A Guide to the Interpretation of Sea Trout Scales

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A Guide to the Interpretation of Sea Trout Scales

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SUMMARY

The overall purpose of this guide is to provide a manual for the collection and interpretation of sea trout scales. A brief introduction considers the advantages and disadvantages of using scales to determine age and growth. To ensure that scales are interpreted in a consistent manner, all major terms are defined and a standard system for age notation is proposed. The methodology for the collection, mounting and interpretation of scales is described in detail, and this is followed by a section on the back-calculation of lengths at different ages. Each topic is discussed critically. The final part of this guide is an atlas illustrating scales from a wide range of sea trout and including not only excellent "type-scales" but also difficult and impossible scales.

Key Words

Salmo trutta, sea trout, scale reading

1. INTRODUCTION

1.1 Purpose of the guide

The overall purpose of this document is to provide a comprehensive guide to the collection and interpretation of sea trout scales. To ensure that scales are interpreted in a consistent manner, the guide also defines all the major terms and proposes a standard system for age notation. Each topic is discussed critically, especially the difficulties of interpreting some scales and the problems of back calculating fish lengths at different ages. An essential part of this guide is an atlas illustrating scales from a wide range of sea trout and including not only excellent "type-scales" but also difficult and impossible scales. Scale interpretation is as much an art as a science and therefore, to some extent, it is a subjective process with disagreements between readers.

1.2 Advantages of scale reading

Different methods are used to estimate the age and growth of fish. Marking and tagging captured fish and then re-capturing them, usually about one year later, is one method of direct determination. A size-frequency distribution constructed from large samples of fish can also be used to determine mean size at different ages, provided there is little overlap in the fish sizes for adjacent age groups, the fish spawn annually and the progeny grow at approximately uniform rates. This method is often restricted to the younger age groups of a population. Finally, the most frequently used method is to interpret growth zones on some hard parts of the fish, e.g. scales, otoliths, opercula, vertebrae. As scale removal does not require the death of the fish, unlike removal of most other hard structures, it is the most popular method, especially for species in the salmon family. The chief advantages of using scales, other than their removal does not require the death of the fish, is that the method is logistically simpler than other methods such as marking and tagging or the removal of large samples of fish for size-frequency distributions. However, as will be seen in the next section, some of these latter methods may have to be used in order to check on the accuracy of the scale reading.

1.3 Some problems and disadvantages of scale reading

The Dutch draper and amateur microscopist of the seventeenth century, van Leeuwenhoek, is usually credited with being the first to recognize the relationship between the marks on the scales and the age of the fish. However, it was not until the start of the present century that scale reading became widely utilized as a technique for ageing fish, the pioneer species being chiefly cod and salmon. The success with salmon scales was chiefly due to their large size and the clear distinction between winter and summer bands on the best scales of many fish. Illustrative examples for spring and autumn run fish are shown in Figure 1.1. Unfortunately, sea trout scales are rarely as clear as this.

One obvious problem with the larger sea trout is that they are sometimes mistaken for Atlantic salmon. Morphological features used to distinguish the two species are beyond the scope of this guide but can be found in standard texts (e.g. Jones 1959, Maitland 1972). It is even more difficult to separate sea trout from large, piscivorous, lake-trout, which are often silvery with black spots. Here, the scales provide a useful diagnostic feature, indicated by Figure 1.2. The lake trout exhibit a much more even distribution of the winter bands or annuli, whereas there is a marked contrast between the river and sea growth for the sea trout. The latter also often show (but not always) some erosion of the scale associated with spawning, but similar spawning marks are very rare in resident brown trout that never migrate to sea (Figure 1.2). When resident brown trout migrate from a small stream to a large river or lake, they may also exhibit a marked increase in growth rate and hence the spacing of the circuli, but this increase is seldom as great as in anadromous fish. As will be seen later, sea trout scales are sometimes difficult to interpret and certainly raise more problems than those of the Atlantic salmon. Many of these problems were recognized in the classic book on sea trout by G. H. Nall (1930). On the other hand, sea trout scales are much easier to interpret than those of slow-growing resident trout in upland streams or in other slow-growing salmonid species such as land-locked Arctic charr. Otoliths, rather than scales, often have to be used to age these slow growing fish.

Finally, the overall purpose of the interpretation of sea trout scales must be addressed. If it is simply to determine for an individual fish the number of years spent in fresh water and at sea, with perhaps additional information on past growth and spawning history, then there is no problem. If, however, the purpose is to obtain information on a sea trout population from a sample of fish, then problems of sampling bias must be considered. Ideally, the sample should be taken at random and should cover a wide range of sizes and ages. This usually does not occur if the fish are caught by anglers or in selective traps such as gill nets. It should also be remembered that even if the sampling methods are adequate, they are only sampling the survivors and conclusions from these may be biased. For example, it may be concluded that the modal age for smolt migration is two years but this may be applicable only to the survivors, fish that migrate at a lower or higher age may have a lower probability of survival, even though they may be numerous at the time of smolt migration.

It is therefore advisable to use other methods of determining age and growth, as well as scale interpretation, whenever this is feasible. Bagenal and Tesch (1978) suggested the following possible criteria for validation:

(1) Agreement with a size-frequency distribution; provided the modes are distinct and represent age groups, not only strong year-classes.

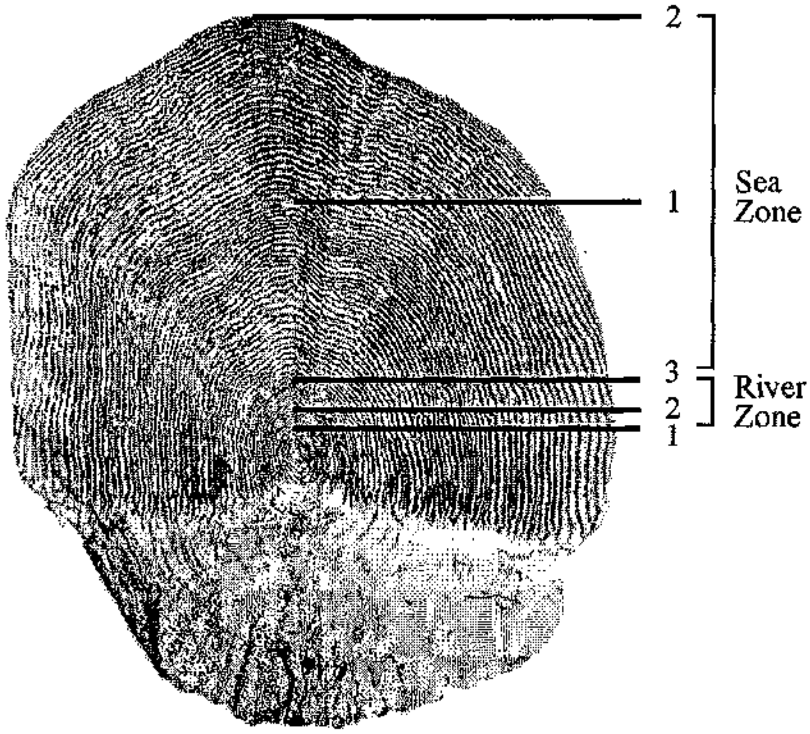
(2) Marking experiments; the period between marking or tagging and recapture should correspond with the number of annuli on the scale (it is not necessary for the fish to be of known age).

(3) Observation of strong and weak year-classes over several years; these year-classes should appear as successively older age groups each year.

(4) Tank or pond experiments in which fish of known age should have annuli corresponding with this age.

Of these four possible criteria, only the second is usually of relevance to sea trout.

(a)



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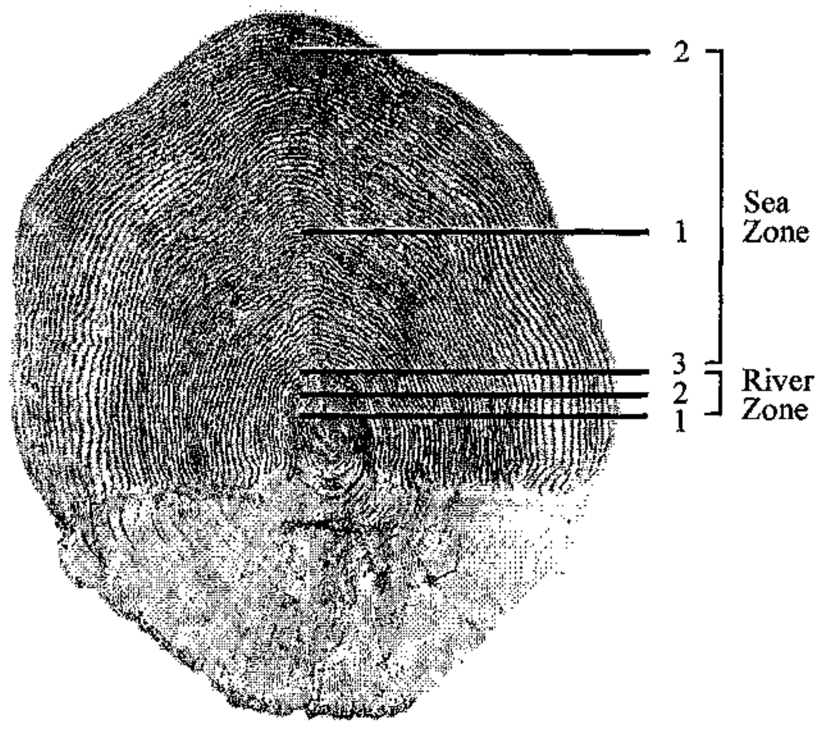
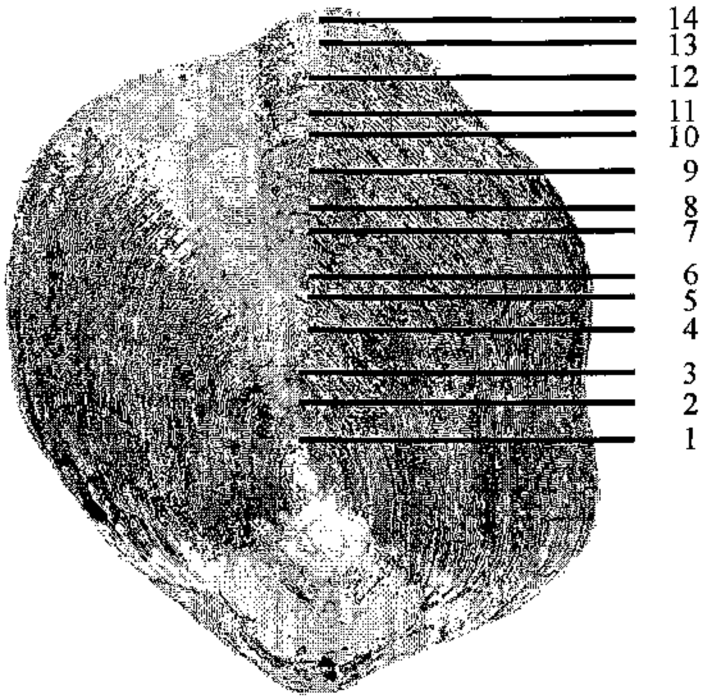


Figure 1.1 Scales of Atlantic salmon; both fish spent three years in the river and two years at sea:

(a) Spring fish with no plus growth at the edge of the scale;
(b) Summer fish with obvious plus growth at the edge of the scale after the fifth winter (second sea-winter).

(a)



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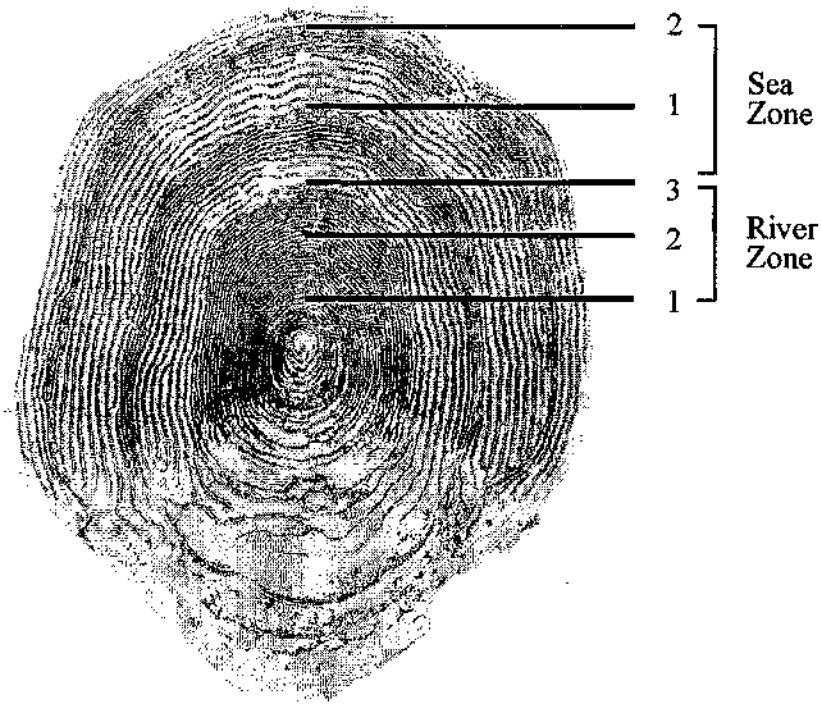

Figure 1.2 Scales of brown trout:

(a) Lake trout caught in November at the start of its fifteenth winter; note the near even spacing of the annual zones and the similar pattern of the circuli within each annual zone;
(b) Sea trout, caught in July, spent three years in the river and just over two years at sea; note the marked increase in the width of the circuli when the fish migrated to sea.

2. DEFINITIONS AND AGE NOTATION

2.1 Definitions

About 50 Latin names were once used to describe different varieties of brown trout, including sea trout, but the current view is that they all belong to one polytypic species, *Salmo trutta* L. (see Chapter 2 in Elliott 1994). "Sea trout" are anadromous brown trout that migrate to the sea or estuary to feed and grow, returning later to fresh water to spawn. All fish migrate to sea in some populations, usually at the age of two years (range one to four years in Britain), but anadromy is essentially a female characteristic in other populations. Although genetic differences occur between neighbouring populations of brown trout that are reproductively isolated, there is no reliable evidence for similar differences between resident and anadromous trout spawning in the same locality (see Chapter 7 in Elliott 1994). Some sea trout return from the sea after spending only a few months away from fresh water and are known as whitling, finnock, school peal, herling or sprods (the term 'whitling' is used in the following text). Most returning fish have been at sea for over a year and, after spawning, they are sometimes called kelts. Sea trout may spawn in successive years with rarely a missed year. A maiden fish (both males and females) is one that has still to spawn for the first time, even though it may have spent one or more post-smolt winters in the river without spawning. The standard terminology for the different stages of the life cycle is summarized by Allan and Ritter (1977).

Several terms describe different features of the scale (see also Figures 2.1, 3.2).

The "**Focus**" is in the centre of the concentric lines on the scale and is usually located towards the posterior, exposed portion of the scale.

The "**Circuli**" appear as darker concentric lines on the scale surface; each circulus is rarely complete, especially towards the posterior portion of the scale.

"**Dark Bands**" on the scale are formed by narrow spaced circuli during a period of slow growth, usually in winter.

"**Light Bands**" on the scale are formed by wide spaced circuli during a period of faster growth, usually in spring and summer.

The "**Annual Zone**" is a concentric region of the scale that covers one complete year of the life cycle, and its outer boundary is defined by the "**Annulus**", usually located on the outer edge of the winter dark band. A count of the annuli is therefore used to determine the age of the fish, each annulus corresponding to one year.

A "**Check**" is a zone of narrow spaced circuli not believed to be an annulus. Checks indicate a period of growth reduction in either summer or winter. One possible explanation for growth checks is a temporary return to fresh water where feeding is usually restricted or ceases.

The "**Plus Growth**" at the outer edge of the scale is a region of wider spaced circuli outside the last distinct annulus and indicates that a growth year is incomplete.

"**Run-out**" is a similar incomplete period that may occur between the last river annulus on the scale and the start of the period at sea. It is indicated by wider spaced circuli that are not as wide as those formed during sea growth. The distinction is clearer in salmon than in sea trout and is usually too difficult to detect in the latter. It is mentioned here for completeness.

The "**River Zone**" on the scale corresponds to the period spent in freshwater before the smolts migrate.

The "**Sea Zone**" corresponds to the period spent at sea after the smolt migration, including any time spent in freshwater as an adult.

"**Erosion**" of the scale is actually reabsorption at the edge of the scale and, more rarely, on its surface. It occurs when sea trout have returned from the sea and spent some time in freshwater. Erosion is often restricted to the posterior portion of the scale but when it occurs elsewhere on the scale, it destroys the pattern of the circuli and the replacement tissue lacks any pattern. If complete bands on the scale are destroyed by erosion, it is impossible to interpret the scale. Erosion is also associated with spawning and the renewed growth after spawning forms a scar or blurring of the circuli, usually close to a section of the annulus and in the outer edge of the winter dark band. Such a scar is usually interpreted as a "**Spawning Mark**" but its absence is no proof that the fish is a maiden sea trout.

2.2 Notation

Different systems of age notation are used for salmonids and this can lead to problems in comparing data. Most of these problems are associated with the spawning mark and, as noted above, the interpretation of the latter is often questionable. There are usually no problems with the notation for the freshwater stage of the life cycle. The system is the same as that used for humans; a 0+ fish is less than one year old, a 1+ fish is between one and two years old, a 2+ fish is between two and three years old. A decimal point (·) or diagonal line (/) is used to separate the periods before and after the smolt migration. Although a diagonal line may be less easily overlooked, especially in hand written records, the decimal point is most frequently used and is the convention used in the following text. If the fish achieved run-out on the scale before smolt migration, then the period in fresh water would be indicated as 2+ · or 3+ · for fish that migrated after their second or third birthday. However, as noted above, it is often difficult to detect run-out on sea trout scales, and therefore it is usually wiser to record the freshwater age as 2 ·, 3 ·, etc.

The notation used for the post-smolt stage of the life cycle is simple as long as spawning marks are ignored. A fish that emigrated after two years in freshwater but returned as a whitling after less than a year at sea would be indicated as 2 · +, or more correctly as 2 · 0+, as proposed by Allan and Ritter (1977). The system is logical because it is the same as that used in the first year of the freshwater stage of the life cycle. Similarly, fish that had spent one, two or three winters at sea would be indicated by 2 · 1+, 2 · 2+ or 2 · 3+ respectively, the + sign indicating plus growth at the outer edge of the scale. Extra years are added where applicable.

Solomon (1994) provided the following example of the problems caused by different notations for the post-smolt stage when spawning marks (SM) are added. For a fish that emigrated after over two years in freshwater (some run-out on scale) and then returned as a whitling to spawn, the notation is 2+ · + according to both Nall (1930) and Went (1962). However, if the same fish returns to spawn for a second time the following year, the notation is 2+ · +SM + according to Nall (1930) and 2+ · SM + according to Went (1962), i.e. without the + after the decimal point. The latter notation could cause confusion between, for example, a fourth time returning fish that had first spawned as a whitling and then spawned in the two following years (2+ · +3SM + according to Nall, 2+ · 3SM + according to Went) and a second time returnee that first returned as a three-sea-winter maiden without plus growth (2+ · 3SM + in both notations). Solomon (1994) notes that such fish without plus growth occur for example in the River Tweed.

One simple way to avoid any ambiguity is to record when the fish first spawned and the total number of spawning times, as recommended by Allan and Ritter (1977). For example, a fish that smolted at two years, first spawned as a whitling, spawned twice in total and is now entering the river to spawn for a third time would be aged 2 · 2+ and described as a 0-sea-winter previous spawner that has spawned twice (2 · 0+ 2SM +). Similarly, a fish that smolted at two years, entered freshwater as a whitling but did not spawn, then returned the next year to spawn (spawned once in total) and is now entering the river to spawn for a second time would also be aged 2 · 2+ but would be described as a 1-sea-winter previous spawner that had spawned once (2 · 1+ 1SM +). This designation indicates the original spawning-pattern, not the original return-pattern, and Allan and Ritter (1977) proposed that this definition is the more important biologically. There is no simple notation for a fish in which the spawning mark is visible in only alternate years and the best policy is to record the years separately, e.g. SM at 1+ and 3+. When in doubt, it is best to state clearly in long-hand what has been interpreted from the scales. Table 2.1 summarizes the notation for a wide range of life histories.

This section has revealed some of the problems in interpreting the spawning mark. Nall (1930) identified one problem: "But many marks or flaws on the scale, which to the inexperienced eye seem to be due to erosion at spawning, are really caused by some injury, e.g. a wound or the shifting of the scale in its pocket." It must be remembered that the spawning mark is formed after spawning and requires some erosion in the first place. If erosion does not occur because the spawning fish remains in freshwater for only a short period of time, then a spawning mark is absent. This frequently occurs with female sea trout when the spawning grounds are near the sea. Nall (1930) also recognized this problem and stated:

Table 2.1 Notation for a wide range of sea trout life histories.

First return as:		Whitling	1 SW Maiden	2 SW Maiden	3 SW Maiden
Total sea age	0	· 0+			
(years)	1	· 0+ 1SM +	· 1+		
	2	· 0+ 2SM +	· 1+ 1SM +	· 2+	
	3	· 0+ 3SM +	· 1+ 2SM +	· 2+ 1SM +	· 3+
	4	· 0+ 4SM +	· 1+ 3SM +	· 2+ 2SM +	· 3+ 1SM +
	5	· 0+ 5SM +	· 1+ 4SM +	· 2+ 3SM +	· 3+ 2SM +
	6	· 0+ 6SM +	· 1+ 5SM +	· 2+ 4SM +	· 3+ 3SM +
	etc	etc	etc	etc	etc

Note:The initial freshwater age is omitted and the inclusion of plus growth may not always be applicable.

"If there is no erosion, therefore, a spawning mark cannot be formed. If the erosion is very slight, the mark may be so indefinite that one cannot be sure it is a true spawning mark." Le Cren (1985) provided examples of tagged sea trout, known to have spawned, but with no clear spawning marks. O'Farrell *et al* (1989) quoted C.P.R. Mills as observing in tagging studies in the Irish Burrishoole system that scale absorption in older sea trout can be so extensive as to obliterate previous growth and/or evidence of spawning with the result that sea age and/or the number of spawnings would be underestimated. It is recommended to follow the conclusions of Frost and Brown (1967) and Elliott (1985) that the presence of a spawning mark is positive evidence of sexual maturity but the absence of a mark is not proof that the sea trout is a maiden. These problems with spawning marks are not unique to sea trout and a guide to interpreting scales of Atlantic salmon identifies similar difficulties, especially with previous spawners (International Council for the Exploration of the Sea 1986).

The final recommendation is that the terminology of Allan and Ritter (1977) should be followed, that spawning marks should be treated with caution, and interpretations should be written out if there are any doubts.

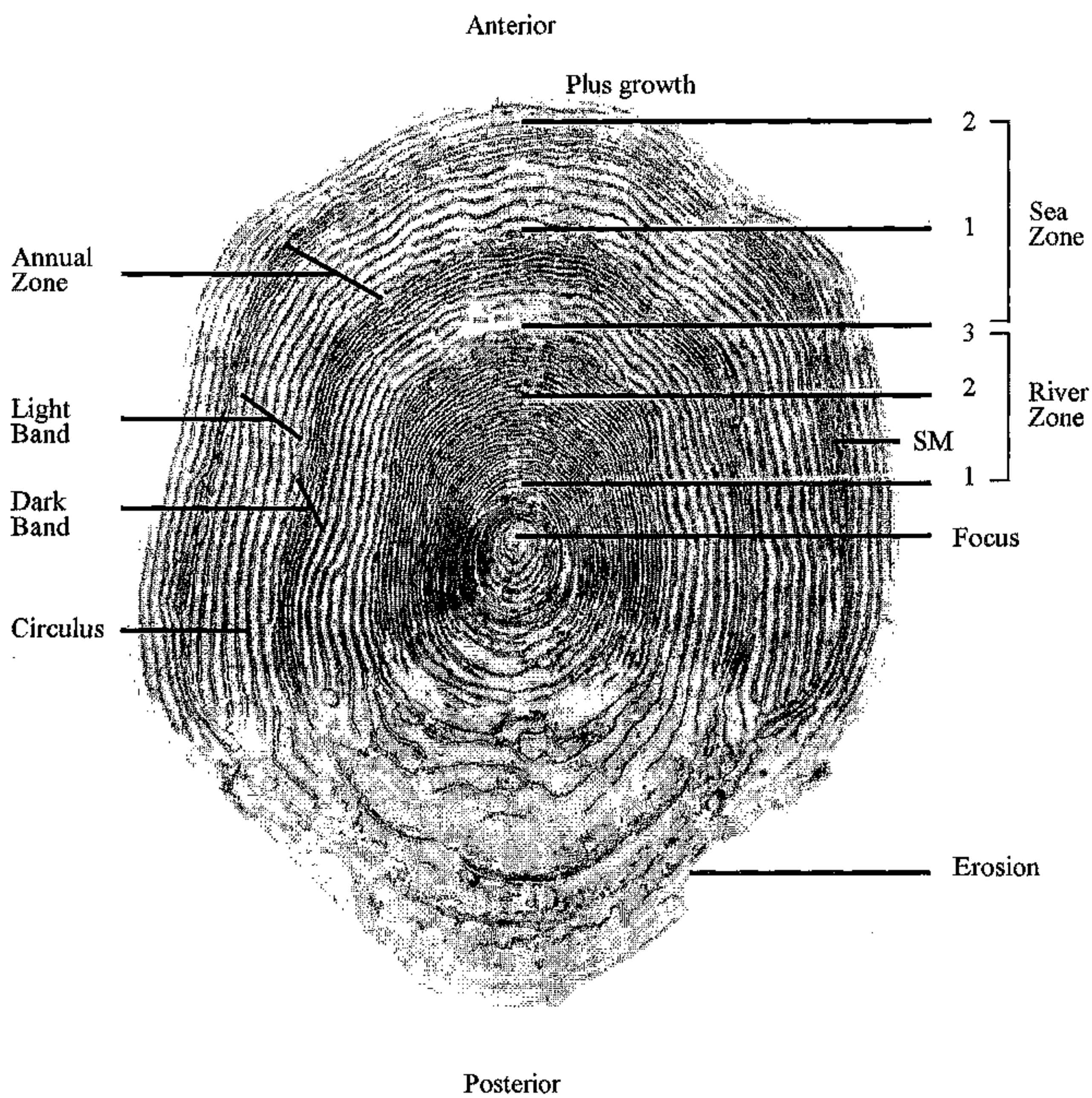

Figure 2.1 The chief terms used to describe the different features of a sea trout scale
(All terms defined in section 2.1, SM = Spawning Mark); the fish is the same as that in Figure 1.2.b, was aged 3 · 2+ and was a 1-sea-winter previous spawner that had spawned once only: 3 · 1+ 1SM+ (notation defined in Section 2.2).

3. COLLECTION AND MOUNTING OF SCALES

3.1 Scale formation and collection

The scale lies in a pocket in the dermis of the skin (Figure 3.1a) with the posterior portion of the scale projecting above the surface of the fish towards its tail. The posterior portion does not pierce the epidermis and is usually devoid of any clear markings of use to the scale reader (Figures 2.1 and 3.2). Features defined in Section 2.1 are all found on the anterior and larger part of the scale (Figures 2.1 and 3.2). Scales are absent from a newly hatched trout and first appear along the lateral line when the fish is about 3 - 4 cm long. They then appear to spread dorsally and ventrally with the region just posterior to the dorsal fin being the first to be covered. Scales used for age determination should be taken from an area near the posterior of the dorsal fin and above the lateral line (Figure 3.1b); it is believed that this is where the largest, most symmetrical and undamaged scales are usually found (Menzies 1936, Frost and Brown 1967, Bagenal and Tesch 1978).

For live fish, the skin should be first wiped or scraped clean and then between five to ten scales should be removed carefully, using forceps. For dead fish, the scales can be removed by forceps or by scraping with a sharp knife towards the head of the fish. Sections of skin should not be cut out. The scales should be wiped off the forceps or knife into a folded sheet of paper and the latter placed in a small paper envelope designed for storing scales. As they dry out, the scales should flatten. Envelopes should not be adhesive or leave traces of material on the scales. Each envelope should be numbered and it is preferable that the most important information about the fish is also recorded on the envelope; records in notebooks can be lost. The sample of scales should be allowed to dry slowly before being stored; a scale may crack or curl if dried quickly. Scale samples should never be placed in plastic bags because this may cause fungi to develop on the scales. The forceps or knife should always be wiped clean between fish.

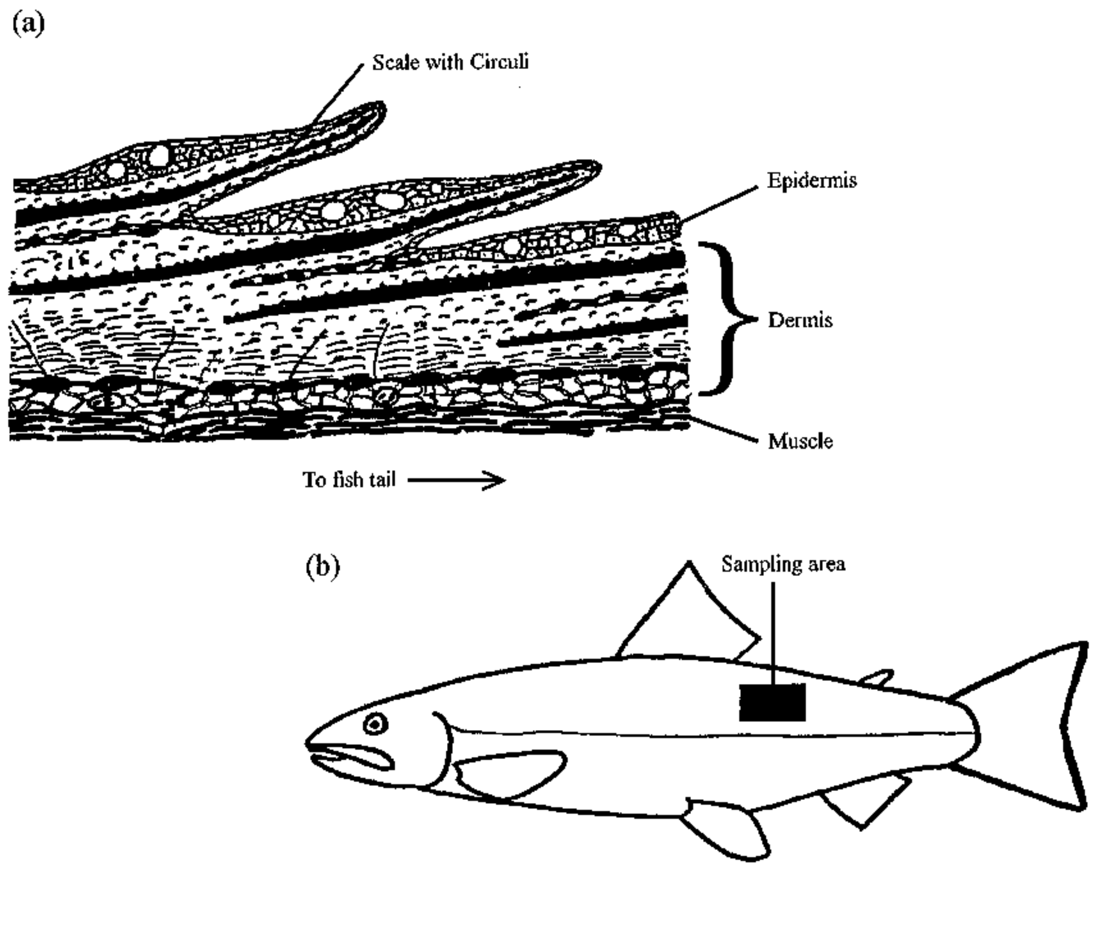

Figure 3.1 Scale formation and collection
(a) Section through the skin showing the scales in pockets of the dermis;
(b) Position on the fish for taking a sample of scales.

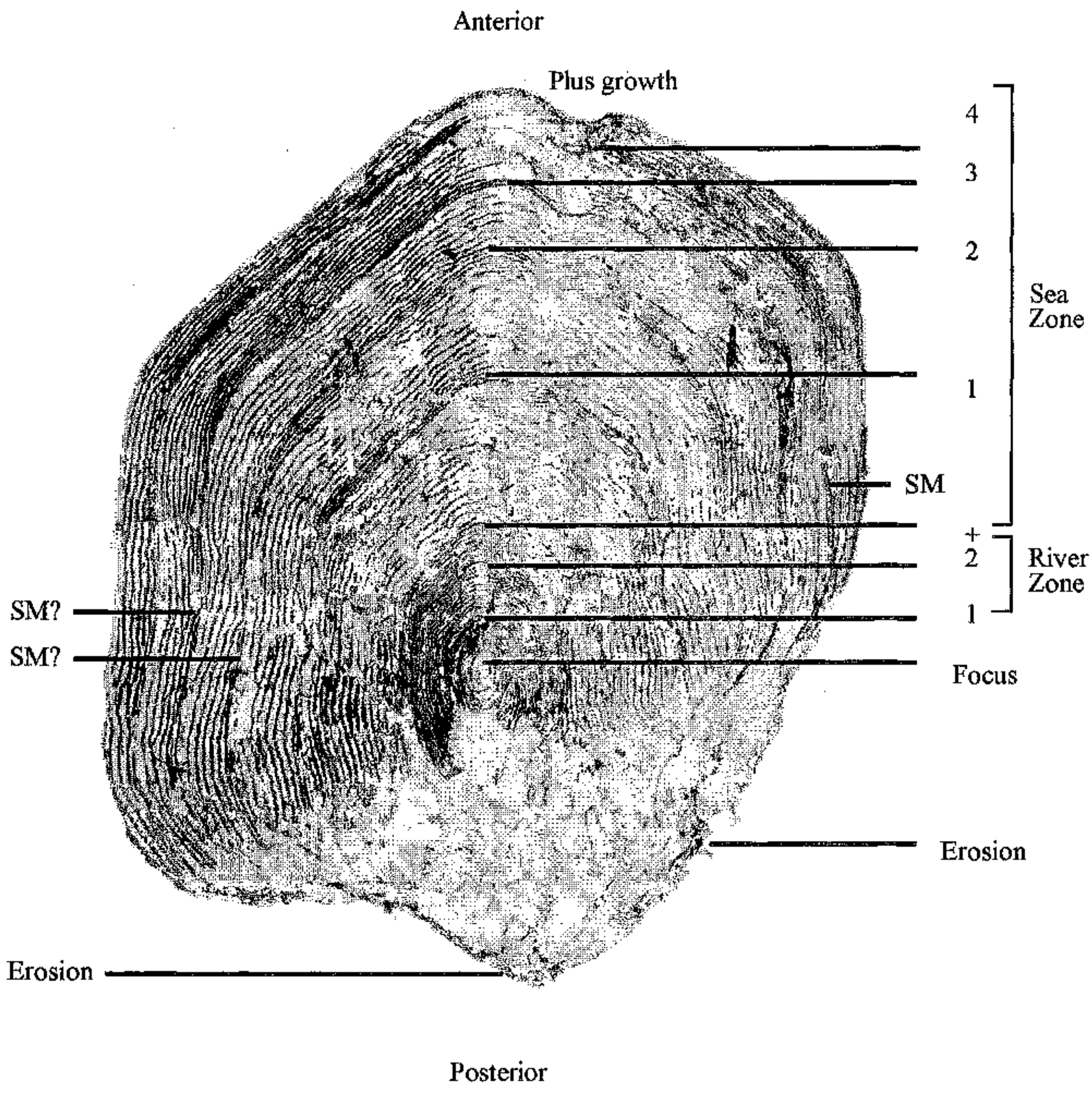

Figure 3.2 Scale of a female sea trout found dead in early February.
Scale shows that the fish spent two years in the river with some run-out on the scale (+) and over four years at sea (the last annual zone at the edge of the scale is almost complete but is interpreted as plus growth rather than 5); the fish was aged 2+ . 4+ and was probably a 1-sea-winter previous spawner that had possibly spawned three times: 2+ . 1+ 3SM+ (it also probably spawned for a fourth time before it died but the spawning mark has not formed). Note that the spawning marks (SM) are difficult to identify with certainty (hence the ?).

3.2 Useful additional information

The following information should be recorded, preferably on the scale sample envelope, whenever possible: (1) Code number for fish; (2) Date when scale sample taken; (3) Sex of fish; (4) Weight of whole fish; (5) Weight of gutted fish; (6) Fork length of fish (tip of snout to fork of tail fin); (7) Total length of fish (tip of snout to the end of the tail fin); (8) Site where fish was captured; (9) Fishing gear used to capture fish; (10) Other notes such as condition of fish, tag number, and whether scales were removed from the recommended area of the body. If the fish is being returned immediately to the water, the minimum requirements are items (2), (6), (8) and possibly (9).

3.3 Cleaning and mounting of scales

The scales must be cleaned. This can be done by placing them in soapy water for about half an hour, or soaking them for about an hour in a weak solution (4%) of sodium hydroxide (caustic soda) which is then washed off. If the caustic soda is used in hard water, it may be necessary to wash the scales in distilled water to prevent precipitation. Each treated scale is then rubbed between the thumb and first finger, or with a fine brush, to remove the soft tissue.

Whilst using caustic soda for cleaning the scales, the code of practice relating to safe handling of corrosive substances should be followed. A laboratory coat, gloves and eye protection should be worn when transferring the caustic soda solution into the soaking dishes and a pipette is recommended for this. Forceps should also be used to transfer the scales from the cleaning solution to the washing water. Caustic soda causes burns and if an accident occurs, the following first aid is essential:

- Eyes, irrigate thoroughly with water for at least 10 min and obtain medical attention;
- Skin, drench with plenty of water, remove contaminated clothing and wash before re-use and, unless contact has been slight, obtain medical attention;
- Mouth, wash out thoroughly, then drink some water and obtain medical attention; do not induce vomiting.

Clean scales can sometimes be examined dry and unmounted, but they often curl and crack. The scales should be examined quickly under a microscope and about five or six of the best ones should be mounted. The selected scales should have a clear focus and show little erosion, apart from spawning marks. If dry, the selected scales should be moistened slightly before being pressed onto a microscope slide. A second slide is used as a cover so that the scales are held in a "sandwich". The ends of the slides are then bound with tape, obviously avoiding the area of the scales. Once again it is preferable to transfer all the information on the scale envelope to the slide because envelopes are easily lost. Four slide labels can be attached to the slides before binding (one at the top and one at the bottom of each slide), and a great deal of information can thus be provided on the slide. Permanent ink should be used to record this information. The slides should always be stored flat.

Other methods have been used to make permanent mounts of scales. A slide can be smeared with gelatin mountant and the scales stuck onto this before adding a cover slip. The scales can be mounted in glycerine jelly before adding a cover slip. Neither of these methods is as simple as the first which provides permanent mounts that last longest.

An alternative to using the actual scale is an impression. In order to make impressions, the scales should be placed between two cellulose acetate (or PVC) strips (about 50 x 25 mm) and passed through a jeweller's press with just sufficient pressure to impress the scale pattern onto the strip. The correct pressure of the rollers depends upon the thicknesses of the scale and the strip, and therefore must be found by "trial and error". This method is most useful when large numbers of scales have to be processed.

4. READING AND INTERPRETATION OF SCALES

4.1 Reading

The mounted scales can be examined under a microscope, but it is easier to use a microprojector that will produce an image with a diameter of 10 - 30 cm. Projection makes it easier to make measurements for back-calculation of lengths at different ages (see Chapter 5), and for several people to discuss interpretation of the scale. The addition of a video camera facilitates a permanent record and may increase clarity.

It is important to choose the best scale available for reading. Scales from the same fish can often be very different and therefore the chosen scale should be marked on the outside of the slide with a wax pencil. The ideal scale should have a well defined focus and obvious annuli in both the river and sea zones on the scale. Erosion should be restricted to the posterior portion of the scale and the spawning marks. It is advisable to examine several scales from the same fish, and to check with other available information for the fish that the scales are a valid sample, i.e. the sample has not been "contaminated" with scales from another sea trout or another species.

4.2 Interpretation

After identifying the best scale, the usual procedure for reading the scale is first to locate the start of rapid sea growth because this defines the boundary between the river and sea zones (Figures 2.1 and 3.2). Next the annuli in the river zone are identified and counted to indicate the number of years spent in freshwater; any run-out is noted. Finally the annuli in the sea zone are identified and counted, and any plus growth and spawning marks are recorded.

Each annual zone on the scale is characterized by a succession of bands of wide spaced and narrow spaced circuli. The annulus forming the boundary between annual zones is usually identified by the transition from narrow spaced to wide spaced circuli or, more rarely, by the first complete circulus of the new annual zone cutting over the last incomplete circulus of the preceding annual zone. The annulus is very rarely represented by a single circulus. It is best considered as a theoretical line running between the last of the narrow spaced circuli of a winter band and the first of the wide spaced circuli of the following summer band. An incomplete summer band at the outer edge of the scale is recorded as plus growth.

In Figure 2.1, the boundary between the river and sea zones is distinct on the scale. The fish was caught in the summer and had spent three years in the river and just over two years at sea (note the plus growth at the scale edge). The fish was therefore aged 3 · 2+ and was a 1-sea-winter previous spawner that had spawned only once: 3 · 1+ 1SM + in the notation recommended in Section 2.2. The spawning mark was fairly distinct near the right-hand edge of the scale (SM in Figure 2.1).

In Figure 3.2, a more difficult example, the boundary between the river and sea zones is also distinct, but there is some run-out on the edge of the river zone (+ in Figure 3.2). The fish was a female that was found dead early in February soon after the spawning season had ended. It had spent just over two years in the river and over four years at sea. Although the last annual zone at the edge of the scale was almost complete, it was interpreted as plus growth rather than a fifth annulus. The female was therefore aged 2+ · 4+ and was probably a 1-sea-winter previous spawner that had possibly spawned three times: 2+ · 1+ 3SM + . It had also probably spawned for a fourth time before it died but there had not been enough time for the spawning mark to form. Unlike Figure 2.1, the spawning marks were difficult to identify with certainty (hence the SM?). As mentioned earlier, this is often a problem, especially with older fish and females that do not remain long in freshwater to spawn. Further examples of scales are presented in the atlas (Chapter 6).

4.3 Problems of interpretation

If a fish loses scales, then these are replaced by scales that have centres of scar tissue. The size of this scar centre depends upon the age of the fish when the scale was lost. Such a scale is useless for interpretation, as is also a badly eroded scale. If a large sample of scales has been taken from a fish, then these scales will be normally discarded before choosing suitable scales. Such useless scales are not therefore a problem unless they are numerous, as sometimes occurs on very old sea trout. The remaining problems in interpreting sea trout scales were all recognized by Nall (1930) and Chapter 3 of his book is recommended reading for all those who think that interpretation is easy. These problems can be divided conveniently into those associated with the river zone, the sea zone and finally spawning.

In fish that spend over two years in freshwater before smolting, growth is usually slow, especially in the first year. Therefore the distance from the focus to the first annulus is usually much less than the distance between successive freshwater annuli (e.g. Figure 2.1). When the freshwater stage lasts about two years, growth is more rapid and the freshwater annuli are more evenly spaced (e.g. Figure 3.2). Occasionally, there is no winter check in the freshwater stage when the parr continue to feed and grow through a mild winter. This is when additional knowledge about the population is useful. If the length for age (see Chapter 5) is exceptionally high, then it is probable that an annulus has been missed. For most rivers in England and Wales, the most probable time spent in freshwater is two years or just over two years, and the next most probable time is three years. Periods of one or four years are rare. The usual decision is, therefore, whether two or three annuli are present for the river zone on the scale.

There are similar problems for the sea zone on the scale. Sea trout behaviour is very variable with some fish returning to the estuary or freshwater for short periods outside the spawning season (for a summary of variable life histories, see Elliott 1994). A "summer check" may occur if the food supply is restricted or if the fish moves briefly back into freshwater without spawning. The check appears as a few narrow circuli between bands of wide circuli, the latter bands being narrower than expected for a spring and summer light band. As in freshwater, there may be little or no winter check because of ideal conditions for winter growth. Such an interpretation should always be considered if a light band is very wide. Once again, the length for age (Chapter 5) will be exceptionally high and is useful confirmation that an annulus has been missed. The absence of growth retardation in winter for some sea trout is why the terms "light" and "dark" bands are preferable to "summer" and "winter" bands. The most difficult problem is the interpretation of spawning marks, as discussed at the end of Section 2.2.

Finally, it is always wise to utilise quality checks by other scale readers to confirm any given interpretation, e.g. about every 10 to 20 scales.

5. BACK-CALCULATION OF LENGTH FOR AGE

5.1 Assumptions and methodology

The back-calculation of fish length at different ages provides a very useful check on the validity of the ages interpreted from the scales. It is less reliable for estimating the mean lengths at different ages for a fish population (see section 5.2). The basic assumptions are that, once formed, the scales are present throughout the life of the fish, that their numbers remain fairly constant and that the increase in scale size is proportional to the increase in fish size. For salmonids, it is often assumed that the body : scale relationship is linear (Figure 5.1a). For example, in a guide to interpreting scales of Atlantic salmon, the assumption of simple proportionality is acknowledged as being strictly incorrect but is considered to provide a satisfactory estimate of length for the purpose of interpreting scales (International Council for the Exploration of the Sea 1986).

As in determining age, the best scales should be identified and viewed on a microprojector screen with an image diameter of at least 10 cm. A thin strip of card is laid along the long axis of the scale image (Figure 5.1b). The positions of the focus, the edge of the scale and each annulus are marked on the card. The length of the fish at the time of scale removal must be known (preferably fork length from tip of snout to the centre of the tail fork and usually to the nearest mm). Lengths for different ages can then be read off a sheet of graph paper with the vertical axis marked in cm or mm. The card strip is laid on the graph paper so that the focus mark corresponds to zero and the scale edge mark to the known length of the fish (e.g. as in Figure 5.1c). It is advisable to repeat this process for several scales from the same fish and use the mean values of the lengths for different ages. Remember to use the same magnification for all scales.

An alternative to the graphical method is to estimate the length for age (L_n) from the simple equation:

$$L_n = L\,(S_n / S) \qquad (1)$$

where L is the fork length at the time the scale is removed, S_n is the distance from the focus to the n th annulus and S is the distance from the focus to the scale edge (both S_n and S are measured in arbitrary units). For the example in Figure 5.1c, L = 340 mm, S = 55 units, $S_{n=2}$ = 20 units and therefore $L_{n=2}$ = 124 mm (such accuracy is difficult to attain in the graphical method).

The most frequent violation of the assumptions inherent in the above methodology is that the linear relationship between body length and scale length does not pass through zero on the graph, i.e. the focus mark corresponds to a length greater than zero. A correction factor (intercept a) has to be added to equation (1) but can be estimated only when information is available for fish of different lengths and ages. These fish must be from the same population, and the magnification level on the microprojector must be constant. A plot of fork length against scale length (in arbitrary units) indicates whether such a linear relationship is apt (e.g. Figure 5.2a). The intercept a can either be read from the graph or estimated more accurately by simple linear regression. The card strip method can still be used but the focus mark must now be placed so that it corresponds to the intercept a whilst the scale-edge mark once again corresponds to the fish length.

An alternative procedure is to use a modified version of equation (1) thus:

$$L_n - a = (L - a)\,(S_n / S) \qquad (2)$$

If intercept a = 20 mm and the other values are as given under equation (1), then $L_{n=2}$ = 136 mm.

The final, "worst-case scenario", is when the body : scale relationship is non-linear. Once again, information must be available for fish of different lengths and ages from the same population, and the magnification level on the microprojector must be constant. A plot of fork length against scale length (in arbitrary units) on log-log graph paper usually indicates a linear relationship, i.e. the relationship between scale length and body length is allometric, not isometric (e.g. Figure 5.2b). A linear regression equation can be fitted to the log-transformed data (log fork length on log scale length). This equation can then be used as a type of "calibration curve" to convert scale lengths to body lengths for different ages. Sometimes, the relationship changes with fish size and two regression lines have to be fitted (e.g. above and below 80mm in Figure 5.2b). Methods of fitting regression lines to log-log transformed data can be found in standard texts on statistics and are now standard in most software packages of statistical methods.

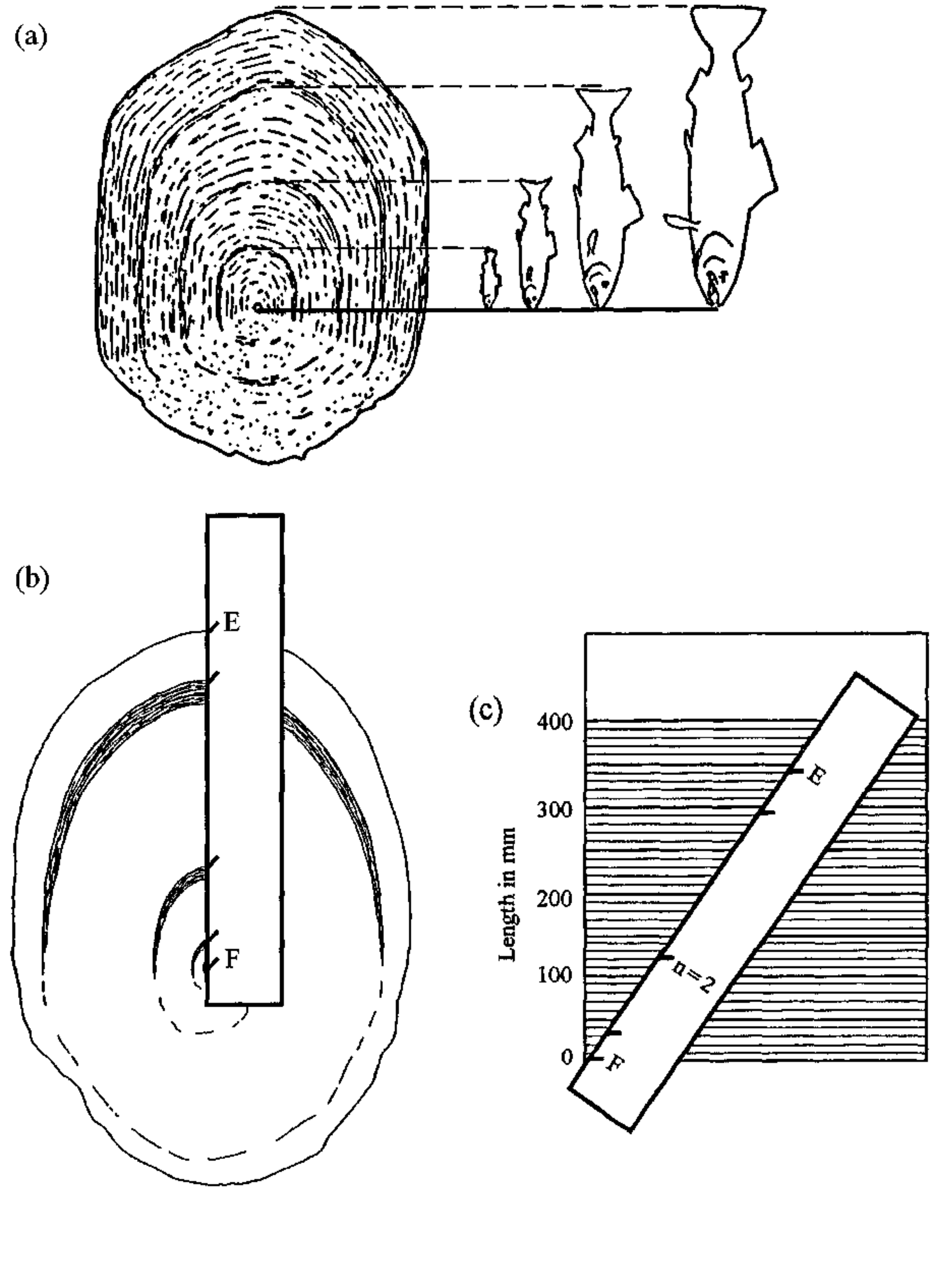

Figure 5.1 Back calcualtion of length from scales
(a) Direct proportionality between scale length and fork length;
(b) Measuring card in position on the long axis of an enlarged image of a scale;
(c) Measuring card in position on graph paper so that lengths can be read off for different ages.

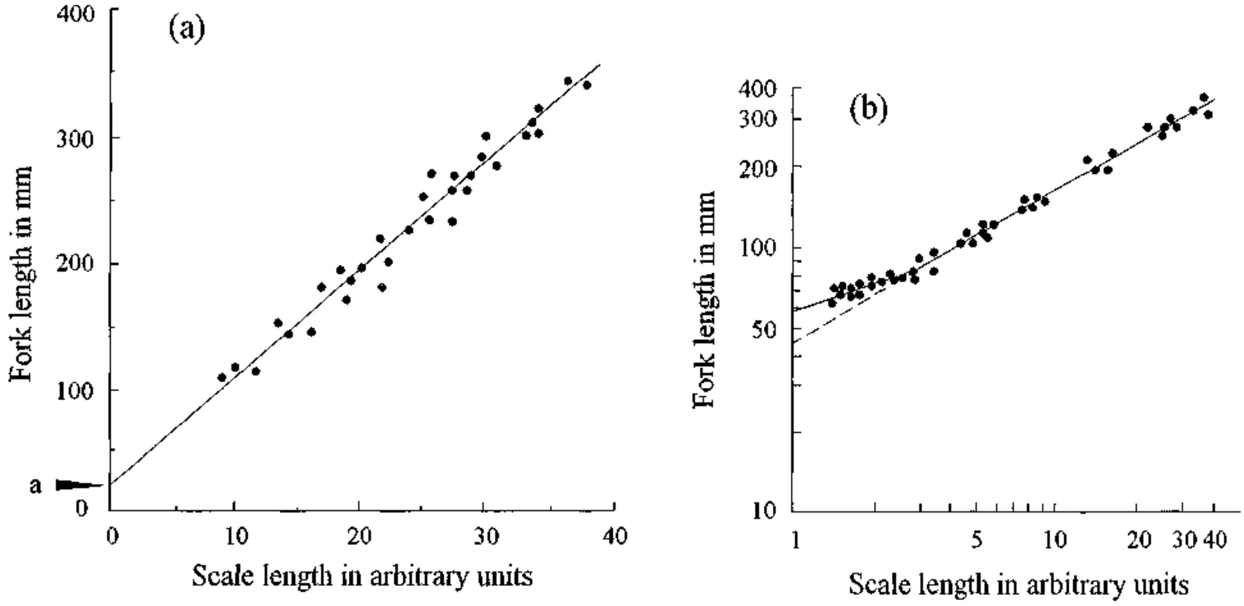

Figure. 5.2 Body length : scale length relationship
(a) In which the linear relationship does not pass through zero;
(b) Which is linear on log-log scales (note that the relationship changes at a fork length of 80 mm).

5.2 Problems of interpretation

Eroded scales or those with spawning marks are again a problem. Nall (1930) states: "In measuring scales for length calculations it is better to avoid those bearing spawning marks, except for special purposes, since erosion introduces a disturbing factor". A workshop on interpreting scales of Atlantic salmon noted: "that it was inadvisable to use back-calculated lengths on scales which showed signs of erosion or spawning marks". Such advice raises serious problems because most of the older sea trout have spawned more than once. The back-calculation of their lengths for different ages must therefore be treated with caution.

Another problem is that as the age of the fish increases, back-calculated lengths for the younger age groups are often under-estimates of the true values. This is known as Rosa Lee's phenomenon after the discoverer who first indicated its importance (Lee 1912). Although Nall (1930) and contemporaries rejected the phenomenon, a substantial amount of work has subsequently validated it (see references in Bagenal and Tesch 1978). Four possible causes have been proposed:

(1) Incorrect back-calculation methodology, e.g. if equation (1) is used when equation (2) is more appropriate;
(2) Non-random sampling of the population, e.g. if the sampling gear is biased towards the larger fish in the younger age groups;
(3) Selective natural mortality so that the scale samples are from surviving fish that are unrepresentative of the mean size of the younger age groups;
(4) Selective fishing mortality, similarly biased.

Some of these points are similar to those raised at the end of Section 1.3 and the solution is similar; use alternative methods such as those listed in that section. Francis (1990) provides a useful critical review of the literature on the back-calculation of fish body length from marks on scales or other hard parts.

It is therefore concluded that back-calculated lengths for different ages are a useful method for checking if the ages are correct. If simple proportionality is not observed, then the most obvious explanation is that an annulus has been missed. However, it should be remembered that the other relationships between scale length and fish size are possible, but these can be explored only if additional information is available for fish of different ages from the same population. Finally, the estimated lengths for age should be treated with caution, especially for the younger age groups.

6. SCALE ATLAS

Photographs of twenty two scales, presented in Figures A1 - A17, illustrate the wide range of types that may be encountered. The scales are arranged in approximate order of fish age, and detailed information on each scale is provided in the figure legends.

The atlas starts with two scales from sea trout smolts (Figure A1) followed by four scales from whitling (Figures A2,3). Scales of one-, two-, and three-sea-winter maiden spawners (Figures A4,5,6,7) are followed by those from whitling, one-sea-winter and two-sea-winter maiden spawners that have spawned at least once (Figures A8,9,10). A useful series is provided by scales taken in different years from the same fish that was trapped three times (Figure A11). Four scales illustrate the pattern expected for multiple spawners (Figures A12 - 15) and, finally, two examples are included to illustrate scales that are impossible to interpret (Figures A16,17).

This wide range of scales should provide a useful guide to those wishing to interpret the scales of sea trout. It is worth emphasizing again that scale interpretation is as much an art as a science and requires a great deal of experience with as wide a range of scales as possible.

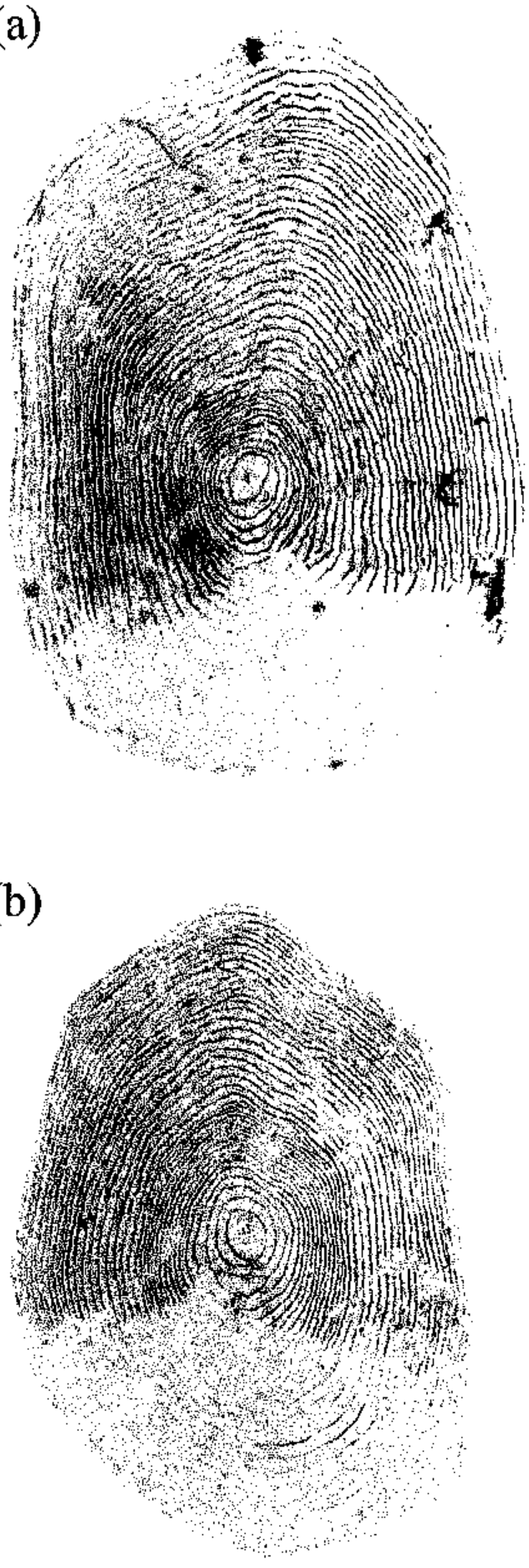

Figure A1 Scales from sea trout smolts that had spent:
(a) just over two years in the river (age 2 +);
(b) just over three years in the river (age 3 +).
(Note that these are photographs of acetate impressions, not the original scales.)

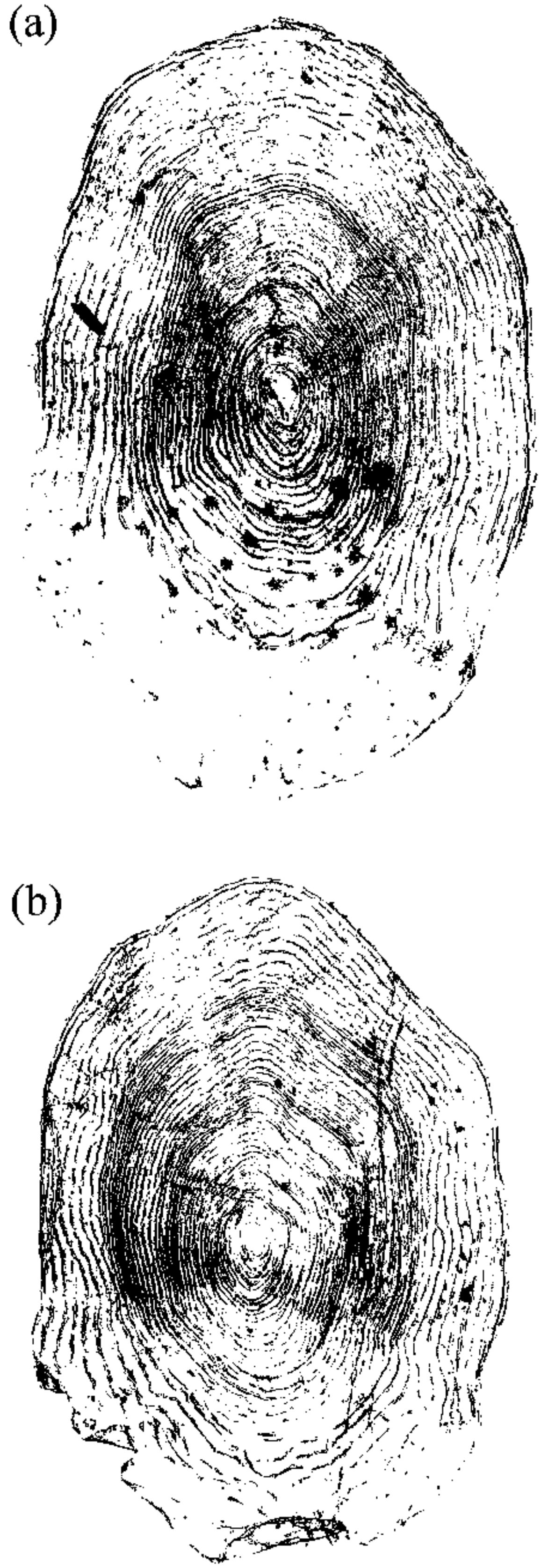

Figure A2 **Scales from sea trout whitling that had spent:**
(a) just over two years in the river (age 2 - 0+), electrofished from River Frome on 12 August 1976, fork length 274 mm;
(b) just over three years in the river (age 3 - 0+), caught in Chester trap on Welsh Dee on 16 July 1984, fork length 327 mm.

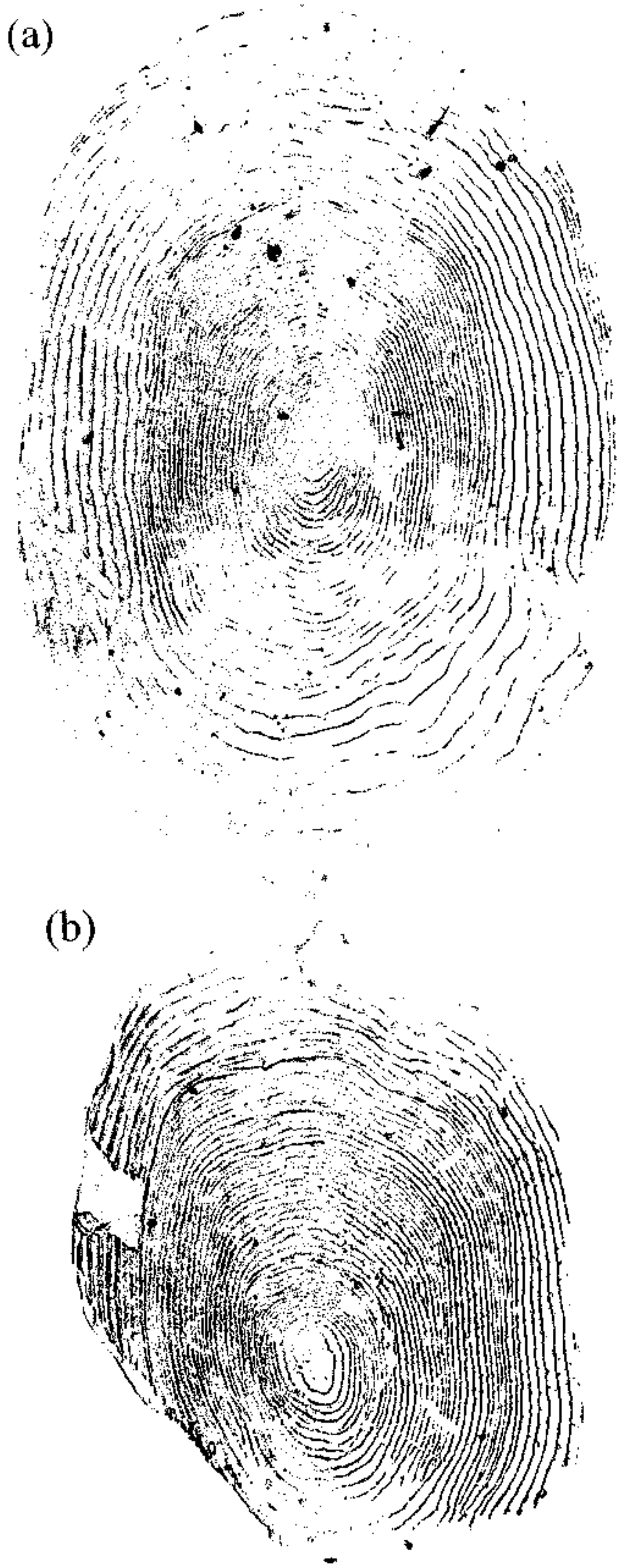

Figure A3 Scales from sea trout from Irish Burrishoole:
(a) whitling that returned to fresh water but did not spawn, and was caught in a downstream trap on 30 April 1986 (age 2 - 0+), fork length 283 mm, wet weight 215 g;
(b) whitling maiden spawner that returned to fresh water and spawned before being caught in a downstream trap on 19 November 1986 (age 3 - 0+ 1SM), male, fork length 313 mm, wet weight 350 g.
(Note that these are photographs of acetate impressions, not the original scales.)

Figure A4 Scale of a one-sea-winter maiden spawner that had spent just over two years in the river (age 2 . 1+); caught in Panteg Trap, River Tawe, on 25 May 1994, fork length 630 mm.

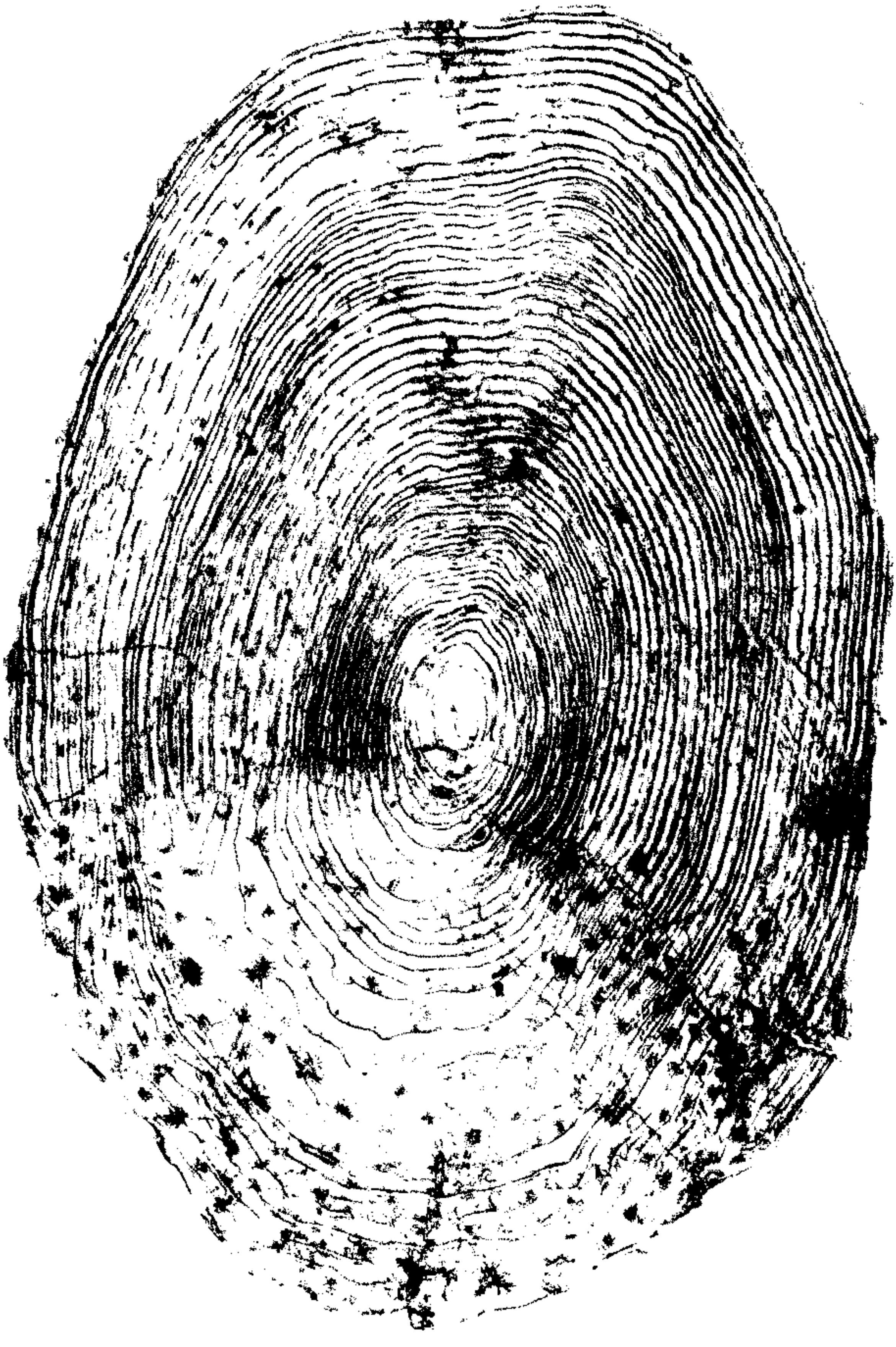

Figure A5 Scale of a one-sea-winter maiden spawner that had spent just over one year in the river (age 1 - 1+); female, rod caught in River Frome on 1 September 1977, fork length 402 mm.

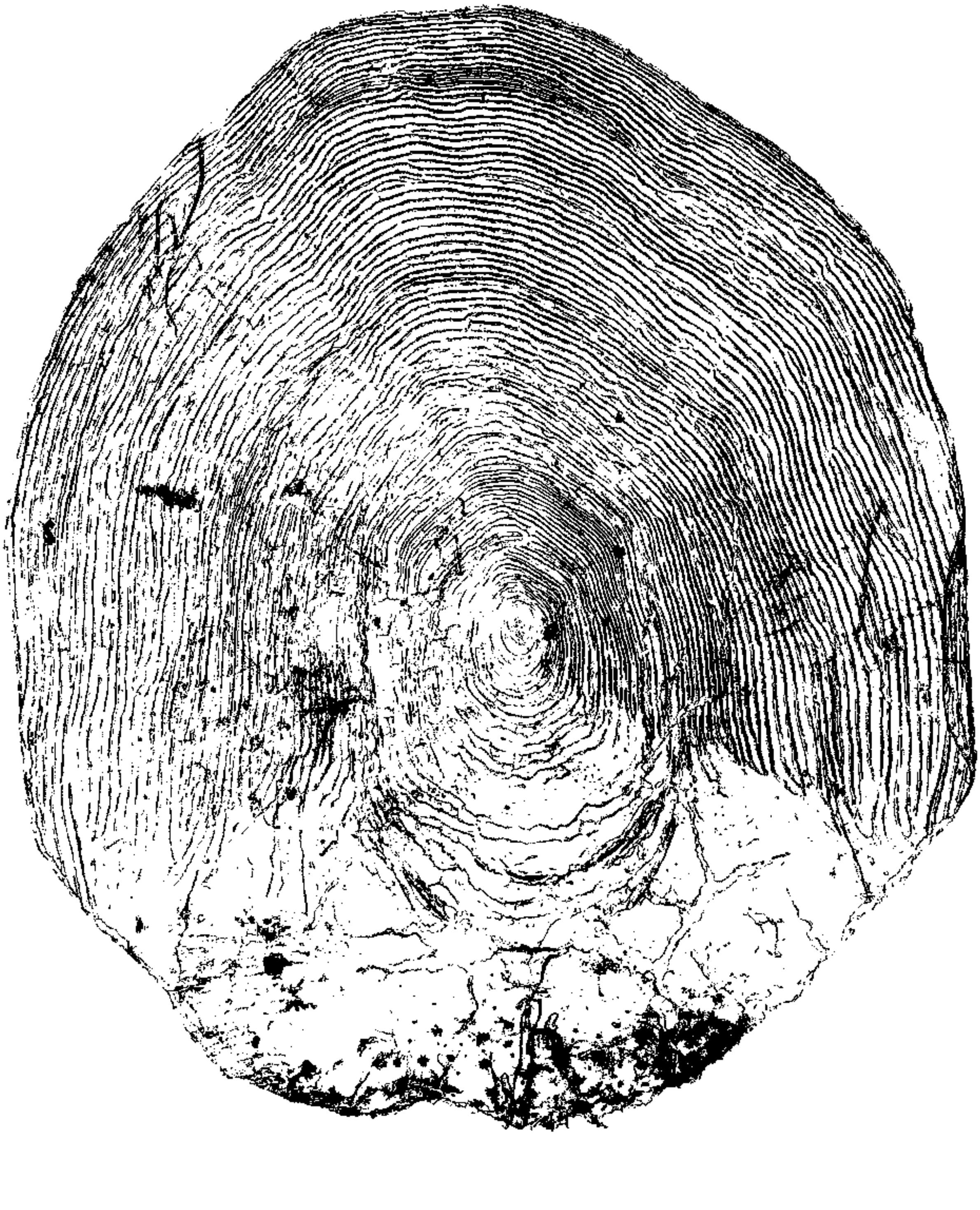

Figure A6 Scale of a two-sea-winter maiden spawner that had spent two years in the river (age 2 . 2+); electrofished from River Aln on 20 July 1994, fork length 686 mm.

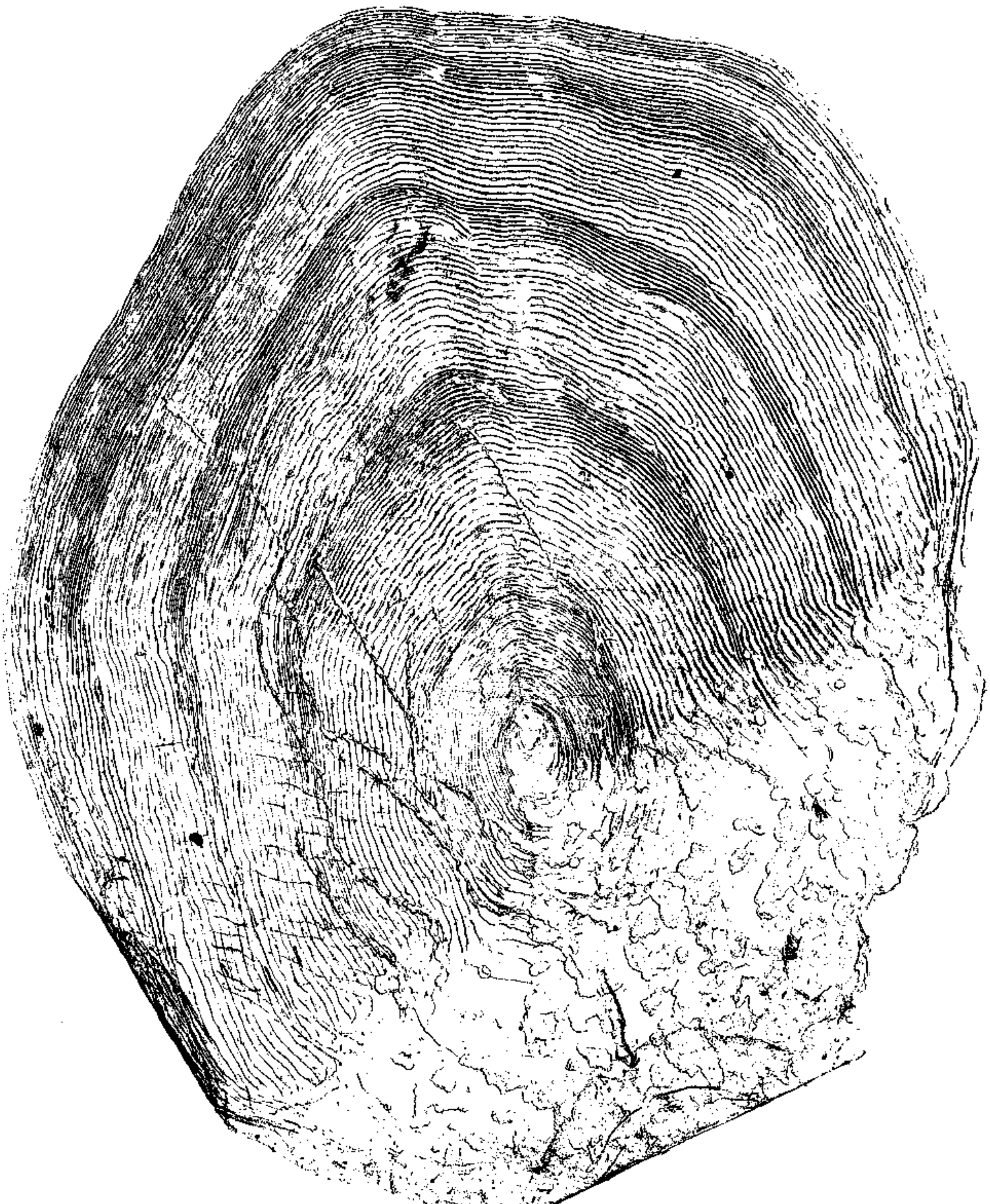

Figure A7 Scale of a three-sea-winter maiden spawner that had spawned twice (age 2 - 3+ 2SM); rod caught in River Teifi on 28 March 1995, fork length 900 mm, wet weight 7.5 kg.

Figure A8 Scale of a whitling maiden spawner that had spawned once, leaving a clear spawning mark (age 2 · 0+ 1SM+), then returned to sea and finally had returned to spawn for a second time (it probably spawned for a second time but the spawning mark has not formed); female, found dead in River Frome on 6 January 1976, fork length 447 mm.

Figure A9 Scale of a one-sea-winter maiden spawner that had spawned once (age 2 · 1+ 1SM+); caught in Panteg Trap, River Tawe, on 30 November 1993, fork length 730 mm.

Figure A10 Scale of a two-sea-winter maiden spawner that had spawned once (age 2 · 2+ 1SM+); caught by a coracle net in the River Tywi estuary on 4 May 1992, fork length 695 mm, wet weight 3.6 kg.

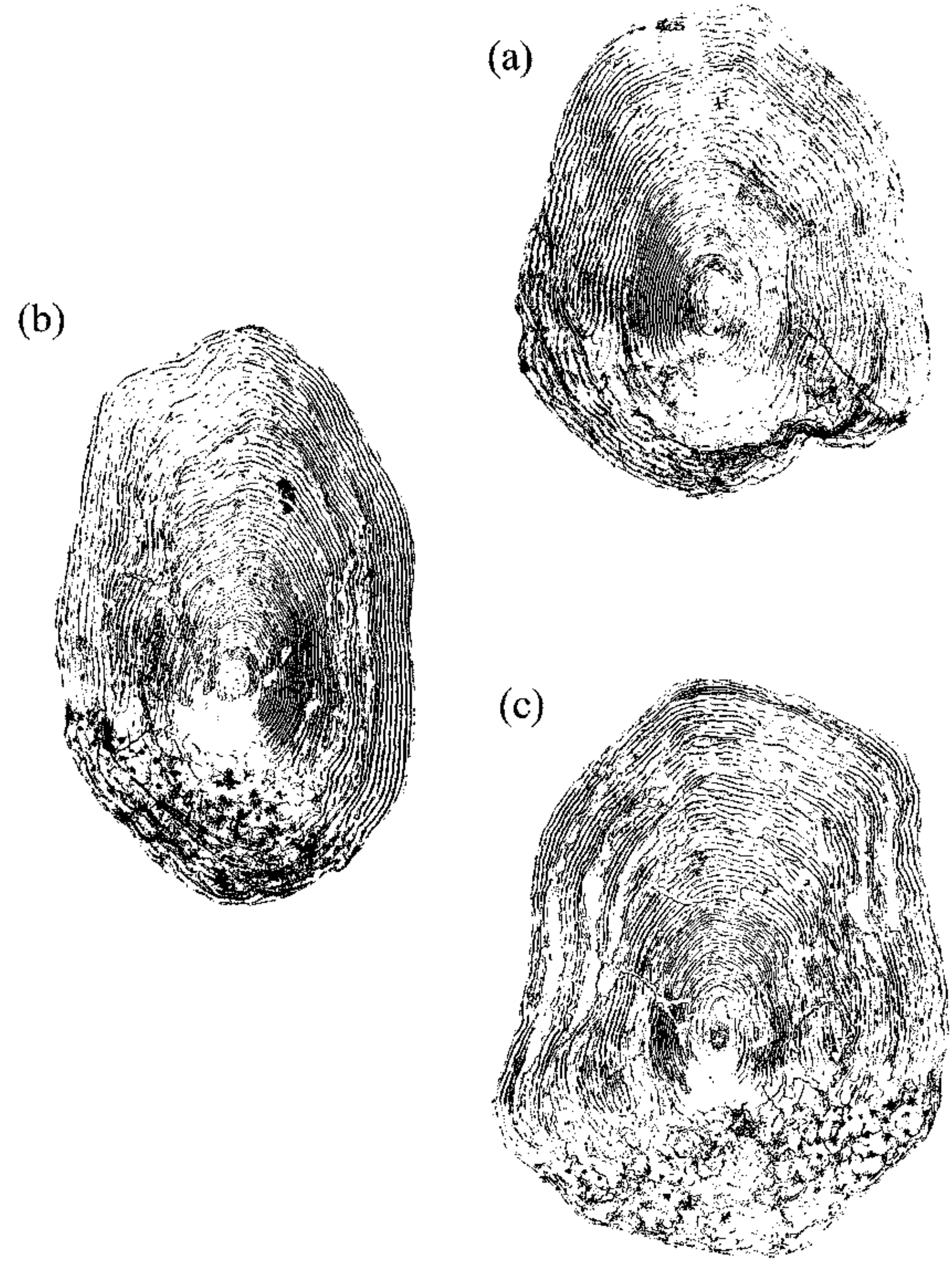

Figure A11 Scales from the same whitling maiden spawner caught in a trap in different years after:
(a) spawning once (age 2 · 0+ 1SM+); (b) spawning thrice (age 2 · 0+ 3SM+);
(c) spawning four times (age 2 · 0+ 4SM+).

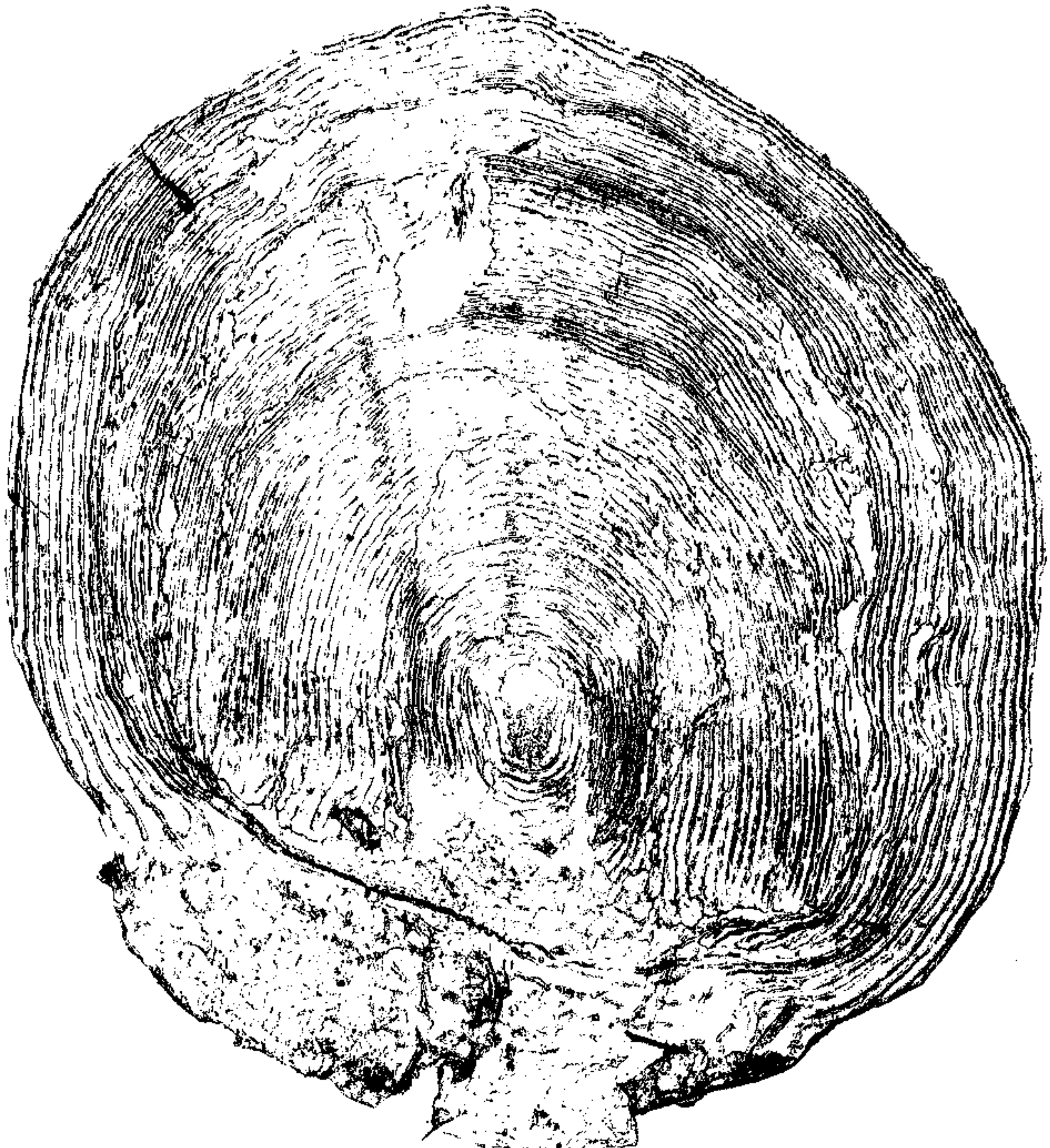

Figure A12 Scale from a one-sea-winter maiden spawner that had spawned twice, but with the freshwater part of the scale impossible to interpret (age ? · 1+ 2SM+); re-caught, after tagging the previous year, in the Panteg Trap, River Tawe, on 7 June 1994, fork length 650 mm.

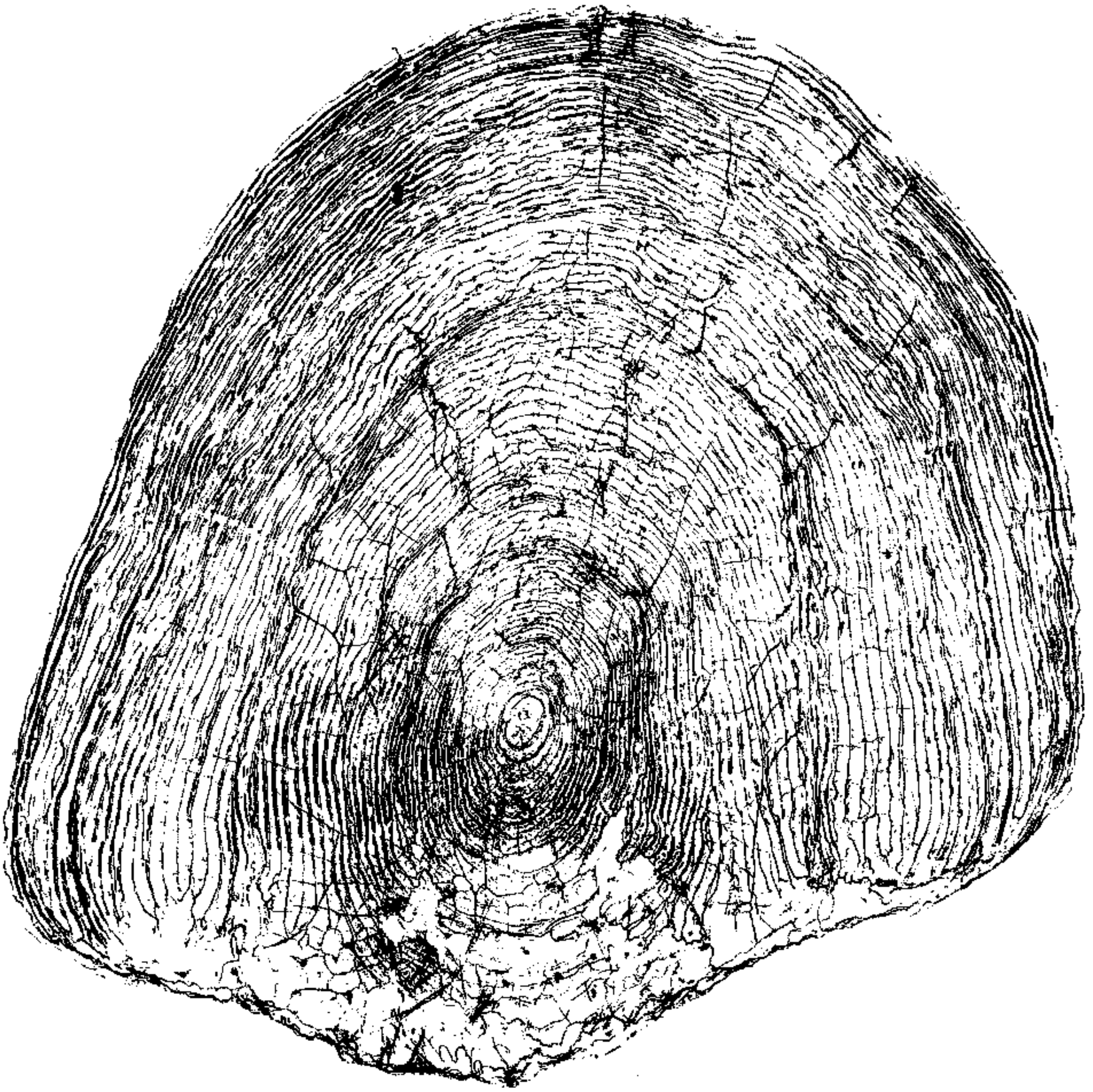

Figure A13 Scale from a whitling maiden spawner that had spawned thrice (age 1+ - 0+ 3SM+); rod caught in River Frome on 3 September 1986, fork length 660 mm.

Figure A14 Scale from a one-sea-winter maiden spawner that had spawned thrice (age 3 · 1+ 3SM+); rod caught in River Coquet in July 1994, wet weight 9.5 kg.

Figure A15 Scale from a one-sea-winter maiden spawner that had spawned four times (age 3 . 1+ 4SM+); rod caught in River West Dart on 23 September 1992, wet weight 4.8 kg (scale shows erosion around the edge).

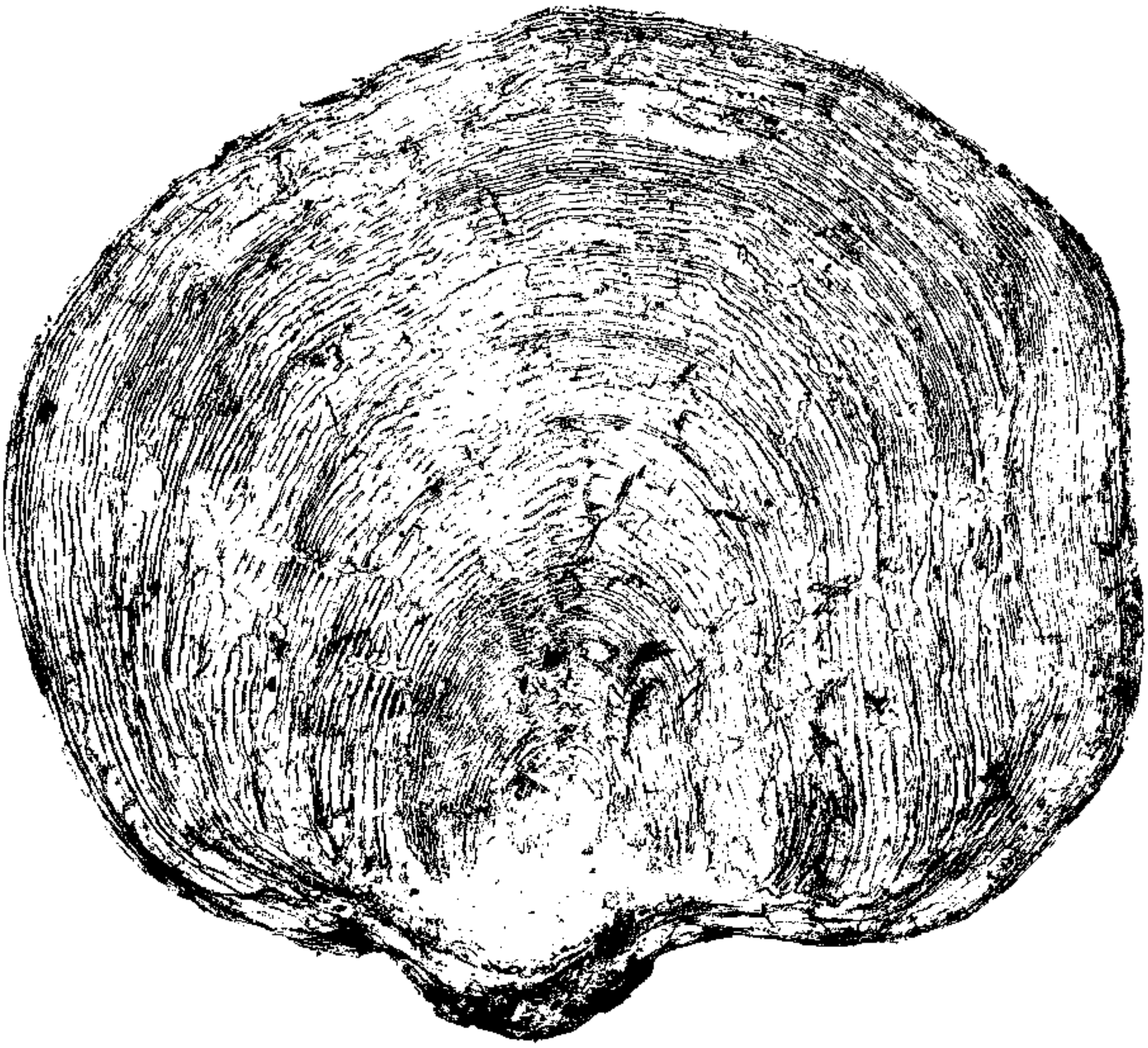

Figure A16 **An impossible scale from an old sea trout that had probably spawned up to ten times; it is virtually impossible to determine smolt age, age at first spawning and total number of spawning marks; rod caught in River Conway on 26 August 1994, fork length 889 mm, wet weight 6.1 kg.**

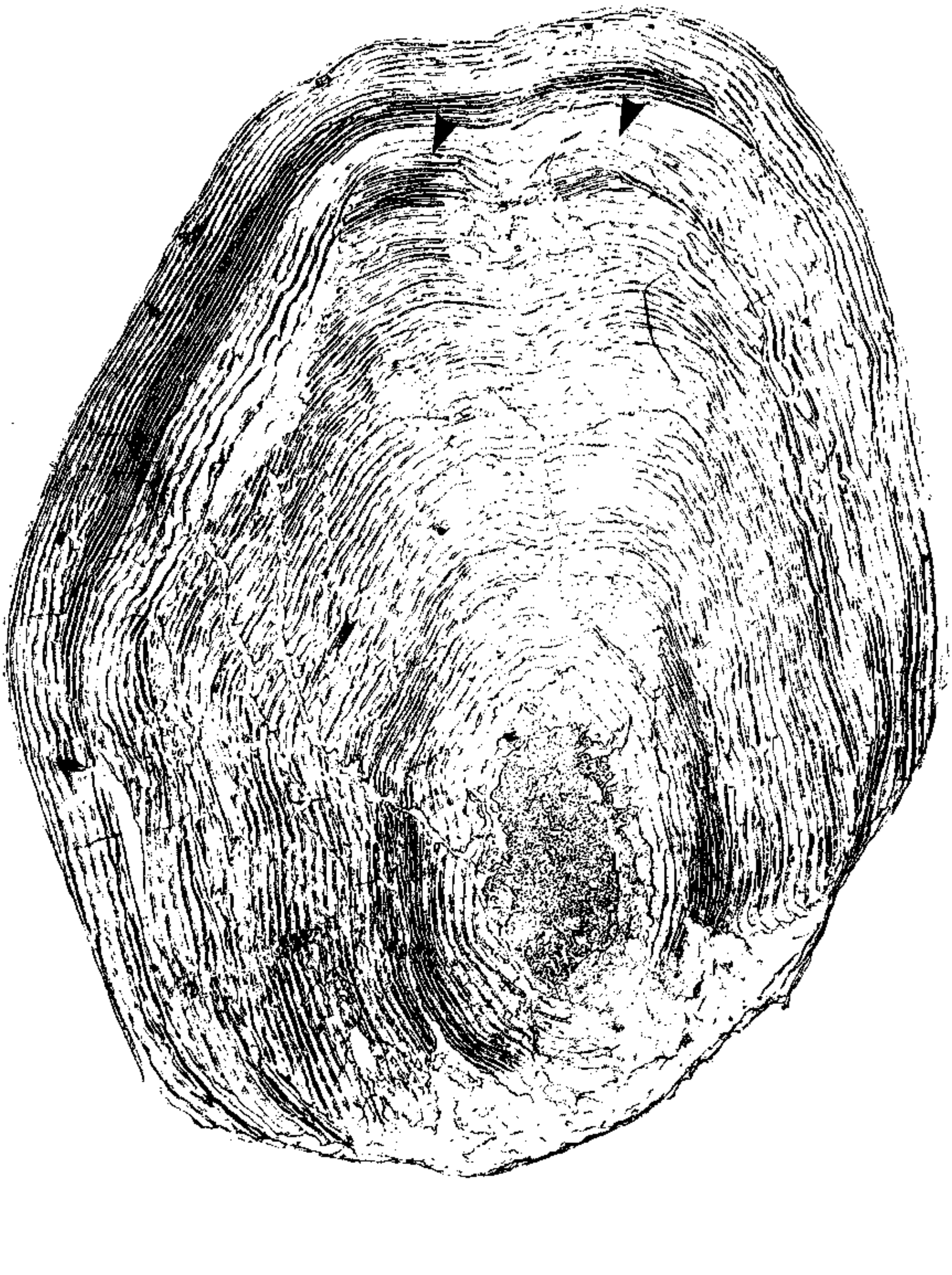

Figure A17 A difficult scale with the centre missing and obscured annuli (arrowed), possibly three spawning marks; rod caught in River Frome on 30 June 1993, fork length 670 mm.

REFERENCES

Allan, I.R.H. and Ritter, J.A. (1977). Salmonid terminology. *Journal du Conseil. Conseil permanent international pour l'exploration de la mer*, 37, 293-299.

Bagenal, T.B. and Tesch, F.W. (1978). Age and growth. In *Methods for Assessment of Fish Production in Fresh Waters* (Bagenal, T., ed.), Oxford: Blackwell.

Elliott, J.M. (1985). Growth, size, biomass and production for different life-stages of migratory trout *Salmo trutta* in a Lake District stream, 1966-83. *Journal of Animal Ecology*, 54, 985-1001.

Elliott, J.M. (1994). *Quantitative Ecology and the Brown Trout.* Oxford: Oxford University Press.

Francis, R.I.C.C. (1990). Back-calculation of fish length: a critical review. *Journal of Fish Biology*, 36, 883-902.

Frost, W.E. and Brown, M.E. (1967). *The Trout.* London: Collins.

International Council for the Exploration of the Sea (1986). Report of the Atlantic salmon scale reading workshop. Aberdeen, Scotland, 23-28 April, 1984. ICES, Copenhagen.

Jones, J.W. (1959). *The Salmon.* London: Collins.

Le Cren, E.D. (1985). *The Biology of the Sea Trout.* Pitlochry: Atlantic Salmon Trust.

Lee, R.M. (1912). An investigation into the methods of growth determination in fishes by means of scales. *Conseil permanent international pour l'exploration de la mer*, paper no. 63, 3-35.

Maitland, P.S. (1972). A key to the freshwater fishes of the British Isles with notes on their ecology and distribution. *Scientific Publication of the Freshwater Biological Association*, 27, 1-139.

Menzies, W.J.M. (1936). *Sea Trout and Trout.* London: Edward Arnold.

Nall, G.H. (1930). *The Life of the Sea Trout: especially in Scottish Waters.* London: Seeley, Service & Co.

O'Farrell, M.M., Whelan, K.F. and Whelan, B.J. (1989). A preliminary appraisal of the fecundity of migratory trout (*Salmo trutta*) in the Erriff catchment, western Ireland. *Polskie Archiwum Hydrobiologii* 36, 273-281.

Solomon, D.J. (1994). Sea trout investigations - Phase 1. Final Report. R&D Note 318, National Rivers Authority, Bristol.

Went, A.E.J. (1962). Irish sea trout, a review of investigations to date. *Scientific Proceedings of the Royal Dublin Society, Series 1A*, No. 10, 265-296.

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