Ageing Precision and Error Analysis of Whole-view and Sectioned Otoliths in Largemouth Bass and Spotted Bass

Anthony V. Fernando, *Aquaculture/Fisheries Center, University of Arkansas at Pine Bluff, 1200 N. University, Box 4912, Pine Bluff, AR 71601*

Clint R. Peacock, *Georgia Department of Natural Resources, 1255 Perry Parkway, Perry, GA 31069*

Brandon W. Baker, *Georgia Department of Natural Resources, 108 Darling Avenue, Waycross, GA 31502*

Michael A. Eggleton, *Aquaculture/Fisheries Center, University of Arkansas at Pine Bluff, 1200 N. University, Box 4912, Pine Bluff, AR 71601*

Abstract: The objectives of this study were to quantify ageing precision for largemouth bass (*Micropterus salmoides*) and spotted bass (*M. punctulatus*), and to evaluate the effect of ageing errors on the estimation of common fisheries metrics. Sagittal otoliths were extracted from 2164 largemouth bass and 738 spotted bass collected from throughout the Arkansas River, Arkansas. Largemouth bass collections occurred during 2004, 2005, and 2010; spotted bass collections were limited to 2004 and 2005. Annuli were counted by two independent readers from digital images of each whole otolith. For individuals aged greater than 2 yrs from whole views, otoliths were transverse sectioned through the focus and polished, with the cross-sectional surfaces imaged and re-aged. Precision between readers of both whole-view and sectioned otoliths was determined for all ages, whereas precision between ages generated from whole-view and sectioned otoliths also was determined. Precision between readers of whole-view otoliths averaged 95% for largemouth bass and 93% for spotted bass, whereas between-reader precision of sectioned otoliths was 92% for largemouth bass and 94% for spotted bass. Between-method precision of spotted bass ages averaged 91%. Although between-method precision of ages averaged 84% overall for largemouth bass, precision declined noticeably from 89% during 2004–2005 to 66% in 2010. Between-method precision suggested that the practice of sectioning otoliths from age-3 and age-4 individuals may be overly conservative for black basses in most instances. Sectioning fewer black bass otoliths should translate into a significant time savings for fisheries researchers. Using a pooled largemouth bass dataset, simulated ageing errors produced ≤5% differences in von Bertalanffy growth and <10% in catch-curve mortality parameters. Observed differences of this magnitude should be tolerable for basic fisheries assessments and many forms of largemouth bass management, though the error may be too large for certain modeling efforts. Results also indicated that spotted bass may be reliably aged using procedures similar to those recommended for largemouth bass.

Key words: double-blind, age and growth, *Micropterus salmoides*, *Micropterus punctulatus*

Journal of the Southeastern Association of Fish and Wildlife Agencies 1:75–82

Age-related metrics are important tools of fisheries management. Age determination enhances fisheries management in that vital rates for the fishery can be better estimated. For example, growth and mortality are two major processes that shape fisheries, and both require determination of fish ages (DeCicco and Brown 2006). In the case of recruitment, age-structured population data provide added insights into reproductive success and subsequent fishery year-class strength (Bradford 1991, Maceina 1997). In the absence of age-structured data, the assessment and management of fisheries are more limited.

Precision is an important aspect of fish ageing procedures. Although scales have historically been used to age many different fishes, they have proven unreliable for many species (e.g., Erickson 1983, Boxrucker 1986, Welch et al. 1993, Hawkins et al. 2004, Stolarski and Hartman 2008, Isermann et al. 2010). Using scales, precision between readers and precision with other aging structures tends to be lower (Maceina and Sammons 2006). As a result, sagittal otoliths have become the preferred ageing structure for many fishes (DeVries and Frie 1996). Although otoliths require sacrificing individual fishes, and require additional procedures and preparation time, their improved reliability provides for more sound fisheries management. Otoliths have become the preferred ageing structure for largemouth bass (*Micropterus salmoides*) (Taubert and Tranquilli 1982, Hoyer et al. 1985). Relatively little work has been done with spotted bass (*M. punctulatus*) (e.g., Long and Fisher 2001), which co-exist with largemouth bass over much of its native range and are often considered an important sport fish (Vogele 1975).

The relative importance of age-structured data in fisheries management has driven the refinement, improvement, and assessment of fish ageing techniques over the past 25 years (Campana and Thorrold 2001). While reliable estimates of age may enhance fisheries management (Beamish and MacFarlane 1983), inaccurate age estimation can be detrimental, and in some instances, potentially misguide or undermine fisheries management (Yule et al. 2008). Age structures generated for fish populations will invariably contain some degree of ageing error or bias. When ageing errors are homogenous throughout a population age structure (i.e., roughly equal amounts of underageing and overageing), effects on metrics used by fisheries managers are usually less (see example in Ricker 1975). Large datasets also may mitigate the cumulative effects of ageing errors, particularly when estimating robust parameters like survival (*S*) and mortality (*A*) (Ricker 1975).

Previous studies with marine fisheries have indicated that biases resulting from ageing errors may compound and produce grossly inaccurate model predictions. Lai and Gunderson (1987) demonstrated that consistent underageing of walleye pollock (*Theragra chalcogramma*) led to underestimations of fishing mortality (*F*), and thus, had the potential to allow overfishing. Tyler et al. (1989) used a dynamic pool yield model to assess the effect of ageing errors on two hypothetical marine fish species with lifespans of 10 yrs and 100 yrs, and sablefish (*Anoplopoma fimbria*), which have a lifespan of 50 yrs. In their study, ageing errors prior to the age of maximum biomass were demonstrated to produce serious underestimates of *F*, which would have risked recruitment overfishing. Bradford (1991) reported that even moderate amounts of ageing error that misassigned individuals from strong to weak year classes consistently reduced estimates of recruitment variation. He further recommended that future studies inflate their recruitment variation estimates to account for probable ageing errors. Reeves (2003) indicated that simulated ageing errors tended to inflate total allowable catch estimates because of error effects on *F*. Conversely, even though ageing error did affect *F* estimates and spawning stock biomass, general conclusions concerning the status of the fishery were still broadly correct. Campana (2001) suggested that the bias associated with ageing errors may be lessened provided that the majority of the ageing error does not occur at the age of maturity.

The objectives of this study were to 1) compare precision of whole-view read and sectioned otoliths in largemouth bass and spotted bass, and 2) conduct a sensitivity analysis that assessed the effect of simulated errors in age determination on population parameters commonly used in fisheries management. These parameters also are commonly used in the management of largemouth bass fisheries. Results will be useful to fisheries managers and potentially save time and resources with respect to fish ageing procedures.

Methods

Fish Collections

Largemouth bass and spotted bass were collected from throughout the Arkansas River, Arkansas, by nighttime boat-mounted electrofishing during May–June in 2004, 2005, and 2010. Additional information concerning fish collections and processing can be found in Eggleton et al. (2011, 2013). During 2004–2005 sampling, largemouth bass and spotted bass were collected from every Arkansas River navigation pool within Arkansas, spanning from the Arkansas Post Canal to the Oklahoma-Arkansas border. Sampling in 2010 was limited to Arkansas River navigation pools 2, 4, 6, and 10, which were considered representative of the river, and only largemouth bass were collected. All individual bass were returned to the laboratory on ice where lengths (total length, mm), weights (g), and sex were determined; both sagittal otoliths were extracted from all specimens for ageing purposes. Although use of the same project personnel across years was not possible, all sampling and associated laboratory processing followed the same protocols each year (Eggleton et al. 2011, 2013). Therefore, handling and processing factors that could potentially influence findings were minimized.

Age Determination and Precision

Whole otoliths were immersed in water in a clear dimple dish and placed on a black plate. A dissecting microscope (Leica MZ95, Leica Microsystems GmbH, Wetzlar, Germany) was used to view otoliths using transmitted light supplied from two 1-mm diameter single-strand optic fibers. Otoliths were imaged using this microscope which was interfaced to a desktop computer. Digital images were taken of each whole-view otolith using Spot Advanced imaging software (Diagnostic Instruments, Inc., Sterling Heights, Michigan). Images were read double-blind by the same two independent readers each year (termed "whole-view" otolith readings) for verification purposes and assessment of reader bias. Between-reader discrepancies were resolved either through consultation between the readers, or by a third reader who served as a tie-breaker. Otoliths in which no agreement could be reached, or those deemed unreadable due to defects or damage from extraction, were discarded from further analysis.

As recommended by Buckmeier and Howells (2003), otoliths determined to be older than age 2 by whole-view reading were transverse sectioned and re-aged. Transverse sectioning was done through the otolith nucleus perpendicular to the longest axis by applying pressure with a thumbnail or forceps. The broken surface (i.e., cross section) was first sanded using 380-grit sandpaper followed by polishing with 1520-grit sandpaper. Otolith cross sections were embedded in a clay-lined dish with the polished surface facing upward, and submerged in water to reduce reflection (termed "sectioned" otolith readings). Discrepancies were resolved using the same method as described for whole-view otoliths.

Between-reader precision represented how often the two readers agreed on ages, whether from whole-view or sectioned otoliths. Between-method precision represented how often ages derived from sectioned otoliths confirmed the ages determined from whole-view otoliths. In all cases, the age determined from the sectioned otoliths was considered the true age of the fish. Precision between readers for whole-view and sectioned readings and between methods was compared across years using Chi-squared analyses, with significance declared at an alpha level of 0.05. For this analysis, the 2004 and 2005 sampling years were pooled for comparison to 2010, given that two different sets of readers were used in 2004–2005 and 2010. This approach also made for a simpler 2 × k contingency table, where k = number of age classes.

To assess the effects of errors in fish ageing, three age structure models were developed using Arkansas River largemouth bass. In this analysis, the largemouth bass age structure generated from sectioned otoliths was considered the "true" population age structure (Model A—without error). From this age structure, two simulated-error structures were generated to assess the effects of ageing errors on the computation of common fisheries metrics. In the first simulated-error structure (Model B), 1 yr was subtracted from the ages of all fish older than 2 yrs. This model simulated consistent underageing of all older fish, and was considered a worst-case scenario with extreme error. In the second error structure (Model C), a random sample of 50% of the fish older than 2 yrs was classified as underaged. This was accomplished by using a uniform distribution to generate a random number between 0 and 1 for each fish in the dataset older than 2 yrs. For those fish assigned a random number less than 0.5, 1 yr was subtracted from their age. Model C depicted a more moderate degree of ageing error, and was considered more typical of the error encountered during fish ageing. The true age structure (Model A) and the two simulated-error age structures (models B and C) were then used to estimate von Bertalanffy model parameters L_∞, K and t_0 using the growth function of the fishmethods package (Nelson 2013) contained in R (R 2.13.1, The R Foundation for Statistical Computing, Vienna). These same datasets also were used to calculate the catch-curve mortality parameters Z and A using the agesurv function from the same software package.

Results

A total of 2164 largemouth bass aged 1 yr or older was collected from across the three sampling years in 2004, 2005, and 2010 (Table 1). Nine largemouth bass were unable to be aged and were discarded from further analysis. A total of 738 spotted bass was collected from across the same sampling efforts during 2004–2005 (Table 1). No spotted bass otoliths were discarded due to an inability to age. Whole-view readings aged 730 largemouth bass and 245 spotted bass as older than 2 years. Transverse sectioning was applied to the otoliths for all 975 of these fish.

Table 1. Age frequency for largemouth bass ($n = 2155$) and spotted bass ($n = 738$) collected from the Arkansas River that were used in this study. Ages from bass aged 3 yrs and older were based on sectioned otoliths. Nine largemouth bass were discarded because they could not be aged.

	Largemouth bass			Spotted bass	
Age	2004	2005	2010	2004	2005
1	395	166	144	105	133
2	307	323	90	121	134
3	142	157	44	104	49
4	58	92	89	8	42
5	33	27	28	19	5
6	7	19	10	2	10
7	5	6	1	5	0
8	2	2	2	1	0
9	0	2	0	0	0
10	2	2	0	0	0
Totals	951	796	408	365	373

Table 2. Precision between readers of whole-view and sectioned otoliths from largemouth bass and spotted bass collected from the Arkansas River.

	Largemouth bass				Spotted bass	
	Whole-view		Sectioned		Whole-view	Sectioned
Age	2004–05	2010	2004–05	2010	2004–05	2004–05
1	99	99	–	–	99	–
2	97	99	–	–	98	–
3	90	91	98	100	85	97
4	87	91	98	92	85	91
5	86	89	87	74	71	88
6	77	80	91	71	50	86
7	46	100	86	63	60	100
8	50	100	100	67	100	100
9	50	–	50	–	–	–
10	0	–	100	–	–	–
12[a]	50	–	–	–	–	–
Overall	94	95	95	86	93	94

a. One age-12 fish whole-view was confirmed as age-10 following otolith sectioning.

Largemouth Bass

During 2004–2005 collections, the overall between-reader precision of largemouth bass otoliths read whole-view was 94%. Precision on whole-view read otoliths was 99% and 97% for ages 1 and 2, respectively, and ranged from 86%–90% for ages 3–5 (Table 2). Precision generally decreased and was more variable at older ages, though sample sizes of largemouth bass for fish older than 5 yrs were much smaller ($n = 47$). For largemouth bass collected in 2010, between-reader precision of otoliths read whole-view was 99% for ages 1 and 2, and ranged from 89%–91% for ages 3–5 (Table 2). As found with the 2004–2005 otoliths, precision was more variable for older ages, though 2010 collections were limited to only 13 specimens older than age 5. For whole-view otoliths, overall precision between readers did not vary significantly among years ($P=0.566$, df = 1, $\chi^2=0.329$), and there were no differences in precision for individual age classes across years ($P=0.422$–0.999, df = 1, $\chi^2=\leq 0.65$) (Table 3). This finding verified that variation in ageing precision of whole-view otoliths was low among years, even though different sets of readers were used.

The overall between-reader precision of largemouth bass sectioned otoliths was 95% during 2004–2005 (Table 2). Precision between readers on sectioned otoliths was 98% for ages 3 and 4 and ranged 50%–100% across ages 5–10 ($n=107$). In 2010, between-reader precision of sectioned largemouth bass otoliths was 100% and 92% for ages 3 and 4, respectively, but decreased to 72% overall (range 63%–74%) for ages 5–8 (Table 2). Overall between-reader precision of sectioned otoliths varied among years ($P=0.002$, df = 1, $\chi^2=9.74$), though the difference appeared to be driven mostly by a modest decline of the precision with age-4 fish in 2010 ($P=0.048$, df = 1, $\chi^2=3.92$) (Table 3).

For largemouth bass collected during 2004–2005, 89% of all fish that were determined to be age 3 or older from the whole-view readings were confirmed as that age by sectioned otoliths (Table 4). However, this percentage decreased to 66% in 2010 ($P=<0.001$, df = 1, $\chi^2=53.93$), with most of the disagreements occurring with ages 3–4 (Table 5). Between-method precision decreased from 96% during 2004–2005 to 75% in 2010 ($P=<0.001$, df=1, χ^2=22.07) for age-3 fish, and from 91% in 2004–2005 to 66% in 2010 ($P=<0.001$, df=2, χ^2=22.07) for age-4 fish (Table 5). Precision between methods of all fish older than age 4 ($n=148$) were variable through time. However, overall precision with these older age classes was not substantially different at 69% in 2004–2005 and 56% in 2010 (Table 4). In 96% of the age disagreements, sectioned otoliths yielded older ages, but only by 1 yr.

Spotted Bass

The overall between-reader precision of spotted bass otoliths read whole-view was 93%, which was similar to largemouth bass (Table 2). Readers agreed on age-1 and age-2 fish 99% and 98% of the time, respectively; precision for ages 3–5 ranged from 71%–85%. With regard to sectioned otoliths, overall between-reader precision was 94%, which was comparable to largemouth bass (Table 2). Using sectioned otoliths, readers agreed on age-3 and age-4 fish 97% and 91% of the time, respectively; precision with ages 5–8 was generally lower, though still 89% overall.

For spotted bass collected during 2004–2005, 91% of all fish aged 3 yrs or older from whole-view readings were confirmed as that age from sectioned otoliths (Table 4). This value was slightly greater than that observed for largemouth bass during the same years. In particular, between-method precision for age-3 and age-4

Table 3. Chi-squared analysis of largemouth bass ageing precision across years. Analyses compared between-reader precision of whole-view and sectioned otoliths between years (2004–2005 and 2010), which corresponded to two different sets of readers. One df was used for all comparisons. **Bold type** indicates statistically significant difference at an alpha level of 0.05.

	Whole-view		Sectioned	
Age[a]	**χ^2**	***P***	**χ^2**	***P***
1	0.01	0.932	–	–
2	0.48	0.491	–	–
3	0.00	1.000	0.23	0.633
4	0.65	0.422	3.92	**0.048**
5	0.00	0.998	1.42	0.233
6	0.00	1.000	0.62	0.431
7	<0.01	0.997	0.00	1.000
8	<0.01	0.760	0.00	1.000
Overall	0.329	0.566	9.74	**0.002**

a. Ages 9–10 were excluded due to small samples sizes.

Table 4. Between-method precision for otoliths of largemouth bass and spotted bass collected from the Arkansas River.

	Largemouth bass		Spotted bass[a]
Age	**2004–05**	**2010**	**2004–05**
3	96	75	97
4	91	66	90
5	73	68	58
6	77	20	83
7	55	0	100
8	25	100	100
9	100	–	–
10	50	–	–
12	0	–	–
Overall	89	66	91

a. No between-reader agreement data available for 2010.

Table 5. Chi-squared analysis for precision of largemouth bass ageing. Analyses compared methods (i.e., whole-view vs. sectioned) between years (2004–2005 and 2010). Years corresponded to two different sets of readers. One df was used for all comparisons. **Bold type** indicates statistically significant at an alpha level of 0.05.

	Between methods	
Age[a]	**χ^2**	***P***
3	22.07	**<0.001**
4	22.07	**<0.001**
5	0.08	0.782
6	7.60	**0.005**
7	0.00	1.000
8	0.75	0.387
Overall	53.93	**<0.001**

a. Ages 9–10 were excluded due to small samples sizes.

spotted bass was 97% and 90%, respectively, but declined to 71% for ages 5–8 (Table 4). As with largemouth bass, sectioned otoliths yielded greater ages by 1 yr in 98% of the age disagreements. Because no between-reader agreement data were available for spotted bass otoliths from 2010, no between-year Chi-squared comparisons of precision were possible.

Sensitivity Analysis

The two age structures that contained different ageing error structures (models B and C) indicated some effect on common fisheries parameters. When considering the combined dataset (i.e., 2004, 2005, and 2010 pooled), the more extreme error structure contained in Model B increased L_∞, K, and t_o parameters from von Bertalanffy growth models compared to no error structure (Table 6). In particular, parameter L_∞, which represents the asymptote of the von Bertalanffy model, was increased by 21 mm or 4% (Table 6). Similarly, parameter K, which represents the rate at which population length approaches approach L_∞, was increased by approximately 14%. The error structure depicted by Model B also produced a catch curve with a steeper slope, which increased A by 9% compared to no error structure (Table 6).

The more moderate error structure depicted by Model C produced generally similar results to Model A, but of lesser magnitude. Model C increased von Bertalanffy parameter K by approximately the same amount as Model B (Table 6). Models B and C both produced large percentage changes on von Bertalanffy parameter t_o, though in this case, percentages are misleading because of the usually small values of that term. Similar to Model B, the error structure in Model C increased A by about 5%; however, the model also produced a small decrease in L_∞ from 480 mm to 476 mm (Table 6).

When individual datasets were assessed (i.e., 2004–2005 and 2010 separate), results were generally similar in direction, though percentage differences were often larger likely because individual datasets were less robust. In the case of the 2004–2005 dataset, the error structure in Model B produced almost no change in L_∞, whereas the more moderate error in Model C produced a 13-mm decrease (Table 6). Using the same dataset, both simulated error structures increased von Bertalanffy parameter K by 23%–30%, whereas only small differences in K were observed when only the 2010 dataset was used (Table 6). Conversely, simulated error structures produced 18%–28% increases in mortality parameter A (Table 6). The findings of this sensitivity analysis may not be universally applicable, and results could have some relationship with the structure unique to individual datasets. However, it does appear that larger, more robust datasets create smaller differences in calculated parameters.

Discussion

Ageing Precision

Transverse sectioning of age-3 and age-4 black bass otoliths is probably overly conservative given average or above-average growth. Buckmeier and Howells (2003) recommended that all largemouth bass otoliths determined to be older than 2 yrs when read whole-view should be sectioned to verify true age. In this study, ages from whole-view and sectioned otoliths exhibited >95% agreement at age 3 and >90% agreement at age 4 for both largemouth bass and spotted bass during 2004–2005. Ricker (1975) suggested that 80%–90% between-reader agreement is very good. Thus, the additional time and resources dedicated to sectioning and re-ageing otolith sections may not be needed for these ages with black basses, with sectioning reserved only for individuals that are aged 5 yrs and older from whole views. Another compromise that could be considered is to section only otoliths aged 3 yrs or older

Table 6. Sensitivity analysis of the effect of simulated ageing error on the estimation of common parameters used in fisheries management. Numbers in parentheses represent percentage change from parameters generated from the true age structure (Model A). Model B represents an error structure generated by consistent underageing (1 yr) of all age classes older than age 2. Model C represents an error structure generated by random underageing of 50% of all age classes older than age 2.

		Fisheries parameters				
Dataset	Error Structure	L_∞	K	t_0	Z	A
Years pooled	A	480	0.342	–0.597	0.73	0.52
Years pooled	B	501 (4)	0.389 (14)	–0.362 (–39)	0.83 (14)	0.56 (9)
Years pooled	C	476 (–1)	0.388 (13)	–0.445 (–25)	0.79 (8)	0.55 (5)
2004–2005	A	478	0.369	–0.437	0.72	0.51
2004–2005	B	480 (<1)	0.479 (30)	–0.101 (–77)	0.80 (11)	0.55 (7)
2004–2005	C	465 (–3)	0.453 (23)	–0.221 (–49)	0.78 (8)	0.54 (6)
2010	A	461	0.340	–0.775	0.55	0.42
2010	B	503 (9)	0.338 (–1)	–0.642 (–17)	0.78 (42)	0.54 (28)
2010	C	470 (2)	0.358 (5)	0.680 (–188)	0.69 (25)	0.50 (18)

from fish where the two readers did not agree. This approach would also amount to a time savings, though disagreements on age-3 and age-4 fish aged whole-view can often be reconciled by the readers following consultation. In addition, this study indicated that otolith sectioning procedures and otolith protocols commonly used for largemouth bass appear to be equally suitable for spotted bass.

Although this may seem a relatively minor recommendation, the time invested into sectioning otoliths can be significant. Isermann et al. (2003) determined that processing and reading thin sections of walleye otoliths took approximately twice as long as processing and reading otoliths whole view. We believe preparing thin sections from black bass otoliths would require a similar time commitment. It is our estimation that transverse sectioning, as done in this study, would require an intermediate time investment between reading whole-view otoliths and preparing thin otolith sections as done by Isermann et al (2003). Assuming that transverse sectioning procedures require 150% of the time requirement for reading otoliths whole-view and considering the Buckmeier and Howells (2003) recommendation of sectioning all otoliths aged greater than 2 yrs whole view, the relative labor costs of reading otoliths for this study were assessed. As the sectioning threshold increases, fewer otoliths need to be sectioned, which will inherently result in a savings of time and labor. In this study, limiting sectioning to largemouth bass older than 4 yrs eliminated 582 otoliths to be sectioned, and would have translated to a labor savings of 11%–13% without compromising accuracy. This time savings translated to about one hour per work day, which may be significant with large or long-term studies that process thousands of fish. Time savings would be different when using other age thresholds for transverse sectioning; thus, thresholds could be matched against time and resource constraints for a given study.

The significant decrease in between-method precision observed with 2010 largemouth bass, especially ages 3 and 4, is problematic, though it may be isolated. In 2004–2005, 96% and 91% of the largemouth bass aged 3 or 4 yrs via while-view reading were verified as such with sectioned otoliths. However, these same figures declined to 75% and 66% for age-3 and age-4 largemouth bass collected from the same population only 5–6 yrs later (2010). Although different sets of readers were necessary in 2010, precision between readers for that year (95% for whole-view; 86% for sectioned) do not suggest this as the reason for lower reliability. Whatever difficulties were encountered ageing 2010 bass were experienced by both readers, which would explain the acceptable between-reader precision. This decrease in between-method precision coincided with a significant decrease in largemouth bass growth in the Arkansas River documented by Peacock (2011). We can only speculate, but feel it was possible that many otoliths contained annuli that were either weakly formed or spaced very closely due to slow growth and, thus, were difficult to distinguish and count. In the case of slower growing populations or populations that have undergone a period of slow growth, sectioning of age-4, and perhaps age-3, otoliths may still be necessary for adequate precision.

Effects of Ageing Errors

The sensitivity analysis indicated that some degree of ageing error might be tolerable in fisheries management, at least with largemouth bass. This finding contradicts several authors that have researched the subject in marine fisheries over the last 25 yrs (e.g., Lai and Gunderson 1987, Tyler et al. 1989, Bradford 1991, Reeves 2003). The two simulated error structures used in this study represented scenarios of slight (1 yr) underageing, consistent with previous studies of Arkansas River black basses (M. Eggleton, unpublished data). Using the combined largemouth bass dataset, the increased predicted L_∞ and K values would have little effect with respect to interpretation of population growth patterns. For instance, using the original von Bertalanffy model parameters without simulated ageing error (Model A; Table 6), largemouth bass would have reached 356 mm total length in 3.4 yrs. By comparison, using the same parameters generated from models B and C produced lower values of 2.8 and 3.1 yrs, respectively. The difference of 0.6 yrs between predictions from Model A (no error) and Model B (extreme error) would not greatly affect the model's basic interpretation for largemouth bass. In addition, the Model B error structure was extreme and would not likely be encountered during normal ageing procedures with experienced personnel. The error structure contained in Model C would be more realistic, but could still be considered extreme provided that personnel were well trained in fish ageing. Thus, while the direction of change of the von Bertalanffy model parameters was consistent with simulation studies from marine fisheries (e.g., Lai and Gunderson 1987, Tyler et al. 1989), the observed differences in this study were much smaller and had much less potential to misguide management.

In the case of mortality parameters Z and A, greater numbers of underaged fish produce catch curves with steeper slopes (i.e., larger negative number), and thus, larger predicted A values (Tyler al. 1989). With the largemouth bass dataset used in this study, negative error was emphasized because underageing had been observed far more often than overageing in previous black bass studies in the Arkansas River, and ageing errors of more than 1 yr were uncommon (M. Eggleton, unpublished data). The 95% confidence limits on predicted A values generated from nonparametric bootstrapping were overlapping for all three estimates. Using the combined largemouth bass dataset, predicted A and 95% confidence limits were 0.52 (0.48–0.57) for Model A, 0.56 (0.50–0.61) for Model B, and 0.55 (0.54–0.58) for Model C. Thus, in this study, differences in predicted *A* for largemouth bass from the true age structure and the two simulated-error age structures were not statistically significant.

Whether or not observed differences in *A* were biologically significant for largemouth bass is not entirely clear. Although observed differences were not large enough to substantially alter largemouth bass management by themselves, there may be situations where ageing errors of this magnitude might be of more concern. In commercial marine fisheries, the need for predicting yields and setting harvest limits or quotas facilitate more modeling efforts, whereby ageing errors can be compounded. For example, growth models and mortality estimates used in fishery yield models can be used to formulate harvest limits for fisheries in light of expected levels of fishing mortality. Using a long-lived hypothetical species and relatively long-lived (i.e., up to 100 yrs) sablefish, Tyler et al. (1989) reported that the degree of ageing error at the age of maturity for the species was critical for model accuracy. Substantial ageing errors in this age range commonly produced overestimates of mean weight at earlier ages, though they made little difference in mean weights of older ages. Ageing errors manifested throughout the modeling, and produced both overestimates and underestimates of fishery yield over long-term time scales. In some modeling scenarios, high levels of ageing error at the age of maturity commonly produced large overestimates of yield, and created the potential for serious overfishing had results been implemented by managers. Lai and Gunderson (1987) also demonstrated that underageing caused frequent overestimation of yield per recruit. However, because their study also involved the longer-lived (i.e., up to 20 yrs) walleye pollock, they modeled ageing errors of up to 6 yrs, which would be excessive for largemouth bass. Largemouth bass and spotted bass used in this study were not especially long-lived (i.e., 8–10 yrs), and such high degrees of ageing error at their ages at maturity (2–3 yrs) would be rare.

There are other situations when ageing error also could have significant effects on accuracy. Assuming that fishing and natural mortality are additive for the fishery, a large overestimation of *A* from severely underaged fish could inflate natural mortality and produce bias in further calculations or modeling (e.g., Mertz and Myers 1997, Clark 1999). In these cases, predicted stock sizes and fishery yield can be biased. However, errors may be offsetting such that long-term average yields may not be greatly biased, provided that natural mortality had not been grossly underestimated (Clark 1999). Extremely high numbers of underaged fish would be needed for this scenario to exist with largemouth bass or spotted bass.

In summary, precision between whole-view and sectioned otoliths from 2004–2005 collections suggested that age-3 and age-4 largemouth bass could be reliably aged using only whole-view reading of otoliths provided the population has average to above-average growth. However, transverse sectioning of largemouth bass otoliths may still be necessary for slower-growing populations, or populations that have experienced a recent growth depression. Although a minor modification to the primary recommendation of Buckmeier and Howells (2003), this recommendation could translate into substantial savings of time and resources without a significant loss of data accuracy. Furthermore, ageing errors of the degree observed in this study with largemouth bass do not appear to be of the magnitude to risk misguiding management of largemouth bass. Because largemouth bass are shorter-lived and there is less potential for high degrees of ageing error at their age of maturity, some degree of ageing error can be tolerated without significantly weakening the fisheries management being done. Similar findings also would apply for spotted bass, a similar species to which much less research has been directed. Future studies are warranted that emphasize how much ageing error can be tolerated before largemouth bass management recommendations would be affected. Additionally, an assessment of the effects of different forms of ageing error on predicted fisheries metrics would be useful. Extrapolation of these findings to other inland sport fishes should be done cautiously in light of the different life-history characteristics of other species.

Acknowledgments

This research was funded by the Aquaculture/Fisheries Center at the University of Arkansas at Pine Bluff (UAPB). We thank the many UAPB students and staff that assisted with fish sampling and processing. Special thanks are extended to Ben Batten and Kelly Goodwin for their extensive efforts towards otolith processing and fish ageing. Helpful review comments were provided by three anonymous reviewers.

Literature Cited

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.

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

Bradford, M.J. 1991. Effects of ageing errors on recruitment time series estimated from sequential population analysis. Canadian Journal of Fisheries and Aquatic Sciences 48:555–558.

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

Campana, S.E. 2001. Accuracy, precision, and quality control in age determination, including a review on the use and abuse of age validation methods. Journal of Fish Biology 59:197–242.

_____ and S.R. Thorrold. 2001. Otoliths, increments, and elements: keys to a comprehensive understanding of fish populations? Canadian Journal of Fisheries and Aquatic Sciences 58:30–38.

Clark, W.G. 1999. Effects of an erroneous natural mortality rate on a simple age-structured stock assessment. Canadian Journal of Fisheries and Aquatic Sciences 56:1721–1731.

DeCicco, A.L. and R.J. Brown. 2006. Direct validation of annual growth increments on sectioned otoliths from adult grayling and a comparison of otolith and scale ages. North American Journal of Fisheries Management 26:580–586.

DeVries, D.R. and R.V. Frie. 1996. Determination of age and growth. Pages 483–508 *in* B.R. Murphy and D.W. Willis, editors. Fisheries Techniques, 2nd edition. American Fisheries Society, Bethesda Maryland.

Eggleton, M.A., B.G. Batten, and S.E. Lochmann. 2011. Largemouth bass fishery characteristics in the Arkansas River, Arkansas. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 64:154–161.

_____, _____, C.R. Peacock, and S.E. Lochmann. 2013. Spotted bass population characteristics and relationships with macrohabitat variables in the Arkansas River, Arkansas. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 66:49–56.

Erickson, C.M. 1983. Age determination of Manitoban walleyes using otoliths, dorsal spines, and scales. North American Journal of Fisheries Management 3:176–181.

Hawkins, L.A., H.M. Tyus, W.L. Minckley, and D.L. Schultz. 2004. Comparison of four techniques for ageing adult Colorado pikeminnow (*Ptychocheilus lucius*). The Southwestern Naturalist 49:203–208.

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

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.

_____, M.H. Wolter, and J.J. Breeggemann. 2010 Estimating black crappie age: an assessment of dorsal spines and scales as nonlethal alternatives to otoliths. North American Journal of Fisheries Management 30:1591–1598.

Lai, H.L. and D.R. Gunderson. 1987. Effects of ageing errors on estimates of growth, mortality, and yield per recruit for walleye pollock (*Theragra chlacogramma*). Fisheries Research 5:287–302.

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. 1997. Simple application of using residuals from catch-curve regressions to assess year-class strength in fish. Fisheries Research 32:115–121.

_____ and S.M. Sammons. 2006. An evaluation of different structures to age freshwater fish from a northeastern U.S. river. Fisheries Management and Ecology 13:237–242.

Mertz, G. and R.A. Myers. 1997. Influence of errors in natural mortality estimates in cohort analysis. Canadian Journal of Fisheries and Aquatic Sciences 54:1608–1612.

Nelson, G.A. 2013. Fishery science methods and models in R. CRAN Repository, website: *http://cran.r-project.org/web/packages/fishmethods/index.html*. Accessed 24 October 2013.

Peacock, C.R. 2011. Largemouth bass fishery in the lower Arkansas River: assessment of length-limit regulations, stock relationships with hydrology and stock structure. Master's Thesis. University of Arkansas at Pine Bluff, Pine Bluff.

Reeves, S.A. 2003. A simulation study of the implications of age-reading errors for stock assessment and management advice. ICES Journal of Marine Science 60:314–328.

Ricker, W.E. 1975. Computation and interpretation of biological statistics in fish populations. Fisheries Research Board of Canada, Bulletin 191.

Stolarski, J.T. and K.J. Hartmann. 2008. An evaluation of the precision of fin ray, otolith, and scale age determinations for brook trout. North American Journal of Fisheries Management 28:1790–1795.

Taubert, B.D. and J.A. Tranquilli. 1982. Verification of the formation of annuli in otoliths of largemouth bass. Transactions of the American Fisheries Society 111:531–534.

Tyler, A.V., R.J. Beamish, and G.A. McFarlane. 1989. Implications of age determination errors to yield estimates. Pages 27–35 *in* R.J. Beamish and G.A. McFarlane, editors. Canadian Journal of Fisheries and Aquatic Sciences, Special Publication 108.

Vogele, L.E. 1975. The spotted bass. Pages 34–45 *in* H. Clepper, editor. Black bass biology and management. Sport Fishing Institute, Washington, D.C.

Yule, D.L., J.D. Stockwell, J.A. Black, K.I. Cullis, G.A. Cholwek, and J.T. Myers. 2008. How systematic age underestimation can impede understanding of fish population dynamics: lesson learned from a Lake Superior cisco stock. Transactions of the American Fisheries Society 137:481–495.

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.