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PHOTOGRAPHIC ATLAS OF SOCKEYE SALMON SCALES

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ABSTRACT

Photographic plates of sockeye salmon scales, with explanatory text, illustrate in detail the variations in scale features in this species. These illustrations of zones of fresh-water and ocean growth (and of complete scales) can be used as: (1) standards to which scales under study may be referred for determination of age and race, (2) guides in choosing scale characters for racial and other studies, and (3) aids in the training of scale scientists. Examples of regenerated, resorbed, and other atypical scales are also shown.

Sockeye salmon *(Oncorhynchus nerka)* is the most valuable species of Pacific salmon in North America and has been the subject of scientific study since the 1870's. Most of the extensive research for the INPFC (International North Pacific Fisheries Commission) by Canada, Japan, and the United States now is directed toward this species. Many of these projects use data obtained from study of the scales of sockeye salmon.

Sockeye salmon spend their early lives in fresh water, migrate to the North Pacific Ocean, and finally return to their natal streams to spawn and die. The growth zones formed on the scales record the growth of each individual fish. The fresh- and salt-water zones differ from each other in appearance. The zones can reveal the number of years that the fish spent in each environment; they also divulge the year in which the fish was hatched and the year it migrated to sea. Scale features have been used in age studies of sockeye salmon since 1910 (Gilbert, 1913). Recently, scale features have also been used in racial studies to determine the origin of fish taken at sea (Krogius, 1958; Kubo, 1958; Kubo and Kosaka, 1959; Henry, 1961; Mosher, Anas, and Liscom, 1961; Anas, 1963; Mosher, 1963; and Anas, 1964).

No detailed information has been published, however, on how to interpret the scales. The purpose of this atlas is to show the features of sockeye salmon scales in detail so that workers can interpret the scales they are working with to provide the data required in their studies.

A section on the use of the atlas in age studies and for describing scale features follows the illustrations of the scale features.

MATERIALS AND METHODS

Scientists of BCF (Bureau of Commercial Fisheries) have examined many thousands of sockeye salmon scales in recent years to supply information to the United States Section of INPFC. From these thousands I have selected certain scales to illustrate the variations in scale characters among fish. Variations may be genetic or environmental, or both, but generally many of the differences in the characters of scales are linked to geographic localities; therefore, a study of these variations offers a means of determining the mainland (racial) origin of fish taken beyond their natal streams.

For scale studies, workers of the research agencies of the INPFC (Fisheries Agency of Japan, Fisheries Research Board of Canada, and BCF) collect scales from the side of the fish as shown in Mosher, 1963. The "preferred scale" is in the second scale row above the lateral line in the diagonal scale row downward from the posterior edge of the dorsal fin. If this scale is missing on both sides of the fish, a scale is taken as close as possible to the preferred position, but not from the lateral line or the first row above or below the line.

The plates of the atlas are made from negative

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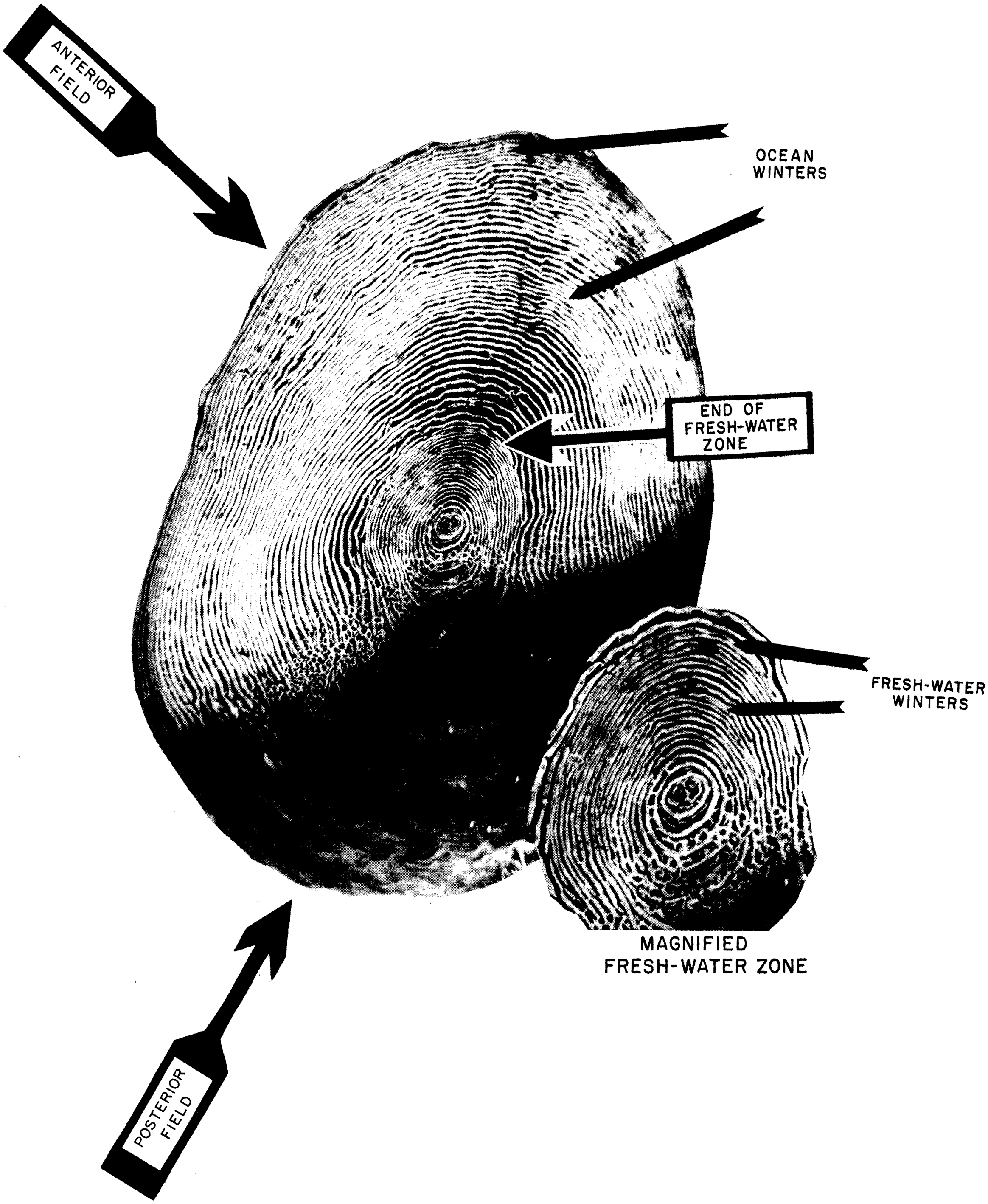

PLATE 1.—Sockeye salmon scale.

prints of projected plastic impressions of scales.[1] Explanations and descriptions of the various features accompany the plates.

The original plates were assembled on 15- by 20-inch mounting sheets. Magnification of the individual scales and scale sections was adjusted for reduction onto the usual 8- by 10½-inch page; in this reduction, however, the clarity of the scale characters varies somewhat; therefore, I suggest that the reader keep a small magnifying glass (2 to 4X) handy for examination of specific portions of the plates as needed.

Examples of negative and positive prints of scales, a comparison of scales and their plastic impressions, the appearance of scale features under various magnifications, a glossary of terms used in scale studies, and the method of making the photographs are presented in the appendix.

The following order of topics has been chosen as the most useful for study of scales from sockeye salmon:

1. Gross features of sockeye salmon scales (plates 1 and 2).
2. Circuli, winter zones, and ages in the fresh-water growth zone (plates 3, 4, and 5).
3. Transition zone between fresh-water and ocean growth (plate 6).
4. Appearance, number, and spacing of circuli, winter zones, and ocean ages in the ocean growth zone (plates 7-11).
5. Age group combinations in sockeye salmon (plates 12-16).
6. Anomalies which make some scales unusable for age and racial studies (plates 17, 18, and 19).
7. Use of the atlas.
8. Appendix.

FEATURES OF SCALES FROM SOCKEYE SALMON (Plate 1)

Under magnification, a sockeye salmon scale shows two distinct areas: (1) The anterior or sculptured field, which was embedded in the scale pocket and (2) the posterior or unsculptured field, which protruded from the scale pocket and overlapped the adjacent posterior scale pockets. The examples shown in plate 1 and plate 2 illustrate these and other gross features described below. Scales of Pacific salmon are cycloid scales.

ANTERIOR FIELD

The upper surface of the anterior field is sculptured with ridges (circuli) and grooves (interspaces). See Koo and Finn (1964) for photographs of magnified cross sections of salmon scales. Under magnification the circuli and interspaces appear as alternating light and dark concentric "rings" which result from differences in transmission of light through the grooves and ridges of the translucent scale material.[2] The contrast between circuli and interspaces varies from high (heavily marked circuli) to low (lightly marked circuli).[3] Circuli are formed on the edge of the scale as it grows (Neave, 1936; Welander, 1940; Wallin, 1957). When the scales are growing rapidly (in late spring and summer), the circuli are deposited relatively far apart and have a broad and heavy appearance and texture (as if drawn with a blunt pencil or stub-tipped pen). The periods of retarded growth (in the fall, winter, and early spring) show on the scale as bands of circuli lying closer together than the circuli of the summer growth zone. These bands have been called annual marks, annual rings, winter zones, winter checks, winter growth zones, resting zones, or annuli.[4] Where zone dimensions are needed, most salmon scale workers measure to the last circulus of this band of closely spaced circuli.

The circuli laid down while the fish is in fresh water are of finer texture than those deposited later while the fish is in the ocean (as if drawn with a sharp pencil or fine-tipped pen). This cen-

[1] See Mosher (1950) for a description of the scale projector. See Clutter and Whitesel (1956) or Koo (1962a) for a description of the method of making plastic impressions of the scales.

[2] The circuli appear as the light rings in the negative prints and the interspaces as the dark rings (see appendix plate 3).

[3] The differences in contrast between circuli and interspaces are not as evident in the photographs as they are when the scales or scale impressions are examined directly. For reproduction I have adjusted the contrast between the light and dark tones to near maximum wherever possible.

[4] Annuli of sockeye salmon scales, unlike those of most other fish, are bands of closely spaced circuli formed during the winter and early spring. The usual definition of an annulus as a line of discontinuity between successive growth zones does not describe most annuli in the ocean growth zones of the sockeye salmon scale. Such lines of discontinuity often occur between the fresh-water and ocean growth zones whether or not an annulus is present and often occur on the scale at various places not related to the presence of the bands of closely spaced circuli which form each winter.

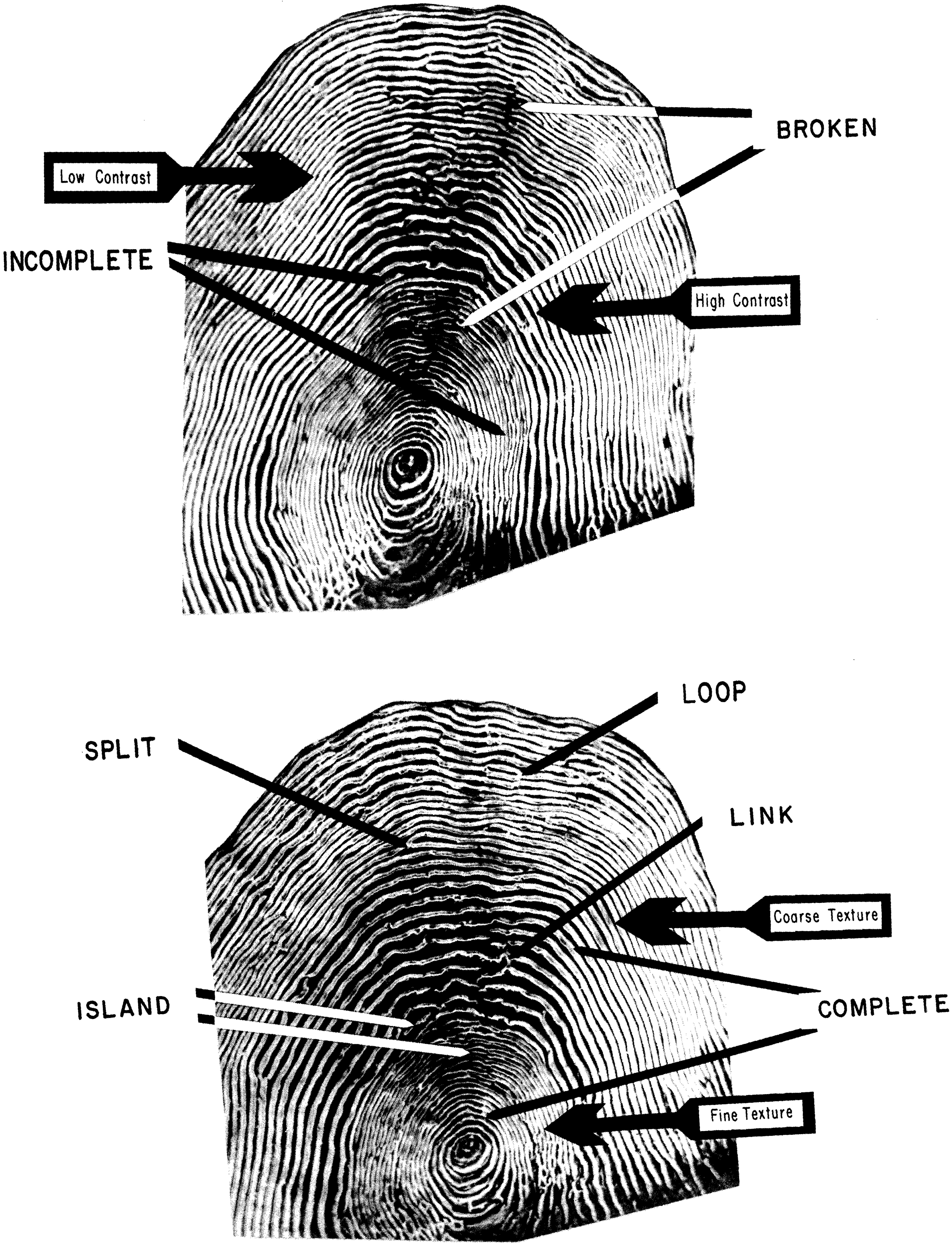

PLATE 2.—Types of circuli.

tral zone of closely spaced circuli is often called the nucleus. The area enclosed by the first circulus is called the focus of the scale or the central platelet. Only the first few circuli encircle the focus; the rest are arcs that do not extend into the posterior field.

POSTERIOR FIELD

The posterior field is a relatively clear area without distinctive growth features. It photographs black because it is uniformly translucent (see appendix plate 3).

TYPES OF CIRCULI (Plate 2)

The circuli of fresh-water and ocean growth may be described as:

1. Complete, or regular—circuli that are unbroken over most of their arc.
2. Incomplete, or irregular—circuli that are broken, split, or otherwise discontinuous in the anterior portion of their arc. Several types of incomplete or irregular circuli may be identified as follows:
   a. Broken—circuli that are broken or discontinuous in the anterior portion of their arc.[5]
   b. Split—circuli that divide into two or more circuli.
   c. Incomplete—circuli that end in a cul-de-sac against another one or two circuli, or circuli that are not complete around the anterior field of the scale.
   d. Island—a small segment of a circulus that is not joined to another circulus, but stands by itself.
   e. Loop—a segment of one or two circuli that form a loop.
   f. Link—an interconnection between adjacent circuli.
   g. Miscellaneous—circuli that are modified in various other ways.

FRESH-WATER (LACUSTRINE) GROWTH

Plates 3, 4, and 5 show the fresh-water portions of adult sockeye salmon scales and give examples of zones of complete, "average," and irregular circuli; various types of winter zones; and various fresh-water ages. The same criteria can be applied to scales from young salmon collected in fresh water.

FRESH-WATER CIRCULI (Plate 3)

This plate shows examples of different types of circuli in fresh-water growth of ages 1., 2., and 3.[6] See plate 2 for examples of various types of circuli. Figures labeled A are scales with predominantly complete circuli; those labeled B are more or less "average" scales, some circuli complete, others broken and irregular; and those labeled C are scales with predominantly broken and irregular circuli. Arrows indicate end of winter growth.

On the North American side of the Pacific Ocean complete circuli generally predominate on scales of fish from Bristol Bay, Karluk River, Fish Creek (in Cook Inlet), Alaska; Skeena and Fraser Rivers, British Columbia; and the Columbia River. On the Asian side of the Pacific, complete circuli occur frequently on scales of fish from the Ozernaia, Kamchatka, and Dalinaia Rivers of Kamchatka.

Broken and irregular circuli predominate on scales of fish collected in the Aleutian Islands, the Alaska Peninsula, Cook Inlet (except Fish Creek), and Southeastern Alaska; Smith and Rivers Inlets, British Columbia; and in Blinjinaia and Bolshaia Rivers of Kamchatka.

Fish scales from any area may have some complete and some broken circuli in the fresh-water zones.

WINTER ZONES IN FRESH-WATER GROWTH (Plate 4)

As mentioned previously, winter zones are formed when the growth of the scale slows down during the fall, winter, and early spring. The circuli are formed closer together and are broken or otherwise interrupted so that the winter growth zone shows up as a band of circuli more closely spaced than the adjacent circuli nearer

[5] Krogius (1958) used counts of broken circuli as a scale character in racial studies.

[6] Age designation of salmon in reference to fresh-water life only follows the recommendations of Koo (1962b) : an Arabic numeral indicating the winters the fish spent in fresh water from hatching, followed by a dot.

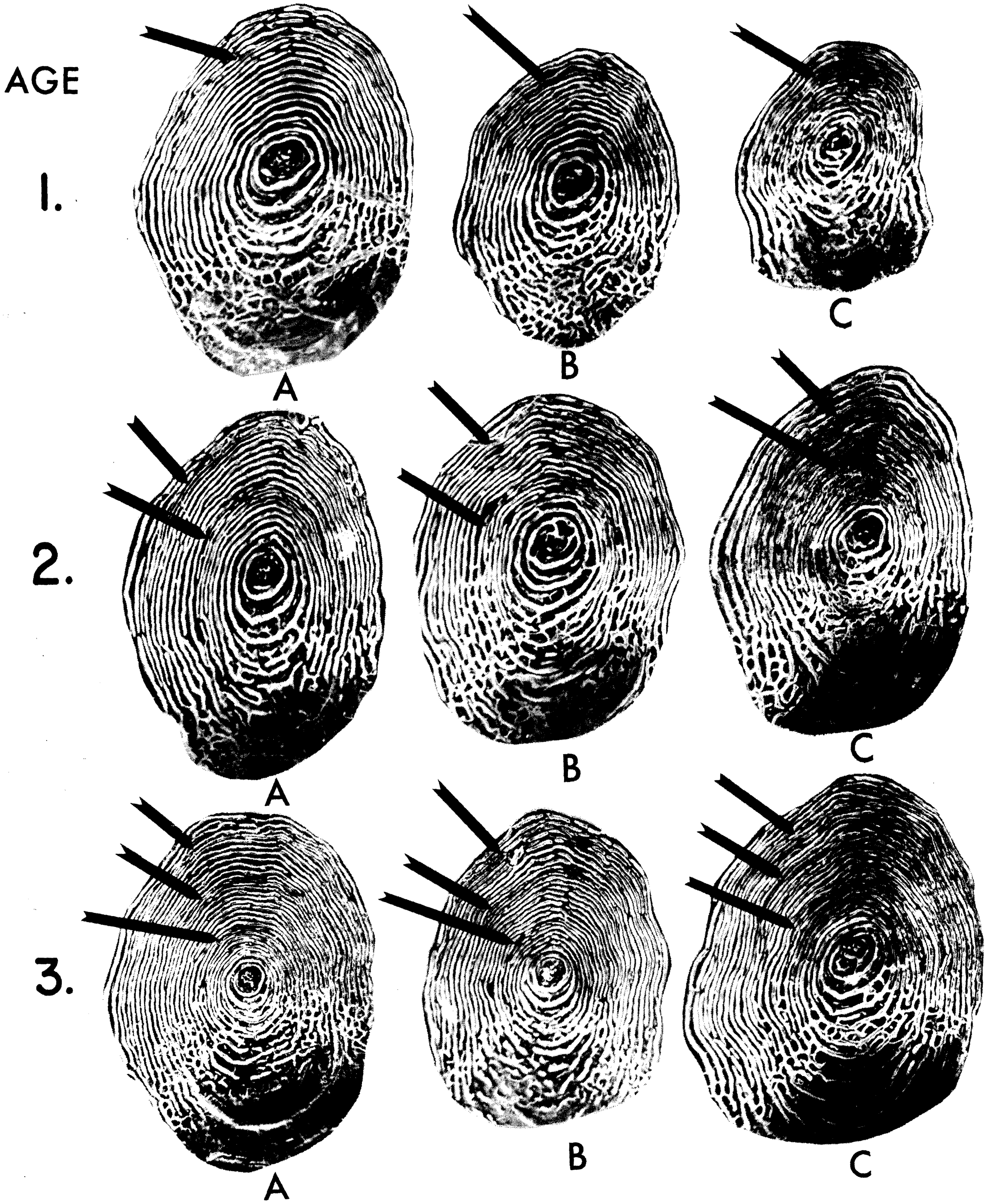

PLATE 3.—Fresh-water circuli.

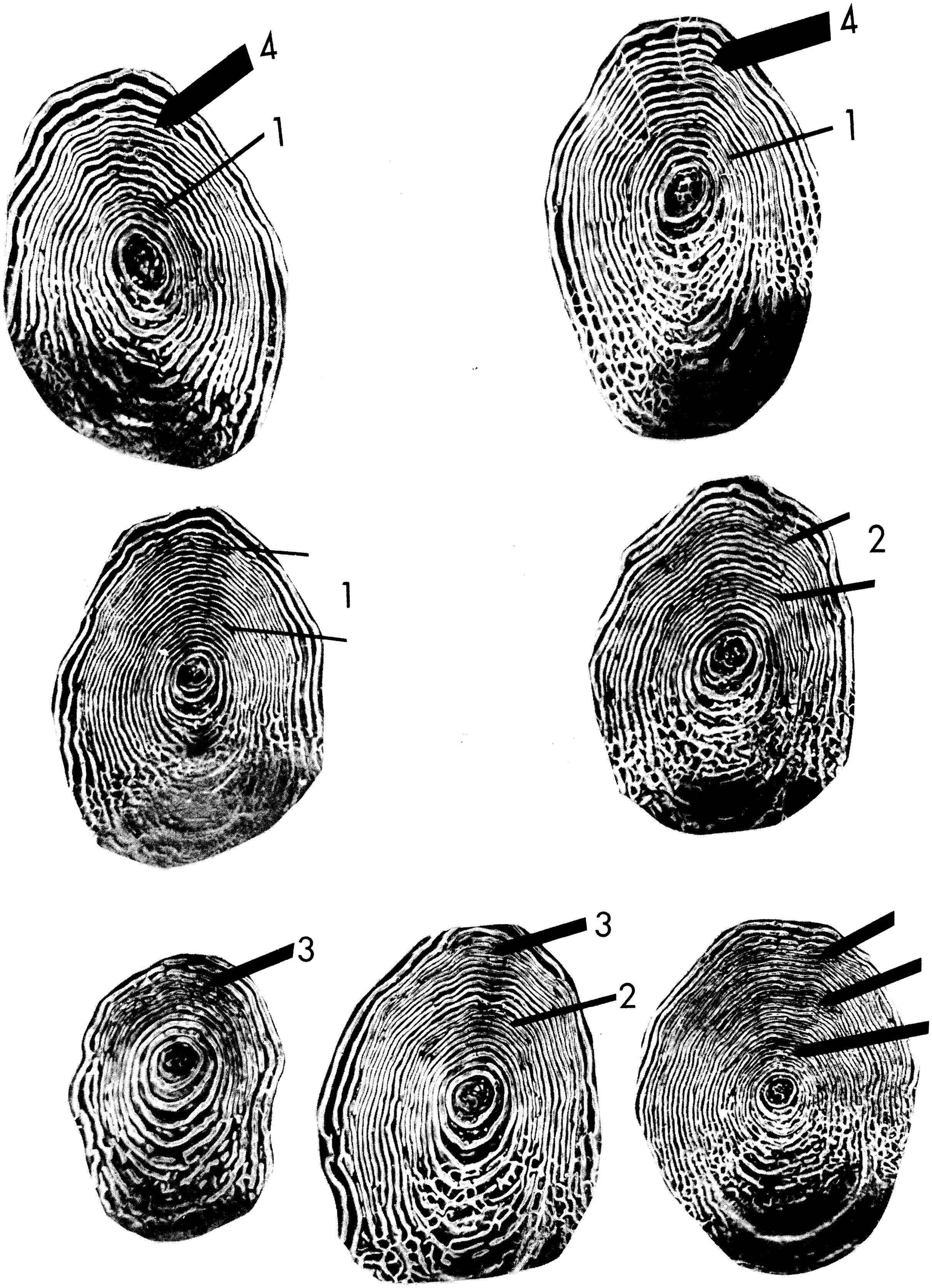

PLATE 4.—Winter zones in fresh-water growth.

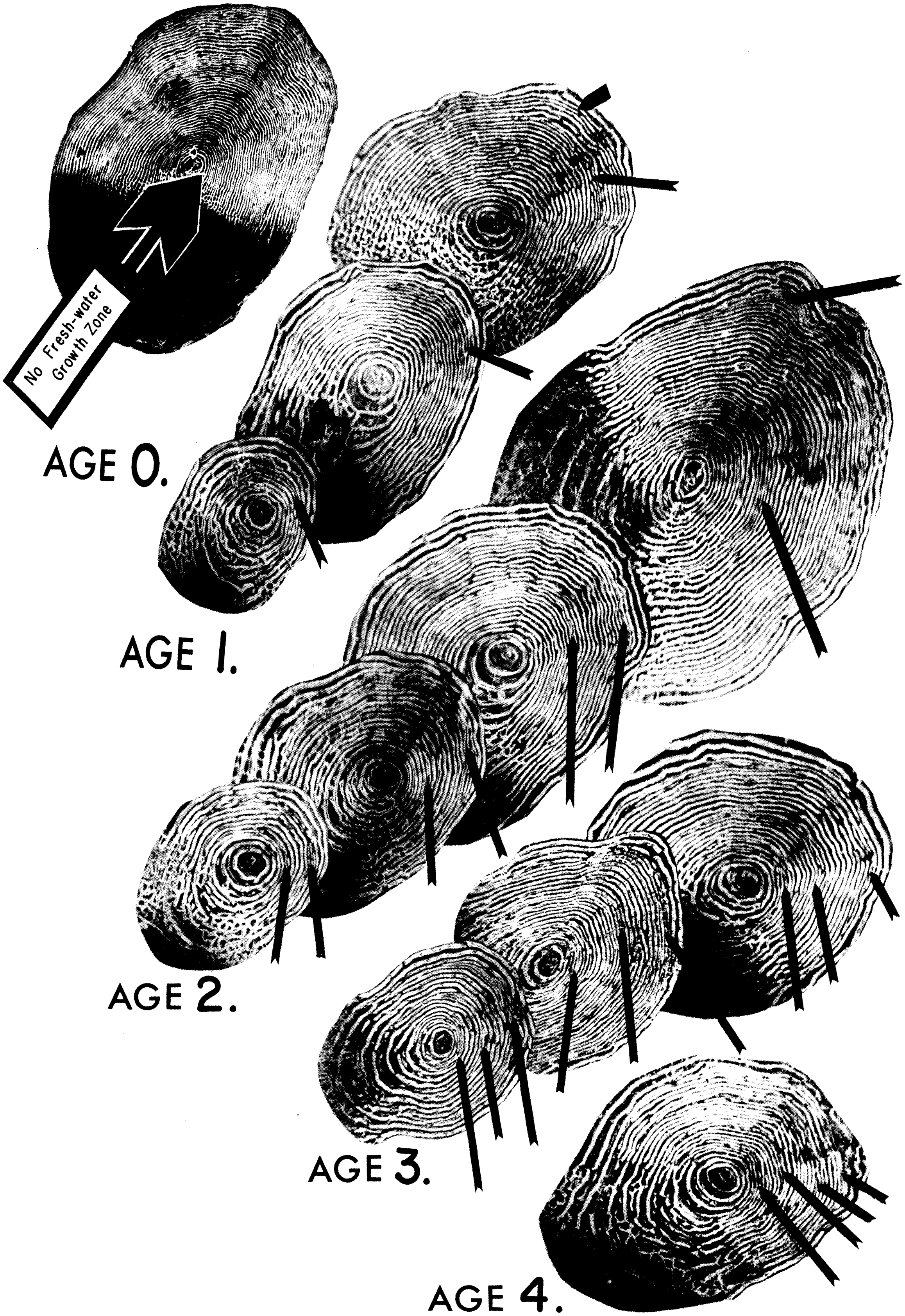

PLATE 5.—Fresh-water ages.

to the focus or to the edge of the scale. Because the circuli of the fresh-water zone are closer together and more finely lined and the growth zones may be composed of fewer circuli than in the ocean, the winters of fresh-water growth are sometimes indistinct and difficult to identify.

To assist in interpretation of the fresh-water zone, winter growth zones are classified into four types (numbers 1 to 4 in plate 4 correspond with the following descriptions):

1. Those made up of two or three circuli close together. This type of winter zone is the most distinct and easiest to identify and measure because it looks almost like a continuous line around the anterior field. The width of the arrows indicates the relative width of the winter zone.
2. Those made up of three or more circuli lying close together in a narrow band. This type of zone is relatively easy to identify, but less easy to measure or delimit than those of type 1.
3. Those made up of a number of complete or broken circuli lying close together in a broader band than those of type 2.
4. Those made up of a few circuli that are not much closer together than the adjacent circuli of the summer growth. These zones are diffuse and difficult to identify and measure.

FRESH-WATER AGES (Plate 5)

Plate 5 shows the range of fresh-water ages and the range of sizes of fresh-water zones of each age that may be found in sockeye salmon scales. The complete scale of the O. age fish is magnified about 20 X. All other photographs are of the fresh-water zones of scales from adult sockeye salmon and show the relative sizes of the various zones as they appear when projected at about 40 X. The winters in fresh water are indicated by arrows.

Age 0. A complete scale from a fish in its third year that migrated to the ocean soon after hatching, magnified about 20 X. The few sockeye salmon that migrate seaward early in their first year usually reach the ocean before scales are formed; thus, their scales lack a fresh-water growth zone. Additional examples are shown in plate 12 and in Koo (1962c).

Age 1. Scales from fish that migrated seaward after one growing season in fresh water (in the second year). Small to large zones are illustrated. The small zone is typical of fish from Southeastern Alaska and some British Columbia areas. The large zone is typical of fish from Fish Creek, Cook Inlet, Alaska. (The stub pointer near the top of the upper scale in this series indicates the end of the transition zone; see plate 6.)

Age 2. Scales from fish that migrated to the sea after two full growing seasons in fresh water (in their third year). Small to very large zones are shown. The small zone is common in fish from Asian areas. The very large ones have been found only in fish from Dalinaia River, Kamchatka.

Age 3. Scales from fish that migrated to the sea after three full growing seasons in fresh water (in their fourth year). Small to large zones illustrated. The small zone is common in fish from Asian areas.

Age 4. A scale from a fish that migrated to sea after four full growing seasons in fresh water (in its fifth year). Fish of this fresh-water age are rare.

TRANSITION ZONE BETWEEN FRESH-WATER AND OCEAN GROWTH (Plate 6)

Correct interpretation of the zone of transition between fresh-water and ocean growth is important in age determination. Many disagreements on the age of individual sockeye salmon can be traced directly to different interpretations of this portion of the scales.

In most areas of western Alaska, new growth beyond the zone of narrow winter circuli is evident on the margin of nearly all scales of young fish in fresh water by mid-June (Koo, 1962a; and Mosher[7]) and earlier in areas to the south.

[7] Mosher, Kenneth H. Time of fresh-water annulus formation on the scales of young sockeye salmon from western Alaska. U.S. Fish and Wildlife Service, Bureau of Commercial Fisheries Biological Laboratory, Seattle, Wash. [Manuscript.]

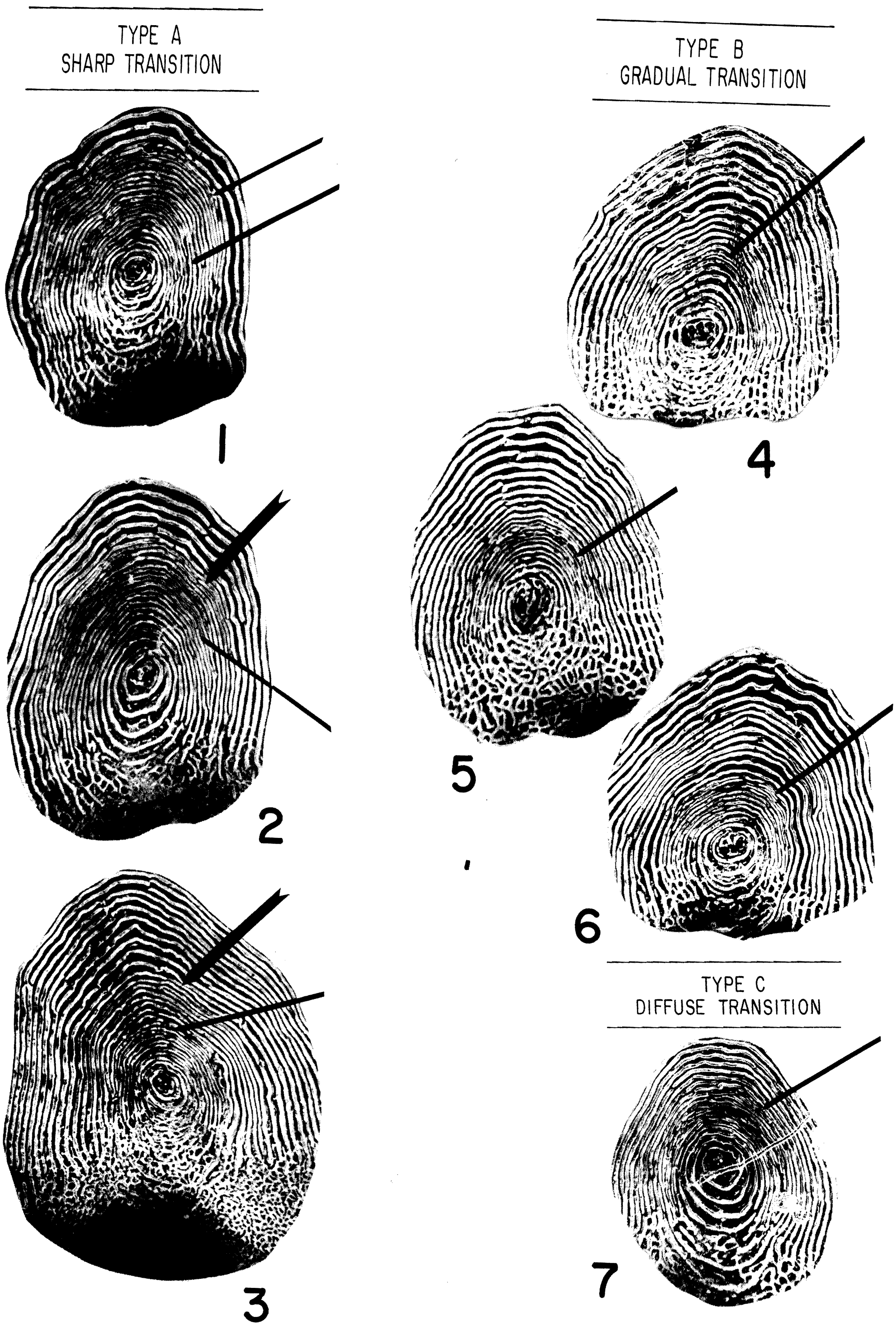

PLATE 6.—Transition zone between fresh-water and ocean growth.

Wider, darker circuli usually are laid down after this zone in the year in which the fish migrates seaward. If the fish reaches the ocean about the time this zone of narrow circuli is completed, the transition from narrow, light-textured fresh-water circuli to wider, heavier textured ocean circuli is abrupt. If the winter zone is completed before the fish reaches salt water, however, a varying number of circuli, intermediate in appearance between the fresh-water and ocean circuli, may be formed. This type of growth is called plus, transitional, intermediate, incidental, or spring growth.[8]

If the transition zone merges gradually into the ocean growth zone, it is usually easy to identify, although not to delimit. If, on the other hand, an adventitious mark (called a "migration check") forms and the zone is large, the migration check might be mistaken for another fresh-water winter (Mosher[9]).

Three general types of transition between fresh-water and ocean growth zones can be identified: type A, sharp or abrupt; type B, gradual; and type C, diffuse. These general types can be found in fish of all fresh-water ages.

Examples of the three types of transition zones are shown in plate 6. (The winter zones are indicated by arrows, and the migration checks in figures 2 and 3 by wider arrows.)

Type A. Sharp or abrupt transition is shown by the following photographs:

Figure 1. No plus growth. The transition from the fine-lined, closely spaced fresh-water circuli to the widely spaced ocean circuli is sudden. This type of transition poses no problems for accurate age determination.

Figure 2. Little plus growth after the winter zone formed. A migration check is between the transitional growth and the ocean growth. That the portion of the scale between the two arrows is plus growth is evident from the narrowness of the zone and the appearance of the circuli, which are intermediate in width and spacing between the circuli of the fresh-water and ocean growth zones.

Figure 3. Extensive plus growth after the winter zone formed. The weak migration check at the end of the transition might be mistaken for another winter in fresh water. Note, however, that the seven or eight circuli immediately preceding the broad, widely spaced circuli of the ocean zone are intermediate in width and spacing between the circuli of the fresh-water and ocean growth zones.

Type B. Gradual transition is shown by the following photographs:

Figure 4. No plus growth. The two or three circuli following the winter zone gradually expand into the broader ocean-type circuli.

Figure 5. Little plus growth. A few circuli of intermediate type are present, and the boundary of the transition is difficult to identify.

Figure 6. Extensive plus growth. The zone of intermediate growth is wide. Because there is no migration check at the end of the plus growth, the chance is small that it will be interpreted as another year's growth in fresh water.

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[8] The term "spring growth" is usually applied to the intermediate or plus growth observed on scales of seaward migrant fish, not adult fish.

[9] Mosher, Kenneth H. The plus or intermediate growth of sockeye salmon scales. Bureau of Commercial Fisheries, Biological Laboratory, Seattle, Wash. [Manuscript.]

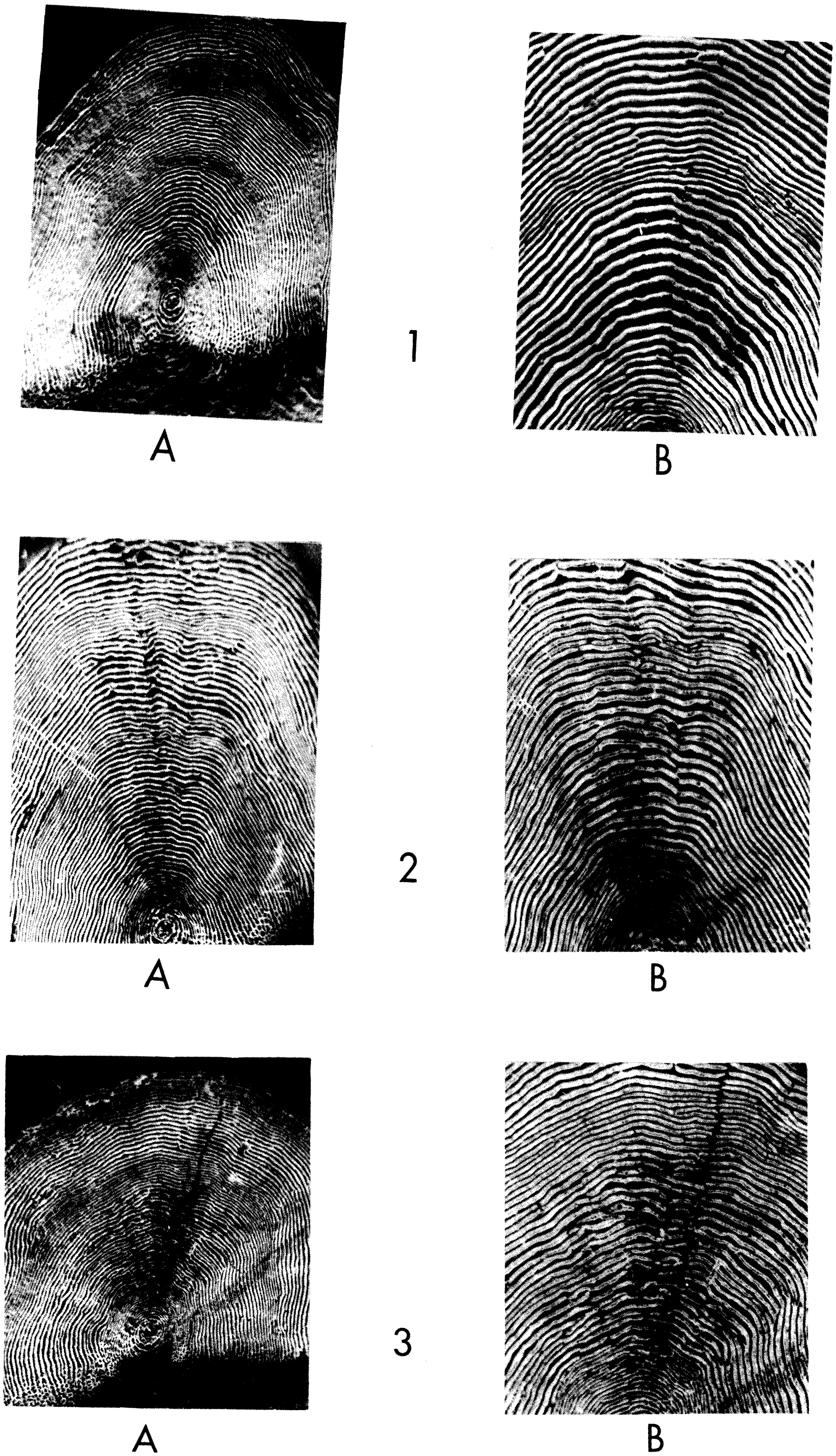


PLATE 7.—Appearance of ocean growth zones based on type of circuli.

Type C. Diffuse transition is shown in figure 7. The transition between the fresh-water and ocean growth is so broken up by irregular circuli that the exact boundaries of the fresh-water and plus growth (if any) are difficult to determine.

OCEAN GROWTH

The following plates show details of the ocean growth zone, including the variations in:

1. appearance of zones based on type of circuli (plate 7).
2. number of circuli (plate 8).
3. spacing of circuli within the zones (plate 9).
4. appearance of the winter zones (plate 10).
5. ocean ages (plate 11).

APPEARANCE OF OCEAN GROWTH ZONES BASED ON TYPE OF CIRCULI (Plate 7)

The relative numbers of complete and interrupted circuli affect the appearance of the different ocean zones and the ease and accuracy with which measurements and counts of circuli and winters of life can be made. See plate 2 for examples of various types of circuli. Three broad categories of ocean growth zones, based on the circuli, are illustrated in plate 7. Each category is illustrated by two photographs.

Figure A shows the major portion of a scale magnified about 20 X; figure B, which is the central portion of the same scale magnified about 40 X, shows the circuli of the first ocean zone in greater detail. The categories of ocean-growth zones are described as follows:

Category 1. A scale with mostly complete circuli in the ocean-growth zones.

Category 2. A scale with complete and irregular circuli in the ocean-growth zones (an "average" scale).

Category 3. A scale with nearly every circulus broken or otherwise interrupted in the ocean-growth zones.

NUMBER OF OCEAN CIRCULI (Plate 8)

The mean number of circuli in the first ocean growth zone of scales from adult fish differ by geographical areas (table 1). The largest mean numbers are on scales of sockeye salmon from Rivers Inlet, British Columbia. Mean numbers of circuli tend to be progressively lower on scales of North American fish taken southward to the Columbia River and northwestward to Bristol Bay, Alaska. Scales from Asian fish have greater mean numbers of circuli than the Bristol Bay sockeye. This difference in mean numbers of circuli holds true in all ocean zones but is most pronounced in the first ocean zone.

The scales in plate 8 were selected to show the numerical differences in the number of circuli in the first ocean zone (number of circuli between each pair of pointers) among sockeye salmon from different geographical areas, as follows:

Figure 1. Asia, 25 circuli.

Figure 2. Bristol Bay, 22 circuli.

Figure 3. Ketchikan, Alaska (as representative of the area from Cook Inlet to the Nass River, British Columbia), 27 circuli.

Figure 4. The Skeena River, British Columbia, 29 circuli.

Figure 5. Rivers Inlet, British Columbia, 32 circuli.

Figure 6. The Columbia River, Oregon-Washington, 26 circuli.

SPACING OF OCEAN CIRCULI (Plate 9)

Spacing of circuli within the ocean growth zones may also vary between scales from fish collected in different geographical areas. In general, scales with relatively large numbers of circuli in the first ocean zone tend to have more uniformly spaced circuli than those with fewer circuli. On scales from Bristol Bay fish, the widest spaced circuli are usually deposited near the closely spaced fresh-water portion. On scales from Asian fish, the widest spaced circuli are often deposited just before the closely spaced winter ocean circuli. On scales from fish taken east and southeastward of Bristol Bay, the position of the widest spaced circuli of the ocean zones is less consistent. They may occur in the same position as in the Bristol Bay or the Asian

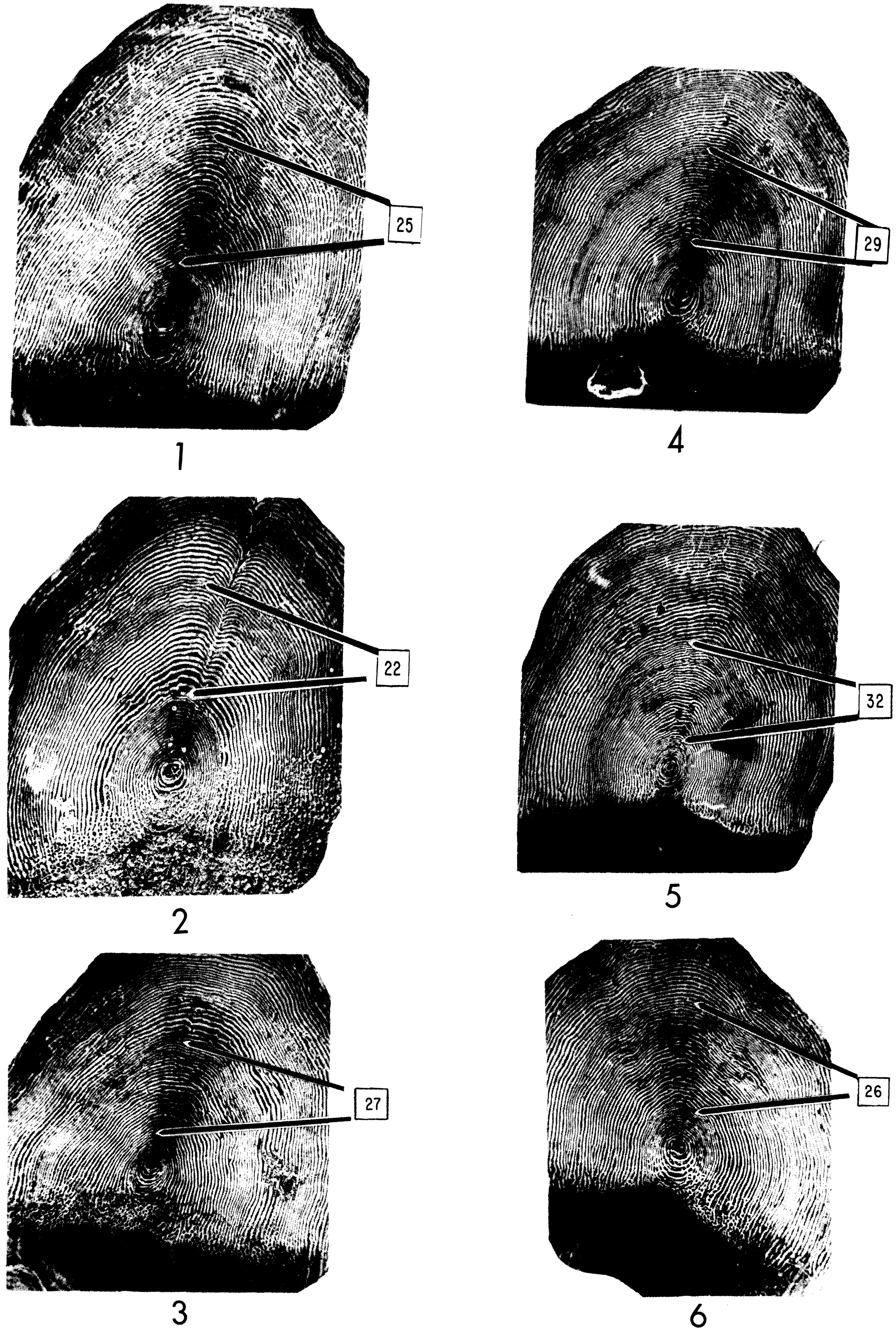


PLATE 8.—Number of ocean circuli.

TABLE 1.—*Percentage frequency distribution[1] and mean number of circuli in the first ocean zone of scales from sockeye salmon collected in 1963*

[Asterisks indicate modes]

Number of circuli	Asla[2]	Alaska: Bristol Bay[2]	Alaska: Chignik[3]	Alaska: Cook Inlet[2]	British Columbia: Nass[2]	British Columbia: Skeena[3]	British Columbia: Rivers Inlet[3]	British Columbia: Fraser[3]	Columbia River[3]
	Percent								
13	0.2	....	....	....	....	....	....	....	....
14	.5	....	....	....	....	....	....	....	....
15	.2	0.5	....	....	....	....	....	....	....
16	....	1.5	....	....	....	....	....	....	....
17	.5	4.4	....	....	....	....	....	....	....
18	1.4	9.1	0.6	....	....	....	....	....	....
19	3.1	14.7	1.4	0.4	0.6	....	....	....	....
20	6.5	*19.1	2.3	2.0	1.5	....	....	....	....
21	9.0	18.7	4.5	4.6	2.0	....	....	....	0.9
22	9.3	14.5	8.5	7.3	1.8	0.6	....	....	4.0
23	11.9	10.0	14.2	10.4	2.6	1.7	....	0.3	7.3
24	*15.9	5.2	*17.3	14.6	5.6	4.8	....	3.4	9.8
25	15.4	1.7	15.6	*17.8	9.2	10.5	0.3	9.2	14.0
26	10.6	.5	13.4	16.0	13.0	15.1	.9	12.9	*18.0
27	5.9	.1	9.9	12.1	*14.4	*15.6	1.2	*14.7	16.8
28	3.8	....	6.0	7.9	12.2	13.6	2.9	*14.7	12.2
29	2.5	....	3.7	3.7	10.2	12.2	6.2	13.6	8.2
30	1.4	....	2.0	2.1	10.2	10.2	8.8	11.5	5.2
31	1.0	....	.6	1.1	9.0	6.8	12.0	6.9	2.4
32	.7	....	....	....	5.4	4.0	*14.7	4.3	.9
33	.2	....	....	....	1.7	2.3	*14.7	4.3	.3
34	....	....	....	....	.4	1.1	11.5	2.8	....
35	....	....	....	....	.2	.6	7.9	1.1	....
36	....	....	....	....	....	.6	7.4	.3	....
37	....	....	....	....	....	.3	6.2	....	....
38	....	....	....	....	....	....	3.5	....	....
39	....	....	....	....	....	....	1.5	....	....
40	....	....	....	....	....	....	.3	....	....
Mean number of circuli	24.1	20.6	24.7	25.1	27.5	27.9	32.8	28.4	26.3
Number of fish	156	650	88	145	98	88	85	87	82

[1] Actual frequencies smoothed according to Henry (1961).

[2] Combined 1. and 2. fresh-water ages.

[3] 1. fresh-water ages only.

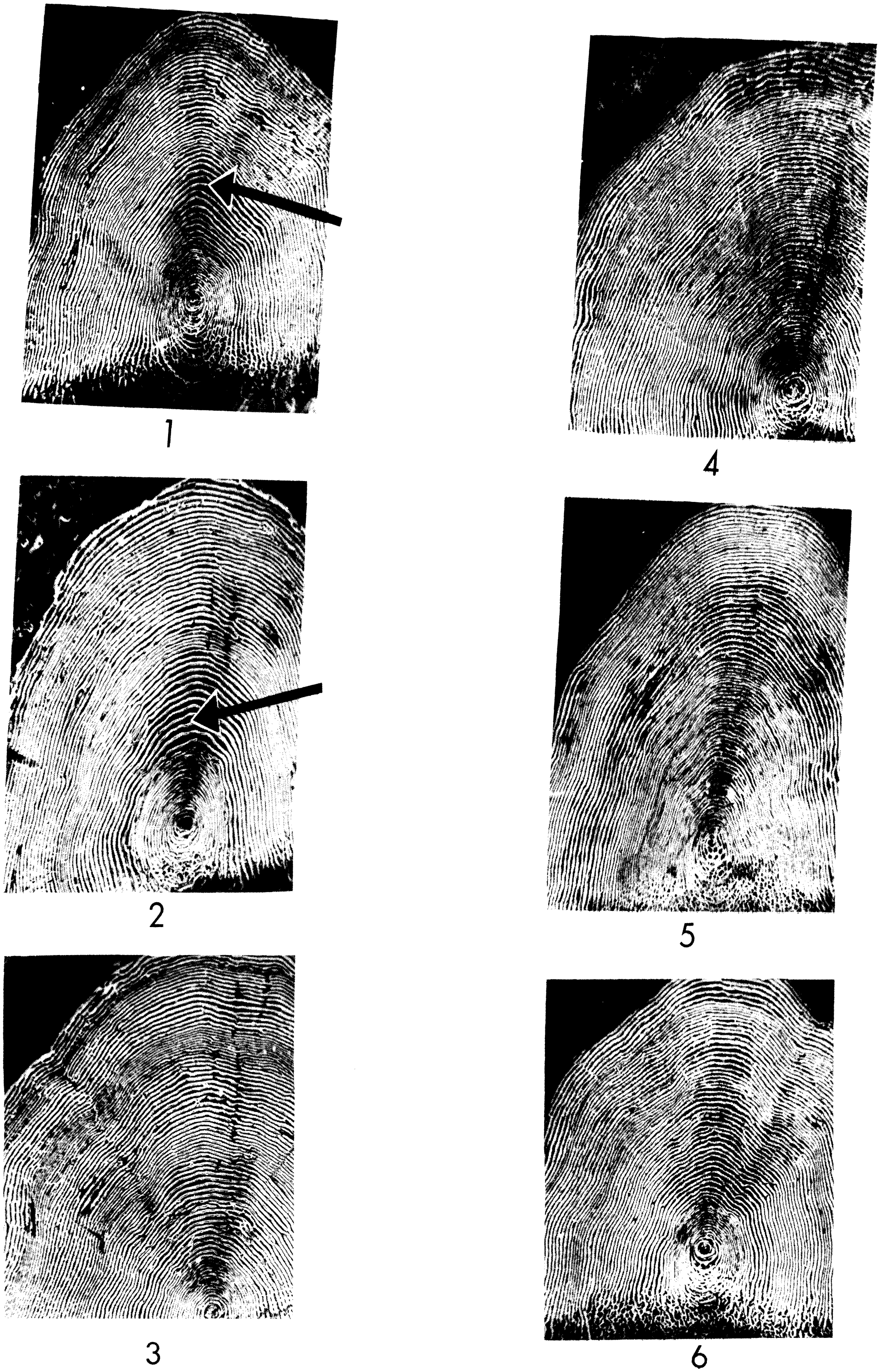


PLATE 9.—Spacing of ocean circuli.

fish, but often the circuli are so uniformly spaced that no area of widest spacing can be identified.

Plate 9 shows examples of these variations in spacing of circuli within the first ocean growth zone, as follows:

Figure 1. A scale from an Asian sockeye salmon with the widest spaced circuli (arrow) immediately preceding the winter ocean growth.

Figure 2. A scale from a Bristol Bay sockeye salmon with the widest spaced circuli (arrow) formed immediately after migration to the ocean.

Figure 3. A scale from a Cook Inlet sockeye salmon with a summer growth zone of widely and uniformly spaced circuli.

Figure 4. A scale from a Skeena River sockeye salmon with a summer growth zone of uniformly spaced circuli.

Figure 5. A scale from a Rivers Inlet sockeye salmon with a summer growth zone of evenly and closely spaced circuli.

Figure 6. A scale from a Columbia River sockeye salmon with a summer growth zone of widely and uniformly spaced circuli.

WINTER ZONES IN OCEAN GROWTH (Plate 10)

Winter zones in the ocean growth result from slower scale growth in the fall, winter, and early spring, during which time the circuli are formed closer together than during the faster growth in the late spring and summer. Zones of winter growth in the ocean, like those in the fresh-water portion of the scale, also vary in appearance; they may be classified into four general groups on the basis of appearance (winter zones in the illustrations are numbered as follows):

1. Clear-cut zones made up of a number of closely spaced circuli.
2. Zones made up of circuli less closely spaced or more numerous than those of group 1.
3. Diffuse zones the boundaries of which cannot easily be identified. Whereas the circuli are closer together than the adjacent summer growth zones, either the difference between the spacing of circuli is so slight or the narrowing of the circuli into the winter zone is so gradual that it is difficult to be sure of the exact boundaries of the zone.
4. Winter zones characteristic of the first ocean zone of most sockeye salmon from Rivers and Smith Inlets, British Columbia, where the circuli are often only slightly closer together than the closely spaced circuli of the summer growth.

The winters of ocean life of the fish not only must be accurately identified for age determination, but their location and boundaries must be measured exactly in many racial and other studies; therefore, scales with diffuse winter zones (group 3) may be difficult or impossible to use in some of these studies.

AGE GROUPS BY NUMBER OF WINTERS IN THE OCEAN (Plate 11)

Sections of sockeye salmon scales showing ocean growth zones illustrate the range of ocean ages found in this species.[10] Arrows indicate the winter growth zones.

.0 — only a few months in the ocean, no winter growth zone
.1 — one winter in the ocean
.2 — two winters in the ocean
.3 — three winters in the ocean
.4 — four winters in the ocean
.5 — five winters in the ocean

SCALES WITH DIFFERENT COMBINATIONS OF FRESH-WATER AND OCEAN AGE

All the combinations of fresh-water and ocean age that I have found in sockeye salmon are illustrated in plates 12 to 16. Age designations of adult salmon follow the recommendations of Koo (1962b). Two methods may be used—the European method or the Gilbert and Rich (1927) method. The Gilbert and Rich method is used on the following plates; in the text, age designa-

[10] Age designation of salmon in reference to marine life only follows the recommendations of Koo (1962b): a dot followed by the number of winters the fish spent in the ocean.

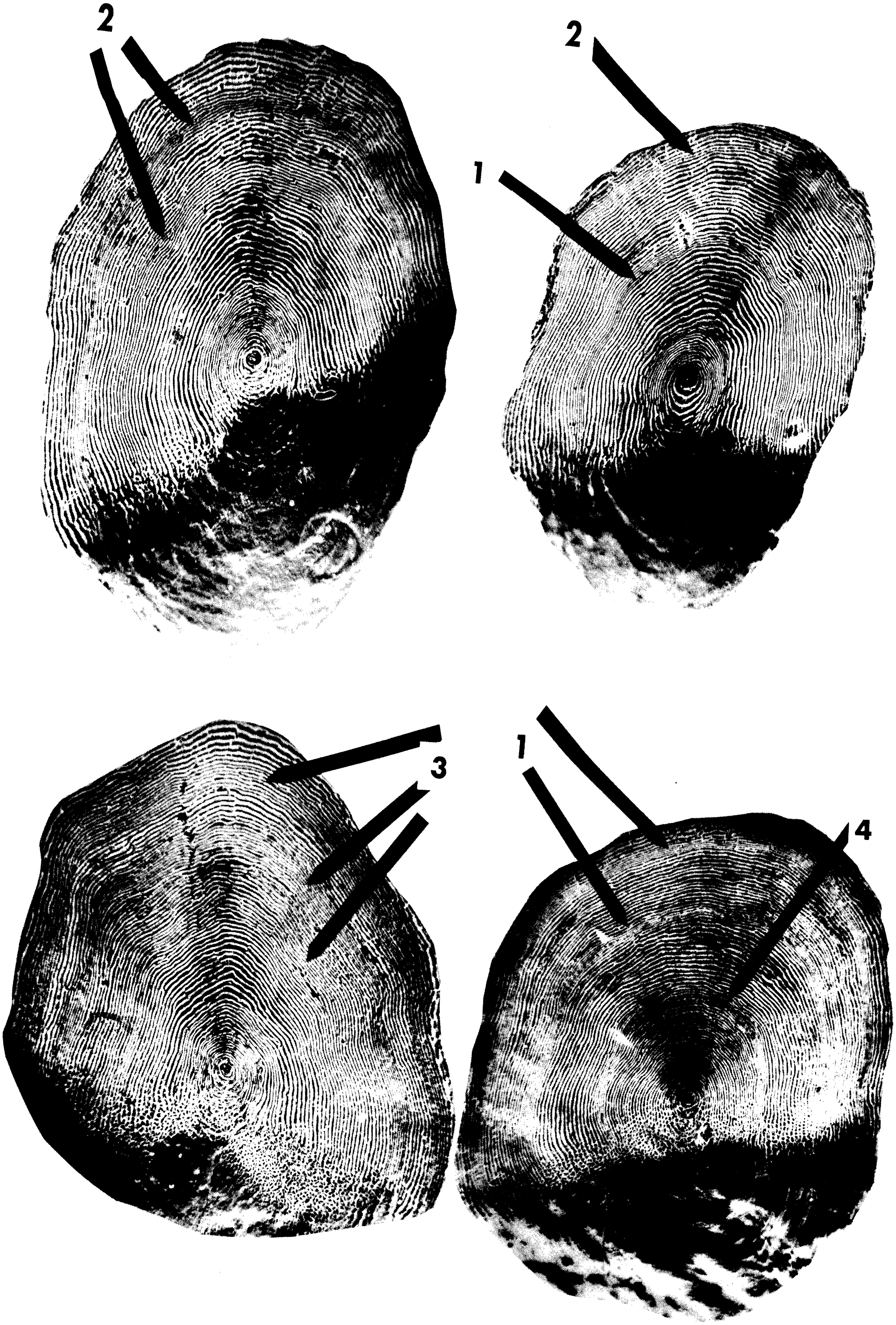


PLATE 10.—Winter zones in ocean growth.

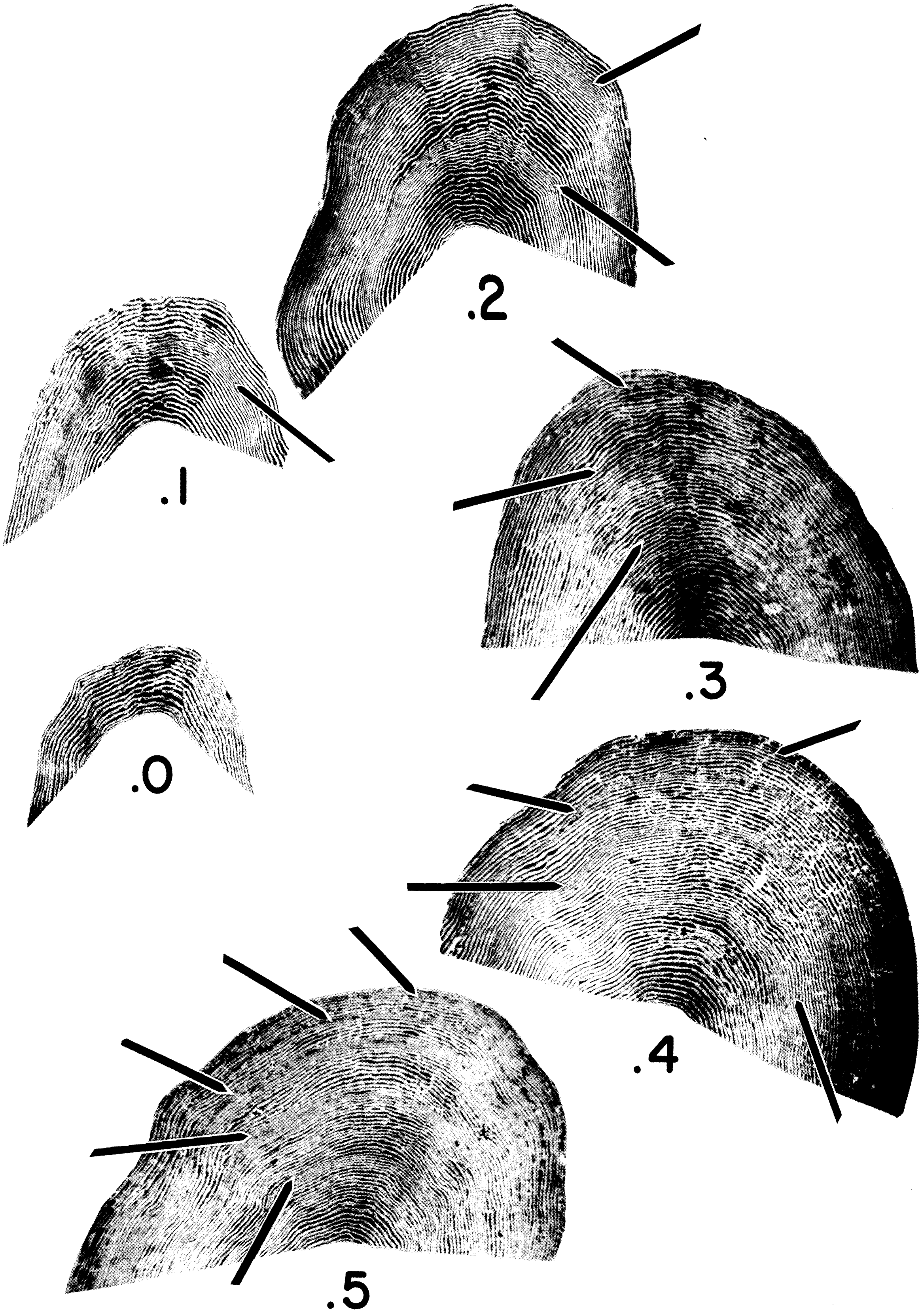


PLATE 11.—Age groups by number of winters in the ocean.

tion by the European method is shown in parentheses.

In the Gilbert and Rich designations, an Arabic numeral indicates the number of winters from spawning of the parents to capture. A second digit, usually written as a 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).

In the European method, the number of winters the fish spent in fresh water from hatching and in the ocean are separated by a dot. To determine the year of spawning that produced the fish, add 1 to the sum of the two digits and subtract from the year of capture.

A comparison of the major age groups in the three methods of age designation follows:

Gilbert and Rich	European	U.S.S.R.
4_1	0.3	3_0
4_2	1.2	3_1
5_2	1.3	4_1
5_3	2.2	4_2
6_3	2.3	5_2
6_4	3.2	5_3
7_4	3.3	6_3

Runs of sockeye salmon often include individuals, considerably smaller than the average, that have returned to spawn after only one winter at sea. These fish are known as "jacks" as they are almost invariably males, except in the Columbia River where they may be of either sex.[11]

In the following plates the winter growth zones are indicated by arrows—wide arrows in the ocean portion of the scale (plates 12-18) and narrow arrows in the fresh-water portion (plates 13-18). Stub arrows when present indicate the end of plus growth.

[11] Occasionally the small females in the Columbia River are called "jennies."

AGE GROUPS WITH NO SCALE GROWTH IN FRESH WATER (Plate 12)

Fish of these age groups migrate to the sea before or immediately after scale formation. Because most sockeye salmon live in fresh water for a year or more, few scales of these ages are collected; they are usually in the 3_1 and 4_1 age groups.

Examples of these age groups are shown:

Age group 2_1. (0.1) one winter in the ocean zone. Spawning fish are "jacks."

Age group 3_1. (0.2) two winters in the ocean zone.

Age group 4_1. (0.3) three winters in the ocean zone.

Age group 5_1. (0.4) four winters in the ocean zone.

AGE GROUPS WITH ONE GROWING SEASON IN FRESH WATER (Plate 13)

These age groups make up many of the important runs of sockeye salmon. From the Columbia to the Copper River, and in the Wood River-Nushagak system in Bristol Bay, fish with this fresh-water history predominate every year.

Fish of a given year class may first be present in a spawning run as age group 3_2 ("jacks"); dominate the run the next year as age group 4_2 and (in some areas) the following year as age group 5_2; and provide occasional 6_2's and 7_2's in subsequent years. Thus, it is possible that fish of a year class with one growing season in fresh water could be present in the spawning migration over a 5-year period, but in most areas the period lasts only 3 or 4 years.

Examples of the following age groups are shown:

Age group 2_2 (1.0). One winter in fresh water, none in the ocean. (This illustration is from an immature fish, not an adult.)

Age group 3_2 (1.1). One winter in fresh water, one in the ocean.

Age group 4_2 (1.2). One winter in fresh water, two in the ocean.

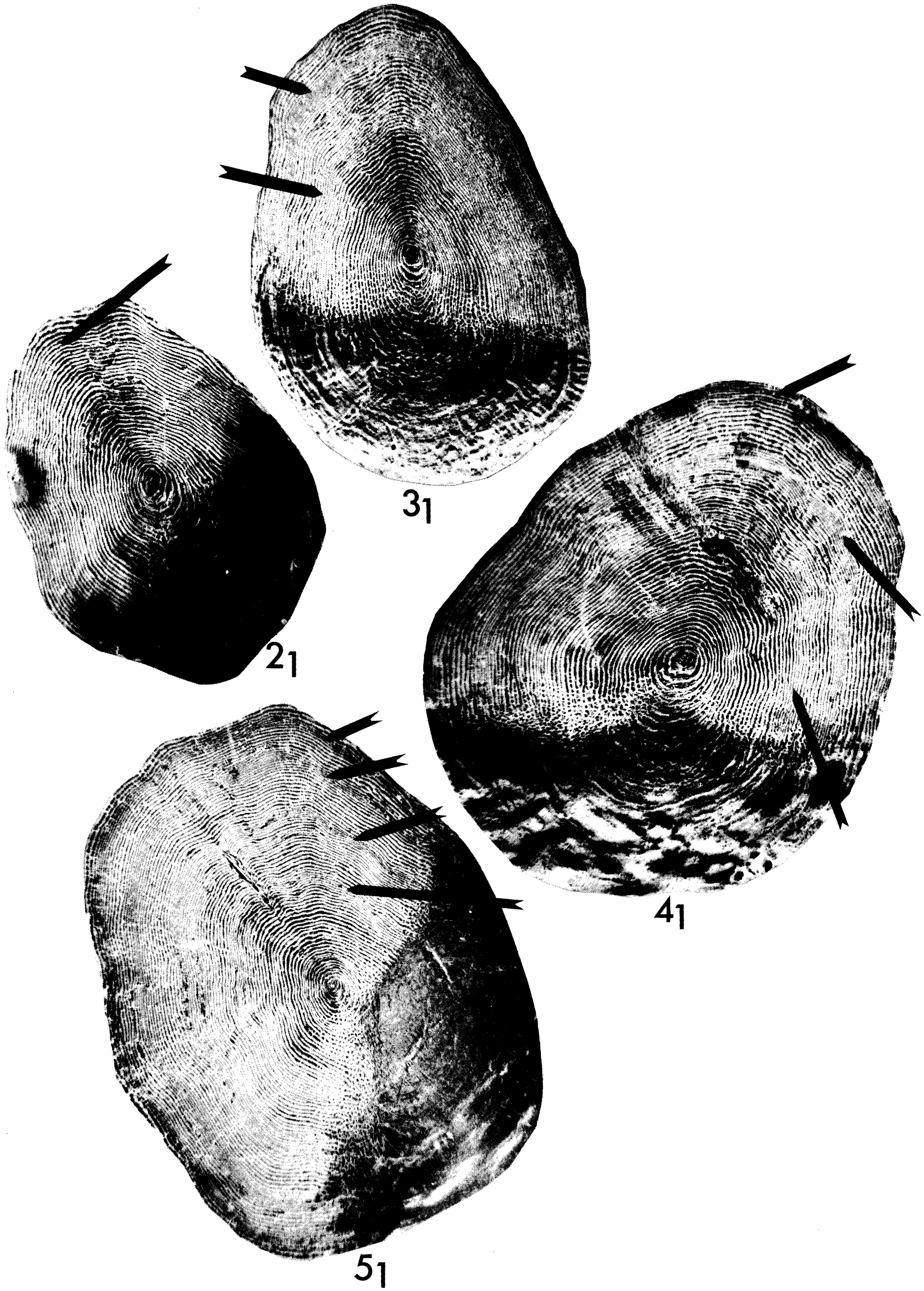


PLATE 12.—Age groups with no scale growth in fresh water.

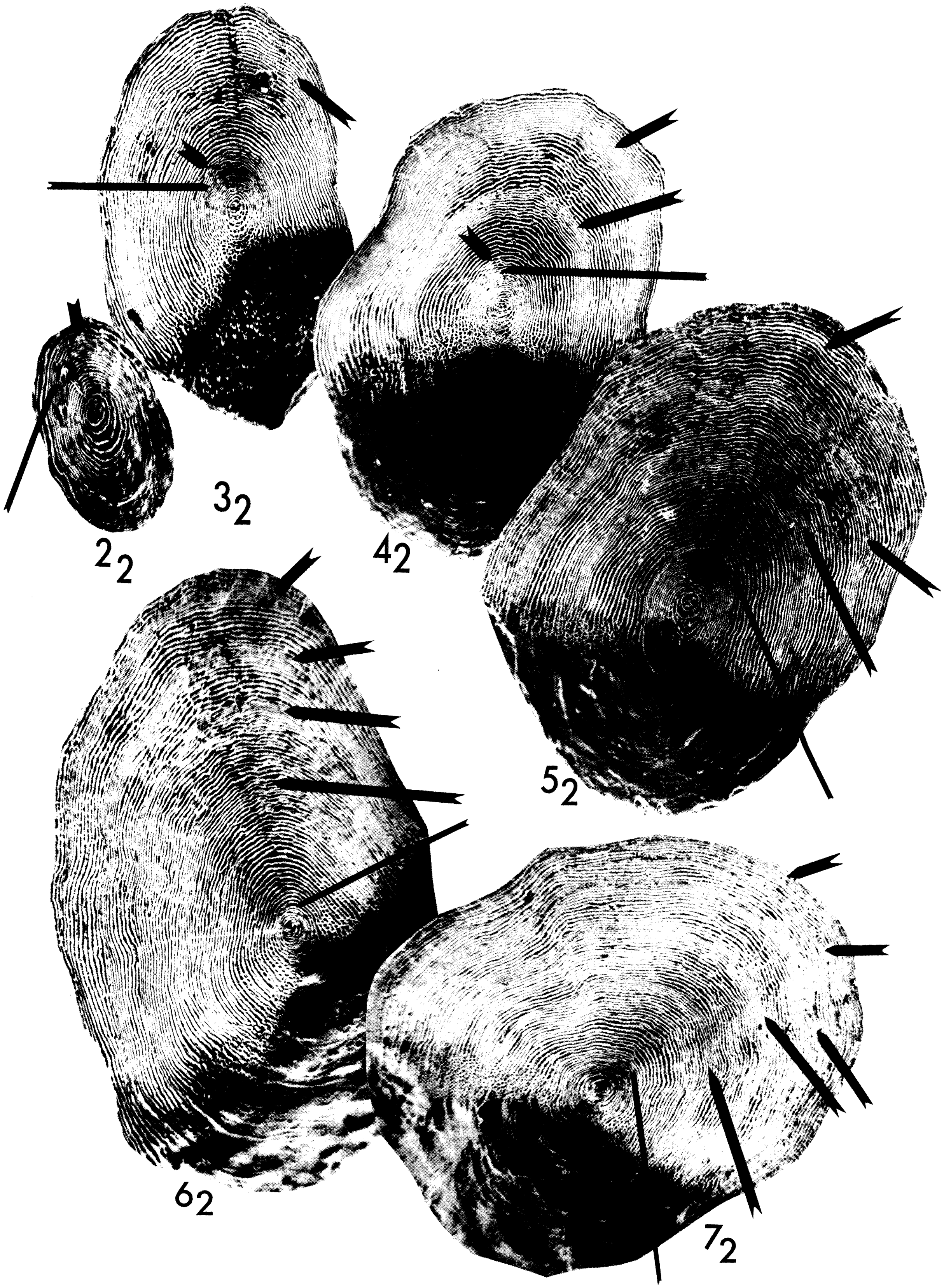


PLATE 13.—Age groups with one growing season in fresh water.

Age group 5_2 (1.3). One winter in fresh water, three in the ocean.

Age group 6_2 (1.4). One winter in fresh water, four in the ocean.

Age group 7_2 (1.5). One winter in fresh water, five in the ocean.

AGE GROUPS WITH TWO GROWING SEASONS IN FRESH WATER (Plate 14)

These age groups also make up many important runs of sockeye salmon. The Ozernaia River in Asia, a number of tributaries of Bristol Bay, and Karluk River on Kodiak Island are areas where fish of these age groups predominate in the spawning runs in most years. Fish of a given year class may be in the spawning run one year as age group 4_3 ("jacks"); dominate the run the next year as age group 5_3 and (in some areas) the following year as 6_3's; and produce an occasional 7_3 the following year.

Examples of the following age groups are shown:

Age group 3_3 (2.0). Two winters in fresh water, none in the ocean. (This illustration is from an immature fish, not an adult.)

Age group 4_3 (2.1). Two winters in fresh water, one in the ocean.

Age group 5_3 (2.2). Two winters in fresh water, two in the ocean.

Age group 6_3 (2.3). Two winters in fresh water, three in the ocean.

Age group 7_3 (2.4). Two winters in fresh water, four in the ocean.

AGE GROUPS WITH THREE GROWING SEASONS IN FRESH WATER (Plate 15)

Fish of these age groups are common in the Karluk River, Alaska, and in some Asian areas. In some years they may make up a substantial portion of the spawning runs in these areas, primarily as age groups 6_4 and 7_4. Examples of the following age groups are shown:

Age group 4_4 (3.0). Three winters in fresh water, none in the ocean. (This illustration is from an immature fish, not an adult.)

Age group 5_4 (3.1). Three winters in fresh water, one in the ocean.

Age group 6_4 (3.2). Three winters in fresh water, two in the ocean.

Age group 7_4 (3.3). Three winters in fresh water, three in the ocean.

Age group 8_4 (3.4). Three winters in fresh water, four in the ocean.

AGE GROUPS WITH FOUR GROWING SEASONS IN FRESH WATER (Plate 16)

In areas where fish with three growing seasons in fresh water are common, occasional fish stay in fresh water another year. These fish are rare. Examples of the following ages are shown:

Age group 6_5 (4.1). Four winters in fresh water, one in the ocean.

Age group 7_5 (4.2). Four winters in fresh water, two in the ocean.

Age group 8_5 (4.3). Four winters in fresh water, three in the ocean. This group is very rare.

SCALES WITH IRREGULAR OR DEFORMED FEATURES

Some scales are of little or no value for age or racial study because they are regenerated (plate 17). Others may be unsuited for these studies because of resorption (plate 18), or for a number of other reasons (shown in plate 19).

REGENERATED SCALES (Plate 17)

When a salmon loses a scale, a new one rapidly replaces it.[12] The new scale does not form circuli until it approximates the size of the scale that was lost. Normal scale growth then resumes, and circuli form regularly thereafter. Regenerated areas range from a small portion of the center of the scale to almost the complete scale. When a scale is lost from large fish, the resulting regenerated scale is often of atypical size and shape.

Scales that were regenerated before the fish migrated to the sea can be used to determine the

[12]Unpublished results of my experiments a few years ago showed that lost scales of coho (*O. kisutch*) and chinook (*O. tshawytscha*) salmon were replaced and had resumed normal growth within 1 month, even in fish which were in poor physical condition.

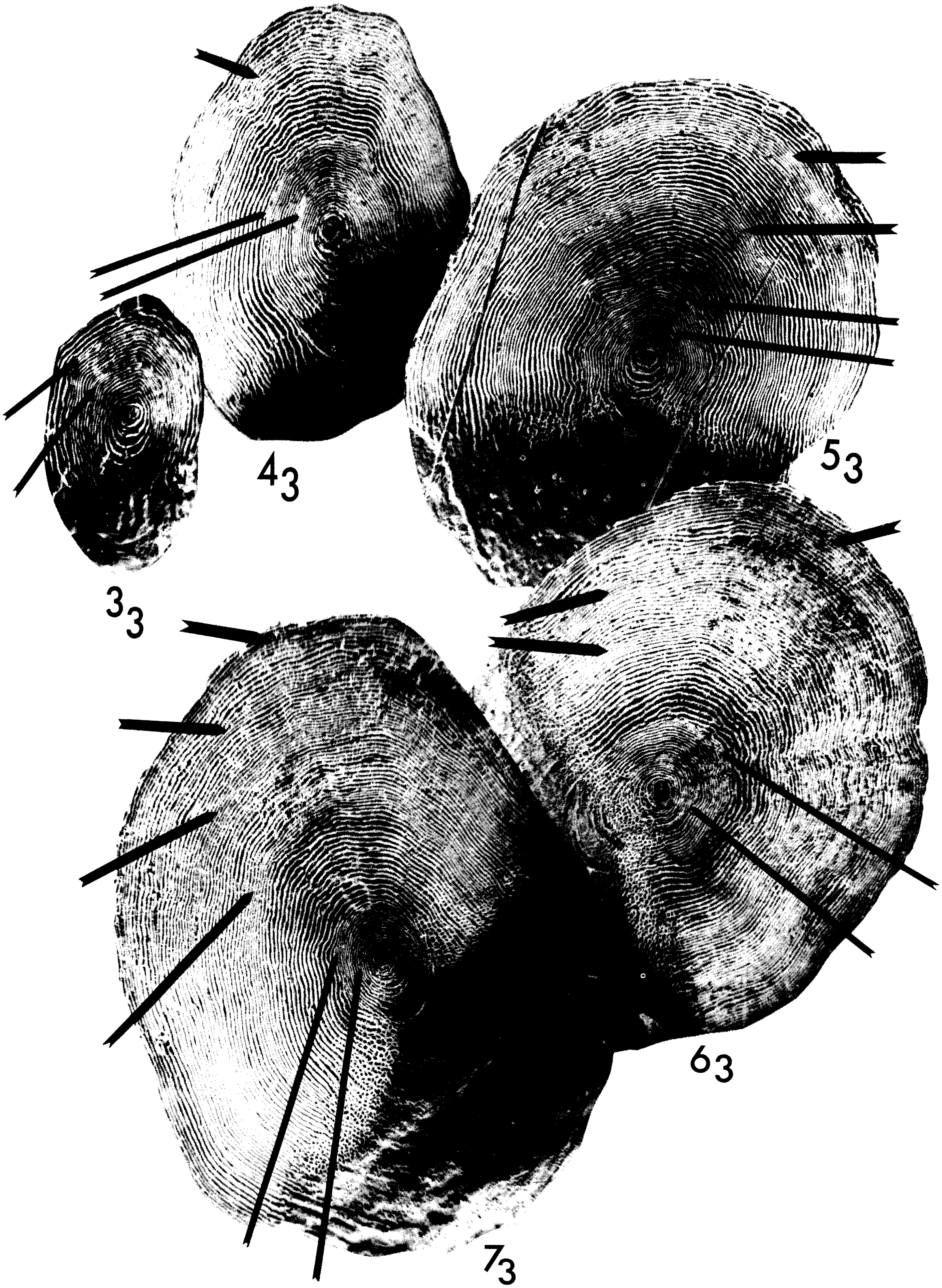


PLATE 14.—Age groups with two growing seasons in fresh water.

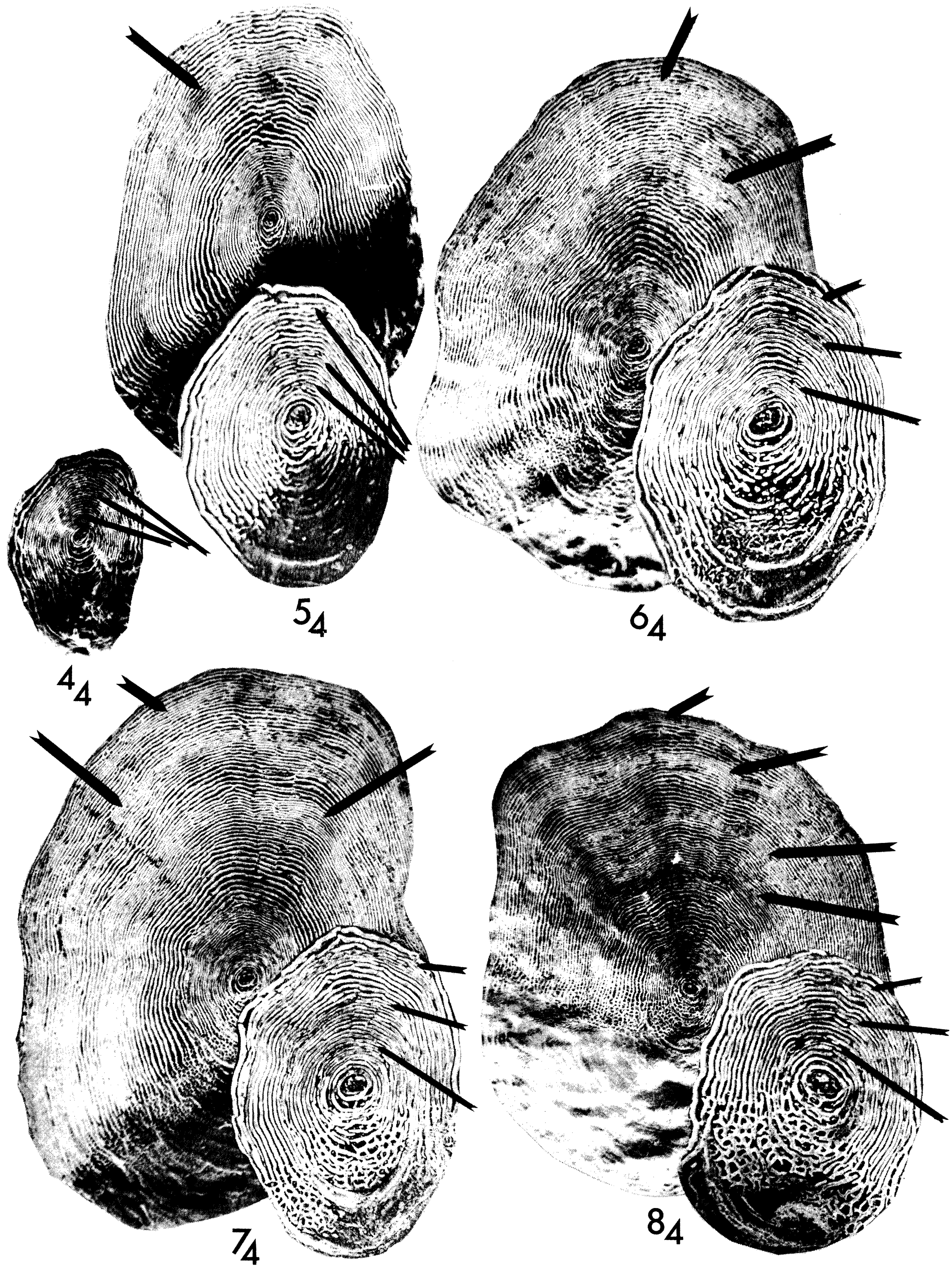


PLATE 15.—Age groups with three growing seasons in fresh water.

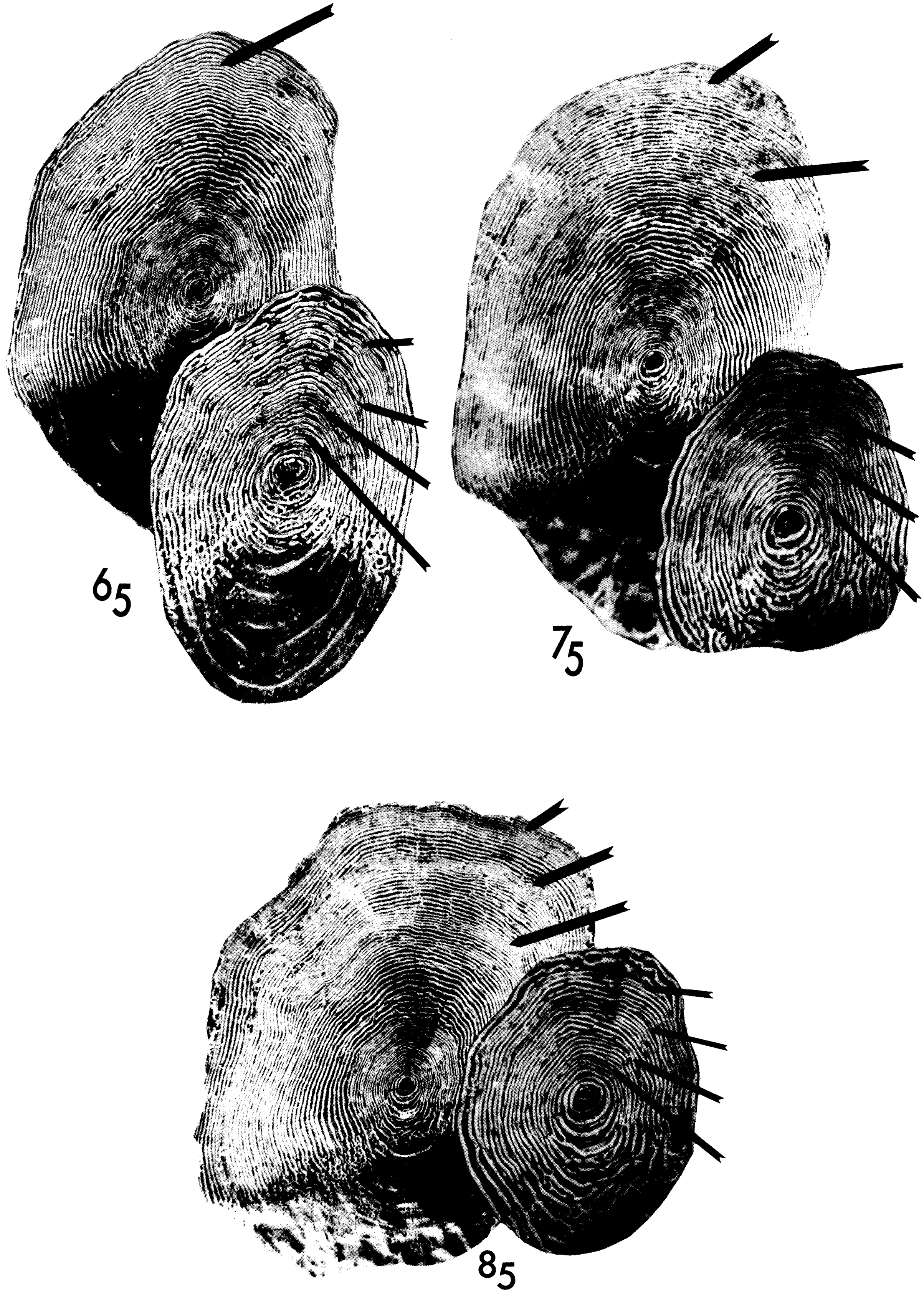


PLATE 16.—Age groups with four growing seasons in fresh water.

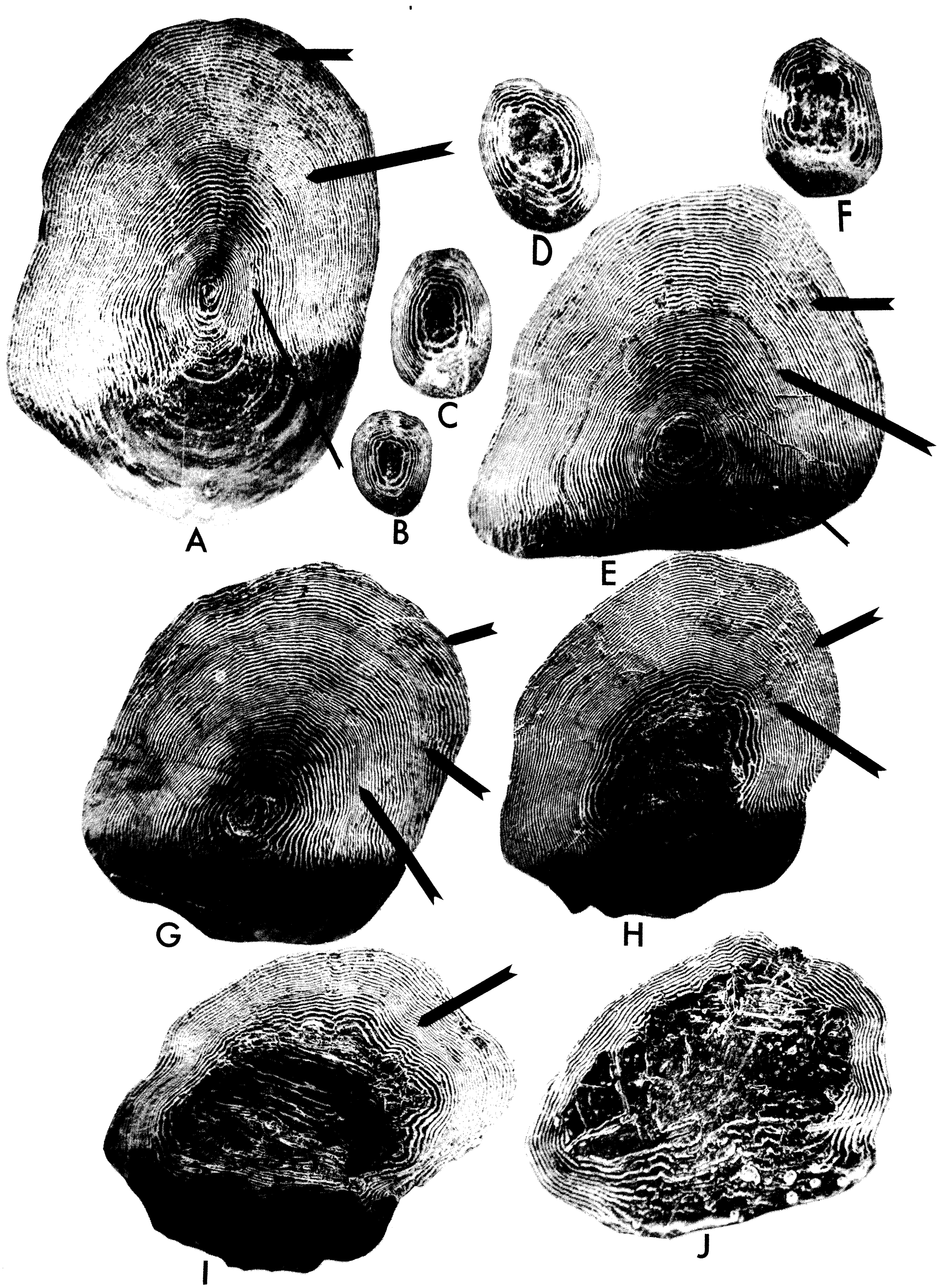


PLATE 17.—Regenerated scales.

ocean age of the fish, but only those that were replaced before the first winter reveal the total age.

Regenerated scales may be used to back-calculate the year of scale loss; for instance, scales taken from scars on the body of the fish may show the number of years since the injury. This technique can be applied to fish with gill net marks.

The scales on plate 17 are arranged to show increasing amounts of regeneration. Figures A and B, D and E, and F and G are pairs; the large scale of each pair shows about the same amount of regeneration of the fresh-water zone as the small scale of the pair. To illustrate how regenerated scales may be used to date an injury that removed the original scale, I arbitrarily assume that all the scales from adult fish on this plate were collected in the summer of 1965.

Scale A. A scale from an adult sockeye salmon shows regeneration of only a few central circuli; the fish spent one winter in fresh water and two winters in the ocean. This scale replaced one lost in 1962, a short time after the original scale was formed.

Scale B. A scale from a young sockeye salmon taken in fresh water shows regeneration that involves only a few circuli. At adult size the scale of this fish would look much like scale A.

Scale C. A scale from a young sockeye salmon. This scale shows a larger area of regeneration.

Scale D. A scale from a young sockeye salmon shows regeneration of about half of the scale.

Scale E. A scale from an adult sockeye salmon shows regeneration that involves about half of the fresh-water zone (scale D). This scale shows that the fish spent two winters in the sea and at least one in fresh water. This fish also lost the original scale in 1962; the age of the fish at that time could have been from a few months to over a year. The total age of the fish cannot be determined from this scale.

Scale F. A scale from a young sockeye salmon shows regeneration of most of the scale.

Scale G. A scale from an adult sockeye salmon shows regeneration of the entire fresh-water zone (scale F). This scale shows only that the fish spent three winters in the ocean and that the scale replaced one lost in 1962.

Scale H. A scale from an adult sockeye salmon shows regeneration of fresh-water growth and most of the first summer at sea. This scale shows that the fish spent two winters at sea after it lost the original scale in the summer of 1963.

Scale I. A scale from an adult sockeye salmon with only the winter and last summer's growth completed before capture. Because of extensive regeneration, even the ocean age of this fish cannot be determined. The scale is of slightly atypical shape; it replaced one lost in the summer of 1964.

Scale J. A scale from an adult sockeye salmon with only a few months' growth complete. The scale is atypical in size and shape; it replaced one lost in the spring of 1965 and is unusable for age or racial studies.

RESORBED SCALES (Plate 18)

At some time during the migration toward their spawning streams, sockeye salmon stop feeding and subsist on stored fat and other body materials. As they work their way up the streams, the material in the scales is resorbed. Resorption generally starts along the lateral margins of the scale near the base of the anterior field and progresses until the whole scale margin is affected. Scales taken from spawning fish may have only a small central portion left. On most resorbed scales taken from spawning fish the fresh-water growth may still be present, but usually the ocean growth zones are too badly eroded to permit determination of total age with confidence. With greatly resorbed scales, study of otoliths or length frequencies may be required to estimate the age of the fish.

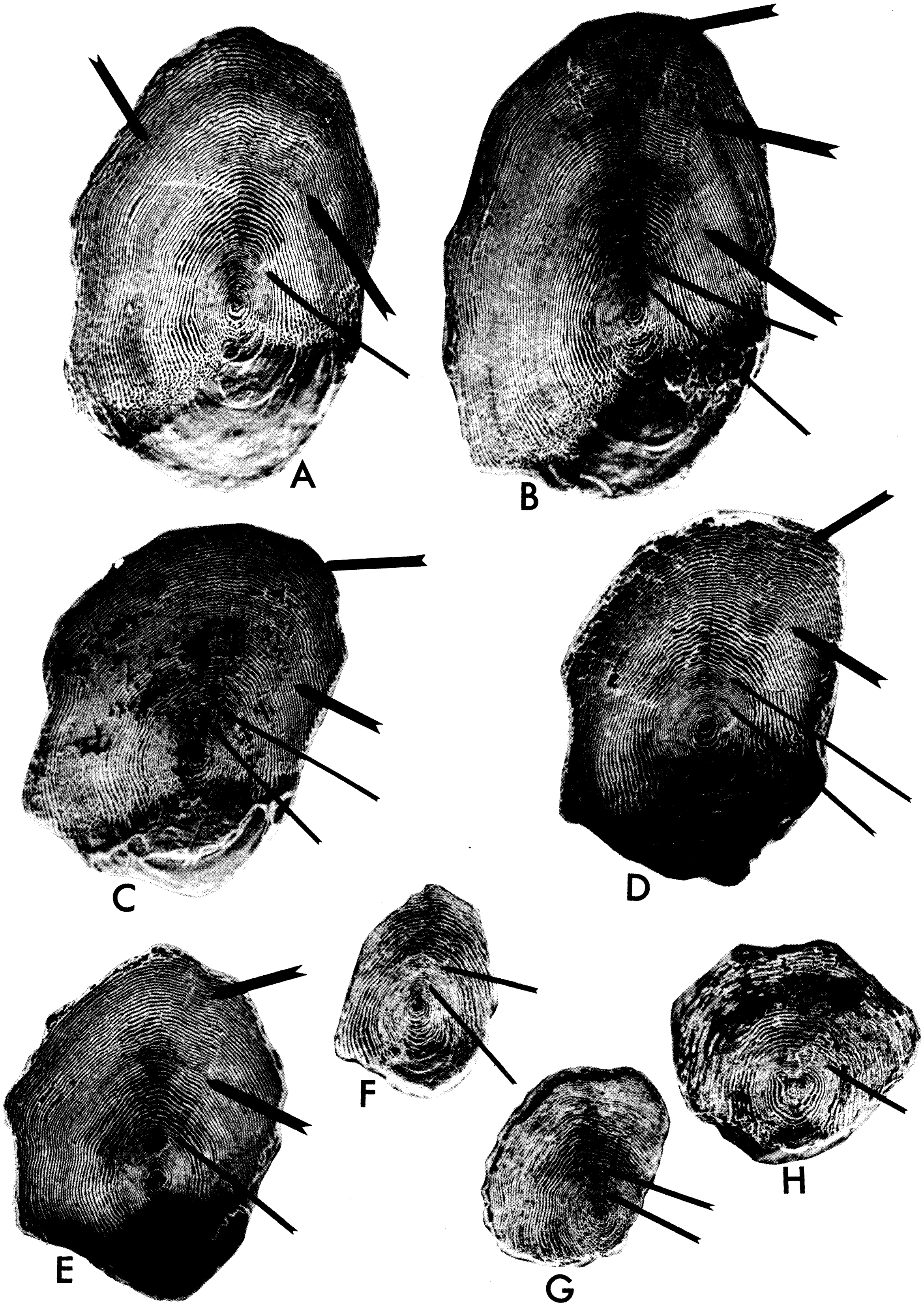


PLATE 18.—Resorbed scales.

The scales on this plate are arranged to show increasingly greater degrees of scale resorption, from A to H.

Scales A and B. These scales show slight resorption. Age determination is possible with these scales.

Scales C and D. These scales show considerable resorption. Age determinations are subject to error.

Scale E. This scale shows a greater amount of resorption than scales C and D, age determination is subject to considerable doubt.

Scales F and G. Only the fresh-water growth and a portion of the first year's ocean growth of these scales remain. Determination of total age is not possible.

Scale H. This scale shows considerable resorption and a regenerated center; it is useless for age or racial studies.

OTHER SCALES NOT SUITED FOR AGE OR RACIAL STUDIES (Plate 19)

Scales can be unusable for a number of reasons other than regeneration or resorption, as shown by the following examples:

Scale A. Scales may be distorted with atypical sculpturing. These scales often adjoin regenerated scales.

Scale B. Scales of adult and young fish may have a twisted center or other distorted area. If the growth pattern is not too badly distorted, the correct age may be determined from the scale.

Scale C. Scales may have scars (arrow). Here again, if the damage is not too serious, the correct age may be determined. Scars are more common in the ocean growth zones than in the fresh-water zone—perhaps because the scales of small fish are more easily lost than displaced in the scale pocket.

Scale D. Scales from the lateral line have a trough or tubelike structure that forms part of the lateral line organs. Scales near the lateral line may also be distorted to a varying degree, but some may be usable.

Scale E. Scales of atypical size and shape occur near the bases of the fins and the operculum; they should not be used for age or racial studies as they usually have fewer circuli than preferred scales.

USE OF ATLAS

Now that we have examined the features of sockeye salmon scales in detail, we are ready to use the atlas for specific purposes. This section is divided into two parts: (1) The use of the atlas in age studies and description of the scale features and (2) the use of the atlas in racial and other studies.

USE OF THE ATLAS FOR AGE STUDIES AND DESCRIPTION OF IMPORTANT SCALE FEATURES

This section demonstrates the use of the atlas to describe the physical features of the scale and to determine the fresh-water, ocean, and total age of the sockeye salmon from its scales. Compare the scale being studied with the plates in sequence, starting with plate 3. Compare the individual features of the scale with the variations shown on the appropriate reference plate. Select the one that is most similar to the feature under study.

The scale shown in plate I is used here to illustrate this method. Compare the scale in plate I with the various reference plates as follows:

Plate 3. Column A, chiefly regular, unbroken circuli.

Plate 4. First winter zone in the fresh-water growth is of type 1, sharp, the second is of type 2, moderately sharp.

Plate 5. Fresh-water age 2., medium-sized zone.

Plate 6. A sharp transition from fresh-water growth to ocean growth without plus growth. Type A (like fig. 1).

Plate 7. First ocean growth zone is of type 1; circuli are chiefly unbroken and uniformly spaced. Second ocean growth zone is of type 2, "average."

Plate 19.—Other scales not suited for age or racial studies.

Plate 8. The first ocean zone has 24 circuli; the second has 21.

Plate 9. The widest spaced circuli of the first ocean zone are near the fresh-water growth; in the second ocean zone, they are near the previous winter zone.

Plate 10. Both ocean winter zones are of type 2, "average."

Plate 11. This fish is ocean age .2.

Plates 12 to 16. This fish is of age group 5_3 (2.2), shown on plate 14.

USE OF ATLAS FOR RACIAL AND OTHER STUDIES

Numerous scale characters are being used to determine the continent of origin of sockeye salmon when they are caught away from natal streams. Some scale characters and methods of analysis were reported by Krogius, 1958; Kubo, 1958; Kubo and Kosaka, 1959; Henry, 1961; Mosher et al., 1961; Anas, 1963; Mosher, 1963; and Anas, 1964. Methods now under study to determine the stream of origin range from identification based on appearance of the scale to multivariate techniques that make use of scale data collected with precision. Although numerous characters have been examined for racial studies, many more could be defined and used; some of the additional characters might be better than ones now in use.

This atlas can be used to (1) find additional characters for racial study, (2) decide which circuli or parts of circuli to count or measure for consistent results, (3) provide a basis for developing "standard" descriptions of the scale characters of sockeye salmon from the different spawning regions of North America and Asia, and (4) choose characters for special studies in which data on sockeye salmon scales are used.

No specific list of additional characters is given here, but ingenuity and imagination of the scientist in discovering and developing use of scale characters and methods of analysis will open new possibilities for the study of sockeye salmon.

LITERATURE CITED

ANAS, RAYMOND E.

1963. Red salmon scale studies. *In* Report on the investigations by the United States for the International North Pacific Fisheries Commission—1961. Int. N. Pac. Fish. Comm., Annu. Rep. 1961: 114-116.

1964. Sockeye salmon scale studies. *In* Report on the investigations by the United States for the International North Pacific Fisheries Commission—1963. Int. N. Pac. Fish. Comm., Annu. Rep. 1963: 158-162.

CHUGUNOVA, N. I.

1959. Rukovodstvo po izucheniyu vozrasta i rosta ryb (Age and growth studies in fish). Izdatel 'stvo Akademii Nauk SSSR, Moskva, 1959. Translation available Office of Tech. Services, Washington. OTS 61—31036, 132 pp.

CLUTTER, R. I., and L. E. WHITESEL.

1956. Collection and interpretation of sockeye salmon scales. Int. Pac. Salmon Fish. Comm., Bull. 9, 159 pp.

GILBERT, CHARLES H.

1913. Age at maturity of the Pacific coast salmon of the genus *Oncorhynchus*. U.S. Bur. Fish., Bull. 32: 1-22.

GILBERT, CHARLES H., and WILLIS H. RICH.

1927 Investigations concerning the red-salmon runs to the Karluk River, Alaska. U.S. Bur. Fish., Bull. 43(2): 1-69.

HENRY, KENNETH A.

1961. Racial identification of Fraser River sockeye salmon by means of scales and its applications to salmon management. Int. Pac. Salmon Fish. Comm., Bull. 12, 97 pp.

KOO, TED S. Y.

1962a. Age and growth studies of red salmon scales by graphical means. *In* Ted S. Y. Koo (editor), Studies of Alaska red salmon, pp. 49-121. Univ. Wash. Press, Seattle, Publ. Fish., N.S., 1.

1962b. Age designation in salmon. *In* Ted S. Y. Koo (editor), Studies of Alaska red salmon, pp. 37-48. Univ. Wash. Press, Seattle, Publ. Fish., N.S., 1.

1962c. Sea-type red salmon in 1961 Nushagak run. *In* Ted S. Y. Koo (editor), Research in fisheries—1961, pp. 7-9. Univ. Wash. Coll. Fish., Contrib. 139.

KOO, TED S. Y., and EARL FINN.

1964. Circulus height and related morphology of sockeye salmon scales as determined from sections. *In* Research in fisheries—1963, pp. 15-18. Univ. Wash. Coll. Fish., Contrib. 166.

KROGIUS, F. V.

1958. O stroenii cheshui Kamchatskoi krasnoi raznykh lokal'nykh stad (On the scale pattern of Kamchatka sockeye of different local populations). *In* Materialy po biologii morskogo perioda zhizni dal'nevostochnyk lososei, pp. 52-63. Moscow, Vsesoyuznyi Nauchnoissledovatel'skii Institut Morskogo Rybnogo Khozyaistva i Okeanografii (VNIRO). (Translated by R. E. Foerster, 1958, Fish. Res. Board. Can., Biol. Sta., Nanaimo, B.C., Canada, Transl. Ser. 181.)

KUBO, TATSURO.

1958. Study of sockeye salmon stocks by means of the growth pattern of scales (preliminary report). Fac. Fish., Hokkaido Univ. (Hakodate), Part I—Text, 15 pp. (In Japanese); Part II—2 plates and 16 figures (In English). (Translation of Part I by H. Kasahara, Int. N. Pac. Fish. Comm., Vancouver, B.C., Canada, Doc. 206, 9 pp.)

KUBO, TATSURO, and JUN KOSAKA.

1959. A study on 5_3 age group red salmon stocks by scale growth formula. Suisan Cho (Fisheries Agency, Japan), 27 pp. [Processed.] (Int. N. Pac. Fish. Comm., Doc. 326.) (In Japanese, with English abstract, headings, tables, and figure legends.)

MOSHER, KENNETH H.

1950. Description of a projection device for use in age determination from fish scales. [U.S.] Fish. Wildl. Serv., Fish. Bull. 51: 405-407.

1963. Racial analysis of red salmon by means of scales. Int. N. Pac. Fish. Comm., Bull. 11: 31-56.

MOSHER, KENNETH H., RAYMOND E. ANAS, and KENNETH L. LISCOM.

1961. Study on scales. *In* Report on the investigations by the United States for the International North Pacific Fisheries Commission—1961. Int. N. Pac. Fish. Comm., Annu. Rep. 1960: 88-95.

NEAVE, FERRIS.

1936. The development of the scales of *Salmo*. Trans. Roy. Soc. Can., Ser. 3, 30(5): 55-72.

WALLIN, OLLE.

1957. On the growth structure and developmental physiology of the scale of fishes. Fish. Board. Sweden, Inst. Freshwater Res., Rep. 38: 385-447.

WELANDER, ARTHUR D.

1940. A study of the development of the scale of the chinook salmon (*Oncorhynchus tschawytscha*). M.S. thesis, Univ. Wash., Seattle, 59 pp. [Typescript.]

APPENDIX A

GLOSSARY OF TERMS

Adventitious mark or check.—A nonperiodic interruption in the regular pattern of scale growth. The check may or may not resemble a winter growth zone. See plates 6 (migration checks), 19B (twisted areas), and 19C (scar).

Annual ring, annulus, resting zone, winter ring, winter zone, winter mark, year mark, or year ring.*—A concentration of circuli or a series of interrupted circuli denoting a winter of life of the fish. See plates 1, 4, and 10.

Annulus.—See annual ring and footnote 4.

Anterior field, sculptured field.*—The portion of the scale that was embedded in the scale pocket toward the head of the fish and is sculptured with circuli. See plate 1. All plates show anterior fields.

Bases of circuli.—On the sockeye salmon scale only the first few circuli encircle the center or focus of the scale. The circuli beyond these first few are arcs. The ends of the circuli at the posterior field are their bases.

Central platelet or focus.—The area enclosed by the first or central circulus.

Circulus (plural, circuli), stria, or sclerite.*—A ridge on the upper surface of the anterior field of the scale. See Neave (1936), Welander (1940), or Wallin (1957). The circuli and interspaces (grooves) appear under magnification as concentric light and dark rings around the anterior field of the scale. All plates show circuli.

Clear field or area, posterior field or area.*—The portion of the scale which protrudes from the scale pocket toward the tail of the fish. This portion of the scale is a relatively clear area without distinctive growth features. See plate 1.

Focus.—See central platelet.

Fresh-water growth, fresh-water zone, fresh-water growth zone, lacustrine growth, lacustrine zone, lacustrine growth zone, or nucleus.*—The central portion of the scale formed while the fish was in fresh water. See plates 1 and 3 through 5.

Incidental growth, incidental zone, incidental growth zone, intermediate growth, intermediate zone, intermediate growth zone, plus growth, plus zone, plus growth zone, transitional zone, transitional growth zone, transitional zone, or spring growth.*—The portion of some scales between the fresh-water and the ocean growth

* here and later indicates the term I prefer.

zones where the difference between the fresh-water and ocean type circuli is not clear. See plate 6.

Intercirculus space, interspace.—A groove between two circuli. See circuli.

Intermediate growth, intermediate zone, intermediate growth zone.—See incidental growth zone.

Interspace.—See intercirculus space.

Lacustrine growth, lacustrine zone, lacustrine growth zone.—See fresh-water growth.

Marine growth, marine zone, marine growth zone, ocean growth, ocean zone, or ocean growth zone.*—The portion of the scale formed while the fish was in the ocean. See plates 1 and 7 through 11.

Migration check. — An adventitious check formed on some scales at the end of the incidental or plus growth. See plate 6.

Nucleus.—See fresh-water growth.

Ocean growth, ocean zone, ocean growth zone.*—See marine growth.

Plus growth, plus zone, plus growth zone.*—See incidental growth.

Posterior field or area.*—See clear field.

Regenerated scale.—A scale that replaces one that has been lost. The new scale grows without the formation of circuli until it reaches the approximate size of the scale which was lost. See plate 17.

Resorbed or eroded scale.*—A scale with the margins eroded because of sexual maturation. See plate 18.

Resting zone.—See annual ring. This term is often used by Japanese scientists.

Scar.—An abrupt change in the regular pattern of scale growth marked by a displacement of the natural configuration of the circuli. See plate 19C.

Sclerite.—See circulus. This term is widely used in Europe.

Sculptured field or area.—See anterior field.

Spring growth or spring growth zone.—See incidental growth and footnote 8.

Stria.—See circulus.

Transition zone, transitional growth, transitional growth zone, transition zone.—See incidental growth.

Winter ring, winter mark, or winter zone.*—See annual ring.

Year mark or year ring.—See annual ring.

APPENDIX B

EFFECT OF MAGNIFICATION ON APPEARANCE OF SCALE FEATURES (Appendix Plate 1)

The magnification which should be used for examination of scales from sockeye salmon varies with the size of the scales, the intended use of the data, and the preference of the scientist. The photographs in appendix plate 1 show how features of sockeye salmon scales appear at different magnifications and indicate the relative magnifications for various scale studies. (The arrows indicate the same feature on each scale section.)

Scale sections (shown at various magnification) follow:

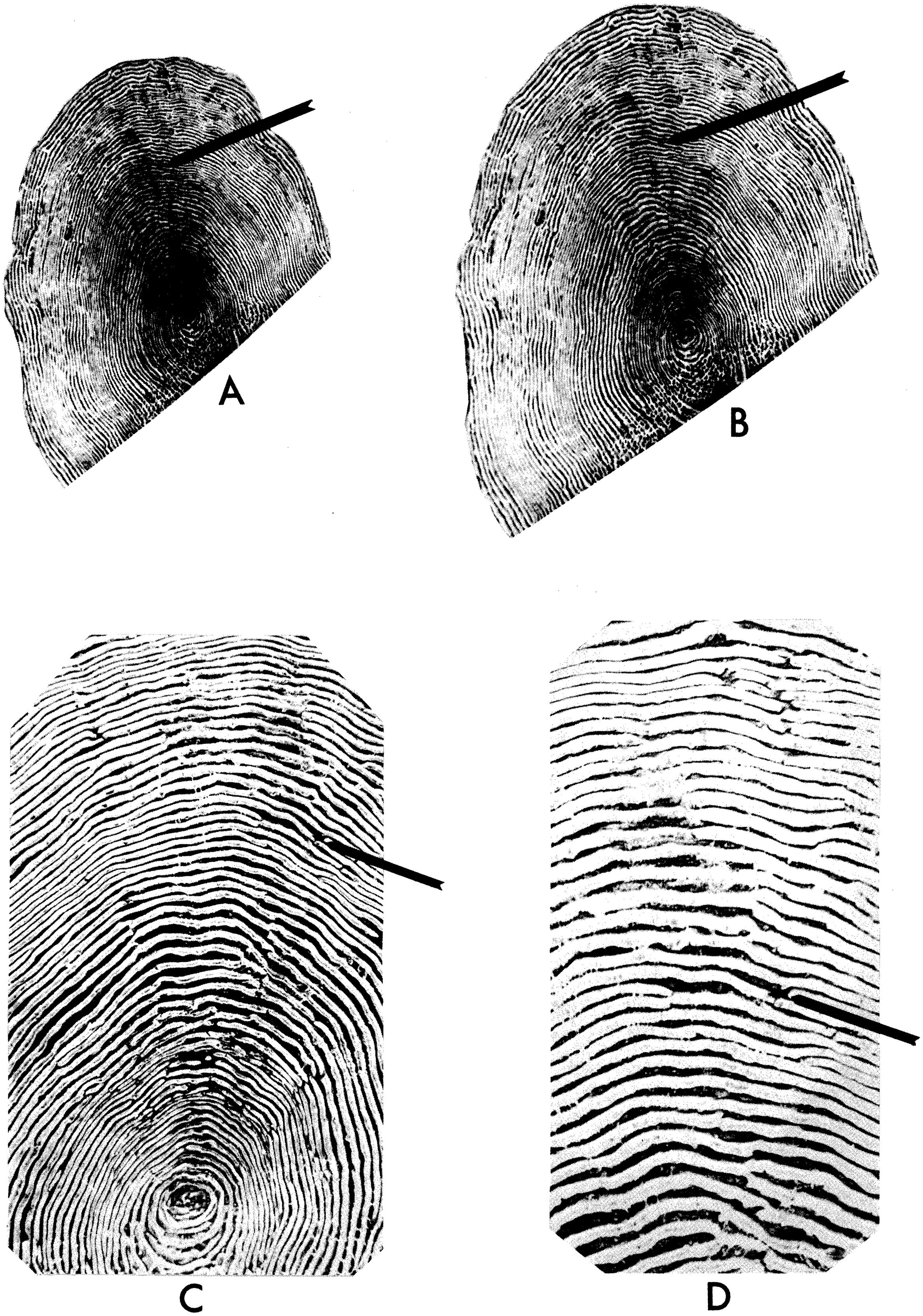
Section A. About 19 X. Note how difficult it is to identify any of the scale features on this photograph.

Section B. About 25 X. Note that the ocean winter zones are distinct at this magnification, but the fresh-water features are difficult to determine.

Section C. About 50 X. The ocean winter zones are less distinct at this magnification, but the details of the fresh-water zone are clear.

Section D. About 100 X. The ocean winter zones are very difficult to identify and delimit at this magnification.

Thus, the scales should be studied first at a magnification of between 25 X and 50 X to observe the whole scale in perspective and the details of the ocean zone. Then a magnification of between 50 X and 100 X should be used for the fresh-water zone, counts, and measurements of circuli, . . . These ranges of magnification are suggested as a starting point, because the exact magnification needed depends on the use of the data and on the temperament and visual habits of the investigator.



Appendix plate 1.—Effect of magnification on appearance of scale features.

APPENDIX C

APPEARANCE OF SCALES AND SCALE IMPRESSIONS (Appendix Plate 2)

Impressions of scales in plastic offer a number of advantages over the use of the scales themselves:

1. The effect of dirt on the scales is minimized—especially dirt on the unsculptured surface.
2. Duplicates can be made that are exact copies of the scales.
3. Impressions are easier to file and store than scales mounted on glass slides and the chance of breakage is reduced.

The process of making plastic impressions was described by Clutter and Whitesel (1956) and by Koo (1962a). Impressions made with a cold roller are not as satisfactory for salmon scales as those made with the heat-press method. (In 1955, a series of salmon scale impressions made with a jeweler's cold roller were compared with those made with a heat press. The heat-press impressions were greatly superior.)

In appendix plate 2, scale A shows a section of a sockeye salmon scale, and scale B shows an impression of the same scale section. The photograph of the impression shows slightly sharper circuli with less fuzziness from dirt and foreign material on the surface of the scale. Note that the photograph of the impression was reversed for comparison.

APPENDIX D

APPEARANCE OF NEGATIVE AND POSITIVE PRINTS (Appendix Plate 3)

When plastic impressions are made of the scales, the ridges on the scale surface become valleys in the impressions. Koo and Finn (1964) found that the sharp troughs of the impressions and the ridges on the scales both appear as dark rings when examined by transmitted light. When either the scale or its impression is examined by reflected light, these structures appear as light rings. Because the circuli and adjoining interspaces over much of the scale have about the same width, and because some workers project the scales by transmitted light and others use dark-field techniques for direct microscopic examination, it makes little difference whether the scale photograph is a positive or a negative print.

In appendix plate 3 there is an example of each type: Scale A is a positive print and scale B a negative print of the same sockeye salmon scale.

The only real difference in the prints is in the posterior field where growth features are absent anyway. The density of the negative print more nearly matches the image seen under the projector, or through the microscope; negative prints, therefore, were used in making this atlas.

APPENDIX E

TECHNIQUES OF PHOTOGRAPHING SCALES

The scales were photographed by placing a piece of high-contrast photographic enlarging paper under the image from a scale projector set up in a darkroom. The image was first carefully focused on a white paper in a printing frame. Then, with only a darkroom safelight on, a piece of the enlarging paper was substituted for the focusing paper, exposed, developed in a high-contrast paper developer (minimum exposure-maximum development), and fixed, washed, and dried in the usual manner.

Positive prints can be made by taking a picture of a scale with a microscope camera (a single lens reflex camera on a microscope), or by photographing the projected image with a camera, then exposing and processing the same as for any photograph of a high-contrast subject.

A

B

APPENDIX PLATE 2.—Appearance of scales and scale impressions.

A

B

APPENDIX PLATE 3.—Appearance of negative and positive prints.

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