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Red hake
Urophycis chuss

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Red hake is a demersal gadoid inhabiting the continental shelf waters from Nova Scotia to North Carolina. North of Nova Scotia this species is thought to be rare; its sibling species, the white hake (*Urophycis tenuis*) is much more common in that region (Musick 1974). However, according to Markle et al. (1980) and Svetovidov (1982), confusion still exists as to the identity of *Urophycis* species in Canadian waters, at least on the eastern part of the Scotian shelf. *Urophycis chuss* is most abundant from southwest Georges Bank to the New York Bight (Anderson 1982).

Two stocks of red hake are currently recognized: one inhabiting the Gulf of Maine-northern Georges Bank region and a second stock inhabiting the area from southern Georges Bank to Cape Hatteras (Conservation and Utilization Division 1985). The migratory movements of this species are largely inshore-offshore in response to seasonal changes in water temperatures. Spawning occurs May through November from the New York Bight to Georges Bank. It may not begin until June in the Gulf of Maine based on the absence of red hake eggs and larvae through May in those waters (Marak and Colton 1961, Colton and St. Onge 1974).

Growth of this species is sexually dimorphic, with females generally larger and longer lived than males. Males attain a maximum length and age of about 53 cm (21 inches) and 11 years, respectively, contrasting with 63 cm (25 inches) and 12 years for females. Most red hake are sexually mature by age 2 (McBride and Brown 1980).

Rikhter (1968) presented the results of age and growth studies of red hake using otoliths but did not describe methods other than his technique for preparing samples. At the Woods Hole Laboratory, age determinations have been conducted for a number of years. Validation studies (unpublished) indicate that hyaline zones traceable in the sulcus acusticus area of the transverse section (the collum) are valid annuli.

The otoliths of red hake from southwest Georges Bank to Cape Hatteras generally exhibit well-defined annular zones, including the first annulus. Accurate age determinations of northern Georges Bank and Gulf of Maine fish are considerably more challenging. The pattern of first annulus formation is more variable, and subsequent annuli are often weak, split, or difficult to trace around the periphery of the otoliths. Prominent second-summer checks also occur which are difficult to distinguish from annular zones. Time of annulus formation is variable and difficult to assess because of the formation of split zones. Thus far, seasonal progression of age groups (based on age-length keys) in the length-frequencies indicate that the methods are valid, but the possibility for error appears to be much greater for northern Georges Bank and Gulf of Maine red hake than for more southern areas.

Rikhter (1968) prepared red hake otoliths by cutting them in half and then polishing and burning the cut surfaces. The method developed at the Woods Hole Laboratory and now in current use involves removing a thin transverse section (0.20-0.23 mm) from the thickest part of the otolith through the nucleus. As a rule the otolith is not heated, although in some cases those from Gulf of Maine fish with weak growth patterns are baked at 450°F for 2-3 minutes before sectioning.

All thin-sections are viewed in ethyl alcohol under reflected light against a black background at 15-20×. The orientation of the thin-section from unbaked otoliths in relation to the light source may be critical to accurate evaluation of annuli in the sulcus acusticus area. This part of the section is very important for age determination of this species. The sulcus is more translucent than other parts of the otolith; therefore, the angle of incident reflected light affects

the appearance of the annuli in the sulcus. They are most clearly evident if oriented perpendicular to incident light so that they are reflecting light rather than channeling light rays through them.

Observed differences in otolith growth patterns between the southern and northern stocks reflect differing times of annulus formation, growth rates, and environmental/genetic factors. These differences are stable from year to year and tend to support current stock definition. Silver hake from southwestern Georges Bank to Cape Hatteras exhibit clear growth patterns with strong distinct annuli. Red hake of the northern Georges Bank and Gulf of Maine region are faster growing after age 2 than more southern fish based on age-length keys, resulting in more widely spaced annuli, and their typically anomalous growth patterns often make analysis difficult. Some fish from this area do exhibit clear growth patterns, but the relatively wide growth increments between annuli often distinguish them as Gulf of Maine fish.

Annulus formation (completion of hyaline zone) of most red hake from the southern group is complete by April or May. By convention, a birthdate of 1 January is used; from that date until seasonal growth resumption, the hyaline zone evident on the edge of the otolith is interpreted as an annulus whether or not it is complete. The type (opaque or hyaline) and amount of edge is somewhat variable during most seasons of the year. The observed edge during the spring months may be narrow-to-wide hyaline, depending, in part, on the width of the annulus being formed (Fig. 1), or growth resumption may be indicated by the presence of narrow opaque edge (Fig. 2). Age-1 fish often show wide opaque edge (Fig. 3). In general, the edge evaluation can best be made on the dorsal tip of the transverse section, which is the longest radius of the section.

By September or October, seasonal growth is largely complete, especially for young fish. While opaque edge will persist on some otoliths, others exhibit large amounts of hyaline material that indicate that the beginning of annulus formation is well under way (Fig. 4). An advanced cycle of seasonal growth for young relative to older fish is not as predictable as it tends to be for other fish species. For that reason, the otolith edge should be interpreted with caution.

The pattern and rate of growth reflected on otoliths of red hake of the southern group is in many respects similar to what is observed for silver hake (*Merluccius bilinearis*) of the same geographic area. However, the growth patterns are less complex. The first annulus of red hake otoliths is usually a well defined hyaline zone in the central part of the otolith (Fig. 3). This zone, however, is variable in strength, size, and complexity due to individual variations and differences in spawning time. But, as with silver hake, the generally large growth increment between the first and second annulus facilitates interpretation of this zone (Fig. 2). On some otoliths the first annulus is tiny and/or coincident with the larval (pelagic) zone, or not evident at all, especially if the otolith was not sectioned precisely across the nucleus (Fig. 5). The large increment to the second annulus, however, indicates that the otolith is from a late-hatched fish with no apparent first annulus.

A small "settling" check surrounding the nucleus, which is representative of a shift from the larval pelagic habitat to the demersal habitat, is evident on the otoliths of both red and silver hake. This zone is fully described in the accompanying article concerning the latter species. The settling check on red hake otoliths is usually a weak zone and not easily confused with the first annulus (Fig. 3). In some cases where the first annulus is weak, however, the settling check may appear relatively prominent (Figs. 1, 2, and 4).

Check formation is characteristic of the second season of growth following the first annulus. However, since annuli on red hake otoliths from the southern area are normally distinct, they can usually be readily differentiated from spring, summer, or autumn checks. Figure 3 shows an otolith section from a 13-cm, age-1 fish sampled in April which shows a very narrow hyaline edge indicative of the formation of a spring check. Figure 6 shows an otolith taken from a 40-cm, age 3+ fish with complex check formation. A check formed just before the second annulus on some otoliths may be confused with that zone, except that the check is not strongly evident in the sulcus and is a relatively thin or weak ring. Figure 4 shows an otolith section from a 45-cm, age 4(3)+ fish with a weak second hyaline zone interpreted as the second annulus because it was rather distinct in the sulcus. In general, checks are not prominent in the sulcus area. Figure 7 is an otolith section from a 47-cm, age-5 female red hake with a small second annulus not interpreted as a check because of the width and strength of the zone.

The second and subsequent annuli on these otoliths tend to be wide, prominent hyaline zones, and closely parallel to one another for slow-growing fish, particularly males (Figs. 1 and 8). Annuli on some otoliths, although strong, are somewhat split or diffuse, and narrow growth increments between the annuli can make it difficult to distinguish one annulus from another. In addition, the increments between annular zones often become increasingly translucent after age 2 or 3. Examination of these zones in the sulcus area tends to minimize these problems, because annular zones develop resolution into clear separate bands in the sulcus (Figs. 4 and 8), due to the nature of its crystalline structure and its discontinuity with the rest of the otolith. With increasing age, red hake of the southern group do not usually become more difficult to interpret. In fact, many of them show unusually clear growth patterns (Fig. 9). The annuli, however, are spaced increasingly close together out to the edge of the section.

The rounded ventral part of the section can be useful in identifying the first few annuli because of the prominence of hyaline zones in this area. Nevertheless, it should be used with caution when interpreting subsequent annuli, because hyaline zones tend to fuse together on this part of the otolith. Also, the crowding of zones near the edge may result in underinterpretation of age (Figs. 1 and 8).

Time of annulus formation for red hake of the northern group is as variable as observed for the southern group. Correct edge evaluations are often quite difficult due to the extensive splitting of hyaline zones on many of the otoliths. With the exception of some young fish, growth resumption in the Gulf of Maine is not as advanced as observed further south. By April or May, annuli may not be completely formed judging by the presence of only tiny amounts of hyaline edge on some of the otoliths (Fig. 10). Relatively few of these otoliths exhibit opaque edge indicating seasonal growth resumption.

During the late summer (late July and August), most otoliths of all age groups exhibit at least some opaque edge (Fig. 11). In October or November, many otoliths continue to exhibit small to large amounts of opaque edge indicating that seasonal growth is not complete (Fig. 12).

It may be inferred from these observations that annulus formation for some Gulf of Maine red hake may not be complete until the early summer months. The presence of split hyaline zones and the shift in time of annulus formation from north to south may confuse attempts to decide whether or not the edge of the otolith should be included in the age. In addition, the type of edge observed may vary on different parts of the same otolith. It is helpful in this situation to locate the last fully formed annulus in the sulcus, which shows the annuli more clearly. However, the amount of newly formed

material will be somewhat underestimated because the short radius from the nucleus to the edge of the sulcus results, overall, in less accreted material on this part of the otolith (Fig. 12).

The pattern of growth observed on many red hake otoliths from the northern area appears quite anomalous when compared with the southern group or to the closely related white hake (*U. tenuis*). The latter species often exhibits weak growth patterns on its otoliths, but few other anomalies complicate age determination. As will be shown, some red hake otoliths from the Gulf of Maine tend to resemble those of white hake both in terms of external morphology and the internal growth pattern. It is sometimes difficult to distinguish the two species using otoliths alone in this geographic area.

Similar to the southern group of red hake, the first annulus on northern group otoliths is variable in size and complexity. However, the integrity of hyaline zones in the center of the otolith representative of the first annulus can be difficult to establish because of the formation of numerous and sometimes prominent checks, and because the growth increment to the second annulus is sometimes rather small (Fig. 13). In addition, the first and second annuli are sometimes not very strong hyaline zones (Figs. 13 and 14). All of these factors result in the blurring of distinctions between annular zones.

One pattern especially difficult to interpret involves a relatively simple first hyaline zone formed some distance away from the nucleus that, because of its size, could represent a large first annulus or a small second annulus in otoliths of older fish (Fig. 15). The interpretation of this pattern is a persistent problem. However, by first establishing reference measurements of the second annulus on otoliths of known age-2 fish (via length-frequencies), it is possible to measure the questionable annulus and interpret it based on a comparison with reference measurements (for each year-class).

Subsequent to the first annulus, age interpretation of anomalous otoliths encounters further problems. Some otoliths generally form distinct annular zones, but the second and possibly third annuli are very weak. However, the structure of these wide (although weak) hyaline zones, especially in the sulcus, and their relative spacing, tends to confirm their identity as annuli (Figs. 13, 14, and 15).

Some otoliths exhibit a very weak growth pattern. Enhancement by baking may be necessary to identify any of the annuli (Fig. 16). Usually, traces of these zones are evident in the sulcus or on other parts of the otolith. If not, these otoliths cannot be interpreted.

Hyaline zones may be prominent in some otoliths, but each annulus is split into two or more hyaline zones. Strong checks are often associated with this pattern to further confuse age interpretations (Fig. 17). Figure 18 shows an otolith section from a 42-cm, age 5(4) female sampled in May where the pattern of annulus formation is so obscure that the sulcus is required to identify the annular zones.

Occasionally, the sulcus is of no use in distinguishing annuli because growth zone formation is discontinuous around the periphery of the otolith. Annuli on these otoliths cannot be traced with any confidence through the sulcus, since discrete hyaline zones that are recognizable as annuli may not be exhibited. Fortunately, the pointed dorsal area of the otolith section often shows enough evidence of discrete zones to estimate age with some accuracy (Fig. 15).

Red hake otoliths with anomalous patterns are typical in the Gulf of Maine. The reasons for these patterns are not understood. Some otoliths, however, exhibit a clearer pattern that resembles that of red hake of more southern waters, although relatively wider growth increments between annuli are characteristic because of a faster growth rate in the Gulf of Maine. The growth patterns on these otoliths are usually characterized by 1) a generally prominent first annulus; 2) relatively discrete annular zones, and 3) few anomalies such as splits and checks. Age interpretation of Gulf of Maine otoliths may not be more difficult with increasing age, despite anomalous growth patterns. Deposition of subsequent annuli may actually elucidate the pattern of earlier growth on the otolith (Fig. 19).

Some otoliths collected in the Gulf of Maine, particularly from the northwestern and eastern part near the Bay of Fundy, vary morphologically from red hake otoliths sampled elsewhere. Removed from fish taxonomically identified as *U. chuss*, these otoliths show characteristics that appear to be intermediate between what is normally observed for *U. chuss* and for *U. tenuis*. Red hake otoliths are characterized by a smooth surface and curvature, are rounded in cross-sectional dimension, and have smooth, reduced rostra (Fig. 20, left). In contrast, white hake otoliths are more angular, exhibit numerous surface ridges and dentations, are somewhat flattened in cross-sectional dimension, and have more prominent rostra (Fig. 20, right). "Mixed" otoliths are more angular than those of red hake, may show more surface irregularities, are more flattened, and have larger rostra (Fig. 20, center).

Since otolith shape and size are sensitive to genetic variations and are often used to trace the evolutionary patterns of fishes (e.g., Gaemers 1976), it is interesting to speculate as to whether the observed variation in otolith morphology is characteristic of red hake of the Gulf of Maine, or whether the existence of a hybrid *Urophycis* is indicated. Musick (1973) noted significant meristic-morphometric differences between white hake of Nova Scotian and southern New England waters and red hake from the Gulf of Maine and southern New England waters. However, his samples from the Gulf of Maine were collected from the southwest and southeastern parts of the Gulf and *not* from the northwestern-northeastern area where the "mixed" otolith types are most frequently observed. The ambiguity represented by the mixed otolith types is a problem for age determination because the growth patterns also reflect a mixed pattern. Since the spawning season and, therefore, the interpretation of the first annulus, differs for red hake and white hake, some uncertainty exists as to ageing methods for these otoliths. Thus far, the approach has been to assume these fish to be red hake until other evidence is available. Fortunately, white hake otoliths normally exhibit weaker growth patterns and wider growth increments than red hake otoliths with mixed patterns (compare Figures 21 and 22).

In summary, age determinations of red hake from southern Georges Bank to the Mid-Atlantic are as straightforward and reliable as the same procedure is difficult and relatively unreliable for many red hake of northern Georges Bank and the Gulf of Maine. Aspects of the growth patterns of red hake of the southern group are similar to what is observed for silver hake from the same area. Otolith growth patterns of the more northern group are often anomalous. In addition, some otoliths from the northwestern and eastern parts of the Gulf of Maine show characteristics that are intermediate in type between what is normally observed for red hake and for white hake.

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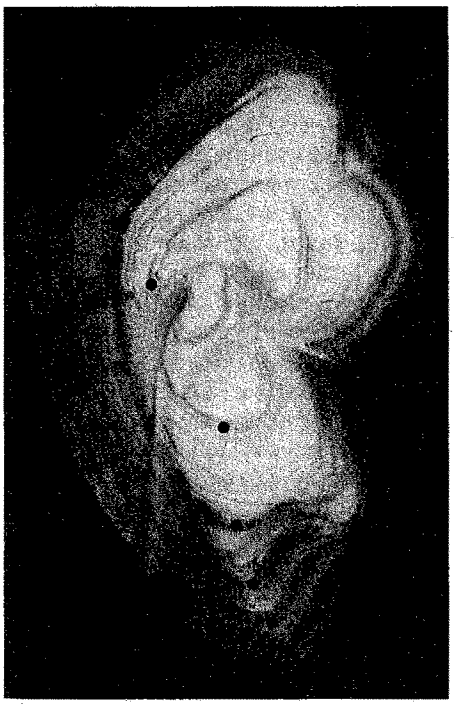

Figure 1
Otolith section of a 37-cm age-6 male red hake (southern stock) collected in April showing strong annuli and a hyaline edge.

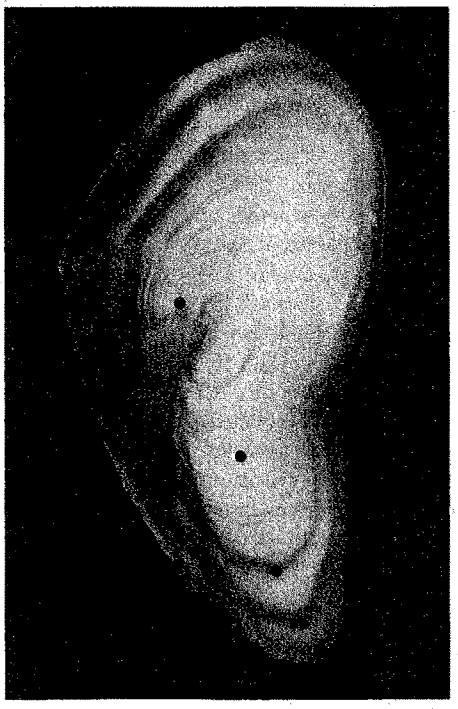

Figure 2
Otolith section of a 36-cm age-4 female red hake (southern stock) collected in April showing a strong settling check, weak first annulus, and narrow/opaque edge.

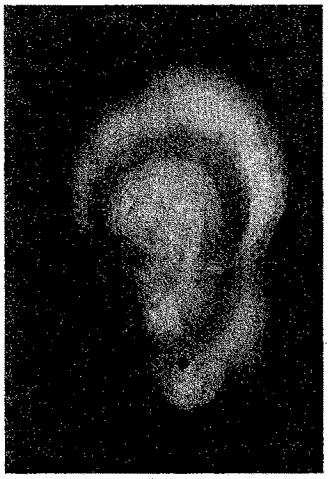

Figure 3
Otolith section of a 13-cm age-1 red hake (southern stock) collected in April showing a spring check forming on the edge.

Figure 4
Otolith section of a 45-cm age 4(3)+ female red hake (southern stock) collected in October showing a weak diffuse second annulus and narrow hyaline edge.

Figure 5
Otolith section of a 34-cm age-4 male red hake (southern stock) collected in April with no first annulus evident.

Figure 6
Otolith section of a 40-cm age 3+ female red hake (southern stock) in October showing a diffuse first annulus and summer and autumn checks between the first and second annuli.

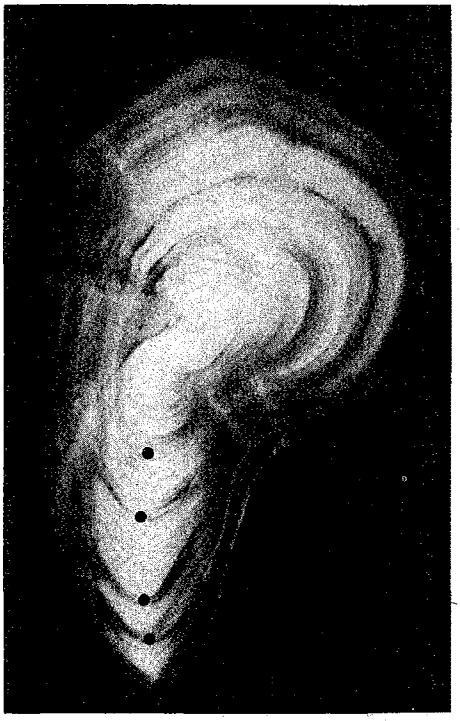

Figure 7
Otolith section of a 47-cm age-5(4) female red hake (southern stock) collected in April showing a large first annulus and small second annulus.

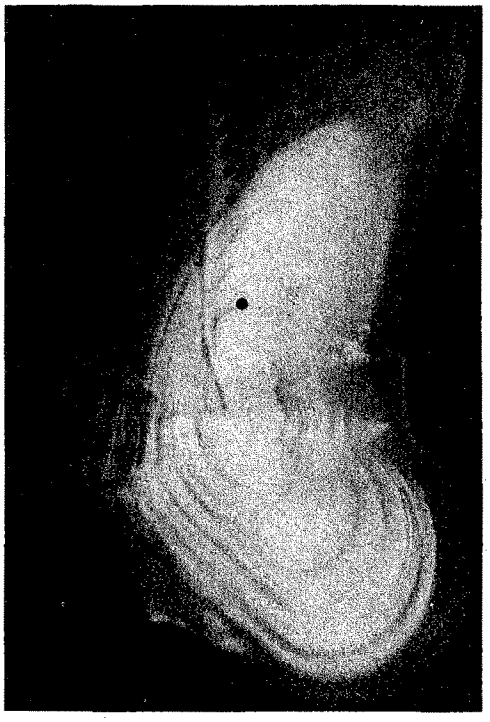

Figure 8
Otolith section of a 34-cm age-7 male red hake (southern stock) collected in April showing closely spaced annuli.

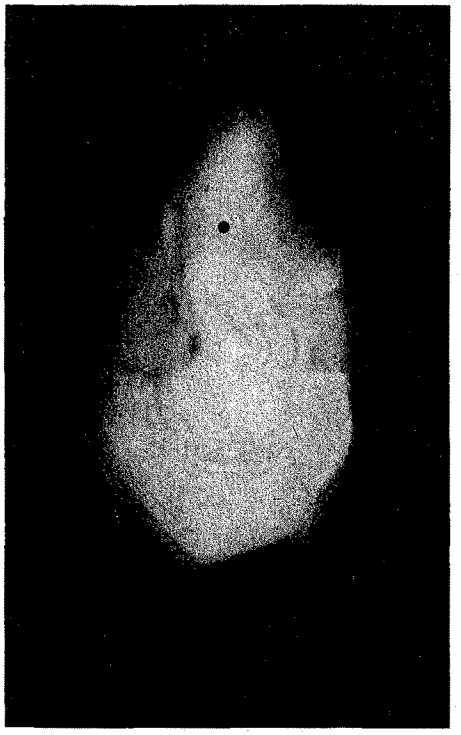

Figure 10
Otolith section of a 26-cm age-2 male red hake (northern stock) collected in April showing a weak first annulus and narrow hyaline edge.

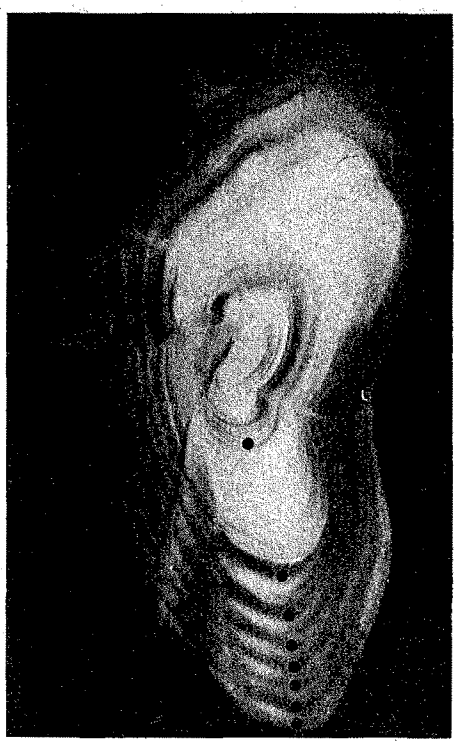

Figure 9
Otolith section of a 45-cm age-8 female red hake (southern stock) collected in April showing clear annuli.

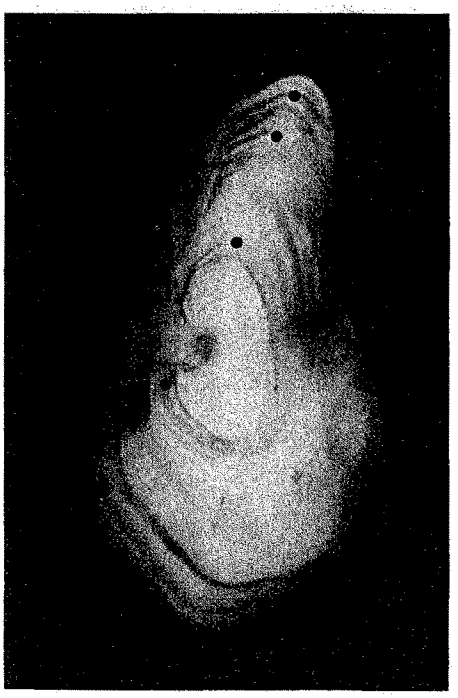

Figure 11
Otolith section of a 40-cm age 3+ female red hake (northern stock) collected in August showing split annuli and opaque edge.

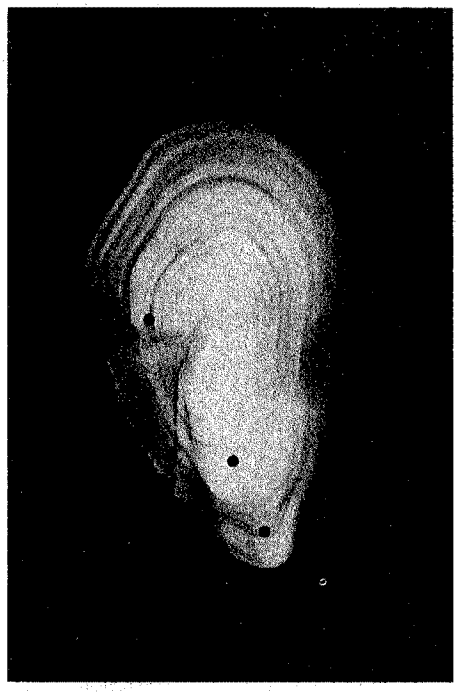

Figure 12
Otolith section of a 28-cm age 2+ male red hake (northern stock) collected in October showing a split second annulus in the ventral area and opaque edge.

Figure 13
Otolith section of a 40-cm, age-6(5) male red hake (northern stock) collected in May showing a small weak second annulus.

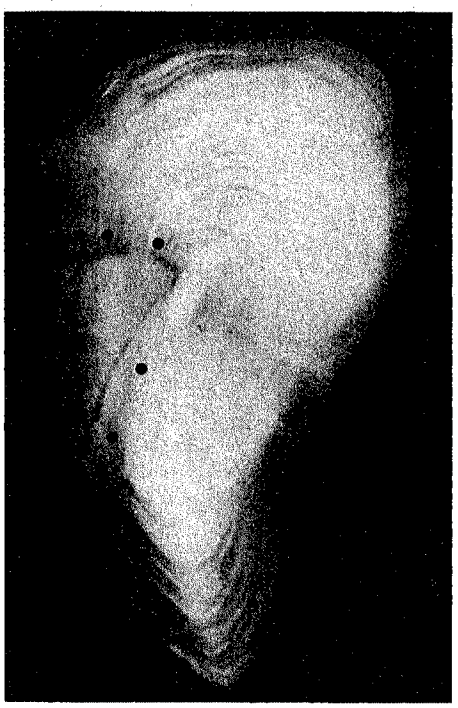

Figure 14
Otolith section of a 42-cm age-5(4) female red hake (northern stock) collected in May showing a weak second annulus that may be a check.

Figure 15
Otolith section of a 40-cm age-6 male red hake (northern stock) collected in April showing a large first annulus and weakly formed second and third annuli.

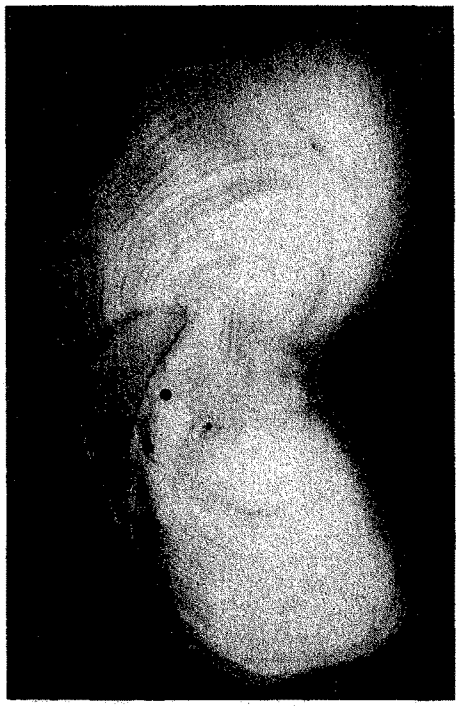

Figure 16
Otolith section of a 40-cm age 5? female red hake (northern stock) collected in April showing very weak annuli interpretable mainly in the dorsal area near the sulcus.

Figure 18
Otolith section of a 42-cm age-5(4) female red hake (northern stock) collected in April showing an obscure pattern of annulus formation requiring use of the sulcus to identify annuli.

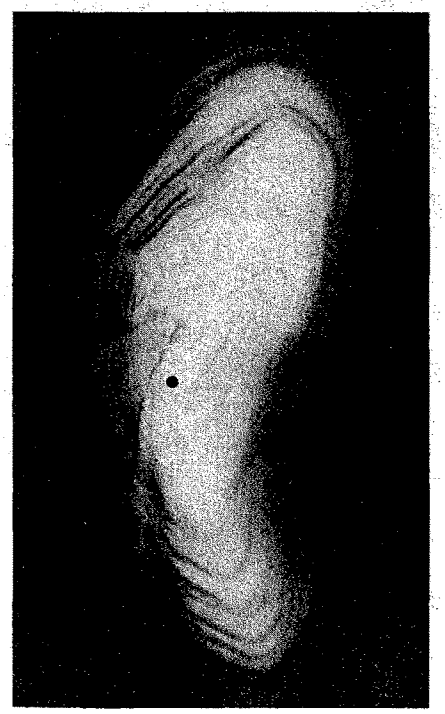

Figure 17
Otolith section of a 46-cm age-4 female red hake (northern stock) collected in May showing checks and split annuli.

Figure 19
Otolith section of a 59-cm age-12(11) female red hake (northern stock) collected in May showing numerous annuli interpretable ventral to the sulcus.

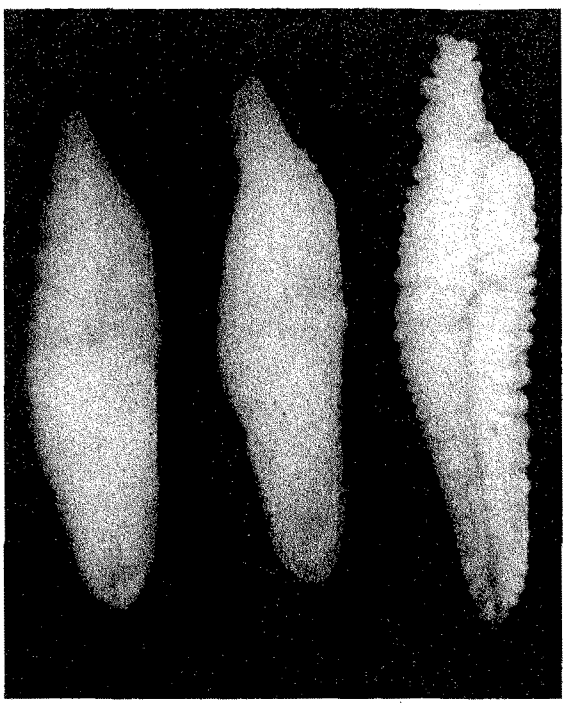

Figure 20
(Left) Whole otolith of a 46-cm red hake; (center) Whole otolith of a 48-cm red hake with "intermediate" characteristics; (right) Whole otolith of a 54-cm white hake.

Figure 21
Otolith section of a 48-cm age 5+ female red hake collected in May showing an "intermediate" type growth pattern.

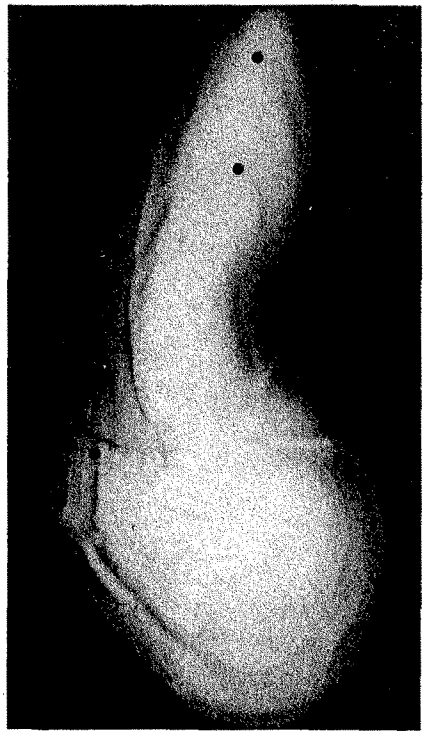

Figure 22
Otolith section of a 54-cm age 2+ female white hake collected in November showing weak annuli separated by wide growth increments.