Transactions of the American Fisheries Society 131:634–642, 2002

Comparison of Calcified Structures for Aging Spotted Seatrout

THOMAS F. IHDE* AND MARK E. CHITTENDEN, JR.

College of William and Mary, Virginia Institute of Marine Science, Gloucester Point, Virginia 23062, USA

Abstract.—Aging structures for spotted seatrout *Cynoscion nebulosus* have been compared for the first time by using sectioned pectoral fin rays, sectioned dorsal fin spines, scales, and whole and sectioned otoliths from 50 fish of 300 to 731 mm total length. We considered the following criteria: processing time, reader confidence, reader agreement (precision), agreement of mark counts between structures, and growth with presumed age. Processing time—more than 1 h per fish—was unreasonably high for sectioned pectoral fin rays, so we did not evaluate their use further. Sectioned dorsal fin spines were clear and easy to read, but mark counts disagreed with those of other structures and were not significantly related to the growth of the fish or that of the aging structure. Scale marks often were inconsistent, which led to low confidence and low agreement between readers. Scale ages also showed systematic disagreement with sectioned-otolith ages. Reader confidence was relatively low for whole-otolith age readings in comparison with sectioned readings of the same otolith, and whole-otolith ages showed systematic disagreement with sectioned-otolith ages. Sectioned otoliths were far superior to all other structures in all criteria: marks were clearest, reader confidence was highest, agreement was 100% both within and between readers, and both fish size and structure size increased significantly with presumed age. Consequently, we recommend that sectioned otoliths be the preferred structure for determining the age of spotted seatrout.

Though numerous studies exist on the age and growth of spotted seatrout *Cynoscion nebulosus*, most of these studies have relied on scale-based aging (including Pearson 1929; Iversen and Tabb 1962; Brown 1981). Although a few have used sectioned otoliths (Sundararaj and Suttkus 1962; Maceina et al. 1987; Murphy and Taylor 1994), no other structures have been reported for aging spotted seatrout. Thus the relative usefulness of various structures for aging remains unknown in this commercially and recreationally important species.

Accurate age determination underlies all fisheries research. Because the usefulness of calcified aging structures can vary geographically, many workers have suggested that various calcified structures be compared and evaluated for both precision and accuracy in each population studied (Chilton and Beamish 1982; Beamish and McFarlane 1983; Casselman 1983). Few studies, however, have performed such evaluations in the Chesapeake Bay region. Sectioned otoliths are the preferred aging structure for two other medium-sized marine fishes in that area: weakfish *Cynoscion regalis* (Lowerre-Barbieri et al. 1994) and summer flounder *Paralichthys dentatus* (Sipe and Chittenden 2001). Sectioned otoliths have also been validated for aging three sciaenids in this region: Atlantic croaker *Micropogonias undulatus* (Barbieri et al. 1994), weakfish (Lowerre-Barbieri et al. 1994), and black drum *Pogonias cromis* (Campana and Jones 1998). Yet no comparison among structures has been published for spotted seatrout anywhere in their range, and validations of spotted seatrout otolith aging (Maceina et al. 1987; Murphy and Taylor 1994) and scale aging (Moffett 1961; Stewart 1961; Tabb 1961) have been performed only in the southern portion of their range—in Texas by Maceina et al. and in Florida by the others.

The primary objective of this study was to determine the best calcified structure for aging spotted seatrout. To do so, we compared the four structures most commonly used for aging fish (Chilton and Beamish 1982; Brothers 1983): otoliths, scales, fin spines, and fin rays. Criteria to determine the ''best'' aging structure included processing time, reader confidence, within and between reader agreement (precision), agreement of mark counts between structures, and growth of both the structure assessed and the fish with presumed age. An additional objective was to evaluate the usefulness of whole otoliths, which could provide a timesaving alternative to sectioned otoliths.

Methods

Collection of fish.—All fish used in this study (*N* = 2,448) were caught in commercial haul-seines in

* Corresponding author: tihde@vims.edu

Received March 8, 2001; accepted December 20, 2001

the Chesapeake Bay region. A size-stratified subsample of these fish ($N = 782$) was used to compare whole versus sectioned otoliths. The comparison of all other calcified structures was based on a separate collection of 50 fish caught during August 1997. Collections for the comparison of sectioned otoliths, scales, fin spines, and fin rays were limited to 1 month to minimize mark variation over time within each calcified structure and to avoid difficulties in interpreting structure edges during the period of annulus formation. August was chosen because this month is far from the time of annulus formation (Tabb 1961; Maceina et al. 1987). In addition, a wide size range of fish was available then.

To include as many age-groups as possible, we sought 20 fish from each of three length strata from the catch: small fish (<380 mm total length [TL]), medium fish (380–509 mm TL), and large fish (≥510 mm TL). Only 10 large fish were collected. The fish collected ranged in size from 300 to 731 mm TL, and the maximum weight was 3,158 g (7.0 lb.).

Standard length (SL), TL, girth (G), total weight (TW), eviscerated weight (EW), and sex were recorded for each of the 50 fish collected. The first spinous dorsal fin and the left soft-rayed pectoral fin were removed from each fish, placed flat in coin envelopes and stored frozen, as recommended by Chilton and Beamish (1982). Both sagittal otoliths were removed, wiped clean, and stored dry as pairs in plastic cell wells. Scales were removed from just above the lateral line, between the first and second dorsal fin, and stored dry in coin envelopes. This location was chosen because preliminary study showed that scales from below the lateral line and behind the pectoral fin—the standard location for spiny-rayed fishes (Lagler 1952)—were mostly regenerated and of little use.

Preparation of calcified structures.—Specific pectoral fin rays and first dorsal fin spines were chosen for analysis after a preliminary review of all possible rays and spines in the sectioned fins of two fish, one 463 mm TL and the other 643 mm. That review indicated that rays and spines of intermediate size possessed the best combination of features for aging—small vascular cores, the most distinct presumed annual marks, and the greatest number of observed marks—compared with all other rays or spines. Consequently, pectoral rays number 6–8, and dorsal fin spine number 2 were chosen for examination from each fish.

Progressive 0.5-mm-thick sections were taken in the preliminary review to determine the optimal location for sectioning the rays and spines. Optimal sectioning distances were observed to be 3 and 4 mm from the base of the rays and spines, respectively; accordingly, only these distances were used in subsequent sectioning.

Fin rays and spines were prepared for reading by first dipping whole fin structures in boiling water for about 1 min. Excess tissue was then wiped away, and the structures were air-dried. Dried structures were mounted on cardboard for cross-sectioning according to Chilton and Beamish (1982), but we used Crystalbond (Aremco Products, Inc.) adhesive rather than epoxy for mounting. Cross-sections were then taken from the initial mounts, mounted again (not immersed) in Crystalbond on glass slides, and viewed in transmitted light under a microscope to count the presumed annual marks. Annual marks (see Figures 1A, 1B) were presumed to be the distal edge of the translucent bands (Williams and Bedford 1974; Chilton and Beamish 1982; Casselman 1983). When a mark appeared at the edge of the structure, it sometimes was difficult to determine whether it was an actual mark or an artifact of preparation. A second reading of the structure in reflected light was helpful in these cases.

Scales were cleaned before mounting by immersing them in warm water and gently brushing them as required. Scales were then taped to acetate sheets (0.02 gauge) and pressed between two additional acetate sheets in a Carver Laboratory Press (model C, equipped with heated platens) for 2 min at 20,000 psi (1 psi [lb/in^2] = 6.895 kPa) and 75°C. Scale impressions were viewed at 20× and 32× on a Bell and Howell R735 microfiche reader to count the presumed annual marks. Presumed annual marks on the ctenoid scales (see Figure 1C) were determined primarily by ‘‘cutting over’’ (Lagler 1952) where a completed circulus or ridge forms past the unfinished endpoint(s) of one or more incomplete circuli in both lateral fields of the scale. The presumptive annual mark on scales was generally accompanied by (1) the origin of multiple secondary radii; (2) a clear, narrow zone in the anterior field; and (3) an additional ridge in the posterior field of the scale in presumably older fish.

Either the right or left otolith was chosen randomly for transverse sectioning. The nucleus was marked for sectioning, sulcal side down, on a lighted slide viewer. Marked otoliths were mounted, sulcal side down, onto cardboard for sectioning as described above for fin rays and spines. A section that included the otolith nucleus (as described by

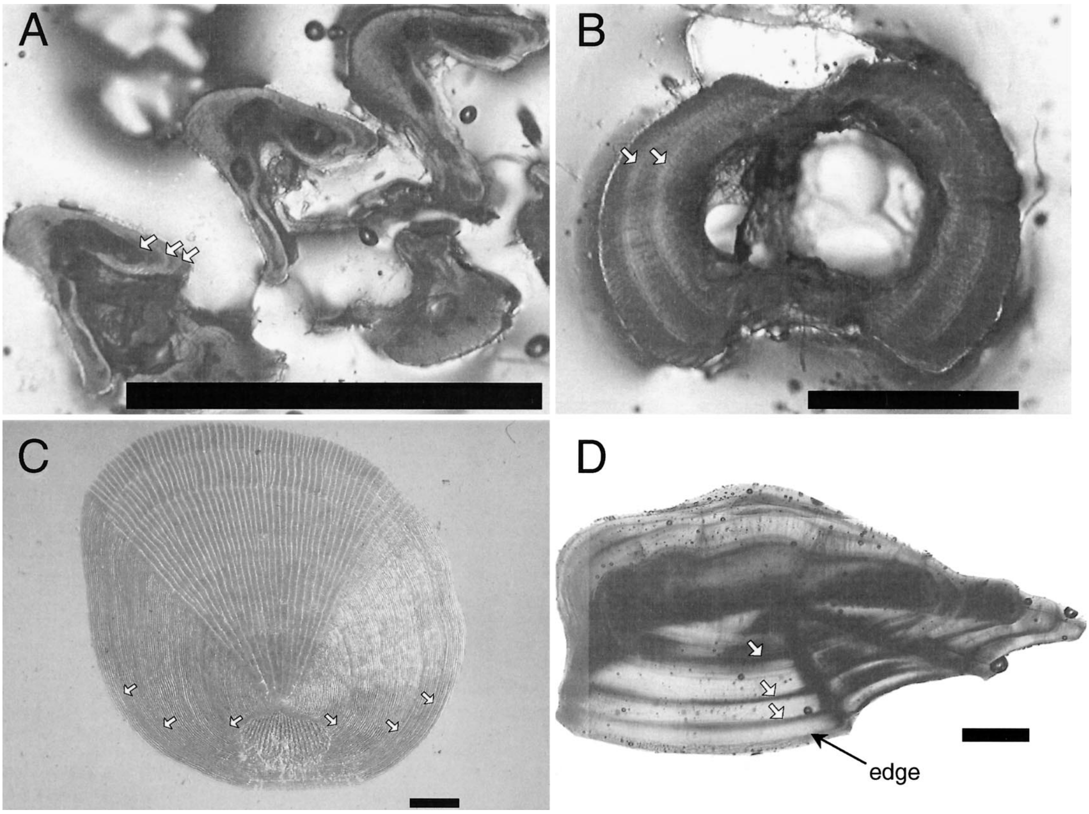

FIGURE 1.—Comparative appearance of presumed annual marks on **(A)** sectioned pectoral fin rays, **(B)** a sectioned dorsal fin spine, **(C)** a scale, and **(D)** a sectioned otolith of a 657-mm-TL, 2,865-g female spotted seatrout. The pectoral fin ray sections show rays 6 (upper right) through 8 (lower left). The dorsal fin spine shows a section of spine 2. The edge of the otolith section is indicated in **(D).** Presumed annual marks are indicated by white arrows. All images were taken in transmitted light. Solid bars are 1 mm long.

Chilton and Beamish 1982), or ''true center'' (Williams and Bedford 1974), was obtained to ensure that the first mark was visible for counting. Sections were then immersed in Crystalbond on a glass slide for viewing and counting the presumed annual marks. Annual marks were presumed to be the distal edge of the translucent bands (Figure 1D) (Williams and Bedford 1974; Chilton and Beamish 1982; Casselman 1983).

Immersion of the otolith sections in Crystalbond reduced the light refraction off the surface of the section and allowed for easier viewing of the presumed mark or marks. This medium offered several advantages over a liquid cover slip (e.g., Flotexx, described by Chilton and Beamish 1982): (1) There was no need to treat sections with oil before immersion to improve the clarity of the growth zones, (2) Crystalbond fully hardened immediately on cooling, and (3) sections were easily repositioned or even removed from the medium if desired after initial mounting. The only disadvantage to Crystalbond was the occasional presence of bubbles in the medium and the production of bubbles with excessive heating.

All structure sections were made with a variable-speed Buehler Isomet saw, and sections were viewed on a Wild stereomicroscope at magnifications of 120–1,000× or on a Zeiss compound microscope at magnifications of 1,000× or greater.

Evaluation of aging structures.—Processing time was evaluated by comparing the mean times required for processing and reading each structure per fish. Reader confidence was evaluated by having each reader assign a confidence rank to each structure reading, using a ranking of 1 (low confidence) to 5 (high confidence) based on the clarity of the presumed annual mark(s), as recommended by Casselman (1983). Differences in confidence rankings between structures were tested with the Mann–Whitney test for ordinal data (Minitab 1996; Zar 1996).

Within-reader agreement was evaluated by percent agreement for assigned age between the first and second readings by one reader, and between-reader agreement was evaluated by percent agreement between the first readings by two readers. All readings were done independently and without knowledge of fish size. Second readings were done in random order with at least a week between readings.

Agreement of mark counts between structures of the same fish, a verification procedure described in Brothers (1983), was evaluated by using (1) a linear regression *t*-test for the null hypothesis that the slope (β) of the linear regression of the counts for the two aging structures equaled 1 (that is, that $x = y$, indicating that there was no difference in counts between the two aging structures), with the coefficient of determination, r^2 (Zar 1996), being used to quantify the amount of variation in y associated with variation in x; (2) a paired *t*-test for the null hypothesis that the difference between counts was zero; and (3) a test of symmetry for the null hypothesis that there was no systematic difference in counts between the two aging structures, as in Hoenig et al. (1995). For all comparisons of mark counts between structures, we made the assumption that sectioned-otolith age counts were accurate. This assumption was based on studies validating use of sectioned otoliths for spotted seatrout in the southern United States. (Maceina et al. 1987; Murphy and Taylor 1994), and studies validating sectioned otoliths of other sciaenids, including Atlantic croaker (Barger 1985; Barbieri et al. 1994), black drum (Beckman et al. 1990; Campana and Jones 1998), red drum *Sciaenops ocellatus* (Murphy and Taylor 1991), and weakfish (Lowerre-Barbieri et al. 1994).

Growth of calcified structures with presumed age was evaluated in two ways. First, linear regression (SAS Institute 1991; Zar 1996) of the standard length of the fish on presumed age was used to determine whether fish size increased with age, as would be expected if an aging technique was accurate. Second, linear regression of the calcified structure size on presumed age was used to determine whether structure size increased with age.

To express structure size, we used sectional surface area, excluding vascularized core areas, as a measure of fin ray and spine size; scale radius and whole-otolith length were used as measures of scale and otolith size. Calibrated measurements of fin ray and spine surface areas and scale radii were taken with a compound video microscope and the Optimas (version 6.0) image analysis system. In doing so, scale radius was measured from the focus to the scale edge (along the ventral angle) where circuli curve from the anterior field to the lateral field. Whole-otolith length was measured from the tip of the rostrum to the midposterior edge with an ocular micrometer at 120×.

Comparison of whole and sectioned otoliths.—Processing methods were similar to those described above for sectioned otoliths, except that the age of the whole otolith was estimated by counting presumed annual marks before sectioning. In doing so, the presumed annual mark was taken as the proximal edge of the opaque growth bands observed in transmitted light on a lighted slide viewer. Confidence rankings were assigned to each whole-otolith reading as described above. The whole and sectioned-otolith readings were then evaluated by comparing reader confidence via a Mann–Whitney test for ordinal data ($N = 576$ fish) as described above and by comparing the agreement of mark counts between whole and sectioned-otolith readings of the same fish ($N = 783$) through (1) a linear regression *t*-test, (2) a paired *t*-test, and (3) a test of symmetry, as described above.

Length–length relationship.—A regression of TL on SL was calculated ($N = 1{,}357$) to convert between lengths for Chesapeake Bay spotted seatrout. Because torn or damaged caudal fins were common, calculations and reported TL values are based on SL.

Results

Comparative Appearance of Aging Structures

Sectioned pectoral fin rays were very small structures, and their marks were often difficult to read and interpret (Figure 1A). These marks seemed to indicate age, but early marks were sometimes obscured or consumed by the vascular core of the fin ray. Further, marks were visible only under high magnification and even then were faint and difficult to read.

Sectioned dorsal fin spines were relatively large structures that showed initially promising, clear, well-defined marks (Figure 1B). Dorsal fin spines, however, like pectoral fin rays, have vascular cores that eventually may consume early marks.

Scales showed presumed annual marks that often were clear and well defined (Figure 1C). However, various inconsistencies often made scales dif-

TABLE 1.—Mean processing time per fish and mean reader confidence rankings of the calcified structures compared for spotted seatrout. Processing time included the time required to prepare and read each structure. Reader confidence rankings with the same letter are not significantly different.

Structure	Mean processing time (min)	Reader confidence ± 1 SE
Sectioned otoliths	6.5	4.90 ± 0.03 z
Scales	8.1	3.35 ± 0.16 y
Dorsal fin spines	15.4	3.50 ± 0.18 y
Pectoral fin rays	75.2	

ficult to read and interpret. For example, in one type of inconsistency, scale marks—indicated by some degree of ‘‘cutting over’’—were present in only one lateral field of an individual scale with no indication of a mark in the same position on the opposite lateral field. In a second type of inconsistency, a well-defined mark was evident on one scale but not on a neighboring scale of the same fish.

Sectioned otoliths were large structures. Their presumed annual marks were consistently clear, well defined (Figure 1D), and consequently easy to read.

Evaluation of Structures

Processing time varied greatly among structures. The mean time required to prepare and read pectoral fin rays—a very long 75.2 min per fish—was nearly five times longer than that required for dorsal fin spines, the most time-consuming of the other three structures (Table 1). Consequently, pectoral fin rays were excluded from further analysis. Mean processing times were reasonable for the other structures, although that for dorsal fin spines (15.4 min/fish) was two to three times as much as for either sectioned otoliths (6.5 min/fish) or scales (8.1 min/fish).

Reader confidence also varied greatly among structures. Reader confidence was greatest for sectioned otoliths. The confidence ranking of 4.90 ± 0.03 (mean ± SE) for sectioned otoliths (Table 1) was significantly greater than that for scales (3.35 ± 0.16; $P < 0.0001$) or dorsal fin spines (3.50 ± 0.18; $P < 0.0001$). There was no significant difference in the confidence rankings of scales versus dorsal fin spines ($P = 0.22$).

Agreement varied greatly among structures. Agreement between readings was greatest for sectioned otoliths. Within-reader agreement was 100% between the first and second otolith readings of reader 1, and between-reader agreement also was 100%. In comparison, scale agreement was 94% within readers but only 74% between readers, and dorsal fin spine agreement was 86% within readers and 74% between readers.

Presumed age counts from dorsal fin spines generally disagreed with counts from either sectioned otoliths or scales. Dorsal spines showed only 10% agreement with ages on sectioned otoliths and 36% agreement with scales (Table 2). Linear regression t-tests and paired t-tests rejected the respective null hypotheses, implying significant differences (linear regression test, $P < 0.0001$; paired test, $P = 0.000$) in presumed age counts between dorsal fin spines and otoliths and between dorsal spines and scales. Dorsal fin spines generally overestimated the age of age-1 and age-2 fish and underestimated that of fish older than age-2 when compared with presumably accurate ages from sectioned otoliths (Figure 2A). Some fish classified as age 1 by sectioned otoliths were considered age 3 or 4 from dorsal fin spines, whereas one fish classified as age 5 by otolith was only age 3 from dorsal spine classification. Only 6% of the variation in dorsal spine age was associated with variation in either otolith or scale age. And finally, a test of symmetry rejected the null hypothesis that dorsal spine ages did not differ systematically from otolith ages ($P < 0.001$) or from scale ages ($P < 0.001$).

TABLE 2.—Summary of test statistics comparing the presumed age counts on scales, sectioned otoliths, and dorsal fin spines in spotted seatrout ($n = 50$). The linear regression t-values evaluate the null hypothesis that the slope equals 1; the paired t-values evaluate the null hypothesis that the difference between counts is zero. For both t-tests the critical value is 2.011 (two-tailed t-test, $\alpha = 0.05$, df = 49), and P is the probability of observing a greater value of t. The test of symmetry expresses the probability (P) that the null hypothesis of 1:1 count correspondence is true.

Structures compared	% Agreement	r^2	t-value (P) Linear regression t-test	Paired t-test	Test of symmetry
Scales and sectioned otoliths	86	0.90	−6.99 (<0.0001)	−1.14 (0.261)	$0.05 < P < 0.10$
Spines and sectioned otoliths	10	0.06	−9.28 (<0.0001)	4.04 (0.000)	$P < 0.001$
Spines and scales	36	0.06	−6.95 (<0.0001)	5.26 (0.000)	$P < 0.001$

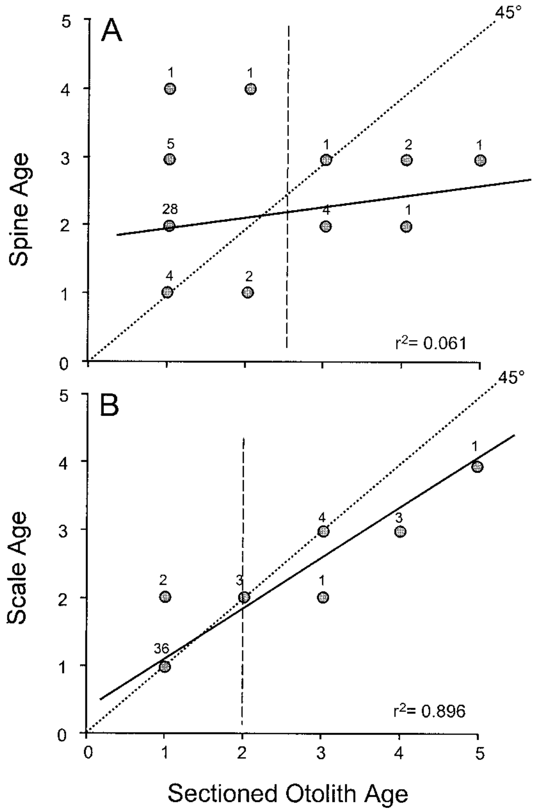

FIGURE 2.—Plots of **(A)** dorsal spine age and **(B)** scale age versus sectioned-otolith age (all in years) to evaluate agreement between aging structures. The dashed line denotes the age at which spines and scales begin to systematically underage the fish in comparison with sectioned otoliths. The equal-age line (45° diagonal) represents a 1:1 correspondence of age readings. Numbers of observations are indicated at each point.

Presumed age counts based on aging by scales agreed fairly well with counts based on sectioned otoliths, but the plot clearly suggests systematic disagreement between these structures (Figure 2B). Scales generally overaged age-1 fish and underaged fish older than age 2 in comparison with presumably accurate sectioned-otolith ages. Age differences between scales and otoliths, however, were only 1 year throughout the otolith age range of 1–5 that we observed. Scale ages showed 86% agreement with sectioned-otolith ages (Table 2), and 90% of the variation in scale age was associated with the variation in sectioned-otolith age. The linear regression *t*-test rejected the null hypothesis that $\beta = 1$, thus implying significant differences ($P < 0.0001$) in presumed age count between scales and sectioned otoliths. Both the paired *t*-test ($P = 0.261$) and a test of symmetry ($0.05 < P < 0.10$), however, failed to reject the respective null hypotheses that the difference between scale and sectioned-otolith counts is zero and that there is no systematic difference in mark counts between these structures (Table 2).

Fish size increased significantly with presumed age ($P < 0.0001$) for both sectioned-otolith and scale ages; however, no significant relationship was found for sectioned dorsal fin spines ($P = 0.16$). The size of the aging structure also increased significantly with presumed age for both sectioned-otolith and scale ages ($P < 0.0001$), but again, no significant relationship was found for sectioned dorsal fin spines ($P = 0.27$).

Comparison of Whole and Sectioned Otoliths

Sectioned otoliths were generally superior to whole otoliths for aging spotted seatrout. Although agreement was high between whole and sectioned otoliths (87%), and 91% of the variation in whole-otolith-estimated age was associated with variation in sectioned-otolith-estimated age, reader confidence was significantly greater for sectioned-otolith ages. Mean ± SE confidence rank values were 4.97 ± 0.008 for sectioned otoliths but only 3.29 ± 0.04 for whole otoliths. All three significance tests—a linear regression *t*-test ($P < 0.0001$), a paired *t*-test ($P = 0.000$), and a test of symmetry ($P < 0.001$)—rejected their respective null hypotheses, implying significant and systematic differences between whole and sectioned readings from the same otolith. A plot of the structure ages around an equal-age line suggests whole otoliths overage fish at ages less than 3 and underage those at ages greater than 3 compared with ages based on sectioned otoliths (Figure 3).

Length–Length Relationship

The observed TL–SL regression was

$$TL = 10.56 + 1.1537 \cdot SL$$

$$(r^2 = 0.995;\ df = 1, 356;\ P = 0.0001).$$

Discussion

We found that sectioned otoliths were far superior to whole otoliths, scales, pectoral fin rays, and dorsal fin spines in all criteria for aging spotted seatrout. Sectioned-otolith marks were extremely clear, reader confidence was high, agreement within and between readers was 100% for each, and fish size and structure size both increased significantly with otolith age. In addition, sectioned-

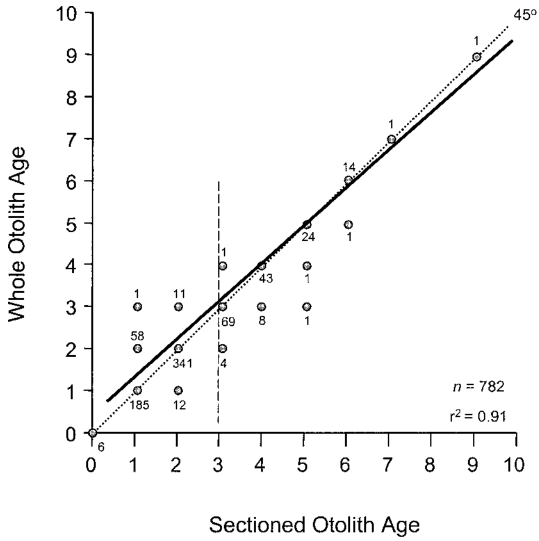

FIGURE 3.—Plot of whole-otolith-estimated age versus sectioned-otolith-estimated age to evaluate agreement between structures. The dashed line denotes the age at which whole otoliths begin to systematically underestimate fish age compared with sectioned otoliths. See the caption to Figure 2 for additional details.

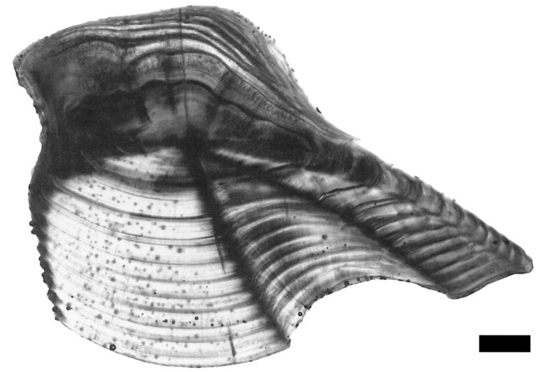

FIGURE 4.—Sectioned otolith of 10-year-old, 817-mm-TL, 4,352-g female spotted seatrout. The solid bar is 1 mm long.

otolith marks were clear, even on very old fish. The sectioned otolith of a 10-year-old fish (Figure 4) caught in the Chesapeake Bay, for example, approaches the record for the oldest spotted seatrout ever reported (a 12-year-old fish aged with sectioned otoliths; Maceina et al. 1987)[1], yet that otolith still exhibited clear marks. As a result, we believe sectioned otoliths should be the preferred structure for aging spotted seatrout. These results are similar to those previously published for two other medium-sized fishes of the Chesapeake Bay. Sectioned otoliths were found to be superior to scales, dorsal spines, and pectoral fin rays in weakfish (Lowerre-Barbieri et al. 1994) and superior to scales and opercular bones in summer flounder (Sipe and Chittenden 2001).

We found processing time for pectoral fin rays of spotted seatrout to be unreasonably high and thus did not further evaluate them as an aging structure. Though sectioned dorsal fin spines showed initial promise, their presumed age readings were poorly correlated with, and showed low agreement with, age estimates based on both scales and sectioned otoliths. In addition, neither fish size nor dorsal spine size was significantly related to presumed dorsal spine age. Our findings indicate that neither pectoral fin rays nor dorsal fin spines are desirable aging structures for spotted seatrout. Barber and McFarlane (1987) found similar results for Arctic char *Salvelinus alpinus* in Alaskan and Canadian waters. Barber and McFarlane (1987) reported that dorsal and pelvic fin rays were unsuitable as aging structures because they lacked the clarity and definition of the other fins, and pectoral and anal fin rays were unsuitable for aging Arctic char because marks were difficult to distinguish, precision was poor, and these fin rays gave significantly younger ages than otoliths (*t*-test; $P < 0.05$). Likewise, Lowerre-Barbieri et al. (1994) found pectoral rays and dorsal spines to be unusable for aging weakfish because of their inconsistency and difficulty of interpretation. Our findings on pectoral fin rays and dorsal spines are new for spotted seatrout; no other studies have evaluated these structures in this species.

We found very high within-reader agreement (94%) when using spotted seatrout scales. Similarly high agreement in using scales has been reported by many previous workers (Klima and Tabb 1959; Moffett 1961; Tabb 1961), though Wakeman and Ramsey (1985) found only 76% agreement.

Despite the high within-reader agreement that we and many other workers have found using scales, we feel that their use in aging spotted seatrout gives results that are difficult to interpret because of the inconsistencies in the scale marks. As a result of these inconsistencies, we had low reader confidence in aging results and relatively

[1] Brown (1981), using scales, reported a 15-year-old spotted seatrout from the Chesapeake Bay that measured 776 mm TL and weighed 5,443 g. This scale age may be inaccurate, however, since a fish this length and weight would correspond to only an 8.7-year-old spotted seatrout aged with sectioned otoliths in our 1996–1999 collection from the Chesapeake Bay.

low between-reader agreement when using scales. Our findings on the difficulty of aging spotted seatrout by using scales generally agree with the literature: Wakeman and Ramsey (1985) noted that false annuli were often difficult to distinguish from true annuli, and Stewart (1961) noted that both partial marks and false marks were common. Many workers have also reported high percentages of unusable scales in spotted seatrout (Pearson 1929; Klima and Tabb 1959; Moffett 1961; Stewart 1961; Brown 1981). In addition, we found systematic disagreements between scales and sectioned otoliths: scales tended to overage young fish and underage older fish in comparison with otoliths. This result appears similar to what Cottrell (1990) described; although he did not report at what ages scales overaged the fish in comparison with sectioned otoliths, he did note that in 82% of aging disagreements, scales overaged by 1 year.

Though Moffett (1961), Stewart (1961), and Tabb (1961) have validated scale aging for age-2 and age-3 spotted seatrout in Florida, sectioned otoliths have been validated for the age1–3 fish in Florida (Murphy and Taylor 1994) and the age1–4 fish in Texas (Maceina et al. 1987). Validation of populations north of Florida is still needed; however, the Florida and Texas studies suggest that otolith-estimated ages are accurate over a longer age range than the scale-estimated ages. Thus, we suggest that scales should not be used to age spotted seatrout for these reasons: (1) interpreting scale age is fundamentally difficult because of inconsistent marks, (2) the systematic disagreement between scale-based and sectioned-otolith-based ages implies that scales age differently than otoliths at certain ages of the fish, (3) otoliths have been validated for a wider age range, and (4), according to our findings here, sectioned otoliths are superior to scales as aging structures.

Whole otoliths produced mixed results as an aging structure for spotted seatrout. Whole otoliths have not previously been evaluated for this species and, despite their opaque appearance and often misleading surface features, whole-otolith ages showed a very high overall percent agreement with sectioned-otolith ages (87%) and correlated well with the latter ages (r^2 = 0.91). However, reader confidence in whole-otolith readings was lower than for the sectioned otoliths, and whole-otolith-estimated ages were significantly different from sectioned-otolith-estimated ages. As a result, we recommend that whole otoliths not be used to age spotted seatrout.

Acknowledgments

We thank the Chesapeake Bay commercial fishermen and James Owens for helping us obtain samples. We thank A.M. Sipe for aging all structures as reader 2, and H.M. Austin, J.G. Loesch, J.D. Milliman, and J.A. Musick, for reviewing the thesis on which this manuscript is based. Funding for this study was provided by the College of William and Mary, Virginia Institute of Marine Science, and by a Wallop/Breaux Program Grant from the U.S. Fish and Wildlife Service through the Virginia Marine Resources Commission for Federal Aid in Sport Fish Restoration Act, Project No. F-88-R-2. Contribution No. 2434 from the Virginia Institute of Marine Science, School of Marine Science, College of William and Mary, Gloucester Point, VA 23062.

References

Barber, W. E., and G. A. McFarlane. 1987. Evaluation of three techniques to age Arctic char from Alaskan and Canadian waters. Transactions of the American Fisheries Society 116:874–881.

Barbieri, L. R., M. E. Chittenden, Jr., and C. M. Jones. 1994. Age, growth, and mortality of Atlantic croaker, *Micropogonias undulatus*, in the Chesapeake Bay region, with a discussion of apparent geographic changes in population dynamics. U.S. National Marine Fisheries Service Fishery Bulletin 92:1–12.

Barger, L. E. 1985. Age and growth of Atlantic croakers in the Northern Gulf of Mexico, based on otolith sections. Transactions of the American Fisheries Society 114:847–850.

Beamish, R. J., and G. A. McFarlane. 1983. The forgotten requirement for age validation in fisheries biology. Transactions of the American Fisheries Society 112:735–743.

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. Transactions of the American Fisheries Society 119:537–544.

Brothers, E. B. 1983. Summary of round table discussions on age validation. Pages 35–44 *in* E. D. Prince and L. M. Pulos, editors. Proceedings of the international workshop on age determination of oceanic pelagic fishes: tunas, billfishes, and sharks. NOAA Technical Report NMFS 8.

Brown, N. J. 1981. Reproductive biology and recreational fishery for spotted seatrout, *Cynoscion nebulosus*, in the Chesapeake Bay area. Master's thesis. College of William and Mary, Williamsburg, Virginia.

Campana, S. E., and C. M. Jones. 1998. Radiocarbon from nuclear testing applied to age validation of black drum, *Pogonias cromis*. U.S. National Marine Fisheries Service Fishery Bulletin 96:185–192.

Casselman, J. M. 1983. Age and growth assessment of fish from their calcified structures—techniques and tools. Pages 1–17 *in* E. D. Prince and L. M. Pulos, editors. Proceedings of the international workshop on age determination of oceanic pelagic fishes: tunas, billfishes, and sharks. NOAA Technical Report NMFS 8.

Chilton, D. E., and R. J. Beamish. 1982. Age determination methods for fishes studied by the groundfish program at the Pacific Biological Station. Canadian Special Publication of Fisheries and Aquatic Sciences 60.

Cottrell, S. A. 1990. Age and growth of spotted seatrout in the Indian River Lagoon, Florida. Master's thesis. University of Central Florida, Orlando.

Hoenig, J. M., M. J. Morgan, and C. A. Brown. 1995. Analyzing differences between two age determination methods by tests of symmetry. Canadian Journal of Fisheries and Aquatic Sciences 52:364–368.

Iversen, E. S., and D.C. Tabb. 1962. Subpopulations based on growth and tagging studies of spotted seatrout, *Cynoscion nebulosus*, in Florida. Copeia 3: 544–548.

Klima, E. F., and D.C. Tabb. 1959. A contribution to the biology of the spotted weakfish, *Cynoscion nebulosus*, (Cuvier) from northwest Florida, with a description of the fishery. Florida State Board of Conservation, Technical Series 30, Miami.

Lagler, K. F. 1952. Freshwater fishery biology. Brown, Dubuque, Iowa.

Lowerre-Barbieri, S. K., M. E. Chittenden, Jr., and C. M. Jones. 1994. A comparison of a validated otolith method to age weakfish, *Cynoscion regalis*, with the traditional scale method. U.S. National Marine Fisheries Service Fishery Bulletin 92:555–568.

Maceina, M. J., D. N. Hata, T. L. Linton, and A. M. Landry, Jr. 1987. Age and growth analysis of spotted seatrout from Galveston Bay, Texas. Transactions of the American Fisheries Society 116:54–59.

Minitab. 1996. Minitab reference manual, release 11 for Windows. Minitab Inc., State College, Pennsylvania.

Moffett, A. W. 1961. Movements and growth of spotted seatrout, *Cynoscion nebulosus* (Cuvier), in west Florida. Florida State Board of Conservation, Technical Series 36, Miami.

Murphy, M. D., and R. G. Taylor. 1991. Direct validation of ages determined for adult red drums from otolith sections. Transactions of the American Fisheries Society 120:267–269.

Murphy, M. D., and R. G. Taylor. 1994. Age, growth, and mortality of spotted seatrout in Florida waters. Transactions of the American Fisheries Society 123: 482–497.

Pearson, J. C. 1929. Natural history and conservation of redfish and other commercial sciaenids on the Texas coast. U.S. Bureau of Fisheries Bulletin 64: 178–194.

SAS Institute. 1991. SAS language and procedures: usage 2, version 6, 1st edition. SAS Institute, Cary, North Carolina.

Sipe, A. M., and M. E. Chittenden, Jr. 2001. A comparison of calcified structures for aging summer flounder, *Paralichthys dentatus*. U.S. National Marine Fisheries Service Fishery Bulletin 99:628–640.

Stewart, K. W. 1961. Contributions to the biology of the spotted seatrout (*Cynoscion nebulosus*) in the Everglades National Park, Florida. Master's thesis. University of Miami, Coral Gables, Florida.

Sundararaj, B. I., and R. D. Suttkus. 1962. Fecundity of the spotted seatrout, *Cynoscion nebulosus* (Cuvier), from Lake Borgne area, Louisiana. Transactions of the American Fisheries Society 91:84–88.

Tabb, D. C. 1961. A contribution to the biology of the spotted seatrout, *Cynoscion nebulosus* (Cuvier), of east-central Florida. Florida State Board of Conservation, Technical Series 35, Miami.

Wakeman, J. M., and P. R. Ramsey. 1985. A survey of population characteristics for red drum and spotted seatrout in Louisiana. Gulf Research Reports 8:1–8.

Williams, T., and B. C. Bedford. 1974. The use of otoliths for age determination. Pages 114–123 *in* T. B. Bagenal, editor, The ageing of fish. Gresham Press, Old Woking, UK.

Zar, J. H. 1996. Biostatistical analysis, 2nd edition. Prentice Hall, Upper Saddle River, New Jersey.