The use of otolith microstructure in resolving issues of first year growth and spawning seasonality of white hake, *Urophycis tenuis*, in the Gulf of Maine–Georges Bank region

Kathy L. Lang
Frank P. Almeida
George R. Bolz
Woods Hole Laboratory, Northeast Fisheries Science Center
National Marine Fisheries Service, NOAA
Woods Hole, Massachusetts 02543

Michael P. Fahay
J. J. Howard Laboratory, Northeast Fisheries Science Center
National Marine Fisheries Service, NOAA
Highlands, New Jersey 07732

White hake, *Urophycis tenuis*, has become an increasingly important commercial species in the northeastern United States. Landings from the Gulf of Maine–Georges Bank region steadily increased from less than 1,000 metric tons (t) in the late 1960's to approximately 7,500 t in 1984, averaged about 5,800 t during 1986–91, and increased to an average of 9,300 t during 1992–93 (NEFSC, 1995; Burnett et al.[1]). An assessment of white hake conducted in 1984 indicated that landings above 6,000 t would probably not be sustainable. However, a lack of information regarding the biology of the species and the fishery (e.g. catch-at-age data) left the evaluation uncertain (Burnett et al.[1]). Recent analyses have estimated the long-term potential catch to be about 6,500 t (NEFSC, 1995).

The stock structure of white hake in the Gulf of Maine–Georges Bank region is uncertain. While previous assessments of the population in U.S. waters have assumed a single stock inhabiting the waters of the Gulf of Maine south to the mid-Atlantic Bight (Burnett et al.[1]), the existence of two reproductively isolated stocks in the northwest Atlantic has been revealed, and their spawning seasonality determined by Fahay and Able (1989).

Fahay and Able (1989) concluded that the southern stock of white hake spawns along the continental slope, primarily south of Georges Bank, but also on the Scotian Shelf and off southern New England in the spring. The northern stock reportedly spawns in the shallow waters of the southern Gulf of St. Lawrence and Scotian Shelf in the summer (Fahay and Able, 1989). These conclusions were based on the distribution and abundance of early life history stages as well as known circulation patterns throughout the region. Their results also indicated that there is negligible successful spawning of the species within the Gulf of Maine (Fahay and Able, 1989). Further, on the basis of circulation patterns between the Gulf of St. Lawrence and southern New England waters, Fahay and Able (1989) provided support for the hypothesis of Musick (1969) that pelagic juveniles actively migrate across Georges Bank into the Gulf of Maine.

Accurate age data on the adult component of the stock greatly enhance estimates of spawning stock size and predictions of future catch and abundance. Several ageing studies have been conducted for white hake (Nepzky, 1968; Beacham and Nepzky, 1980; Hunt, 1982; Clay and Clay, 1991). Ages determined by counting the number of hyaline zones visible on transverse sections of the sagittal otoliths have been validated for white hake inhabiting the Gulf of St. Lawrence by comparing mean lengths at age with observed length-frequency modes (Hunt, 1982). However, the results of a preliminary analysis of age data collected from the Gulf of Maine–Georges Bank region indicated that there is still uncertainty about the first hyaline zone and therefore the location of the first annulus.

Researchers ageing white hake have noted the presence of a hyaline zone between the nucleus and what has been regarded as the first annulus (Hunt, 1982; Clay and Clay, 1991). This hyaline zone varies in intensity and in distance from the nucleus. Most experienced age readers believe that this zone is located too close to the nucleus to be the first annulus and have assumed that it is a check formed either when pelagic larvae settle into a

[1] Burnett, J., S. H. Clark, and L. O'Brien. 1984. A preliminary assessment of white hake in the Gulf of Maine–Georges Bank area. Natl. Mar. Fish. Serv., Northeast Fisheries Science Center, Woods Hole Lab. Ref. Doc. 84-31, 33 p.

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demersal habitat (Hunt, 1982) or during the first winter when the fish are about six months of age (Clay and Clay, 1991).

The hyaline check observed on white hake otoliths is probably analogous to checks that have been documented on the otoliths of other gadoid species such as Barents Sea cod, *Gadus callarias* (Trout, 1954); silver hake, *Merluccius bilinearis* (Hunt, 1980; Dery, 1988a); and red hake, *Urophycis chuss* (Dery, 1988b). Timing of the check on silver hake otoliths was resolved by Nichy (1969), whose back-calculated lengths at the time of check formation corresponded well with the size at which silver hake become demersal. A similar check on the otoliths of capelin, *Mallotus villosus*, was also shown to be formed when the fish undergoes metamorphosis (Bailey et al., 1977). These studies support the assumption that the first hyaline zone observed on white hake otoliths is a check, probably formed when pelagic juveniles settle into a demersal lifestyle. To date, however, there has been no direct determination of the timing of this check.

The objectives of this study are to determine the timing and nature of the check on white hake otoliths, to estimate the daily growth rates of juvenile white hake, and to estimate spawning dates of these juveniles in order to evaluate Fahay and Able's (1989) theory that there are two distinct spawning stocks of white hake in the Gulf of Maine–Georges Bank region.

Methods

Juvenile white hake were obtained from archived specimens collected from several locations off the northeast coast of the United States throughout the mid-Atlantic Bight, Georges Bank, and Gulf of Maine (Fig. 1). Collection dates ranged from June 1986 through September 1992. Sampling gears that successfully captured white hake included MOCNESS (multiple opening-closing net and environmental sensing system), otter trawl, and beach seine (Table 1).

In the laboratory, fish were measured to the nearest 0.1 mm TL and all otoliths were removed. Sagittae were stored whole and dry and were examined with a dissecting microscope for the presence of hyaline zones. Each pair of lapilli and asterisci were mounted whole on glass slides and examined with a compound microscope to enumerate daily rings. Both the sagittae and asterisci of the juveniles were irregularly shaped and difficult to age. Lapilli, which had

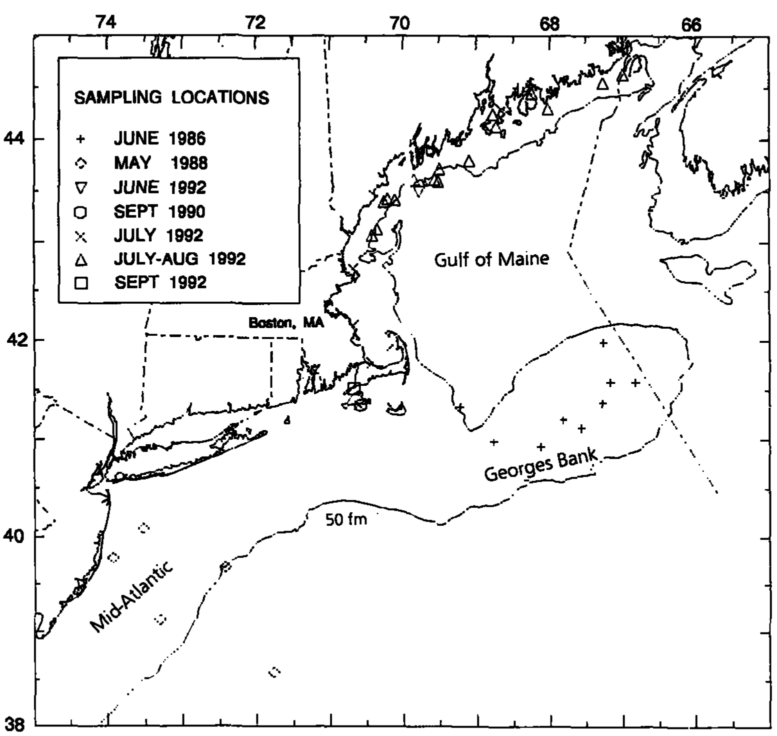

Figure 1
Locations of juvenile white hake, *Urophycis tenuis*, samples by year of collection.

Table 1

Dates, locations, and sampling gears that collected juvenile white hake, *Urophycis tenuis*, utilized in growth analyses.

Date	Region	Sampling program/Gear	Sample size
Jun 1986	Georges Bank	NEFSC/MOCNESS	22
May 1988	Mid-Atlantic	MARMAP/MOCNESS	5
Sep 1990	Coastal Massachusetts	MA State Bottom Trawl Survey	6
Jun 1992	Gulf of Maine	NEFSC–Maine DMR Bottom Trawl Survey	1
Jul 1992	Woods Hole, MA	Beach seine	4
Jul–Aug 1992	Coastal New England	NEFSC Bottom Trawl Survey	40
Sep 1992	Coastal Massachusetts	MA State Bottom Trawl Survey	45

more discernible rings, were polished with 1,200-grit paper and surface viewed at magnifications ranging from 500 to 1,000× by two readers. The 500× magnification was subsequently chosen as appropriate for these otoliths.

A Gompertz growth model was fitted to the daily increment data and the *Y* intercept taken as an estimate of the time of formation of the lapilli. Spawning dates were estimated for each individual by subtracting the increment count from the date of capture.

Results

A total of 123 juvenile white hake were available from seven sampling programs (Table 1). Fish ranged in size from 28 to 187 mm TL, and in age from 40 to 146 days. A hyaline check was found on the sagittal otoliths of fish collected from inshore estuarine locations. The check was on the edge of the otoliths of the juveniles collected from Woods Hole, Massachusetts, in July 1992. These fish were 70–104 mm TL and 59–73 days old.

Juvenile white hake distribution varied by size and age. The smallest fish were collected in very deep water (>100 m) offshore in the mid-Atlantic Bight in May and still had pelagic countershading, whereas the largest fish were collected in shallow waters off Martha's Vineyard, Massachusetts, in September. Smaller fish were generally caught earlier in the year (May) (Fig. 2) and farther south (mid-Atlantic Bight, Georges Bank), whereas larger individuals were taken later in the year (July–September) from locations farther north (Cape Cod, Gulf of Maine). Younger fish were collected only from May to July, whereas older fish were collected only from August to September (Fig. 3).

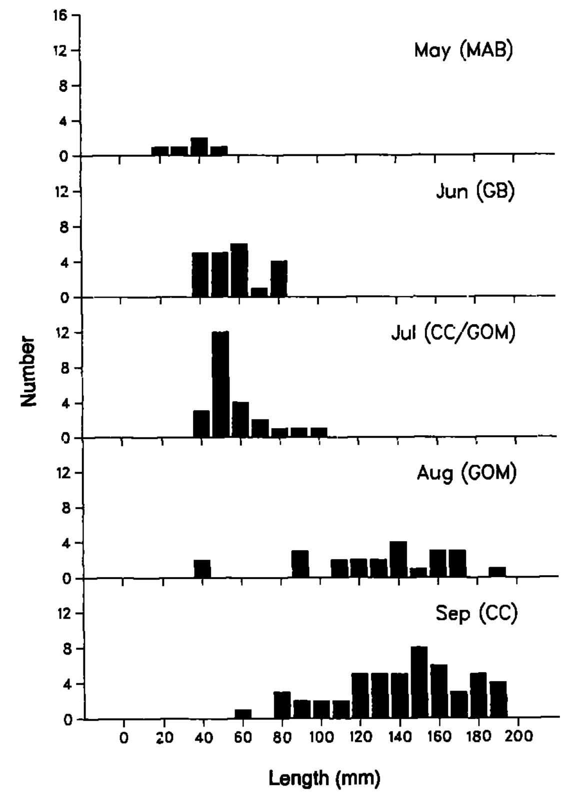

Figure 2

Size distribution of juvenile white hake, *Urophycis tenuis*, by month of collection. (MAB=mid-Atlantic Bight; GB=Georges Bank; CC=Cape Cod; and GOM=Gulf of Maine.)

During July–August 1992, juvenile hake of two size classes were collected. Smaller individuals (40 to 57 mm TL) were collected off New Hampshire and southwestern Maine (Biddeford Pool) and larger individuals (86 to 186 mm TL) were taken from locations off eastern Maine. Only one small fish (41 mm) was taken off eastern Maine during this period.

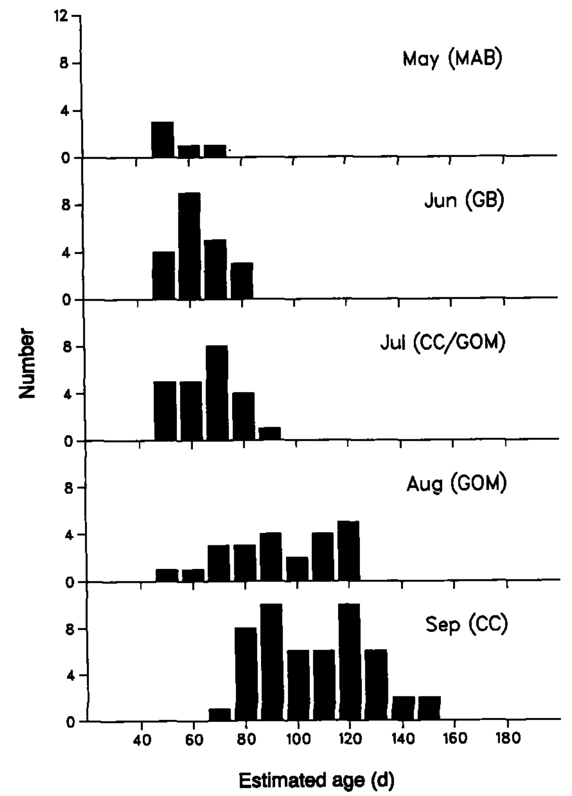

Figure 3

Age distribution of juvenile white hake, *Urophycis tenuis*, by month of collection. (MAB=mid-Atlantic Bight; GB=Georges Bank; CC=Cape Cod; and GOM=Gulf of Maine.)

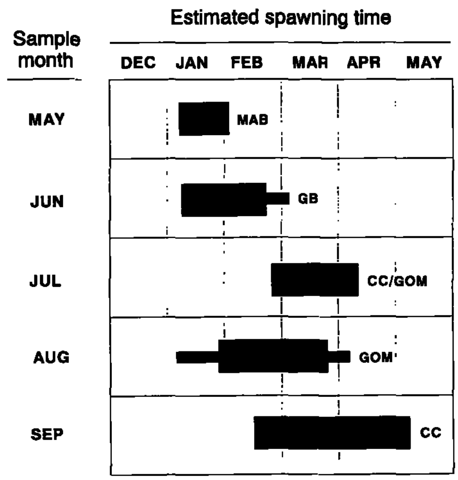

Figure 4

Back-calculated spawning times of juvenile white hake, *Urophycis tenuis*. Narrow bars indicate single observations. (MAB=mid-Atlantic Bight; GB=Georges Bank; CC=Cape Cod; and GOM=Gulf of Maine.)

Back-calculated spawning dates indicated that peak spawning occurred in the late winter for fish collected from the mid-Atlantic Bight and Georges Bank (smaller, younger individuals), whereas peak spawning occurred in late spring (March–April) for fish collected along coastal New England (larger, older individuals) (Fig. 4).

Age-length data of the juvenile hake (all data combined) were best described by a Gompertz curve (Fig. 5):

$$LEN = 210.760e^{-19.9812e^{-0.0303(AGE)}}, \quad [r^2=0.883, n=123]$$

where *LEN* = total length in mm, and
AGE = number of days (increments) from spawning.

Evident in the distribution of data presented in Figure 5 is the observation that small white hake (28–77 mm) collected in May–June grew at the same

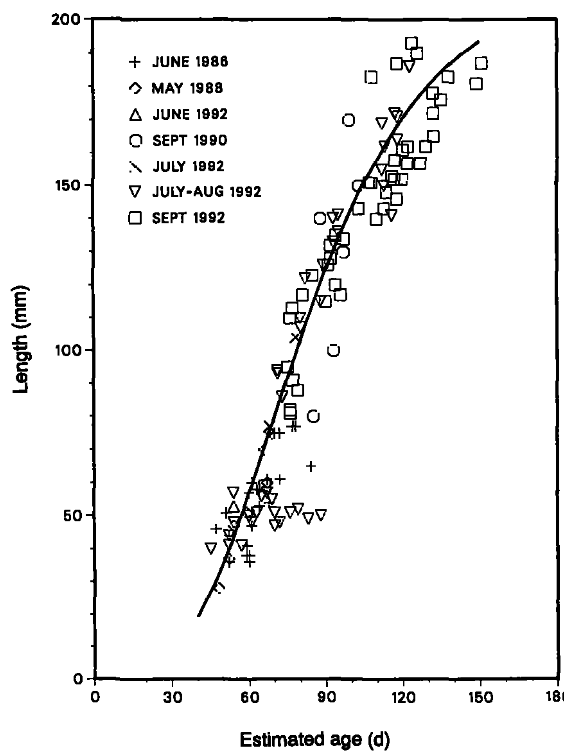

Figure 5

Gompertz growth curve fitted to total length vs. age data for white hake, *Urophycis tenuis*.

rate during each of the three years for which we obtained samples (1986, 1988, and 1992). Likewise, fish collected during July–September grew at similar rates during 1990 and 1992. An average growth rate of 1.01 mm/day for the first 200 days was estimated from the equation. When the data were analyzed by time of collection (and consequently by separating smaller, younger fish from larger, older fish), the equation for the June 1986 samples was

$$LEN = 167.193e^{-6.2611e^{-0.0184(AGE)}}, \qquad [r^2=0.588, n=22]$$

with an estimated growth rate of 0.71 mm/day, and the equation for July–September (1992) samples was

$$LEN = 206.980e^{-17.7158e^{-0.2299(AGE)}}, \qquad [r^2=0.877, n=89]$$

with an estimated growth rate of 0.99 mm/day.

Discussion

A hyaline zone, or check, can form on fish otoliths in response to a significant change in environmental conditions such as temperature or food availability, or both (i.e. by the transition from a pelagic to a demersal lifestyle). Our samples of juvenile white hake reflect the dramatic change in habitat experienced by this species because the smallest, youngest fish (pelagic juveniles) were collected from deep offshore areas and the largest, oldest fish (demersal juveniles) were collected from shallow inshore locations.

The juveniles collected in Woods Hole, Massachusetts, in August, 1992 (70–104 mm TL) had hyaline edges on their sagittal otoliths which would have appeared as a check on adult otoliths. Previous studies suggest that juvenile white hake "settle out" from a pelagic to demersal lifestyle at about 50 to 80 mm TL (Musick, 1974; Markle et al., 1982). They may also actively migrate to inshore areas at this time because juvenile hake in this size range have often been collected from shallow inshore areas (Bigelow and Schroeder, 1953; Musick, 1969; Markle et al., 1982; Comyns and Grant, 1993). The ages of the juveniles collected in Woods Hole (59–73 days) confirm that this hyaline zone was a check rather than the first annulus.

Daily ages were also used to calculate growth rates for the juvenile hake. We found that juveniles grew about 0.99 mm/day in June and September (1992), a rate that coincides with Fahay and Able's (1989) estimate of 1.02 mm/day for demersal juveniles collected during June–October 1986, which they calculated by means of length-frequency progression. This relatively fast growth rate may reflect the benefit to juvenile fish of moving into warm, shallow areas where prey abundance can be high.

Our results also support Fahay and Able's (1989) hypothesis that juvenile white hake are recruited northward along the east coast of the United States. As mentioned above, only smaller, younger individuals were collected from southern locations (in the mid-Atlantic Bight) and only larger, older fish were collected from areas farther north (in the Gulf of Maine). Whereas only cruises with positive catches of white hake were utilized for this study, Fahay and Able (1989) obtained similar results after an extensive series of surveys conducted during 1984–87, using various sampling gear and covering areas from Cape Fear, North Carolina, to the Scotian Shelf (Tables 1 and 2 in Fahay and Able, 1989). Fahay and Able (1989) also reviewed the results of other researchers which documented the absence of eggs and larvae in Georges Bank–Gulf of Maine waters and the northward progression of juvenile stages in the study area (Chenowith, 1973; Colton and St. Onge, 1974; Bolz et al., 1981; Laroche, 1982; Townsend, 1984).

In light of the northward recruitment theory, and given the northward progression of sizes and ages, all of the fish in this study probably came from one spawning population located offshore from the mid-Atlantic Bight and Georges Bank region. Our collections from the Gulf of Maine in July and August 1992 may indicate that there were two successful spawning periods (or one very protracted spawning period) that year because they included two size classes of juvenile hake. We found no evidence of a summer-spawning Scotian Shelf stock, possibly because of the timing of our sampling of the northernmost stations (in July–August 1992). These results again support Fahay and Able's (1989) hypothesis that there is no significant spawning within the Gulf of Maine.

In summary, our results confirm details of the early life history of white hake. Pelagic juveniles settle into a demersal existence at 50 to 80 mm TL, when they are approximately 50 to 60 days old. Many individuals settle in shallow estuarine nursery areas which results in the formation of a hyaline check on their sagittal otoliths. We therefore support previous ageing studies in which the check on adult otoliths was not counted in ageing. We also confirm with daily ageing a growth rate of about 1 mm/day for juvenile white hake. Finally, we provide additional evidence that there is apparently a major spawning population of adults located offshore of the mid-Atlantic Bight–Georges Bank region, and that juvenile hake spawned from this group are recruited northward into the Gulf of Maine.

Acknowledgments

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