Validation of otolith-based ageing and a comparison of otolith and scale-based ageing in mark-recaptured Chesapeake Bay striped bass, *Morone saxatilis*

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Anadromous striped bass, *Morone saxatilis*, populations in the mid-Atlantic region comprise important commercial and recreational fisheries (ASMFC[1]). Stock assessments for these fisheries depend upon age estimates using annular structures of scales (Merriman, 1941; Mansueti, 1961; Kahnle et al.[2]; Hornick et al.[3]). Age estimation for large adults (>91 cm) has been problematic owing to the presence of false annuli and to difficulty in interpreting narrow annuli in peripheral fields of the scale (Scofield, 1928a; Merriman, 1941; Tiller, 1950; Mansueti, 1961). Recent work on otolith microchemistry to decipher environmental histories of migratory striped bass has provided age estimates that were considerably greater than those previously reported (Secor, 1992). Longevity of female Chesapeake striped bass was estimated to exceed 31 years based on examination of otolith microstructure (Secor et al.[4]).

An investigation of the rate of annulus formation in the otoliths of Chesapeake Bay striped bass was performed to verify estimates of growth and longevity (Secor et al.[4]). For otolith microchemistry applications (Secor, 1992), it also was critical to verify that annuli formed at a yearly rate so that seasonal patterns in Sr/Ca ratio (exposure to varying salinity) could be interpreted. Heidinger and Clodfelter (1987) reported yearly rates of annulus formation in otoliths of striped bass from one to four years in age in a midwest reservoir, but no specific measurements of accuracy or precision were presented. No other studies have been published on annulus formation in striped bass otoliths.

A mark-recapture study on hatchery-produced striped bass (Rago et al., 1993; Hornick et al.[3]) provided samples of known-age resident and migratory fish that were 3 to 7 years old. From 1985 to 1992, approximately 5.5 million juvenile striped bass were stocked in Chesapeake Bay tributaries (Rago et al., 1993). All fish were implanted with a binary-coded wire tag which indicated year of origin and provided information on their hatchery source and release date and site. The objective of this study was to verify the rate of annulus formation by comparing annulus counts with the known age of recaptured hatchery fish. A second objective was to compare scale and otolith ages of large striped bass (>91 cm, total length [TL]) to determine the accuracy of age estimates derived from scales.

Methods

Known-age study

Striped bass otolith ageing techniques were verified by using two sets of known-age, coded-wire tagged (CWT) adults. A group of 24 CWT fish was obtained from a collaborative study of migratory striped bass conducted by the Maryland Department of Natural Resources (DNR); the National Marine Fisheries Service; the North Carolina Department of En-

[1] ASMFC (Atlantic States Marine Fisheries Commission). 1990. Source document for the supplement to the striped bass FMP-Amendment No. 4. Atlantic States Marine Fisheries Commission. Prepared by Versar, Inc., Columbia, MD, 414 p.

[2] Kahnle, A. W., D. Stang, K. Hattala, and W. Mason. 1988. Haul seine study of American shad and striped bass spawning stocks in the Hudson River estuary. New York State Dep. of Environmental Conservation, Albany, NY.

[3] Hornick, H. T., R. K. Schaefer, D. T. Cosden, K. J. Booth, J. L. Markham, C. B. McCollough, D. M. Goshorn, M. L. Gary, W. S. Barbour, and R. J. Dickinson. 1992. Investigations of striped bass in Chesapeake Bay. USFWS Federal Aid Performance Report. Project F-42-R-5. Maryland Dep. Natural Resources, Tidewater Administration, Fisheries Div., 219 p.

[4] Secor, D. H., H. T. Hornick, and J. Markham. Lost and found generations of Chesapeake Bay striped bass: improvement in year-class representation of Chesapeake Bay striped bass due to the 1985–1991 Maryland striped bass moratorium. Unpubl. manuscr.

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vironment, Health, and Natural Resources; and the U.S. Fish and Wildlife Service. Between 6 and 8 February 1993, migratory fish were captured off the North Carolina coast by the crew of the NOAA vessel *Chapman* by means of a 90-ft, 2-seam fish trawl that was towed for a maximum of 30 minutes (Laney and Cole, 1993). A second group of 13 CWT fish was obtained from DNR commercial drift gillnet and poundnet surveys between 5 October 1992 and 23 February 1993. Pound nets and drift nets were located in shoal areas of the upper Chesapeake Bay, off Kent Island, MD.

Fish in the study group had been tagged with binary coded wire tags as age-0+ juveniles. Tags were removed from recaptured fish and decoded by personnel at the U.S. Fish and Wildlife Service laboratory in Annapolis, MD, to determine their ages.

Otoliths were extracted, soaked in 10% sodium hypochlorite solution, rinsed with deionized water, and embedded within a Spurr epoxy (Secor et al., 1991). Transverse sections, approximately 1 mm thick, were then cut through the otolith cores with a Buehler Isomet saw. The sections were mounted on glass slides, polished on 600-grain sandpaper, and polished again on a slurry of 0.3-μm alumina until their surfaces were free of pits and abrasions. Polished sections were viewed under a light microscope, and otolith annuli were counted by two independent readers. Annuli comprised a narrow opaque zone and a wide translucent zone under transmitted light microscopy (magnification at 60 or 150×). Annuli were counted along the sulcal ridge in transverse sections. The otolith ages were compared with each other and with the known age of the fish.

Scale vs. otolith study

Scales and otoliths were sampled from recreational landings of striped bass (>91 cm TL) during the May 1992 Maryland "Trophy Striped Bass Fishery." These fish were assumed to have spawned recently in upper Chesapeake Bay tributaries. Five additional fish, large females (>100 cm) collected in 1991 and 1992 from the Patuxent and Nanticoke Rivers by DNR for hatchery propagation purposes, were included in the comparisons. Scales and otoliths were aged independently by a reader at Chesapeake Biological Laboratory (otoliths) and at DNR (scales). Otoliths were prepared and aged as described above. Scale samples for ageing had been removed from the left side of the fish above the lateral line and below the first dorsal fin. Age was determined from either direct interpretation of the scale's annuli or from acetate impressions of the scales. Otoliths and scales were coded so that fish length was unknown to readers.

Results

Known-age study

Striped bass collected in pound nets and drift gill nets in Upper Chesapeake Bay were 3- to 7-year-old males and females. The migratory hatchery striped bass from offshore samples tended to be older, ranging in age from 4 to 7 years old (Fig. 1).

Agreement between known and estimated age for resident striped bass was 100% for both otolith readers (n=13). Exact agreement between estimated and known age for migratory fish (n=24) was 79% and 87% for reader 1 and reader 2, respectively. All migratory fish were estimated to be within one year of their true age. The mean age difference between readers for migratory fishes was not significantly different from 0 (paired t-test: n=37; P=0.66). The mean absolute difference between ages estimated by reader 1 and known-age, a measure of precision, was estimated at 0.13 years. Precision estimated for reader 2 was 0.08 years. Error in age estimates was not related to fish length or age.

Scale vs. otolith study

Age estimates from scales and otolith sections were not significantly different for fish with otolith-estimated ages of 5 to 11 years (Fig. 2; paired t-test: n=30; P=0.41). However, fish with otolith-estimated ages of 22 to 31 years had scale-estimated ages which were, on average, 9 years less than otolith age estimates (Fig. 2; paired t-test: n=30; P<0.0001).

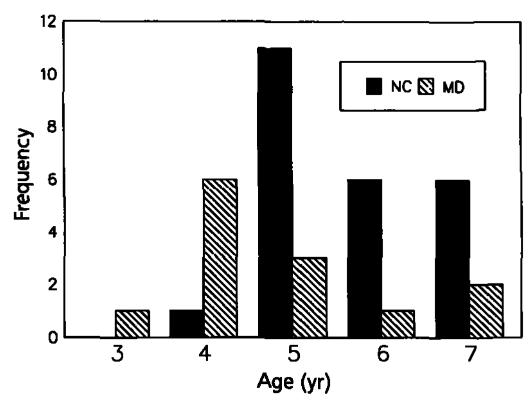

Figure 1

Age-frequency distribution of known-age striped bass from Upper Chesapeake Bay, Maryland (MD) and coastal North Carolina (NC).

Discussion

Annulus formation in otoliths and scales

We verified age estimates of striped bass from annuli observed in sectioned otoliths of fish 3 to 7 years old. Annuli precisely and accurately reflected ages in both resident and migratory Chesapeake Bay striped bass. Annulus appearance at 6 and 7 years was similar to that of annuli from otoliths of much older individuals (Fig. 1 in Secor, 1992). Therefore, we believe that annuli also are formed at a yearly rate in older individuals (e.g. >20 years). Tagged hatchery striped bass represent over 5% of the striped bass population which over-winters in coastal waters off North Carolina (Laney and Cole, 1993). Thus, these fish will continue to provide a pool of known-age material to verify age estimates in older fish. In the next decade it will be possible to verify annulus formation in the oldest fish of the population.

The timing of annulus formation in otoliths was not quantitatively evaluated; samples among months of the year were insufficient to conduct a marginal increment analysis (see Beckman et al., 1988, 1990, 1991). However, we did consistently observe that samples collected during the Maryland Trophy Striped Bass Season in May 1991 and 1992 (see Secor, 1992) contained a newly formed annulus and that no such annulus was observed in otoliths of resident or migratory fish collected in February 1993. Therefore, annulus formation probably occurs during the February–April period. This observation agrees with observations on season of annulus formation in striped bass scales (Merriman, 1941; Heidinger and Clodfelter, 1987).

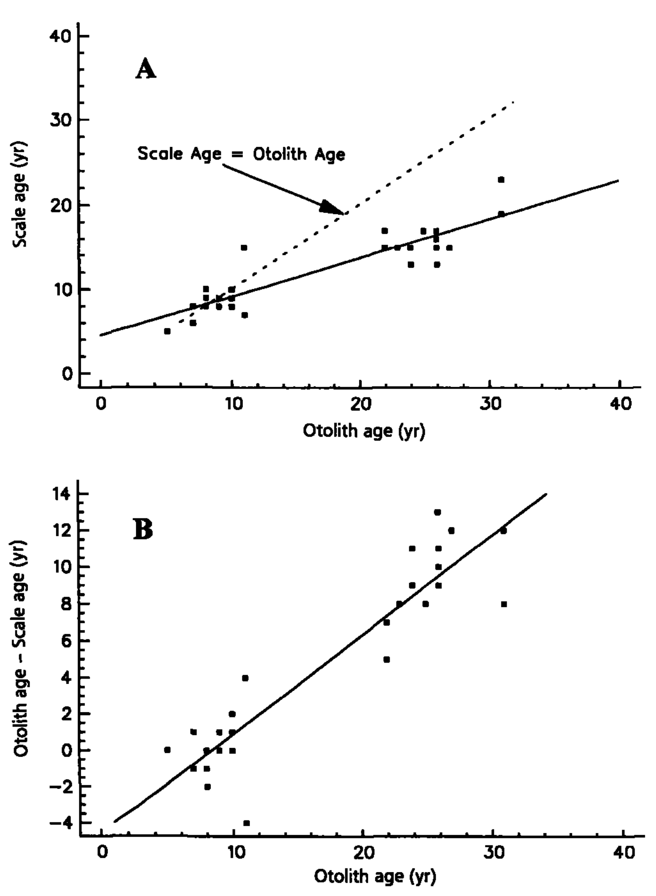

Figure 2

(A) Scale-estimated age vs. otolith-estimated age for Maryland Trophy striped bass (>91 cm TL). Scale age = 4.55 + 0.46 otolith age; n=45; r^2=0.85. For reference, a line corresponding to scale age = otolith age has been plotted. (B) Discrepancy between otolith-estimated and scale-estimated age vs. otolith-estimated age for Maryland Trophy striped bass (>91 cm TL). (Otolith age-Scale age) = –4.55 + 0.54 otolith age; n=45; r^2= 0.88.

On the basis of evidence that annuli in otolith ages represent true age in older fish, we believe that scales significantly underestimate age in fish older than 20 years. Scale ages were not significantly different from otolith ages for fish aged 5 to 11 years, ages that corresponded to fish 91 to 110 cm TL. Scale ages were, on average, 9 years less than otolith ages in fish older than 20 years that corresponded to fish >120 cm TL. Because samples were unavailable for ages 12 to 19 years owing to the scarcity of individuals from these year classes (Secor et al.[4]), we could not determine the accuracy of scale ages for this period. In a similar study on southeastern U.S. riverine and reservoir striped bass, Welch et al. (1993) observed that scale ages were in good agreement with otolith ages for fish <90 cm TL but that scale ages were significantly lower than otolith ages for fish 90–10 cm TL. For Sacramento-San Joaquin striped bass, Scofield (1928a) found good agreement between age estimates made from either hardpart for the first eight years of fish life.

Ageing in striped bass stock assessments

Errors in ageing can result in large biases in stock assessments and in mismanagement of fishery resources (Beamish and McFarlane, 1983; Richards et al., 1992). Scientists at the turn of the century recognized that otoliths often provide more accurate and precise estimates of age than do other hard parts (Heinke, 1904; Cunningham, 1905; Haempel, 1910). Indeed, early verification of age estimation based on scales of striped bass relied upon comparisons of age estimates with those based on otoliths

(Scofield, 1928, a and b). However, the popularity and ease of age estimations using scales caused investigators to overlook the importance of verifying ageing methodology (Beamish and McFarlane, 1983).

All stock assessments on migratory populations of striped bass currently rely on interpreting annular features on scales, a largely unvalidated method. Annulus formation in scales of striped bass has been verified for fish up to age three (Humphreys and Kornegy, 1985) and four years (Heidinger and Clodfelter, 1987) in nonmigratory striped bass. Our data indicated that annuli in scales may adequately estimate age for fish less than 12 years of age. Thereafter, scales provided a continuous age distribution between 11 and 20 years of age, and otolith ageing indicated an absence of fish corresponding to these ages (Fig. 2). Therefore, we inferred that otolith-based age determination will provide more accurate estimates after 12 years of age.

A major disadvantage of using otoliths for age determinations is that fish must be sacrificed. Because large and old members of coastal populations have potentially high reproductive values and may be important contributors to annual recruitments (Rago and Goodyear, 1987; Zastrow et al., 1989; Secor et al., 1992; Cowan et al., 1993), it may be undesirable to sacrifice large numbers of these individuals for stock assessment purposes. An alternative approach would be to correct the age estimates from scales by using an otolith vs. scale calibration curve (Fig. 2). Our reported relationship was somewhat variable (r^2=0.85), but with additional otolith samples, reliable prediction of age from scale annuli may be possible.

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Literature cited

Beamish, R.J., and G.A. McFarlane.
1983. The forgotten requirement for age validation in fisheries biology. Trans. Am. Fish. Soc. 112:735–743.

Beckman, D. W., C. A. Wilson, and A. L. Stanley.
1988. Age and growth of red drum, *Sciaenops ocellatus*, from offshore waters of the Northern Gulf of Mexico. Fish. Bull. 87:17–28.

Beckman, D. W., A. L. Stanley, J. H. Render, and C. A. Wilson.
1990. Age and growth of black drum in Louisiana waters of the Gulf of Mexico. Trans. Am. Fish. Soc. 119:537–544.
1991. Age and growth-rate estimation of sheepshead *Archosargus probatocephalus* in Louisiana waters using otoliths. Fish. Bull. 89:1–8.

Cowan, J. H., Jr., K. A. Rose, E. S. Rutherford, and E. D. Houde.
1993. Individual-based models of young-of-the-year population dynamics. II: Factors affecting recruitment in the Potomac River, Maryland. Trans. Am. Fish. Soc. 122: 439–458.

Cunningham, J. T.
1905. Zones of growth in the skeletal structures of Gadidae and Pleuronectidae. *In* 23rd annual report of Fisheries Board of Scotland, 1905, Part II: Scientific investigations, p. 125–140.

Haempel, O.
1910. Ueber das Wachstum des Huchens (*Salmo hucho* L.). Ein Beitrag zur Altersbestimmung der Teleostier. Int. Rev. Hydrobiol. Hydrogr. 3:136–155.

Heidinger, R. C., and K. Clodfelter.
1987. Validity of the otolith for determining age and growth of walleye, striped bass, and smallmouth bass in power plant cooling ponds. *In* R. C. Summerfelt (ed.), Age and growth of fish, p. 241–252. Iowa State Univ. Press, Ames, IA.

Heinke, F.
1904. Occurrences and distributions of the eggs, larvae and various age-groups of the food fishes in the North Sea. J. Cons. Int. Explor. Mer, General Report, 1902–1904:1–39.

Humphreys, M., and J. W. Kornegy.
1985. An evaluation of the use of bony structures for aging Albermarle Sound-Roanoke River striped bass (*Morone saxatilis*). North Carolina Wildlife Resources Commission Report, Raleigh, NC, 17 p.

Kimura, D. K.
1977. Statistical assessment of the age-length key. J. Fish. Res. Board Can. 34:317–324.

Laney, R. W., and W. W. Cole.
1993. Tagging summary for mixed striped bass stocks offshore North Carolina and Virginia. *In* Abstracts, 1993 striped bass study, striped bass workshop, p. 144–147. Natl. Mar. Fish. Serv., Silver Spring, MD.

Mansueti, R. J.
1961. Age, growth and movements of the striped bass, *Roccus saxatilis*, taken in size selective fishing gear in Maryland. Chesapeake Bay Sci. 2:9–36.

Merriman, D.
1941. Studies of the striped bass (*Roccus saxatilis*) of the Atlantic coast. U.S. Fish Wildl. Serv., Fish. Bull. 50: 1–77.

Rago, P. J., and C. P. Goodyear.
1987. Recruitment mechanisms of striped bass and Atlantic salmon: comparative liabilities of alternative life histories. Am. Fish. Soc. Symp. 1:402–416.

Rago, P. J., H. Upton, and P. I. Washington.
1993. Estimated contribution of hatchery-reared striped bass to commercial and recreational fisheries of Maryland 1991–1992. *In* Abstracts, 1993 striped bass study, striped bass workshop, p. 177–184. Natl. Mar. Fish. Serv., Silver Spring, MD.

Richards, I. J., J. T. Schnute, A. R. Kronlund, and R. J. Beamish.
1992. Statistical models for the analysis of ageing error. Can. J. Fish. Aquat. Sci. 49:1801–1815.

Scofield, E. C.
1928a. Preliminary studies on the California striped bass. Trans. Am. Fish. Soc. 1928:139–144.
1928b. Striped bass studies. Calif. Fish and Game 14:29–37.

Secor, D. H.
1992. Application of otolith microchemistry analysis to investigate anadromy in Chesapeake Bay striped bass *Morone saxatilis*. Fish. Bull. 90:798–806.

Secor, D. H., J. M. Dean, and E. H. Laban.
1991. Manual for otolith removal and preparation for microstructural examination. Belle W. Baruch Institute, Univ. South Carolina Press, Columbia, SC, 85 p.

Secor, D. H., J. M. Dean, T. A. Curtis, and F. W. Sessions.
1992. Effect of female size and propagation methods on larval production at a South Carolina striped bass (*Morone saxatilis*) hatchery. Can. J. Fish. Aquat. Sci. 49:1778–1787.

Tiller, R. E.
1950. A five-year study of the striped bass fishery of Maryland, based on analyses of scales. Chesapeake Biological Lab. Publ. 85, 30 p.

Welch, T. J., M. J. Van den Avyle, R. K. Betsill, and E. M. Driebe.
1993. Precision and relative accuracy of striped bass age estimates from otoliths, scales, and anal fin rays and spines. N. Am. J. Fisheries Manage. 13.616–620.

Zastrow, C. E., E. D. Houde, and E. H. Saunders.
1989. Quality of striped bass (*Morone saxatilis*) eggs in relation to river source and female weight. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 191:34–42.