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Atlantic cod
Gadus morhua

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The Atlantic cod is a cold-temperate, demersal gadoid distributed in the Northwest Atlantic from Greenland to North Carolina; commercially important concentrations occur southward from Greenland to Cape Cod. Wise (1963) proposed the existence of four separate groups of cod in the New England area: Gulf of Maine, Georges Bank, Southern New England, and Mid-Atlantic coastal cod. The latter group spends the summer in Southern New England. Age data from the Southern New England and Mid-Atlantic groups are usually combined because of the difficulties experienced in separating cod from the two groups collected during the autumn (Penttila and Gifford 1976). They migrate towards the south and west (shoaler waters) in winter and early spring and towards the north and east (deeper waters) in late spring and summer (Schroeder 1930, Wise 1963). Growth rates for males and females are similar and sexual maturity is typically attained at age 2 or 3. Spawning occurs from December through April. Maximum age is in excess of 20 years, and a record size of a 96 kg (211 pounds) fish >180 cm in length is reported (Bigelow and Schroeder 1953). Cod commonly attain lengths of 120-130 cm, and 12-15 year old fish are often landed.

Early studies depended on scales for age determination, but Schroeder (1930) concluded that they were not reliable for individuals older than 6 or 7 years. Studies at the Woods Hole Laboratory during the early 1970's confirmed that scales are not generally reliable even for younger specimens, and, accordingly, age determinations for Atlantic cod are based on otoliths. An improved method of otolith preparation involves baking to produce brown hyaline zones in contrast to white opaque zones. This enhances visibility of the annuli during examination with reflected light. Otolith thin-sections may also be prepared, but require much more time than baking and do not appreciably improve the distinction of annuli. Ageing criteria and techniques based on baking have been informally validated by comparing cod length frequencies from 1969-74 research vessel surveys with corresponding age-length frequencies. Jensen (1970) validated the use of otoliths for Gulf of Maine cod, and Kohler (1964) validated otoliths for western Gulf of St. Lawrence cod.

Otoliths are stored dry, and one otolith from each fish is baked at 275°C (525°F) for 3-6 minutes, or until it turns a caramel brown color. Smaller otoliths require a longer baking time than do larger otoliths, perhaps because their hyaline zones are not so well defined. The otolith is then broken in half at the nucleus and examined under a binocular microscope at a magnification of about 15× using reflected light. Wetting the broken surface of the otolith with undiluted Kodak Photo-Flo 200 solution enhances visibility of the rings. Rings formed during periods of slow winter-type growth appear as brown, hyaline zones, while growth increments formed during periods of rapid summer-type growth appear as white, opaque zones. Shifted or crystallized otoliths should not be aged (Fig. 1).

The annulus is defined as a hyaline zone marking the end of a year of growth, i.e., the winter growth zone. It has the following characteristics (following Jensen and Wise 1962): 1) it is concentric with the margin of the otolith; 2) it can be traced entirely around the otolith; and 3) it is separated from other such zones and does not ordinarily meet them at any point. Age determinations for cod are usually made by counting from the nucleus out to the distal edge of the otolith. On older specimens, the dorsal end of the otolith may be best for distinguishing annuli close to the edge. Also, the proximal edge on either side of the sulcus groove often displays clear annuli.

By convention, the birthday of all fish in the northern hemisphere is 1 January, therefore, a winter hyaline zone forming on the edge of the otolith is counted as an annulus on 1 January, even though the zone is not complete. Opaque edge material generally forms on the otolith during the late spring, summer, and early fall (Fig. 2); hyaline edge forms during the late fall, winter, and early spring (Fig. 3). Older fish begin depositing opaque edge material later than younger fish, and the hyaline edge also tends to form earlier.

A check may be distinguished by its width and location relative to true annuli. If two hyaline zones are found relatively close together, but all the other hyaline winter zones on the otolith are relatively far apart, one of these zones is considered a check, or the annulus is termed split (Fig. 4). For a split annulus, it is often difficult to determine which zone is the check. Checks and splits may also be distinguished by following them around the otolith to the proximal side near the nucleus to determine if they merge to form one annular zone. On otoliths from older fish, annuli formed after the fifth or sixth year are often split and these annuli are expected to be fairly close together (Figs. 2, 3, 5, 6, 7, 8).

General patterns based on the geographic origin of the fish may also be used as an aid in identifying annuli. Fish from Georges Bank grow more rapidly than do fish from other areas and tend to have more checks on their otoliths. They generally have a large, checky first year with the first annulus situated a good distance out from the nucleus, and may often show a strong check before the second annulus (Figs. 3 and 5). The second annulus is generally the strongest (i.e., the darkest or widest hyaline zone) on the otolith (Fig. 9). Annual growth increments are usually largest during the first and second years but good growth still occurs through the third year, followed by a gradual decrease in growth thereafter (Figs. 6 and 7).

Cod from Southern New England show a small first-year growth increment and rapid growth in the second year, followed by a gradual decrease in growth in subsequent years (Fig. 10). Their growth rate is slower than that of Georges Bank fish for the first two years, but after the third year, growth is comparable (Penttila and Gifford 1976).

Fish from the Gulf of Maine have a slower growth rate and a fairly small first-year annulus. Comparatively good growth in the second year is followed by a decrease thereafter (Figs. 2, 8, 11).

Browns Bank and Scotian Shelf cod exhibit the slowest growth of any of the areas. Browns Bank cod otoliths often exhibit a growth pattern characteristic of the area with comparatively slow growth during the first three years, followed by better growth in the fourth through sixth years, and then a gradual decrease in subsequent years (Fig. 12).

A major problem in age determinations of cod is distinguishing between the settling check and the first annulus. The settling check is usually a thin, single, or split hyaline zone immediately surrounding an amorphous, translucent nucleus. This check tends to be more nearly circular in shape than annuli, and a definite opaque summer zone found inside the first hyaline annulus is not apparent inside a settling check (Figs. 5, 7, 8).

Difficulties may arise in finding the first annulus on otoliths that have not been broken precisely at the collum of the sulcus. Inability to find the settling check or the appearance of an abnormally small or irregularly shaped first annulus usually indicates that the otolith was not properly broken at the nucleus and that the remaining stored otolith for the fish should be processed. Figure 13 shows serial sections cut from a single cod otolith, from the anterior to the posterior area of the first annulus. This figure illustrates the change in appearance and shape of the settling check and first annulus according to how far off the collum the break or cut is made.

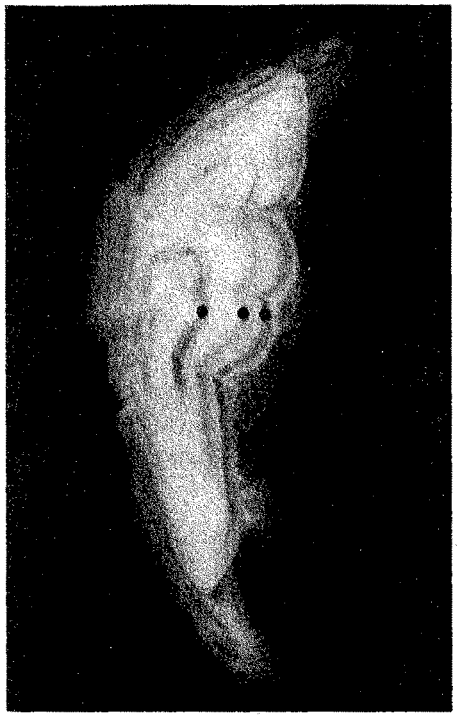

Figure 1
Otolith section cut from a typical shifted otolith of an 88-cm, age ?? cod collected in July from Georges Bank.

Citations

Bigelow, H., and W. Schroeder
1953. Fishes of the Gulf of Maine. U.S. Fish Wildl. Serv., Fish. Bull. 53(74):182-196.

Jensen, A.C.
1970. Validation of ages determined from otoliths of Gulf of Maine cod. Trans. Am. Fish. Soc. 1970(2):359-362.

Jensen, A.C., and J.P. Wise
1962. Determining age of young haddock from their scales. U.S. Fish Wildl. Serv., Fish. Bull. 195(61):439-450.

Kohler, A.C.
1964. Variations in the growth of Atlantic cod (*Gadus morhua* L.). J. Fish. Res. Board Can. 21(1):57-100.

Penttila, J.A., and V.M. Gifford
1976. Growth and mortality rates for cod from the Georges Bank and Gulf of Maine areas. Int. Comm. Northwest Atl. Fish. Res. Bull. 12:29-36.

Schroeder, W.C.
1930. Migrations and other phases in the life history of the cod off Southern New England. U.S. Bur. Fish., Bull. 46:1-136.

Wise, J.
1963. Cod groups in the New England area. U.S. Fish Wildl. Serv., Fish. Bull. 63(1):189-203.

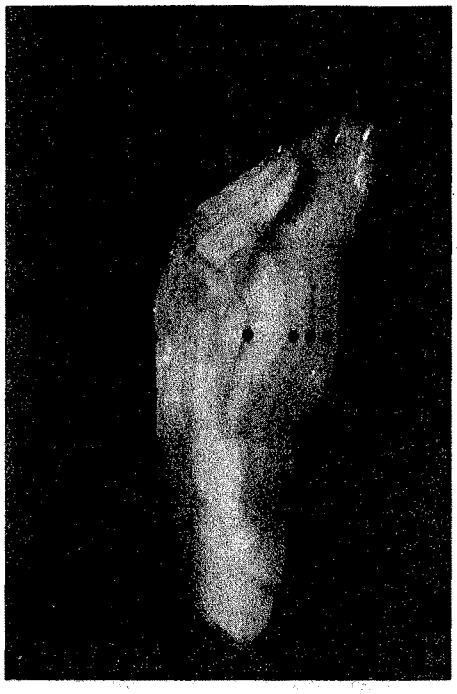

Figure 2
Baked otolith half from a 79-cm age-4 cod collected in September from the Gulf of Maine showing split second and fourth annuli, with opaque edge still forming.

Figure 4
Baked otolith half from an 87-cm age-5 cod collected in January from Georges Bank showing a split fourth annulus.

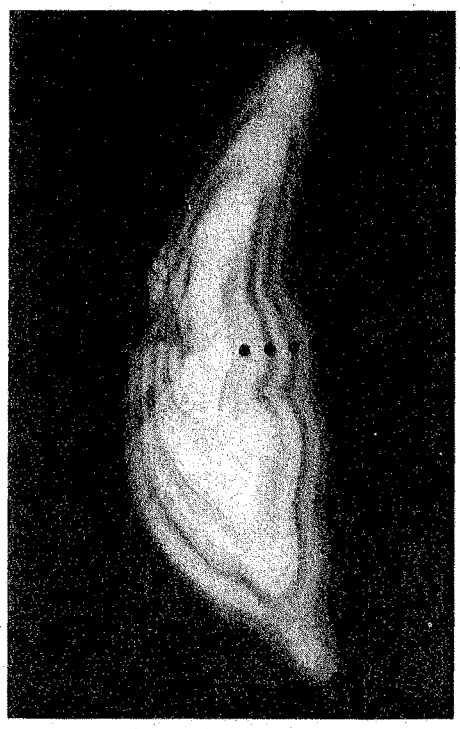

Figure 3
Otolith section from a 59-cm age-4 cod collected in the spring from Georges Bank showing a checky first annulus with hyaline edge still forming.

Figure 5
Baked otolith half from a 70-cm age-5 cod collected in March from Georges Bank showing a strong settling check, large and checky first annulus, and a strong check before the second annulus.

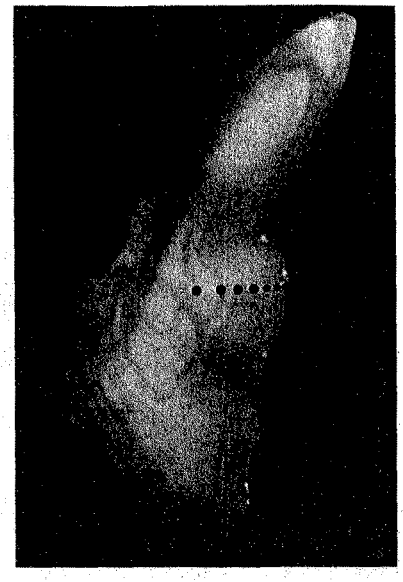

Figure 6
Baked otolith half from a 122-cm age-7 cod collected in July from Georges Bank showing a split third annulus.

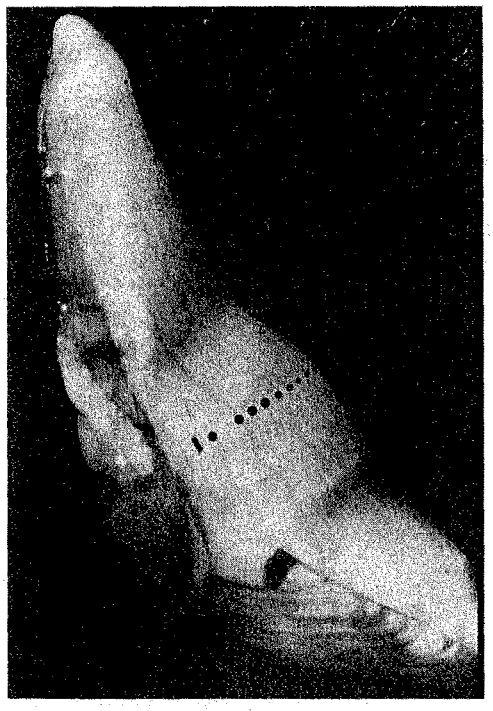

Figure 7
Baked otolith half from a 107-cm age-9 cod collected in August from Georges Bank showing a clear settling check.

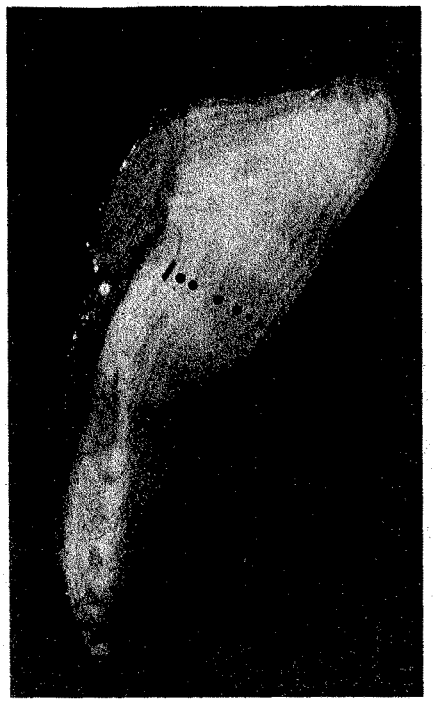

Figure 8
Baked otolith half from a 90-cm age-7 cod collected in September from the Gulf of Maine showing a strong settling check and a split third annulus.

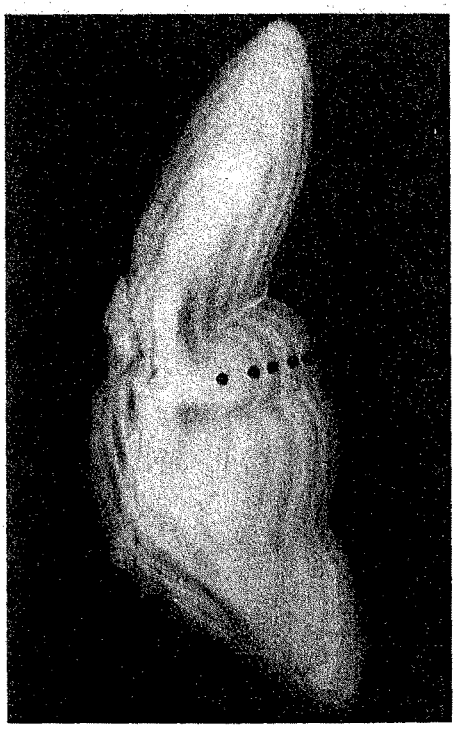

Figure 9
Otolith section from an 88-cm age-6(5) cod collected in the spring from Georges Bank showing a strong second annulus and a possible weak fifth annulus (?) close to the sixth annulus forming on the edge.

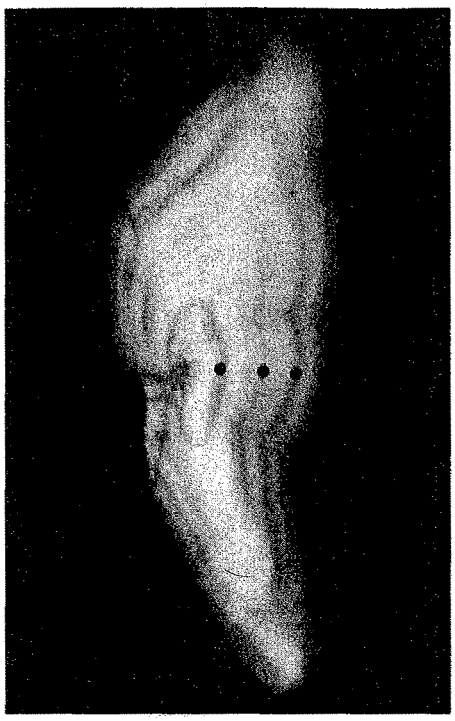

Figure 10
Otolith section from a 69-cm age-4 cod collected in the spring showing the small first annulus typical of Southern New England cod.

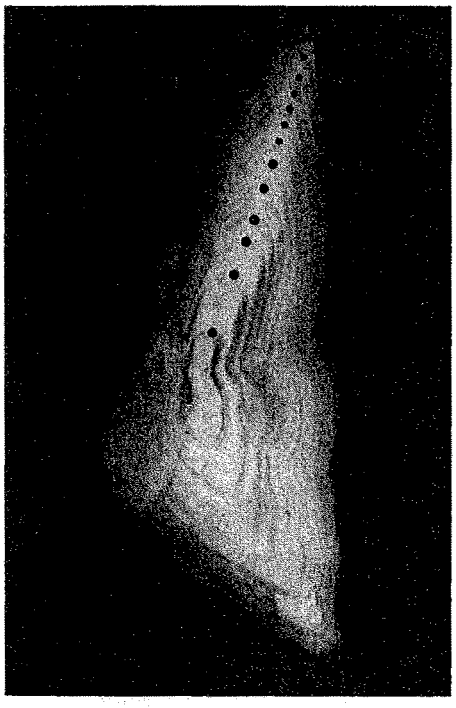

Figure 11
Otolith section from a 130-cm age-14? cod collected in the spring from the Gulf of Maine showing the small first annulus typical for this area.

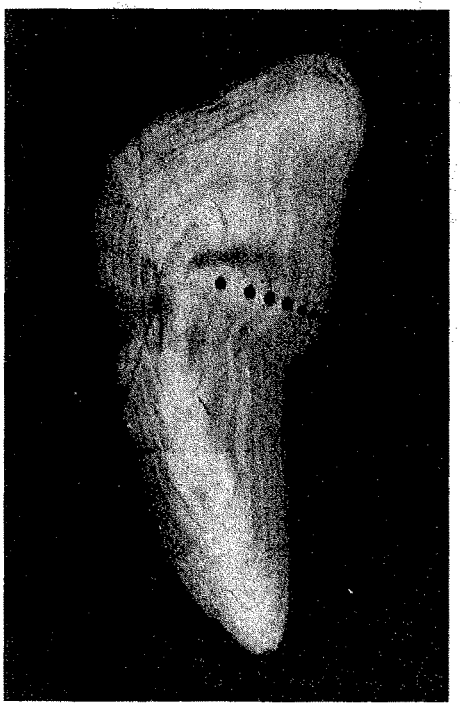

Figure 12
Otolith section from a 97-cm age-7 cod collected in the spring from Browns Bank showing the close first, second, and third annuli typical of this area.

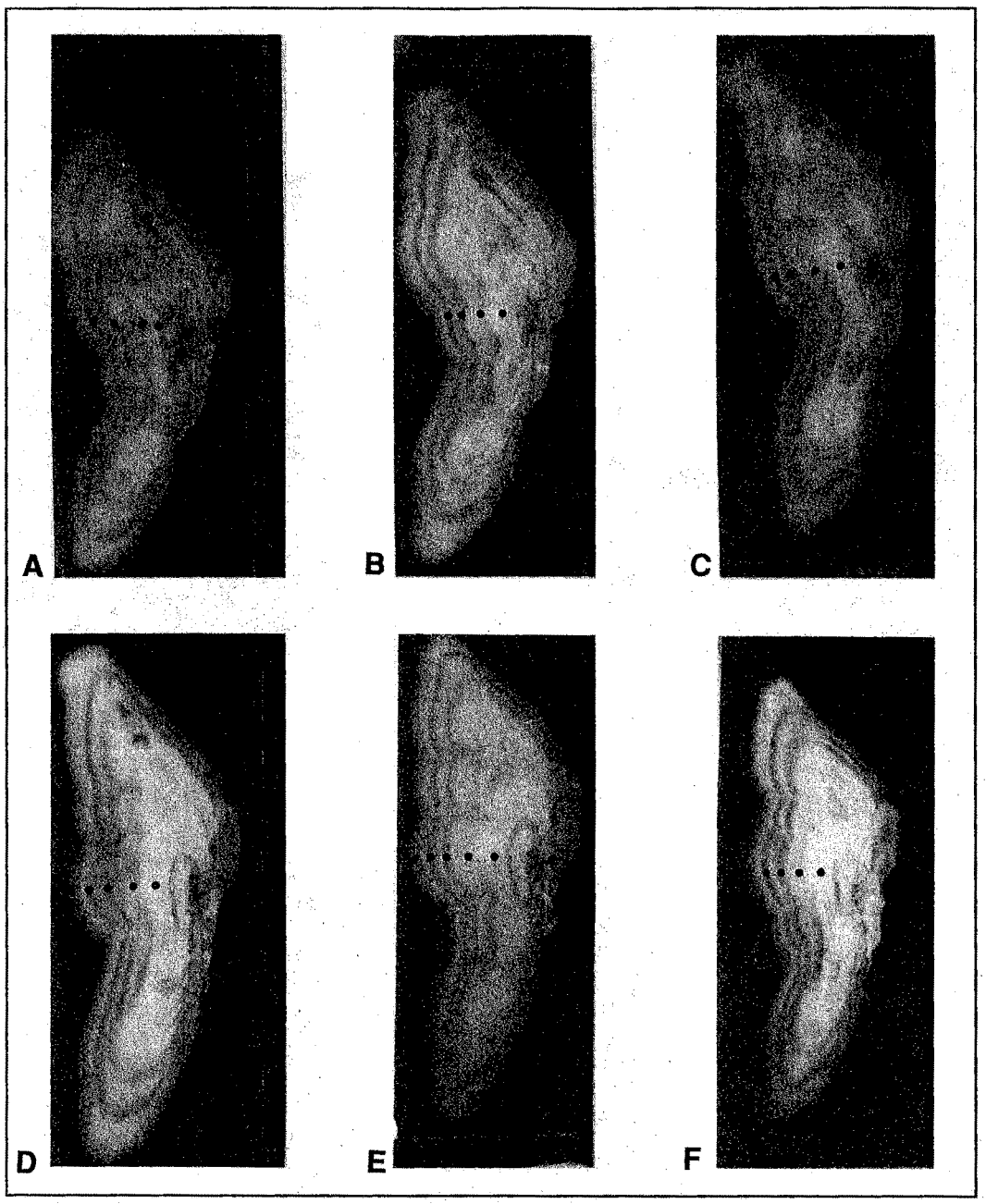

Figure 13

Series of sections cut from a single cod otolith (84-cm age-5 cod collected in the spring from Southern New England), from the anterior (13A) to the posterior (13F) of the first annulus. Section cut at the center of the nucleus is 13C.