2014

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Identification of Stocks of Pacific Salmon by Means of Scale Features

INTRODUCTION

The scales of Pacific salmon (*Oncorhynchus* spp.) hold an impressive amount of information. Their surfaces bear a sculptured record of the growth experience of the individual fish. Properly interpreted, this record enables us to determine the age and the area of origin of the fish. It is our objective here to: (1) show the features of salmon scales and their relation to the life history of the different species; (2) outline the methods for collecting, preparing, analyzing, and interpreting the scales of Pacific salmon; (3) survey the methods in which data derived from scales have been used to identify stocks of Pacific salmon; and (4) discuss the future of scale analysis in stock identification and other studies.

Initially we will describe the general features of salmon scales and show how these features are related to the life history of the different species. Development of scales of teleost fishes, a matter so capably detailed by Elson (1939), Neave (1940), Welander (1940), and Wallin (1957), will not be reported here.

We can begin by envisioning the upper surface of the anterior field of a scale as a series of concentric ridges called circuli, striae, or sclerites. Figure 1 shows plan and cross-sectional views of a sockeye salmon (*O. nerka*) scale. Note how the circuli in the cross-section resemble rose thorns or saw teeth, separated by relatively flat interspaces.

Growth of the scale roughly parallels growth of the fish but the two need not be exactly synchronized. Scales begin as a single small central platelet soon after the fish become free-swimming, the exact size depending on the species and individual fish but usually being from 2 to 6 cm (total length). Generally, circuli that are laid down in the late spring and summer – when the fish is growing rapidly, are more elevated and more widely spaced than those that are laid down in the autumn and winter – when the fish is growing slowly. Circuli laid down during autumn and winter are collectively known as annular rings or marks. The exact amount of time involved in laying down circuli and interspaces is unknown.

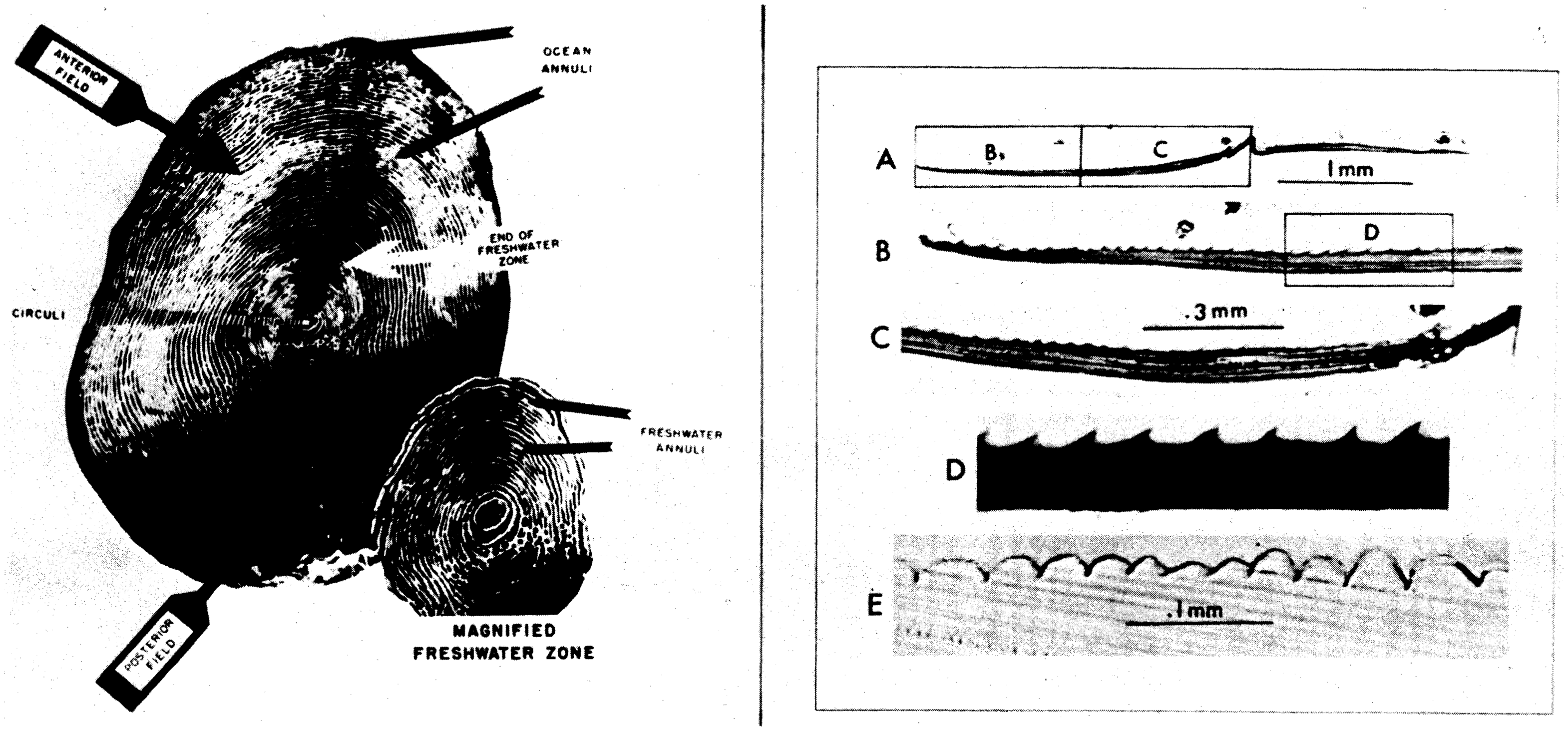

FIGURE 1

COMPLETE SOCKEYE SALMON SCALE, SECTIONS OF A SOCKEYE SALMON SCALE AND A PLASTIC IMPRESSION OF A SCALE.
LEFT: COMPLETE SOCKEYE SALMON SCALE.
RIGHT: SECTIONS (FROM KOO AND FINN. 1964).
A. LONGITUDINAL SECTION OF THE ENTIRE SCALE ALONG THE ANTERO-POSTERIOR AXIS THROUGH THE FOCUS.
B. PART B IN FIG. A, ENLARGED.
C. PART C IN FIG. A, ENLARGED SAME AS FIG. B.
D. PART D IN FIG. B, ENLARGED.
E. SECTION OF PLASTIC IMPRESSION, ENLARGED SAME AS FIG. D.

On scales of the species of salmon that have a freshwater residence before going to the ocean (sockeye; coho, *O. kisutch;* and chinook, *O. tshawytscha,* salmon), the circuli formed in fresh water are finer and closer together than those formed in the ocean. Sometimes a few circuli are formed between the typical freshwater and ocean zones. These circuli, intermediate in spacing and height, are called "plus growth." "Plus growth" appears to be distinctive of certain stocks from limited areas, such as from individual

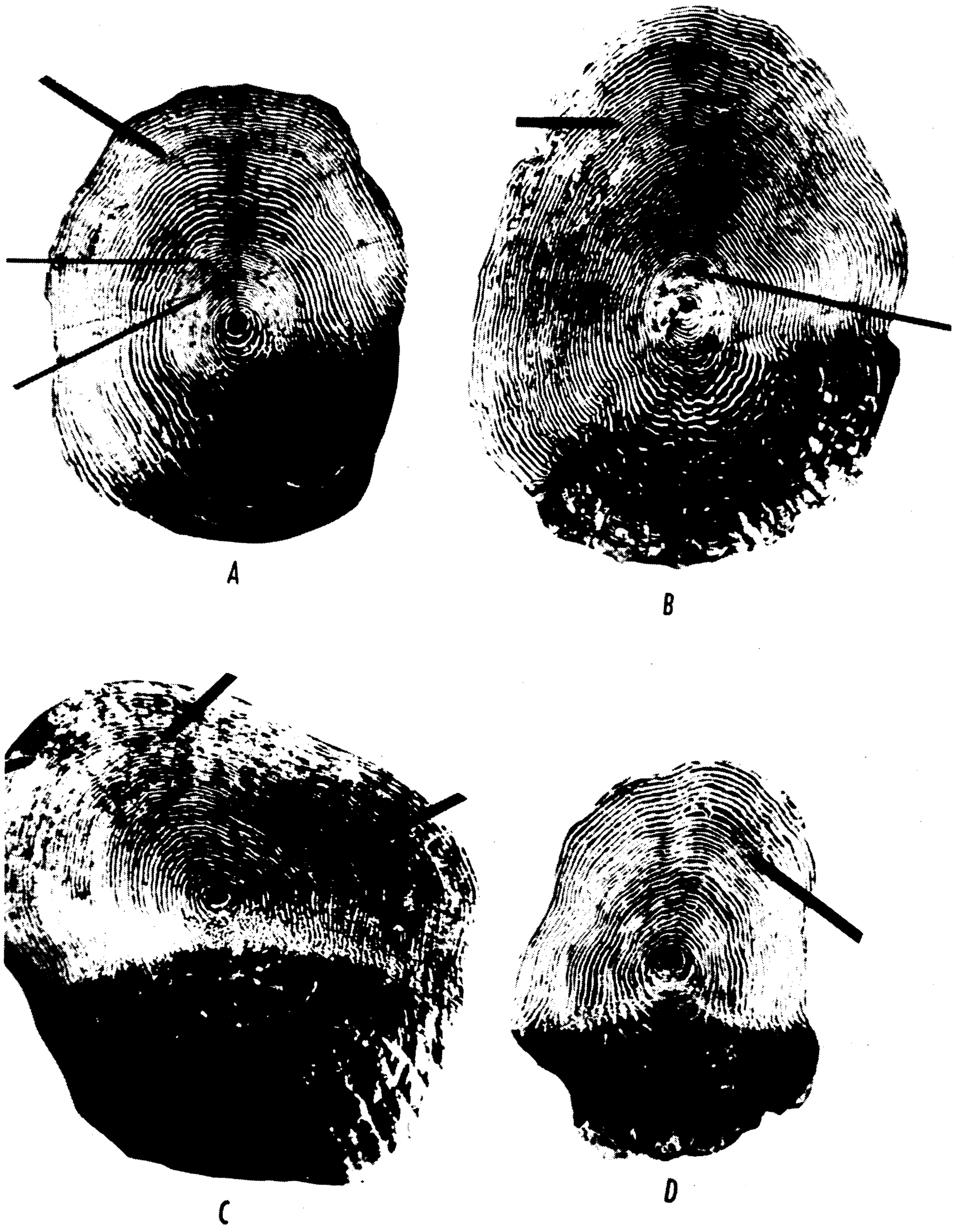

FIGURE 2 – SALMON SCALES
A. SOCKEYE SALMON, B. COHO SALMON, C. CHUM SALMON, D. PINK SALMON (NARROW POINTERS INDICATE FRESH-WATER WINTER ZONES; WIDE POINTERS, OCEAN WINTER ZONES).

tributaries. Scales of fish that go directly to salt water after hatching, (pink, *O. gorbuscha*, and chum, *O. keta*, salmon), show rapid growth of ocean type circuli immediately from the central plate outward. Scales of sockeye, coho, chum, and pink salmon are presented for comparison in Figure 2.

The outer edges of scales of Pacific salmon deteriorate during migration to the spawning ground. Because this deterioration occurs at the same time that the fish ceases to feed and grow and at a time, therefore, when the fish is drawing on its stored body constituents to sustain itself, the deterioration of the scale is called resorption. Resorbed scales are of little or no value for determining age, but may be used in certain stock identification studies.

Up until the approach of spawning, then, scales portray a growth record of the individual fish – a record as complete as any mechanical tracing, but a record that requires interpretation. Interpretation is often difficult.

COLLECTION AND ANALYSIS OF SALMON SCALES AND THE PRINCIPAL FEATURES USED FOR STOCK IDENTIFICATION

To minimize the difficulties in interpreting salmon scales and the accompanying sources of error, scientists who work with the scales have developed standardized procedures for collection, storage, and analysis. The more important procedures will be presented here as an aid to other scientists who may wish to initiate studies of fish scales. The most commonly used scale features will also be reviewed.

Collection and analysis of scales

One important standardization in the collection of salmon scales is the designation of an optimum zone of the body from which the scale should be taken, or even the designation of a "preferred" scale. This is desirable because scales vary with body area. Scales develop first in the "A" zone (see Figure 3) of sockeye salmon and are, therefore, the oldest and most complete scales on the fish. Whenever possible, scales collected for study under the auspices of the INPFC (International North Pacific Fisheries Commission) are taken from the "A" zone – the "preferred" scale if possible. Scientists from the U.S.S.R., on the other hand, take scales from the area of the fish designated as the "C" zone by the INPFC. When comparing data derived from scales taken from different body zones, one obviously must be aware of potential differences attributable to the body zone itself. Sex, time of sampling, and brood year are examples of other features according to which scale characters may vary. The effects of these variables must be assessed for each study.

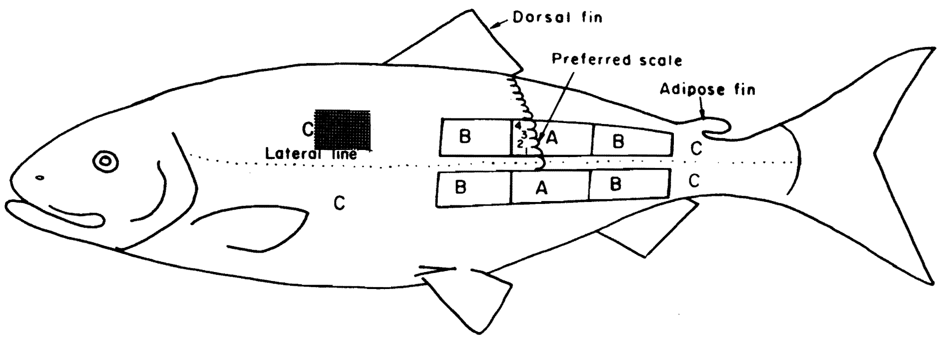

FIGURE 3
LOCATION OF "PREFERRED SCALE", AND BODY ZONES A, B, AND C. CROSS HATCHED AREA IS POSITION FROM WHICH U.S.S.R. WORKERS TAKE SCALE SAMPLES (KROGIUS, 1958).

A standard procedure for collecting, preparing, and analyzing scales is used at the National Marine Fisheries Service (N.M.F.S.) North Pacific Fisheries Research Center. The scale is removed from the fish and placed on a gummed card (a 3 x 5-inch [75 x 125-mm] strip of white gummed paper). Scales from 40 fish may be placed on each card. Cards are labelled and from them impressions are formed onto plastic (0.020-inch [0.75-mm] thick, transparent cellulose acetate). Up to 8 or 10 plastic impressions can be made from the original gummed scale card. Images of impressions are studied by projecting the impressions through a microscope. Magnification varies, depending on the type of information required; counts and measurements are usually made at 100 X. Gummed cards, scale press, plastic impressions, and scale projector are shown in Figure 4. Clutter and Whitesel (1956) and Koo (1962a) described the details for making scale impressions; Mosher (1950) described a typical scale projector.

Principal scale features used for stock identification

In studies with Pacific salmon, a scale character is any feature of the scale that might help to identify the mainland area where the fish originated. A character can be a count (the number of circuli in a prescribed area of the scale, the number of annular rings etc.), a measurement, a ratio of counts or measurements, or something considerably more subjectively appraised – such as the texture (coarseness of circuli) or general appearance of the scale. Techniques for obtaining scale characters should be standardized as much as possible.

Some generalizations can be made about the scale characters of Pacific salmon. Scale characters vary widely by coastal region; those varying most are the: (1) number of winter and summer growth zones, (2) features of the freshwater zone, (3) features of the ocean zone, and (4) appearance of the circuli of the scale. Let us examine sockeye salmon scales in terms of these characters, noting differences for the other species where appropriate.

Number of winter and summer growth zones

As mentioned earlier, an annular ring or mark is formed each autumn-winter season. These zones can be counted to determine the age of the individual fish. In the southern portions of their ranges, sockeye and chum salmon tend to mature at a younger age than in the northern areas. For example, most sockeye in the Fraser River spawn at age 1.2[1] (4_2)[2]; those in western Alaska spawn at ages 1.2 (4_2), 2.2 (5_3), 1.3 (5_2), and in some years, 2.3 (6_3). Asian sockeye salmon tend to spawn at ages 1.3 (5_2), 2.3 (6_3), and even 3.3 (7_4). These differences can aid in apportioning samples containing mixed stocks into their component parts, e.g., to region or continent or origin. Age composition of mature pink and coho salmon is of little use in this regard as all pink salmon and most coho salmon spawn after only one winter at sea.

1 The European method of age designation as recommended by Koo (1962b): the number of winters the fish spent in fresh water from the time of hatching is noted to the left of the dot, the number of winters spent in the ocean to the right.

2 The Gilbert and Rich (1927) method of age designation: the Arabic numeral to the left indicates the number of winters from spawning of the parents to capture. The right-hand digit, usually written in subscript, indicates the winters from spawning of the parents to seaward migration. Because the fish do not form scales until after the first winter in the gravel, the number of winters of growth is one less than shown by the age formula, but the fish is in the indicated year of life. To assign a fish to its parent brood year, subtract the first digit from the year of capture; e.g., a fish of age group 5_3 caught in 1965 was produced by the spawning in 1960 and migrated to the ocean in 1963. Scientists of the U.S.S.R. use a modified Gilbert and Rich system in which the age is computed from hatching instead of spawning of the parents (Krogius, 1958).

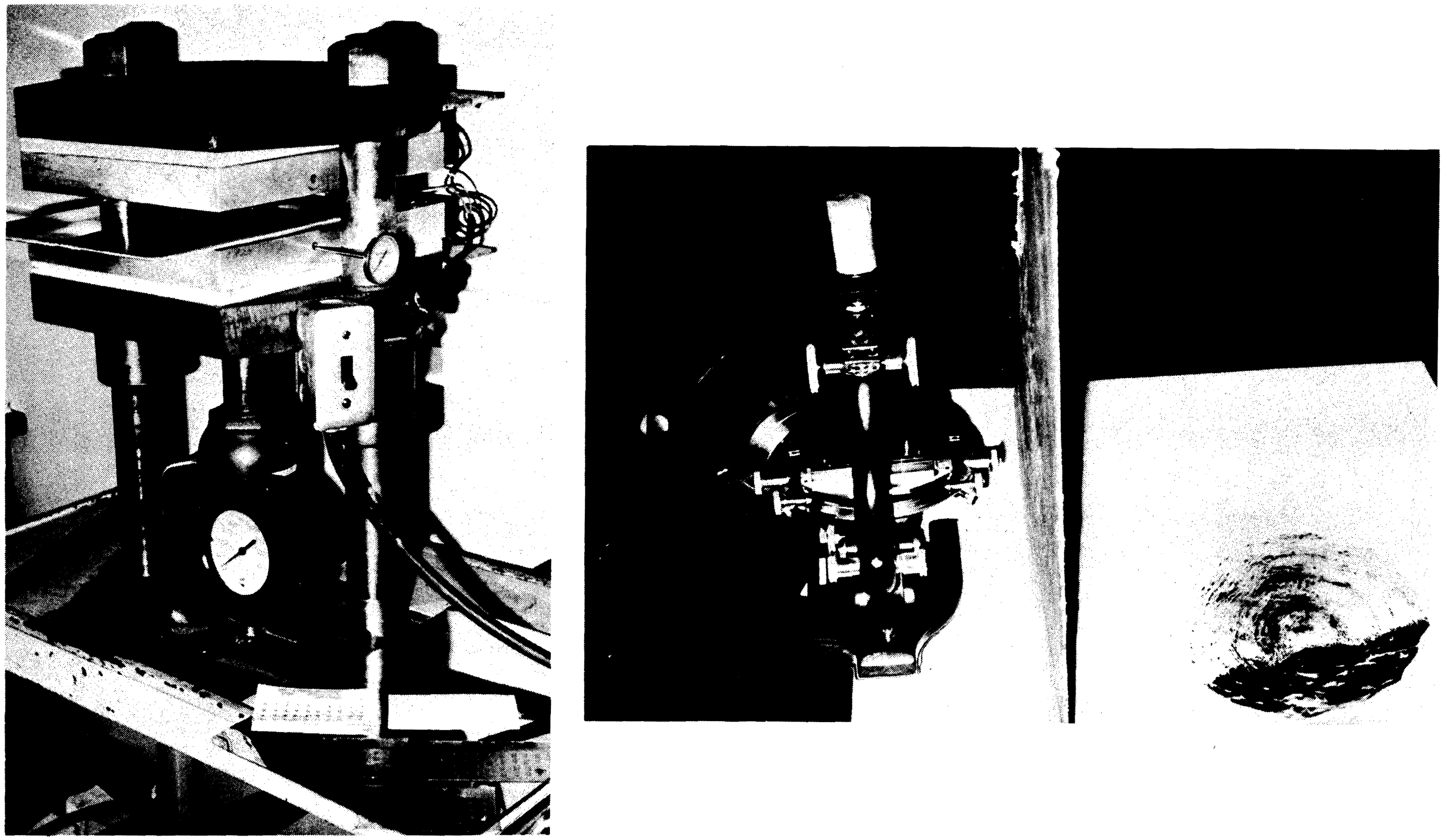

FIGURE 4 – SCALE PRESS AND SCALE PROJECTION DEVICE.

LEFT: SCALE PRESS, SHOWING GUMMED CARDS WITH SCALES AND PLASTIC CARD WITH IMPRESSIONS.

RIGHT: SCALE MICROPROJECTOR, SHOWING ARRANGEMENT OF THE LAMP, MICROSCOPE AND PRISM (IN HOLDER), AND MIRROR TO PROJECT THE IMAGE OF THE SCALE TO THE WHITE SCREEN.

Features of the freshwater zone

The number of circuli in the freshwater zone and the size of the zone vary by area for both sockeye and coho salmon. A portion of sockeye salmon scales from Dalnee Lake, Kamchatka (U.S.S.R.), Cook Inlet, the Nimpkish and Columbia Rivers, have distinctively large freshwater zones. Scales from adjacent areas, on the other hand, might have small freshwater zones with few circuli. The variation noted in coho salmon is less, yet some coho from Cook Inlet have unusually large freshwater zones. Scales of this type can be assigned to their most probable area of origin by their general appearance. Scales of sockeye salmon with very large and very small freshwater zones are shown in Figure 5.

Features of the ocean zone

The number of circuli in the ocean zones of sockeye, chum, coho, and pink salmon varies in a cline from the highest number in the southern portions of the range on each continent to the lowest number in the Bristol Bay-Aleutian Island-Kamchatka areas. Sockeye scales from four areas are shown in Figure 6.

Spacing of the circuli within the ocean zones varies by area of origin. The widest spaced circuli of the first ocean zone of sockeye salmon from Bristol Bay, for example, are usually near the freshwater zone, whereas those of the Asian fish are usually near the first ocean winter mark, or at least some distance from the freshwater zone. This difference provides the basis for one method of determining the continent of origin of sockeye salmon taken in the Japanese mothership fishing area in the North Pacific Ocean and Bering Sea (Anas and Murai, 1969). Scales of fish originating southeastward from Bristol Bay tend to have more uniformly spaced circuli in the first ocean zone than those from either Bristol Bay or Asia. Scales of the other species also have variations in the spacing of circuli in the ocean zones, but the relation of these variations to area of origin has not been studied as extensively as with sockeye.

Appearance of the circuli of the scale

Variations in the appearance of circuli of scales from fish of a particular area are apparent to an experienced scale analyst. Fish from certain areas may have scales of a distinct texture or general appearance. For example, nearly all sockeye from Rivers and Smith Inlets and some sockeye from the nearby Nimpkish River, B.C.; pink and chum salmon from Ketchikan, Alaska, southward; and some coho salmon from Puget Sound, Wash., southward have scales with two zones of distinctly different texture. The freshwater and first-ocean zone are of fine texture and the subsequent zones are of coarse texture. These scales can be identified to area of origin at a glance. In contrast to these scales with a finely textured central area, scales of four species (sockeye, chum, coho, and pink salmon) from the Bristol Bay, Alaska, and Kamchatka, U.S.S.R., areas have a rather "open" appearance produced by coarse, well spaced circuli and relatively clear interspaces throughout the entire scale except for the winter zones.

To this point we have described several types of qualitative differences that can be seen in the scales of Pacific salmon. In the next section we will see how these differences have been used to identify some stocks of salmon.

A REVIEW OF STUDIES TO IDENTIFY STOCKS OF SALMON BY SCALE CHARACTERS

Now that we have a basic understanding about the scales of salmon, it is appropriate to survey the studies in which scales have been used to identify stocks of Pacific salmon. Because these efforts are exemplified by the studies with sockeye salmon, we will consider this species first, then move on to pink and chum salmon. There are no published records

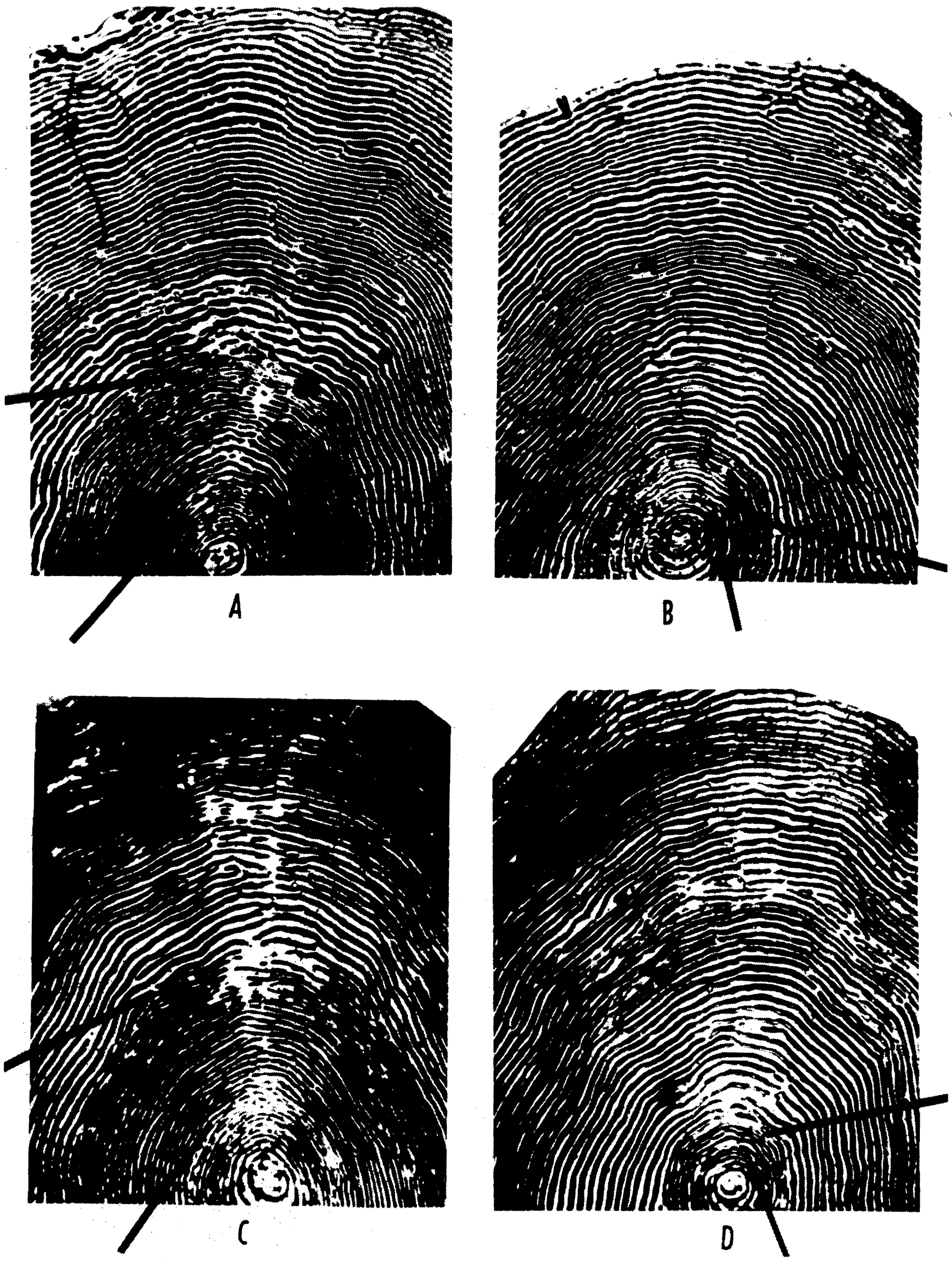

FIGURE 5
FRESH-WATER ZONE OF SOCKEYE SALMON SCALES TAKEN FROM FISH FROM VARIOUS SPAWNING AREAS.
A. DALNEE LAKE, KAMCHATKA PENINSULA; B. BLIZHNEE LAKE, KAMCHATKA PENINSULA; C. COLUMBIA RIVER, WASHINGTON AND OREGON; D. COPPER RIVER, ALASKA.

of concerted efforts to identify stocks of either coho or chinook salmon by differences in scale characteristics.

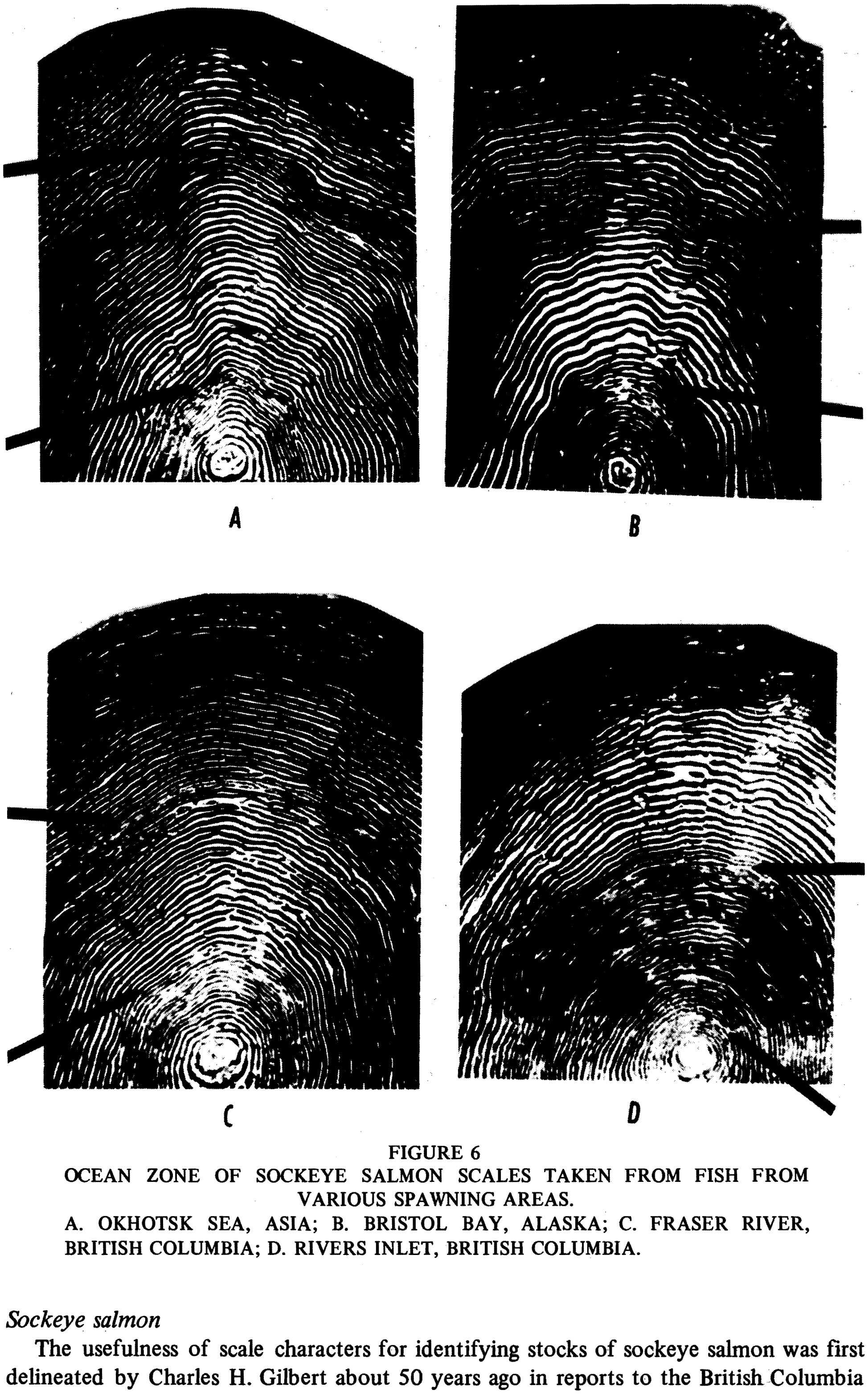

FIGURE 6
OCEAN ZONE OF SOCKEYE SALMON SCALES TAKEN FROM FISH FROM VARIOUS SPAWNING AREAS.
A. OKHOTSK SEA, ASIA; B. BRISTOL BAY, ALASKA; C. FRASER RIVER, BRITISH COLUMBIA; D. RIVERS INLET, BRITISH COLUMBIA.

Sockeye salmon

The usefulness of scale characters for identifying stocks of sockeye salmon was first delineated by Charles H. Gilbert about 50 years ago in reports to the British Columbia Fisheries Department. Gilbert observed differences in the freshwater growth zones of scales of sockeye salmon from the various spawning-rearing areas of the Fraser River watershed in British Columbia, Canada. Nearly a quarter-century later the International Pacific Salmon Fisheries Commission incorporated Gilbert's findings into a comprehensive scheme for identifying and managing the units of Fraser River sockeye salmon. Henry (1961) described the method.

First, the frequency distribution of the number of circuli in the freshwater zone of each major run is determined. This information is obtained from out-migrants or from fish of the same brood year that have returned a year or more earlier, from jacks for example. Next, samples from the fishery are aged and the frequency distribution of the freshwater circuli count for each age group in each sample is smoothed. Finally, the smoothed count is separated into racial components.

Table I and Figure 7 portray a hypothetical example of how the system works. In the example, we know from earlier tagging studies that only three major races – A, B, and C are present. For race A, the range of circulus counts is 8 to 22, the mean is 15, and the shape of the curve is such that the frequency of circulus count 15 is approximately 3 times that of circulus count 11. A quasi-normal curve fulfilling these requirements is superimposed on the frequency curve from the fishery sample. This procedure is repeated for races B and C, the height being controlled by the requirement that the combined area occupied by curves A, B, and C must equal the area under the sample curve.

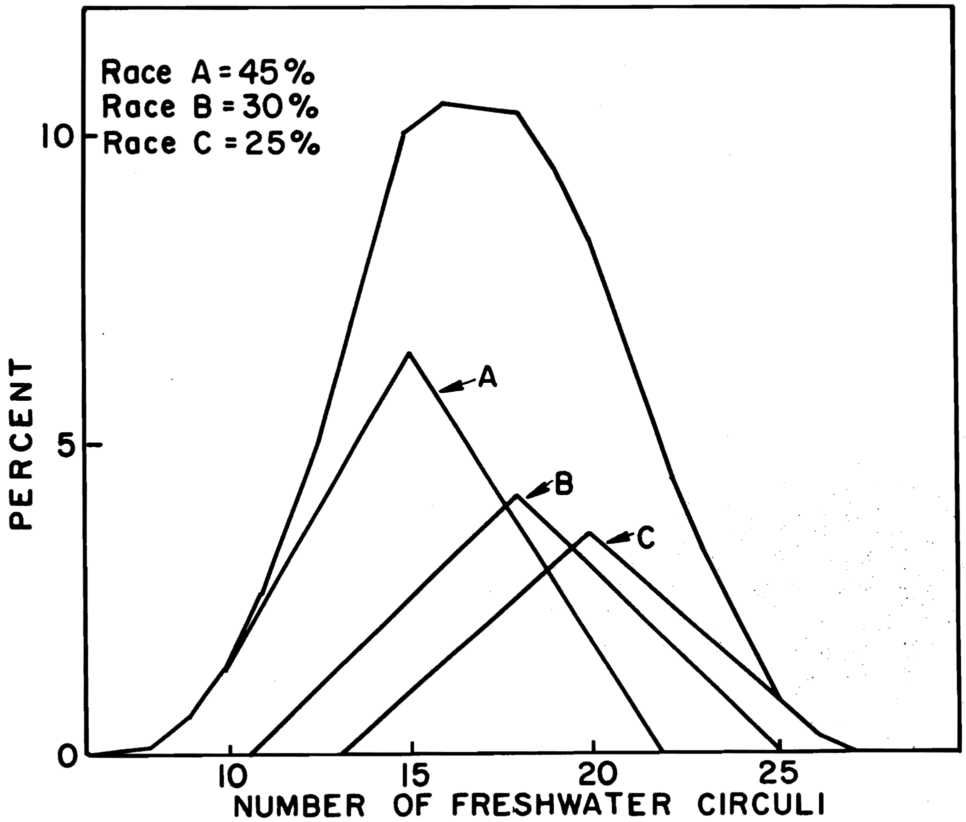

FIGURE 7
SMOOTHED FREQUENCY DISTRIBUTION (BELL-SHAPED CURVE) OF CIRCULI FROM A HYPOTHETICAL SAMPLE OF SOCKEYE SALMON TAKEN IN THE FISHERY, AND THE ESTIMATED FREQUENCY DISTRIBUTION OF THE THREE RACES (A, B, AND C) EXPECTED TO BE PRESENT. DATA APPEAR IN TABLE I. SEE TEXT FOR FURTHER EXPLANATION.

TABLE I

FREQUENCY DISTRIBUTION OF CIRCULI COUNTS ON THE SCALES OF 3 HYPOTHETICAL RACES OF SOCKEYE SALMON AND HOW THEY ARE USED TO ESTIMATE THE ABUNDANCE OF THE 3 COMPONENT RACES IN A MIXED FISHERY SAMPLE KNOWN TO CONTAIN ONLY THOSE THREE RACES; THE SMOOTHED PERCENTAGES OF THE FREQUENCY DISTRIBUTION OF THE FISHERY SAMPLE AND THE ESTIMATED DISTRIBUTION FOR THE 3 RACES ARE SHOWN IN FIGURE 7. (FROM HENRY, 1961).

	Year (N)						*Year (N + 1)*				
	Samples of age 3_2 sockeye taken on the spawning grounds						*Sample of age 4_2 sockeye taken in the fishery*		*Fishery sample (adjacent columns) broken into racial components on basis of age 3_2 spawning ground samples year (N)*		
Number of circuli	*Race A*		*Race B*		*Race C*						
	Number of fish	*Smoothed %*	*Number of fish*	*Smoothed %*	*Number of fish*	*Smoothed %*	*Number of fish*	*Smoothed %*	*Race A*	*Race B*	*Race C*
		0.29						0.13			
9	1	1.44					5	0.64	5		
10	3	3.45					15	1.54	15		
11	5	5.75		0.51			25	2.73	25		
12	7	8.05	2	2.04			41	4.22	35	6	
13	9	10.34	4	4.08		0.21	57	5.92	45	12	
14	11	13.22	6	6.12	1	1.24	75	8.08	55	18	2
15	15	14.94	8	8.16	4	3.31	107	9.99	75	24	8
16	11	13.22	10	10.20	7	5.79	99	10.45	55	30	14
17	9	10.34	12	12.24	10	8.26	101	10.40	45	36	20
18	7	8.05	14	13.27	13	10.74	103	10.30	35	42	26
19	5	5.75	12	12.24	16	13.22	93	9.58	25	36	32
20	3	3.45	10	10.20	19	14.46	83	8.24	15	30	38
21	1	1.44	8	8.16	16	13.32	61	6.41	5	24	32
22		0.29	6	6.12	13	10.74	44	4.66		18	26
23			4	4.08	10	8.26	32	3.30		12	20
24			2	2.04	7	5.79	20	2.06		6	14
25				0.51	4	3.31	8	0.98			8
26					1	1.24	2	0.31			2
27						0.21		0.05			
Total	87		98		121		971		435	294	242
Mean	15.00		18.00		20.00				45%	30%	25%

It is apparent that the shapes of the racial curves, the mean circuli counts, and the ranges are very important for the application of this method. Even with this information, it is frequently necessary to depart from the stylized triangle-shaped curves to achieve a complete apportionment of the sample curve into its racial components. Experience and extensive auxilliary information about the timing of the runs are also essential to this method.

The accuracy of the method was examined on a theoretical basis and then on an empirical basis through paired analyses and results from test fishing. Comparison of the estimated racial percentages of the same samples by independent observers indicated that the method yielded reliable results. The closeness of the estimated and actual enumerated escapements further verified the accuracy of the method.

The International Convention for the High Seas Fisheries in the North Pacific Ocean in 1953 stimulated a multi-faceted research program to determine the distribution of different stocks of salmon on the high seas. Scale studies to determine continent of origin of sockeye salmon were part of this effort. Scores of papers resulted but only a few have described methods for classifying samples into continental components and then gone on to estimate the accuracy of the method. This is an essential step in making the delicate transition from the qualitative to the quantitative stages of investigation. We will discuss three of these papers here.

Mosher (1963) used freshwater age and two other scale characters to classify sockeye to continent of origin. For fish that had spent 2 or 3 years in freshwater, he used circuli counts in the freshwater zone and in the first ocean zone. For 4-year fish he used the sizes of these zones.

The classification procedure was straightforward. Bivariate frequency tables were constructed for each freshwater age group in each standard population. The standard populations were from Kamchatka and western Alaska, the only areas assumed to contribute significant numbers of sockeye to the critical Japanese mothership fishing area. Bivariate tables for a particular freshwater age group were superimposed to determine their relation (Table II).

Cells were marked N for western Alaska or A for Asia; cells with no fish were marked N′ or A′ depending on the designations of adjacent cells; and empty cells where it was impossible to make a decision were marked D for doubtful. Individual fish were assigned accordingly and summed to obtain the proportion of Asian and western Alaska sockeye in each sample. These values were adjusted by the error of classification that occurred in the standards. Unweighted error was 21% in 1956 and 14% in 1957 – the two years investigated.

Margolis, Cleaver, Fukuda, and Godfrey (1966) concluded that, in general, the bivariate method of determining origin of high seas sockeye provided reliable results.

Anas and Murai (1969), using scale characters in a discriminant function analysis, further quantified the identification of sockeye taken on the high seas. Their work culminated earlier studies (Anas, 1963; 1964) in which a comprehensive screening of 32 characters indicated three to be useful in distinguishing western Alaskan from Asian sockeye. The selected characters were: the number of circuli in the first half of the first ocean zone and the distances between circuli 1 and 6 and 13 and 18 in the first ocean zone.

TABLE II

CONTINENTAL DETERMINATION CHART OF MOSHER (1963) FOR SOCKEYE SALMON CAPTURED IN 1967 THAT HAD LIVED IN FRESH WATER FOR 3 YEARS (A, OF PROBABLE ASIAN ORIGIN; N, OF PROBABLE WESTERN ALASKAN ORIGIN; AND D, CONTINENT OF ORIGIN DOUBTFUL).

Number of circuli in fresh-water zone	Number of circuli in first ocean zone																	
	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
8																		
9																		
10							A	A′	A′	A	A	A	A′	A′				
11						A	A	A	A′	A′	A	A	A′	A′				
12					A	A	A	A	A	A′	A	A	A	A	A′			
13					A	A	A	A′	A	A	A	A	A	A′	A′			
14					A	A	A	A	A	A	A	A	A	A	A			
15					A′	A	A	A	A	A	A	A	A	A	A	A′		
16					A	A	A	A	A	A	A	A	A	A	A′	A′	A	
17					A	N	A	A	A	A	A	A	A	A	A	A	A′	A′
18				N	N	A	A	A	N	A	A	A	A	A	A	A′	A′	A
19			N	N	N	N	N	A	N	A	A	A	A	A	A′	A	A′	A′
20			N	N	N	N	N	N	N	N	N	A	A	A	A′	A′	A′	A′
21			N	N′	N	N	N	N	N	N	N	A	A	A	D	A′	A′	A
22		N	A	N	N	N	N	N	N	N	A	N	A	A′	N	A	A′	
23		D	N	N	N	N	N	N	N	N	N	N	A	A′	A	A′		
24		D	N	N	N	N	N	N	N	N	N	N	A	A	A′			
25		A	N	N	N	N	N	N	N	N	N	A	A′	A′				
26				N′	N	N	N	N	N	N	A	A′	A′	A				
27				N	N	N′	N′	N′	N	A	A′	A′	A					
28					A		N	N′			A′	A′						
29								D			A							
30								A										

The discriminant function is a statistical tool for classifying individuals from mixed samples into their natal populations. A set of measurements and counts from an individual is reduced to a single value by which the individual is assigned to one group (in this case – either Asian or western Alaskan). The discriminant function computed from the 1957 data, for example had a breaking point of 1.051; fish having a larger score were classified as Asian, those having a lower score were classified as western Alaskan.

Mean discriminant scores for various river systems in the two standard areas and for high seas samples – taken near the Asian mainland and assumed, therefore, to represent Asian stocks – are shown in Figure 8. In practice, individual fish are assigned to one population or the other, their numbers summed to obtain the observed proportion of Asian and western Alaskan fish present; they are then adjusted by the errors of classification found in the standard populations. Error of classification has averaged 23% over a 12-year period, 1956-67.

Fredin and Worlund (MS. 1970) utilized a commonly used scale character – age – to classify sockeye salmon taken in the Japanese mothership fishery to their continent of origin. They divided the mothership fishing area into three time areas; one assumed to contain only Asian sockeye; another, both Asian and western Alaskan sockeye; and the third, only western Alaskan sockeye. There is abundant evidence to support these assumptions. Figure 9 shows the areas and dates before and after which Asian and western Alaskan fish are assumed to be intermingled or segregated in the Japanese mothership fishing area. Mature and immature populations are treated separately. Age composition from the area of intermingling is compared with those from the standard areas to estimate the proportion of Asian and western Alaskan sockeye present.

The difference between the point estimates of the percentages of maturing western Alaskan sockeye in the catches in the area of intermingling and their respective lower or upper confidence limits is about 15% for the big cycle years of the Bristol Bay runs and about 25% for the low years. For immature sockeye, the average difference is about 20%.

Pink Salmon

From the INPFC research, a dozen or so papers have been published on the scale studies of pink salmon. Most of these involved variations of a single scale character – the number of circuli in the first year zone and the spacing of circuli near the center of the first year zone. Analysis almost always involved the comparison of mean values and frequency distributions. Two of the studies are summarized here.

The Fisheries Research Board of Canada (1967) reported a key based on the number of circuli and the width of the first year scale band to classify pink salmon sampled in the Gulf of Alaska as being from either the Alaskan or British Columbia-Washington State areas. The scales of many fish were intermediate and, therefore, unclassifiable. To estimate the percentage of pinks originating in either area that would be correctly classified, the samples of known origin were processed through the key as if they were of unknown origin, that is as if they were taken at sea. Results: about two-thirds of the pinks originating in the Fraser River and central British Columbia areas were classified as British Columbia-Washington State type. The percentages of British Columbia-Washington State type fish from farther north in British Columbia were lower. Pinks from the areas along the northern shore of the Gulf of Alaska were more accurately identifiable as Alaskan type than were those from southeastern Alaska and Prince William Sound. The ability to type high seas samples to region or origin ranged from good in some areas to poor in others.

Pearson (1967, 1969) also endeavored to classify samples of pink salmon taken in the eastern North Pacific Ocean to their region of origin. He used the distance from the

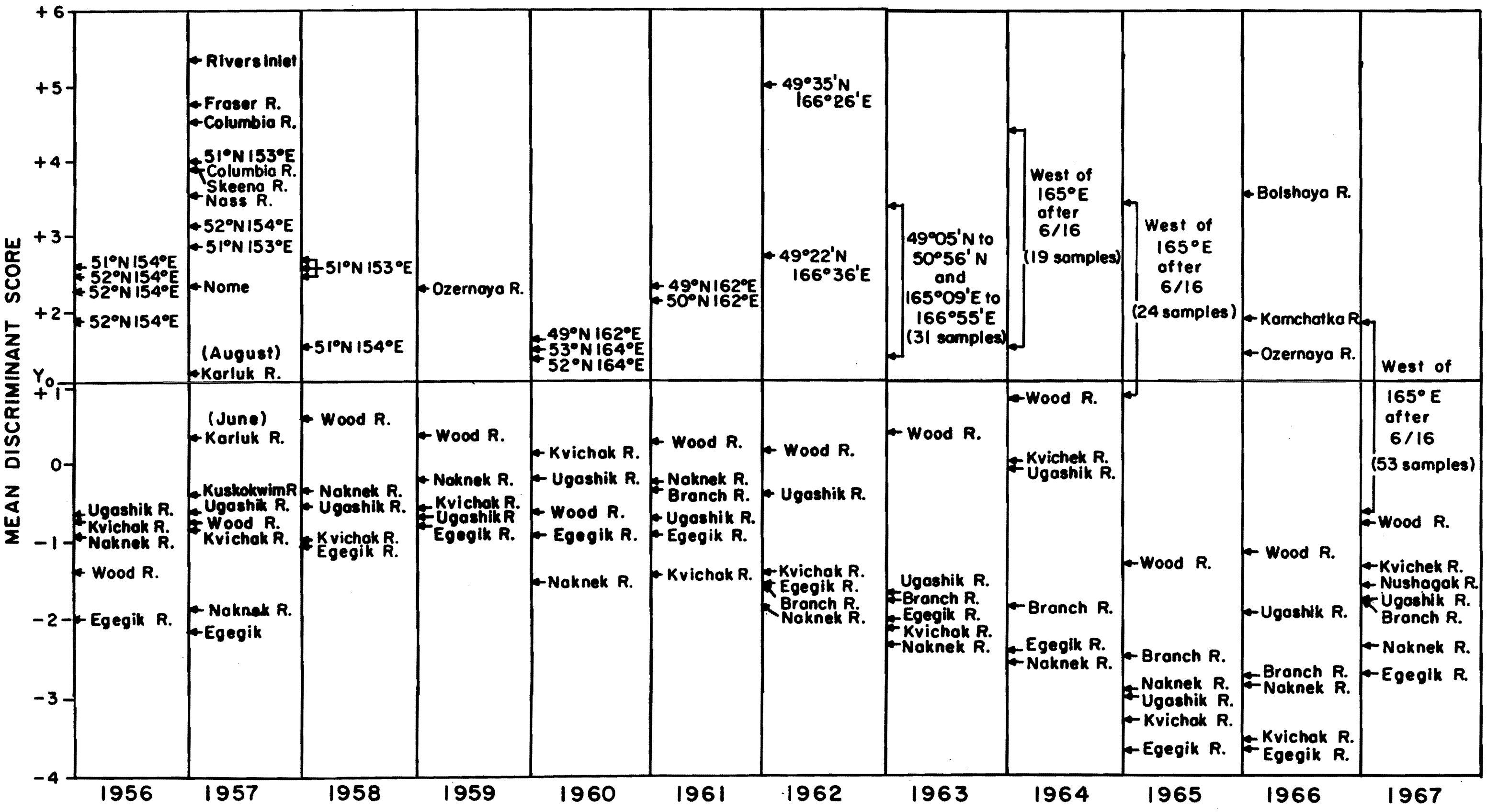

FIGURE 8

LINEAR COMPARISON OF MEAN DISCRIMINANT SCORES FOR SAMPLES OF SOCKEYE SALMON COLLECTED FROM WESTERN ALASKA AND ASIAN COASTAL AREAS, 1956-67, AND OTHER NORTH AMERICAN AREAS, 1957. THE DISCRIMINANT FUNCTION WAS COMPUTED FROM DATA COLLECTED IN 1957. (FROM ANAS AND MURAI, 1969.)

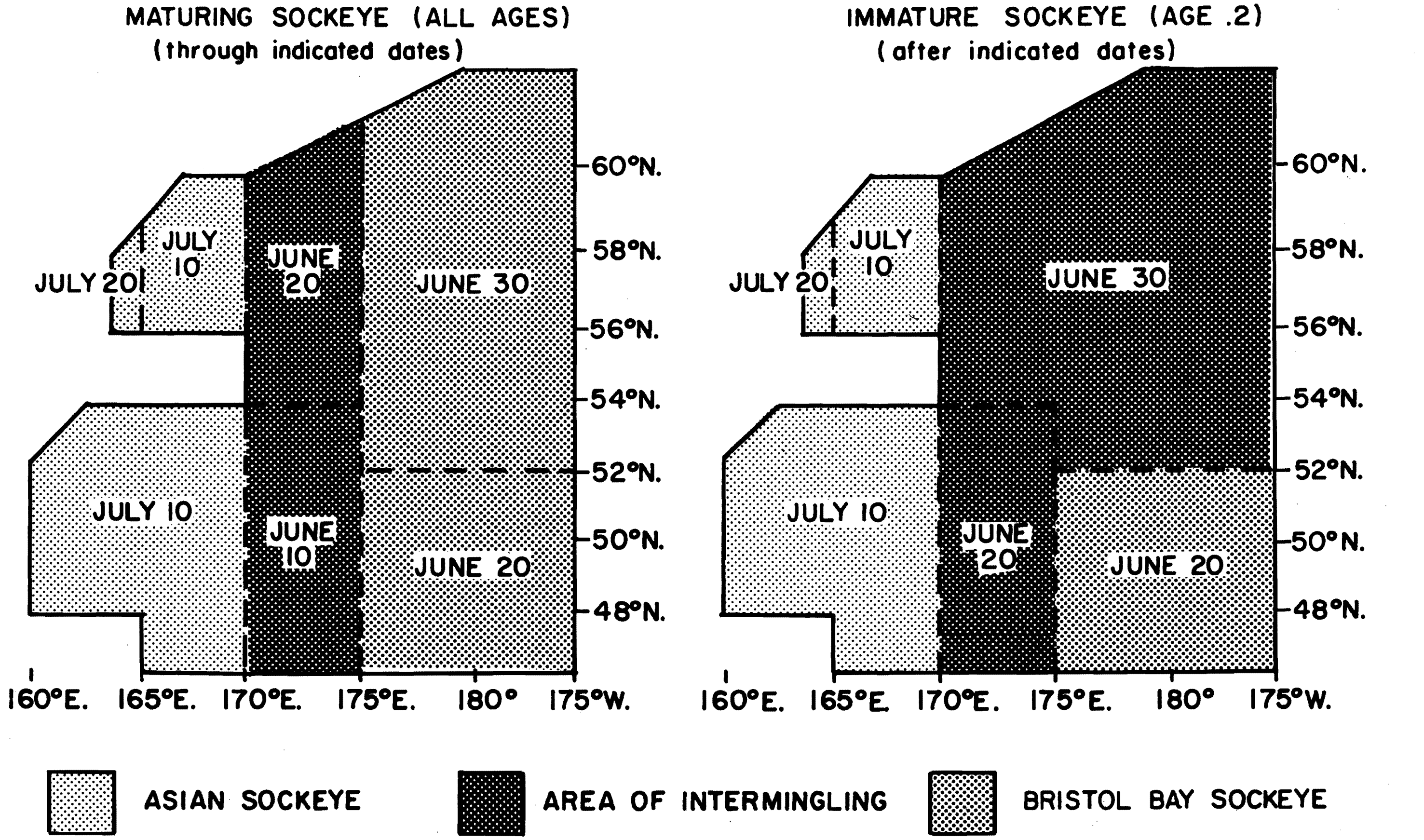

FIGURE 9
AREAS AND DATES BEFORE AND AFTER WHICH ASIAN AND WESTERN ALASKAN SOCKEYE SALMON ARE ASSUMED TO BE INTERMINGLED OR SEGREGATED IN THE JAPANESE MOTHERSHIP FISHING AREA. (FROM FREDIN AND WORLUND, MS, 1970.)

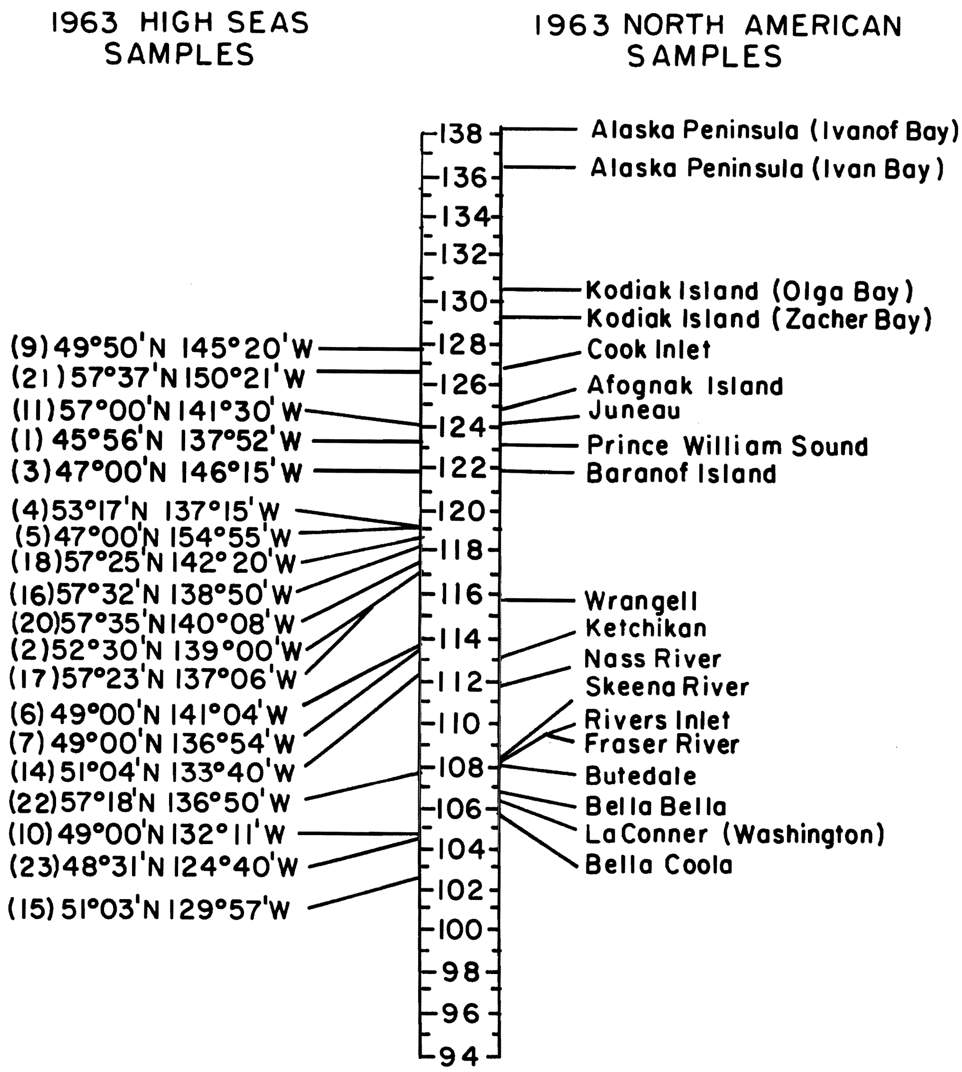

FIGURE 10
COMPARISON OF MEAN VALUES OF THE WIDTH FROM CENTER OF FOCUS TO 30th CIRCULUS, 1963 NORTH AMERICAN AND HIGH SEAS SAMPLES OF PINK SALMON. (FROM PEARSON, 1969.)

center of focus to the 30th circulus. Because standard deviations of the selected character for samples from inshore spawning areas did not exceed 11 in any given year, Pearson automatically considered all high seas samples with a standard deviation greater than 11 to be of mixed stock and unclassifiable to a particular region.

Mean values from high seas samples with standard deviations less than 11 and from North American coastal samples taken in 1963 are shown in Figure 10. Of the high seas samples examined, 19 had means similar to mean values observed in inshore regions; 4 could not be associated with any particular region.

Chum Salmon

Chum salmon have also been the subject of a broad research program under the auspices of the INPFC. Several authors have reported differences in the scale patterns of chums originating in different areas. The methods of using these qualitative differences vary. Sato (1959) used "probability" graph paper to divide polymodal frequency distributions into component unimodal distributions. Tanaka, Shepard, and Bilton (1969) used a key method similar to that described by the Fisheries Research Board of Canada for pink salmon. Differences were not great enough to identify all individuals. Some could be identified to one of four regions, some to continent, other not at all. The efficiency of this procedure was determined by processing through the key, chums of known origin as if they were of unknown origin. Results: British Columbia-southeastern Alaskan chums were identified to area of origin 60% of the time; northern Alaskan chums, 18%; fish from the Soviet Union, 29%; and from Japan 7 to 43%, depending on brood year.

These examples barely scratch the surface both in the number of papers written and the extent to which they have been examined. They have been brought forth essentially to stimulate further inquiry.

FUTURE OF SCALE ANALYSIS IN STOCK IDENTIFICATION AND OTHER STUDIES

We will now look at the status of the salmon scale reading art to see how it might be made more objective and its potential more fully developed.

Use of scales to interpret biological statistics about a fish has advantages over other methods. Scale samples may be collected rapidly; without killing or mutilating the fish, they may be converted to scale impressions cheaply and stored or distributed at low cost. In recent years the use of plastic impressions has become almost universal around the Pacific Ocean rim and has virtually eliminated the comparatively expensive process of hand mounting scales on glass slides. Impressions have one singular advantage over scales – they are easier to read because mucous and much of the debris found on the scale does not transfer to the impression. The use of "preferred" scales has led to more consistency in results obtained by scale readers at different laboratories.

Limitations of present scale reading procedures

While the use of preferred scales and plastic impressions has become common and while equipment for projecting scales or impressions has improved over the years, the methods of reading scales are essentially those used by Gilbert in the early years. The interpretation is still largely by visual subjective criteria. Differences in results between readers are common and results of repetitive reading by a single reader may be different. When quality controls are imposed to make results acceptable, reader output drops – the more rigid the controls the less the production.

Most experienced readers can read ages from 400 to 1,000 impressions or read characters from 100 to 200 scales per day depending on the quality of impressions, complexity of the characters, and somewhat on origin of the fish. In some situations (Henry, 1961) up to 200 per hour may be read. In general, however, the reading process is so slow the results cannot be used in day to day fishery management.

Training a scale reader may take from 3 to 6 months and must be followed with periodic examinations of the techniques and data of the reader. Some people are not temperamentally suited to read scales day after day. Thus the time spent in training is wasted when they go to other jobs or an undue amount of time must be spent on quality control.

Most scale readers are of the considered opinion that if information on the scale could be extracted faster, scales would have a greater utility in fishery management. However, efforts to improve the utility have been frustrated by the rate at which scales can be read. Some experimental reading in our laboratory to extract all possible information from a scale required about 1½ man hours per scale to read and transcribe the results for analysis. However, once this time consuming process is finished, information can be rapidly analyzed by computers. Ages can be determined, characters may be defined and rapidly exploited to maximize the opportunities to determine origin, and other possible uses may be explored. As an example, some of our studies indicate that it may be possible to predict sexual maturity of sockeye salmon. If this could be done, the information could be used in predicting the size of returning runs in a particular year. Also, if scale growth-fish growth could be pursued rapidly, biomass assessments could be made. Obviously scales are not being fully utilized.

Approaches to the machine reading of scales

The ultimate objective in scale reading is to read a scale once to get all information that is needed to determine age, origin, maturity, and growth. It is also desirable to do this and to make the analysis on the day the scale is collected. In order to accomplish this objective, it will be necessary to replace criteria that are often subjective with objective criteria and to develop some kind of scale reading machine. If such a machine can be found, it must produce data at a rate which will offset the cost of the machine and operating personnel. Resulting data should be consistent and preferably comparable with results obtained by human readers.

Machines that might be used to read scale impressions include surface roughness analyzers, densitometers, and optical scanning devices. Other possibilities include ultrasonic and laser devices, although none are known at the present that may be applied to scale reading problems.

Surface roughness analyzers

Surface roughness analyzers (profilometers) move a stylus on a single line across an object and give an electrical signal proportional to the changes in elevation of the stylus. The signal may be amplified and filtered and the results presented on a strip chart recorder.

A commercial profilometer was used at our lab on a number of pink and sockeye salmon scale impressions. An example of part of a strip chart recording from a trace made across the center of the focus of the impression along part of a selected axis is shown in Figure 11. A single tracing across an impression required about 1 man hour. After the trace was completed, freshwater and ocean growth zones had to be identified before height of circuli could be measured. No criteria could be found to dependably identify these zones from the strip chart alone. It was finally accomplished by matching the strip chart with a photograph of the same magnification. Computation of the mean height was done by hand, requiring close to an hour per scale.

Differences in mean height of circuli in the freshwater growth zone and in the first year of ocean growth were found in sockeye salmon scales from three areas. The full significance of the difference was not established. Although further studies of circulus height may have some merit, they will have to await the development of faster methods of acquiring and processing the data.

Densitometers

Densitometers use a light sensitive element that is either moved across an object or the element is fixed and the object is moved. The element gives an electrical signal that is proportional to the amount of light present in a small area.

In the early 1960's, Dr. Julius Rockwell of our lab worked on the development of a densitometer using a photoelectric cell to scan an enlarged image of a salmon scale. Problems in instrumentation and in interpreting the machine output were encountered which could not be resolved at the time and the investigation was

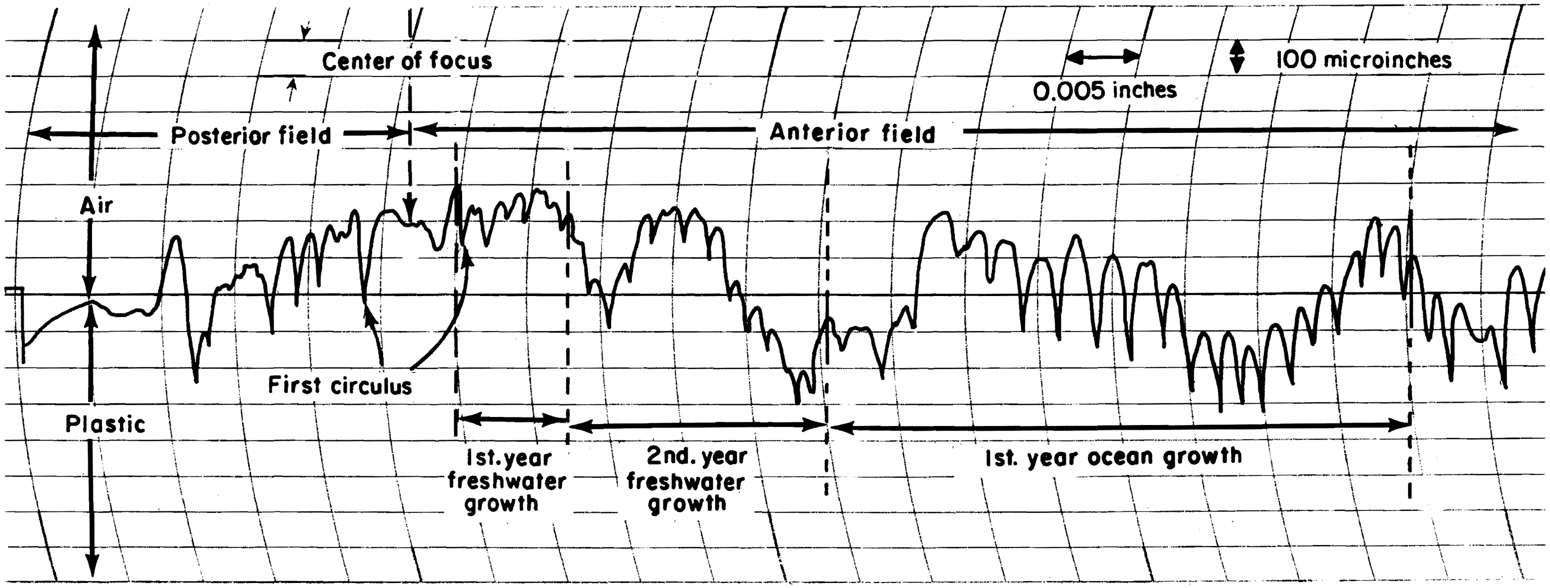

FIGURE 11
TRACE OF SURFACE ROUGHNESS OF A PLASTIC IMPRESSION OF A SCALE FROM A SOCKEYE SALMON SHOWING HEIGHT OF CIRCULI IN FRESHWATER GROWTH ZONES AND FIRST YEAR OF OCEAN GROWTH.

terminated. Today there are a number of different densitometers available commercially which could be adapted to read photographic negatives of scales. These instruments are comparatively slow, requiring several minutes per scan. In practice it is probable that multiple scans would be required as well as machine methods of processing the data.

In 1965, Kuroki and his associates (Kuroki, Kyushin, Kawashima, and Sato, 1965) reported the results of a study of a semiautomatic scale reading recorder that they developed around a densitometer. Their densitometer used a cadmium sulphide cell, both as a fixed and as a moving element. Changes in electrical signal strength were amplified and filtered. An example of basic machine output is shown in line AA of Figure 12 and as a partially processed signal in line BB. The latter was further processed to identify circuli and annuli. While an acceptable degree of agreement between human and machine determined ages was achieved, the differences in rate of production of results between human and machine were marginal. The machine could not be used to read characters due to errors in identifying circuli.

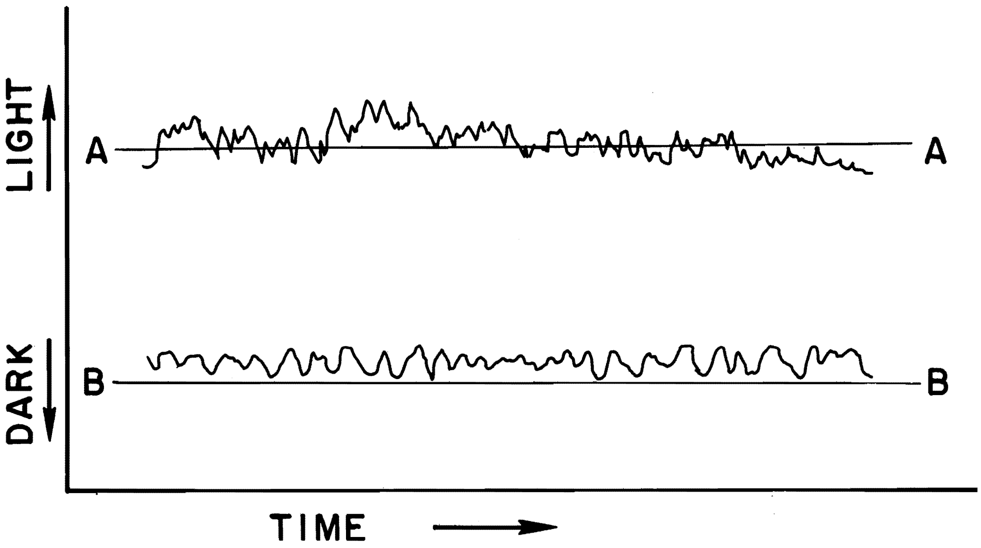

FIGURE 12
EXAMPLE OF UNFILTERED (AA) AND FILTERED (BB) OUTPUT FROM SEMIAUTOMATIC SCALE READING RECORDER USED BY KUROKI *ET AL.,* 1965.

Optical scanners

In the last 10 years, developments in the technology of taking, transmitting, and presenting pictures from outer space suggest that the time may now be at hand when scales can be machine read. After a review of the approximate costs and capabilities of various types of scanning devices, our lab acquired a computer controlled optical scanning system. The machine has been altered and is currently being programmed to accommodate some of the problems encountered in semiautomatic machine reading of plastic impressions of salmon scales. As presently used, the operator selects a readable plastic impression and places it on the stage of a microscope. While viewing the image on a Fresnel screen, the operator orients the image so that the desired scale reading axis and "start to read" point lies on a target etched on the screen. An image splitting mirror in the microscope diverts the image seen by the operator onto the face of a camera, an image dissector tube.

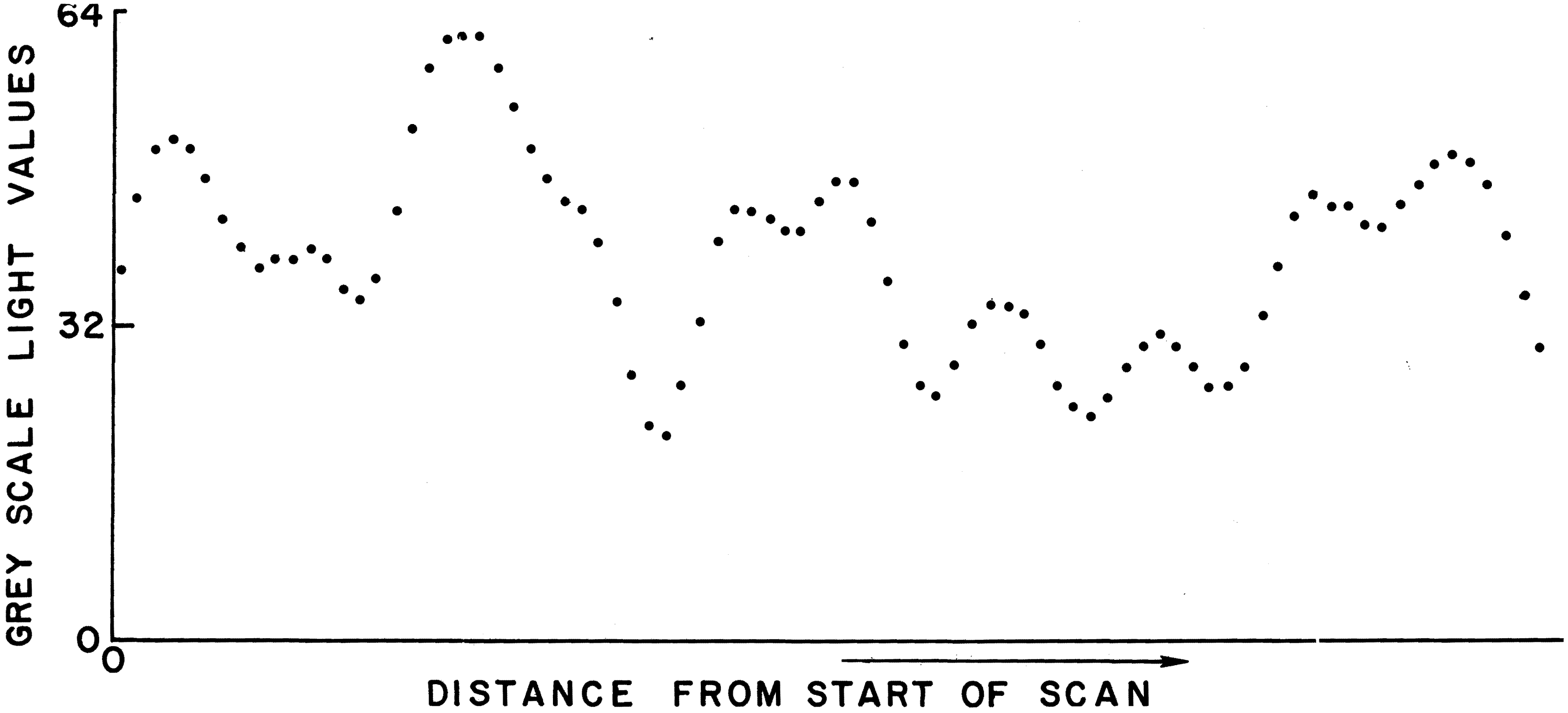

FIGURE 13
GREY SCALE VALUES FROM A SCAN ACROSS PART OF A PINK SALMON SCALE.

In response to each instruction from the computer to examine a single x, y coordinate on the image, the camera reports which of 64 possible shades of grey it recognized. The number of coordinates to be examined, their sequence, and location is directed by the operator through the computer. The results may be either printed out on paper in table or graph form, punched on paper tape, or stored in memory for analysis and output after a desired number of points have been interrogated. The camera can examine 4,096 points on the x-axis and 4,096 on the y-axis at rates of 1, 10, or 100 points per second. Figure 13 is a graph of the type of data produced by the machine after scanning from the center of the focus toward the edge of an impression of a pink salmon scale.

Rapid acquisition of grey scale values at different points immediately presents another problem, that of analysis and discrimination into identifiable features. This requires the establishment of objective criteria that will identify circuli, intercirculus spaces, annuli, fresh and saltwater growth zones, and the edge of the scale impression. These criteria must apply uniformly over a wide range of variation in quality of scale impressions; in variations in light-dark contrasts in different scale impressions and in a single scale impressions; in variations in sharpness of focus over different parts of the image; in the presence of branched, broken, or looped circuli; and in the presence of some scratches and dirt on the plastic.

As this report was being written, an evaluation was being made of a computer program designed to define, measure and count circuli and intercirculus spaces. If the results are satisfactory, they will allow programming to account for broken, branched, and looped circuli. Thereafter, programming to determine age, origin, possible pending sexual maturity, and growth can be undertaken – the sequence of the work depending on need and priorities. Ultimately, we hope to be able to completely process an impression in less than a minute.

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