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Silver hake
Merluccius bilinearis

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Silver hake is an important gadoid ranging from Newfoundland to South Carolina and is most abundant from Nova Scotia to New Jersey (Bigelow and Schroeder 1953). Silver hake are found over a wide range of depths, from shallow waters to depths greater than 400 m (Almeida 1984).

Two genetically distinct stocks have been defined south of Nova Scotia: a "northern stock" occupying the Gulf of Maine-northern Georges Bank region and a "southern stock" occurring from southern Georges Bank to Cape Hatteras (Anderson 1974, Schenk 1981, Almeida 1984). Some mixing of the two stocks occurs throughout all or most of the year, perhaps facilitated by the wide temperature tolerance of this species.

Silver hake of the southern stock overwinter primarily along the outer continental shelf from Georges Bank to Cape Hatteras. During spring and summer, these fish move northward and inshore onto the southern and southeast parts of Georges Bank (Almeida 1984). Spawning occurs on the southern slopes of Georges Bank from May to November, reaching a peak in Southern New England and mid-Atlantic waters by May and June. Silver hake of the northern stock overwinter in deep basin areas of the Gulf of Maine, moving into shallower waters in late spring-early summer. Spawning occurs in inshore waters from Cape Cod to Grand Manan Island from June through November, peaking in July and August (Bigelow and Schroeder 1953, Colton and St. Onge 1974, Fahay 1974). Secondary spawning occurs on the north to northwestern slopes of Georges Bank (Sauskan 1964, Sauskan and Serebryakov 1968).

Female silver hake grow faster and live longer than males. Males attain a maximum length and age of about 42 cm (17 inches) and 10 years, respectively, contrasting with 67 cm (26 inches) and 12 years for females (Dery unpubl. data). Most silver hake are sexually mature by age 2.

Ageing methods for silver hake, based on the otoliths, remain somewhat controversial despite intensive research (Nichy 1969; Anderson and Nichy 1975; ICNAF 1976, 1977, 1978; Hunt 1980a). All investigators have counted hyaline zones as annuli. The prolonged spawning season of this species, and the variability of growth patterns due to genetic and environmental factors have made accurate identification of the first annulus, and discrimination between checks and annuli, difficult. In addition, age interpretation using whole otoliths may differ significantly from interpretations based on thin otolith sections and or sectioned halves. The edge type on some otoliths, either hyaline or opaque, has appeared to some investigators to be inconsistent with the season of the year, causing confusion with regard to edge interpretation. Age validation studies for silver hake of the Scotian Shelf have been conducted by Hunt (1978, 1979, 1980b). Although relatively few otoliths of these fish have been examined at this laboratory in recent years, some of the growth patterns appear similar to that observed on Gulf of Maine otoliths, and others resemble those of the southern stock.

The methods used at Woods Hole Laboratory have evolved from early studies by Nichy (1969) on the growth of young silver hake, from participation in age and growth workshops (ICNAF 1976, 1977, 1978), and from research on types of silver hake growth patterns and their distribution in the study area (Dery unpubl. data). Particular attention has been focused on otolith growth patterns of young fish (age 0+ to 1) to facilitate accurate interpretation of the first annulus, and to avoid assigning earlier hatched fish of the southern stock, and later hatched northern Georges Bank-Gulf of Maine fish, to different year classes. Hunt (1980a) summarized previous research in the literature concerning ageing methods used for this species. He described some aspects of otolith growth patterns as characteristic of given geographic areas but did not present an integrated description of these patterns for different stocks of silver hake. The method of presentation of Hunt's interpretations, in addition to his use of whole otoliths rather than thin-sections, makes difficult direct comparisons of his criteria with those used at Woods Hole. Validation of methods at Woods Hole has involved comparisons of modal groups in fish length-at-age data with the modal groups in length frequencies, and monitoring modal progression of prominent year-classes in the fishery on a seasonal and annual basis.

Methods of preparing otoliths have been described by Nichy (1969, 1977), Anderson and Nichy (1975), ICNAF (1976, 1977, 1978) and by Hunt (1980a). Such methods have involved storage of whole otoliths in glycerin or some other medium to "clear" the otolith and enhance the hyaline zones. Other methods include dry storage and soaking for a short period in ethyl alcohol before viewing. At the Woods Hole Laboratory, otoliths are stored dry in coin envelopes. A thin transverse section 0.20-0.23 mm thick is removed at the nucleus and examined under reflected light against a dark background, using a method developed by Nichy (1977). The cut surfaces of the sectioned otolith may be used in addition to, or instead of, the thin-section, depending on the degree of complexity of the growth pattern.

For some fish, whole otoliths, examined in ethyl alcohol, are used to verify age from thin-sections, but are not considered completely reliable. This is because the pattern of early growth on the otolith, which is often difficult to interpret, tends to be obscured by subsequent calcification, despite the use of strong clearing media such as glycerin (Anderson and Nichy 1975). In general, silver hake otoliths become thicker with increasing age relative to an increase in width. Therefore, misinterpretation of early growth, especially of older fish, is more likely. Nevertheless, some whole otoliths exhibit a clearer pattern of annulus formation than do thin-sections, especially if the annular zones are weak or diffuse.

Growth patterns observed on silver hake otoliths tend to support Almeida's (1984) definition of two separate stocks from the Gulf of Maine to Cape Hatteras. Variations in the growth patterns on otoliths with geographic location include size and formation of the first annulus, relative growth increment widths between annuli due to differences in growth rate, formation of checks and split zones, and time of annulus formation. Although characteristic growth patterns can be identified for each stock, some patterns are difficult to classify (due in part to individual variability). Other patterns are intermediate in type, with aspects characteristic of both Gulf of Maine fish and those further south. This may reflect stock intermixture as suggested by Almeida (1984). Seasonal shifts in the distribution of growth patterns also appear to be consistent from year to year and seem to reflect observed migratory movements (Dery unpubl. data).

The otoliths of silver hake from the southern stock tend to exhibit moderate to large amounts of opaque edge as early as March or April, indicating that annulus formation is complete by the end of the winter and probably earlier (Fig. 1). By convention, a birthdate of 1 January is used; the hyaline zone evident on the edge of the otolith is interpreted as an annulus whether or not it is complete. As is typical for many fish species, seasonal growth resumption is quite advanced for young fish relative to older individuals (Fig. 2) and age-1 fish otoliths show considerable amounts of "+" growth as early as April (Fig. 3). The timing of annulus initiation in the autumn is somewhat variable. Opaque edge may persist on the otoliths of age 0+ or 1+ and older individuals into autumn (September-October) (Fig. 4); however, most otoliths collected during autumn tend to exhibit a narrow hyaline edge which is not included in the age determination (Figs. 5 and 6).

In spite of variability in size and timing of formation of the first annulus, the characteristically large growth increment (wide opaque zone) between the first and second annuli provides a means of distinguishing between the two zones (Figs. 1 and 6). The differences in mean length at age-1 and age-2 in the spring months do not fully reflect the magnitude of this growth increment, because of the early growth resumption of age-1 fish (growth beyond the first annulus). The first annulus frequently appears as a small, dense, but split zone of hyaline material surrounding the nucleus of the otolith (Fig. 2), not evident on the otoliths of 0+ fish (Fig. 5). The annulus may also be a large and/or complex zone, with a significant amount of opaque material formed between the nucleus and the first annulus (Fig. 2). Occasionally, however, there is minimal evidence of this annulus, probably due to later hatching (Fig. 4).

The "pelagic" zone, or settling check, traditionally noted as important in age determination (Nichy 1969; ICNAF 1976, 1977, 1978; Hunt 1980a), was initially described by Nichy (1969) in his study of the growth of small silver hake as a small weak zone of hyaline material surrounding the nucleus that appears to form between the pelagic and demersal stages in the life history of this species. Some investigators including Hunt (1980a) have interpreted the "pelagic" ring as an occasionally large and strong zone of hyaline material that may be formed as late as 5 months of age. According to Fahay (1974), however, the length of the pelagic phase following hatching is about 2 months. Therefore, it is possible that a small first annulus formed close to the nucleus of later hatched or slower-growing fish is occasionally mistaken for the pelagic zone by some age readers. At the Woods Hole Laboratory, the pelagic zone has been conservatively interpreted as a small, usually weak zone, following the criteria of Nichy (1969) and verified by the appearance of this zone on age 0+ otoliths (Figs. 4 and 7). It should be noted, however, that accurate differentiation of the pelagic zone from the first annulus is difficult and remains a significant source of error.

Checks formed between the first and second annuli on otoliths collected from southern stock individuals may confuse interpretation of annular zones. The formation of a spring check on age-1 otoliths has been documented by Nichy (1969) (Fig. 6) and similar checks may also be formed later in the season. A check formed in late summer to early autumn, close to the time at which the annulus begins to form, is characteristic of most silver hake otoliths of the southern stock. Such checks are usually weak and/or discontinuous zones that are not as prominent as annuli in the sulcus area (Figs. 6 and 8). By comparison, the second and subsequent annuli are strong and consistent around the periphery of the otolith, particularly on the proximal (sulcus) and distal sides of the section (Figs. 2, 6, and 8). Typically, annular zones on otoliths of silver hake of this stock are evident as thick dense bands of hyaline material layered on the proximoventral part of the otolith (Figs. 6 and 8). Occasionally, however, these bands are split into several rings that must be traced around the periphery of the section in order to resolve the annular zones (Figs. 9 and 10). Whole otoliths can be especially useful in helping to resolve anomalous zones such as checks and split zones on thin otolith sections.

Subsequent to the second annulus, growth increments tend to be quite narrow on otolith sections due to a decrease in growth rate, so that annuli are layered rather closely together. This is particularly characteristic of male silver hake whose growth rate is slower than females after age-2 (Fig. 6). Because of these narrow growth increments, older fish may be difficult to age, especially if there are strong checks in between the annuli. Even where growth increments are relatively wide, annuli may be weak or diffuse (Fig. 10). If growth is "shifted," that is, if there is an unusual amount of growth on one part of the section in contrast to the normal pattern of deposition, interpretation should be focused in the direction of the shift in growth in order to avoid underinterpretation of age. The large amount of accreted material in each growth zone as a result of this shift enhances definition between the annuli and therefore facilitates age interpretation.

Time of annulus formation for the northern stock is later relative to hake further south, and follows a more seasonal pattern, as would be expected for more northerly latitudes (Williams and Bedford 1974). Annuli of these fish are completed in the late-winter to early-spring months with the exception of age-1 fish, some of whom resume growth during the winter months. Therefore, the otoliths of most fish in March and April may continue to exhibit hyaline edge or a small amount of opaque edge, particularly on the thin-sections (Fig. 11), while age-1 fish may exhibit a larger amount of opaque edge (Fig. 12). By October-November, some hyaline edge is usually evident on otoliths of age 2+ and older fish (Fig. 13), while opaque edge is likely to persist somewhat longer on age 0+ and 1+ fish.

The first annulus on otoliths of Gulf of Maine fish is somewhat variable in size, reflecting a tendency for some year-classes (e.g., 1982, 1984) to evidence a bimodal distribution of length at age-1. The first annulus on small one-year-old fish (e.g., 5 cm) may appear as a relatively weak hyaline zone and coincident with the pelagic zone (Fig. 14). It may be difficult to distinguish from the pelagic zone, spring check, and second annulus because the growth increment between the first and second annulus in the Gulf of Maine is generally smaller than further south, and because more of these fish are hatched later in the year. In some cases, the first annulus may not be evident but is assumed near the nucleus because of the large growth increment between the nucleus and the first strong hyaline zone that can be interpreted as an annulus (Fig. 15). While this interpretation may not appear justifiable biologically, it is necessary in order to avoid assigning these fish, and earlier hatched individuals, to different year-classes. Figure 16, for example, shows a section from a 13-cm fish sampled in April with no evidence of an annulus. This fish is interpreted as age-1 (late hatched) and not 0+, because spawning in the Gulf of Maine does not begin until the summer months.

Otoliths from larger age-1 fish may exhibit a well-defined hyaline zone (first annulus) formed some distance from the pelagic zone, which may be more prominent on these otoliths (Figs. 13 and 17). No marked discontinuity appears to exist between the growth patterns of these large age-1 fish and age-2 fish with a tiny first annulus. One technique for differentiating large age-1 fish from small age-2 fish with similar growth patterns involves measurement of the first annulus on otoliths collected from fish identified as age-1 using length-frequency data. Such measurements can provide an estimate of average and maximum first-annulus width for adult fish so that overinterpretation of age can be avoided in cases where the pelagic zone is prominent.

The weak zone formed around the pelagic zone on some silver hake otoliths can be difficult to identify as either a spring check (typical for silver hake of the southern stock) or a weak first annulus (more characteristic of the northern stock), since these zones form at the same time (April-May) (compare Figures 6, 13, and 14). Some silver hake from the Gulf of Maine exhibit a large first annulus with a very weak or nonexistent pelagic zone (Fig. 18). This type of pattern is more commonly observed on silver hake from the Scotian Shelf. Because of the variations in first-year growth patterns observed in the Gulf of Maine, the detail available on the otolith section seems necessary in order to make the most accurate interpretation possible.

The otoliths of Gulf of Maine silver hake are narrower and thicker in cross-section in contrast to those from more southern areas. Subsequent to the second annulus, accurate annulus interpretations of these fish are facilitated by this increased thickness and relatively wide increment widths between annuli resulting from faster growth (Figs. 11 and 14). In addition, the annular zones are quite easy to interpret because of relatively few anomalies (checks and split zones) and because the annular zones are strong and well defined (Figs. 14 and 19). Prominent checks are evident on some Gulf of Maine otoliths, but they are easily recognized by weak formation in the sulcus area in contrast to the annular zones (Fig. 11).

Some fish collected in the Southern New England and southern Georges Bank area exhibit growth patterns that appear to be hybrids of the two basic growth patterns described above. For example, the growth increment between the first and second annulus is intermediate in width, or the growth pattern will exhibit larger numbers of checks than is characteristic for the Gulf of Maine but fewer than typically seen further south (Fig. 20). Other otoliths, especially from southern Georges Bank fish, exhibit numerous strong checks and split zones that make annulus identification difficult (Fig. 21). In general, growth patterns observed among fish collected in the spring from the southern New England-southern Georges Bank area are rather heterogeneous compared with the greater consistency observed in the mid-Atlantic or northern Georges Bank-Gulf of Maine areas.

In summary, systematic study of the types of otolith growth patterns exhibited by silver hake of various stocks may facilitate consistency of age interpretation of these fish because of their prolonged spawning season and the variability of their growth patterns. Although bias may be created in anticipating an interpretation based on the geographic location of the sample, errors due to inconsistent interpretations could be more serious. Age readers at the Woods Hole Laboratory, having noted the variability of growth patterns on silver hake otoliths, attempt to apply standard criteria for the identification of annuli and checks that are agreed upon as valid by other age readers.

Citations

Almeida, F.P.
1984. An analysis of the stock structure of silver hake, *Merluccius bilinearis*, off the northeast coast of the United States. Masters thesis, Oregon State Univ., Corvallis, OR 97331, 141 p.

Anderson, E.D.
1974. Comments on the delineation of red and silver hake stocks in ICNAF Subarea 5 and Statistical Area 6. Res. Doc. 74/100, Ser. 3336, Int. Comm. Northwest Atl. Fish., Dartmouth, Nova Scotia, Canada B2Y 3Y9, 8 p.

Anderson, E.D., and F.E. Nichy
1975. A comparison of US and USSR silver hake ageing. Res. Doc. 13, Ser. 3457, Int. Comm. Northwest Atl. Fish., Dartmouth, Nova Scotia, Canada B2Y 3Y9, 5 p.

Bigelow, H.B., and W.C. Schroeder
1953. Fishes of the Gulf of Maine. U.S. Fish Wildl. Serv., Fish. Bull. 53(74), 577 p.

Colton, J.B., Jr., and J.M. St. Onge
1974. Distribution of fish eggs and larvae in continental shelf waters, Nova Scotia to Long Island. Am. Geogr. Soc. Ser. Atlas Mar. Environ. Folio 23, 2 p. + 11 plates.

Fahay, M.P.
1974. Occurrence of silver hake eggs and larvae along the Middle Atlantic continental shelf during 1966. Fish. Bull., U.S. 72:813-834.

Hunt, J.J.
1978. Age, growth and distribution of silver hake, *Merluccius bilinearis*, on the Scotian Shelf. Sel. Pap. 3, Int. Comm. Northwest Atl. Fish., Dartmouth, Nova Scotia, Canada B2Y 3Y9, p. 33-44.
1979. Backcalculation of length at age from otoliths for silver hake on the Scotian Shelf. Sel. Pap. 5, Int. Comm. Northwest Atl. Fish., Dartmouth, Nova Scotia, Canada B2Y 3Y9, p. 11-17.
1980a. Guidelines for age interpretation of silver hake, *Merluccius bilinearis*, using otoliths. J. Northwest Atl. Fish. Sci. 1:65-79.
1980b. Age validation of silver hake, *Merluccius bilinearis*. Northwest Atl. Fish. Org., SCR Doc. 80/II/20, Ser. NO52.
(ICNAF) International Commission for the Northwest Atlantic Fisheries
1976. Report of the silver hake ageing workshop, Dartmouth, Canada, 1-3 April 1976. Sum. Doc. 21, Ser. 3850, Int. Comm. Northwest Atl. Fish., Dartmouth, Nova Scotia, Canada B2Y 3Y9, 6 p.
1977. Report of silver hake ageing workshop, St. Andrews, Canada, 14-18 March 1977. Sum. Doc. 13, Ser. 5073, Int. Comm. Northwest Atl. Fish., Dartmouth, Nova Scotia, Canada B2Y 3Y9, 15 p.
1978. Report of silver hake ageing workshop, Dartmouth, Nova Scotia, Canada, March 1978. Sum. Doc. 10, Ser. 5211, Int. Comm. Northwest Atl. Fish., Dartmouth, Nova Scotia, Canada B2Y 3Y9, 10 p.
Nichy, F.E.
1969. Growth patterns on otoliths from young silver hake, *Merluccius bilinearis*, (Mitchell). Int. Comm. Northwest Atl. Fish. Res. Bull. 6:107-117.
1977. Thin sectioning fish ear bones. Sea Technol. 2:27.
Sauskan, V.A.
1964. Results of Soviet observations on the distribution of silver hake in the areas of Georges Bank (5Z) and Nova Scotia (4W) in 1962-63. Res. Doc. 61, Int. Comm. Northwest Atl. Fish., Dartmouth, Nova Scotia, Canada B2Y 3Y9, 8 p.
Sauskan, V.I., and V.P. Serebryakov
1968. Reproduction and development of the silver hake, *Merluccius bilinearis*, (Mitchell). Vopr. Ikhtiol. 8(3):398-414.
Schenk, R.
1981. Population identification of silver hake (*Merluccius bilinearis*) using isoelectric focusing. Ref. Doc. 81-44, Woods Hole Lab., Northeast Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Woods Hole, MA 02543, 31 p.
Williams, T., and B.C. Bedford
1974. The use of otoliths for age interpretation. *In* Bagenal, T.B. (ed.), Ageing of fish, p. 114-132. Unwin Bro., Gresham Press, Old Woking, England.

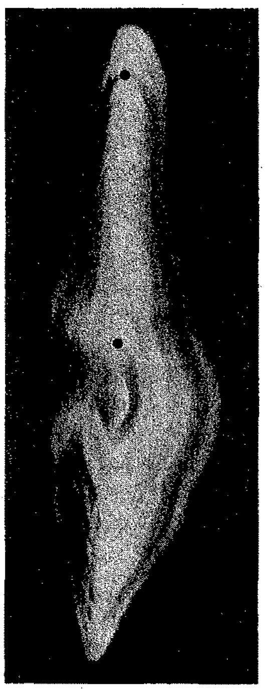

Figure 1
Otolith section of a 31-cm age 2+ female silver hake (southern stock) in April showing strong first and second annuli and wide opaque edge.

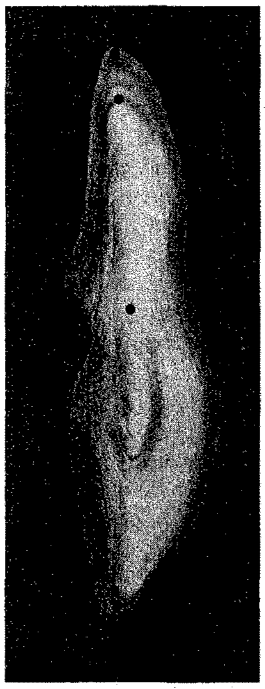

Figure 2
Otolith section of a 28-cm age-3 male silver hake (southern stock) collected in April showing strong annuli and a hyaline edge. Checks are evident between the second and third annuli.

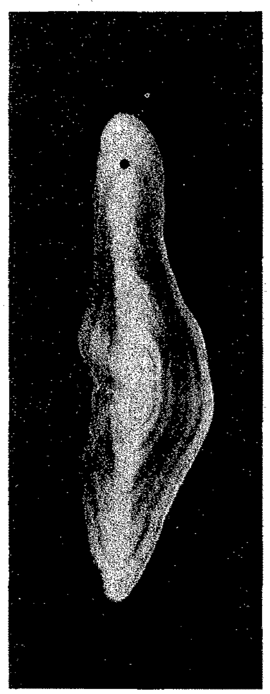

Figure 3
Otolith section of an 18-cm age 1+ silver hake (southern stock) collected in April showing a weak settling check, large and complex first annulus, and opaque edge.

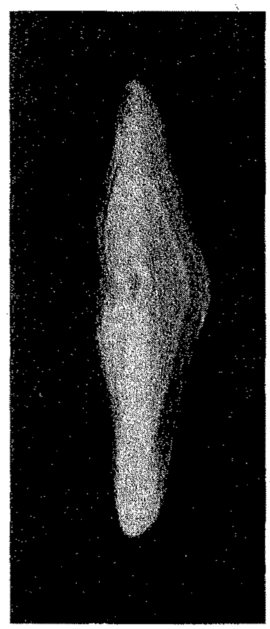

Figure 4
Otolith section of a 24-cm age 1+ silver hake (southern stock) collected in October showing no evidence of a first annulus, and opaque edge.

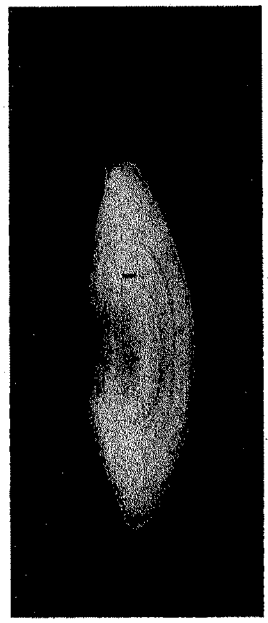

Figure 5
Otolith section of a 10-cm age 0+ silver hake (southern stock) collected in October showing a weak settling check and narrow hyaline edge.

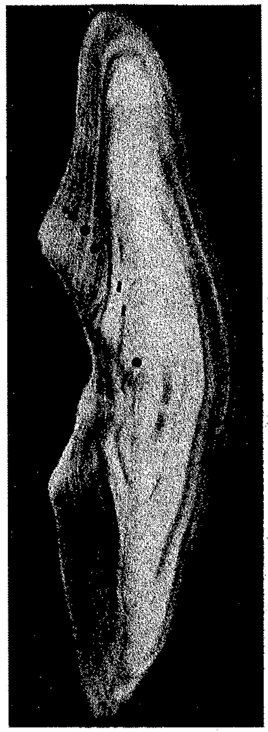

Figure 6
Otolith section of a 33-cm age 5+ male silver hake (southern stock) collected in October showing spring, summer, and autumn checks between the first and second annuli and a narrow hyaline edge. Annuli 2-5 are closely spaced.

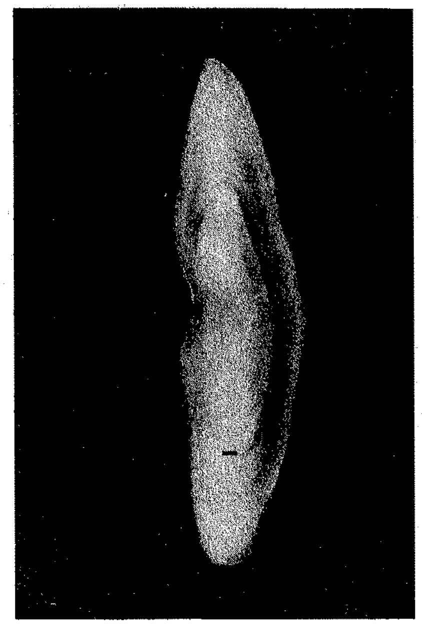

Figure 7
Otolith section of a 13-cm age 0+ silver hake (southern stock) collected in September showing a strong settling check.

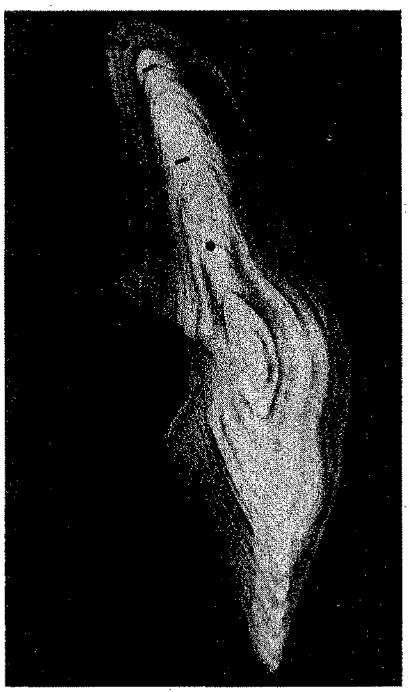

Figure 8
Otolith section of a 36-cm age-5 male silver hake (southern stock) collected in April showing strong annuli with spring and autumn checks between the first and second annuli.

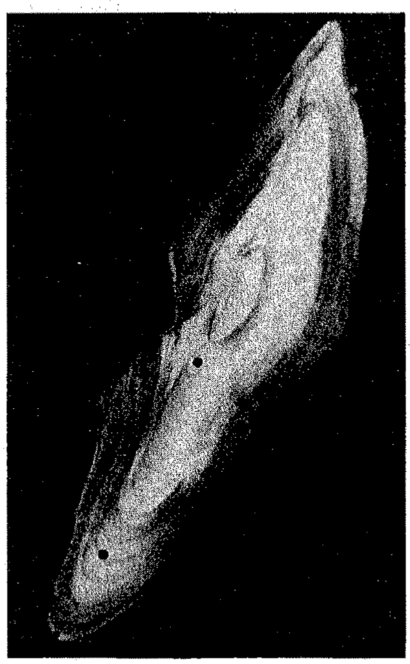

Figure 9
Otolith section of a 42-cm age-4? female silver hake (southern stock) collected in April showing split diffuse annuli and numerous checks between the second and third annuli.

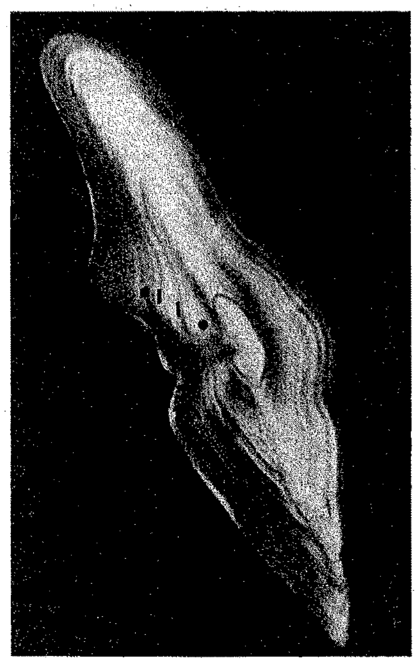

Figure 10
Otolith section of a 39-cm age-4? female silver hake (southern stock) collected in April showing vague diffuse annuli and spring and autumn checks formed between the first and second annuli.

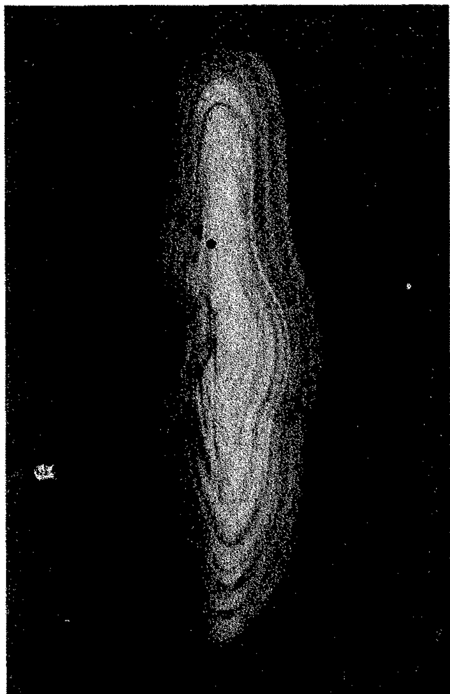

Figure 11
Otolith section of a 48-cm age-5 female silver hake (northern stock) collected in May showing strong widely spaced annuli, a check formed between the first and second annuli, and hyaline edge.

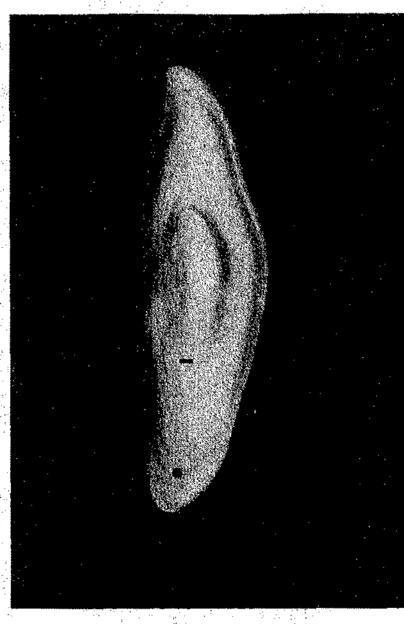

Figure 12
Otolith section of a 10-cm age-1 silver hake (northern stock) collected in May showing a prominent settling check and opaque edge.

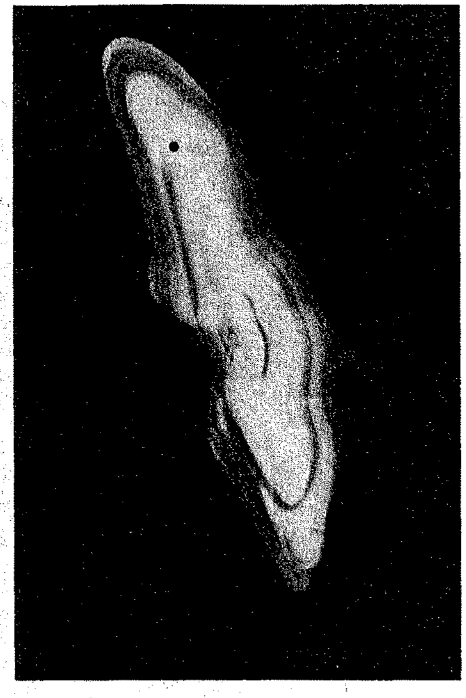

Figure 13
Otolith section of a 30-cm age 2+ female silver hake (northern stock) collected in October showing a prominent settling check, large first annulus, and narrow hyaline edge.

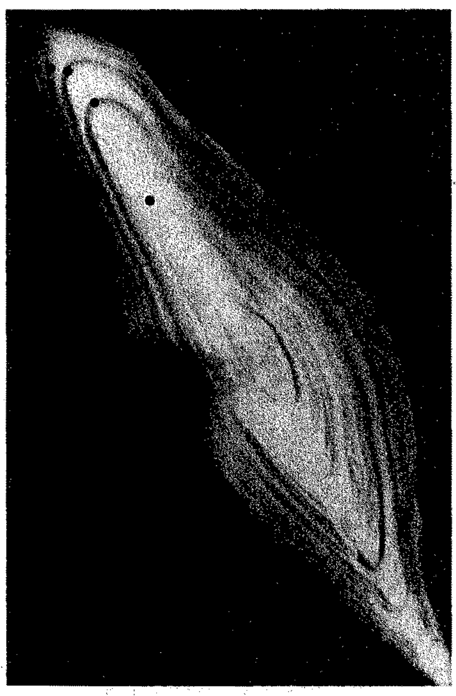

Figure 14
Otolith section of a 48-cm age-5 female silver hake (northern stock) collected in November showing a small weak first annulus followed by a spring check and strong, widely spaced annuli 2-5.

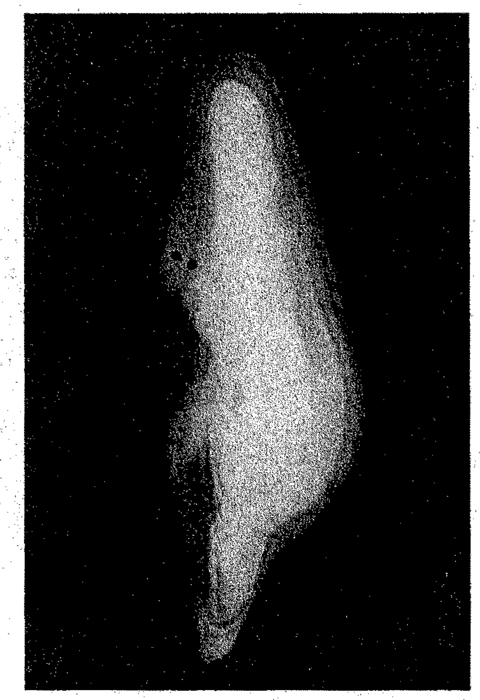

Figure 15
Otolith section of a 39-cm age-4 female silver hake (northern stock) collected in November showing a large second annulus and no evidence of a first annulus.

Figure 16
Otolith section of a 13-cm age-1 silver hake (northern stock) collected in April showing a weak settling check but no first annulus, possibly due to a late hatch date.

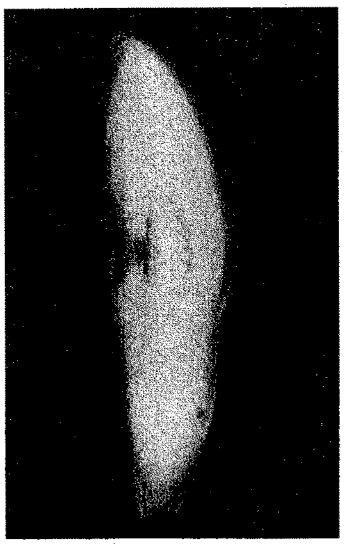

Figure 17
Otolith section of a 14-cm age-1 silver hake (northern stock) collected in April showing a weak settling check and strong first annulus formed on the edge.

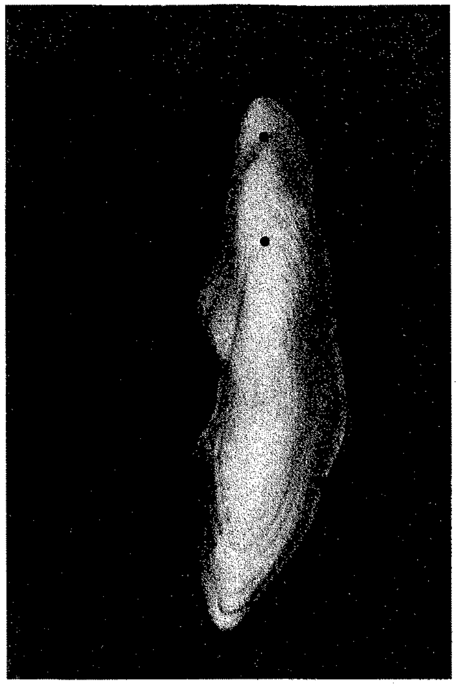

Figure 18
Otolith section of a 31-cm age 2+ female silver hake collected in November showing a Scotian Shelf type with a large first annulus and very weak or non-evident settling check.

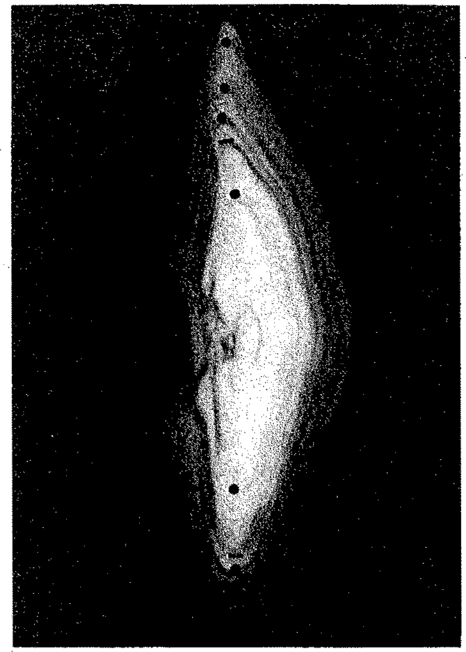

Figure 19
Otolith section of a 41-cm age 4+ female silver hake (northern stock) showing a large first annulus and strong, widely spaced annuli on the ventral tip due to shifting of otolith growth.

Figure 20
Otolith section of a 35-cm age-9 male silver hake collected in April from Southern New England waters showing a large complex first annulus and closely spaced annuli 3-9.

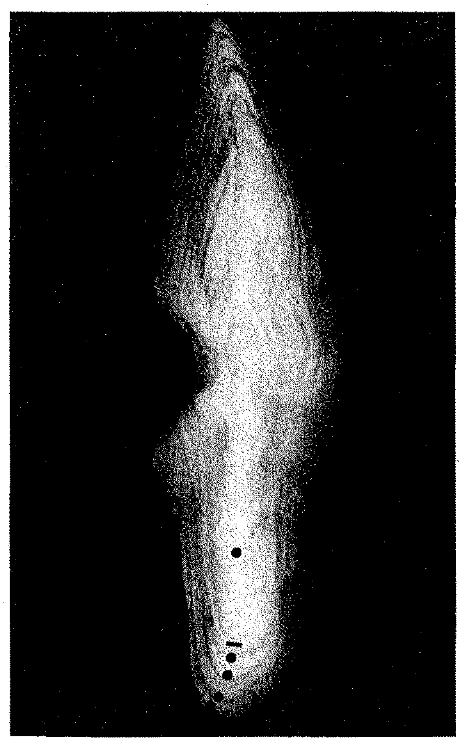

Figure 21
Otolith section of a 44-cm age-5? female silver hake collected in April from the southern edge of Georges Bank. Numerous checks and split zones are evident on this section.