Age Estimate Precision of Bluegill and Redear Sunfish Using Broken and Whole Otoliths

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Abstract: Age estimate precision is essential for fisheries managers when evaluating age structure, growth, and mortality rates for fish populations; therefore, establishing the method with the greatest precision for a particular species is critical. We compared ages estimated from broken and whole otoliths of 693 bluegill (*Lepomis macrochirus*) and 432 redear sunfish (*L. microlophus*) from five small impoundments (6.5–101 ha) in Oklahoma. Bluegill ages ranged from 0 to 10, and redear sunfish ranged from 0 to 9. We observed high agreement and precision between readers for ages estimated using broken and whole otoliths for bluegill and redear sunfish (percent agreement = 88%–100%; mean CV = 0–5%; average percent error = 0–3.5%). Although rare, when bias was observed, the ages of older fish (≥age 6) of both species were underestimated using whole otoliths compared to broken otoliths, and this was more noticeable when evaluating between-reader precision rather than final consensus ages. Agreement between final consensus ages was high for bluegill (95%–99%) and redear sunfish (98%–100%) across populations. Sunfish growth rates may be sufficient to prevent annuli from constricting on the otolith edge in southern U.S. waters, allowing the use of whole otoliths for age estimation. Small differences in aging precision were observed between species and among lakes, suggesting that aging precision should be evaluated on a case-by-case basis to ensure accurate population parameters are calculated using a particular aging method.

Key words: sagitta, reader agreement, *Lepomis macrochirus*, *Lepomis microlophus*

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In many aquatic systems throughout the United States, sunfish (*Lepomis* spp.) populations create very popular recreational fisheries (Sammons et al. 2006). When assessing sunfish population dynamics (growth, mortality, and recruitment) for management of these species, it is essential to have accurate age information (Mantini et al. 1992). It is largely accepted that otoliths are the most reliable and accurate aging structure for most species of fish (Spurgeon et al. 2015). Like other centrarchids, otoliths are the preferred structure for estimating sunfish age (Schramm 1989, Mantini et al. 1992, Crawford and Allen 2006, Sammons et al. 2006, Kowalewski et al. 2012), as age estimates from this structure are considered more accurate compared to other aging structures (Hoxmeier et al. 2001). Annulus formation has been validated in sagittal otoliths of bluegill (*Lepomis macrochirus;* Schramm 1989, Hales and Belk 1992, Mantini et al. 1992) and redear sunfish (*L. microlophus;* Mantini et al. 1992), making this structure appropriate for estimating ages.

Whole-viewed otoliths have been used to estimate ages of centrarchid species, including bluegill (Hoxmeier et al. 2001, Kowalewski et al. 2012), crappie (*Pomoxis* spp.; Schramm and Doerzbacher 1982, Boxrucker 1986, Maceina and Betsill 1987, Ross et al. 2005), and black bass (*Micropterus* spp.; Hoyer et al. 1985, Long and Fisher 2001, Buckmeier and Howells 2003, Fernando et al. 2013). An advantage of whole-viewed otoliths is the relatively minimal preparation needed to obtain age estimates. However, examination of whole otoliths may result in inaccurate age estimates for older fish or for species or populations that are slow growing, resulting in the need to break or section otoliths to generate precise age estimates (Hales and Belk 1992, Long and Fisher 2001, Buckmeier and Howells 2003, Edwards et al. 2005, Fernando et al. 2013). Many aging protocols dictate that otoliths be sectioned at a certain age to provide the most precise age estimates (Quist et al. 2012). The age chosen to switch to sectioned otoliths varies but is usually chosen to approximate the age where annuli are expected to begin crowding near the otolith edge, making delineation of individual rings difficult. Hales and Belk (1992) and Edwards et al. (2005) found that bluegill otoliths should be sectioned for fish older than age 5, but studies aging black bass otoliths have used various ages to begin sectioning, and is typically driven by population-specific growth rates (Hoyer et al. 1985, Buckmeier and Howells 2003, Fernando et al. 2013). Conversely, ages are often assigned to crappie collected from southern U.S. waters using only whole otoliths, because annuli are easily distinguished and these fish have short longevity, resulting in accurate and precise age estimates (Schramm and Doerzbacher 1982, Boxrucker 1986, Ross et al. 2005).

Sunfish in southern U.S. populations are relatively short lived and may have fast growth rates (Ott et al. 2001, Sammons et al. 2006). Therefore, use of whole-viewed otoliths may result in acceptable aging precision of these species without the added effort required for sectioned otoliths. Furthermore, aging precision has not been evaluated for redear sunfish, and because age estimation is a critical component in describing population dynamics, there is a need to determine the appropriate aging method for this species. Because the use of otoliths is considered the most reliable aging technique (Maceina et al. 2007, Phelps et al. 2017), we compared precision using two otolith methods. Therefore, the objective of this study was to compare aging precision between two otolith preparation methods (whole view and broken) for bluegill and redear sunfish collected from five Oklahoma populations.

Methods

Bluegill and redear sunfish were collected from Lake Elmer, New Spiro City Lake, Pawhuska Lake, Sparks Lake, and Stilwell City Lake, Oklahoma. The study lakes ranged in size from 6.5–101 ha. Sunfish were collected during October–November 2016 using standardized fyke nets (Miranda and Boxrucker 2009) set at randomly selected sites to ensure that all nearshore habitat types were surveyed. During sampling, all bluegill and redear sunfish were measured for TL (mm). For aging purposes, we attempted to collect a sample of 10 fish per 10 mm length group (for each species) to ensure that all size and age classes were represented in the sample. In the laboratory, each fish was measured for TL and weight (g), and sagittal otoliths were removed for age estimation.

Each otolith preparation method was evaluated separately and in random order by two independent readers to assign age estimates (Hoff et al. 1997). Readers had no knowledge of the size or sex of an individual fish or the other reader's age estimates. Both readers had experience aging centrarchids using otoliths, reader 1 with crappie (four years) and reader 2 with black bass and sunfish (13 years). First, all fish were assigned age estimates using otoliths in whole view. Once all whole-view age estimates were attained, otoliths were then broken through the nucleus in the transverse plane, sanded with wetted 600-grit sandpaper, and polished with 2000-grit wet/dry sandpaper. If an otolith was broken poorly or was too robust to break, it was ground to the nucleus using a Dremel tool with a silicon carbide grinding stone (No. 85422, Dremel, Racine, Wisconsin) and polished. Both whole-view (concave side up) and broken otoliths (stood polished side up) were placed in a black, clay filled dish, submersed in water, and then viewed with a fiber optic light source under a dissecting microscope. When there was a disagreement between readers on an estimated age, the otolith was reexamined by both readers and a final consensus age estimate was determined.

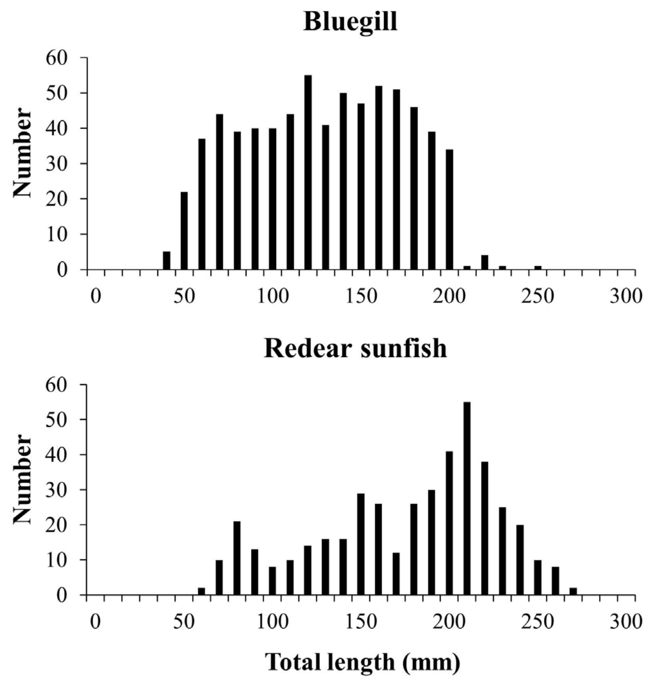

Figure 1. Length distribution of bluegill and redear sunfish aged using broken and whole otoliths.

Precision between readers was analyzed between structures using data collected by each reader independently and was calculated by percent reader agreement (Campana et al. 1995), average percent error (APE; Beamish and Fournier 1981), CV (Chang 1982), and paired *t*-tests (Hurley et al. 2004). Age-bias plots were generated to evaluate consistency among paired age estimates and compared against final consensus ages for broken and whole otoliths (Campana et al. 1995). Differences between final consensus ages were evaluated using paired *t*-tests. All statistical results were considered significant at $P < 0.05$.

Results

Totals of 693 bluegill and 432 redear sunfish were collected for age estimation; aged bluegill ranged 42–251 mm TL and redear sunfish ranged 66–276 mm TL (Figure 1). Bluegill age estimates ranged from 0 to 10 for whole and broken otoliths, and redear sunfish age estimates ranged from 0 to 9 for whole and broken otoliths.

Precision was high (i.e., CVs were low) between readers for bluegill (CV = 0.08%–3.9%, 2.6% for all lakes combined) and redear sunfish (CV = 0–5%, 2.1% for all lakes combined; Table 1, Figure 2) using whole otoliths. Precision was even higher between

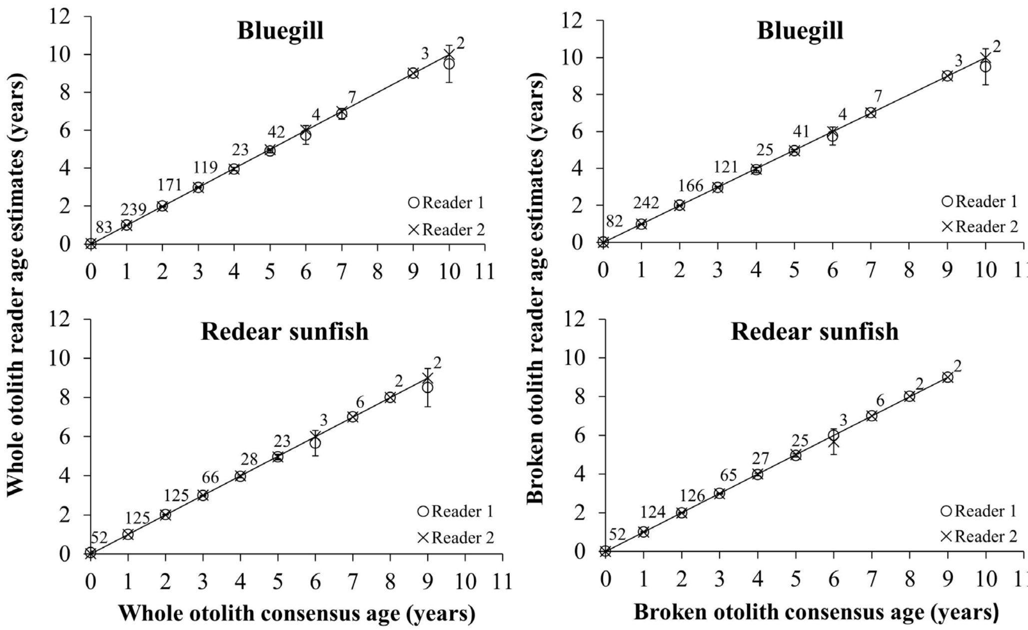

Figure 2. Age-bias plots comparing reader 1 and reader 2 age estimates from whole and broken otoliths to final consensus age estimates for whole and broken otoliths for bluegill and redear sunfish collected from five small impoundments in Oklahoma. Error bars represent the 95% confidence interval. The diagonal line represents 100% agreement between structures. Numbers above each point represent sample size of that age group.

Table 1. Percent reader agreement, average percent error (APE), mean CV, and outcomes of paired *t*-tests for ages estimated between whole and broken otoliths of bluegill and redear sunfish collected from five small impoundments in Oklahoma. N/A = could not be tested because readers were in full agreement.

Lake	Species	Aging method	*n*	% Agreement	APE	Mean CV (%)	*t*	df	*P*
Elmer	Bluegill	Whole	94	95.8	0.9	1.2	0.00	93	1.000
		Broken	94	91.5	1.6	2.2	0.71	93	0.482
	Redear	Whole	58	87.9	1.8	2.6	0.38	57	0.709
		Broken	58	96.6	0.7	1.0	0.00	57	1.000
New Spiro	Bluegill	Whole	160	97.5	1.6	2.2	1.00	159	0.319
		Broken	160	96.9	1.2	1.7	−0.45	159	0.656
	Redear	Whole	113	96.5	3.5	5.0	2.03	112	0.045
		Broken	113	99.1	0.3	0.4	1.00	112	0.319
Pawhuska	Bluegill	Whole	83	97.6	0.6	0.8	0.00	82	1.000
		Broken	83	94.0	1.8	2.6	1.35	82	0.181
	Redear	Whole	19	89.5	0.8	1.1	−1.46	18	0.162
		Broken	19	94.7	0.5	0.7	1.00	18	0.331
Sparks	Bluegill	Whole	169	94.1	2.3	3.2	0.63	168	0.529
		Broken	169	95.9	0.8	1.1	−0.38	168	0.710
	Redear	Whole	99	100.0	0.0	N/A	N/A	N/A	N/A
		Broken	99	99.0	0.3	0.5	1.00	98	0.320
Stilwell	Bluegill	Whole	187	93.6	2.7	3.9	−1.16	186	0.249
		Broken	187	94.7	2.6	3.7	−1.91	186	0.058
	Redear	Whole	143	98.6	0.8	1.1	−1.42	142	0.158
		Broken	143	96.5	1.8	2.3	−0.45	142	0.656

readers for bluegill (CV = 1.1%–3.7%, 2.3% for all lakes combined) and redear sunfish (CV = 0.4%–2.3%, 1.2% for all lakes combined; Table 1, Figure 2) using broken otoliths. Similarly, low APE values suggest precision was high between readers for bluegill (APE = 0.6%–2.7%) and redear sunfish (APE = 0–3.5%; Table 1) using whole otoliths. Compared to whole otoliths, APEs were lower for bluegill (APE = 0.8%–2.6%) and redear sunfish (APE = 0.3%–1.8%; Table 1) using broken otoliths.

For bluegill, between-reader agreement using whole otoliths was 94%–98% (95% for all lakes combined) and broken otoliths was 91%–97% (95% for all lakes combined; Table 1). For redear sunfish, between-reader agreement using whole otoliths was 88%–100% (97% for all lakes combined) and broken otoliths was 95%–99% (98% for all lakes combined; Table 1). Age estimates between the two readers were similar in all cases except for whole otolith estimates of redear sunfish from New Spiro Lake (Table 1).

Agreement between final consensus ages of whole and broken bluegill otoliths was high (95%–99%, 97% for all lakes combined; Table 2, Figure 3). Agreement between final consensus ages of whole and broken redear sunfish otoliths was higher ranging from 98%–100% (99% for all lakes combined; Table 2, Figure 3). Final consensus ages were similar between whole and broken otoliths for each species at each lake (Table 2).

Discussion

Between-reader agreement generally exceeded 90% using broken or whole otoliths, and it was difficult to determine an age at

Table 2. Percent reader agreement, average percent error (APE), and outcomes of paired t-tests for final age estimates of whole and broken otoliths of bluegill and redear sunfish collected from five small impoundments in Oklahoma. N/A = could not be tested because readers were in full agreement.

Lake	Species	*n*	% Agreement	APE	*t*	df	*P*
Elmer	Bluegill	94	95.7	0.8	–1.00	93	0.319
	Redear	58	98.3	0.2	–1.00	57	0.321
New Spiro	Bluegill	160	98.1	1.0	–1.74	158	0.083
	Redear	113	100.0	0.0	N/A	N/A	N/A
Pawhuska	Bluegill	83	97.6	0.3	–1.42	82	0.159
	Redear	19	100.0	0.0	N/A	N/A	N/A
Sparks	Bluegill	169	94.7	2.4	1.00	168	0.318
	Redear	99	99.0	0.5	–1.42	98	0.158
Stilwell	Bluegill	187	98.9	0.1	1.42	186	0.158
	Redear	143	99.3	0.1	–1.00	142	0.319

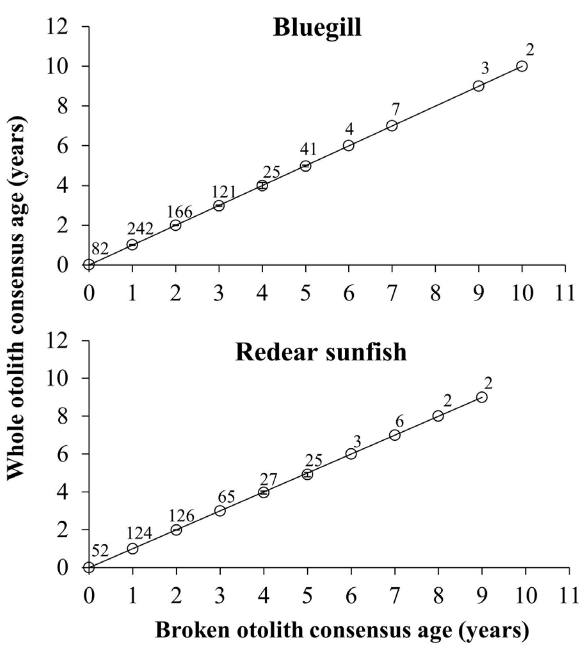

Figure 3. Age-bias plots comparing final consensus age estimates from whole otoliths to final consensus age estimates from broken otoliths for bluegill and redear sunfish collected from five small impoundments in Oklahoma. Error bars represent the 95% confidence interval. The diagonal line represents 100% agreement between structures. Numbers above each point represent sample size of that age group.

which otoliths should be broken rather than viewed whole for bluegill and redear sunfish. Although rare, when bias was observed, ages of older fish (usually ≥age 6) were underestimated using whole otoliths compared to broken otoliths, and this was noticed more when evaluating between-reader precision rather than final consensus ages. Hales and Belk (1992) likewise found that sectioned and whole otolith age estimates of bluegill were not always in agreement, observing additional annuli in sectioned otoliths compared to whole otoliths, especially for fish age 5 and older. Edwards et al. (2005) supported these results, suggesting that bluegill otoliths be broken or sectioned for fish older than age 5. Buckmeier and Howells (2003) suggested sectioning largemouth bass (*Micropterus salmoides*) otoliths of fish older than age 2. Fernando et al. (2013) determined that the need to section otoliths of spotted bass (*M. punctulatus*) depends on growth rates of fish from a particular population. In slow growing populations, they recommended that otoliths should be sectioned for fish age 2 or older; however, for fast growing populations, otoliths should be sectioned for fish age 4 or older. Hoyer et al. (1985) also determined that whole otoliths are useful for aging fast growing largemouth bass or those age 3 or older. The age when otoliths should be broken is not commonly reported in the literature; however, it likely varies depending on the species and population. Otoliths from older fish should be broken to obtain the most accurate and precise age estimate, especially when constriction of annuli is observed on the otoliths margin (Hoxmeier et al. 2001). Breaking and polishing (or sectioning) otoliths of bluegill and redear sunfish may be more critical in populations where growth is slower and longevity is higher (Edwards et al. 2005).

High precision and relatively low bias observed in both whole and broken otolith age estimates could be a result of the fast growth rates of these populations. Faster growing fish have wider between-annuli distances, making each annulus easier to distinguish and count. However, as fish age increases, growth slows and otolith annuli constrict making it more difficult to interpret annuli (Hoxmeier et al. 2001). Sunfish longevity in our study was high for southern U.S. populations, particularly for bluegill (bluegill = 10 years, redear sunfish = 9 years; Ott et al. 2001, Sammons et al. 2006), but aging precision remained high with little bias. This high level of precision suggests that otoliths may produce accurate age estimates (Welch et al. 1993).

Although precision was high using both otolith techniques, this study did not have known-age fish, so we cannot definitively say that otoliths age estimates were accurate. However, in most cases otoliths are considered accurate because they are easier to interpret and material is not reabsorbed by fish (Isely and Grabowski 2007). Further, annulus formation has been confirmed in otoliths of bluegill and redear sunfish (Schramm1989, Hales and Belk 1992, Mantini et al. 1992). We attempted to assess redear sunfish relative aging accuracy by estimating ages of redear sunfish that were tagged at age 1 (133 to 181 mm TL) in 2015 at Sparks Lake and subsequently recaptured during annual sampling. However, only two redear sunfish were recaptured, one in 2016 that both readers estimated to be age 2, and one in 2017 that both readers estimated to be age 3. These ages corresponded to the correct number of annuli that should have formed since tagging (M. Porta, unpublished data). Even though sample size was low, it appears that an annulus forms yearly in redear sunfish otoliths and they can be aged reliably to age 3; however, a more robust mark and recapture study is needed to confirm these results. This suggests that otoliths are appropriate aging structures that likely produce accurate age information for these sunfish species, which supports findings by Mantini et al. (1992).

This is the first evaluation of aging precision for redear sunfish in the primary literature. Further, it supports previous findings suggesting otoliths provide reliable age estimates for bluegill. In this study, broken and whole view otoliths provided precise age estimates for bluegill (up to age 10) and redear sunfish (up to age 9). There is significant savings in effort, materials, and equipment when using whole otoliths for age estimation when compared to broken or sectioned otoliths, as there is no processing time needed for whole otoliths. Isermann et al. (2003) found the total processing time was more than twice as long when sectioning walleye otoliths (mean = 34.7 min per 10 otoliths) compared to whole otoliths (mean = 16.0 min per 10 otoliths). Using similar methods to our study, Maceina (1988) found that 15 centrarchid otoliths can be prepared and aged in 1 h. Further, Buckmeier and Howells (2003) determined that 20–25 largemouth bass otoliths could be processed and read in 1 h using similar methods.

Sunfish growth rates may be sufficient to prevent annuli from constricting on the otolith edge in southern U.S. waters. However, we recommend breaking or sectioning otoliths if fisheries managers believe a sunfish population is stunted or when annuli constriction is observed on the otolith margin. Differences, although minimal, were observed between broken and whole otolith ages estimates from each lake. Although these small differences likely would not affect population dynamic parameters estimated using the ages determined from either method in this study, it does suggest that an evaluation of aging precision should be completed on a case-by-case basis to ensure age estimates used by fisheries managers to calculate population dynamics are accurate for sunfish in other aquatic systems.

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Literature Cited

Beamish, R. J. and D. A. Fournier. 1981. A method for comparing the precision of a set of age determinations. Canadian Journal of Fisheries and Aquatic Sciences 38:982–983.

Boxrucker, J. 1986. A comparison of the otolith and scale methods for aging white crappies in Oklahoma. North American Journal of Fisheries Management 6:122–125.

Buckmeier, D. L. and R. Howells. 2003. Validation of otoliths for estimation ages of largemouth bass to 16 years. North American Journal of Fisheries Management 23:590–593.

Campana, S. E., M. C. Ann, and J. I. McMillan. 1995. Graphical and statistical methods for determining the consistency of age determinations. Transactions of the American Fisheries Society 124:131–138.

Chang, W. Y. 1982. A statistical method for evaluating the reproducibility of age determination. Canadian Journal of Fisheries and Aquatic Sciences 39:1208–1210.

Crawford, S. and M. S. Allen. 2006. Fishing and natural mortality of bluegills and redear sunfish at Lake Panasoffkee, Florida: implications for size limits. North American Journal of Fisheries Management 26:42–51.

Edwards, K. R., Q. E. Phelps, J. L. Shepherd, D. W. Willis, and J. D. Jungwirth. 2005. Comparison of scale and otolith age estimates for two South Dakota bluegill populations. Proceedings of the South Dakota Academy of Science 84:181–186.

Fernando, A. V., C. R. Peacock, B. W. Baker, and M. A. Eggleton. 2013. Aging precision and error analysis of whole-view and sectioned otoliths in largemouth bass and spotted bass. Journal of the Southeastern Association of Fish and Wildlife Agencies 1:75–82.

Hales, L. S., Jr., and M. C. Belk. 1992. Validation of otolith annuli of bluegills in a southeastern thermal reservoir. Transactions of the American Fisheries Society 121:823–830.

Hoff, G. R., D. J. Logan, and D. G. Markle. 1997. Otolith morphology and increment validation in young Lost River and shortnose suckers. Transactions of the American Fisheries Society 126:488–494.

Hoxmeier, R. J. H., D. D. Aday, and D. H. Wahl. 2001. Factors influencing precision of age estimation from scales and otoliths of bluegills in Illinois reservoirs. North American Journal of Fisheries Management 21:374–380.

Hoyer, M. V., J. V. Shireman, and M. J. Maceina. 1985. Use of otoliths to determine age and growth of largemouth bass in Florida. Transactions of the American Fisheries Society 114:307–309.

Hurley, K. L., R. J. Sheehan, and R. C. Heidinger. 2004. Accuracy and precision of age estimates for pallid sturgeon from pectoral fin rays. North American Journal of Fisheries Management 24:715–718.

Isely, J. J. and T. B. Grabowski. 2007. Age and growth. Pages 187–228 *in* C.S Guy and M. L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

Isermann, D. A., J. R. Meerbeek, G. D. Scholten, and D. W. Willis. 2003. Evaluation of three different structures used for walleye age estimation with emphasis on removal and processing times. North American Journal of Fisheries Management 23:625–631.

Kowalewski, L. K., A. P. Maple, M. A. Pegg, and K. L. Pope. 2012. Latitudinal influence on age estimates derived from scales and otoliths for bluegills. North American Journal ofFisheries Management 35:1175–1179.

Long, J. M. and W. L. Fisher. 2001. Precision and bias of largemouth, smallmouth, and spotted bass ages estimated from scales, whole otoliths, and sectioned otoliths. North American Journal of Fisheries Management 21:636–645.

Maceina, M. J. 1988. Simple grinding procedure to section otoliths. North American Journal of Fisheries Management 8:141–143.

_____ and R. K. Betsill. 1987. Verification and use of whole otoliths to age white crappie. Pages 267–278 *in* R. C. Summerfelt and G. E. Hall, editors. Age and growth of fish. Iowa State University Press, Ames.

_____, J. Boxrucker, D. L. Buckmeier, R. S. Gangl, D. O. Lucchesi, D. A. Isermann, J. R. Jackson, and P. J. Martinez. 2007. Current status and review of freshwater fish aging procedures used by state and provincial fisheries agencies with recommendations for future directions. Fisheries 32:329–340.

Mantini, L., M. V. Hoyer, J. V. Shireman, and D. E. Canfield, Jr. 1992. Annulus validation, time of formation, and mean length at age of three sunfish species in north central Florida. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 46:357–367.

Miranda, L. E. and J. Boxrucker. 2009. Warmwater fish in large standing water. Pages 29–42 *in* S.A. Bonar, W.A. Hubert, and D.W. Willis, editors. Standard methods for sampling North American freshwater fishes. American Fisheries Society, Bethesda, Maryland.

Ott, R. A., Jr., T. J. Bister, and J. W. Schlechte. 2001. Assessment of a 178-mm minimum length limit of bluegill at Purtis Creek State Park Lake, Texas. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 55:334–345.

Phelps, Q. E., S. J. Tripp, M. J. Hammel, R. P. Koenigs, and Z. J. Jackson. 2017. Choice of structure for estimating fish age and growth. Pages 81–105 *in* M.C. Quist and D.A. Isermann, editors. Age and growth of fishes: principles and techniques. American Fisheries Society, Bethesda, Maryland.

Quist, M. C., M. A. Pegg, and D. R. DeVries. 2012. Age and Growth. Pages 677–731 *in* A. V. Zale, D. L. Parrish, and T. M. Sutton, editors. Fisheries Techniques, 3rd edition. American Fisheries Society, Bethesda, Maryland.

Ross, J. R., J. D. Crosby, and J. T. Kosa. 2005. Accuracy and precision of age estimation of crappies. North American Journal of Fisheries Management 25:423–428.

Sammons, S. M., D. G. Partridge, and M. J Maceina. 2006. Differences in population metrics between bluegill and redear sunfish: implications for the effectiveness of harvest restrictions. North American Journal of Fisheries Management 26:777–787.

Schramm, H. L., Jr. 1989. Formation of annuli in otoliths of bluegills. Transactions of the American Fisheries Society 118:546–555.

_____ and J. F. Doerzbacher. 1982. Use of otoliths to age black crappie from Florida. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 36:95–105.

Spurgeon, J. J., M. J. Hamel, K. L. Pope, and M. A. Pegg. 2015. The global status of freshwater fish age validation studies and a prioritization framework for further research. Reviews in Fisheries Science and Aquaculture 23:329–345.

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. North American Journal of Fisheries Management 13:616–620.