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Identification of a nonlethal method for aging tautog (*Tautoga onitis*)

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Abstract—Aging of tautog (*Tautoga onitis*) has historically required sacrificing fish to obtain opercula and otoliths. Use of these structures for age determination has hindered researchers from obtaining samples from fish that were to be released alive, as well as from commercially collected fish that are commonly sold whole. In this study we evaluated the use of scales, dorsal-fin spines, pelvic-fin spines, opercula, whole sagittal otoliths, and sectioned sagittal otoliths as structures for age determination of tautog. Our results indicate that pelvic-fin spines provide high-precision age estimates without bias. Dorsal-fin spines had well-defined annuli, but vascularization near the core prevented consistent identification of the first annulus and led to biased ages. Scales were difficult to read and provided highly biased ages in older (>age 7) fish. The precision of age estimations derived from pelvic-fin spines was better than the precision of age estimations derived from the other structures. Pelvic-fin spines provide suitable age estimates for tautog, and these structures can be collected easily from a wider variety of sample sources than can the structures currently being collected for age determination of this species.

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The tautog (*Tautoga onitis*) is a species of fish from the family Labridae that ranges from Nova Scotia (Scott and Scott, 1988) to South Carolina (Grimes et al., 1982). It is a commercially and recreationally important species from Massachusetts to Virginia (ASMFC[1]). Tautog grow to approximately 90 cm in total length (TL) and 10.2 kg in weight (Bigelow and Schroeder, 1953). It is a slow growing and long-lived species that reaches maturity at age 3 (Hostetter and Munroe, 1993) and has been estimated to live up to age 34 (Cooper, 1965, 1967; Hostetter and Munroe, 1993). Cooper (1965, 1967) and Hostetter and Munroe (1993) were able to estimate the age of tautog from marks on their opercula. Hostetter and Munroe (1993) were also able to justify the assumption that marks on the opercula were deposited annually and, therefore, justify the use of those marks for age determination through marginal increment analysis. For these reasons, opercula have been the primary and recommended structure for estimating the age of tautog (ASMFC[1]).

In 2012, representatives from 10 different laboratories attended a workshop on aging tautog (ASMFC[2]). Although staff at the majority of the laboratories had considerable experience aging tautog, with the use of the operculum as the structure for determining age, and staff at a few of the laboratories had experience with otoliths of tautog, the precision of age estimates between laboratories was similar for both structures. The results from that workshop indicated that, with increased experience by the staff, the use of sectioned otoliths from tautog may yield age estimates of higher precision than the use of opercula. After that workshop, sectioned otoliths have been used as a supplementary method for age determination (ASMFC[2]).

Although current methods for age determination of tautog are based on opercula and otoliths, multiple structures have been used to age other fish species, including opercula, otoliths, vertebrae, fin rays, fin spines, and scales (Beamish and McFarlane, 1987; Panfili et al., 2002). Fin rays, fin spines, and scales have the distinct advantage in that their collection is nonlethal. Phelps et

[1] ASMFC (Atlantic States Marine Fisheries Commission). 2015. Tautog benchmark stock assessment and peer review reports, 283 p. AFMFC, Arlington, VA. [Available at website.]

[2] ASMFC (Atlantic States Marine Fisheries Commission). 2012. Proceedings of the tautog ageing workshop, 88 p. AFMFC, Arlington, VA. [Available at website.]

al. (2007) and Watkins et al. (2015) were able to successfully determine the age of common carp (*Cyprinus carpio*) using cross sections of fin rays. Carbines (2004) compared ages of blue cod (*Parapercis colias*) derived from otoliths and fin spines and determined that spines yielded precise estimates. In comparisons of otoliths, dorsal-fin spines, and teeth of the leopard coralgrouper (*Plectropomus leopardus*), Hobbs et al. (2014) found that the most cost- and time-efficient structure for age determination was the dorsal-fin spine. Fin rays or spines also have been found to be useful by Sylvester and Berry (2006) for white sucker (*Catostomus commersonii*), by Zymonas and McMahon (2009) for bull trout (*Salvelinus confluentus*), by Burton et al. (2015) for gray triggerfish (*Balistes capriscus*), by Keller Kopf et al. (2010) for billfishes (*Kajikia spp*.), and by Murie et al. (2009) for Atlantic goliath grouper (*Epinephelus itajara*).

Management recommendations for tautog stocks are a product of the stock assessment process, which currently is based on values derived from an age structured assessment model. The benchmark stock assessment for tautog, conducted in 2015 by the Atlantic States Marine Fisheries Commission (ASMFC) and incorporating an external peer review, gave evidence that tautog in all management areas (Southern New England, which includes Massachusetts and Connecticut; New York–New Jersey; and Delaware, Maryland, and Virginia) were overfished and that overfishing was occurring for the stock in Southern New England (ASMFC[1]). The assessment came with several research recommendations that included 1) examination of differences in tautog growth rates by using data that are representative of the full size–age structure of the species, 2) expanded biological sampling of the commercial catch (including collection of structures for age estimates), 3) enhanced collection of age information for smaller fish (<20 cm TL), and 4) maintaining and improving the precision of age readings between state agencies that are estimating the ages of tautog (ASMFC[1]).

To address the aforementioned research recommendations from this stock assessment is difficult with current aging methods, primarily because removal of opercula and otoliths from tautog require sacrificing and disfiguring the fish. In Massachusetts, many of the commercially captured fish are sold whole, both alive and dead. Many of the commercial dealers do not want their fish damaged by the removal of opercula or otoliths; therefore, the collection of age samples from the commercial harvest is not feasible without the expense of purchasing fish. Identification of a structure that could be used for age determination without the need of sacrificing or altering the marketability of the fish would enable more samples to be collected across a variety of sources. In this study, the precision of age estimates generated from multiple structures was examined to establish an alternative to the current use of opercula and sectioned otoliths as the primary aging structures.

Materials and methods

Tautog were collected by rod and reel, as well as from the trawl survey of the Massachusetts Division of Marine Fisheries in the waters of Buzzards Bay, Massachusetts, in May, September, and October 2014. Specimens were transported frozen or on ice to the Annisquam River Marine Fisheries Station of the Massachusetts Division of Marine Fisheries in Gloucester, Massachusetts, for further processing. Total length in millimeters, weight in grams, and sex were recorded. Scales were removed from the side of each fish just posterior to the pectoral fin and placed in an envelope. The fourth dorsal-fin spine and the first pelvic-fin spines were removed with wire cutters as close to the body of the fish as possible and stored frozen in plastic bags. Both opercula were removed with a knife and stored frozen in plastic bags. Sagittal otoliths were removed with a serrated knife and fine forceps and then rinsed, dabbed dry on a paper towel, and stored dry in microcentrifuge tubes.

Opercula were placed into boiling water for 2 min and a small brush was used to remove any flesh still adhering to the bone. Opercula were allowed to air dry for a minimum of 24 h before being examined without magnification by using a combination of reflected and transmitted light. Annuli were defined as alternating pairs of translucent and opaque growth zones. Both left and right opercula were examined together to aid in discriminating between annuli and checks. As noted by both Cooper (1967) and Hostetter and Munroe (1993), the thickness of the bone in some opercula obscured the area of earliest growth, occasionally hiding the first annulus.

Dorsal- and pelvic-fin spines were placed into boiling water for 2 min, and a small brush was used to remove any flesh still adhering to the spines. Spines were allowed to air dry for a minimum of 24 h before being placed in bullet molds and embedded in epoxy. The epoxy block with the embedded spine was sectioned with an IsoMet Low Speed Saw[3] (Buehler, Lake Bluff, IL) affixed with 4 blades and a 0.75-mm-thick spacer between each blade. Sections were affixed sequentially (from the spine base to the tip) to labeled glass microscope slides with Flo-Texx liquid coverslip (Thermo Fisher Scientific, Waltham, MA). Sections of pelvic- and dorsal-fin spines were examined through a compound microscope with transmitted light at 100× magnification. Each section from each spine was examined to determine the age of the structure. Annuli were considered to consist of alternating pairs of opaque and translucent growth zones.

Whole sagittal otoliths were cleaned with water as needed before being placed in a black dish filled with mineral oil and were viewed through a dissecting microscope with reflected light at 30–40× magnification.

[3] Mention of trade names or commercial companies is for identification purposes only and does not imply endorsement by the National Marine Fisheries Service, NOAA.

Left and right otoliths were examined side by side to aid in discerning between annuli and checks. The distal surface of the otoliths provided the clearest view of the annuli, which were identified as alternating bands of opaque and translucent growth zones.

One sagittal otolith from each fish was randomly selected for sectioning. Otoliths that showed any sign of malformation were not sectioned. Otoliths were placed on a porcelain tray that had been heated to 400°C for approximately 30 s or until they reached a caramel brown color. Otoliths were then embedded in epoxy in silicon bullet molds, and each epoxy block was marked with a pencil through the core of the otolith perpendicular to the sulcal groove. This mark was used as a guide to cut a section with an IsoMet Low Speed Saw affixed with 2 blades and a 0.5-mm-thick spacer between them. The resulting section was affixed to a microscope slide with a Flo-Texx liquid coverslip and labeled. If the first otolith produced an undesirable section, the second otolith was cut. Otolith sections were examined through a compound microscope with transmitted light at 100× magnification. Annuli were counted as alternating bands of opaque and translucent growth zones.

Scales were briefly soaked in water to soften any attached tissue before being rubbed clean with a paper towel. Impressions of the scales were made by pressing them into acetate sheets for 3 min with a heat press set at 100°C and with 5.5 metric tons of pressure. Impressions were made for scales in which the anterior portion of the scale appeared to make a "v" shape, signaling a nonregenerated scale. Regenerated and nonregenerated scales were counted to create an estimation of the percentage of regenerated scales. Scale impressions were examined under a microfiche reader at 25× magnification. Breakages in the circuli that continued around the anterior portion of the scale were counted as the outer margin of annual growth zones. True annuli were differentiated from false annuli by confirming that the circuli breakages continued through the transitional area between the anterior and posterior portion of the scale.

All ages were assigned on the basis of year class. Fish captured in May, before annulus deposition was complete, had the edge counted as the final annulus. Fish captured in September and October had growth past the final annulus; therefore, the edge was not counted. In all structures, the outside edge of the winter growth was treated as the end of one annual growth zone and the beginning of the next. All structures were independently assigned an age by 2 readers and each individual read each structure twice. All ages were assigned without knowledge of fish size, sex, or previously assigned ages. When ages assigned for a structure of a fish did not agree between the 2 readers, both readers examined the structure together and reached a consensus-based age. A final age for each fish was reached by the 2 readers considering consensus-based ages of all structures, as well as the quality of each structure. For example, a fish determined to be age 7 with the use of opercula, age 8 with the use of whole otolith, age 8 with the use of sectioned otolith, age 7 with the use of dorsal-fin spine, age 8 with the use of pelvic-fin spine, and age 6 with the use of a scale would be assigned a final age of 8 years if the opercula was thick at the base, the dorsal-fin spine was vascularized, and the scale was of poor quality.

Precision of readings was measured by using percent agreement and coefficient of variation (CV) (Chang, 1982). Estimates of precision were generated for comparisons 1) within reader for each structure, 2) between readers for the first reading of each structure, 3) between readers for the second reading of each structure, 4) between consensus-based ages for sectioned otoliths and consensus-based ages for each other structure, and 5) between consensus-based ages for each structure and final ages assigned to a fish. The following equation was used to calculate CV, as shown in Campana (2001):

$$CV_j = 100\% \times \frac{\sqrt{\sum_{i=1}^{R} \frac{\left(x_{ij} - x_j\right)^2}{R-1}}}{x_j}.$$

This equation gives the CV for the jth fish,

where x_{ij} = the ith age estimate of the jth fish;

x_j = the average age estimate of the jth fish; and

R = the number of times that that a fish was read.

For all CV analyses, consensus-based ages were treated as a single reading. Coefficients of variations listed in this article were averaged across all fish aged.

Tests of symmetry (Bowker, 1948; Evans and Hoenig, 1998) were used to examine bias between consensus-based ages for each structure and the final age assigned to the fish, as well as between consensus-based ages for sectioned otoliths and consensus-based ages for each other structure. McBride (2015) suggested that Bowker's test (Bowker, 1948) has a lower type-1 error rate at high levels of precision than the type-1 error rate with Evans and Hoenig's test (Evans and Hoenig, 1998). We, therefore, used Bowker's test when the CV was less than 5% and Evans and Hoenig's test when the CV was above 5%.

Results

In this study, 119 tautog were collected and analyzed (52 female, 51 male, and 16 of unknown sex). Fish ranged from 35 mm TL to 506 mm TL (average: 313 mm TL). Males were slightly larger on average (346 mm TL) than females (335 mm TL), and fish of both sexes were larger than fish of unknown sex (140 mm TL).

All structures examined contained annuli (Fig. 1). Scales yielded ages 0–10, opercula yielded ages 0–11, and all ages estimated for other structures ranged from 0 to 12 years. For all structures, average consensus-based ages of structures agreed within 1 year of

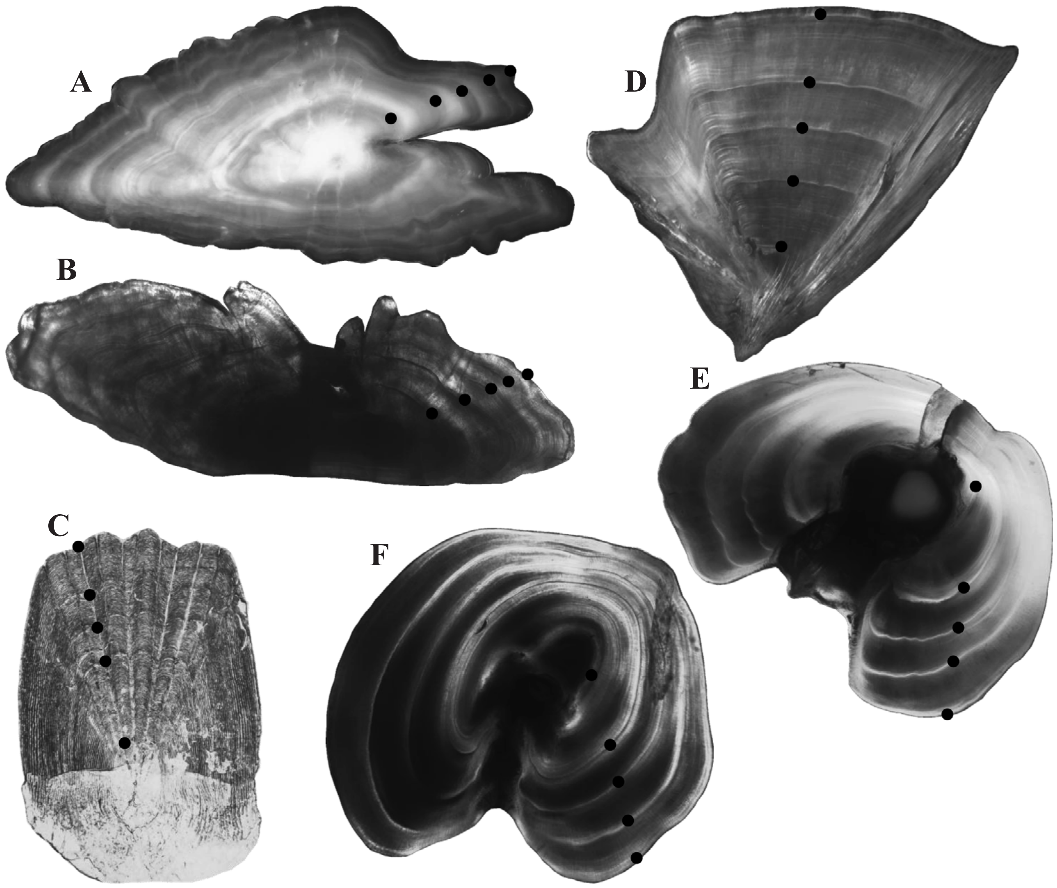

Figure 1

Multiple structures were used in this study for age determination of tautog (*Tautoga onitis*) captured in Buzzards Bay Massachusetts, in 2014. This figure shows (**A**) a whole sagittal otolith, (**B**) a sectioned sagittal otolith, (**C**) a scale, (**D**) an operculum, (**E**) a dorsal-fin spine, and (**F**) a pelvic-fin spine from an age-5 tautog captured in June 2014. Black dots represent the location of annuli.

the final ages of fish up to final age of 7 years. Beyond age 7, ages derived from scales diverged by more than a year, and ages derived from whole otoliths diverged at the final age of 12 years (Table 1). The percentage of regenerated scales ranged from an average of 59% at age 1 to an average of 91% at age 11 (average estimate: 74.3% for all fish examined).

Tests of symmetry against ages derived from sectioned otoliths yielded no bias for ages from whole otoliths, dorsal-fin spines, or pelvic-fin spines. Opercula and scales produced biased ages compared with ages from sectioned otoliths. The bias seen in ages from scales increased with the age of the fish, whereas the bias observed in ages from opercula appeared to be systematic because the age for a portion of the fish was underestimated by 1 year (Fig. 2). Comparisons between final ages and consensus-based ages for structures showed that only pelvic-fin spines and whole otoliths yielded ages that were not biased in comparison with the final ages determined for fish (Fig. 2). All other structures yielded ages that were biased younger than the final ages (Fig. 2). The bias in age estimates from scales became greater with fish age, whereas the other structures appeared to produce ages with a systematic bias of underestimating a portion of the fish by 1 year.

Within-reader comparisons showed reader 1 had the best precision (CV=1.51%, 89.9% agreement) with pelvic-fin spines (Table 2). Reader 2 had the best precision (CV=2.39%, 80.7% agreement) with opercula, followed closely by that for pelvic-fin spines (CV=2.69%, 79.0% agreement). Between-reader precision was best in the second reading of whole otoliths (CV=1.96%, 84.0% agreement). For 4 of the 6 structures, between-reader precision increased between the first and second readings. Precision decreased only between readings for scales (CV changed from 6.99% to 8.97%) and pelvic-fin spines (CV changed from 4.68% to 5.28%).

Table 1

Average age and sample size for each type of structure examined for each final age assigned for tautog (*Tautoga onitis*) collected in Buzzards Bay, Massachusetts, in 2014. Final ages were assigned by 2 age readers taking into account ages assigned, and quality of all structures examined for each fish. Ages for each structure are ages based on the consensus of 2 readers, each performing 2 readings. Standard errors of the mean appear in parentheses after the average ages.

Final age	*n*	Scale	Opercula	Dorsal-fin spine	Pelvic-fin spine	Whole otolith	Sectioned otolith
0	6	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
1	6	1.17 (0.17)	1.50 (0.22)	1.00 (0.00)	1.17 (0.17)	1.00 (0.00)	1.00 (0.00)
2	3	2.33 (0.33)	2.00 (0.00)	2.33 (0.33)	2.00 (0.00)	2.00 (0.00)	1.67 (0.33)
3	3	2.67 (0.33)	2.33 (0.33)	2.67 (0.33)	3.33 (0.33)	3.00 (0.00)	2.67 (0.33)
4	5	4.00 (0.32)	4.00 (0.00)	4.00 (0.00)	4.20 (0.20)	4.00 (0.00)	4.00 (0.00)
5	11	4.91 (0.16)	4.82 (0.12)	4.82 (0.12)	5.09 (0.09)	5.00 (0.00)	5.00 (0.00)
6	14	5.71 (0.13)	5.71 (0.16)	5.79 (0.11)	6.00 (0.00)	5.93 (0.07)	6.00 (0.00)
7	32	6.53 (0.13)	6.69 (0.08)	6.94 (0.04)	6.97 (0.03)	7.00 (0.04)	6.97 (0.05)
8	20	6.70 (0.16)	7.45 (0.14)	7.60 (0.15)	8.00 (0.07)	7.75 (0.12)	7.70 (0.11)
9	6	8.17 (0.31)	8.33 (0.21)	8.67 (0.21)	9.00 (0.00)	9.00 (0.00)	8.50 (0.22)
10	9	7.89 (0.42)	9.22 (0.22)	9.56 (0.18)	10.00 (0.17)	9.78 (0.15)	9.56 (0.29)
11	2	5.50 (0.50)	11.00 (0.00)	10.00 (0.00)	11.00 (0.00)	10.50 (0.50)	11.00 (0.00)
12	2	8.50 (1.50)	11.00 (0.00)	11.50 (0.50)	12.00 (0.00)	10.50 (0.50)	11.00 (0.00)

Consensus-based ages from sectioned otoliths had the best precision when compared with consensus-based ages from whole otolith ages (CV=2.11%, 87.4% agreement), followed by consensus-based ages from pelvic-fin spines (CV=2.99%, 79.0% agreement). Consensus-based ages from pelvic-fin spines had better precision for final ages than any other structure (CV=1.17%, 92.4% agreement). The CV estimate for comparisons between final ages and consensus-based ages from whole otoliths was identical to that for consensus-based ages from pelvic-fin spines, but the agreement was not as high (CV=1.17%, 87.4% agreement) (Fig. 2).

Discussion

In this study, we made age determinations based on the examination of multiple structures from tautog in an effort to find a nonlethal aging method for this species and, thereby, increase the availability of sample sources. Current standard aging techniques for tautog are based on opercula and otoliths, which necessitates sacrificing and damaging the fish. Scales were evaluated as possible aging structures for tautog by Cooper (1967) and Hostetter and Munroe (1993). Before this study, no one had evaluated fin spines for aging tautog.

Fin spines have proven useful for aging a variety of fish species (e.g., Carbines, 2004; Hobbs et al., 2014; Burton et al., 2015; Watkins et al., 2015). Among the structures that could be removed in a nonlethal way, we found pelvic-fin spines to be the best structure for aging tautog. Pelvic-fin spines had strong annular marks (Fig. 1), yielded high-precision age estimates (Table 2) and a lack of bias (Fig. 2). The precision of age estimates was higher for pelvic-fin spines in comparison with final ages than from any other structure tested. Furthermore, with the pelvic-fin spines used in this study, we did not find the core to be obscured by vascularization as has been seen in fin spines of other species (e.g., Keller Kopf et al., 2010; Kopf and Davie, 2011; Landa et al., 2015). Although the tautog in our study reached only age 12, we believe that the growth bands in the spines would be discernible in tautog of considerably older ages. To support this assumption, we examined a whole otolith, sectioned otolith, opercula, and a pelvic-fin spine from an 895-mm-TL tautog. Using the opercula and pelvic-fin spine, we determined that the fish was age 20. The whole and sectioned otoliths, however, indicated that the fish was age 21 (senior author, unpubl. data). Annuli on all structures examined were clear all the way to the edge. The discrepancy in ages between structures is presumed to be related to difficulty in finding the first annulus.

Dorsal-fin spines had strong annular marks that were very similar to those on pelvic-fin spines (Fig. 1), but the dorsal-fin spines had more vascularization near the core than the pelvic-fin spines. The vascularized core left the readers unsure at times whether the first visible annulus was the age-1 or the age-2 annulus. This uncertainty led to decreased precision and systematic bias in the age estimates.

Scales have been a primary structure for nonlethal age determination in many other fish species (e.g., Penttila and Dery, 1988; Welch et al., 1993; Secor et al., 1995; Elzey et al.[4]), but our data support the find-

[4] Elzey, S. P., K. J. Trull, and K. A. Rogers. 2015. Massachusetts Division of Marine Fisheries Age and Growth Laboratory: fish aging protocols. Massachusetts Div. Mar. Fish. Tech. Rep. TR-58, 43 p. [Available at website.]

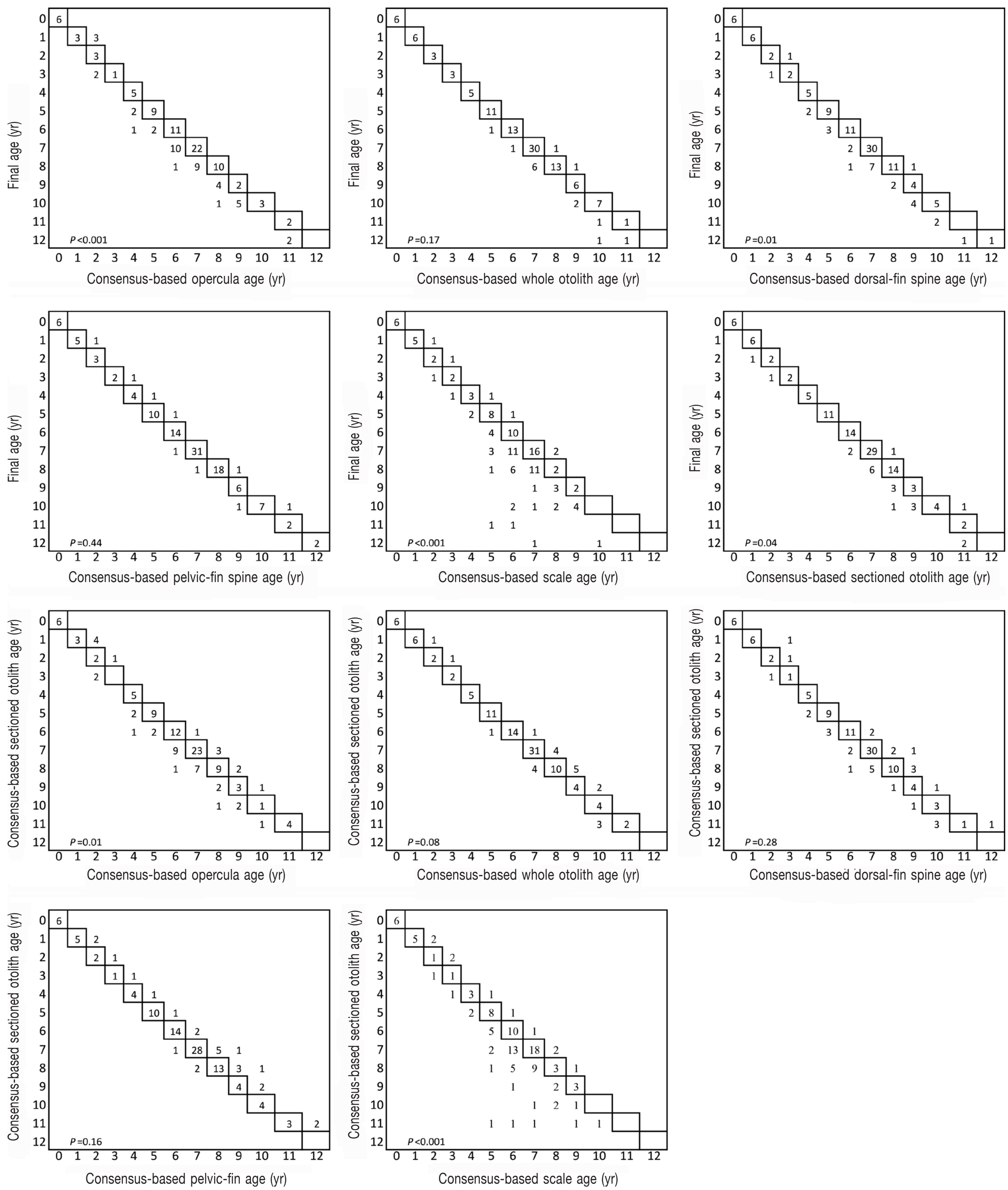

Figure 2

Age bias plots for tautog (*Tautoga onitis*) collected in Buzzards Bay, Massachusetts. Final age versus consensus-based age for each structure, as well as sectioned otolith consensus-based age versus consensus-based age for each other structure are presented. Numbers within each plot represent the number of fish assigned each age. *P*-values are the results of Bowker's (1948) (whole otoliths, dorsal-fin spine, pelvic-fin spine, and sectioned otoliths) or Evans and Hoenig's (1998) (opercula and scales) test of symmetry.

Table 2

Percent coefficient of variation (CV%) and percent agreement were used to examine the precision of age estimates for tautog (*Tautoga onitis*) collected in 2014 in Buzzards Bay, Massachusetts. Comparisons were made within reader for each structure, between readers for each of 2 readings of each structure, between consensus-based readings from sectioned otoliths and consensus-based readings from other structures, and between consensus-based readings from each structure and final readings.

Comparison	Aging structure	CV%	Agreement (%)
Between readings, reader 1	Opercula	4.02	82.4
	Whole otolith	1.58	84.9
	Dorsal-fin spine	3.02	79.0
	Pelvic-fin spine	1.51	89.9
	Scale	5.94	65.5
	Sectioned otolith	1.93	84.0
Between readings, reader 2	Opercula	2.39	80.7
	Whole otolith	3.05	76.5
	Dorsal-fin spine	3.12	76.5
	Pelvic-fin spine	2.69	79.0
	Scale	6.56	56.3
	Sectioned otolith	7.55	69.5
Between readers, reading 1	Opercula	4.91	79.8
	Whole otolith	2.60	79.0
	Dorsal-fin spine	4.36	71.4
	Pelvic-fin spine	4.68	64.7
	Scale	6.99	54.6
	Sectioned otolith	8.53	66.1
Between readers, reading 2	Opercula	3.85	79.0
	Whole otolith	1.96	84.0
	Dorsal-fin spine	3.32	76.5
	Pelvic-fin spine	5.28	65.5
	Scale	8.97	45.4
	Sectioned otolith	3.92	73.1
Consensus-based readings from sectioned otolith vs. consensus-based readings from other structures	Opercula	5.55	64.7
	Whole otolith	2.11	81.5
	Dorsal-fin spine	3.52	73.9
	Pelvic-fin spine	2.99	79.0
	Scale	8.61	48.7
Consensus-based readings from each structure vs. final readings	Opercula	5.01	64.7
	Whole otolith	1.17	87.4
	Dorsal-fin spine	2.60	77.3
	Pelvic-fin spine	1.17	92.4
	Scale	8.79	47.1
	Sectioned otolith	2.06	82.4

ings of Cooper (1967) and Hostetter and Munroe (1993) that indicate that scales are not suitable for use with tautog. The percentage of regenerated scales ranged from an average of 59% at age 1 to an average of 91% at age 11 (overall average: 74.3%). The large amount of regenerated scales in this species made it difficult to attain an adequate sample for age determination. Additionally, annuli on scales were not well defined (Fig. 1), and discrimination between true and false annuli was problematic, all of which led to poor precision and bias toward underestimating ages of fish older than age 7 (Table 1, Fig. 2).

Currently, the majority of age data for tautog is gathered from the examination of opercula (ASMFC1). Cooper (1967) and Hostetter and Munroe (1993) were both able to use marginal increment analysis to justify that growth marks on opercula were deposited annually. We found that growth marks on opercula were distinct (Fig. 1), and we were able to achieve good precision with age estimates (CV<5%) between and within readers (Table 2). However, in the comparison between final ages of fish and consensus-based ages for opercula, the CV was slightly higher (5.01%) and we found significant bias. Furthermore, we found a similar CV (5.55%) and bias between consensus-based ages from sectioned otoliths and consensus-based ages from opercula. The bias we observed in our data appears to be systematic and most prevalent in fish age 4 and older (Fig. 2). The most likely explanation for such a bias would be a failure to correctly identify the first annulus because of the thickness of the bone in older fish. As was found by both Cooper (1967) and Hostetter and Munroe (1993), this thickening can obscure the first annulus.

Otoliths can be viewed whole or cross-sectioned and have been the most reliable structure for age determination in many fish species (e.g., Barnes and Power, 1984; Boxrucker, 1986; Welch et al., 1993; Secor et al., 1995; Sipe and Chittenden, 2001; Robillard et al., 2009; Zymonas and McMahon, 2009; Stolarski and Sutton, 2013; Elzey et al., 2015). In this study, we examined whole and sectioned sagittal otoliths. Ages derived from whole otoliths provided good precision within readers, between readers, and between consensus-based ages for structures and final ages of fish (Table 2). No evidence of bias was observed for the consensus-based ages from whole otoliths and the consensus-based ages from sectioned otoliths or final ages (Fig. 2). Hostetter and Munroe (1993) found that whole otoliths were useful only in young fish because, as the otolith grew thicker, the annuli near the core of the otolith became obscured; however, we did not often encounter this problem. As the age of the fish increased and growth increments decreased, we found it increasingly more difficult to distinguish between annuli near the edge of the otolith. The oldest age assigned as a final age in this study was age 12, but ages from whole otoliths were assigned to age 11. A larger sample size that includes older fish would give us the ability to determine where ages from whole otoliths diverge from ages determined from other, more accurate structures.

Precision of the consensus-based ages from sectioned otoliths in comparison with final ages of fish was good (CV=2.06%). Although bias was detected, the percent agreement was more than 80%, indicating that the bias may have been less severe than the bias seen from other structures. Because otoliths of tautog are small (~5-mm in length), cutting a section exactly through the origin and getting the sectioning plane correct is difficult. If the cut is not made correctly through the core, the first annulus can be missed. Because the sections are aged with transmitted light, a section that is not perpendicular to the annual growth can lead to difficulties in interpreting annuli close to the edge. Both of these problems that can be encountered with sectioned otoliths can introduce bias.

Before this study, age determination of tautog was based on methods that require sacrificing fish to harvest the structures used for aging. Removal of these structures alters the appearance of the fish, thereby affecting the marketability of a species that is largely sold as whole fish. The need to kill and alter fish to obtain age data negatively affects the sample sources available and the costs associated with collecting adequate samples from juvenile and commercially captured fish. The use of pelvic-fin spines for age determination should allow samples to be taken from more diverse sources covering a wider selection of the stock of tautog. Strong annuli on the pelvic-fin spines also lead to high-precision age estimations. The availability of high-precision age data will strengthen the stock assessment of this species. The use of pelvic-fin spines as a primary structure for age determination would allow researchers to more easily gather the information that is necessary to successfully manage tautog with an aged-based assessment model.

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