 1-α critical level of Student's *t* for n-1 degrees of freedom
$F_{1-\beta}(n-1, m-1)$ is the 1-β critical level for the variance ratio for n-1 and m-1 degrees of freedom
n is the sought for sample size
m is the size of the sample from which S_1 is calculated

By transposing the equation:

$$n = \frac{S_1^2}{d^2} \cdot t_{1-\alpha}^2 (n-1) \cdot F_{1-\beta} (n-1, m-1) \tag{2}$$

If we wish an overall confidence level of, say about 95 per cent then let:

$\alpha = 0.95$, $\beta = 0.99$; $\alpha \cdot \beta = 0.94$

then:

$$n = \frac{S_1^2}{d^2} \cdot t_{.05}^2 (n-1) \cdot F_{.01} (n-1, m-1) \tag{3}$$

From here the procedure will vary depending on the population variance (S_1^2), the size of the sample (m) from which that variance was calculated, and the desired length of the confidence interval (2d).

By way of example, from the analysis of a single observer, the Chilko spawning grounds scales for the years 1938 to 1952 have a mean standard deviation of: $S_1 = 1.57$ circuli, calculated from a total sample of: m = 2690 scales. If a confidence interval of 1.0 circulus is desired: d = 0.5.

Substituting these values in equation (3) and solving by approximation: n=60. If a confidence interval of 0.5 circulus is desired: n = 240.

It is possible to use a slight modification of the above method when no exact estimate of the expected standard deviation is known but a maximum value can be used.

In this case $n = \frac{S_2^2}{d^2} \cdot t_{.05} (n-1)^2$, (4)

where S_2 is an estimate of the maximum expected standard deviation of the sample.

The Chilko spawning grounds scales for the years 1938-1952 have from readings of a single observer a maximum standard deviation in any given sample of S_2=1.97, or, for simplicity, S_2=2. If a confidence interval of 1.0 circulus is desired: d=0.5. Substituting these values in equation (4) and solving by approximation: n=64. If a confidence interval of 0.5 circulus is desired then n=248.

The sample size determination techniques delineated above relate to the calculation of mean numbers of lacustrine circuli for growth and survival studies. Spawning ground lacustrine growth scale readings are also used to compare with commercial fishery catch samples. The spawning ground samples of 3_2 jacks are used in commercial catch unit-stock segregation during the following year, whereas the samples from adults are used to compare with the commercial scales acquired earlier in the same year.

In relating spawning ground nuclear circulus counts to commercial fishery nuclear circulus counts the shape of the circulus count curve is more important than the mean circulus count itself. The shape of the curve is determined by the relative number of the scales which fall within each circulus count class interval. To determine the proportion within each class interval with only a given relative error it is necessary to know the standard deviations of the circulus counts to this degree of accuracy. Greenwood and Sandomire (1950) present a graphical method of finding the sample size required to estimate the standard deviation to any degree of accuracy at any confidence level. The relative number of scales within the modal circulus count class interval varies around 25 per cent among most spawning grounds samples. If the true value were, say, 25 per cent and it is desired to restrict the estimates of this true value to a maximum error of 0.20 — i.e. the estimates would vary from 20 per cent to 30 per cent — with 0.95 confidence then a sample of about 45 scales would be required. If the maximum allowable error with 0.95 confidence were 10 per cent — wherein the estimates would vary from 22.5 per cent to 27.5 per cent — then a sample of 190 would be required. This matter of sample size necessary to closely retain the true shape of the ring count curve is discussed further on page 79, under theoretical sample size determination for commercial fishery samples.

Empirical—The accuracy of estimation of mean nuclear circulus count from samples of varying magnitude has been tested with empirical values. Samples from Chilko River spawning populations have been selected as examples. The scales analysed for nuclear circulus count by two observers making independent counts. Combined means have been calculated by the method outlined on page 21. The results are shown in TABLE 37. These data have been previously analysed in connection with change in mean nuclear scale circuli by time, but no consistent differences by time were apparent, therefore it seems that these differences may be the result of random sampling variation occasioned by the true variation in the population and the artificial or interpretational variation.

The maximum yearly divergence of both the individual and combined observers' subsample means is shown in TABLE 38. The values are calculated from TABLE 37 by finding the greatest differences between the yearly subsamples and the best estimates of the population means. These best estimates

TABLE 37—Comparison of mean number lacustrine scale circuli among subsamples of varying magnitude. Chilko River spawning runs of adult 4_2. Combined independent interpretations of two observers.

SAMPLING YEAR	NUMBER SCALES IN SAMPLE	MEAN NUMBER NUCLEAR CIRCULI		
		Observer *a*	Observer *b*	Average of *a* and *b*
1944	96	13.1	13.1	13.10
	98	12.4	12.7	12.55
	96	12.7	13.0	12.85
	290	12.73	12.93	12.83
1946	72	13.5	13.5	13.50
	86	13.2	13.5	13.35
	87	13.2	13.2	13.20
	245	13.30	13.40	13.35
1948	184	11.9	11.6	11.75
	155	11.9	12.0	11.95
	167	11.8	11.7	11.75
	506	11.87	11.77	11.82
1952	151	12.1	11.8	11.95
	159	11.7	11.5	11.60
	310	11.90	11.65	11.78
1953	100	12.6	12.5	12.55
	100	12.6	12.4	12.50
	100	12.3	12.1	12.20
	100	12.6	12.3	12.45
	100	12.2	12.3	12.25
	500	12.46	12.32	12.39

are represented by the combined observers' yearling mean for each population. The greatest deviation of the subsamples from the best estimate of the population mean is 0.43 circulus for individual means and 0.28 circulus for combined means. It is not proposed that all mean lacustrine circulus counts for all runs of Fraser River sockeye will exhibit no more variation than this, but these data indicate that for populations with circulus count standard deviations no greater than ± 2 circuli a sample of even one hundred scales limits the natural variation adequately. However, because of possible variation caused by differing interpretation of nuclear circulus counts, as discussed on page 18, it is the policy of the Commission to acquire samples of about two hundred scales for unit-stock lacustrine growth studies.

A field sample of a given number of scales does not yield an equal number of readable scales for examination. Examination of many thousands of scales has shown that 8 to 10 per cent of all Fraser River sockeye scales have regenerated centers, and an additional ½ to 2 per cent may be otherwise unreadable.

TABLE 38—Divergence in mean number lacustrine circuli between subsamples and best estimate of yearly population mean. Samples of varying magnitude from Chilko River spawning runs of adult 4_2.

Sampling Year	Approximate (Average) Number Scales in Subsamples	Number Subsamples	Maximum Difference from Best Estmiate Population Mean	
			Individual Observers	Combined Observers
1944	97	3	0.43	0.28
1946	82	3	0.15	0.15
1948	169	3	0.22	0.13
1952	155	2	0.28	0.18
1953	100	5	0.29	0.19

Further, when duplicate scale readings are made an additional 5 to 10 per cent of the scales are discarded (see page 21).

In summarizing the determination of sample size for unit-stock lacustrine growth studies it may be said that there are inherently three types of variations: *(1)* natural or random sampling variation, *(2)* observer variation from scale to scale, tending to average out in the sample, and *(3)* observer variation between samples. Sampling theory shows that sampling variation can be kept to $\pm\frac{1}{2}$ circulus with a sample of about 60 scales and to $\pm\frac{1}{4}$ circulus with a sample of about 240 scales. The method of combined check readings appears to limit the variation to $\pm\frac{1}{4}$ circulus with a sample of only 100 scales, at least for the usual sample. However, since the probability of a greater natural variation with a sample of only 100 is more than 0.05 and since unforseen reader variation must be allowed for, samples of about 200 are to be preferred. All field samples must be increased by a factor of about 10 per cent to account for regenerated or otherwise unreadable scales.

Commercial Fishery Sampling

Theoretical—Sample estimates of unit-stock composition in a complex population will vary. If it be assumed that the ideal case exists, that is, that all factors causing non-representative sampling are eliminated, then the estimates of the proportion of any given unit-stock in a complex population will follow a binomial distribution. The amount of variation in the estimates of the unit-stock proportion is dependent on the number of fish in the catch, the number in the sample, and the true proportion of the sought-for group in the mixed population. There is more than one method of finding sample sizes necessary to keep the variation of the estimates within desired limits. Chapman (1948, page 82) presents criteria for determining the best method, and tables for computing such sample sizes appear in Snedecor (1948, Table 11) and elsewhere.

Where the binomial distribution closely approximates the normal distribution the relationship between the variation of the estimates and the number in the sample is:

$$\rho^2 = \frac{p\ (1-p)}{n} \qquad (5)$$

where ρ^2 is the variance of the estimates, p is the actual proportion of the sought-for unit-stock and n is the size of the sample. About 95 per cent of the estimates will fall within ± 1.96 standard deviations from the mean; to keep the variation (V) within certain limits with 95 per cent confidence:

$$\pm V = \pm 1.96\ \rho \qquad (6)$$

Substituting from (5):

$$n = \frac{3.84\ p(1-p)}{V^2} \qquad (7)$$

These calculations assume that the identification of the members of the sought-for group is invariable. Since unit-stock identification is made by analysis of lacustrine growth, and the various units of a mixed run may more or less overlap in characteristics this formula designates only a minimum sample size.

The analysis of complex ring count frequencies involves the same interpretational problems as for simple spawning grounds frequencies, and this increases the variation of the estimates of proportions. Variation from this source is manifested in the varying proportions of the sample appearing within each circulus-count class interval. The amount of variation within the class interval is a function of the consistency of the scale reader, as discussed on page 18, and the number of scales in the sample. A formula has been developed by Dr. D. G. Chapman of the University of Washington Department of Mathematics by which the sample size necessary to control this variation can be calculated.

Let:

n = number fish in commercial sample
0_i = observed proportion of fish in commercial sample having ring count i
ρ = relative error of the 0_i
α = confidence coefficient
Z = $1-\alpha$ critical level of Normal distribution

The 0_i are approximately normally distributed with variance approximately equal to:

$$\frac{0_i\ (1-0_i)}{n}$$

In order to restrict the relative error of the 0_i to the desired degree at the desired confidence level (α) it is necessary to choose a sample of size n.

Where:

$$Z\sqrt{\frac{0_i\ (1-0_i)}{n}} \leqq \rho 0_i \qquad (8)$$

Or, at the critical level:

$$n = \frac{Z^2\ (1-0_i)}{0_i} \qquad (9)$$

Empirical data reveal that the maximum 0_i in commercial samples of mixed unit-stocks is rarely more than 0.20. By choosing the 95 per cent confidence level and arbitrarily deciding that the maximum 0_i should not vary by more than 20 per cent of their own true values the following substitutions can be made in equation (9):

$$0_i=0.20, \ \alpha=0.95, \ \rho=0.20$$

This yields a sample size of n = 384, which will guarantee with 0.95 confidence that the maximum 0_i will vary only between 0.16 and 0.24.

A sample of about this size would limit the variation of an 0_i of 0.05 to a variation of ±0.02 with 95 per cent confidence. Since $\frac{1-0_i}{0_i}$ increases as the value of 0_i decreases, ρ must increase as 0_i decreases if n is kept constant. This poses no problem in practical sampling because the per cent variation of the lower values of 0_i are never as important as the per cent variation of the modal values in management research analyses.

The decision of how closely variations are to be controlled and whether the calculated sample sizes are either inadequate or excessive for practical collection and analysis remains with the researcher, and will vary with circumstances of application.

Empirical—Analyses of commercial fishery scale samples show that in certain seasonal migrations where the number of unit-stocks in a mixed population is only two or three, small samples can yield good results. This is exemplified in FIGURE 40. These daily catch samples show a progressive change in unit-stock composition over a short period of time. As shown in FIGURE 40 the changing pattern of nuclear scale circulus counts is closely duplicated at two separate sampling stations. The daily relative numbers of sockeye composed of the higher circulus count group are compared between sampling stations in TABLE 39. The percentage of the higher circulus count distribution changed by time of sampling in much the same degree for the two sampling stations. The greatest divergence occurred on July 9, when there was a difference of 6.3 per cent in relative number of fish with fifteen or more nuclear circuli. The samples of about two hundred scales appear to have been reasonably adequate in determining the daily composition of the run. Theoretically a variation in composition of as much as 7 per cent is expected in five out of one hundred samples of this magnitude.

Analyses of commercial fishery scale samples have shown that where the number of unit-stocks intermixed becomes more than about three the degree of overlapping of nuclear circulus counts increases. This decreases the number of scales in each circulus count class interval and necessitates increased samples. The greatest potential variation in the estimates of unit-stock proportion appears where the sought-for stock makes up half of the catch. When the sought-for group makes up 50 per cent of the catch it is necessary to have daily samples of about 400 fish to keep the variation in the estimated proportion within 5 per cent in 95 out of 100 samples.

The Commission generally follows a policy of taking samples of about two hundred readable scales per day when only two or three unit-stocks are involved

TABLE 39—Comparison between two commercial fishery sampling stations of relative number sockeye with fifteen or more nuclear circuli. United States purse seine catches, 1951.

SAMPLING DATE	Per Cent of Scales With 15 or More Nuclear Circuli	
	Anacortes	Blaine
July 9	84.3	90.6
July 10	82.5	79.7
July 11	74.4	71.6
July 12	61.9	62.1

and about four hundred per day when the run is more complex. The samples must be increased when more than one age group is included so that the unit-stock composition by age group can be calculated.

AGE DETERMINATION STUDY

Age composition must be assessed to determine the total production of adults from a given spawning because the returns may take place over a period of two or three years. Further, the close study of variation in age composition of certain populations may assist in the study of dynamics of these populations. Where a certain population has numerous representatives of an uncommon age group the time of migration through the commercial fishery waters and the unit-stock fishing mortality may be facilitated through a study of age composition. The importance of age composition to population studies warrants full investigation and substantiation of methods of age determination and careful design of sampling procedures so that age composition estimates will be representative of the populations under study.

The following sections are composed of discussions of *(1)* sockeye age classification, *(2)* age determination from scales and its limitations, *(3)* supplementary age determination from studies of length frequencies, *(4)* supplementary age determination from otoliths or ear bones, and *(5)* design of sampling procedures for age composition study in general.

Age Classification

Fraser River sockeye have complex life histories. They begin life in autumn as eggs deposited in the gravel of rivers and smaller streams, and live through the winter as developing embryos, to hatch during the winter and emerge from the gravel in spring. Upon emergence they pass into lakes where they live for one year usually and sometimes two. After one or two years of lake residence they pass to sea in the spring. They forage in the sea from about one-and-one-half to three-and-one-half years and return to spawn in the summer and autumn at three, four, or five years of age. As with all Pacific salmon death follows close upon spawning, and a cycle is completed.

Scales form on the young fry shortly after emergence and the pattern of growth is recorded on the scales thereafter. During each succeeding winter period

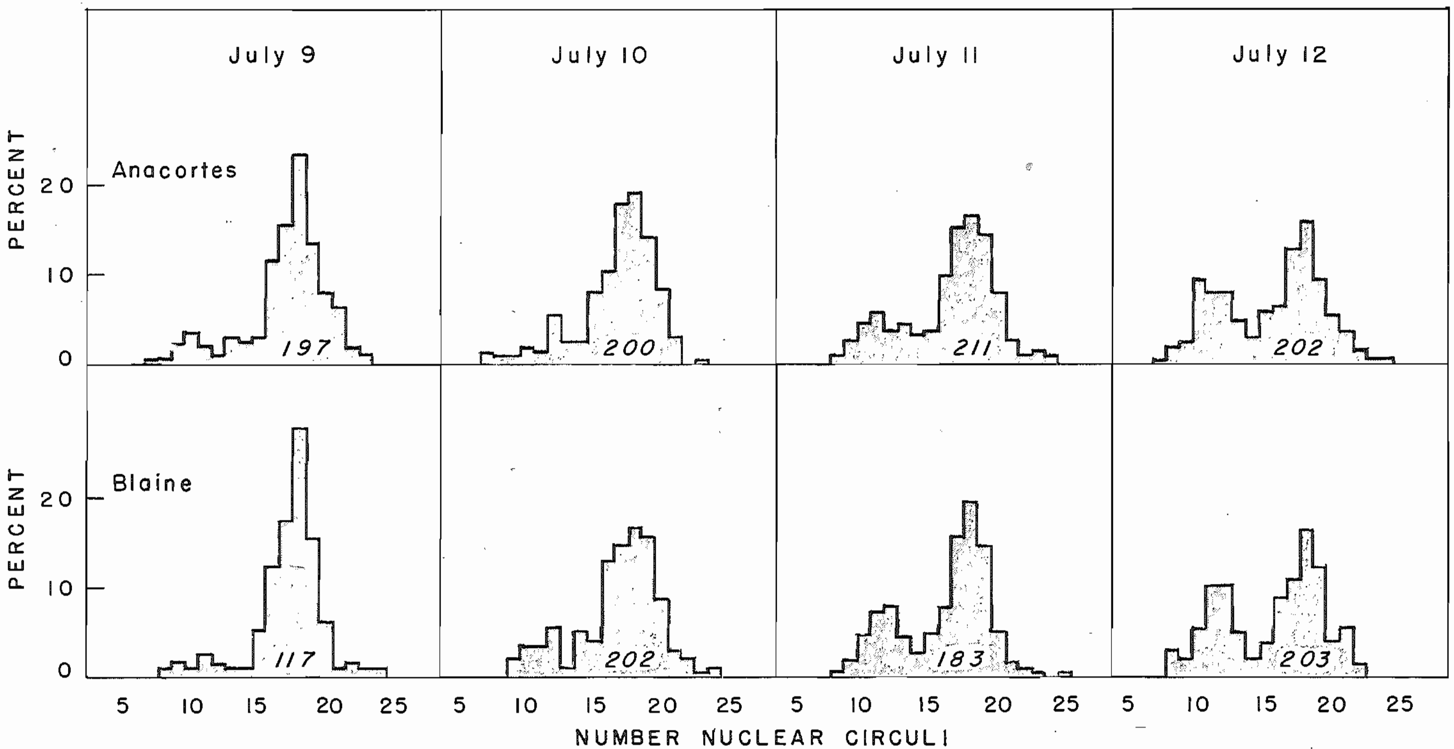

FIGURE 40—Comparison of daily scale nuclear circulus count frequencies between two commercial fishery sampling stations. Adult 4_2 sockeye from United States purse seine catches, 1951. Sample sizes as noted in histograms.

the circuli of the scales become crowded and finely etched, forming an annulus. The adult sockeye is one year older than the number of annuli formed on the scales.

As introduced on page 10 a two-digit symbol is used to express the age of sockeye — a superscript to denote the age at spawning and a subscript to denote the year of life in which the sockeye migrated to sea. Thus a 4_2 sockeye is one which spawns and dies at an age of four years and which remains one year in the lake to migrate to sea in its second year of life. A 3_2 jack sockeye is one which has returned from the sea one year earlier than a 4_2. Sockeye of 4_3 and 5_3 ages have the same period of sea residence as a 3_2 and 4_2, respectively, but live an additional year in fresh water. A 5_2 lives in the sea one year longer than a 4_2. This conventional symbolic age classification was originated by Gilbert and Rich (1927).

Age Determination from Scales

The validity of scale age interpretations has been demonstrated for certain species, but in many cases it has largely been assumed to be correct. Age determination criteria are not so specific as those for interpreting the nuclear area of sockeye scales. The annuli of sockeye scales arrange themselves spatially according to fairly fixed patterns and are usually distinctive. The annuli are identifiable by the sudden change in growth pattern and the crowding of adjacent circuli and by the incompleteness or irregularity of their formation. Accessory checks, which appear occasionally, are almost always recognizable by their unusual position in the pattern of scale growth. The determination of age by scales is discussed in this section under three headings including validation of scale age interpretations, selection of sampling location on the body of the fish and the effect of scale absorption on age determination of spawning sockeye.

VALIDATION OF AGE INTERPRETATIONS FROM SCALES

Absolute proof of the validity of age interpretation from scales is given by the recovery of marked fish of known early life history and known age at recovery. Artificially-hatched and reared sockeye which had been marked by the excision of the adipose and one of the ventral fins returned to the Fraser River in 1951 and 1953. Forty commercial fishery recoveries were made by technical staff members, and scale samples were taken from these recoveries. Each of the fish was of the 4_2 age group and the typical 4_2 scale pattern was exhibited on the scales (FIGURE 41), showing the conventional interpretation to be correct.

The examination of marked 4_2 sockeye scales shows that the sea growth of the scales has been correctly interpreted. The smaller size of 3_2 fish compared with 4_2 is further evidence of the correctness of interpretation. Eighty-nine Cultus Lake sockeye which had been marked as yearlings by the removal of both ventral fins by the Fisheries Research Board of Canada in 1936 were recovered as 3_2 in commercial fishery samples in 1937. Concurrent with this collection in 1937 there were seventy-two 4_2 recovered which had been marked as yearlings by

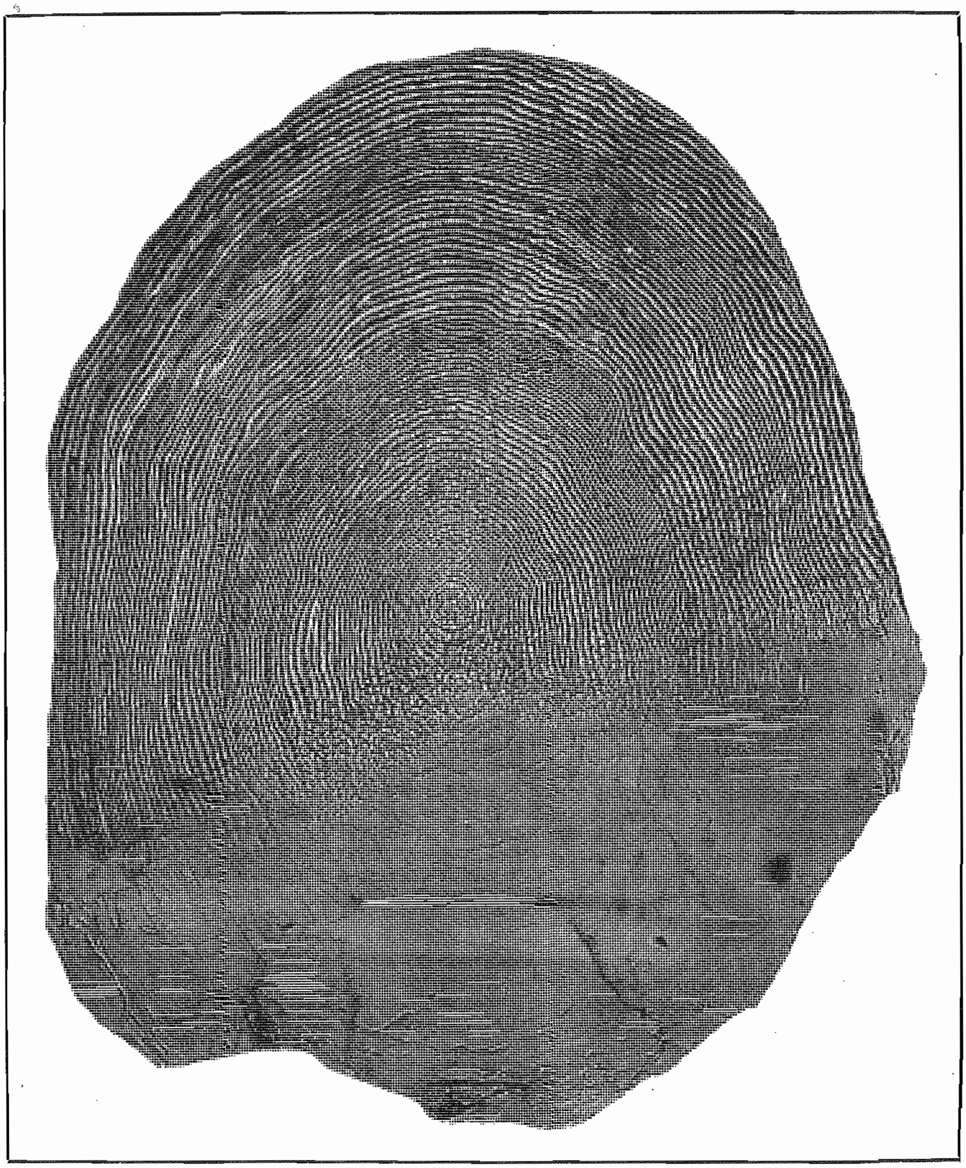

FIGURE 41—Scale of known age marked 4_2. Artificially hatched and reared. Recovered in commercial fishery, 1951.

the excision of adipose and both ventral fins in 1935. Scale samples were taken from each group.

The scales of the known three-year-old fish exhibited the typical 3_2 pattern (FIGURE 42) and the four-year-old scales the 4_2 pattern. The 3_2 were markedly smaller than the 4_2 of the same sex, as shown by a comparison of the length frequencies of the two age groups (FIGURE 43).

Five-year-old Fraser River sockeye are of two types, 5_2 and 5_3. The 5_2

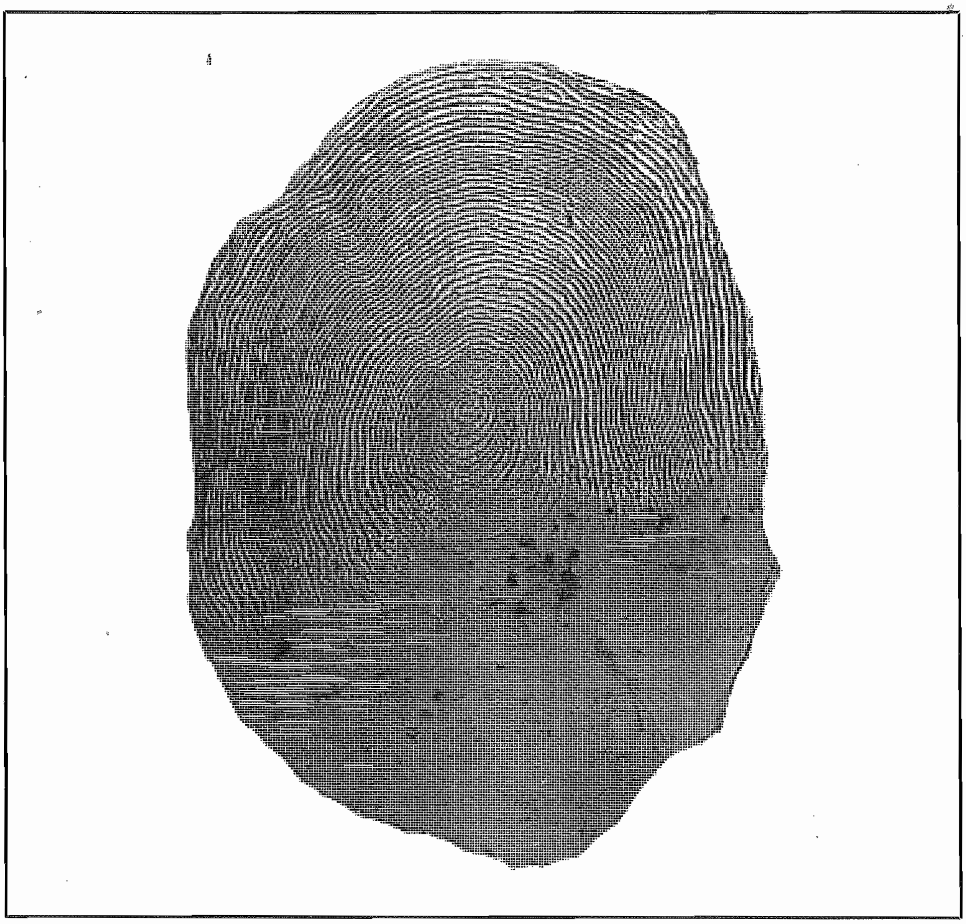

FIGURE 42—Scale of known age marked 3_2. Recovered in commercial fishery, 1937.

scale has one more year of sea growth than the 4_2 whereas the 5_3 spends the additional year in the lake. Because of the lesser numbers of 5_2 and 5_3 sockeye among those Fraser River populations which have been marked, no commercial fishery scale samples from known 5_2 age fish have been recovered by Commission observers. Circumstantial evidence of difference in size supports the interpretation of 5_2 age from scales. Samples of mixed runs in commercial catches show 5_2 to be larger on the average than 4_2 taken at the same time. To show this one hundred sockeye of each sex have been selected at random from both age groups of commercial fishery samples of July 14-18, 1952, and the length frequencies are shown in FIGURE 44. The degree of overlapping of size may be more pronounced in this mixed population sample than within specific unit-stock populations.

The aging of one-year-in-lake type sockeye, i.e. 3_2, 4_2 and 5_2, from scales has been shown to be correct. The validity of the interpretation of two-year-in-lake types, i.e. 4_3 and 5_3, remains to be shown. Certain populations of Fraser River sockeye have members which remain two years in the lake areas and migrate to

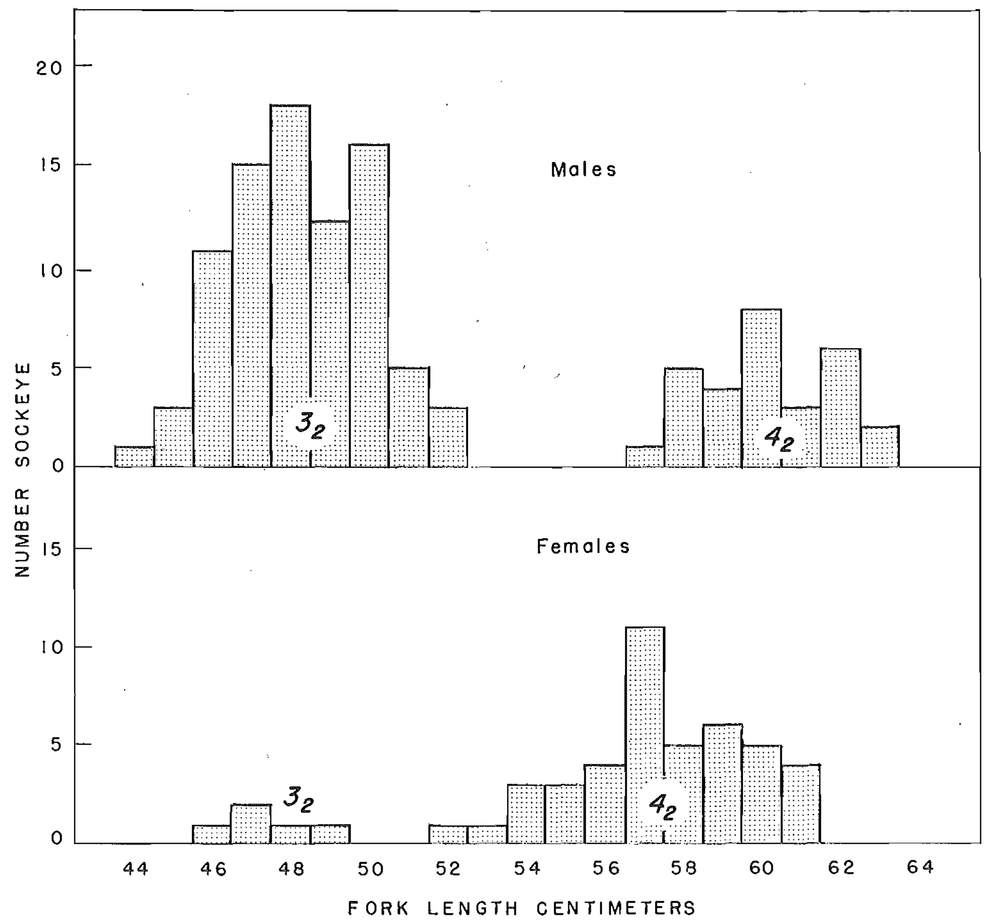

FIGURE 43—Length frequencies of known age marked Cultus Lake sockeye recovered in 1937 commercial fishery samples; 161 fish in samples.

sea in the spring of their third year of life. Most often the scales of these two-year-olds show fairly distinct first winter checks and are readily identifiable as two-year lake types both when migrating as smolts and when returning as adults to spawn. That the alleged two-year-lake type scales are not merely one-year-olds with large growth and an accessory check in the nuclear area can be shown by observing the lengths of the downstream migrants of the two groups and their total nuclear ring count frequencies. Using Chilko River smolts as a typical example. FIGURE 45 shows that there is almost no overlapping in either the fork lengths or total fresh water circulus-counts of the two age groups. The scales of the returning adults of two-year lake residence exhibit nuclear areas similar to the scales of the two-year-old smolts of the same brood year (FIGURE 46).

Occasionally two-year-in-lake sockeye return to spawn as four-year-olds. These 4_3 have the same period of sea residence as 3_2 and are more nearly the

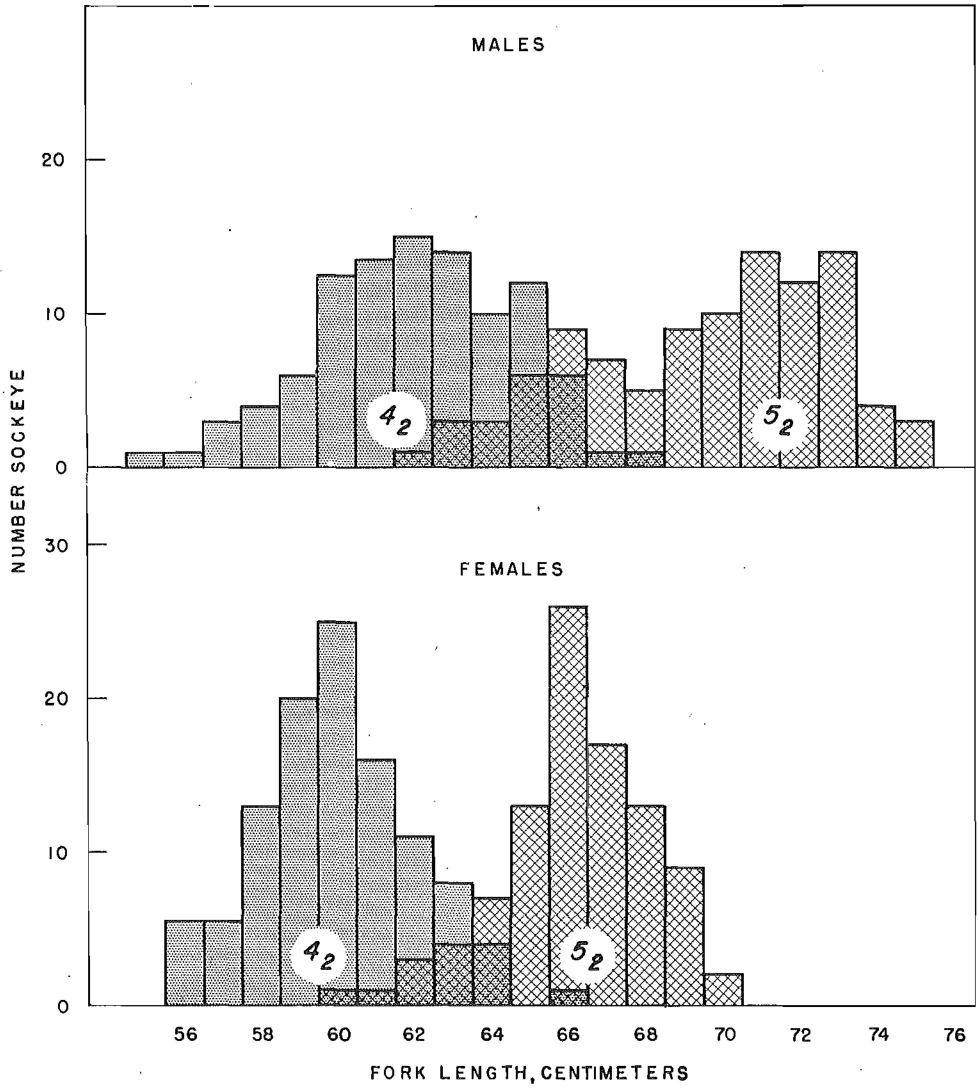

FIGURE 44—Length frequencies of mixed stocks from commercial catches, San Juan Islands, July 14-18, 1952—showing difference in size between 4_2 and 5_2; 401 fish in samples.

TABLE 40—Comparison of fork lengths of 3_2 and 4_3 sockeye from Birkenhead River and Chilko River, 1951.

AREA	3_2		4_3	
	Mean Fork Length, cm.	No. in Sample	Mean Fork Length, cm.	No. in Sample
Birkenhead River	41.0	695	43.2	171
Chilko River	47.6	407	49.1	44

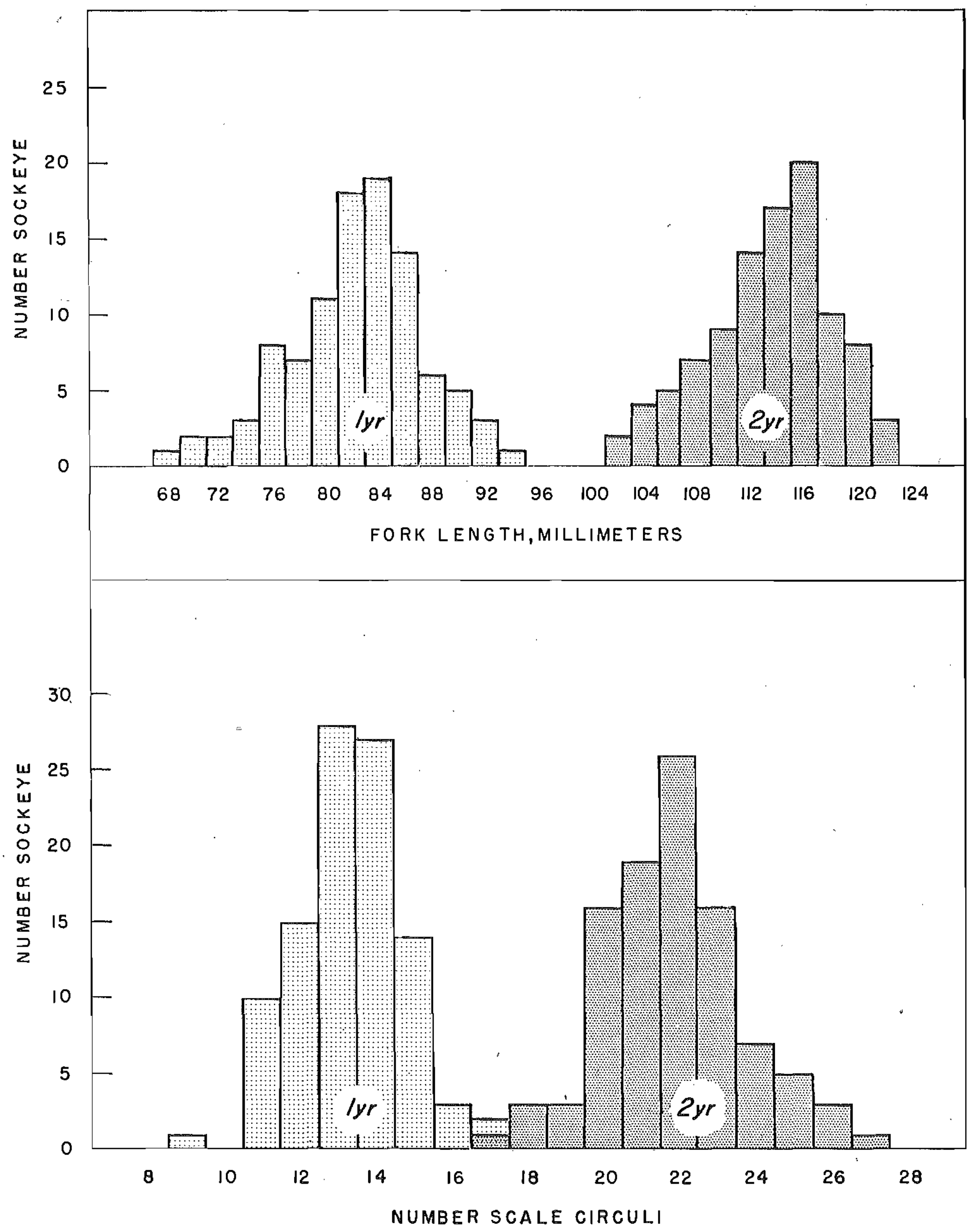

FIGURE 45—Fork length and number scale circuli of one-year and two-year smolts, 1952 Chilko Lake, showing difference between age groups; 200 smolts in each of samples.

size of 3_2 than 4_2. This similarity is apparent in samples from two distinct spawning areas shown in TABLE 40. In the tabulation the sexes are not treated separately because of the very low proportion of females in these two age groups. The 4_3 are slightly larger than the 3_2 both at Birkenhead River and Chilko River. This slight difference in size at maturity apparently results from the extra year of fresh water growth of the 4_3.

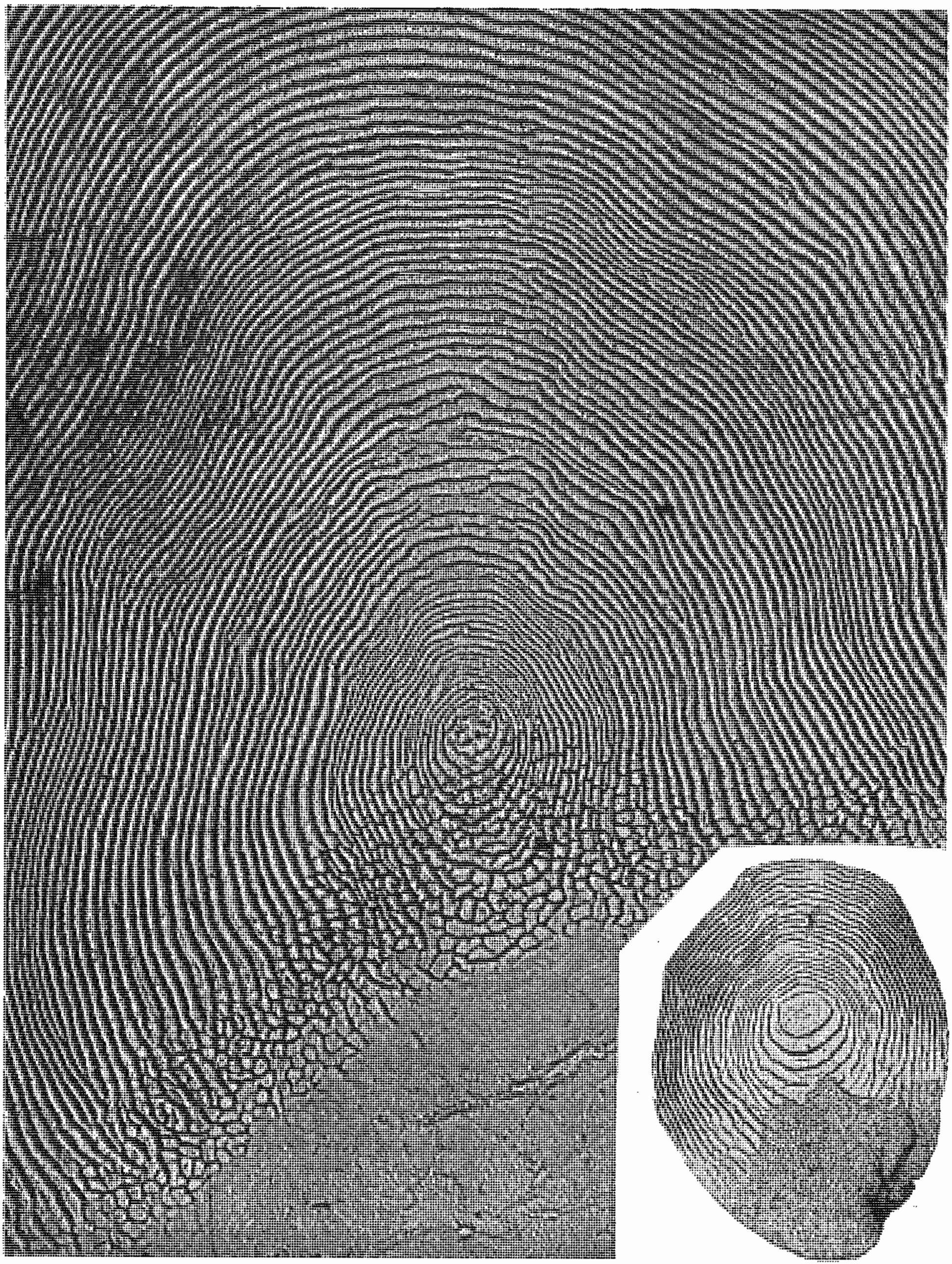

FIGURE 46—Two-year-in-lake type sockeye scales: *1.* 1952 Chilko Lake two-year smolt. *2.* 1954 Chilko Lake 5_3. Showing similar lacustrine growth.

Although two-year-in-lake types are usually clearly distinguishable from one-year-in-lake types it can be demonstrated that identification is not infallible. In 1943 the Chilko River population was composed of a high percentage of 5_3, but these scales did not show a clear cut two-year lake residence growth pattern

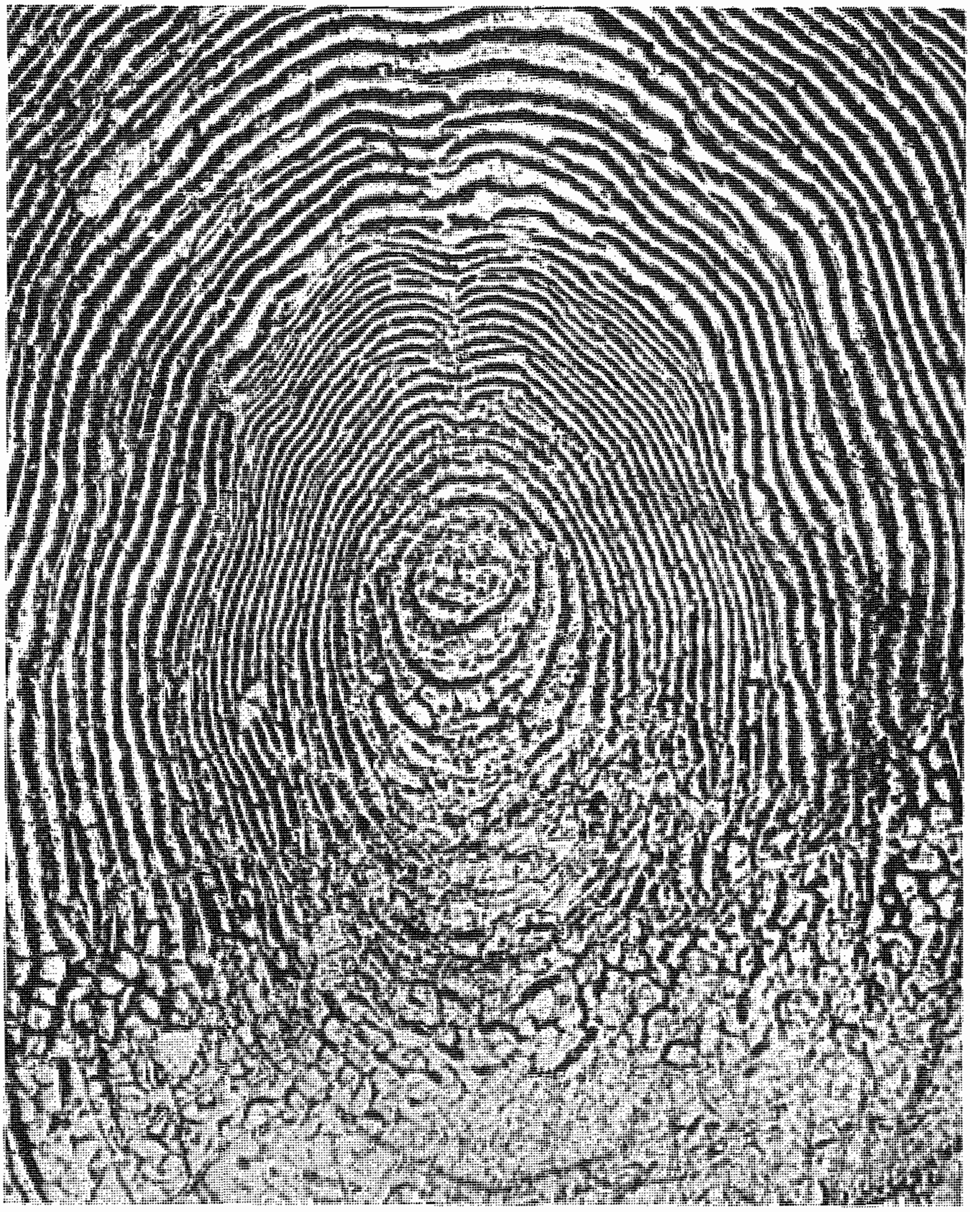

FIGURE 47—Chilko River 5_3 from 1943 spawning run, showing absence of first freshwater winter check.

(FIGURE 47). In 1943 a sample of seventy-six Chilko River scales were taken —seventeen in Hell's Gate tagging samples and fifty-nine in spawning ground samples. The distribution of the total nuclear circulus counts of these fish is bimodal (FIGURE 48). The larger second mode could only have been composed of two-year-in-lake type sockeye, i.e. 5_3. This is unquestionably so because in seventeen years of sampling the one-year-in-lake type Chilko adults, i.e. 4_2, have never had a mean nuclear circulus-count which exceeded 14.8. Thus two-year-in-

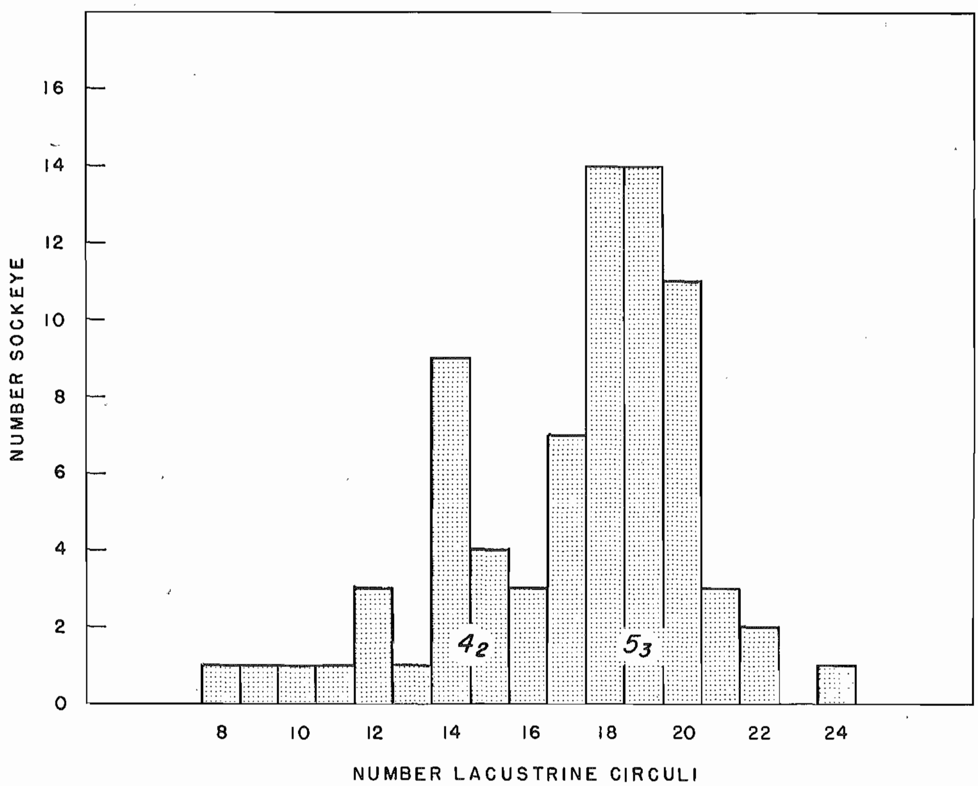

FIGURE 48—Nuclear circulus count of 1943 Chilko adults, showing bimodal distribution; 76 fish in samples.

lake types can always be identified at Chilko River even when the first lacustrine winter check is indistinct. However, the problem becomes much more difficult when 5_3 types are being sought in the mixed run commercial fishery catches. Here there are runs present which have high nuclear ring counts from a single year of growth in the lake, and the scales of these may be largely indistinguishable from the obscure two-year-in-lake types. Fortunately, extensive spawning grounds scale analyses have shown that indistinguishable 5_3 do not often occur.

General circumstantial evidence also shows that scale age determinations are correct. Because of the very marked regularly-recurring oscillations of abundance, adult Fraser River sockeye were thought to be largely four-year-olds even before Gilbert (1913) used scales for age determination. The current cyclic fluctuations in abundance also corroborate the age determinations. The greatest number of 3_2 occur in the year preceding a large run of 4_2. This was illustrated in 1953 when a run of roughly one-half million Adams run 3_2 preceded the 1954 Adams run of about 10 million 4_2. Gilbert (1913) noted the increased abundance of 3_2 in the years preceding the "big years" during the era of high production prior to 1914.

SELECTION OF SCALE SAMPLING LOCATION ON BODY OF FISH

As shown previously there is unequal scale growth on different parts of the bodies of sockeye. This phenomenon has no effect on age determination from scales of different location as long as the periods of rapid and decreased growth form annuli on all scales, and as long as every scale begins its formation during the first year of life. Brown and Bailey (1952), and others, have found trout which had passed their first winter after hatching without scales, but such is not the case with Fraser River sockeye as shown by examination of yearling smolts and corroborated by comparing age of adult scales taken from different positions on the body. Scale selection position is not vital to age determination studies but the more centrally located and first formed scales are the most regular in shape and the easiest to interpret for age.

SCALE ABSORPTION AND ITS EFFECT ON AGE ANALYSIS

During the last few weeks of life, after feeding and body growth ceases, the margins of sockeye scales are progressively absorbed and determination of age at maturity from scales eventually becomes impossible or at best questionable. This is clearly illustrated by successive samplings of adult sockeye of a known spawning stock from the migration path and the spawning grounds. In 1938 Adams River sockeye were tagged and scale samples taken at Sooke traps in Juan de Fuca Strait and at the Sandheads near the mouth of the Fraser River. Samples were also taken from dead spawned fish on the Adams River spawning grounds. The tagged fish are identifiable as Adams River stock because of subsequent recovery on the Adams River spawning grounds. The scales taken at Sooke traps (August 20) are mostly unabsorbed, the scales taken at the mouth of the Fraser (August 27) show moderate absorption and the scales taken from the spawning ground dead (November 3) are deeply absorbed (FIGURE 49). Not all runs of sockeye have scales which are absorbed by the time they reach the mouth of the Fraser. The earlier migrating runs which do not delay off the mouth of the river (see Killick, 1955) do not show scale absorption until they have passed some distance up the Fraser, or in some cases until they reach the spawning beds. Scale absorption varies and may sometimes not make inroads past the last outer sea-growth winter check. However, even though absorption may be light one cannot be certain how much of the original scale remains. Scale absorption takes place on scales all over the body of adult sockeye. The scales of forty sockeye were examined, ten from Adams River, ten from Chilko River and twenty from Cultus Lake. Scales were examined from thirty-six different positions on the bodies of each of the forty fish, and absorption was apparent on each of the scales. Absorption varies among fish, and it is particularly pronounced among males.

Fortunately the scales of no run of sockeye absorb to the extent that the lacustrine growth area of the scale is obliterated, therefore scale absorption does not affect the identification of two-year-in-lake types. The determination of the number of years of sea residence is the greatest problem in examining spawning grounds scales. The 3_2 age group is distinguishable from the 4_2, 5_3, and 5_2 groups on the basis of size alone, and 5_3 can usually be separated from 4_2 and 5_2 because of two-year lacustrine growth. The difference between 4_2 and 5_2 scales is the additional band of sea growth on 5_2 scales. If absorption progresses past this outer band the 5_2 appears as a possible 4_2. As evidence of the possibility of misinterpretation, two samples of 1945 Chilko River adult scales were compared. One sample of scales was taken from dead fish on the spawning ground and the other from live fish at Hell's Gate. The Hell's Gate scales are known to be of Chilko origin because the fish were tagged and later recovered on the Chilko River spawning grounds. The results of attempted identification of 5_2 in these two differentially absorbed scale samples appears below. Even though the scales

	No. Scales in Sample	Number 5_2	Per cent 5_2
Hell's Gate	172	21	12.2
Chilko River	170	2	1.2

were examined by the same observer, the Hell's Gate sample yielded more than ten times as many identifiable 5_2 as the spawning ground sample.

Age Determination from Length Frequencies

In lieu of determining age compositions of spawning stocks from scales, other methods must be sought; one supplementary method is the study of length frequencies. This method makes use of the differences in size which exist between sockeye of different ages. The subject matter of this section includes collection of length data, derivation of sexual dimorphism and conversion factors, and explanation of the basic method.

COLLECTION OF LENGTH DATA

Length data may be collected for both smolts and adults. Measurements are made of some populations of smolts at the time of seaward migration. Smolt length data are not always essential in other than special sampling programs because the smolt scales are not absorbed and can be analysed for age. At Chilko River, downstream migrant enumeration programs are conducted with photographic sampling methods, and here age from length is essential because the age composition is calculated through inspection of periodic sample photographs wherein the two-year migrants are identifiable at sight by their much larger size.

Length data may be collected from commercial catch samples to substitute for scale sampling where length analysis is more efficient, to substantiate length-age determinations on the spawning grounds, and for other purposes such as fishing gear selectivity studies. Length data may also be collected from live fish as they are captured at points on the river migration, as they pass through counting weirs, and as they are captured for tagging in migration or routine enumeration studies. The most usual source of length data for individual unit-stocks is dead spawned fish sampled on spawning grounds.

One or all of three length measurements may be taken from each fish in particular samples; these are fork length, standard length and snout length. The

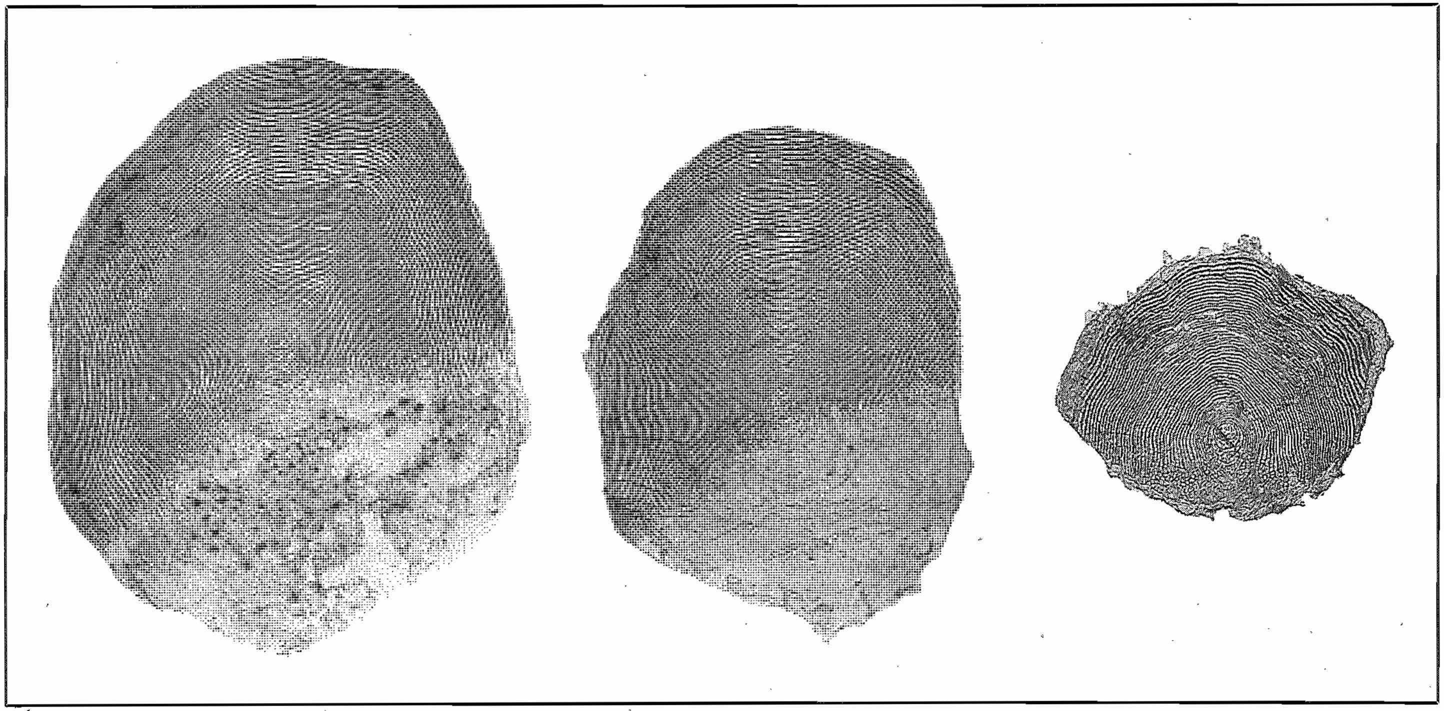

FIGURE 49—Scales from adult sockeye of 1938 Adams River stock sampled at: *1.* Sooke Traps August 20, *2.* Fraser River mouth August 27, *3.* Adams River spawning ground November 3. Showing progressive absorption.

fork length is the distance from the tip of the snout to the fork of the tail as defined by the tips of the median caudal fin rays. The standard length is the distance from the tip of the snout to the posterior extremity of the hypural plate bones of the vertebral column. The position of the end of the hypural plate may be found by cutting away the skin and flesh in the caudal area, or with practice the position can be located externally by touch. The snout length is the distance from the tip of the snout to the anterior external extrimity of the eye socket. The use of three lengths is necessary when comparing fish taken in the commercial fishery with those on the spawning grounds. The fork length is the most convenient, efficient, and accurate measurement to make, but spawning sockeye, especially females, wear away their caudal fins in varying extent so that fork length is meaningless, and standard length must be substituted in spawning grounds sampling. Since the snouts of sockeye, especially, males, increase in development as spawning time approaches it is necessary to adjust for the change between commercial and spawning grounds sampling.

Measurements are made on a plane measuring board with a millimeter scale inset and a head board. The snout length is measured by a small millimeter rule mounted on a hinge on the head board so that it can be laid over the head of the fish. On dead fish all measurements are taken to the nearest millimeter. On live fish fork length only is taken to the nearest centimeter. The need for rapid handling of live fish and the lessened accuracy of millimeter measurement on live fish preclude the use of more accurate measurement. All dead fish measurements of fork or standard length are plotted in centimeter classes, but field measuring to the nearest millimeter eliminates digit bias. Sexes are recorded for all fish measured. In commercial sampling the external sexual differences are not pronounced enough to allow accurate sexing by external observation. The sex of commercial fish is positively established by slitting the body cavity so that the gonads may be identified by sight or touch. Several fish are opened to check by sight until touch identification becomes positive. Among spawning fish males are distinguished from females by external or secondary sex characteristics alone. Males are more deeply red in color usually and have enlarged snouts and dorsal humps.

Adult measurement and sex data are entered in scale books (cf. page 3) in the spaces opposite corresponding scales. In spawning grounds sampling, the data for males and females are placed in separate books to insure that each sex comprises half of the sample and to expedite subsequent analysis. Each sampling book is labelled as to date and place of sampling, condition of the fish (i.e. live or fresh dead), and in the case of commercial samples the place and date of capture and the name of the gear with which the fish had been caught. The sampling books are subsequently numbered and cataloged in the laboratory.

SEXUAL DIMORPHISM AND CONVERSION FACTORS

Within a given age group and a given unit-stock, males and females differ in average length, due partly to difference in overall body length and partly to difference in snout development. Because of this ever-present difference the data on males and females must be analysed separately. Other factors exist which might affect determination of age from length frequencies, such as change in length by time during the run to a given area, differences in length between years and differences in length between areas. Since it is known that for an individual sockeye snout development increases as spawning time approaches it is apparent that these possible changes in length could be the result of snout development alone. It is therefore necessary to study the snout development in all aspects.

Snout length can be expressed as a constant factor for a given sample, in which case the average can be used, or it can be expressed as a fraction of the body length. Since standard length is taken for spawning grounds samples, snout lengths are here compared with standard length. TABLE 41 shows that the mean standard length of males in Adams River in 1950 increased from the first to the second sample and decreased thereafter. The 1950 female sampling was begun a few days earlier by measuring fresh-killed fish from egg taking experiments. The female mean standard lengths increased from the first to the third sample, the greatest mean length coinciding by date with the largest males. The trend of mean lengths of females decreased thereafter, with the last sample increasing slightly over the previous sample. The changes in length were due partly to change in snout length in that the snout lengths of both males and females decreased over the period of sampling. The sample of largest mean standard length was taken about five days before the period of maximum dead recovery, which was about October 25, and dead recovery extended for one week beyond the last sampling period. These changes by time in mean length of snout relative to mean standard length are not of sufficient magnitude to affect the calculation of age composition through length frequencies in one centimeter class intervals.

Samples were taken at Adams River during three periods in 1951 (TABLE 41). The length data exhibited no trends; the central period sample, which was taken about one week before the peak of dying, had the smallest ratio of snout length to standard length.

In comparing snout lengths between years for a given spawning area the changes by period must be considered unless the run is sampled at a comparable time in each year. Samples taken from Adams River about the same dates in 1950, 1951, and 1952 show no significant difference between years in the relationship between snout length and standard length, although the range of variation is greater than that within the run of a single year. Within each sex the snout length is almost a constant fraction of the standard length. Among all samples for all years summarized in TABLE 41 the percentage of the standard length comprised by snout length varies from 11.1 per cent to 12.2 per cent for males, and from 6.7 per cent to 7.7 per cent for females—the greatest error being only 1 per cent, which is negligible in practical age analysis.

Variations in snout length-standard length relationship between spawning areas are greater than those between years within a given spawning area. As shown in TABLE 42 the range of variation of the snout length-standard length ratio is 9.5 per cent to 11.6 per cent for males, and 6.3 per cent to 7.6 per cent

TABLE 41—Relationship between standard length and snout length of adult 4_2 sockeye from Adams River spawning ground.

YEAR AND DATE	MALES						FEMALES					
	No. in Sample	Mean Standard Length mm.	Mean Snout Length mm.	Snout / Standard	Correlation Coefficient r	Regression Coefficient b	No. in Sample	Mean Standard Length mm.	Mean Snout Length mm.	Snout / Standard	Correlation Coefficient r	Regression Coefficient b
1950 Oct. 11							30	553	43	0.077	0.64	4.52
Oct. 16	100	598	71	0.119	0.70	1.95	89	556	42	0.076	0.50	2.02
Oct. 20	91	605	71	0.116	0.44	1.51	99	560	42	0.075	0.39	1.27
Oct. 25	100	601	71	0.118	0.68	1.84	100	556	42	0.075	0.53	2.53
Nov. 2	97	598	69	0.115	0.68	2.01	93	543	39	0.071	0.49	1.86
Nov. 6	114	597	68	0.114	0.64	1.95	99	548	39	0.070	0.32	0.77
1951 Oct. 10, 11	86	622	71	0.114	—	—	243	588	42	0.071	—	—
Oct. 16	82	631	70	0.111	—	—	34	586	39	0.067	—	—
Oct. 22	43	613	74	0.121	—	—	76	573	43	0.076	—	—
1952 Oct. 22	50	636	77	0.122	—	—	162	583	45	0.077	—	—

TABLE 42—Relationship between standard length and snout length of adult 4_2 sockeye from various spawning grounds, 1951.

AREA	MALES				FEMALES			
	No. in Sample	Mean Standard Length, mm.	Mean Snout Length, mm.	Snout / Standard	No. in Sample	Mean Standard Length, mm.	Mean Snout Length, mm.	Snout / Standard
Adams River	211	623	71	0.114	353	584	42	0.072
Chilko River	146	589	64	0.108	165	559	42	0.076
Kynoch Creek	146	580	55	0.095	190	551	35	0.063
Stellako River	302	592	61	0.103	297	565	38	0.067
Weaver Creek	135	631	73	0.116	130	567	37	0.065

TABLE 43—Relationship between standard length and snout length of sockeye of different ages at maturity.

AREA AND YEAR	AGE	MALES				FEMALES			
		No. in Sample	Mean Standard Length, mm.	Mean Snout Length, mm.	Snout / Standard	No. in Sample	Mean Standard Length, mm.	Mean Snout Length, mm.	Snout / Standard
Upper Pitt River 1952	4_2	39	617	85	0.137	21	541	43	0.079
	5_2	240	690	99	0.143	268	612	51	0.083
Chilko River 1951	3_2 & 4_3	46	427	35	0.082	—	—	—	—
	4_2 & 5_3	146	589	64	0.109	165	559	42	0.075

for females; the range for males is 2.1 per cent and for females 1.3 per cent. The mean snout length-standard length relationship is significantly different among the five areas sampled in 1951. Apparently the length of the snout is not wholly dependent on the length of the fish. For example, the mean standard lengths for both males and females are respectively larger at Stellako River than at Chilko River, but the mean snout lengths are smaller. These differences have no particular affect on age analysis through lengths because such analysis is carried out on the fish of given spawning stocks, but the variation may be sufficient to consider in studies such as selectivity analysis.

The final source of snout variation investigated — one which is very pertinent to age analysis from length frequency — is the difference in snout development for fish of different ages. TABLE 43 shows that at Pitt River in 1952, snout development was significantly greater among 5_2 than among 4_2, even when the greater standard length is discounted. The relative development of snouts among jacks (3_2 and 4_3) is less than among the adult (4_2 and 5_3) males, although greater relative to the length of the fish than among females, as exemplified by the 1951 Chilko River sample.

Among all these standard length-snout length correlations and comparisons none of the differences within an area is sufficiently great within one sex and length group to affect age analysis from length frequencies.

Often mean lengths are compared between live and dead samples on the spawning grounds or between commercial samples and spawning ground dead. Since fork length is used for live fish and dead commercially-caught fish and standard length for spawned fish it is necessary to establish the relationship between standard length and fork length. Measurements used to establish this relationship were taken from dead fish. Data were collected from the commercial fishery at times when the catch was known to consist predominantly of particular single stocks (TABLE 44) and from fish killed on the spawning grounds prior to redd digging so that the caudal fins were intact (TABLE 45). All samples show a very close linear correlation, the lowest value of r being 0.92.

Comparison of the regression coefficients for fish taken from the commercial fishery in the Early Stuart period in three of four successive years, 1951, 1952 and 1954, shows no significant difference among the males and only slight differences among the females (TABLE 44. A comparison among cycle-years (four-year cycle) is made using sockeye caught by purse seines in the commercial fishery during the Lower Adams migration period (TABLE 44). Statistically, the 1954 fish were significantly different from 1942 and 1946. In 1954 both males and females had measurements indicating slightly shorter caudal fins compared with the size of their bodies. The existing differences are, however, very small; the ratio of mean standard length to mean fork length varies only from 0.91 to 0.92 in all samples included in both Early Stuart and Lower Adams migration periods.

TABLE 45 shows similar results for spawning grounds samples taken from mature fish just prior to spawning. These samples include fish of various lengths and ages from five different spawning areas. The ratios of mean standard length

TABLE 44—Relationship between standard length and fork length of adult 4_2 sockeye taken from commercial fishery purse seine catches during specific unit-stock migration periods.

MIGRATION PERIOD AND YEAR	MALES						FEMALES					
	No. in Sample	Mean Fork Length mm.	Mean Standard Length mm.	Standard / Fork	Correlation Coefficient r	Regression Coefficient b	No. in Sample	Mean Fork Length mm.	Mean Standard Length mm.	Standard / Fork	Correlation Coefficient r	Regression Coefficient b
Early Stuart												
1951	244	627	573	0.91	0.95	0.95	254	612	559	0.91	0.92	0.94
1952	92	621	567	0.91	0.99	0.88	122	606	553	0.91	0.95	0.85
1954	185	620	568	0.92	0.99	0.92	202	606	554	0.91	0.99	0.92
Lower Adams												
1942	191	634	575	0.91	0.98	0.89	2.08	605	548	0.91	0.97	0.90
1946	197	621	557	0.91	0.99	0.89	204	583	530	0.91	0.99	0.90
1954	210	632	581	0.92	0.995	0.94	363	614	563	0.92	0.99	0.96

Table 45—Relationship between standard length and fork length of mature sockeye taken on spawning grounds just prior to spawning.

AREA AND YEAR	AGE	MALES						FEMALES					
		No. in Sample	Mean Fork Length mm.	Mean Standard Length mm.	Standard / Fork	Correlation Coefficient r	Regression Coefficient b	No. in Sample	Mean Fork Length mm.	Mean Standard Length mm.	Standard / Fork	Correlation Coefficient r	Regression Coefficient b
Adams River 1951	4_2	86	682	622	0.91	0.98	0.98	243	640	582	0.91	0.98	0.93
Birkenhead River 1952	3_2	206	416	383	0.92	0.98	0.92	—	—	—	—	—	—
Gates Creek 1952	4_2	79	650	596	0.92	0.93	0.86	111	596	552	0.93	0.94	0.82
Pitt River 1943	4_2 & 5_2	25	701	647	0.92	0.98	1.00	30	630	582	0.92	0.95	0.90
1952	4_2 & 5_2	86	707	643	0.91	0.98	0.91	95	667	601	0.90	0.95	0.88

to mean fork length varied from 0.90 to 0.93. In making these conversions between fork length and standard length it is only necessary to do so with mean values. The weighted average ratio of means of 0.91 is a sufficiently accurate factor for this purpose.

METHOD OF AGE ANALYSIS

The length of a sockeye at spawning is primarily dependent upon the number of years which it has lived in the sea. Within any given spawning population in one year, sockeye of common age and concurrent sea residence have a length frequency curve which approximates a normal curve. Where more than one sea growth group is present the curve exhibits as many modes as there are groups. The distance between such modes decreases as the ages of the contiguous groups being compared increase.

Certain age groups are easily distinguishable from others on the basis of length alone. Jack sockeye, the small 3_2 and 4_3 age groups, mostly males, are normally separated from the larger 4_2, 5_3, and 5_2 age groups in this manner for convenience, even though unabsorbed scales may be available. As evidence of the accuracy of this method the length frequency of a sample of mixed-run commercial sockeye is presented (FIGURE 50). In 1953, at a time when there was a particularly heavy run of jacks (mostly 3_2), a purse seine sample was taken and separated into jacks and adults on the basis of length frequency. The dividing line was, by inspection, set between 51 and 52 centimeters. After segregation a scale was taken from each fish. Upon aging the scales it was found that the jack group included one 4_2 and the adult group included one jack. Thus there were two fish among 341, or 0.6 per cent, which were erroneously assigned. In this example the errors cancel each other so that there is no error in the final estimated percentage of jacks and adults. The dividing line between length groups must be established separately for each sample analysed because of variation in length of jacks and adults from year to year and population to population.

Two-year-in-lake type sockeye, i.e. 4_3 and 5_3, can be distinguished from 3_2, 4_2 and 5_2 by scale analysis even in spawning grounds samples because scale absorption never extends to the fresh water growth zone. The 4_3, being jacks of the 5_3 runs, are much smaller than the 5_3 and are easily distinguished in the manner described above. Thus, except for 4_2 and 5_2, each age group is readily distinguishable from the others.

To determine the relative abundance of 4_2 and 5_2 in mixed samples of these age groups from a length frequency distribution two curves are drawn by eye such that their peaks correspond with the modes of the length curve or histogram and their combined areas equal that of the entire curve or histogram. Thus the area under each of the two approximately-normal fitted curves is proportional to the abundance of the age group of corresponding mean length. Histograms of length by age, determined from scale analysis, and sex have been presented in FIGURE 44 in the section on age analysis from scales. FIGURE 44 illustrates the overlapping of length frequencies of 4_2 and 5_2 from mixed stocks sampled in the commercial fishery.

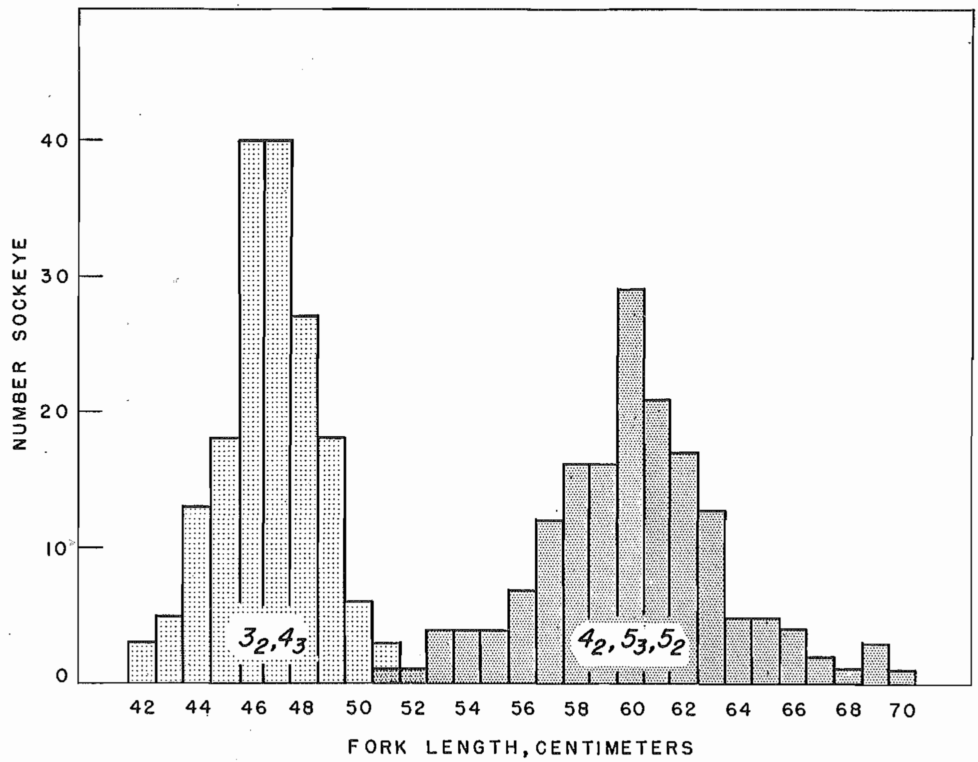

FIGURE 50—Length frequency of random sample purse seine catch, Point Roberts, Aug. 12, 1953. Showing difference in length between jacks and adults; 341 fish in samples.

In order to study length by age from scales of a complex age population of known pure unit-stock test fishing was conducted in Lower Pitt River in 1952. The fish taken were newly-arrived and would delay and not spawn until about one month later in Upper Pitt River. Since these fish were still very green the scales were unabsorbed and the ages easily discernable. The length distributions of this sample is shown in FIGURE 51 according to age as determined from scales. There is some overlapping in length between the 4_2 and 5_2 but the 5_2 are on the average larger for each sex.

In an attempt to improve on the method of assigning age proportions log-normal (probability) graph paper was employed following the method of Cassie (1954), which is an elaboration of the method initiated by Harding (1949). Since this method also depends ultimately on visual judgment the results seemed to be but little more accurate than fitting curves by eye, and much more time consuming.

Age Determination from Otoliths

A second supplementary method of determining age composition of spawning stocks is otholith examination. Among other bony structures in the bodies of fishes the otoliths, or ear bones, give evidence of seasonal changes in the fishes' environment through which the age can be determined. Apparently all bony structures in the bodies of sockeye are absorbed somewhat as spawning time and death

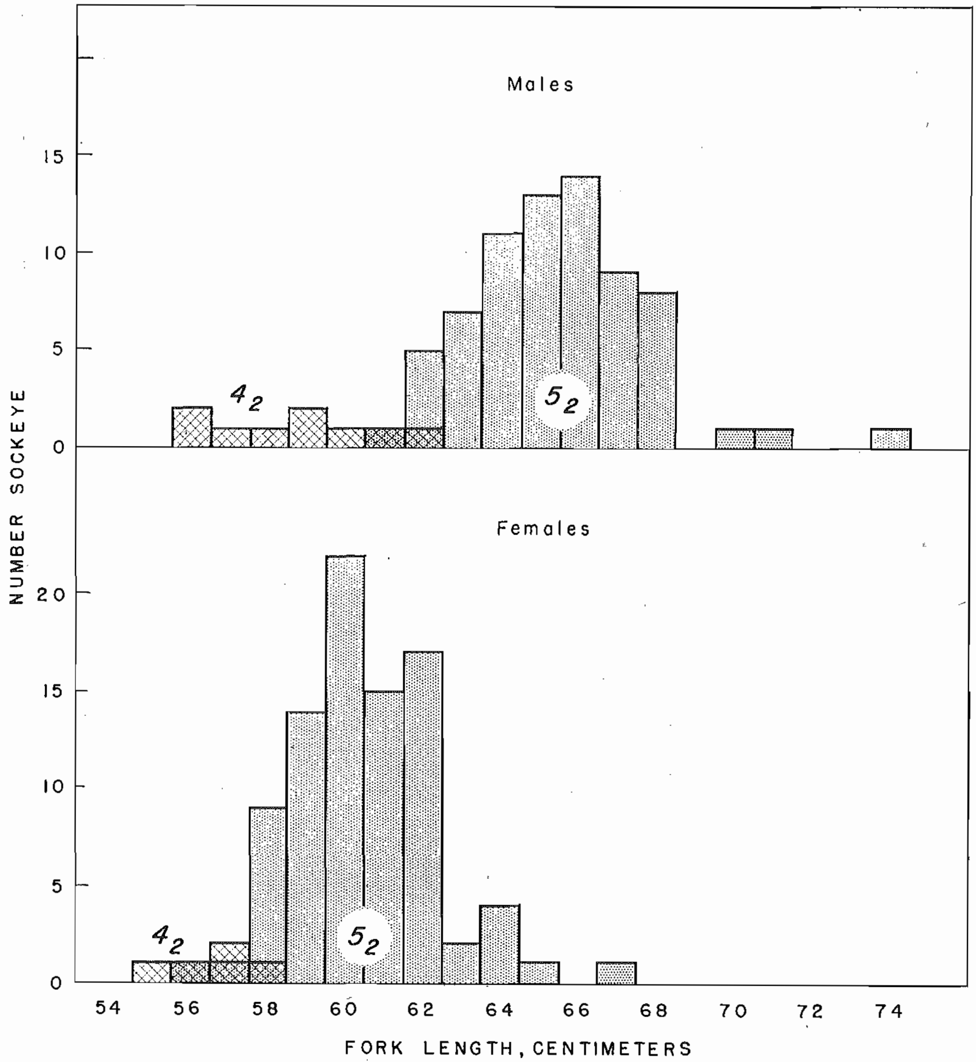

FIGURE 51—Comparison of length frequencies of 1952 Pitt River 4_2 and 5_2 sockeye aged from scales; 172 fish in samples.

approaches; the otoliths are not absorbed to the extent that the scales are and are usually virtually intact.

COLLECTION AND EXAMINATION OF OTOLITHS

Dissections have shown that otoliths are present in sockeye at least as early as the advanced fry stage, and they are probably present from the earliest stages of bone development. They remain throughout the life and death of the animal. The otoliths—there are two, mirror images of each other—which are removed for examination are actually only one of three types which are present in the ear structure of the sockeye. Those sought are by far the largest (in a 4_2 sockeye about 6 centimeters on the long axis) and most easily found of the three types and are called sagittae. Each sagittus is fairly flat, disc-like, slightly irregular in shape and has ring-like bands in its structure. Each is contained in a fluid-filled sacculus. These otoliths lie close together on either side of the vertical midline of the head in the cranial cavity just beneath the posterior part of the brain. The otolith or otoliths may be removed by cutting the fish's head along the vertical midline and removing the sacculus and enclosed otolith with fine-tipped curved forceps. The sacculus is removed and discarded at this time so that it will not dry on the otolith and interfere with subsequent examination.

The otoliths may be placed without liquid medium in scale books or coin envelopes, or they may be placed in glycerin or some other medium in small vials. The current practice of the Commission is to place the otoliths in the scale books (see page 3) along with the corresponding scales and adjacent to the corresponding recorded length and sex data. (Otolith sampling does not obviate scale sampling because scales are used for lacustrine growth study.) This collection method has the disadvantage of forcing the otoliths rather tightly into compartments where they are subject to considerable breakage upon drying if the scale books are mishandled. The advantages of this system are great in that it is not necessary for the field observers, who work under a great variety of conditions, to place scales and recorded data in scale books and then turn to another collecting device for otoliths. The scale book method insures that the otoliths are not mixed or disassociated with the corresponding scales and recorded data.

Upon being received in the laboratory the otoliths are removed from the scale books at the time the scales are removed for mounting; the scale, otolith, and recorded data all receive a common index number. The otoliths are then placed dry in special scale books in which photograph corners have been affixed and numbered.

The otoliths are not placed in any liquid medium until they are examined. Various authors recommend storing in such media as tri-sodium phosphate, xylol, glycerine, etc., but there seems to be no universally accepted medium. For simplicity, and because no positively better method has been found, all otoliths are stored dry at room temperature. One sample of otoliths which had been stored dry in a scale book for eight years was found to have mostly interpretable otoliths.

Sockeye otoliths require no grinding or polishing prior to examination, as is apparently desirable for certain marine species. They are examined by being placed in water in syracuse watch glasses painted black on the outside surfaces. The watch glass and otolith are placed on the stage of a low power binocular dissecting microscope and illuminated by concentrated reflected light rather than transmitted light. Examination is done at a magnification of about fifteen diameters; greater magnification is of no advantage and is sometimes a detriment.

VALIDATION OF OTOLITH AGE INTERPRETATION

Sockeye otoliths have alternating zones of translucent and opaque material which are more or less concentric. The center of each otolith is translucent and apparently an additional translucent zone is formed during seasonal periods which include the spring months; one such zone is formed every year. Thus the age of a sockeye otolith is disclosed by the number of translucent zones.

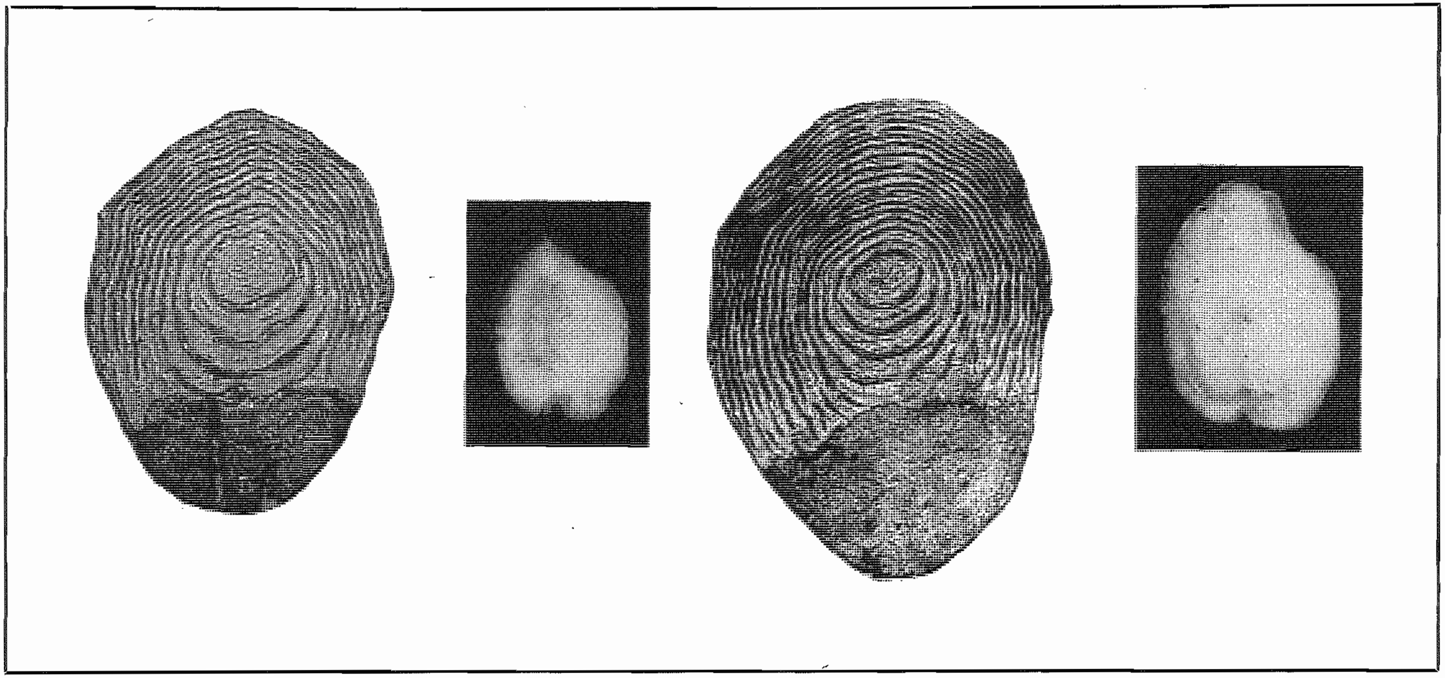

FIGURE 52—Photomicrographs of sockeye otoliths (saggitae) and corresponding scales: *1.* One-year-old smolt, *2.* Two-year-old smolt.

Yearling smolts have two such translucent zones with an intervening opaque zone (FIGURE 52). The translucent zone appears dark and the opaque zone appears white in reflected light. Two year smolts have three translucent zones and two opaque zones (FIGURE 52). The next age group from which otoliths have been taken are 3_2 which appear during the summer and autumn as spawning migrants. These fish have formed one additional translucent zone, one complete opaque zone and one partial opaque zone (FIGURE 53). The partial opaque zone is apparently formed in the last summer of the fish's life just prior to emigration from the sea. Neither the translucent zone nor the opaque zone is strictly comparable with the winter check zone of the scale; the winter check of the scale may not be formed precisely during the calendar winter but it is formed sometime between autumn and spring in sockeye. According to Fitch (1951) the opaque zones of Pacific mackerel otoliths are composed of the same basic material as the translucent zones except that they are heavily impregnated with organic matter during the summer period of rapid growth. In sockeye the scales seem to more nearly reflect the growing periods than otoliths. The opaque zones of sockeye otoliths appear during the summer and apparently continue to be formed well into the winter period. Thus the otolith growth zone development seems to lag the scale growth zone development by several weeks or even months.

A typical 4_2 sockeye otolith, as shown in FIGURE 54, has one more translucent zone than the 3_2 and the incomplete outer opaque zone of the 3_2 is of course completed in the 4_2. However, the new growth of the last summer period just prior to spawning migration may be only slightly represented as an incomplete opaque zone or it may not be present at all. The 5_3 otolith (FIGURE 55) is exactly the same

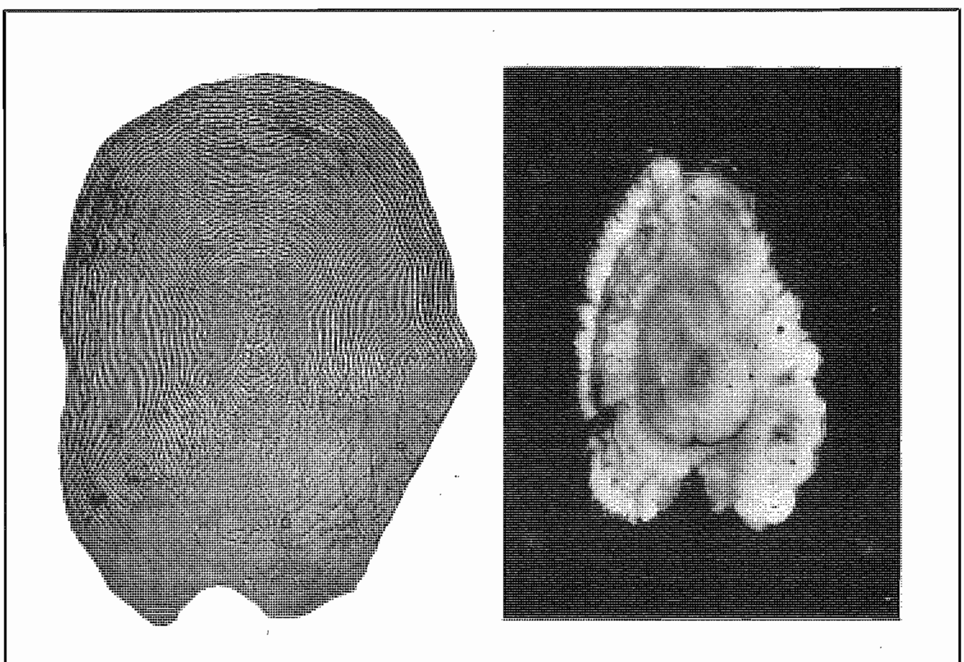

FIGURE 53—Photomicrograph of 3_2 sockeye otolith and corresponding scale.

as the 4_2 in sea growth formation but one additional year of fresh water growth is recorded on the inner portion.

The 5_2, which have one additional year of sea residence, have one more translucent zone than the 4_2, but none of the many thus far examined have any semblance of a final opaque summer zone (FIGURE 56). This same general condition is true for scale growth in that the amount of scale growth, in radius, during the last summer just prior to spawning migration becomes ever more restricted as the number of years of sea growth increases.

The correctness of otolith age interpretation is attested to by length frequency analyses as well as by individual comparisons with scales. The length frequency distribution appearing in FIGURE 57 is exemplary of this. The Birkenhead River population is composed of a complex of age groups. Both one-year and two-year lake types are present; these two general types can be segregated through scale analysis because scale absorption does not extend to the nuclear areas of the scales. Among the Birkenhead River males there are six different groups. After the 4_3 and 5_3 are segregated four groups remain. Otolith examination reveals that two of these groups fall within the 4_2 classification and the remaining two are 3_2 and 5_2. FIGURE 57 shows that the 3_2, as aged by otoliths, are much smaller than any of the others and the 5_2 are on the average larger than the group of larger 4_2. The group of larger 4_2 are comparable in size with 4_2 from other spawning areas, but there is no group of 4_2 elsewhere which is clearly equivalent to the smaller Birkenhead male 4_2. This group of smaller 4_2 males has one characteristic in common with 3_2 jacks in that there are no females of corresponding size.

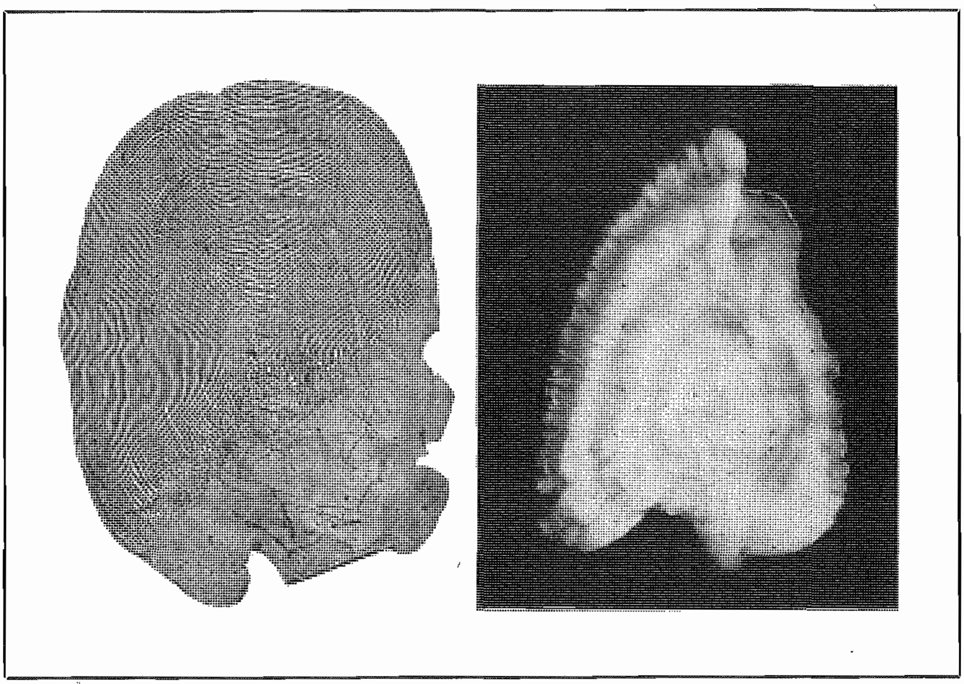

FIGURE 54—Photomicrograph of 4_2 sockeye otolith and corresponding scale.

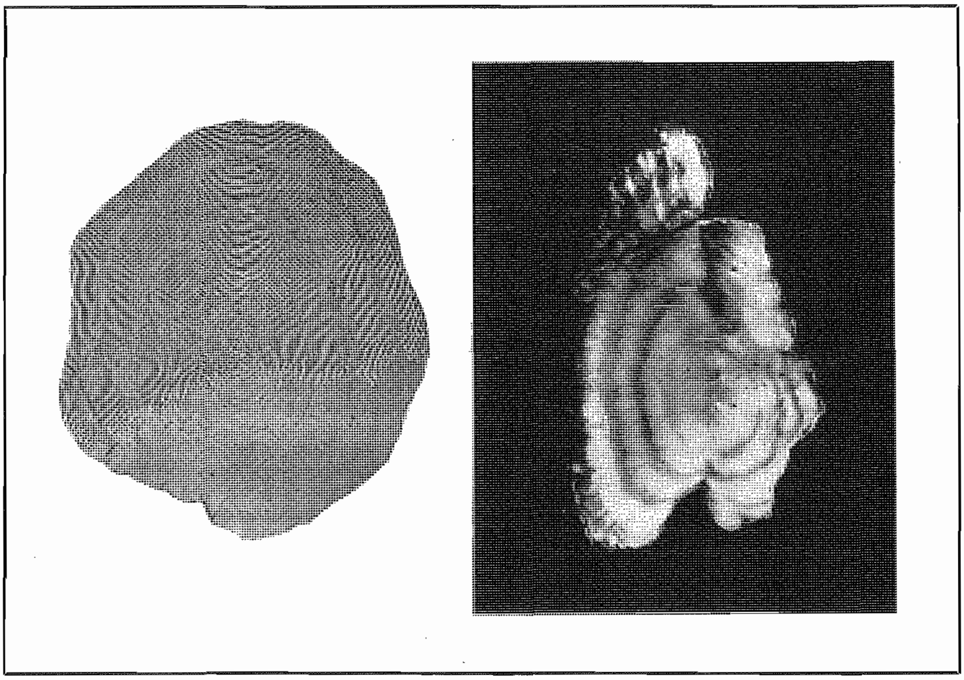

FIGURE 55—Photomicrograph of 5_3 sockeye otolith and corresponding scale.

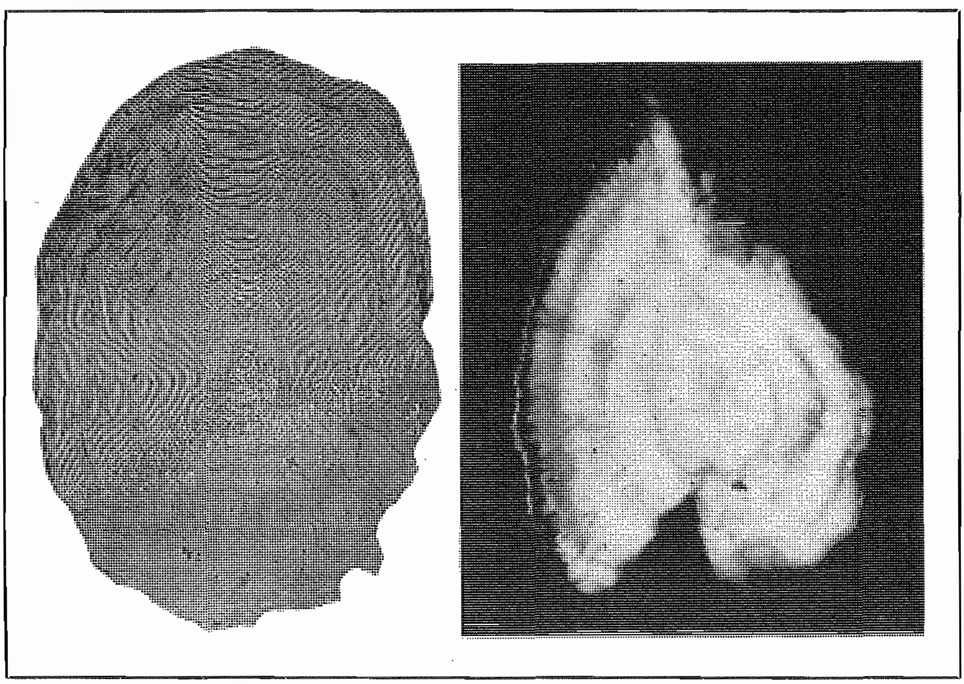

FIGURE 56—Photomicrograph of 5_2 sockeye otolith and corresponding scale.

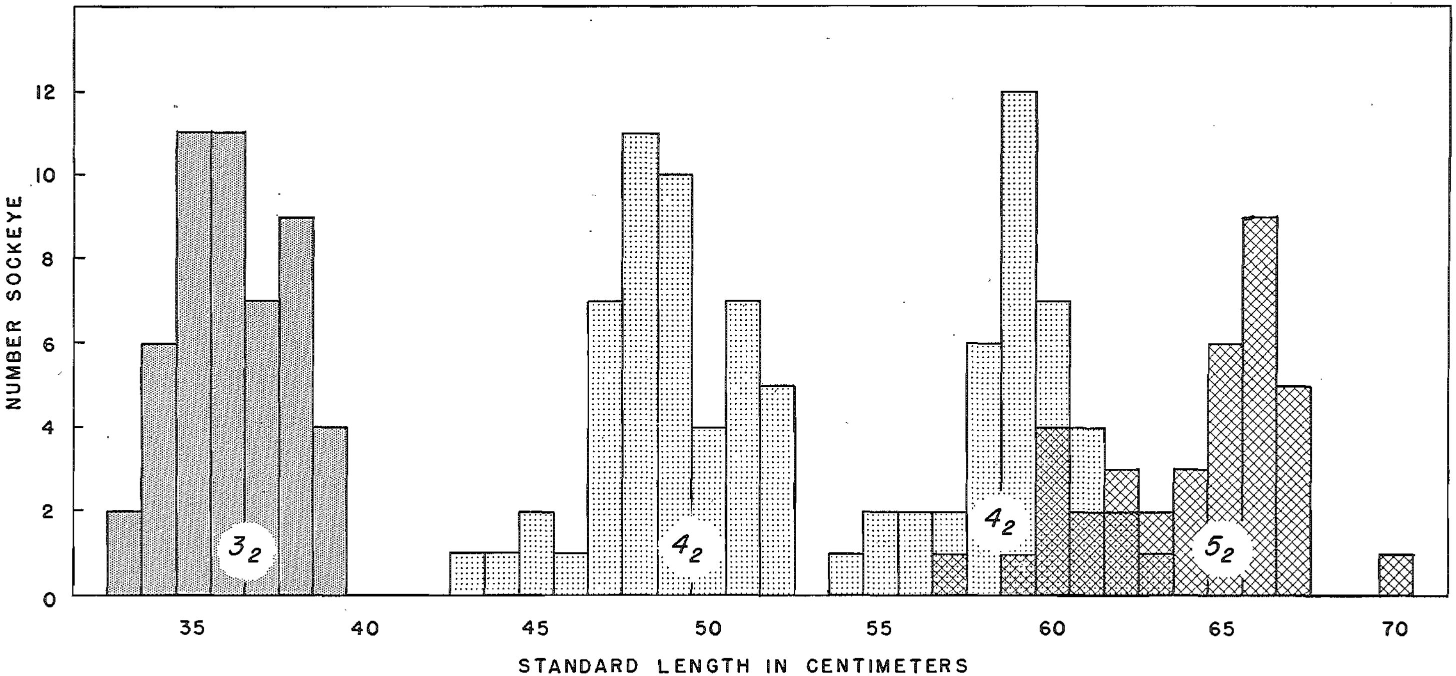

FIGURE 57—Length frequencies by age group, as determined from otoliths. 1956 Birkenhead River fresh dead male spawners; 175 fish in samples.

Variations in otolith growth patterns sometimes appear among sockeye of the same age group and can be perplexing to one who has had little experience in otolith examination and can even be difficult for an experienced observer to interpret if the alternating translucent and opaque bands are not clear-cut. Almost all otoliths with clearly distinguishable growth bands can be correctly aged by an experienced observer.

Sockeye otolith examination may be made in lieu of scale analysis when absorption renders scale-age interpretation questionable. Some otolith absorption also occurs, but it is not sufficient to invalidate age determination. Jacks (3_2 and 4_3) are usually easily separated from adults (4_2, 5_3, 5_2) by the extreme difference in body size; and two-year-in-lake types (4_3, 5_3) can be distinguished from one-year-in-lake types (3_2, 4_2, 5_2) from scales, even though they may be absorbed. Therefore for most populations only 4_2 and 5_2 need be distinguished by otoliths. This can be accomplished by an experienced observer most of the time. Due to breakage in sampling and transport, and the presence of unreadable otoliths, rather large initial samples of otoliths are necessary to determine age composition accurately. For this reason otolith age determination is sometimes more laborious than length frequency age determination and need not therefore be used in all routine spawning grounds age studies.

Design of Sampling Procedures for Age Composition Study

Regardless of which method of age determination is used, sampling procedures must ensure reasonably representative results. Possible temporal and spacial variability must be recognized and accounted for, and samples must be sufficiently large to keep sampling error within desired limits. In this section the effect of size selectivity is discussed, and examples of variability of age composition by time, between sexes, between years and areas are presented. The section ends with a discussion of the problem of determining sample size. These factors are common to all phases of the problem of determining age composition.

EFFECT OF SIZE SELECTIVITY

Age composition is determined for daily commercial fishery catches and for spawning populations. Both analyses contribute to calculating the total population size by age group for each major unit-stock, on which survival studies, population dynamics, and prediction indices are based.

Calculation of the age composition of the entire adult population of a unit-stock is possible from spawning ground sampling alone only when the various age groups retain the same relative numbers as in the unfished population prior to its passage through the commercial fishery. The assumption that the relative age composition of the spawning fish is the same as that of the original total population is not necessarily valid.

Maturing Fraser River sockeye are of essentially three size groups. The categories are determined by the number of years of sea residence because sea growth has much more effect on final size than lacustrine growth. The smallest group, ranging from about 35 centimeters to 55 centimeters (14 inches to 22 inches) fork length, usually referred to as jacks, is composed of 3_2 and 4_3 age groups. These age groups have on the average about sixteen months of concurrent sea residence, the 4_3 are slightly larger than the 3_2 (TABLES 40 and 46). The intermediate group is composed of 4_2 and 5_3 of similar length at maturity, ranging from about 50 centimeters to 70 centimeters (20 inches to 28 inches) fork length. Both reside in the sea concurrently for a period of about twenty-eight months, the 5_3 may be about the same average size as the 4_2 or slightly larger, depending on the unit-stock (TABLE 46). The largest group, about 60 centimeters to 80 centimeters (24 inches to 31 inches) fork length, is predominantly represented only by 5_2, 6_3 Fraser River sockeye being rare; this size group spends about forty months in the sea.

TABLE 46—Comparison of mean lengths[1] of 3_2 with 4_3 and 4_2 with 5_3; Chilko River and Birkenhead River spawning ground populations.

AREA AND YEAR	AGE	MALES		FEMALES	
		Number in Sample	Mean Length, mm.	Number in Sample	Mean Length, mm.
Chilko River 1951	3_2	407	476	—	—
	4_3	44	489	—	—
Birkenhead River 1954	4_2	156	608[2]	279	552
	5_3	15	629	39	568
Chilko River 1954	4_2	544	564	626	547
	5_3	138	573	111	546

[1] 3_2 and 4_3 are fork lengths; 4_2 and 5_3 are standard lengths.
[2] Representing only the larger size group of male 4_2 (see FIGURE 57).

These age groups of differing average length are taken in the commercial fishery by four different types of fishing gear: purse seines, gill nets, reef nets, and traps. These different types of gear do not all catch every size of fish in equal proportions. Gill nets are more selective of certain sizes of fish than the other types of gear.

Because of the great difference in size of jacks (3_2 and 4_3) compared with the larger fish size selectivity is most pronounced among jacks. Daily sampling of commercially caught sockeye reveals a great disparity in the relative numbers of jacks taken by the various types of gear. In 1953 there was a large run of 3_2, most of which were destined for Adams River. An example of the differences in relative numbers of jacks taken by the different types of fishing gear in a restricted fishing area on a single day is presented by the San Juan Islands catch in United States waters on August 11, 1953:

	No. Sampled	No. Jacks	Per cent Jacks
Gill nets	343	1	0.3
Reef nets	259	96	37.1
Purse seines	866	405	46.7

The disparity between the different types of gear may not necessarily always be this great but such possibility exists; for example, it must not be proposed that reef nets will always take only four-fifths as many jacks as purse seines but in this particular sample this was the case. The highest percentage of jacks taken by the San Juan Islands purse seines during the 1953 season was 75 per cent on August 20. The remaining fish of the same group moved into the area off the mouth of the Fraser where they subsequently became available to the Canadian gill netters operating in that area. The highest percentage of jacks taken by the Fraser River gill net fleet was 28 per cent on September 4. This much lower relative jack catch was made with about 95 per cent of the fleet using nylon nets, according to Canada Department of Fisheries findings, and nylon nets tend to take a wider range of sizes of fish than linen nets. Also this lower percentage was taken in spite of an increased actual proportion of jacks resulting from prior selectivity in the United States gill net fishery. The effect of such selectivity is very marked where gill nets take a larger part of the overall catch.

Gill nets are selective of jacks on the basis of size as shown by a comparison of length frequencies of fish taken by the two types of gear (FIGURE 58). The average length of the jacks taken in gill nets was larger than that of purse seines. The purse seine sample was taken at Point Roberts in United States waters on August 12 and the gill net sample from the area near the Fraser River mouth on August 25 to 28, but the same stocks of fish were involved because of the propensity of this particular group to delay for some time off the mouth of the Fraser. Some of the increase in length between the two samples may be attributed to continuing maturational snout development but this was insufficient to be responsible for the marked difference in average length. The average lengths of the gill net and purse seine samples cannot be compared directly because all jacks of length greater than 50 centimeters were arbitrarily excluded from the gill net sample.

Even though purse seines are normally considered to be non-selective of sockeye because of the small mesh size of the nets there may be disproportionate selectivity of particular unit-stock populations of jacks. As shown in FIGURE 59 the 1951 Chilko River spawning ground 3_2 were of greater length than the 1951 Birkenhead River 3_2, and the same relationship is evident for the respective 4_3 populations. This difference in length is apparently partly natural and partly artificial. Daily samples of purse seine-caught fish were sampled in the United States fishery throughout the period of migration of these two stocks. Relative to the magnitude of the spawning ground population the Birkenhead jacks were much less abundant than the Chilko stock in the purse seine catches. Also the very small sizes of Birkenhead jacks were very rare in the purse seine samples. Close observation of pure purse seine samples showed that some net marked fish were present even among the size group of jacks which were actually caught, thereby indicating that at least some of the smaller sizes could have passed through the purse seine web thus contributing to the disparity in apparent age composition between the two stocks.

Selectivity of certain age groups in commercial catches is not restricted to the jack group only. Peterson (1954) amply illustrated that linen gill nets are selective

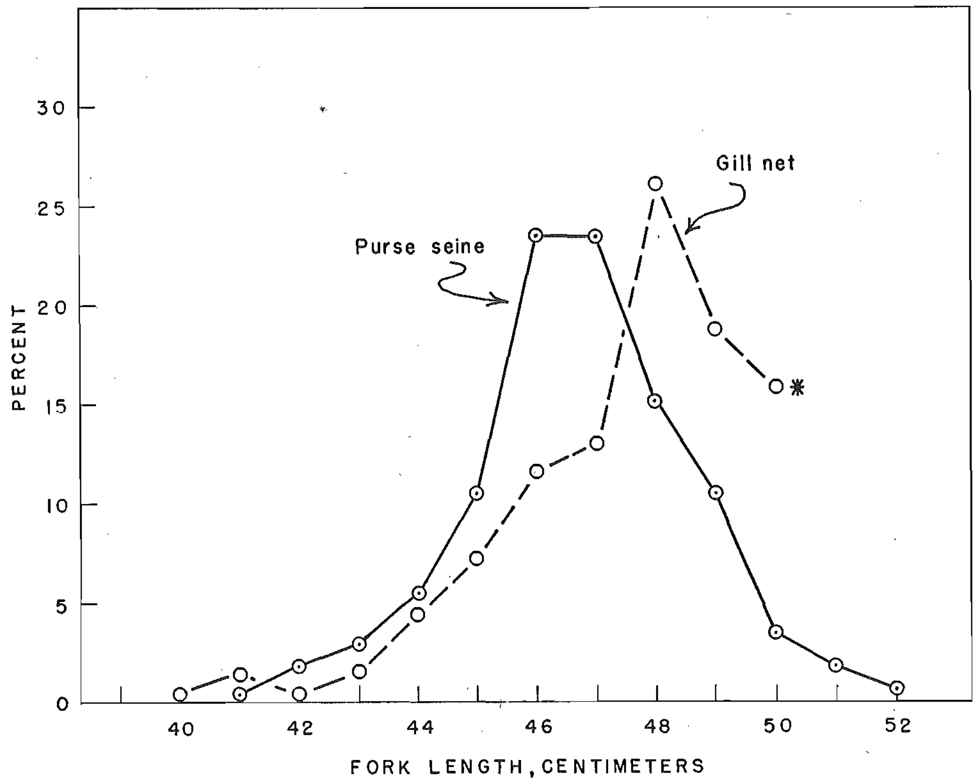

FIGURE 58—Comparison between purse seines and gill nets of fork length of 3_2 sockeye taken in commercial fishery, 1953; 240 fish in samples.
* No gill net fish larger than 50 centimeters measured.

for larger fish and therefore selective for males over females and 5_2 over 4_2 age groups. Currently most of the gill nets used in the fishery for Fraser River sockeye are constructed of nylon web. Since nylon nets have different elasticity from linen nets they cannot necessarily be expected to be selective in exactly the same degree. To find evidence of possible selectivity several paired samples of purse seine and gill net fish caught during the same twenty-four hour period were taken from 1956 commercial fishery catches. Purse seines are assumed to be non-selective of any fish in the adult size range. The results of this sampling from two areas are shown in TABLE 47. Each of the Point Roberts samples represents a catch taken the first fishing day of the week, each following a three day closure. The San Juan Islands samples were taken from catches of various weekdays. Among the total of seven pairs of samples the weighted mean percentage 5_2 is 13.8 per cent for purse seines and 15.8 per cent for nylon gill nets. For all samples the unweighted percentage 5_2 is 14.5 per cent for purse seines and 15.6 per cent for gill nets. For the Point Roberts samples alone the weighted percentage 5_2 is 15.0 per cent for purse seines and 18.2 per cent for gill nets, and the unweighted percentage is 16.3 per cent for purse seines and 18.1 per cent for gill nets. For the San Juan Islands samples alone the weighted percentage 5_2 is 13.0 per cent for purse seines and 13.4 per cent for gill nets, and the unweighted percentage is 13.2 per cent for purse seines and 13.8

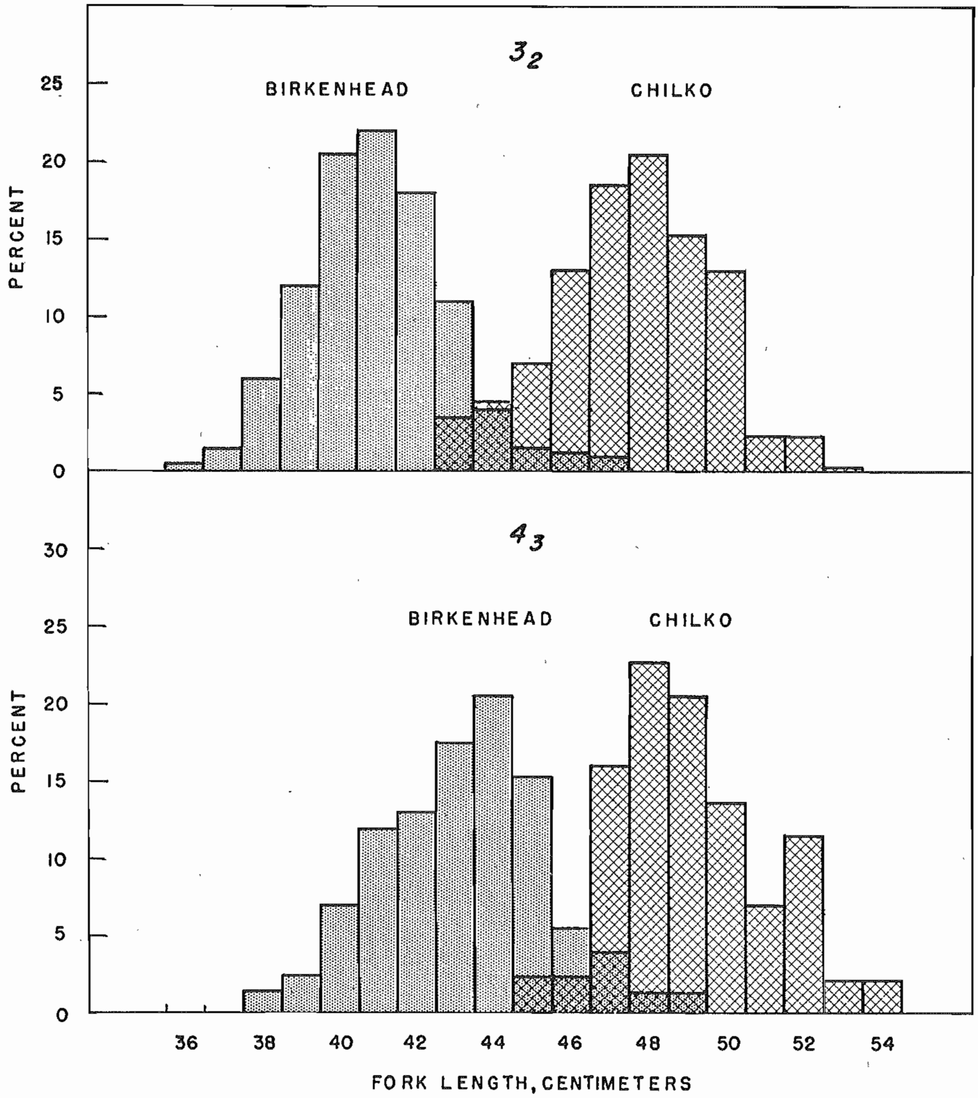

FIGURE 59—Comparison of lengths of 3_2 and 4_3 sockeye from Birkenhead River and Chilko River spawning grounds, 1951; 1,317 fish in samples.

per cent for gill nets. In all of these comparisons the percentage 5_2 is, on the average, slightly higher among gill net catches. Considering the amount of apparently random variation between samples average differences of this magnitude are not important to sampling for age composition of 5_2. Thus it must be concluded that the examples of TABLE 47 show no significant or consistent difference in 5_2 age composition between purse seines and nylon gill nets.

Live sockeye are often caught on spawning grounds for tagging in routine population enumeration programs, and scale, fork length and sex samples procured at the time of tagging. Net selectivity for certain age groups has been shown to be possible in commercial catches, therefore it would appear possible

TABLE 47—Comparison of relative numbers of 5_2 sockeye between concurrent purse seine and nylon gill net catches in 1956.

FISHING AREA	DATE	PURSE SEINES			GILL NETS		
		Number Adults	Number 5_2	Per Cent 5_2	Number Adults	Number 5_2	Per Cent 5_2
Point Roberts	July 23	249	62	24.9	469	134	28.6
	July 30	399	45	11.3	480	78	16.3
	August 6	436	56	12.8	439	41	9.3
San Juan Islands	July 16	198	35	17.7	196	32	16.3
	July 25, 26	546	102	18.7	400	78	19.5
	August 2	417	41	9.8	394	34	8.6
	August 7	415	27	6.5	413	44	10.7
Total		2660	368	13.8	2791	441	15.8

that nets or other devices used to capture fish for tagging may be selective. Direct comparison of tagging and dead recovery samples show discrepancies but it is difficult to assign the error specifically to one sample or the other unless the differences, if any, in availability of dead carcasses is known and whether both tagging and dead samples are taken continuously through the run and in proportion to the total numbers present at the time the samples were taken. Schaefer (1951) indicated that at Birkenhead River in 1940 the trap used to collect fish for tagging did not catch jacks (3_2 and 4_3). Jacks have been tagged at Birkenhead River in recent years; when the numbers of jacks, the number of 4 and 5 year males, and the number of 4 and 5 year females are calculated from the tag recoveries as three separate populations there is disagreement between the calculated percentages of each in the total population and the percentages taken during tagging (TABLE 48). The percentage of females in the tagging samples was always slightly lower than the population percentage, and the percentage of jacks in the tagging samples varied from 23 per cent too high in 1951 to 24 per cent too low in 1954. At Adams River in 1952 the percentage of females tagged was too low. The fish caught for tagging summarized in TABLE 48 were taken with 3 inch mesh (stretched measure) beach seines. Males are apparently more easily captured than females because they are less active and have extensively developed snouts and teeth which entangle in the net web. Where selectivity during tagging is such that the sexes are not evenly represented it is unlikely that the age composition of the tagging samples gives a true indication of percentage in the total spawning ground population.

Differences in age composition between catches of different types of fishing gear have no detrimental effect on calculating the age compositions of the total unit-stock populations provided both commercial fishery catches and spawning grounds populations are sampled in a representative manner. Representative sampling of these populations requires that the catch of each markedly different type of gear

Table 48—Relative numbers of adult males, adult females, and jack in spawning ground tagging samples compared with relative numbers in total spawning ground populations.

AREA AND YEAR	NUMBER TAGGED FISH	PROPORTION IN EACH GROUP			NUMBER IN POPULATION	PROPORTION IN EACH GROUP		
		Per cent Adult Males	Per cent Adult Females	Per cent Jacks		Per cent Adult Males	Per cent Adult Females	Per cent Jacks
Birkenhead River								
1951	895	14.1	12.1	73.8	35,861	20.6	29.0	50.4
1952	2,897	35.8	20.2	44.0	79,082	23.7	37.1	39.2
1953	2,977	43.9	36.6	19.5	53,111	33.6	42.3	24.1
1954	1,752	45.8	23.1	31.1	41,201	20.8	24.1	55.1
1955	1,505	43.1	31.4	25.5	25,355	24.3	35.2	40.5
Adams River								
1952	600	39.0	28.0	33.0	8,692	27.3	43.2	29.5

be sampled independently and that live spawning grounds samples are not taken with some selective type of catching device or that dead fish sampling is actually representative of the total spawning population.

AVAILABILITY OF AGE GROUPS IN DEAD FISH SAMPLES ON SPAWNING GROUNDS

Samples of fresh dead fish may be taken at random during dead recovery for enumeration; the dead recovery period in Fraser River enumeration programs usually covers almost the entire period of dying. No catching gear selectivity is involved in taking dead fish samples on spawning grounds and for this reason one might expect that the daily dead fish samples would be representative of the segment of the population dying at that time. This assumption is not always valid, there are in some cases differences in availability of carcasses of different sex and age group.

Peterson (1954) has shown that for Stellako River and Birkenhead River samples from five different years in each case showed females to be more available than males; whereas for nine other areas sampled there was no consistent significant difference between sexes. Analysis of recovery rates from three additional Fraser River spawning areas over a period of four years is shown in TABLE 49. These data are compiled from routine spawning ground enumeration tagging records. Tags

TABLE 49—Availability of dead adult sockeye between sexes as indicated by relative numbers of tagged fish recovered.

AREA AND YEAR	MALES		FEMALES	
	Number Tagged	Per cent Recovered	Number Tagged	Per cent Recovered
Harrison River				
1952	162	11.1	239	13.8
1953	136	2.9	110	5.5
1954	201	3.5	99	7.1
1955	143	10.5	157	35.7
Upper Pitt River				
1952	504	25.8	453	29.4
1953	265	35.5	224	33.0
1954	163	8.0	182	14.8
1955	244	26.6	309	21.4
Weaver Creek				
1952	176	75.6	224	74.6
1953	215	51.6	229	55.9
1954	333	47.2	251	57.0
1955	337	11.9	259	12.4

are placed on live fish before spawning and recovered from carcasses after spawning has been completed; the percentage recovery of tags from any given area depends on the amount of effort expended in recovery and the length, depth, shore contour and velocity of the stream. Under the best conditions it is possible to recover 75 per cent, but most recovery rates vary between 20 per cent and 50 per cent.

For Harrison River the recovery rate was always higher for females. The Upper Pitt River tag recoveries varied, two of the samples showed females to be more available and two showed males to be more available. At Weaver Creek three of four samples showed females to be more available. TABLE 49 shows that the recovery rate by sex is not entirely a function of the size of spawning stream

TABLE 50—Availability of dead adult male, adult female and jack sockeye from various areas as indicated by relative numbers of tagged fish recovered.

AREA AND YEAR		ADULT MALES		ADULT FEMALES		JACKS	
		Number Tagged	Per cent Recovered	Number Tagged	Per cent Recovered	Number Tagged	Per cent Recovered
Adams River	1952	234	15.0	168	19.1	198	9.6
Birkenhead R.	1953	1306	21.1	1091	22.5	580	12.2
Chilko R.	1951	905	30.7	819	38.0	848	32.7
Forfar Cr.	1952	581	73.7	649	66.9	102	73.5
Weaver Cr.	1953	215	51.6	229	55.9	42	33.3

because both Upper Pitt and Harrison Rivers are large, whereas Weaver Creek is very small.

Schaefer (1951) has shown from tag recoveries that jacks are less available than adults at Birkenhead River. This raises the question of whether the other spawning grounds exhibit this or whether the same situation exists every year at Birkenhead River. TABLE 50 shows the tag recovery rates for adult males, adult females, and jacks (almost all males) from five widely separated Fraser River spawning areas. In three of five samples jacks were less available than either adult

TABLE 51—Availability of dead adult male, adult female and jack sockeye at Chilko River as indicated by relative numbers of tagged fish recovered.

YEAR	ADULT MALES		ADULT FEMALES		JACKS	
	Number Tagged	Per cent Recovered	Number Tagged	Per cent Recovered	Number Tagged	Per cent Recovered
1951	905	30.7	819	38.0	848	32.7
1952	2823	32.8	3067	31.4	90	34.4
1953	1551	33.9	1047	30.5	27	29.6
1954	406	22.9	425	19.8	55	10.9
1955	1165	35.5	1315	27.8	211	29.4

males or adult females, in one sample jacks were less available than adult females but more available than adult males. In the remaining sample jacks were more available than adult females and equally available with adult males.

The 1951 Chilko River sample was different from those of the other spawning grounds in that jacks were intermediate in availability between adult males and adult females. This relative availability is not typical of the Chilko spawning ground. TABLE 51 shows that at Chilko River in two of five years jacks were less available than either adult males or adult females, in one year more available than either of the other two groups, in one year more available than adult males and less available than adult females, and in one year more available than adult females and less available than adult males. Contrary to the results for the areas listed in TABLE 49 adult males are more available than adult females in four of five years at Chilko River.

Birkenhead River is one of the areas which TABLE 50 showed to have jacks less available than adults. This is characteristic of Birkenhead spawning ground dead recovery. From eight years of sampling, jacks are found to be less available than either adult males or adult females in every year (TABLE 52). Also adult

TABLE 52—Availability of dead adult male, adult female and jack sockeye at Birkenhead River as indicated by relative numbers of tagged fish recovered.

YEAR	ADULT MALES		ADULT FEMALES		JACKS	
	Number Tagged	Per cent Recovered	Number Tagged	Per cent Recovered	Number Tagged	Per cent Recovered
1947	930	21.9	615	25.0	324	10.5
1949	811	27.0	607	34.4	140	17.1
1950	240	15.4	178	20.8	20	10.0
1951	126	15.1	108	22.2	661	9.4
1952	1036	24.8	586	28.7	1275	12.6
1953	1306	21.1	1091	22.5	580	12.2
1954	802	27.3	405	33.1	545	14.3
1955	649	28.0	473	40.2	383	19.6

males are less available than adult females in every year. The mean recovery rate over the eight year period is 22.58 per cent for adult males, 28.36 per cent for adult females, and only 13.21 per cent for jacks.

The consistently lower availability of Birkenhead River jacks (mostly males) compared with adult males suggests that availability may be a function of different size within one sex. Variability in relative recovery by size group within each sex exists at Birkenhead River, as shown in FIGURE 60. In this analysis tagging data for the years 1950 through 1955 are combined. The fork lengths taken during tagging are divided into 5 centimeter classes, and the percentage recovery of the tagged fish of each length class determined. The resultant recovery rates show a definite trend toward increasing availability with increasing size within each

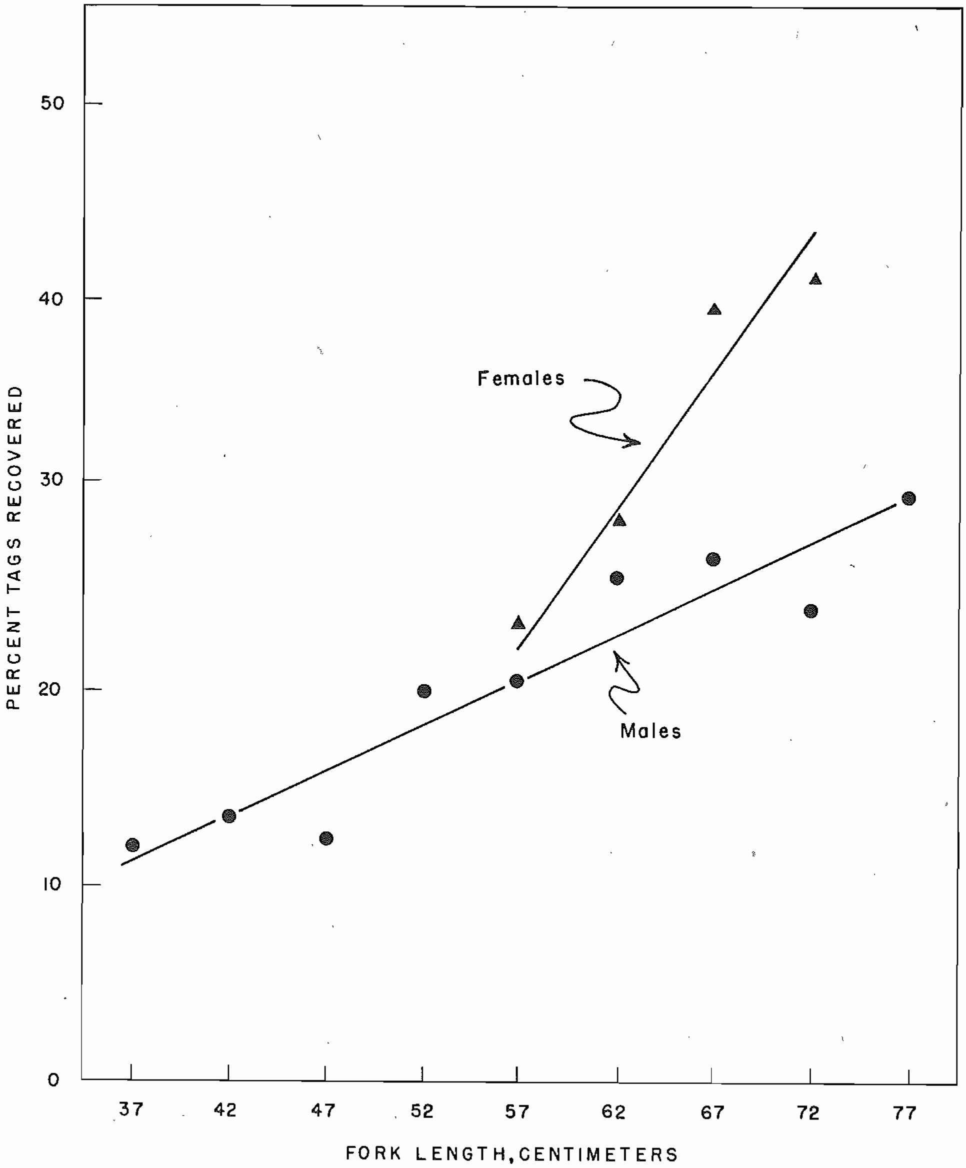

FIGURE 60—Availability by length group and sex of Birkenhead River dead sockeye as shown by percentage of tagged fish recovered 1950-1955 (excluding 1952 females); 9,832 tagged fish in samples.

sex. There are fewer length classes for females because there are almost no females of size comparable with the small males or jacks. The recovery rate is higher for females, as was shown in TABLE 52, and the availability increase is more abrupt for increasing length among females. The general trend was apparent in separate analyses of each of the six yearly samples which were included in the combined analysis, with the exception of 1952 females which exhibited an unexplained decline in availability of the larger sizes and were therefore excluded from the combined sample. The trend lines for the different yearly samples were almost parallel, although of varying vertical position because of varying overall recovery rates between years resulting from different population sizes and fluctuating sampling effort. The tendency of the trend lines to be parallel indicates that the relationship between recovery rates of different size classes is not a constant ratio as might be expected but more nearly a fixed percentage. That is, a recovery rate of say 10 per cent for 37 centimeter males will coincide with a recovery rate of 30 per cent for 77 centimeter males, a three fold difference. Whereas a rate of say 15 per cent for 37 centimeter males will coincide with a rate of 35 per cent for 77 centimeter males rather than the three fold 45 per cent which would occur if the ratio were constant.

The changing ratio of recovery rates between size classes appears to be a function of overall recovery rate in the sampling year. The reason may lie in decreasing availability of the smaller fish by time after death, whereby the smaller fish disappear from the usual dead recovery locations more rapidly than the larger fish and are decreasingly likely to be recovered on subsequent sampling dates. This interpretation is supported by the analysis of percentage jacks recovered by sampling area in the Birkenhead River. The spawning ground is divided into ten sampling areas numbered progressively upstream, the area farthest downstream being number 1. In 1954 fairly intensive sampling of dead sockeye was conducted. Analysis of fresh dead sampling only should give the best estimate of true size composition and show the least variation between areas. This would be expected because the carcasses have less opportunity to diverge in availability by size because the time interval between death and recovery is short. TABLE 53 shows that in

TABLE 53—Comparison among sampling areas of availability of jacks among fresh dead sockeye in Birkenhead River, 1954.

Area Number	Number Fresh Dead Recovered	Per cent Jacks
1	3133	43.3
2	2326	30.0
3	942	34.3
4	74	36.5
5	57	56.1
6	56	39.3
7	191	36.1
8	196	34.2
9	169	37.3
10	105	33.3

1954 the percentage of jacks among fresh dead fish showed no trend from the most downstream to the most upstream areas even though the number of fish sampled varied widely among areas. Sampling of the same areas in 1946 was largely restricted to the lower two areas and jacks were relatively much more abundant in the most downstream area (TABLE 54). This may have been a result of the dead jacks drifting downstream from the upper areas at a greater rate than the larger fish and increasing the normal proportion of jacks in the lower area while decreasing the proportion in the upper areas; or merely very rapid decomposition with resultant decreasing availability of the small jacks. Data from

TABLE 54—Comparison among sampling areas of availablility of jacks among dead sockeye in Birkenhead River, 1946.

Area Number	Number Dead Recovered	Per cent Jacks
1	8,760	12.5
2	17,304	2.9
3 - 10	207	4.8

Schaefer (1951) show essentially the same thing to have occurred at Birkenhead River in 1940 (TABLE 55). A weir was constructed across the lower reaches of the stream between Areas 1 and 2, and dead fish were recovered from the stream below the weir, from the stream above the weir, and from the upstream surface of the weir. The percentage jacks recovered in normal sampling locations above and below the weir were approximately the same, whereas the percentage of jacks was higher among the fish taken from the upstream surface of the weir. This indicates again that either the jacks at Birkenhead tend to drift downstream at a greater

TABLE 55—Comparison among sampling areas of availability of jacks among dead sockeye in Birkenhead River, 1940.

Area Number	Number Dead Recovered	Per cent Jacks
1	617	6.3
Weir	3379	11.7
2	1496	4.5
3 - 10	206	6.3

TABLE 56—Availability by age group of 1952 Upper Pitt River spawning ground dead adults as indicated by relative numbers tagged fish recovered.

Sex and Age	Number Tagged	Per cent Recovered
Males		
4_2	62	24.2
5_2	442	23.1
Females		
4_2	120	15.8
5_2	334	31.4

rate than the larger fish, or the smaller carcasses are easier to recover when concentrated.

Some variability in availability of dead fish by size group was exhibited by the 1952 Upper Pitt River spawning population. As shown in TABLE 56 the larger (5_2) females were more available in dead recovery samples than the smaller (4_2) females; the difference was statistically significant at the 0.95 confidence level showing that this could likely not have occurred from chance alone. Almost no difference between age groups was exhibited by males.

Differential availability between sexes and by size class within a sex has a very important effect on age determination where such condition exists. Not all spawning grounds seem to be affected by differing availability, as indicated by the relatively equal recoverability of males and females, and the equal recoverability of jacks and larger males in some spawning populations. The different availability seems to be a function of the physical characteristics of each particular spawning ground and therefore each must be assessed separately rather than being included in a broad generalization. When consistent differences in availability appear every year on a particular spawning ground the dead recovery samples can be weighted so that they are representative of the whole spawning population in each year.

VARIABILITY OF AGE COMPOSITION BY TIME DURING RUN

Representative age composition sampling can be done from a single sample, no matter how large, only when there is no change in age composition during the period when the population is available for sampling, unless some period is found to represent the average of the changing condition for the whole run.

Age composition may be determined for seaward migrating smolts and returning adults. Both smolts and adults have been sampled by time periods to determine the extent of variation through the course of migration.

Smolts

The young of most populations of Fraser River sockeye migrate to sea at the age of one year, only a few areas have significant proportions of two-year-lake types; and three-year-old smolts are virtually non-existent. Daily samples showing age composition of downstream migrants are analysed for Chilko Lake and Cultus Lake.

Chilko Lake one-year and two-year smolts differ greatly in size, as shown previously (FIGURE 45). Because of this size difference the members of the two age groups are identifiable by sight with a high degree of accuracy. In 1955, as in previous years, the Chilko Lake seaward migrant run was enumerated through periodic photographic sampling of smolts passing through chutes in a weir. The daily proportion of two-year smolts is calculated from the many periodic photographs taken during each daily period of migration. The daily proportion of two-year smolts is represented by the sum of the number of two-year size compared with the sum of the total number of counted smolts in the photographs for the sampling of each day. The numbers of smolts actually counted in the photographs daily varied from about 600 to about 76,000 with only five of a total of thirty daily samples with less than 2000 smolts, and a cumulative total of 516,120

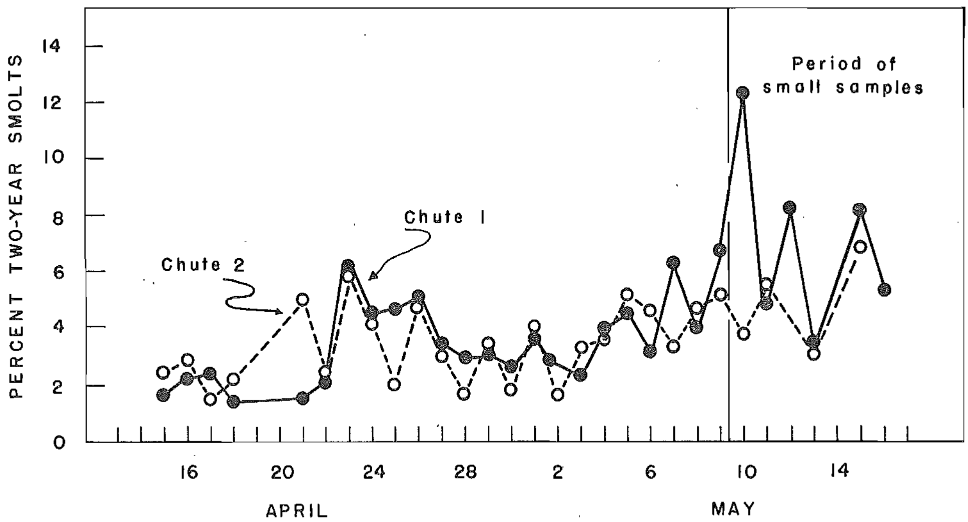

FIGURE 61—Relative number two-year sockeye smolts by time during run. Calculated from photographic sampling in two chutes, Chilko River, 1955; 516,120 smolts in samples.

smolts actually counted. The daily percentage of two-year-olds was calculated separately for each of the two chutes present in the weir in 1955. These relative numbers appear in FIGURE 61. The trends for the two chutes follow similar patterns with slight daily variations until after May 9; after May 9 the samples were

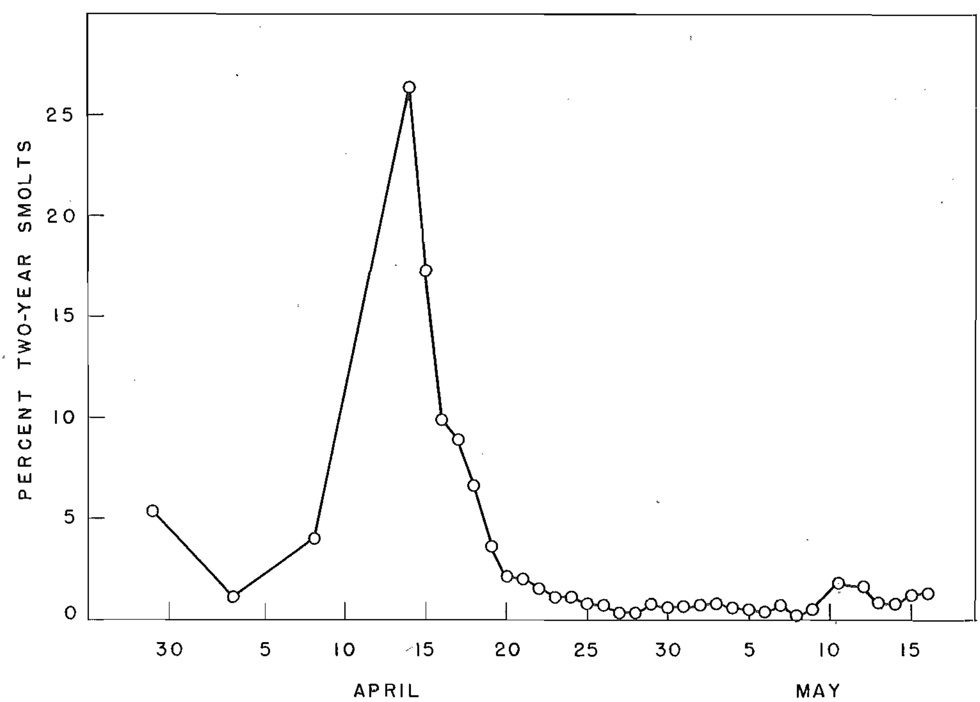

FIGURE 62—Relative number two-year sockeye smolts by time during run, Cultus Lake, 1938; 1,633,581 smolts in sampling period.

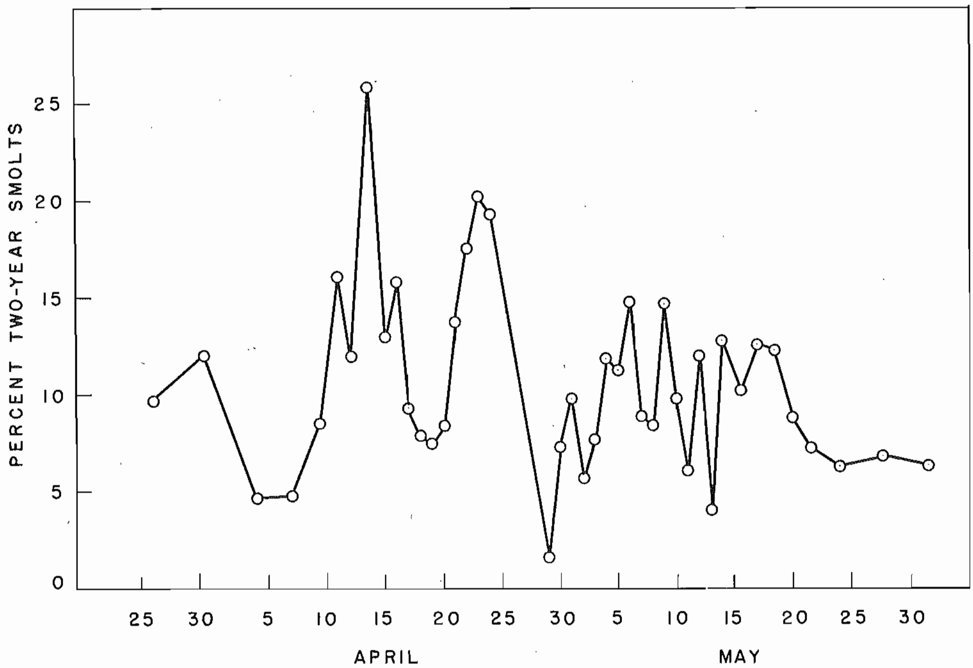

FIGURE 63—Relative number two-year sockeye smolts by time during run, Cultus Lake, 1939; 186,546 smolts in sampling period.

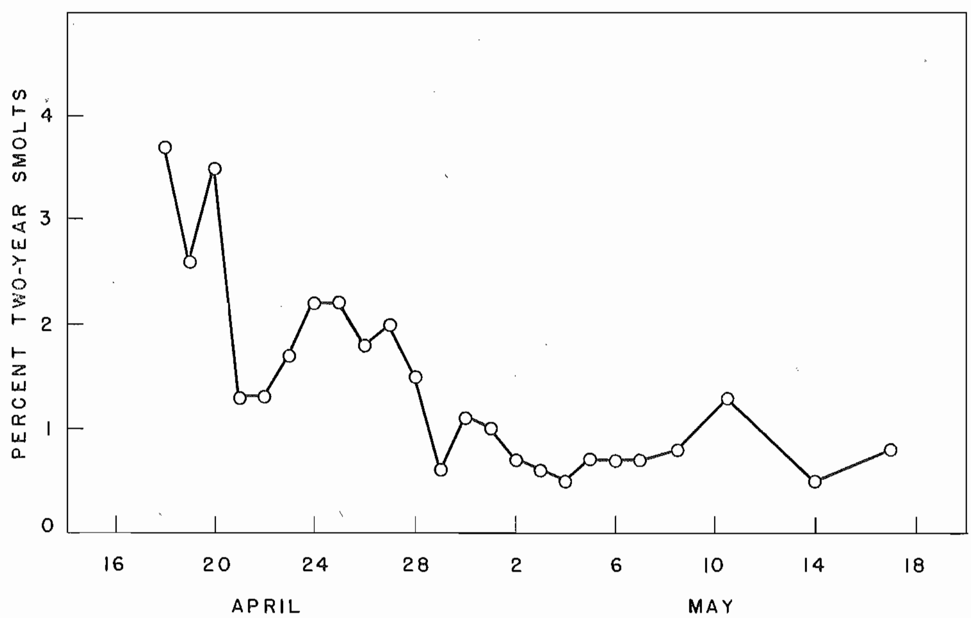

FIGURE 64—Relative number two-year sockeye smolts by time during run, Cultus Lake, 1942; 176,425 smolts in sampling period.

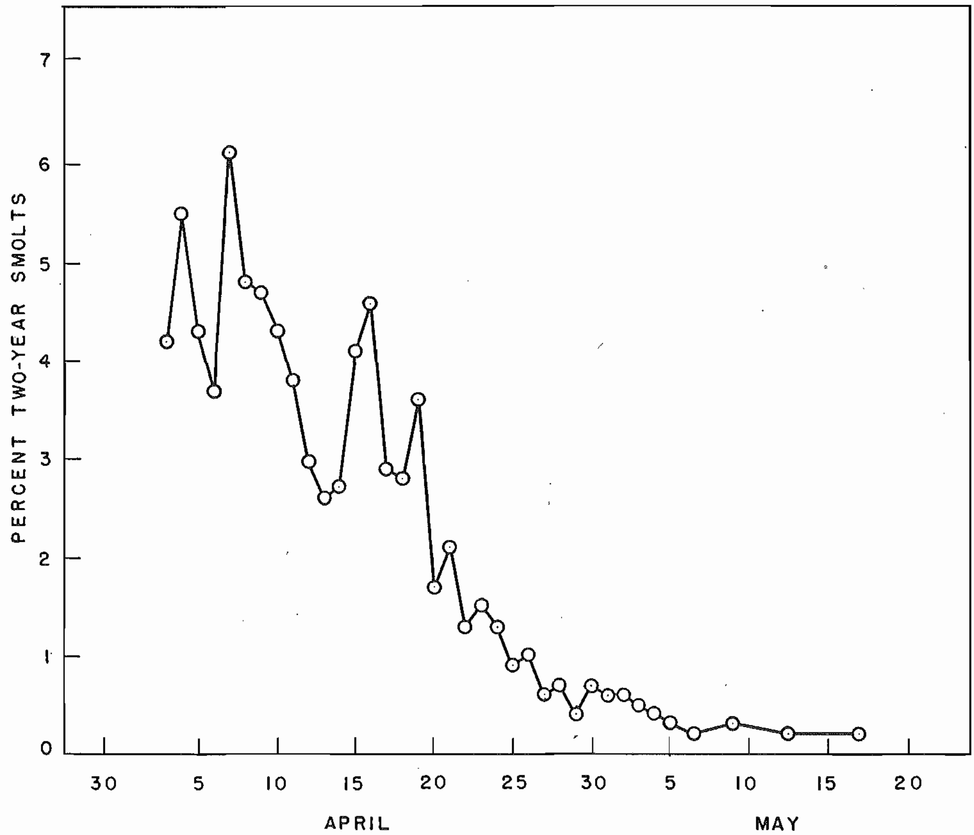

FIGURE 65—Relative number two-year sockeye smolts by time during run, Cultus Lake, 1943; 196,446 smolts in sampling period.

small. There is no consistent seasonal trend in proportion of two-year-olds and the daily percentages were fairly constant during the central period of the run.

Daily proportions of two-year-old smolts have been determined for the Cultus Lake seaward smolt migrations of the years 1938, 1939, 1942, 1943, and 1945. Here the daily age composition was determined in the field at the time of enumeration at a weir which blocked the downstream exit.

In 1938 the daily proportion of two-year-olds (FIGURE 62) rose abruptly to a peak of 26.4 per cent on April 14 and thereafter rapidly declined to April 19, after which date the peak of the smolt migration passed. The daily percentages of two-year smolts was low and slightly variable during the period of significant daily numbers. The 1939 daily percentages of two-year smolts (FIGURE 63) were very erratic even during the central period of migration, with a slight trend toward declining proportion as the season progressed. The small 1942 downstream migration was sampled for proportion of two-year smolts over a month period encompassing the central part of the migration. FIGURE 64 shows that during this period there was a distinct downward trend in proportion of two-year smolts. The same trend of decreasing percentage of two-year-olds was apparent in the 1943 down-

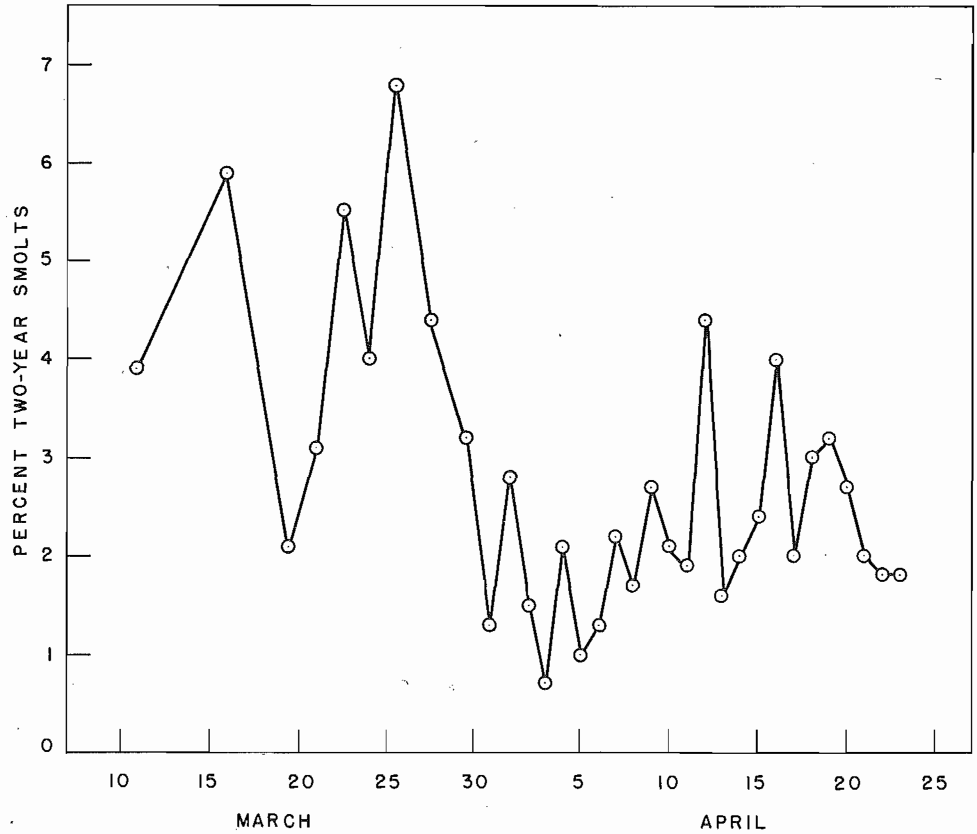

FIGURE 66—Relative number two-year sockeye smolts by time during run, Cultus Lake, 1945; 398,966 smolts in sampling period.

stream migration (FIGURE 65), which was sampled over a period of 45 days encompassing the main period of migration. The 1945 Cultus Lake downstream migrants were sampled over a period of 45 days including the period of main migration which occurred in the latter half of the sampling period. The first half of the period was lightly sampled and the results are somewhat erratic (FIGURE 66). The percentage of two-year smolts declined irregularly from the earliest segment to the beginning of the main migration and thereafter increased slightly to the end of the run. The overall trend of the 1945 run is to decreasing percentage over the run as a whole.

The five years of Cultus Lake samplings indicate that the percentage of two-year-olds can be markedly variable over a seasonal migration period, with the two-year smolts tending to migrate earlier than the yearlings. The percentage throughout the period of greatest numbers tends to be constant. The most representative single period of sampling at Cultus Lake is during the peak of the run when the variation is less and the most smolts are represented. The Chilko migration of 1955 had no trend, indicating that representative samples may be taken from Chilko River at any period when significant numbers of smolts are passing.

However, visual observation has in some migration years shown that two year Chilko smolts sometimes migrate in small schools which do not include many yearlings. Because of this possibility more than a single observation must be made if representative age determination is to be accomplished. The determination of age composition of smolt runs is important but the percentage of two-year seaward migrants can be approximately determined from study of the scales of returning adults; the sampling of age composition of sockeye returning to spawn and the effect thereon of seasonal variation within populations is more complex and of more far-reaching importance.

Jacks and Adults

The potential spawners returning to the Fraser River are three to five years of age. The four-year-old group (4_2) is most important with the 3_2, 5_3, and 5_2 groups ranking secondarily. Variation of age composition by time within specific runs has been studied for live fish passing through a counting weir, for live fish as captured for spawning ground tagging and for dead fish on the spawning grounds. The 3_2, 5_3 and 5_2 age groups are each analysed separately and presented in that order. The 4_2 age group varies in a manner complementary to the minor groups and need not itself be analysed.

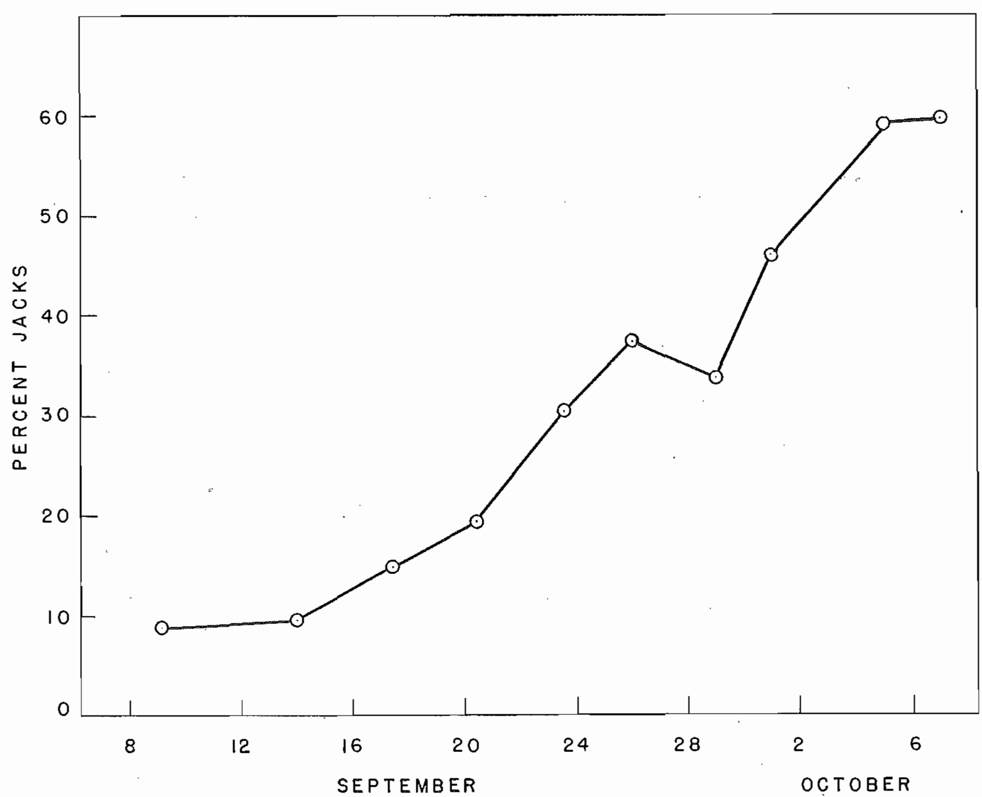

FIGURE 67—Relative number jacks (3_2 and 4_3) by time during run among sockeye caught for tagging, Birkenhead River spawning ground, 1954; 1,752 fish in samples.

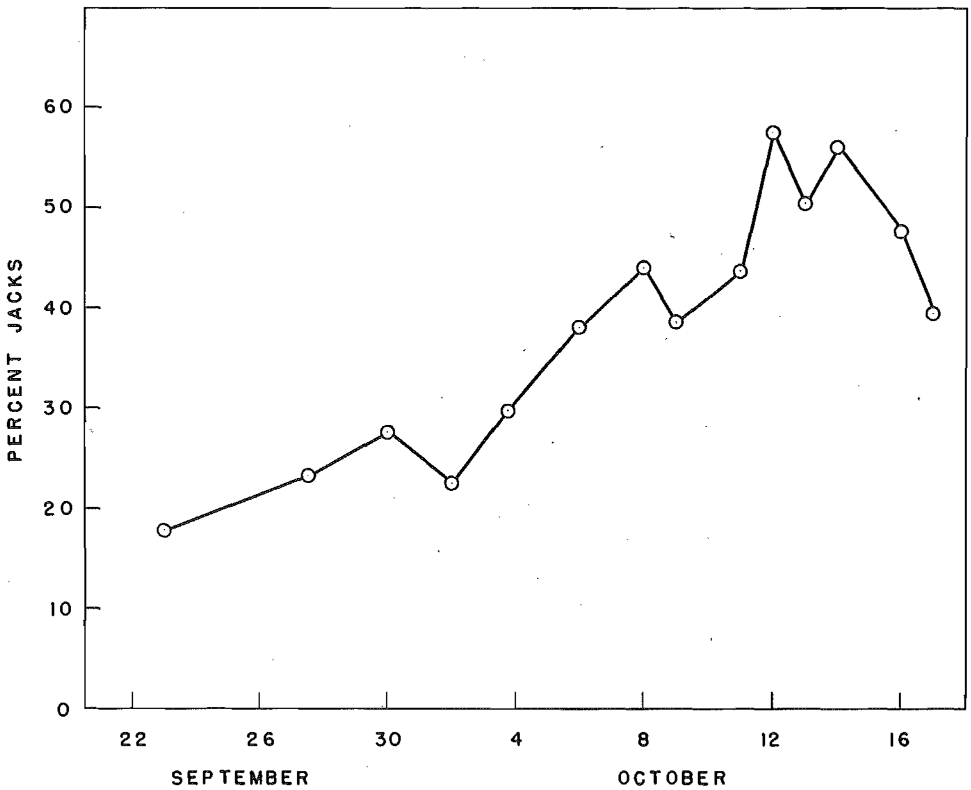

FIGURE 68—Relative number jacks (3_2 and 4_3) by time during run among untagged fresh dead sockeye, Birkenhead River spawning ground, 1954; 8,368 fish in samples.

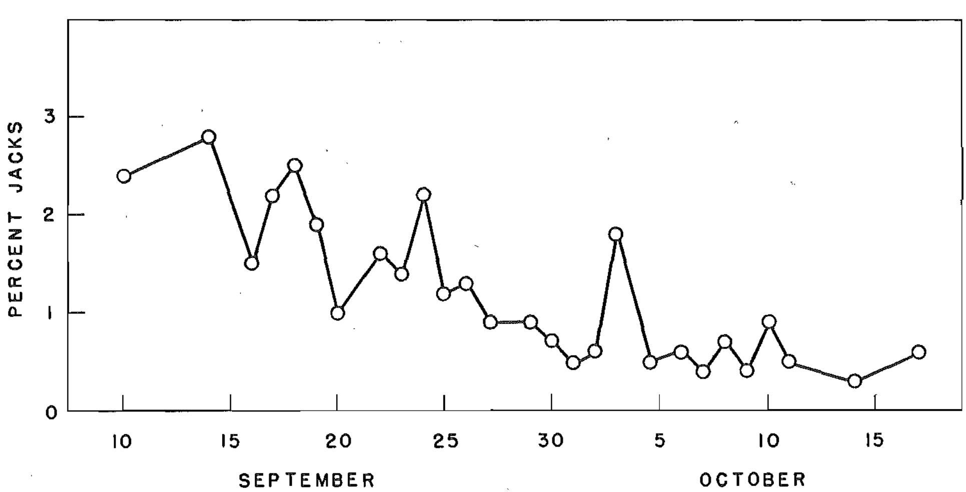

FIGURE 69—Relative number jacks (3_2 and 4_3) by time during run among untagged fresh dead sockeye, Chilko River spawning ground, 1952; 153,902 fish in samples.

3_2—At Birkenhead River in 1954 sockeye were captured for tagging over a period of one month. The relative numbers of jacks in these periodic samples were recorded. There were ten periodic samples, which varied in number of fish tagged from 112 to 273. Each contained the percentage of jacks shown by the points in FIGURE 67. The relative number of jacks increased regularly and very markedly from the beginning to the end of the tagging period. During the ensuing days of the same season (1954) extensive recovery of fresh dead spawned fish was conducted on the Birkenhead River spawning ground. This recovery was made up of both tagged and untagged fish, the untagged fish were more abundant and had not been subjected to any artificial or unnatural treatment, therefore they perhaps provide the most representative data. Analysis of the relative number of jacks among the untagged fresh dead from the periodic samples, varying in number from

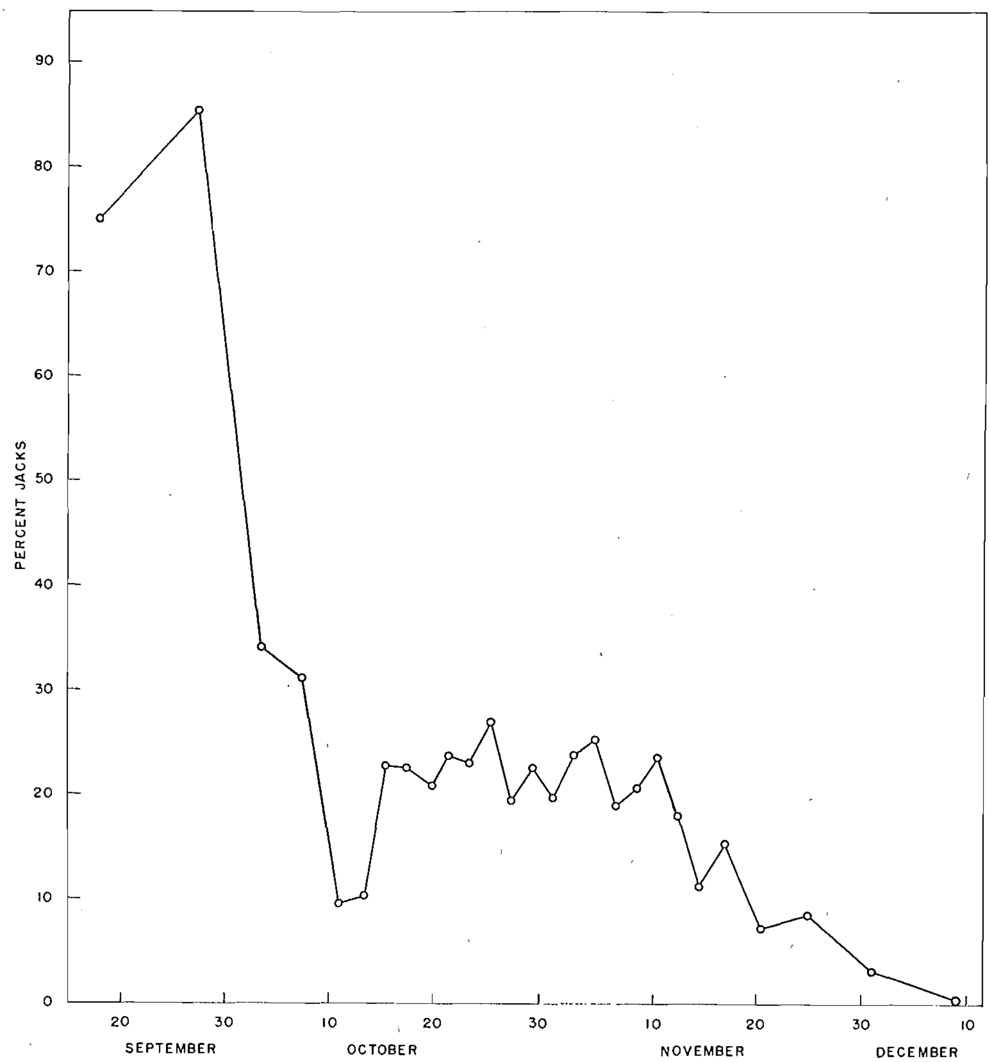

FIGURE 70—Relative number jacks (3_2 and 4_3) by time during run among live sockeye passing Cultus Lake weir, 1941; 18,174 fish in samples.

TABLE 57—Chronological occurrence of jacks (3_2 and 4_3) in various spawning grounds samples as shown by cumulative percentage of seasonal adult sample taken at date when 50 per cent of seasonal jack sample taken.

SPAWNING AREA	YEAR	SOURCE OF SAMPLES	JACKS		ADULT MALES		ADULT FEMALES		COMBINED MALE and FEMALE ADULTS	
			Total Number Sampled	Date 50% Sample Taken	Total Number Sampled	% Seasonal Sample to Date	Total Number Sampled	% Seasonal Sample to Date	Total Number Sampled	% Seasonal Sample to Date
Adams River	1952	Dead Recovery	227	Oct. 21	302	44.7	683	25.2	1,003	31.4
	1953	Dead Recovery	27,860	Oct. 28	182	58.8	381	49.1	563	52.2
Birkenhead River	1952	Tagging	1,275	Sept. 23	1,036	61.8	586	39.2	1,622	53.6
	1952	Dead Recovery	3,808	Oct. 8	4,555	64.5	8,222	51.3	12,777	56.0
	1953	Tagging	580	Sept. 27	1,306	74.0	1,091	58.6	2,397	65.9
	1953	Dead Recovery	1,561	Oct. 6	3,755	68.3	5,034	52.7	8,789	59.4
Chilko River	1952	Tagging	90	Sept. 11	2,823	55.7	3,067	40.3	5,890	47.6
	1954	Dead Recovery	201	Sept. 28	1,499	54.8	2,795	14.4	4,294	28.5
Cultus Lake	1945	Weir	4,194	Nov. 1	—	—	—	—	9,240	46.9
	1952	Weir	1,077	Oct. 25	—	—	—	—	18,910	35.2
Nadina River	1953	Weir	476	Aug. 8	—	—	—	—	39,545	51.3
Stellako River	1953	Dead Recovery	219	Oct. 3	3,929	38.3	5,136	34.2	9,065	36.0

279 to 943, shows again (FIGURE 68) a definite market tendency toward increasing percentage of jacks as the spawning season progresses. Among these dead fish the percentage of jacks decreased somewhat during the last two sampling dates.

A smaller run of jacks (3_2) relative to size of the total spawning population presented itself at Chilko River spawning ground in 1952. Too few jacks were captured during tagging to warrant analysis of tagging data, however an extensive dead recovery program was conducted which provided periodic samples of untagged fresh dead sockeye ranging in number from 333 to 11,983, with all but four of twenty-seven samples numbering more than 1,000. FIGURE 69 shows the percentage of jacks to decrease in a regular trend over the period of dying, contrary to the findings for the 1954 Birkenhead River run.

Cultus Lake spawning runs are enumerated by weir. Jacks are enumerated separately from adults as they arrive and are passed through. In 1941 a substantial part of the spawning run was jacks. The earliest arrivals were mostly jacks (FIGURE 70), but few fish were present at this period. During the main migration of about 30 days duration, from October 15 to November 15, there was only moderate day to day variation with a slight overall trend to declining proportion of jacks. The jack percentage declined to zero during the last days of the run.

The relative number of jacks by time during a run may vary within a season on a given spawning ground, and the pattern of variation, i.e. whether the percentage increases or decreases, may differ between spawning grounds. Whether jacks arrive or die on spawning grounds in different chronological occurrence from adults can be shown by the cumulative percentage of the seasonal adult sample for each sex which has been taken by the date that 50 per cent of the seasonal jack sample is taken. If the percentage of adults sampled as of that date is less than 50 per cent then the jacks have become available earlier in the seasonal sampling period than the adults; conversely, if the percentage of adults sampled as of that date is more than 50 per cent then the jacks have become available later. The chronological occurrence of jacks in various spawning grounds samples is thus illustrated in TABLE 57. The seasonal samples shown in TABLE 57 represent live fish as captured for tagging, live fish as passed through counting weirs and dead fish as recovered on the spawning grounds. Jacks are distinguished from adult males and females in each of the examples, but the live adult males and females are not separated from each other in the daily weir counts. Sex ratios for weir enumeration of populations is usually determined later from dead fish samples on the spawning beds, at which time males and females are easily distinguished. In the nine examples of TABLE 57 where jacks are compared with adult males the jacks were available first in only two cases, in dead recovery at Adams River and Stellako River. In the nine cases where jacks are compared with adult females, jacks were available first in six cases, the three exceptions occurring at Birkenhead River. In TABLE 57 there are twelve cases where jacks are compared with the combined sexes of adults. In six of these cases jacks were available first and in the remaining six, adults were available first. If the examples shown in FIGURES 67-70 are included there are sixteen cases, in eight or half of which jacks were available first. In all six examples from the Birkenhead River the adults preceded the jacks in availability both in tagging and dead recovery samples. The three Chilko River examples, including one tagging sample and two dead samples, showed jacks to precede adults in each case. Jacks also preceded adults in the three Cultus Lake examples of arrival at the weir. In each of the nine samples where male and female adults are compared males preceded females. The chronological occurrence of jacks is variable between spawning populations but generally consistent between years for the same spawning ground, the only exception to this among the four areas where comparisons were made between years was Adams River.

5_3—Chilko River is one of two Fraser River basin spawning grounds which have significant numbers of the 5_3 age group. The Chilko spawning runs of 1946, 1953 and 1954 were among those runs for which scales were sampled by time period which had high enough percentages of 5_3 to be used for comparisons. Dead

TABLE 58—Relative number 5_3 by time during run among fresh dead adults, Chilko River spawning ground, 1946.

DATE	MALES		FEMALES		BOTH SEXES	
	Number in Sample	Per cent 5_3	Number in Sample	Per cent 5_3	Number in Sample	Per cent 5_3
September 11-30	44	9.1	48	10.4	92	9.8
October 1-16	21	61.9	67	40.3	88	45.5

TABLE 59—Relative number 5_3 by time during run among fresh dead adults, Chilko River spawning ground, 1953.

DATE	MALES		FEMALES		BOTH SEXES	
	Number in Sample	Per cent 5_3	Number in Sample	Per cent 5_3	Number in Sample	Per cent 5_3
September 10-14	73	32.9	48	22.9	121	28.9
15-19	64	29.7	87	27.6	151	28.5
20-24	65	30.8	71	21.1	136	25.7
25-28	94	43.6	187	35.8	281	38.4
Sept. 29 - Oct. 5	83	56.0	156	48.7	239	51.5

TABLE 60—Relative number 5_3 by time during run among Chilko River adults migrating past Siwash Bridge, 1954.

DATE	MALES		FEMALES		BOTH SEXES	
	Number in Sample	Per cent 5_3	Number in Sample	Per cent 5_3	Number in Sample	Per cent 5_3
August 4 - 13	20	25.0	51	13.7	71	16.9
14 - 23	104	24.0	206	18.9	310	20.6
Aug. 24 - Sept. 3	351	26.5	371	27.5	722	27.0

spawned adults of the 1946 run were sampled by time period, and samples were combined to allow a comparison of the proportion of 5_3 between the first half and the second half of the dead recovery period. TABLE 58 shows a very marked increase in per cent 5_3 between the earlier and later periods in 1946; the increase was exhibited by both males and females.

More intensive sampling was carried out during the 1953 Chilko River spawning run; the proportions of 5_3 among fresh dead adults on the spawning ground by sampling period are listed in TABLE 59. The percentage remained fairly constant through the first three sampling periods the third of which included the peak of dead recovery, but the percentages rose sharply during the last two periods to a point where the proportion was double that of the central period.

The 1954 Chilko River run was sampled at Siwash Bridge, a point about fifty miles below the spawning ground, and as fresh dead on the spawning ground. The Siwash Bridge sampling was grouped into three periods (TABLE 60) which showed a continuous increase in relative number of 5_3 from the first to the third periods for both sexes combined. This progressive change was due entirely to females because each sample of males showed about the same proportion of 5_3. The 1954 Chilko River spawning ground fresh dead samples, which were taken after spawning from the same population of fish as had passed Siwash Bridge earlier, were grouped into four sampling periods (TABLE 61). The first period, occurring before the peak dead recovery, exhibited about the same proportion of 5_3 as the first Siwash Bridge sample. The second period, including the peak of dying of about October 1, increased in relative number of 5_3 by 10 per cent. The proportion of 5_3 remained constant through the last three sampling periods. The reason for the slight divergence in pattern of 5_3 occurrence between Siwash Bridge and the Chilko spawning ground may be that variation in duration of life after spawning was sufficient to obscure the relationship. Such variation was shown to be possible by Killick (1955).

TABLE 61—Relative number 5_3 by time during run among fresh dead adults, Chilko River spawning ground, 1954.

DATE	MALES		FEMALES		BOTH SEXES	
	Number in Sample	Per cent 5_3	Number in Sample	Per cent 5_3	Number in Sample	Per cent 5_3
September 19-25	191	17.8	59	15.3	250	17.2
Sept. 26 - Oct. 2	189	32.8	116	19.8	305	27.9
October 3 - 9	101	35.6	228	25.4	329	28.5
10 - 16	24	37.5	150	26.0	174	27.6

5_2—Upper Pitt River is one of the few Fraser River tributaries which have numerous sockeye of the 5_2 age groups. The yearly runs to this spawning ground are composed of varying proportions of 5_2 and 4_2. In all of the years for which the chronological occurrence of the two groups could be investigated the 5_2 group appeared to arrive earlier than the 4_2 group. This is apparent for both males and

females as was shown by the 1955 periodic sampling of fresh dead spawners (TABLE 62); the age composition of these samples was determined by length frequency analysis.

These findings for chronological occurrence of all age groups in spawning populations show considerable variation in age composition through the arrival and

TABLE 62—Relative number 5_2 by time during run among fresh dead adults, Upper Pitt River spawning ground, 1955.

DATE	MALES		FEMALES		BOTH SEXES	
	Number in Sample	Per cent 5_2	Number in Sample	Per cent 5_2	Number in Sample	Per cent 5_2
September 12-20	56	89.3	154	89.0	210	89.1
21	73	79.4	114	89.5	187	85.6
22-24	61	63.9	123	76.4	184	72.3
Sept. 26 - Oct. 3	58	44.8	136	66.2	194	59.7

spawning ground habitation periods. Thus to obtain an exact age composition estimate it is necessary to sample throughout the run either in proportion to the numbers present, or at a constant level and thereupon weight each sample by the relative abundance at the time the sample was taken. Both of these methods require much sampling effort on a large run, and sufficiently accurate estimates can be obtained by taking one sample at the peak of the migrating run, or, preferably for Fraser River sockeye, from the peak period of dying. At the peak of the run not only are the greatest number of fish represented but the ratio of age groups approaches its mean value.

COMPARISON OF AGE COMPOSITION BETWEEN SEXES

Age composition analysis includes both sexes. Since males and females exhibit certain differences in time of arrival and length of life after spawning it is necessary to know whether they differ in age composition sufficiently to warrant separate analyses or whether they can be grouped for simplification.

Age composition by sex may be determined for both smolts and adults through scale readings, length frequency analysis, or otolith readings. As mentioned in a previous section smolt sex is determined by dissection, as is most sex analysis of green commercially caught sockeye; spawning grounds samples may be sexed by external or secondary sex characteristics.

Smolts

Age composition by sex of Fraser River sockeye smolts is a difficult subject to study because of the usual small proportion of two-year smolts compared with yearlings. As a somewhat indirect approach to the subject it is possible to compare all available samples wherein smolt sex ratio data are available to see whether marked or consistent differences in sex ratio occur between the two age groups. Sex ratio data for Fraser River one-year and two-year smolts, and one-year smolts from other areas are shown in TABLE 63.

TABLE 63—Relative number males among sockeye smolts from Fraser River and other areas.

Area	Smolt Age, Year	Sampling Year	Number in Sample	Per cent Males
Fraser River				
Chilko River	1	1915[1]	60	51.7
	1	1954	1373	52.4
Cultus Lake	1	1930[2]	123	42.3
Harrison River	1	1950	47	51.1
	1	1953	55	43.6
Horsefly Lake	1	1955	61	47.5
Lillooet Lake	1	1953	129	48.1
	1	1954	535	48.6
Quesnel Lake	1	1915	180	61.1
	1	1919	252	48.4
Seton Lake	1	1914	300	45.3
Shuswap Lake	1	1953	159	45.3
Stuart River	1	1953	375	55.2
Chilko River	2	1953	201	60.7
	2	1954	174	48.3
	2	1955	100	62.0
Non-Fraser River				
Babine Lake	1	1914	238	52.9
	1	1915	389	44.0
Smith Inlet	1	1914	193	45.1
	1	1915	250	52.8
Rivers Inlet	1	1915	900	55.0
	1	1916	2460	52.8

[1] 1914 to 1919 data from Gilbert (1915-1920).
[2] 1930 Cultus Lake data from Foerster (1937).

The average per cent males for the thirteen samples of Fraser River yearlings is 49.3 per cent; this differs but slightly from an even sex ratio. Only three samples of sexed two-year smolts are available and each of these is from Chilko River; the 1954 sample exhibits a nearly even sex ratio but the other two highly favor males, making the average for the three samples 57.0 per cent. The six non-Fraser River samples exhibit an approximately even sex ratio on the average. The mean per cent males for all twenty-two samples, unweighted for sample size, is 50.7 per cent. The mean per cent males for all twenty-two samples weighted for sampled size is 51.7 per cent. A slight preponderance of males among the two-year-olds is indicated at Chilko River, but, relative to the number of yearlings migrating the previous year, the number of two-year-olds is apparently not sufficient to noticeably affect the sex ratio of the yearling sample of the previous year.

If differences in age composition between male and female smolts do exist, sampling for age composition would be affected by changes in sex ratio by time of sampling during the run. The 1954 Chilko River smolt run was sampled over a period of slightly more than a month. Eleven separate samples of yearling smolts were taken, and the sex ratio was determined for each. The sex ratio expressed as per cent males appears in TABLE 64. Males were on the average slightly more abundant, especially during the first half of the run. There was a difference of 2.7 per cent between the first half and last half of the run. Gilbert (1918) sexed periodic samples from the Rivers Inlet area in 1916. These samples were

TABLE 64—Relative number males by time during run, one-year-old sockeye smolts, Chilko River, 1954.

Date	Number in Sample	Per cent Males
April 21	102	49.0
24	119	61.3
28	99	49.5
May 1	101	56.4
6	120	55.8
9	160	48.8
12	114	50.0
16	178	51.7
20	148	48.0
21	94	51.1
23	138	55.8

TABLE 65—Relative number males by time during run, one-year-old sockeye smolts, Owikeno River (Rivers Inlet), 1916.[1]

Date	Number in Sample	Per cent Males	Date	Number in Sample	Per cent Males
May 18-19	22	54.5	June 3	74	50.0
20	65	49.2	4	121	48.0
21	42	54.7	5	75	54.7
22	83	49.3	6	123	52.8
23	57	63.2	7	257	50.2
24	100	41.0	8	138	45.7
25	100	58.0	10	200	57.0
27	95	61.1	11	88	56.8
28	132	58.3	12	90	54.4
29	23	47.8	13	152	52.0
30-31	90	56.7	14	151	53.0
June 1	84	50.0	15	31	61.3
2	43	41.9	16-17	24	58.3

[1] From Gilbert (1918).

taken daily over a month period. As shown in TABLE 65 there were day to day variations but no overall trend to increasing or decreasing per cent males as the season progressed.

Only three small samples of two-year-olds were taken during the 1954 Chilko smolt run, representing mostly the peak and later periods of migration. In these samples the per cent males declined markedly from the first to the third samples (TABLE 66). These samples showing two-year-old sex ratio by time during the run are too small to allow generalization, but variation of this type could possibly be responsible for the differences in per cent males occurring in the smolt samples.

TABLE 66—Relative number males by time during run, two-year-old sockeye smolts, Chilko River, 1954.

Date	Number in Sample	Per cent Males
May 4	77	58.4
9	70	48.6
23	27	18.5

Jacks and Adults

3_2—There is one most outstanding difference in age composition between male and female maturing sockeye. The sometimes sizeable runs of jacks which precede by one year the larger runs of adults are preponderantly males. This is shown by observing the sex ratios of the large samples of jacks which were inspected during dead recovery on various spawning grounds. Examples of varying low per cent females are shown in TABLE 67; these examples were chosen from runs of considerable numbers of jacks but the same general situation exists for all jack runs regardless of population size or spawning ground location. The group of jacks which spend two years in the lake and return as 4_3 exhibits the same tendency.

TABLE 67—Relative number females among 3_2 jack sockeye from various spawning grounds.

Area	Year	Number 3_2 Jacks Sampled	Per cent Females
Adams River	1953	27,860	2.3
Little River	1953	10,224	2.0
Birkenhead River	1952	3,808	0.1
Cultus Lake	1938	1,395	7.0
Horsefly River	1952	2,228	0.6

5_3—Under certain fixed conditions age composition by sex can be accurately calculated from samples unweighted for sex ratio and daily abundance. Often age composition sampling must account for variations in age composition by time during the run. Time-abundance weighted samples take into account the change in sex ratio which is exhibited by Fraser River sockeye spawning populations. As an example of marked change in sex ratio of the Chilko River spawning populations the per cent males among the 1946 daily fresh dead recovered on the

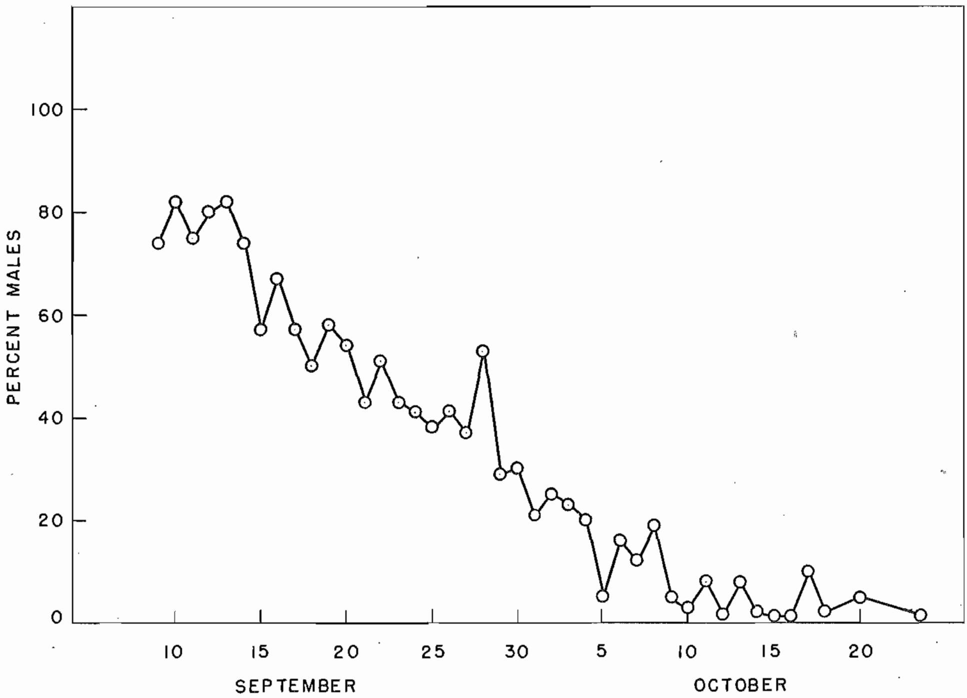

FIGURE 71—Relative number males by time during run among fresh dead Chilko River spawning ground adults, 1946; 4,539 fish in samples.

spawning ground is shown in FIGURE 71. If there is any difference in age composition by time period during the run—even if each sex exhibits the same variation—the changing sex ratio must be accounted for if the overall age composition estimate is to be accurate. In TABLE 68 a comparison of 5_3 age composition between sexes from both unweighted and weighted calculations is shown. The examples are from the Chilko River spawning ground, including the years 1946, 1953, and 1954. Only in 1946 was the age composition estimate by sex changed appreciably by weighting for abundance by sex, and this was the only year when there was a marked disparity in 5_3 composition between sexes, the males having relatively fewer 5_3. The 1953 and 1954 samples are much more reliable than the 1946 sample based on sample size (see TABLES 58, 59, and 61) and in both 1953 and 1954 there were relatively more 5_3 among males, tending to bear out the findings for Chilko River two-year smolts shown in TABLE 63. The sex ratio of spawning grounds

TABLE 68—Comparison between sexes of relative number 5_3 among fresh dead Chilko River spawning ground adults, calculated before and after weighting for relative abundance by sex.

YEAR	UNWEIGHTED		WEIGHTED	
	Males	Females	Males	Females
1946	26.2	27.8	16.8	26.7
1953	39.8	35.2	35.8	32.4
1954	27.7	23.3	28.7	23.9

samples can be a function of selectivity, as shown to be possible by Peterson (1954), and among Chilko River populations it seems unlikely that the proportion of 5_3 within a given sex would be significantly upset by selectivity because of the close similarity in size of 5_3 and 4_2 (see TABLE 46). Selectivity could possibly somewhat affect the 5_3 age composition within sexes at Birkenhead River because of the difference in size between 4_2 and 5_3.

5_2—Differences in 5_2 age composition between sexes in spawning grounds samples are much more pronounced and more variable than those of 5_3. TABLE 67 compares the proportions of 5_2 by sex for four years of sampling at Upper Pitt River and four years at Harrison River. The samples were weighted for daily abundance by sex. The sizes of samples from which the calculations were made are indicated. The Harrison River sockeye, which spawn in the rapids area of the main Harrison River below Harrison Lake, were considered by Gilbert (1918) to be sea type, that is with no period of lake residence but immediate residence in the sea after emergence from the gravel. The proof of his theory has never been fully established and the Harrison River fish called 5_2 here are assumed to have had lake residence, although the reservation is made that some of them could be called 4_1 or sea type according to Gilbert's interpretation. The question of possible sea growth in the first year does not arise with the Upper Pitt River population or any population other than Harrison River rapids.

TABLE 69—Comparison between sexes of relative number 5_2 sockeye in Upper Pitt River and Harrison River spawning ground populations.

AREA AND YEAR	MALES		FEMALES	
	Number in Sample	Per cent 5_2	Number in Sample	Per cent 5_2
Harrison River				
1951	40	10	256	15
1952	165	40	239	92
1953	195	29	141	45
1954	137	13	320	27
Upper Pitt River				
1952	496	85	456	73
1953	241	93	213	91
1954	233	21	184	26
1955	286	71	527	80

TABLE 69 shows that at Harrison River females had a much higher percentage of 5_2 than males in each of the four years listed. The Upper Pitt River populations of the years listed did not show the same tendency; in two of the years 5_2 were more abundant among males and in the other two years more abundant among females, with lesser differences in each case than those exhibited by the Harrison River populations. Peterson (1954) showed that linen gill nets are selective for size of fish and therefore selective for sex and for those age groups wherein differences in duration of sea residence exist. The 5_2 age fish are larger than 4_2 because of the extra year of sea growth; therefore the age composition of mixed 4_2-5_2 spawning grounds populations may be affected by prior commercial fishery selectivity. For this reason the difference in age composition between sexes of spawning populations cannot be solely attributed to original differences existing in the total population—including both catch and escapement—but may be due in part to variable selectivity in the commercial fishery.

In summary, it has been shown that there are no consistent differences in age composition between sexes of yearling smolts but, based on three samples only, males predominate slightly among two-year smolts. Both 3_2 and 4_3 jacks are almost all males, whereas males and females exhibit about the same percentage of 5_3, and the percentage of 5_2 is higher among females at Harrison River but on the average about the same for each sex at Upper Pitt River. In populations where significant differences in age composition occur between sexes, data for males and females must be treated separately, especially where the sex ratio changes markedly through the period of the run.

VARIABILITY OF AGE COMPOSITION BY YEARS AND STOCKS

The age composition of Fraser River sockeye is not necessarily the same for different populations in the same year nor the same from year to year for a given population. Thus this attribute must be sampled in every year and for each area separately.

Yearly Variation Within Stocks

On those spawning grounds where two or more age groups are found the relative abundance of the groups varies from year to year. The late Shuswap run has varying numbers of 3_2 jacks from year to year, and, as shown in TABLE 70, the percentage of the spawning run which is composed of jacks varies widely. This variation in the spawning year populations is partly caused by variation in the size of total runs from year to year but not entirely so. The proportion of the offspring from a given spawning which will become jacks varies from year to year as shown in TABLE 71 for the late Shuswap run.

Variation in relative number of 5_3 from year to year also occurs, as shown by Chilko River spawning ground data (TABLE 72). The great variations in this age composition in spawning years at Chilko is largely due to varying population

TABLE 70—Comparison among four successive spawning years of relative number 3_2 jacks on late Shuswap spawning grounds.

Spawning Year	Per cent 3_2
1951	1.1
1952	32.1
1953	98.1
1954	0.3

TABLE 71—Comparison among brood years of relative number 3_2 jacks produced, late Shuswap spawning grounds.

BROOD YEAR	SPAWNING YEAR		PER CENT 3_2
	Jacks	Adults	
1947	1950	1951	19.8
1948	1951	1952	17.9
1949	1952	1953	46.4
1950	1953	1954	9.6

TABLE 72—Comparison among four successive spawning years of relative number 5_3 among Chilko River spawning ground adults.

Spawning Year	Number in Sample	Per cent 5_3
1952	359	2.5
1953	930	37.3
1954	2132	27.5
1955	554	0.7

TABLE 73—Comparison among brood years of relative number 5_3 among Chilko River spawning ground adults.

BROOD YEAR	SPAWNING YEAR		PER CENT 5_3
	4_2	5_3	
1947	1951	1952	11.1
1948	1952	1953	13.4
1949	1953	1954	7.1
1950	1954	1955	3.3

TABLE 74—Comparison among four successive spawning years of relative number 5_2 among Harrison River spawning ground adults.

Spawning Year	Per Cent 5_2
1951	36.0
1952	67.9
1953	51.4
1954	32.6

sizes from year to year, however there are significant variations in the production of 5_3 between brood years, as shown in TABLE 73.

Tendencies toward yearly variation in age composition are also exhibited by those populations with significant proportions of 5_2 spawners. The Harrison River population for example exhibits considerable variation from year to year (TABLE 74). In mixed 4_2-5_2 runs the age groups differ in body size and are thus subject to possible differential selectivity. This selectivity could have a varying effect from year to year depending on the vagaries of the fishery. Knowledge of the fishing intensity from year to year, however, precludes the possibility that annual variations in age composition on the spawning grounds are caused entirely by the fishery.

Variations in age composition within populations are real and significant, and it is thought that these age composition variations may either have some effect on production or, perhaps more likely, indicate the dynamic population relationship by disclosing the condition of maximum production or perhaps showing the effect of dominance without revealing the cause.

Variation Between Stocks

Of those areas in the Fraser River watershed where mixed ages are found no two necessarily have the same age composition. In particular, the proportion of jacks produced in one spawning area in a given year is not necessarily an indication of what the proportion will be in another area (see TABLE 75).

The Fraser River populations which include 5_3 sockeye are few compared with the total number of unit-stocks, and relative numbers of 5_3 are often low. Nevertheless there are differences between populations within given years; this is shown in TABLE 76. The production of 5_3 appears to be an internal function within each population in its own individual environment, and there is no obvious relationship among the proportions of 5_3 occurring in different areas.

Differences in age composition among areas are especially marked concerning the 5_2 group. Many Fraser River populations have almost no members of this age, whereas a few, including Upper Pitt River in particular, regularly have significant numbers. This is shown in TABLE 77. Even the two areas Harrison River and Weaver Creek, which are very near to each other, are not similar in age composition. Part of the differences in 5_2 composition between areas can be attributed

TABLE 75—Comparison among spawning areas of relative number 3_2 jacks occurring in 1953.

Spawning Area	Per cent 3_2 Jacks
Birkenhead River	23.7
Chilko River	0.3
Cultus Lake	11.2
Late Shuswap	98.1
Stellako River	2.3

TABLE 76—Comparison among spawning areas of relative number 5_3 among adults in 1955.

Spawning Area	Per cent 5_3
Birkenhead River	3.2
Chilko River	0.7
Cultus Lake	0.7
Lower Adams River	4.1
Stellako River	0.0

TABLE 77—Comparison among spawning areas of relative number 5_2 among adults in 1955.

Spawning Area	Per cent 5_2
Adams River	1.07
Chilko River	0.9
Harrison River	44.3
Upper Pitt River	69.6
Weaver Creek	6.2

to variable fishing effect during different periods of the fishing season, but the differences thus caused would not be a very great part of those shown.

DETERMINATION OF SAMPLE SIZE

Age composition must be determined from spawning grounds samples of individual runs and from commercial fishery samples of complex mixed-run populations. In each case the requirements are the same; it is necessary that the sample or samples be large enough to reflect the true nature of the population with only a small amount of error. Again as with sampling for lacustrine growth, sample sizes can be chosen in two ways. First, through application of formulae based on sampling theory and second, through calculation of the limits of accuracy of empirical values.

Theoretical

Estimates of the proportion of any given age group in a complex age population will follow a binomial distribution. Thus the theoretical aspects of sampling for age composition are the same as those discussed in a previous section concerning sampling for separation of unit-stocks (cf. page 43). Age determination of commercial catches from scales is positive, but spawning ground age determination employing length frequency analysis presents the same sample size problem as commercial fishery lacustrine growth study. This occurs because some of the age groups, notably 4_2 and 5_2, overlap in length at maturity. Chapman's formula (equation 8, page 80) therefore can be used to calculate length frequency age determination sample size also.

Empirical

Actual samples of sockeye scales exhibiting varying proportions of given age composition may be divided into subsamples of varying magnitude to show the way in which estimates of age composition become more exact as the sample size increases. The subsamples must be chosen in a way that will eliminate the possible effect of changes in age composition by time during the sampling period. This may be accomplished by selecting the subsamples not in the natural order of appearance but first choosing the number of subsamples *(k)* and then composing the first subsample of fish 1, $k + 1$, $2k + 1$, $3k + 1$, etc., so that all k subsamples

TABLE 78—Relative number 3_2 among systematic subsamples of varying magnitude, Chilko River spawning ground fresh dead, 1954.

	Number in Sample						
	50	100	200	300	400	600	1200
Per cent 3_2 in Subsamples	4.0	2.0					
	0.0		4.5				
	4.0	7.0		4.67			
	10.0				4.75		
	6.0	5.0					
	4.0		5.0			5.33	
	6.0	5.0					
	4.0						
	4.0	6.0		6.00			
	8.0		6.5				
	8.0	7.0					
	6.0				5.25		4.92
	4.0	5.0					
	6.0		4.0				
	4.0	3.0		3.67			
	2.0						
	2.0	3.0					
	4.0		3.5			4.50	
	2.0	4.0					
	6.0				4.75		
	8.0	6.0		5.33			
	4.0		6.0				
	6.0	6.0					
	6.0						

have the same number of fish. That is, if a sample were to be systematically divided into six subsamples, the first systematic subsample would contain the first fish, the seventh, the thirteenth, the nineteenth, etc.

The results of this systematic subsampling of a mixed group of jacks and adults appear in TABLE 78. Here twelve hundred sockeye, represented by scales, are divided into twenty-four subsamples of fifty fish each. The range of estimates of relative number of jacks is from 0.0 per cent to 10.0 per cent in the fifty fish subsamples. Combining these subsamples by pairs into twelve 100-fish subsamples results in estimates ranging from 2.0 per cent to 7.0 per cent; the range decreases steadily thereafter as the sample size is increased.

The range variation of the estimates between subsamples is dependent on the actual proportions *(p)* of the sought for age group; the variation is greatest when *p* is 0.5. This is illustrated by the variation in estimates of per cent jacks in TABLE 79 compared with TABLE 78. The range of variation of the subsamples

TABLE 79—Relative number 3_2 among systematic subsamples of varying magnitude, Point Roberts purse seine catch of August 12, 1953.

	Number in Sample			
	50	100	150	300
Per cent 3_2 in Subsamples	48.0	47.0	46.0	48.7
	46.0			
	44.0	46.0		
	48.0		51.3	
	54.0	53.0		
	52.0			

having higher relative number of jacks (TABLE 79) is 10 per cent, as was that of the samples lower proportion of jacks (TABLE 78), but this equal range occurs even though there are only one-fourth as many subsamples in the latter case. In TABLE 79 the range is halved by tripling the sample size, from fifty fish to one hundred fifty fish.

In TABLE 80 one thousand Chilko River spawning ground adult sockeye are divided into twenty random subsamples of fifty fish each. The variation is from 18.0 per cent to 32.0 per cent in the fifty fish samples, a range of 14.0 per cent. The range of one hundred fish samples is 9.0 per cent, of two hundred fish samples 2.5 per cent, and of five hundred fish samples 0.8 per cent.

TABLE 81 shows the variation in estimates of a population with a small proportion *(p)* of 5_2. The sample is made up of commercial catch samples taken at San Juan Islands in 1953. Here the range of absolute variation is less than in samples of larger *p* but the differences are more marked relative to the magnitude of *p*. This is not critical in most sampling programs because the age groups having low relative abundance are not as important to most analyses as the more abundant age groups.

TABLE 80—Relative number 5_3 among systematic subsamples of varying magnitude, 1954 Chilko River spawning ground adults.

	Number in Sample				
	50	100	200	500	1000
Per cent 5_3 in Subsamples	26.0	28.0	26.5	26.0	25.6
	30.0				
	26.0	25.0			
	24.0				
	26.0	25.0	25.0		
	24.0				
	24.0	25.0			
	26.0				
	26.0	27.0	26.0		
	28.0				
	20.0	25.0		25.2	
	30.0				
	32.0	29.0	26.5		
	26.0				
	24.0	24.0			
	24.0				
	18.0	20.0	24.0		
	22.0				
	32.0	28.0			
	24.0				

These tables show that a sample size of from two hundred to five hundred fish is adequate to keep the variation of estimates of age composition within reasonable limits; samples of greater than five hundred fish do not reduce the variation enough to warrant the additional effort being expended to acquire and analyse the larger samples. The daily sample size may be reduced to the lower limit of two hundred fish when successive samples are being taken, as in commercial fishery catch sampling; whereupon subsequent smoothing of the daily estimates by three day moving averages seems to give good results.

CALCULATION OF CONFIDENCE LIMITS

Calculation of mathematical confidence limits in sampling is predicated on the fundamental assumption that the fish involved are individually independent and the probability of their inclusion in a sample subject to chance alone. This assumption has in previous sections been shown to be invalid in many cases.

TABLE 81—Relative number 5_2 among systematic subsamples of varying magnitude, 1953 San Juan Islands purse seine catch.

	Number in Sample				
	50	100	200	500	1000
Per cent 5_2 in Subsamples	4.0	4.0			
	4.0		2.5		
	2.0	1.0			
	0.0			1.6	
	0.0	1.0			
	2.0		0.5		
	0.0	0.0			
	0.0				
	4.0	2.0			
	0.0		1.5		1.4
	0.0	1.0			
	2.0				
	2.0	2.0			
	2.0		1.0		
	0.0	0.0			
	0.0			1.2	
	4.0	3.0			
	2.0		1.5		
	0.0	0.0			
	0.0				

Calculation of limits of confidence may be justified if the assumption of complete elimination of influencing factors, other than chance, is valid. There are, however, sometimes obscure factors which influence sampling and invalidate calculated confidence limits, factors which ordinarily might be assumed to be non-existent. Thus randomness does not always exist in actual population analysis, even though this assumption seems to have become almost institutional in the application of sampling theory to fishery biology.

To exemplify the influence of an unexpected factor, compare the data of TABLE 82 with those of TABLE 79. The total sample of fish used in these two tables is the same; the subsamples of TABLE 82 are selected exactly in the order the fish appeared when the sample was taken, whereas the subsamples of TABLE 79 were selected systematically such that the first of the six fifty-fish subsamples contains the first fish, the seventh, the thirteenth, etc. Observe that in TABLE 82, compared

TABLE 82—Relative number 3_2 among natural, non-systematic subsamples of varying magnitude, Point Roberts purse seine catch of August 12, 1953.

	Number in Sample			
	50	100	150	300
Per cent 3_2 in Subsamples	32.0	40.0		
	48.0		41.3	
	44.0	53.0		48.7
	62.0			
	60.0	53.0	56.0	
	46.0			

with TABLE 79, the subsample variation in percentage is more than three times as great among the fifty fish subsamples, about twice as great among the one hundred fish subsamples, and about three times as great in the one hundred fifty fish subsamples. Theoretically a variation of 16.7 per cent, which was exhibited by one of the six fifty-fish subsamples, should occur only two to five times in one hundred trials. The occurrence once in six trials is three to eight times as often as should occur by chance alone. In TABLE 82 there are variations from the mean of 7.4 per cent and 7.3 per cent in the two subsamples of one hundred fifty fish. This amount of variation should occur by chance in less than one-third of trials, whereas here it occurred twice in two trials. Obviously the 3_2 were *not* randomly distributed within the fish from which the sample was selected as would conventionally be expected. This is the case even though the fish had been mixed together no less than five times: first in the brailer as they were taken from the purse seines, second as they were dumped into the holds of the boats, third as they were transferred to the holds of the cannery tender, fourth as they were pitched onto the conveyor belt to be carried into the cannery and fifth as they fell into the fish bin in the cannery. The only explanation seems to be that fish of different sizes such as these do not distribute themselves randomly within a mixed body of fish.

A second example of heterogeneity in a case where homogeneity would be expected was found in the course of sampling for the 5_3 age group fish at Chilko River in 1954. A sample of 1,077 Chilko River adult sockeye was taken as the run passed Siwash Bridge; 26.3 per cent were found to be 5_3. A second sample of 1,058 adults from the same run was taken from dead spawned fish on the Chilko River spawning ground; 25.8 per cent of these were 5_3. A third and smaller sample of 205 adult sockeye was taken from live fish of the same population at Chilko River during the population enumeration tagging program. Practically the entire population was present on the spawning ground at this time and spawning had not yet begun, so the whole population was available for sampling. This tagging sample was composed of 34.6 per cent 5_3, thus differing by about 9 per cent from the population figure of about 26 per cent. By mathematically calculated expectation, assuming that live fish can exhibit mathematical randomness, a variation of this magnitude would occur in only three cases out of one thousand from a sample of this size. Difference in length is not responsible for this non-random stratification because the 1954 Chilko River 5_3 sockeye were approximately the same length as 4_2 (see TABLE 46).

A third example of non-random distribution of attributes was found in analysing the sex ratio of smolts from various areas (TABLE 63). If variations in sex ratio are due to sampling chance alone there are certain maximum probable variations to be expected from samples of given magnitude.

It was found that the unweighted mean of the per cent males from the twenty-two available samples of TABLE 63 was 50.6 per cent. To test the extent of variability the assumption was made that the true or universal value was 50 per cent. The deviations of the individual samples from 50 per cent were found, together with the probabilities of occurrence of variations of the determined magnitude if the universal value were in fact 50 per cent. Seven of the twenty-two samples exhibited variation of extent which should occur less than five times per hundred trials if the true per cent males of the populations from which the samples were taken were actually 50 per cent. This amount of variation occurred 6.4 times as frequently as it should have if there were no stratification.

As further test of the variation the samples were all combined, which is the same as calculating a mean per cent males from a weighted mean of the values for all samples. A value of 51.7 per cent males was obtained. The assumption was made that the true or universal value was 52 per cent males. Thereupon the deviations of the individual samples from 52 per cent were found together with probabilities of occurrence of variations of the determined magnitude if the universal value were in fact 52 per cent. It was found that 6 of the 22 samples exhibited variation of the extent which should occur less than 5 per cent of the time if the true values of the populations from which the samples were taken were actually 52 per cent. This amount of variation occurred 5.5 times as frequently as it should have if randomness were completely inherent. To say that this variation occurs more than it should assumes that there are no actual significant differences in sex ratio among populations.

Obviously the variations are due to some factor or factors other than sampling chance alone because the actual values differ considerably from expected values. The variations occurring in the three examples outlined above can be lessened by careful sampling: *1.* estimates of the percentage of jacks in commercial catch samples can be improved by increasing sample sizes or by systematic sampling, *2.* estimates of the proportion of 5_3 among adults at Chilko River are better taken from dead spawned fish than from live fish on the spawning ground, and *3.* more accurate smolt sex ratios can be established sampling periodically through the run and weighting these samples by daily abundance. It may be concluded that calculation of confidence limits based on an unquestioned assumption of inherent mathematical randomness may lead to considerable error in that attributes of fish populations cannot be *a priori* assumed to be random even though this assumption conveniently allows the free use of mathematical analysis.

SUMMARY

This study is an extension of the primary findings of C. H. Gilbert, with particular emphasis on the collection and examination of scales and the substantiation of previous assumptions regarding interpretation of age and growth. The findings will be applied in the development and implementation of fundamental concepts in the scientific management of Fraser River sockeye salmon. The practical application will include primarily *a.* identification of unit-stocks ("races") in commercial fishery catches by examination of the fresh water growth zones of scales—to measure accurately the catch of each unit-stock in each fishing area, *b.* determination of the relationship between fresh water growth and adult survival by examination of the fresh water growth zones of scales collected from specific spawning grounds, and *c.* calculation of the total production from given spawnings through age analysis.

Scale samples may be collected from juvenile sockeye, from commercial catches of jacks (precocious males) and adults, and from spawning ground populations. The scales, with corresponding length and sex data are placed in specially designed books in the field, to be subsequently mounted by the plastic impression method. By examining these plastic mounts with a *Promar* projection microscope an experienced observer can age and measure the lacustrine growth zone of 150 to 200 adult scales per hour.

Scales first form on naturally-incubated juvenile sockeye when they have attained a fork length of about 38 millimeters (hatchery fry about 31 millimeters), and they continue to grow throughout the growing life of the fish. The nuclear area of the sockeye scale represents growth attained during one and sometimes two years of fresh water residence prior to seaward migration. Seaward migration usually occurs shortly after a period of retarded scale growth, but the scales of some fish exhibit fresh water growth beyond the winter check. The fresh water scale growth zone is shown to be distinguishable from the sea water growth zone by the results of a controlled seawater rearing experiment. The ability of untrained observers to interpret and measure fresh water growth from adult scales was tested, and the results showed that differences of opinion occurred which were apparently of a random nature. A similar test of repeated interpretations by an experienced observer yielded remarkably consistent results.

The growth of juvenile sockeye scales is closely correlated with the growth of the body, therefore the measured nuclear growth of adult scales is a valid index of the early life fresh water growth. Enumeration of circuli and measurement of scale radius, scale diameter, or scale area are all accurate in representing juvenile growth, but, specifically, enumeration of circuli along the ventral 20° radial line of the scale is most efficacious. Radius measurement would, however, be more efficient in measuring sea growth.

In collecting and analysing scales for the study of growth and racial population dynamics it is necessary to design sampling procedures which will supply adequate and consistently representative samples. The several factors which influence fresh water growth study of Fraser River sockeye scales are discussed herewith:

1. Scales of sockeye first begin formation on the body near the lateral line in the zone below the dorsal and adipose fins, and the fastest development continues in this zone. Because of this adult scales to be used for nuclear growth studies are always taken from a fixed position on this part of the fishes' bodies.

2. Possible net selectivity for different lengths of fish would have no effect on estimates of lacustrine growth from scales of adults or jacks *within* unit-stock populations because there is no correlation between lacustrine growth and length at maturity of 3_2 and 4_2 within populations. However, since there are slight differences among races in length of adults and jacks, commercial fishing gear selectivity would affect estimates of unit-stock composition in commercial catch samples. To avoid any error resulting from selectivity the catch of each type of fishing gear must be sampled separately. If only one sample can be taken from a fishing area on a single day it should be from that type of gear which takes the greatest number of fish, and gill net samples should be from the catches of several boats having a representative distribution of net mesh sizes.

3. As demonstrated by comparisons made with both smolts and adults, differences in lacustrine growth between sexes are so insignificant that lacustrine growth data of males and females may be combined for any practical application.

4. Considerable variations in length and weight among periods of the runs occur during smolt seaward migrations, but variations in mean lacustrine scale growth of adults during periods of spawning runs are not consistent and apparently represent random sampling variations. Both smolts and adults exhibit little variation in lacustrine growth during the period of peak abundance occurring in the central portions of the migrations. Since the greatest numbers of fish are then present it is advisable to sample during the peak of the migration or, on the spawning grounds, during the peak period of dying.

5. Differences in lacustrine scale growth occur among different age groups of the same unit-stock which have had concurrent residence in the same lake. Adult 4_2 exhibit greater lacustrine scale growth than the smolts of which they had been part, and 3_2 exhibit greater lacustrine scale growth than the 4_2 of the succeeding migration year. As exemplified by Chilko Lake two-year smolt scales and adult 5_3 scales, compared with concurrently resident one-year-olds, juvenile two-year-olds attain much less growth per year during the first year of lake residence and somewhat less growth during the second year than the concurrently resident one-year-olds. Extrapolation of growth values between different age groups of concurrent lake residence cannot be accomplished accurately without the use of correction factors.

6. Adult scale studies show that growth of juvenile sockeye residing in the same lake can fluctuate in growth by more than 50 per cent between years, and differences in growth between lake rearing areas can approach 100 per cent. These fluctuations, together with evidence of change in growth with transplantation to new rearing areas, indicate that fresh water growth is strongly influenced by ecological conditions. Since lacustrine growth of Fraser River sockeye is neither necessarily constant from year to year nor necessarily the same among different stocks, each area must be sampled every year.

7. As determined by considering both sampling theory and empirical data, samples of about two hundred readable scales are adequate for unit-stock spawning ground lacustrine growth analysis. In commercial fishery unit-stock segregation analyses samples of about two hundred scales per day from each general fishing area are adequate when only two or three unit-stocks are involved, but samples of about four hundred per day are desirable when the run is more complex.

Age composition must be assessed to determine the total production of adults from given spawnings, and close study of variation in age composition of certain populations may assist in the study of dynamics of these populations. Proof of the validity of age interpretation from scales is given by the recovery of marked fish of known early life history and known age at recovery; this direct evidence is supported by circumstantial evidence of differences in size among age groups. For age determination scales may be taken from any part of the fish's body, but the scales formed near the lateral line and in the zone below the dorsal and adipose fins are the most regular in shape.

After feeding and body growth ceases, sockeye scales are progressively absorbed and determination of age therefrom becomes impossible. Scale absorption does not extend into the nuclear area, and, therefore, does not affect the identification of two-year-in-lake types. In lieu of determining the ages of spawning stocks from scales it is necessary to study length frequencies or otoliths. In spite of some variations in snout development among different spawning populations and different age groups, age composition can be adequately determined from length frequency analyses. The age composition of each sex must be determined separately for adults because males are of greater mean length. Although fork length measurement is easier and more accurate it is necessary to measure standard length (tip snout to posterior hypural plate) on dead spawned fish because the caudal fins are worn away during redd digging.

Since sockeye otoliths are not absorbed to the extent that scales are age by enumeration of the translucent zones can be determined for dead spawned fish. Otolith age determination requires more sampling effort than length frequency analysis, but it is somewhat superior because it establishes the age of each individual fish.

Irrespective of whether age composition is determined from scales, length frequencies, or otliths there are several factors which influence age sampling of Fraser River sockeye; these factors are discussed herewith:

1. Size selectivity of commercial fishing gear strongly affects age composition analyses. Gill nets (either nylon or linen) take a much lower percentage of jacks than purse seines or reef nets do, and those jacks taken by gill nets are of greater average length. Disproportionate selectivity of particular unit-stock populations of jacks on the basis of length is indicated for purse seines, although the effect is much less than that of gill nets. Among linen gill nets the percentage of 5_2 increases with increase in mesh size. A comparison of relative numbers of 5_2 between concurrent purse seine and nylon gill net catches in 1956 showed no significant or consistent differences between the

two types of gear. Representative age sampling requires that the catch of each markedly different type of commercial fishery gear be sampled independently, and that live spawning grounds samples are not taken with some selective type of catching device.

2. On some Fraser River spawning grounds differences in availability of spawned carcasses occur both between sexes and among length and age groups within sexes. This condition does not exist in every area, indicating that it is a function of the physical characteristics of each particular spawning ground. Every spawning area should be investigated for this condition, and where it is found to exist the dead recovery samples must be weighted so that they are representative of the whole spawning population.

3. Variation in age composition by time during runs of unit populations of smolts, jacks, and adults differs among populations, and even among years for the same unit-stock. Among smolts the percentage of two-year-olds can be markedly variable over a seasonal migration period, with two-year smolts tending to migrate earlier than yearlings. The 3_2, 4_2, 5_3, and 5_2 age groups all vary in relative numbers by time in one area or another within the Fraser watershed. To obtain the most representative age composition estimate it is necessary to sample throughout the run either in proportion to the numbers present or at a constant level and weigh each sample afterward by the relative abundance at the time the sample was taken. However, sufficiently accurate estimates can usually be obtained by taking one sample at the peak of the run.

4. Analysis of sex ratios of smolts indicates that difference in age composition between sexes is so slight as to be practically unimportant. Jack sockeye from the Fraser River are preponderantly males, whereas there is little difference in percentage of 5_3 between sexes, but females have a higher percentage of 5_2 than males in at least one Fraser River population. Differences in 5_2 composition between sexes on spawning grounds can be attributed to prior selectivity in the commercial fishery and may not have existed in the total unfished population. In sampling areas where differences in age composition exist between males and females the data for each sex must be analysed separately.

5. The age composition of Fraser River sockeye is not necessarily the same for different populations in the same year nor the same from year to year for a given population. Thus this attribute must be sampled in every year and for each area separately.

6. An individual sample size of two hundred to five hundred fish is adequate to keep the variation of age composition estimates within reasonable limits; samples of greater than five hundred fish do not reduce the variation enough to warrant the additional effort being expended to acquire and analyse the larger samples. The daily sample size may be reduced to the lower limit of two hundred fish when successive samples are being taken, as in commercial fishery catch sampling; whereupon subsequent smoothing by three day moving averages seems to give good results.

7. Only when all possible influencing factors are accounted for can mathematical limits of confidence be accurately calculated; the attributes of fish populations cannot be *a priori* assumed to be random.

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