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STEELHEAD AGE DETERMINATION TECHNIQUES

by

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INTRODUCTION

Age determination by examination of steelhead scales (Meigs and Pautzke 1941, Shapovalov and Taft 1954) and otoliths (McKern 1971, McKern et al. 1974) has been used in life history studies. Scales are easy to remove from the fish and need little preparation to be made suitable for reading. However, scales can be damaged, regenerated or lost, particularly while the juvenile fish resides in freshwater. Steelhead have a long freshwater residence (1-5 years), and many scales suffer from extensive regeneration leaving the record of freshwater life history incomplete. Otoliths (sagittae) can be used to supplement freshwater scale ages, since the freshwater record is usually complete and readable, and can also be used to confirm ocean age determination. Collection of otoliths, however, requires sacrifice of the fish, and it is time consuming to prepare them for reading.

This study is an attempt to 1) develop some criteria for steelhead age determination that are based on examination of scales of known age coded-wire tagged (CWT) fish and examination of otoliths, and 2) develop criteria for identification of spawning 'checks' on scales and otoliths. The criteria developed are applied to a large sample of scales collected during 1976-81 and 1983-84 Japanese high seas salmon investigations, and resulting age compositions are compared to those documented by Japan Fisheries Agency (JFA) biologists. Age and spawning history determinations are presented for steelhead from these samples and from samples collected by U.S. observers on Japanese salmon motherships in 1984.

MATERIALS AND METHODS

Scale and Otolith Collections

Biological data and scale impressions from steelhead collected aboard Japanese research vessels during 1976-81 were supplied by JFA. Steelhead collected by Japanese research operations in 1983 and 1984 were provided to the Department of Fisheries and Oceans, Canada (DFO). DFO biologists removed scales and otoliths and sent them to the Fisheries Research Institute (FRI) for age determination. Additional fish were collected by U.S. observers on Japanese motherships in 1984. FRI biologists examined these fish for a wide variety of biological attributes, and collected scales and otoliths for age determination.

Sample Preparation

Acetate scale impressions were viewed with a microfiche reader for age determination.

Otoliths were removed and stored in a mixture of 50:50 glycerine and water for a minimum of one week. The paired otoliths were then mounted with epoxy on microscope slides such that the proximal (sulcus) surface faced down on the slide. Otoliths were polished with a low speed dental handpiece equipped with a medium cuttle polishing disk. Polishing continued until the hyaline features of the annuli were distinct. Care was taken to maintain the concave surface contour, and to lightly polish the edges to prevent bone loss along the otolith perimeter. Otoliths were viewed with a binocular dissecting microscope (30X) using reflected light.

Two FRI biologists examined the full collection of scales and otoliths and each made an age determination. When ages were in disagreement between readers, the specimens were re-examined for a final decision. The 1976-81 Japanese research vessel scale collection provided the basis of comparison between JFA and FRI age determinations. FRI ages were determined independently of JFA age determinations. The 1983 research vessel scale age determinations were not included in this comparison because the scale impressions at FRI are a subset of the JFA collection, and because the impressions were made from different scales than collected and examined by Japanese scientists.

Otolith age determination from the 1983-84 samples were aged while viewing the scale from the same fish, and thus age determinations by otolith and scale methods were not independent. Looking at the scale and otolith together was particularly useful in otolith ocean age determination. However, many scales were regenerated in the freshwater zone and did not offer much information in otolith freshwater age determinations. Fish were given a scale age and an otolith age.

Process of Age Determination Using Steelhead Scales and Otoliths

Scale age is determined from the spacing and thickness of circuli. Fine, closely spaced circuli near the focus indicate freshwater residence, and thick, widely spaced circuli indicate ocean growth. Annuli are shown by a decrease in circuli spacing and thickness, and by breakage and interbraiding of circuli. Annuli are continuous rings on the scale and are present on all the scales from the same fish. During seaward migration, steelhead are known to move out of the estuary quickly and proceed directly into the open ocean (Hartt 1980). Consequently, the scales do not exhibit large areas of intermediate qrowth, but following the last freshwater annulus, freshwater plus growth can often be recognized on the scale immediately before a dramatic change to ocean-type circuli and spacing.

FRI biologists did not make freshwater age determinations from slightly regenerated scales. The first freshwater annulus is often located very close to the focus if the fish emerged late in the summer, and this annulus could be obliterated on slightly regenerated scales.

The appearance and structure of growth zones on salmonid otoliths have been described by Kim and Koo (1963), Kim and Roberson (1968), McKern et al. (1974), and Campana and Neilson (1985). Otolith annuli appear as dark hyaline bands when viewed with reflected light. These bands are primarily composed of a proteinaceous matrix, low in inorganic deposition. Summer growth appears as white opaque bands, much wider than the hyaline bands. Opaque bands are rich with inorganic material.

The appearance of hyaline and opaque bands is used to distinguish freshwater and ocean growth zones. The hyaline and opaque bands of the freshwater zone are smooth and form a continuous, oval pattern which can be traced around the nucleus (McKern et al. 1974, Campana and Neilson 1985). There may be from one to five freshwater annuli. The last freshwater annulus is commonly wider than previous annuli.

In the ocean zone of the otolith, opaque and hyaline bands are broken by transverse notches radial to the nucleus. These deep notches are particularly apparent in the opaque bands (McKern et al. 1974). Interpretation of the ocean zone is sometimes difficult due to the growth patterns in this region. Unlike freshwater growth, ocean annuli tend to be less distinct and are often not continuous.

Ocean growth of the otolith naturally slows as the fish gets older, and this is reflected in an overall thinning of the opaque and hyaline bands. Recent summer growth zones are narrow and so closely spaced with previous years' growth, that the intervening hyaline band is often unrecognizable in steelhead having spent two or more years at sea. Another complication is the time of year that the steelhead are captured. Opaque summer growth of the current year generally does not appear before July in otoliths collected on the high seas. The hyaline band of the previous winter occurs at the edge of otoliths collected before July. Opaque summer growth is present and usually found on the anterior lobe of otoliths collected after the first part of July. In this study, fish caught in early summer were considered as having completed the previous year in the ocean, even before summer opaque growth appeared at the edge of the otolith.

Caution must be taken with interpretation of the ocean zone of steelhead otoliths. Careful otolith polishing ensures that the perimeter is not eroded with subsequent loss of information. Corroboration of otolith ocean ages with information from scales is prudent and necessary for obtaining reliable ages.

We wish to emphasize that the age determinations made in this report only represent our best effort to establish consistency in interpretation of growth patterns, but that validation studies are needed for many of the growth patterns presented herein, particularly in view of the mixed-stock nature of the high seas samples.

RESULTS

Growth Patterns of Scales and Otoliths

The recognition of freshwater age 1. steelhead was based on examination of known-age scales and otoliths collected from high seas coded-wire tagged recoveries. The scales and otoliths from two specimens of known-age 1.2 fish, are shown in Figs. 1, 2, 3 and 4. There are apparently three scale patterns for freshwater age 1. fish. First, the annulus may be lacking entirely, perhaps resorbed by a transition check between freshwater and ocean growth. Second, the annulus may be weak, indistinct, or ambiguous. An example of this is shown in Fig. 1. Generally, the freshwater zone of hatchery-reared steelhead is composed of evenly spaced circuli. A band of thinner circuli indicated by arrow D is probably the freshwater annulus. The ocean zone has two clear annuli, with summer growth present at the edge of the scale. The otolith of this fish (Fig. 2) has an indistinct freshwater annulus. The freshwater zone is almost uniformly dense and opaque. McKern et al. (1974) described otoliths from hatchery-reared steelhead as having a freshwater zone devoid of patterns or changes in density.

The third pattern of the freshwater age 1. fish has several checks in the freshwater zone of the scale (Fig. 3) and otolith (Fig. 4). Several false checks on the scale and otolith are indicated by arrow C. The freshwater annulus is weak, but indicated on the scale by arrow D. The otolith (Fig. 4) has several weak hyaline bands in the freshwater zone (arrow C), making it difficult to determine which band might be a true annulus.

An example of a freshwater age 2. pattern is shown in Figs. 5 and 6. Unlike freshwater age 1. fish, the freshwater annuli are distinct on the scale and otolith. The freshwater summer circuli on the scale are more widely spaced, and the result is the appearance of seasonal growth. The otolith (Fig. 6) shows the typical freshwater age 2. pattern: the two annuli are distinct, and the first summer opaque zone is larger than the second.

Figures 7 and 8 illustrate the common age 3.2 pattern. This age 3.2 scale has the first freshwater annulus close the focus. Ageing slightly regenerated scales can risk loss of this freshwater year. Typically, many more circuli are laid down in the second freshwater summer than in the first. The third annulus appears immediately before the transition from freshwater- to ocean-type circuli. The otolith (Fig. 8) shows a freshwater zone with clear hyaline bands delineating the annuli. This otolith shows the notches in the opaque bands of the ocean zone as compared with the uninterrupted bands of the freshwater zone. The first ocean summer opaque band is wider than the other ocean opaque bands. The first winter annulus is indicated by arrow B where a thin band of hyaline growth is visible. This annulus is accentuated by the opaque band of the following summer, indicated by the opaque area between arrow A and B. The next hyaline band is the second ocean annulus indicated by arrow A. A final opaque band at the tip of the anterior lobe that denotes summer growth in the year of capture is indicated by arrow F. Finding the alternating bands of opaque and hyaline zones is critical for pattern recognition and age determination of otoliths.

The scale and otolith shown in Figs. 9 and 10 have been included to illustrate a typical ocean age .1 pattern. On Fig. 9, arrow A points to a 'double check' pattern at the ocean annulus. There are two bands of closely spaced circuli separated by a zone of wider spaced circuli. This double check is common in scales, especially at the first ocean annulus. We know from CWT returns that the double check is not two separate annuli.

A common 4.1 pattern is shown in Figs. 11 and 12. The ocean annulus in this case does not show the double check pattern. The enlargement of the scale's freshwater zone indicates the first annulus occurs close to the focus, reinforcing the importance of obtaining non-regenerated scales for ageing. The otolith (Fig. 12) shows opaque bands of even thickness in the freshwater zone. The first ocean annulus is at arrow A.

Figures 13 and 14 show growth patterns in an age 5.2 steelhead. The first freshwater annulus is very close to the focus of the scale and the annuli are composed of very thin circuli relative to summer circuli. The otolith shows the five smooth hyaline bands in the freshwater zone. The ocean opaque zones are notched, and the first opaque zone is wider than the second. Two ocean annuli are indicated by the hyaline bands alternating between the opaque bands. Opaque summer growth at the edge of the otolith is indicated by arrow H. The opaque band between the two ocean annuli is wider at the posterior and anterior lobe than along the ventral lobe. Dramatic narrowing of the opaque band at the ventral lobe is the key to finding spawning checks on the otolith.

Identification of Spawning Checks

There is no means of validating the identification of spawning checks in the high seas scale collection. The CWT returns do not provide this information. Therefore, we have attempted to be consistent in our designation of spawning checks on scales and otoliths. Bali (1959) recognized that spawning checks on steelhead scales were caused by energy requirements during the return to freshwater for spawning and that the check was formed by resorption of circuli.

To help with interpretation of spawning checks, the biologists at FRI sought the advice of regional biolgists familiar with scale patterns and interpretation of spawning checks (personal communication with Mr. Maurice Lirette, British Columbia Ministry of Environment, Mr. Bob Leland, Washignton Department of Game WDG, and Ms. Nancy McHugh, Oregon Department of Fish and Wildlife, ODFW). These biologists agreed that spawning checks are characterized by resorption of circuli, primarily along the sides of the scale. This resorption is less noticeable or even nonexistent on the anterior region. The amount of resorption ranges from the loss of 3 to 4 circuli to complete loss of the winter annulus. Scales which have highly eroded areas or complete resorption of the previous winter annulus are characteristic of summer steelhead, which undergo the stress of long freshwater residency prior to spawning. However, scales from winter steelhead are likely to show less scale resorption and retain the previous annulus. Sometimes winter spawners come in as late as April, spawn immediately, and leave little evidence whatsoever of a spawning check on their scales. Additional evidence of spawning is a ridge on the scale impression which wraps completely around the focus, through the posterior portion of the scale, and is continuous with the spawning check in the anterior zone of the scale. Bali (1959) observed both strong and weak spawning checks on scales of steelhead from Oregon, and FRI biologists observed this phenomenon in the high seas steelhead scale collections.

Evidence of a spawning check on otoliths is a dramatic narrowing of an ocean opaque band occurring along the ventral lobe, causing a reduction of the distance between ocean annuli (McKern et al. 1974). If the opaque band is fully resorbed, then the ocean annuli become continuous across the ventral lobe.

Koo's (1962) method of age designation was used in all comparisons of age determinations, but it does not allow for a record of the number and position of spawning checks on scales and otoliths. A code was devised whereby the ocean annuli were counted until a spawning check was encountered, and the check was noted as an "S". This pattern makes note of the number of spawning checks on a scale and their relative position among the unresorbed ocean annuli. To give the scale an ocean age, the number of annuli and spawning checks are simply added. For example, the scale in Fig. 15 is designated as age 3.1S, indicating three freshwater annuli, one ocean annulus and a spawning check at the second ocean annulus; the assigned scale age is 5 years.

Several examples of apparent spawning checks on scales and otoliths are presented in Figs. 15-20. Figure 15 is an example of a strong spawning check on the scale. Large areas of the last winter annulus and part of the previous summer's growth record have been resorbed along both sides of the scale.

Spawning checks are more difficult to find on the otolith than the scale. On Fig. 16 the opaque zone between the first and second ocean annuli narrows (arrow F) from the posterior to the ventral lobe.

The fish represented in Figs. 17 and 18 was designated 2.1S1, indicating a spawning check at the second ocean annulus. The spawning check on the scale in Fig. 17 is weak. The second ocean annulus has been retained along the anterior margin, but several circuli have been resorbed along the sides of the scale. On the right, the annulus is fully resorbed and summer circuli from two different seasons are in close juxtaposition. A spawning check does not appear at the third ocean annulus. Figure 18 shows the narrowing of the opaque band between the first and second ocean annuli at arrow F.

The scale in Fig. 19 illustrates the pattern of a multiple spawner, that is, a fish which is believed to have made more than one spawning migration. This fish, aged 3.1SSS, made three consecutive spawning migrations. The spawning checks at ocean annulus 2 and 3 show resorption at the sides of the scale and the anterior region. The annuli are almost lost; the summer growth periods appear very small and are side-by-side with no intervening winter annuli (except for the spawning checks themselves). The fourth ocean annulus and spawning check are at the edge of the scale, and are shown by the large sections missing from the scale edge. The otolith from this fish (Fig. 20) shows the distinctive pattern of a multiple spawner. The last three ocean annuli (indicated by arrows A, B and C) are separated by wide opaque growth along the anterior lobe, but they become continuous across the ventral lobe (indicated by arrow I). Resorption along the ventral lobe gives it a flattened appearance, as well as causing the anterior lobe to appear hooked (arrow H).

Crystalline Otoliths

Crystalline otoliths were encountered among the samples of otoliths from 1983 and 1984 Japanese research vessels and mothership operations in 1984. Crystalline otoliths are difficult to age because they are featureless, transparent or milky and do not show clear hyaline and opaque bands. We did not age crystalline otoliths. Typically, these otoliths have a dense opaque nuclear region and have an exaggerated concave shape. In Fig. 21, arrow A indicates a convoluted and disproportionately large dorsal lobe. Arrow B shows the dense, opaque nuclear zone. The ocean zone is transparent and has no discernible alternating hyaline and opaque bands.

The occurrence of crystalline otoliths may be higher in hatchery stocks than wild (personal communication, Mr. Ken Williams, Wells Hatchery, WDG). A 40 % incidence of crystalline otoliths has been observed in the Wells Hatchery stock and a 10 % occurrence was noted in wild stocks, although the latter value may be biased downward (K. Williams, pers. comm.).

Comparison of JFA and FRI Steelhead Age Compositions

The number of regenerated steelhead scales found in the Japanese research vessel samples during 1976-81 are summarized in Table 1. The incidence of regenerated scales declined in FRI determinations from 75% in 1976 to 59% in 1981. By 1981 however, still less than half of the scales collected yielded complete freshwater age information.

Both agencies agreed that age 3.1 was the prevalent age class in the 1976-78 samples (Table 2). However, in the 1979-81 samples, the agencies disagreed on which age classes were most numerous. JFA biologists found age 2.1 to predominate in 1979, while FRI biologists found that age 3.1 was predominant in that sample. In 1980, steelhead age 2.2 was found predominant by JFA determination but FRI found age 3.2 predominant. FRI biologists detected more age classes and more freshwater age 1. steelhead than JFA biologists. For instance, in the 1981 sample, FRI observed age 1.1 as the predominant age class.

Both JFA and FRI agreed in sample years 1976-79 and 1981 that the predominant ocean age was .1, comprising as much as 80 % in the 1976 sample and as little as 62 % in the 1979 sample (FRI determinations). In 1980, age readers of both agencies agreed that the predominant ocean age was .2 (59 % by JFA and 48 % by FRI determinations).

Freshwater ages 2. and 3. were found by both agencies to predominate in all sample years. In the 1976-79 and 1980-81 samples both JFA and FRI biologists agreed freshwater age 3. was most numerous. The proportion of freshwater age 3. ranged from 33% (in 1981) to 48% (in 1980) by FRI determination. In the 1979 sample, while FRI determined freshwater age 3. was the predominant freshwater age (36%), JFA biologists found that the principal age was 2. (56%).

Results of a scale-by-scale comparison for freshwater and ocean age determinations by both agencies are summarized in Table 3. Freshwater age readings were not in good agreement (46 % to 68 %), while agreement in ocean ages ranged from 86 % to 96 % depending on the year sampled.

Comparison of Scale and Otolith Age Compositions

A summary of the numbers of scales and otoliths collected from Japanese research vessels during 1983-84 and motherships in 1984, is given in Table 4. The scale regeneration rates for the research vessel samples were 75 % (1983) and 77% (1984). Scale regeneration rates were much lower (43 %) in the 1984 mothership sample since extra scales were collected from the dissected fish. The proportion of crystalline otoliths in all three samples ranged between 11 % and 13 %.

Otoliths were aged while viewing the paired scale from the same fish, so these ages are not independent. However, the age compositions are presented in Table 5 to determine whether the additional freshwater ages gained from otoliths influence the age compositions. In the 1983 research vessel and 1984 mothership scale samples, the prevalent age class was 3.2. The most common age class from otolith age determinations was 3.2 in 1983, and 2.2 in 1984. The 1984 research vessel sample showed age 1.2 and 2.2 age classes were equally abundant, as determined from both scales and otoliths. Ocean age .2 steelhead occurred in the greatest frequency throughout the samples, regardless of the ageing method used.

Comparison of percentage agreement between readable scale and otolith age determinations showed 73 % to 94 % agreement on freshwater ages, and nearly 100% for ocean ages (Table 6).

Frequency and Position of Spawning Checks on Scales

Scales from fish which displayed spawning checks are tabulated in Table 7. There were 110 scales from the combined samples of the research vessels 1976-84 and the mothership samples from 1984 which showed one or more spawning checks. For males and females combined, the most frequent pattern (67%) was for the spawning check to occur at the second ocean annulus, implying the fish spent two summers in the ocean before spawning. Most scales (74 %) had one spawning check evident on the scale. The proportion of females (28%) that spawned more than once was greater than the proportion of males (20%) that spawned more than once. In one instance, a steelhead spawned three times. All multiple spawning males and all but one female repeat spawner were found to have spawned in consecutive years, as shown by checks at consecutive ocean annuli. One female was found to have an ocean annulus between spawning checks.

To determine whether the distribution of spawners was different depending on whether the spawning check was at the last ocean annulus or not, steelhead capture locations in the North Pacific were plotted by 2°-latitude X 5°-longitude areas and month. The months April through June are shown in Fig. 22 and the months July through September are shown in Fig. 23. The figures indicate that among fish with spawning checks there is no strong difference in the distribution between fish that had spawned the previous winter with those that did not. The upper panel of Fig. 22 indicates that a steelhead with a spawning check at the edge of the scale was found as far west as INPFC area W7542 by 30 April. This scale exhibited a strong spawning check because of extensive resorption of circuli from the sides of the scale. The spawning check was on the last ocean annulus at the scale edge.

DISCUSSION

Age composition of steelhead scales collected by Japanese research vessels during 1976-81 indicate that JFA and FRI biologists were in agreement on ocean age. In the sample years 1976-79 and 1981, ocean age .1 steelhead predominated. Sutherland (1973) reported 65% of the scales collected by the U.S. Bureau of Commercial Fisheries in 1955-67 were ocean age .1. Okazaki (1984) indicated that ocean age .1 dominated the catches of steelhead collected by Japanese research vessels during 1972-82. In this study, recent steelhead collections by Japanese research vessels in 1980, 1983-84 and during mothership operations in 1984 indicated a prevalence of ocean age .2 fish in the catches.

Disagreement in freshwater ages occur in the 1979 and 1980 research vessel samples. For 1979, JFA found 2.1 predominant and FRI found age 3.1 predominat. In 1980, JFA found age 2.2 and FRI found age 3.2 the predominat age class. FRI biologists consider the check close to the scale focus to be a freshwater annulus and perhaps this criterion contributes to fish aged an additional freshwater year as compared to JFA ages.

The low percent agreement on ages between the JFA and FRI stems from difficulty in determining freshwater age. Many possible age classes, subjectivity in the definition of regenerated scales, and the difficulty in determination of freshwater age 1. all contribute obstacles to consistent interpretation of the freshwater zone.

Scales and otoliths each offer benefits as structures for age determination. Scales are easy to collect without damage to the fish, and can be quickly prepared for reading. The nature of ocean growth on the scale is such that the annuli are widely separated and can be easily discerned, and resorption of circuli produces a record of spawning checks. However, the freshwater zone of the scale is often regenerated, which precludes freshwater age determination.

The otolith is useful in freshwater age determination because the record is usually complete. Growth patterns of the freshwater zone are relatively easy to interpret because the hyaline and opaque bands are continuous. However, the fish must be dissected to remove the otoliths and it is time consuming to mount and polish the otoliths. Scales and otoliths as structures for age determination complement one another. While the scale indicates ocean age and presence of spawning checks, the otolith provides a freshwater age when the scale is regenerated.

Collection of more non-regenerated scales and otoliths from high seas CWT recoveries will expand the documentation for hatchery growth patterns and contribute to more consistency in freshwater age interpretation.

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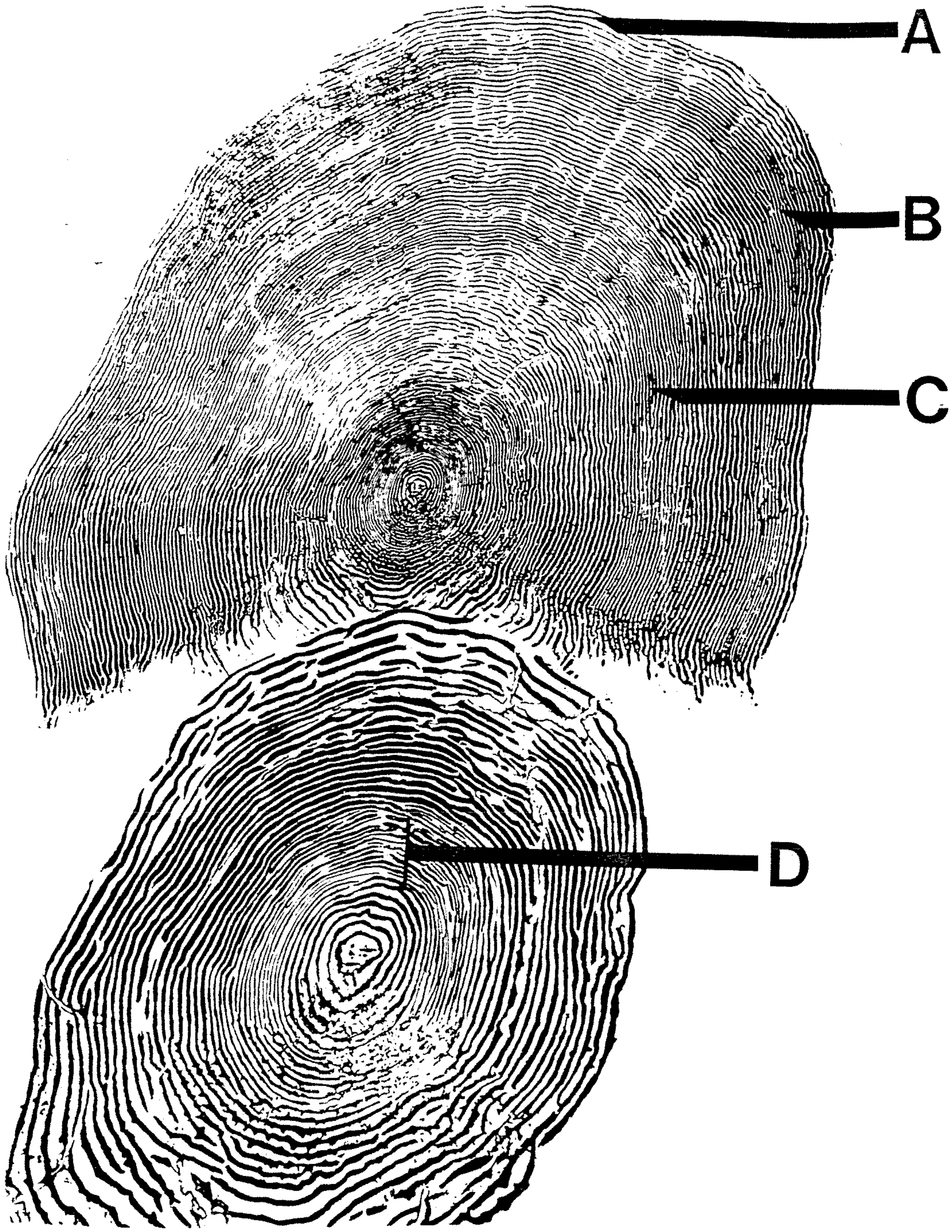

Fig. 1. Full scale and freshwater enlargement of a steelhead CWT recovery. Known-age 1.2, fish length 699 mm, body weight 3800 gms, female, released from Putledge River, B.C. and caught by mothership A06 on 7/17/84. A: summer growth at scale edge, B: second ocean annulus, C: first ocean annulus, D: likely area of freshwater annulus. Photograph of an otolith taken from this fish follows in Figure 2.

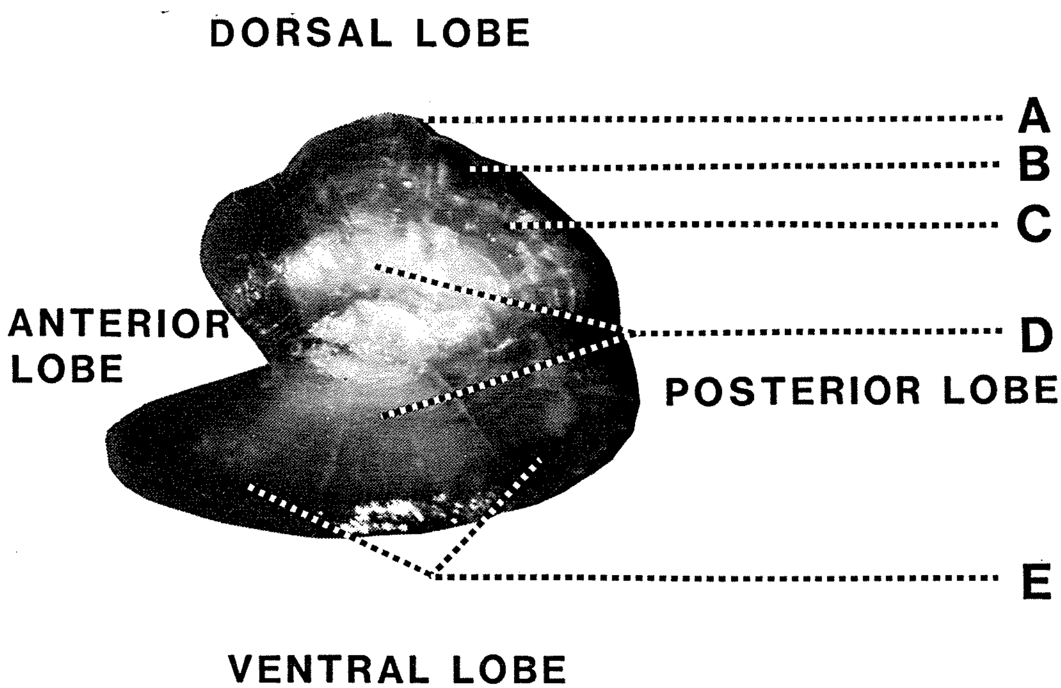

Fig. 2. Photograph of an otolith taken from the fish described in Fig. 1. Letters as described in Fig. 1 for analogous structures. Note the dense opaque freshwater zone at D, and no distinct freshwater annulus. E: ventral lobe almost transparent, crystalline.

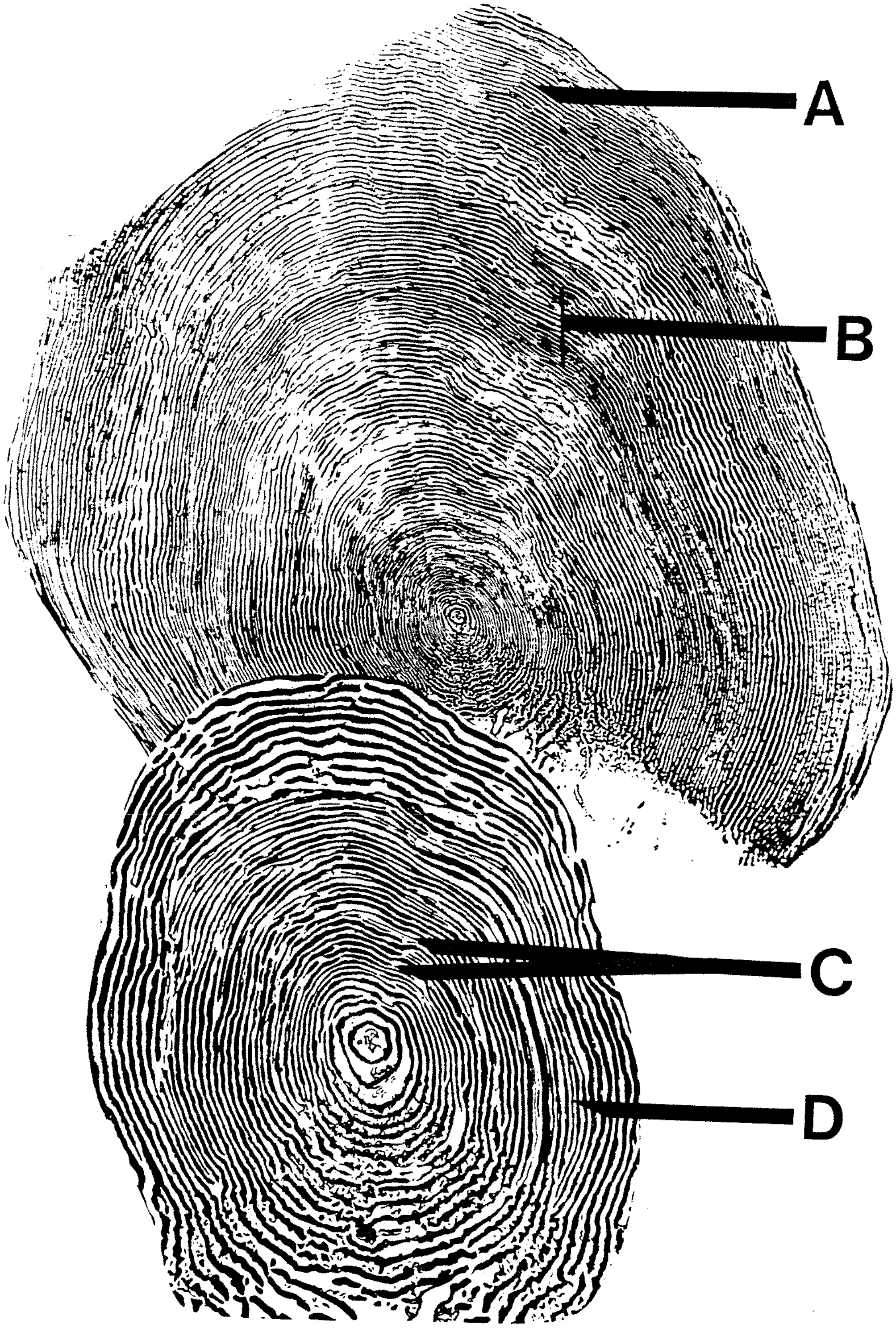

Fig. 3. Full scale and freshwater enlargement of a steelhead CWT recovery. Known-age 1.2, fish length 850 mm, body weight 6600 gms, male, released from the Cowlitz River, WA and caught by mothership A07 on 7/21/84. Scale photograph was clipped at the top of the anterior zone where it was obscured by another scale on the card. A: second ocean annulus, B: double-check first ocean annulus, C: numerous checks in the freshwater zone, D: first freshwater annulus. Photograph of an otolith taken from this fish follows in Figure 4.

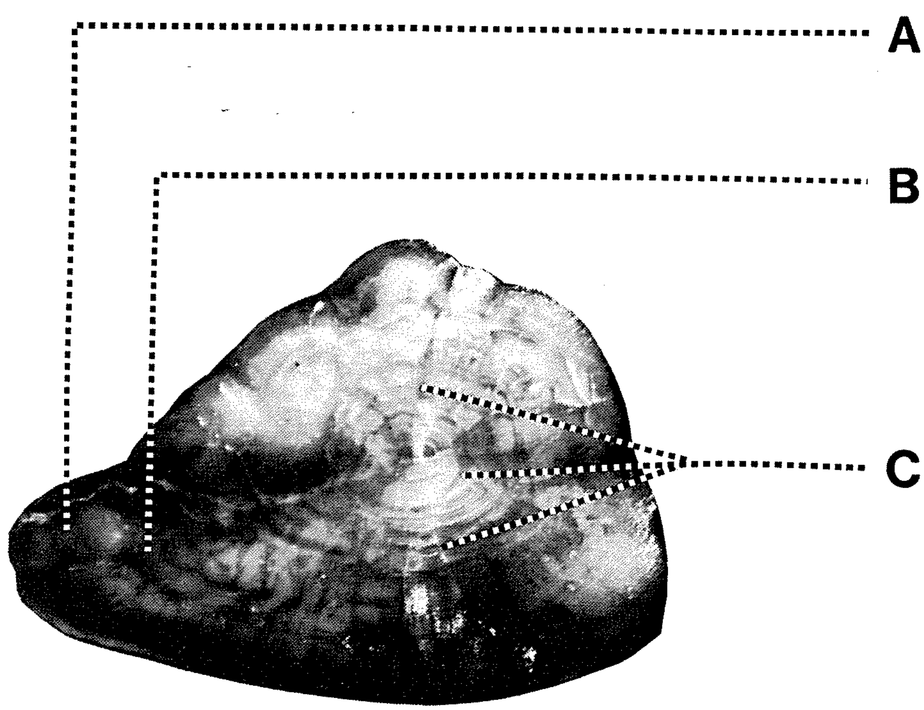

Fig. 4. Photograph of an otolith taken from the fish described in Fig. 3, known age 1.2. Letters as described in Fig. 3 for analogous structures.

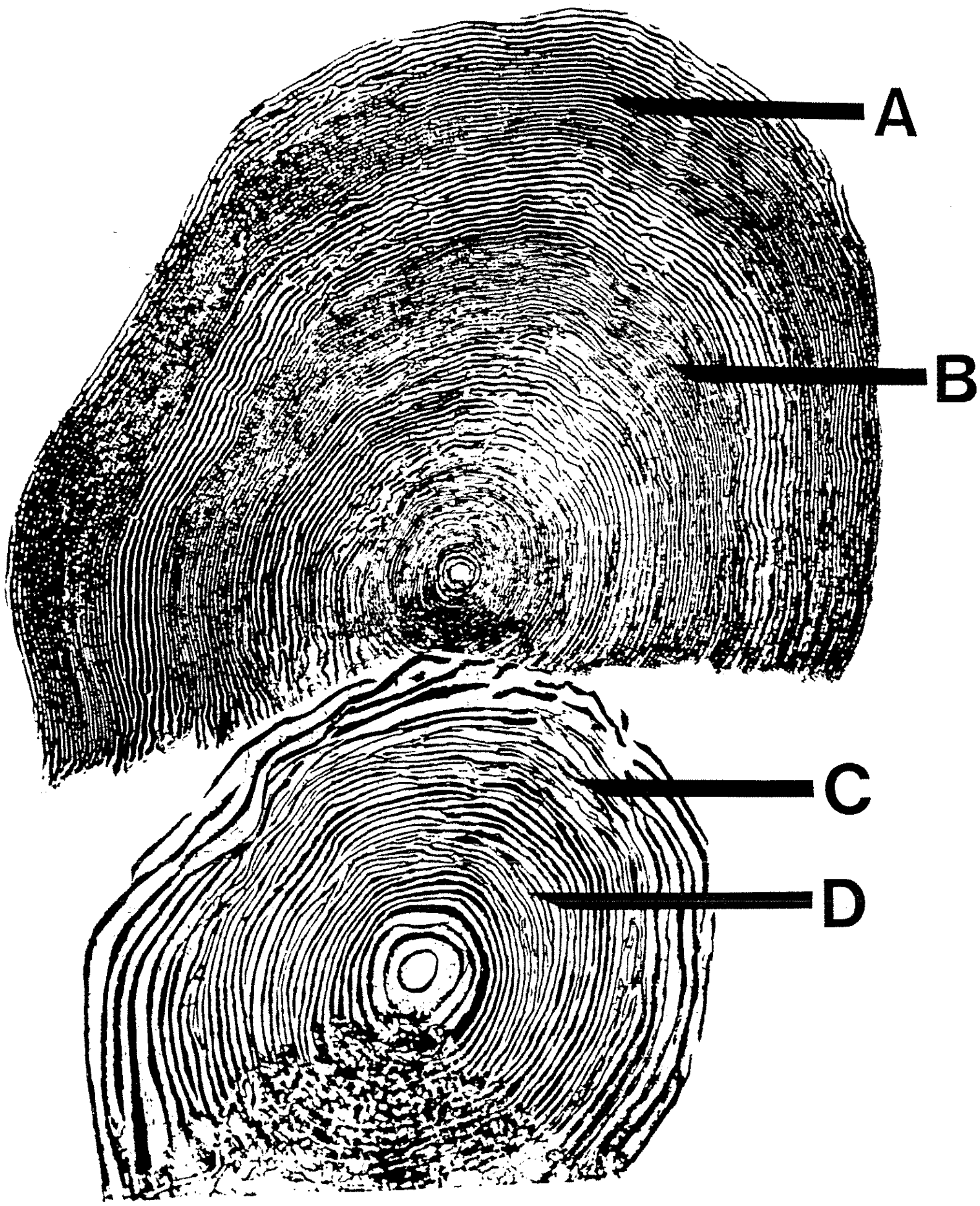

Fig. 5. Full scale and freshwater enlargement of a steelhead with a common 2.2 growth pattern. Fish length 713 mm, body weight 3550 gms, female, caught by mothership A06 on 7/19/84. A: second ocean annulus, B: first ocean annulus, C: second freshwater annulus, D: first freshwater annulus. Photograph of an otolith taken from this fish follows in Fig. 6.

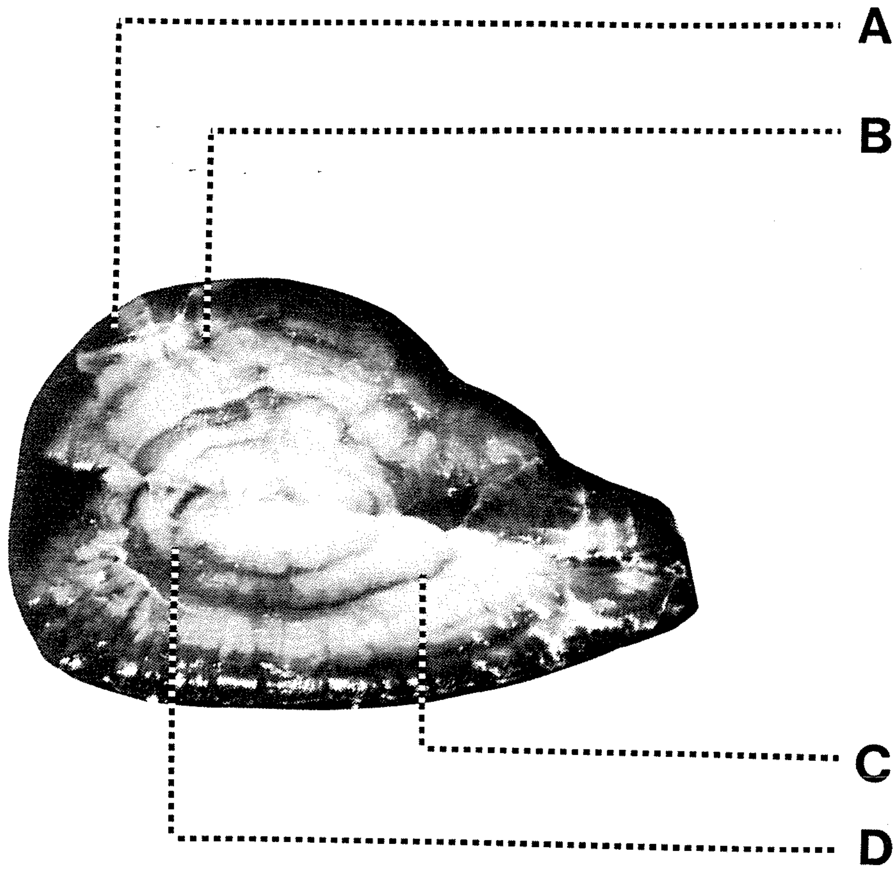

Fig. 6. Photograph of an otolith taken from fish described in Fig. 5, showing a common 2.2 growth pattern. Letters as described in Fig. 5 for analogous structures.

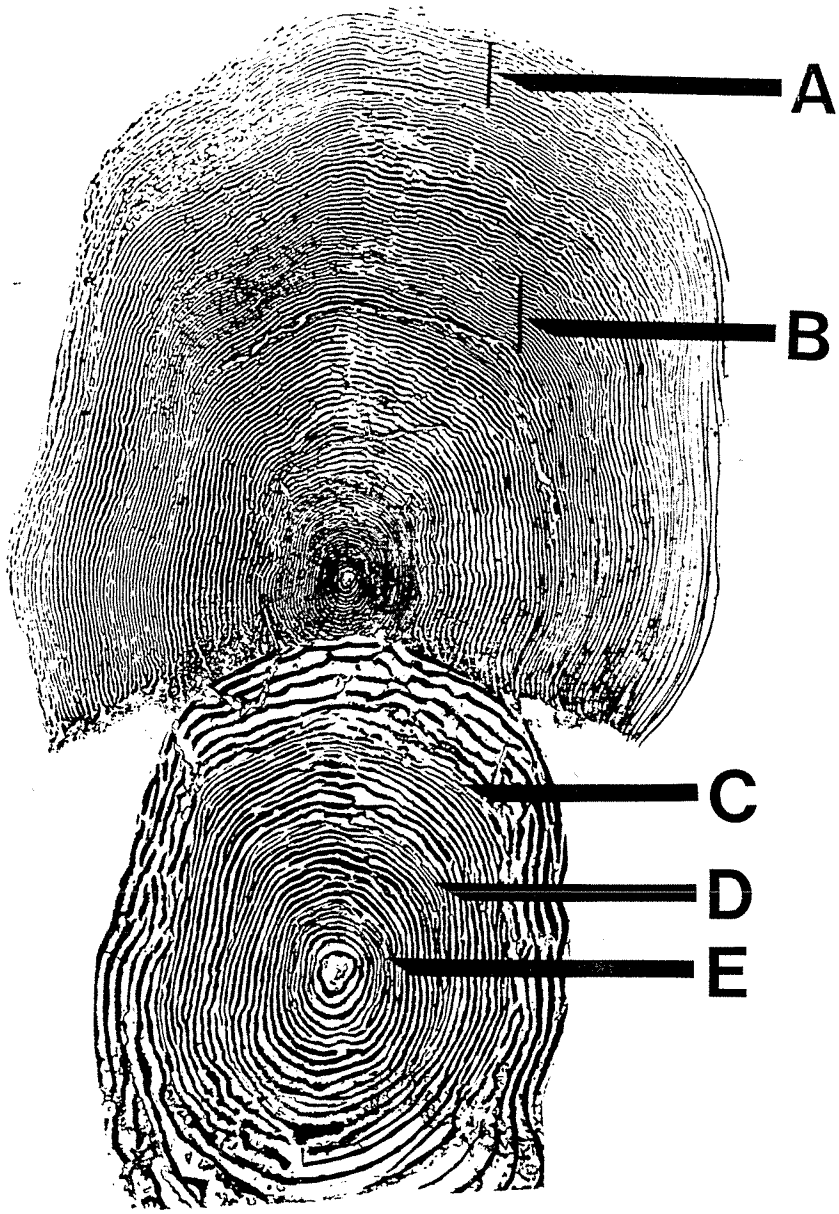

Fig. 7. Full scale and freshwater enlargement of a steelhead with a 3.2 growth pattern. Fish length 700 mm, body weight 4125 gms, female, caught by mothership A03 on 6/24/84. A: second ocean annulus, B: first ocean annulus, C: third freshwater annulus, D: second freshwater annulus, E: first freshwater annulus. Photograph of an otolith taken from this fish follows in Fig. 8.

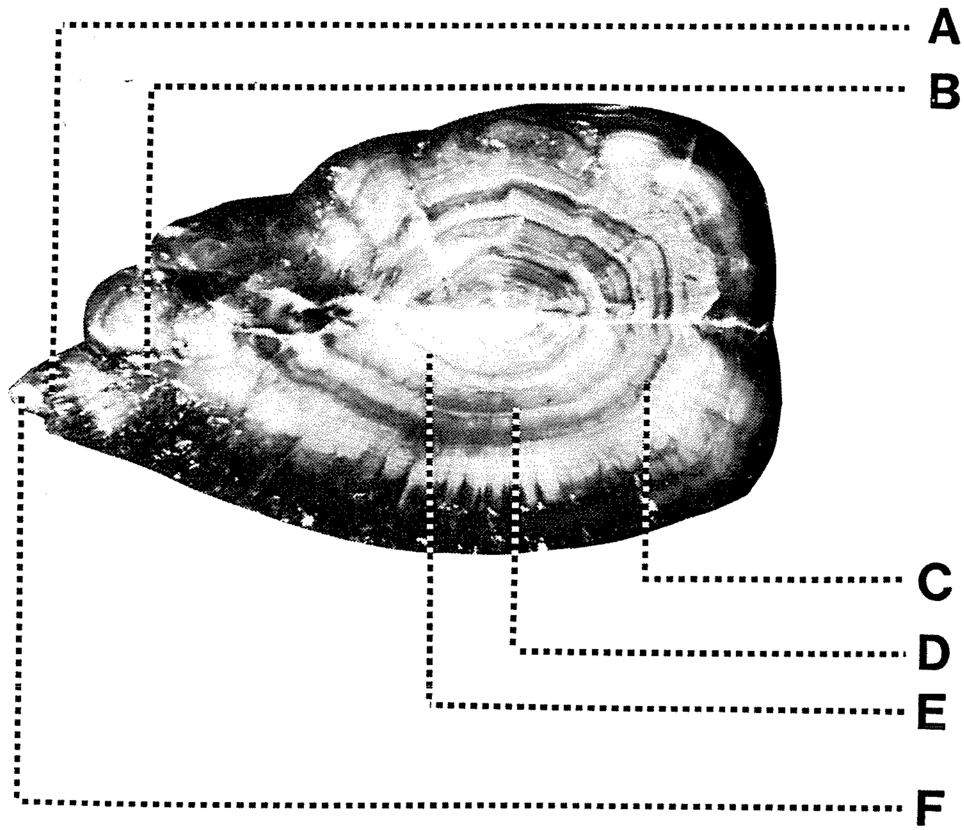

Fig. 8. Photograph of an otolith taken from the fish described in Fig. 7, showing a 3.2 growth pattern. Letters as described in Fig. 7 for analogous structures. F: summer growth at the edge of the otolith.

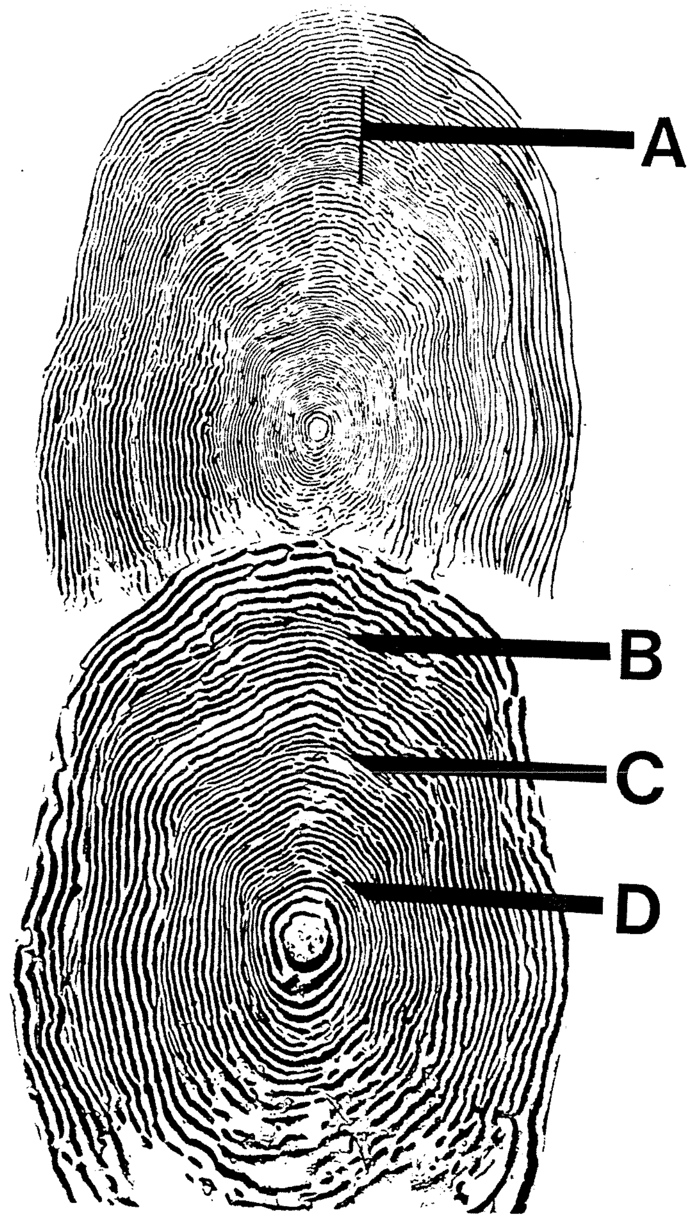

Fig. 9. Full-scale and freshwater enlargement of a steelhead with a 3.1 growth pattern. Fish length 548 mm, body weight 1660 gms, male, caught by mothership A06 on 7/18/84. A: double-check first ocean annulus, B: third freshwater annulus, C: second freshwater annulus, D: first freshwater annulus. Photographs of an otolith taken from this fish follows in Fig. 10.

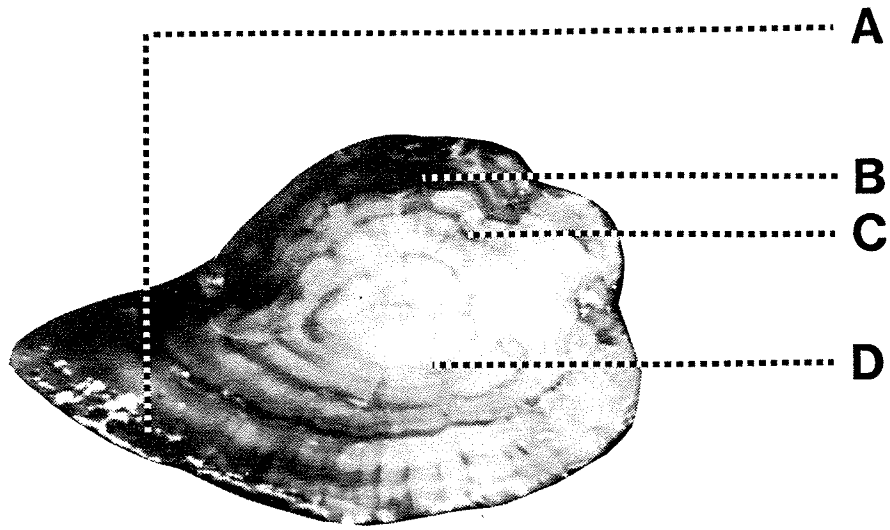

Fig. 10. Photograph of an otolith taken from the fish described in Fig. 9, showing a 3.1 growth pattern. Letters as described in Fig. 9 for analogous structures.

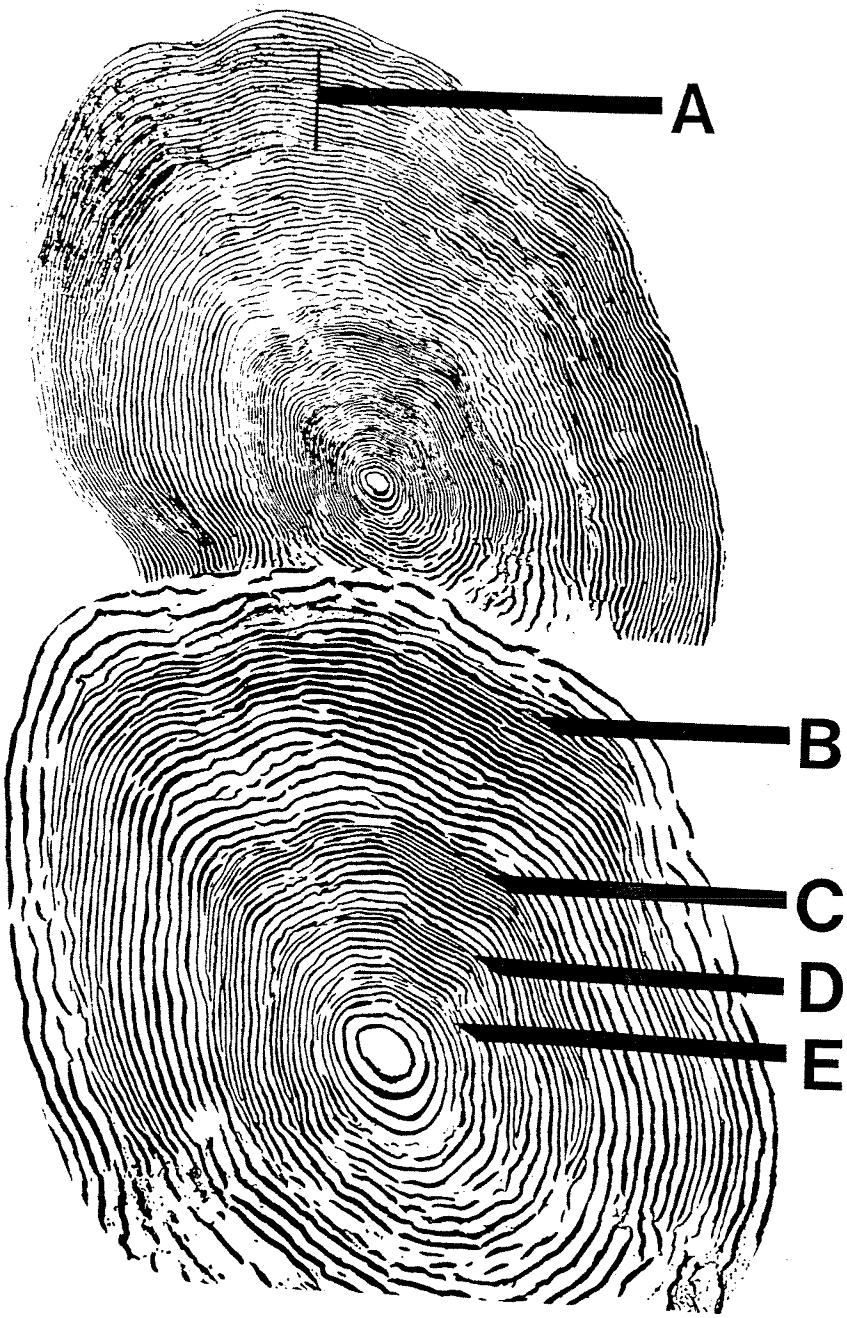

Fig. 11. Full scale and freshwater enlargement of a steelhead with a 4.1 growth pattern. Fish length 533 mm, body weight 1860 gms, female, caught by mothership A06 on 7/20/84. A: first ocean annulus, B: fourth freshwater annulus, C: third freshwater annulus, D: second freshwater annulus, E: first freshwater annulus. Photograph of an otolith taken from this fish follows in Fig. 12.

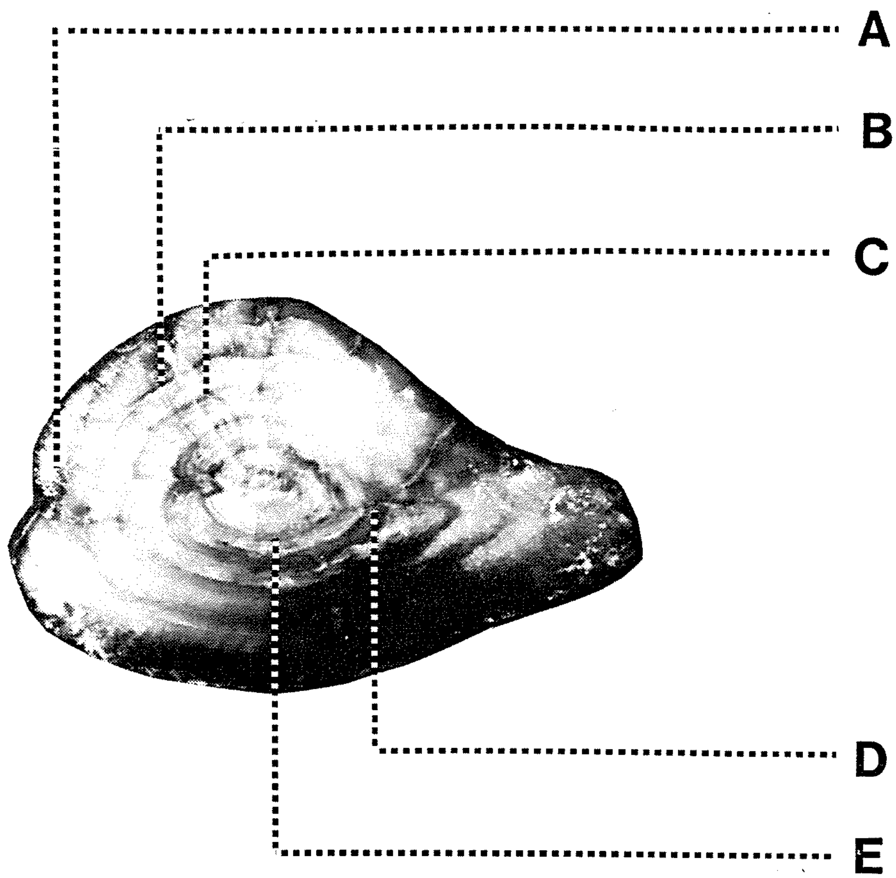

Fig. 12. Photograph of an otolith taken from the fish described in Fig. 11, showing a 4.1 growth pattern. Letters as described in Fig. 11 for analogous structures.

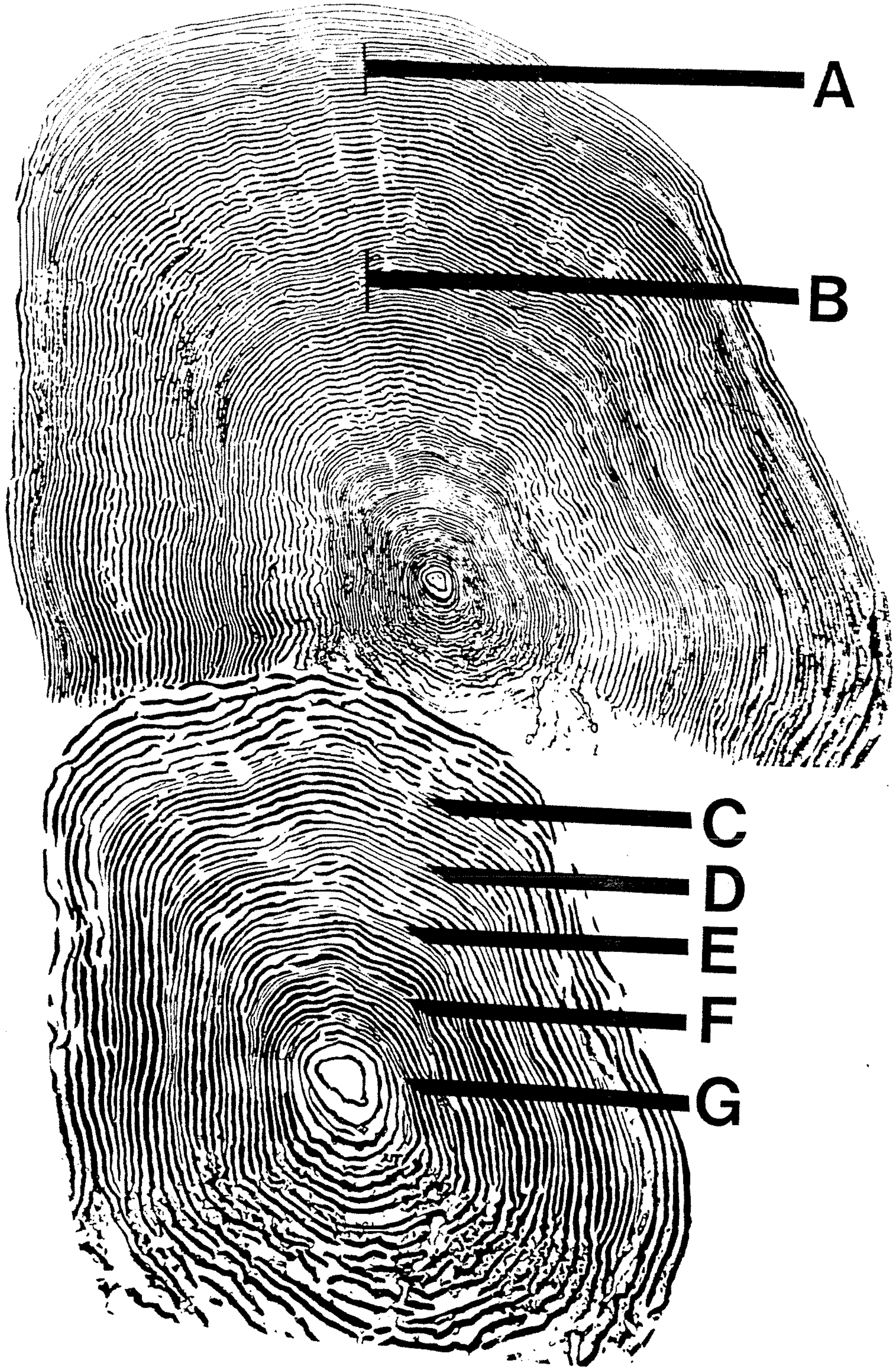

Fig. 13. Full scale and freshwater enlargement of a steelhead with a 5.2 growth pattern. Fish length 734 mm, body weight 4650 gms, male, caught by mothership A08 on 7/21/84. A: second ocean annulus, B: first ocean annulus, C: fifth freshwater annulus, D: fourth freshwater annulus, E: third freshwater annulus, F: second freshwater annulus, G: first freshwater annulus. Photograph of an otolith taken from this fish follows in Fig. 14.

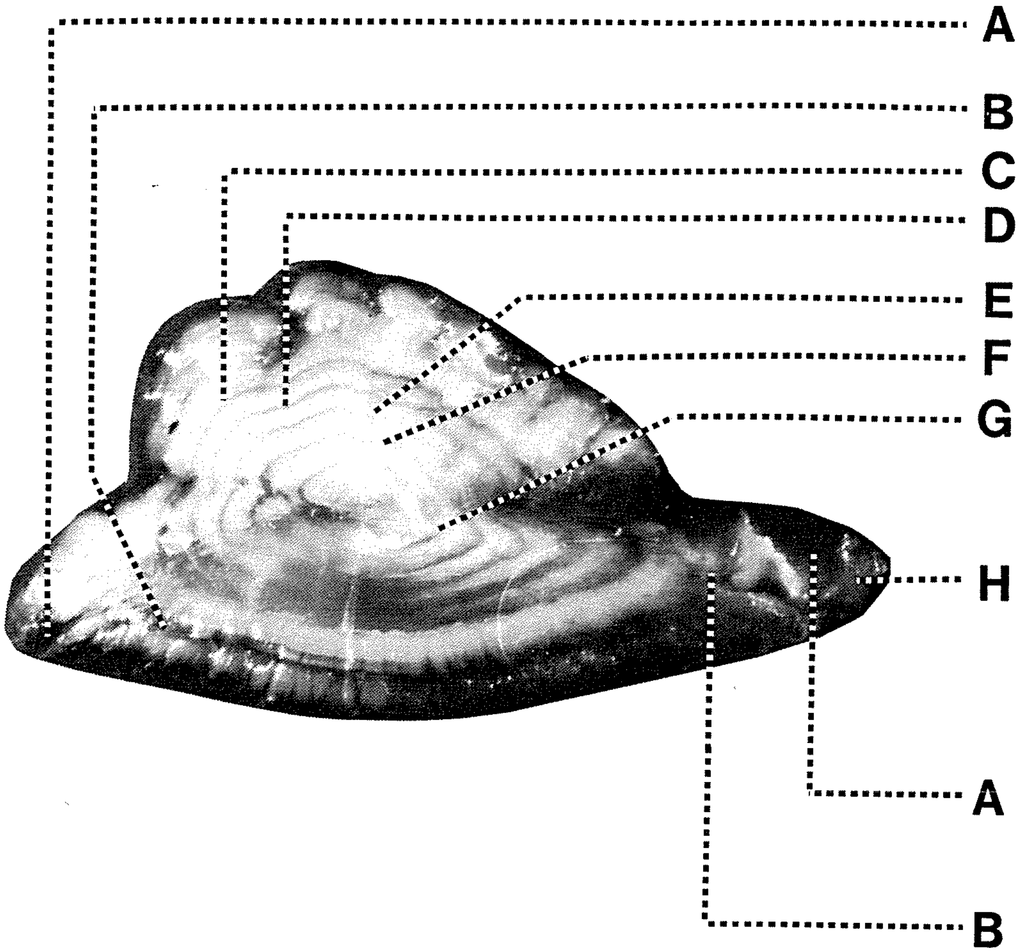

Fig. 14. Photograph of an otolith taken from the fish described in Fig. 13, showing a 5.2 growth pattern. Letters as described in Fig. 13 for analogous structures. H: summer growth at the edge of the otolith.

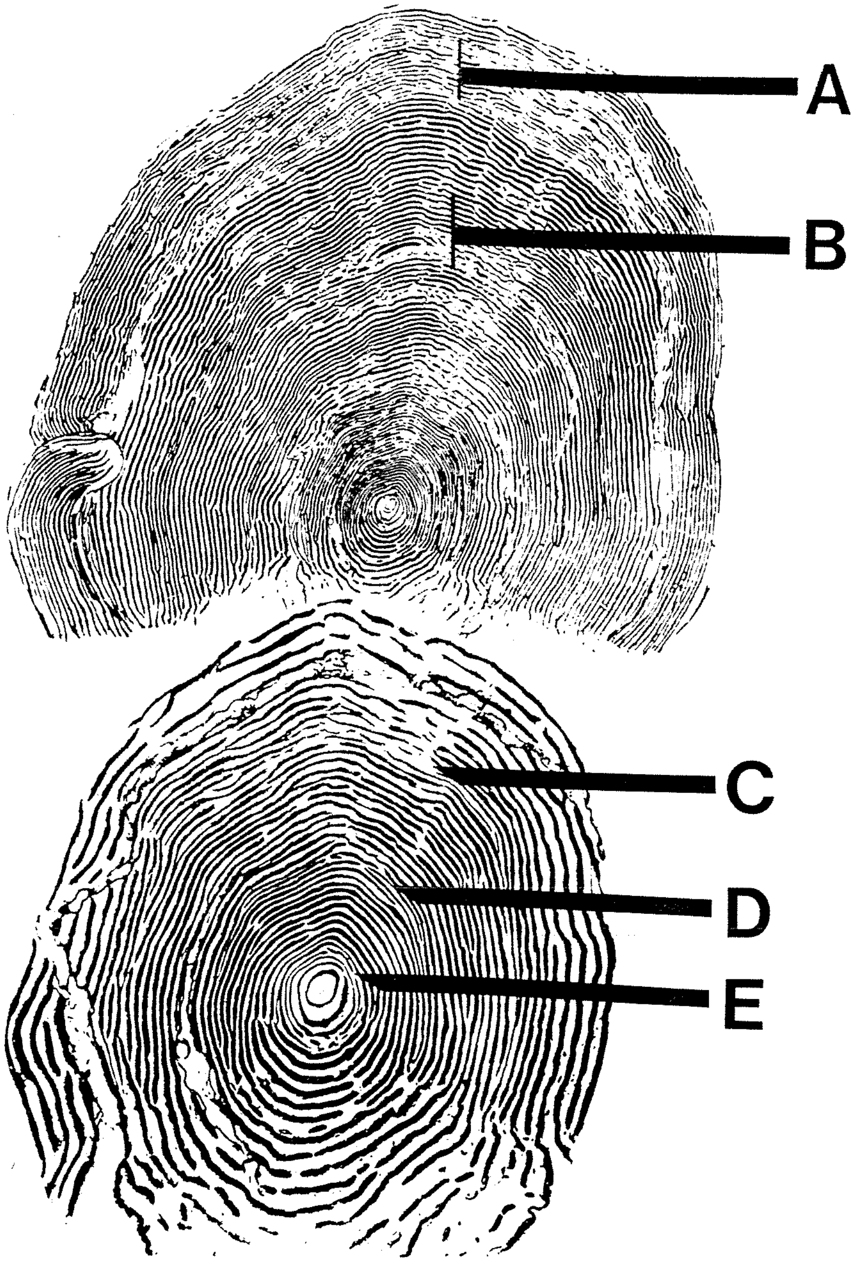

Fig. 15. Full scale and freshwater enlargement of a steelhead with a 3.1S growth pattern. Fish length 620 mm, body weight 2850 gms, female, caught on research vessel R23 on 5/20/84. A: second ocean annulus resorbed strongly by spawning check along the side of the scale, B: first ocean annulus, C: third freshwater annulus, D: second freshwater annulus, E: first freshwater annulus. Photograph of an otolith taken from this fish follows in Fig. 16.

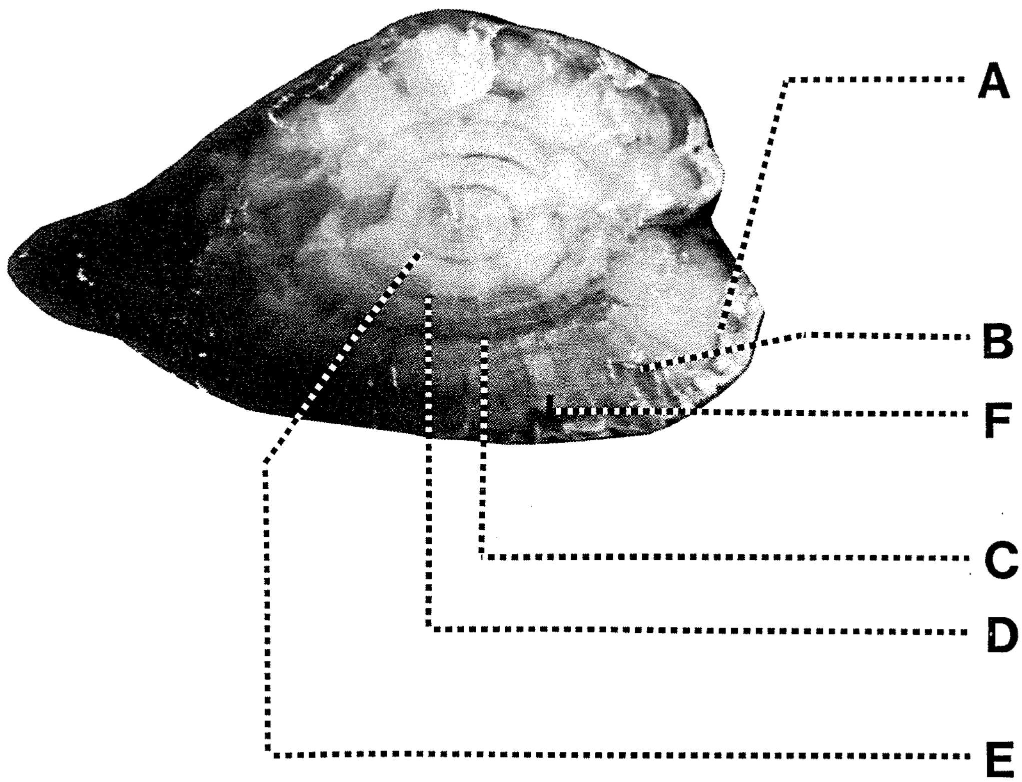

Fig. 16. Photograph of an otolith taken from the fish described in Fig. 15, showing a 3.1S growth pattern. Letters as described in Fig. 15 for analogous structures. F: area of opaque summer growth resorbed between the first and second ocean annulus indicating a spawning check.

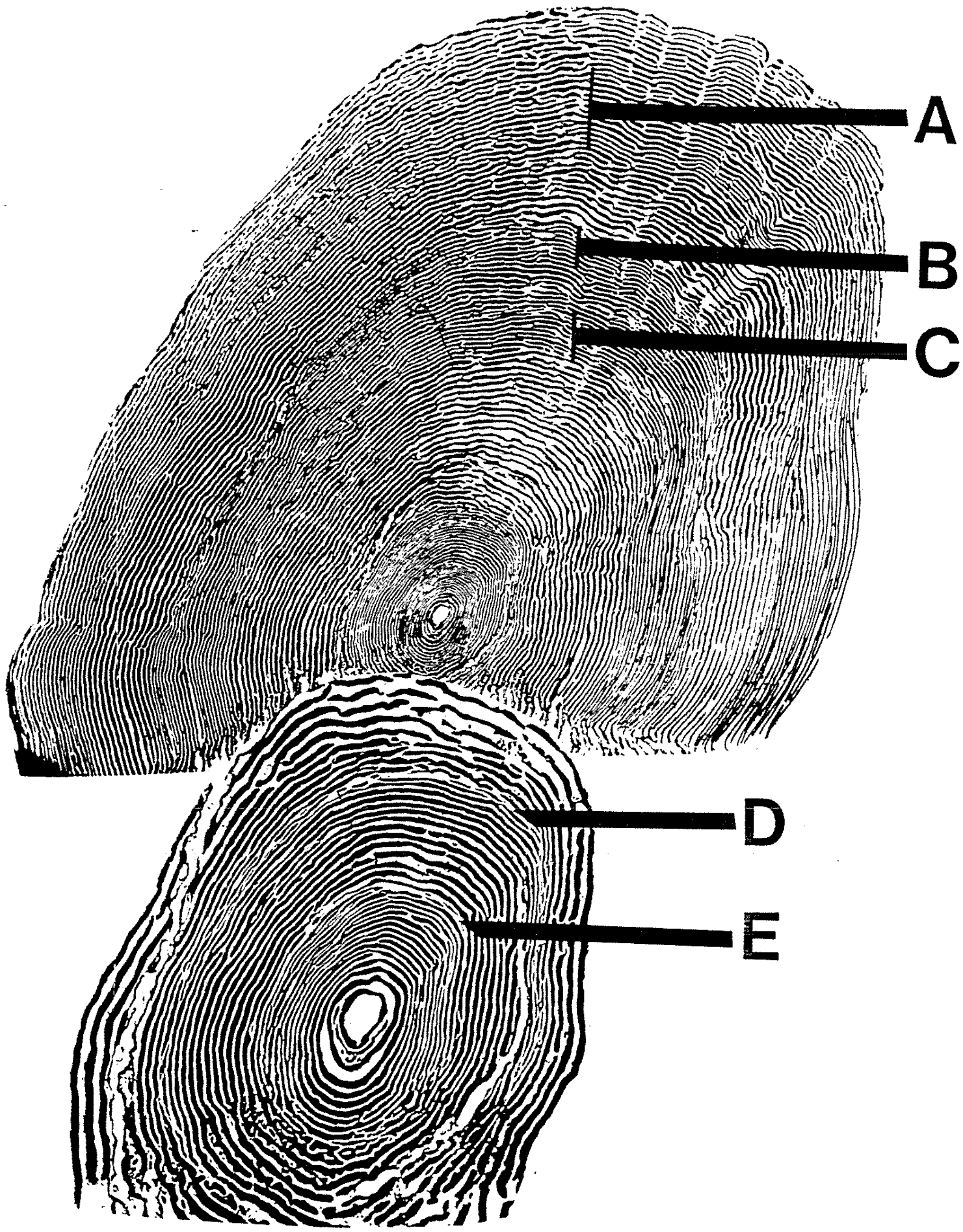

Fig. 17. Full scale and freshwater enlargement of a steelhaed with a 2.1S1 growth pattern. Fish length 765 mm, body weight 4250 gms, male, caught on research vessel R23 on 5/9/84. A: third ocean annulus, B: second ocean annulus and weak spawning check, regeneration along side of the scale, C: first ocean annulus, D: second freshwater annulus, E: first freshwater annulus. Photograph of an otolith taken from this fish follows in Fig. 18.

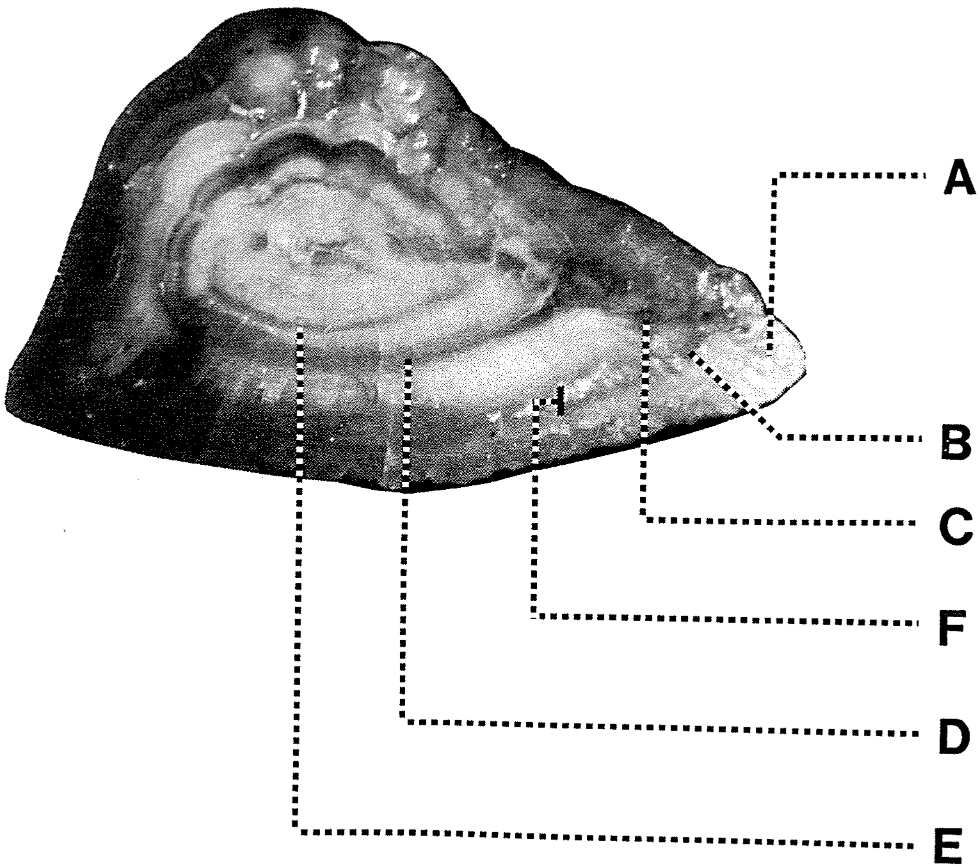

Fig. 18. Photograph of an otolith taken from the fish described in Fig. 17, showing a 2.1S1 growth pattern. Letters as described in Fig. 17 for analogous structures. F: area of opaque summer growth resorbed between the first and second ocean annuli indicating a spawning check.

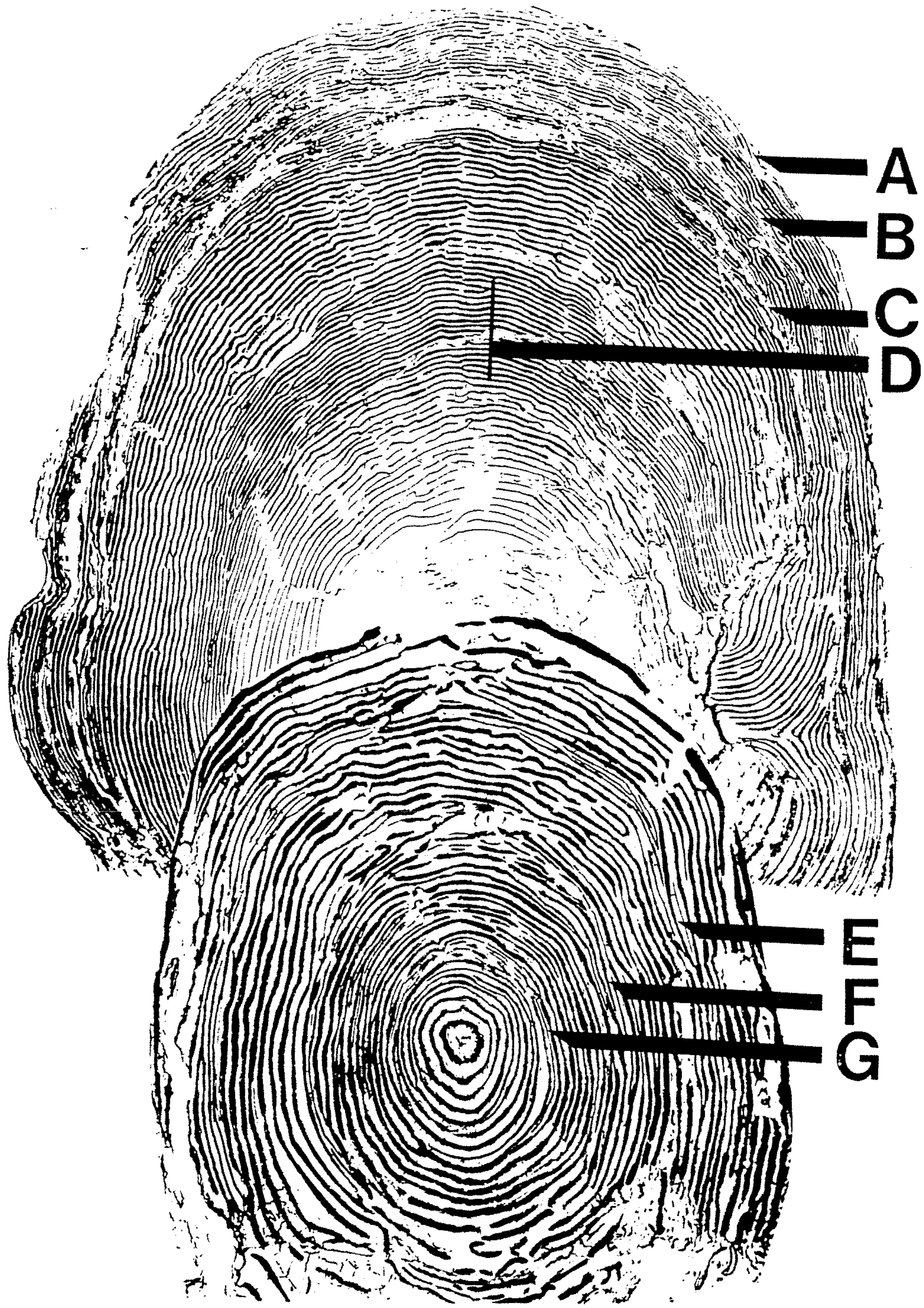

Fig. 19. Full scale and freshwater enlargement of a steelhead with a 3.1SSS growth pattern. Fish length 889 mm, body weight 5750 gms, male, caught on mothership A06 on 7/20/84. A: fourth ocean annulus largely resorbed by spawning check, B: third ocean annulus largely resorbed by spawning check, C: second ocean annulus, resorbed by spawning check, D: first ocean annulus, E: third freshwater annulus, F: second freshwater annulus, G: first freshwater annulus. Photograph of an otolith taken from this fish follows in Fig. 20.

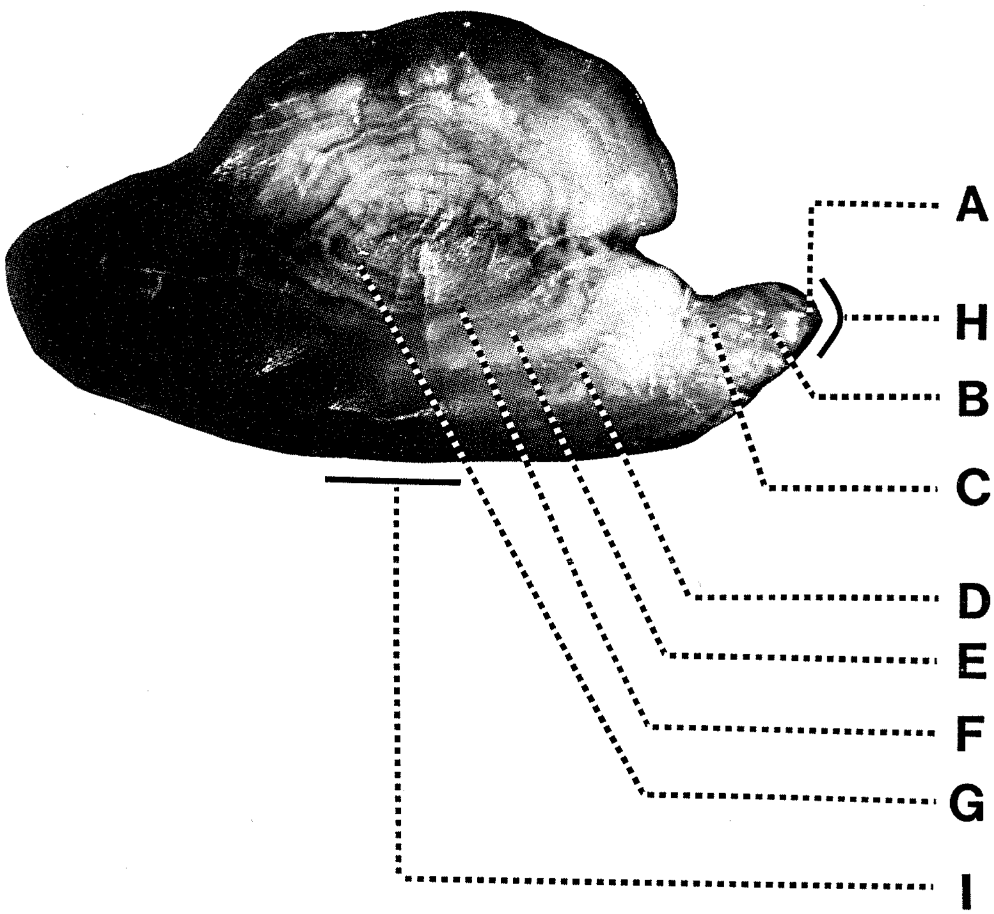

Fig. 20. Photograph of an otolith taken from the fish described in Fig. 19, showing a 3.1SSS growth pattern. Letters as described in Fig. 19 for analogous structures. H: hook-shaped anterior lobe, characteristic of otoliths from fish with multiple spawning checks, I: flattening of the ventral lobe due to extensive resorption.

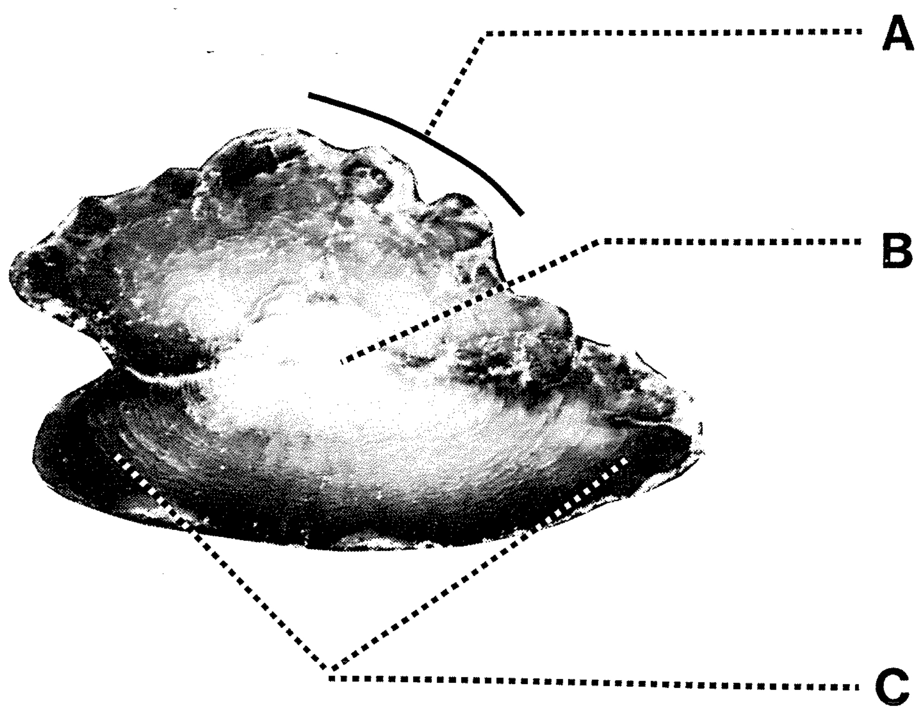

Fig. 21. Photograph of a crystalline otolith from a steelhead. Fish length 540 mm, body weight 1627 gms, scale age X.1, male caught on research vessel R19 on 7/2/83. A: rough and convoluted dorsal lobe, B: dense, opaque nuclear zone, C: translucent ocean zone.

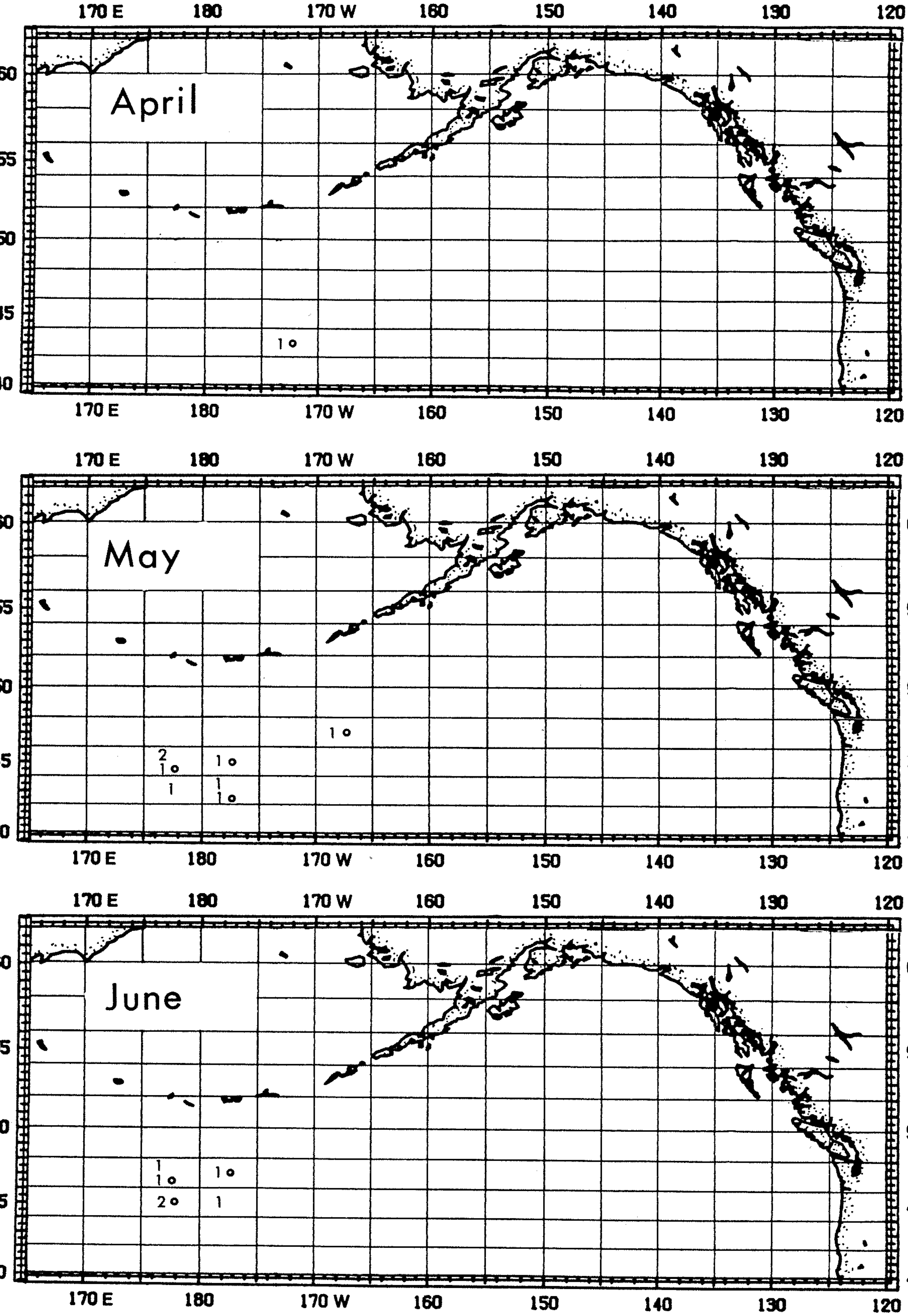

Fig. 22. Top, middle and lower panels indicate the capture locations (by month and 2 X 5 areas) of steelhead, which displayed spawning check(s) on their scales. Numbers followed by "o" indicate scales with a spawning check at the last winter annulus. Numbers without a symbol reflect scales with no evidence of spawning in the previous year. Scale samples from Japanese research vessels 1976-1981, 1983-1984 and 1984 mothership operations have been combined.

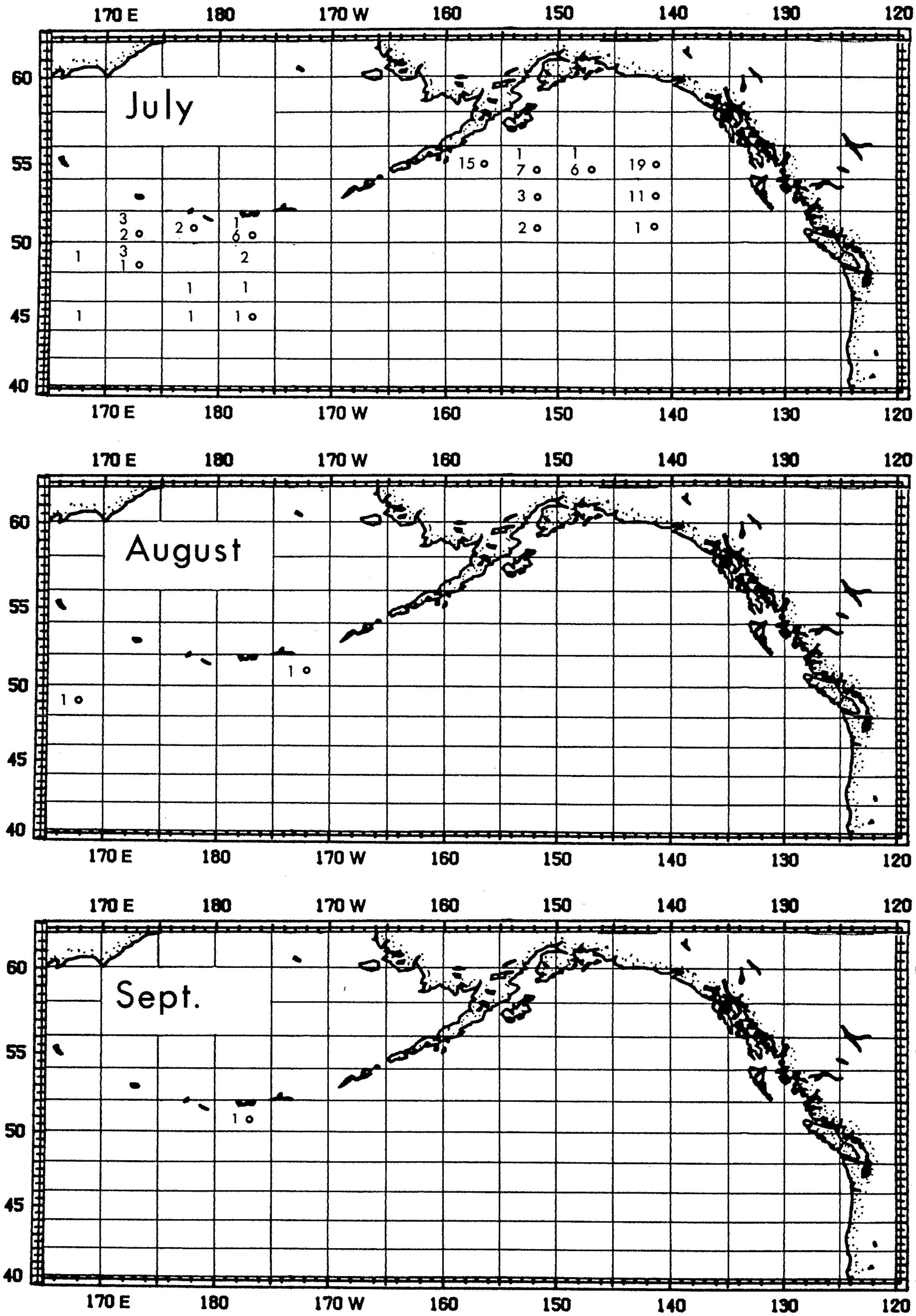

Fig. 23. Top, middle and lower panels indicate the capture locations (by month and 2 X 5 areas) of steelhead, which displayed spawning check(s) on their scales. Numbers followed by "∘" indicate scales with a spawning check at the last winter annulus. Numbers without a symbol reflect scales with no evidence of spawning in the previous year. Scale samples from Japanese research vessels 1976-1981, 1983-1984 and 1984 mothership operations have been combined.

Table 1. Number and percent (%) of regenerated* steelhead scales as determined by Japanese Fisheries Agency (JFA) and Fisheries Research Institute (FRI) biologists in samples collected by Japanese research vessels, 1976-1981.

Sample year	Agency	Total number of scales examined	Number of scales aged	Number of scales regenerated
1976	JFA	643 (100)	204 (32)	439 (68)
	FRI	643 (100)	158 (25)	485 (75)
1977	JFA	458 (100)	147 (32)	311 (68)
	FRI	458 (100)	120 (26)	338 (74)
1978	JFA	605 (100)	217 (36)	388 (64)
	FRI	605 (100)	171 (28)	434 (72)
1979	JFA	1018 (100)	497 (49)	521 (51)
	FRI	1018 (100)	422 (41)	596 (59)
1980	JFA	463 (100)	211 (46)	252 (54)
	FRI	463 (100)	200 (43)	263 (57)
1981	JFA	570 (100)	266 (47)	304 (53)
	FRI	570 (100)	236 (41)	334 (59)

*Or otherwise unreadable, i.e., dirty or obscured.

Table 2. Frequency and (%) age composition of steelhead in samples from Japanese research vessels, 1976-1981, as determined by Japanese Fisheries Agency (JFA) and Fisheries Research Institute (FRI) biologists.

Sample year	Agency	Age groups 1.0	2.0	3.0	1.1	2.1	3.1	4.1	1.2	2.2	3.2	4.2	1.3	2.3	3.3	2.4	3.4	Other	Total aged
1976	JFA	0	0	0	1(1)	48(23)	105(51)	20(10)	0	11(5)	18(9)	1(1)	0	0	0	0	0	0	204(100)
	FRI	0	0	0	9(6)	38(24)	43(27)	36(23)	2(1)	7(4)	12(8)	10(6)	0	0	0	0	1(1)	0	158(100)
1977	JFA	0	1(1)	0	3(2)	46(31)	57(39)	7(5)	3(2)	13(9)	14(9)	2(1)	1(1)	0	0	0	0	0	147(100)
	FRI	0	0	1(1)	6(5)	9(7)	37(31)	25(21)	8(7)	7(7)	14(12)	7(6)	0	0	1(1)	0	0	5(4)	120(100)
1978	JFA	0	0	0	1(0)	37(17)	113(52)	24(11)	2(1)	18(9)	19(9)	2(1)	0	0	1(0)	0	0	0	217(100)
	FRI	0	0	0	33(19)	19(11)	57(33)	25(15)	7(4)	10(6)	10(6)	6(3)	0	0	2(1)	1(1)	0	1(1)	171(100)
1979	JFA	0	0	0	29(6)	235(47)	145(29)	6 (1)	8(2)	44(9)	30(6)	0	0	0	0	0	0	0	497(100)
	FRI	1(0)	0	0	75(18)	76(18)	106(25)	32(8)	41(10)	30(7)	46(11)	7(2)	1(0)	1(0)	2(0)	0	0	4(1)	422(100)
1980	JFA	0	0	0	0	32(15)	49(23)	3(2)	9(4)	62(29)	54(26)	0	0	0	2(1)	0	0	0	211(100)
	FRI	0	0	1(1)	10(5)	16(8)	31(15)	24(12)	12(6)	22(11)	53(27)	8(04)	2(1)	3(1)	11(5)	0	1(1)	6(3)	200(100)
1981	JFA	0	7(3)	7(3)	5(2)	52(19)	60(22)	22(8)	6(2)	50(19)	45(17)	10(4)	0	0	2(1)	0	0	0	266(100)
	FRI	2(1)	2(1)	9(4)	48(20)	18(8)	32(14)	15(6)	22(9)	30(13)	36(15)	12(5)	0	3(1)	2(1)	0	1(0)	4(2)	236(100)

Table 3. Percent agreement between Japanese Fisheries Agency and Fisheries Research Institute biologists on age determinaions* of steelhead scales collected from 1976 through 1981 by Japanese research vessels.

Sample year	Percent agreement on age determination		N**
1976	Freshwater	57	137
	Ocean	96	567
1977	Freshwater	54	114
	Ocean	86	378
1978	Freshwater	60	169
	Ocean	92	541
1979	Freshwater	46	374
	Ocean	86	980
1980	Freshwater	54	177
	Ocean	87	425
1981	Freshwater	51	219
	Ocean	90	515

*Age determinations were compared for cases for which both the JFA and FRI assigned an age, i.e., renegerated scales were not counted.

**Number of cases for which both agencies made an age determination.

Table 4. Number and percent (%) of regenerated* scales or crystalline** otoliths as determined by FRI biologists from samples provided from Japanese research vessels in 1983 and 1984 and Japanese motherships in 1984.

Sample source and year	Item	Total number examined	Number aged	Number of regenerated scales or crystalline otoliths
Japanese research vessels				
1983	Scales	294 (100)	74 (25)	220 (75)
	Otoliths	294 (100)	260 (88)	34 (12)
1984	Scales	426 (100)	96 (23)	330 (77)
	Otoliths	426 (100)	369 (87)	57 (13)
Japanese motherships				
1984	Scales	396 (100)	226 (57)	170 (43)
	Otoliths	396 (100)	353 (89)	43 (11)

*Or otherwise unreadable, i.e., dirty or obscured.
**Featureless, transparent and unreadable.

Table 5. Frequency and (%) age composition of steelhead scales and otoliths as determined by FRI biologists from samples provided from Japanese research vessels in 1983 and 1984 and motherships in 1984.

Sample source and year	Item	Age groups 1.0	2.0	3.0	1.1	2.1	3.1	4.1	1.2	2.2	3.2	4.2	1.3	2.3	3.3	2.4	3.4	Other	Total aged
Japanese research vessels																			
1983	Scales	1(1)	0	0	8(11)	4(6)	16(22)	5(7)	4(6)	9(12)	17(23)	4(5)	0	1(1)	3(4)	9	1(1)	1(1)	74(100)
	Otoliths	1(0)	2(1)	2(1)	12(5)	25(10)	33(13)	12(5)	13(5)	38(14)	60(23)	22(8)	1(0)	6(2)	18(7)	2(1)	1(0)	12(5)	260(100)
1984	Scales	0	0	0	10(10)	10(10)	13(14)	5(5)	19(20)	19(20)	16(17)	2(2)	0	0	1(1)	0	0	1(1)	96(100)
	Otoliths	0	0	0	37(10)	52(14)	26(7)	23(6)	67(18)	71(19)	57(16)	12(3)	4(1)	6(2)	5(1)	2(1)	0	7(2)	369(100)
Japanese motherships																			
1984	Scales	0	0	0	6(3)	10(4)	13(6)	17(7)	33(15)	51(23)	56(25)	19(8)	2(1)	4(2)	7(3)	1(0)	2(1)	5(2)	226(100)
	Otoliths	0	0	0	9(3)	15(4)	18(5)	24(7)	50(14)	99(28)	83(23)	18(5)	3(1)	10(3)	8(2)	4(1)	2(1)	10(3)	353(100)

Table 6. Percent agreement on age determinations* as made by examination of scales and examination of otoliths from samples provided from Japanese research vessels in 1983 and 1984 and motherships in 1984.

Sample source and year	Percent agreement on age determinations		N**
Japanese Research Vessels 1983	Freshwater	94	68
	Ocean	99	210
1984	Freshwater	73	88
	Ocean	97	342
Japanese Motherships 1984	Freshwater	77	211
	Ocean	96	353

*Age determinations were compared for cases where both scale and otolith were assigned an age, i.e., regenerated scales or crystalline otoliths were not counted.

**Number of cases where both scale and otolith were assigned an age.

Table 7. Frequency and percent (%) of steelhead scales with spawning check(s), collected from Japanese research vessels in 1976-1981, 1983-1984, and from Japanese motherships in 1984.

Sample source and year		N	Ocean age before first spawning check 0	1	2	3	Number of spawning checks on each scale 1	2	3	Scales with multiple spawning checks on: Consecutive annuli	Alternating annuli
Research vessels											
1976											
	♂	2	0	1	1	0	2	0	0	0	0
	♀	2	0	1	0	1	2	0	0	0	0
1977											
	♂	1	0	1	0	0	1	0	0	0	0
	♀	1	0	1	0	0	0	0	1	1	0
1978											
	♂	0	0	0	0	0	0	0	0	0	0
	♀	2	0	1	1	0	2	0	0	0	0
1979											
	♂	0	0	0	0	0	0	0	0	0	0
	♀	2	0	1	1	0	2	0	0	0	0
1980											
	♂	4	0	4	0	0	4	0	0	0	0
	♀	5	2	3	0	0	4	1	0	1	0
1981											
	♂	5	0	4	1	0	5	0	0	0	0
	♀	27	3	20	3	1	19	7	1	8	0
1983											
	♂	7	0	6	1	0	3	4	0	4	0
	♀	29	2	18	9	0	19	6	4	9	1
1984											
	♂	3	0	2	1	0	3	0	0	0	0
	♀	11	1	5	5	0	9	2	0	2	0
Motherships											
1984											
	♂	3	0	3	0	0	2	0	1	1	0
	♀	6	0	3	3	0	4	2	0	2	0
TOTAL		110	8	74	26	2	81	22	7	♂ 5(17)	0
			(7)	(67)	(24)	(2)	(74)	(20)	(6)	♀ 23(79)	♀ 1(4)
			Total 110 (100)				Total 110 (100)			Total 29 (100)	