Using Pectoral Spines and Otoliths for Estimating Ages of Channel Catfish and Effects on Estimating Population Parameters

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Abstract: Accurate and precise age estimates are required to correctly estimate fish population metrics such as age, growth, mortality, and recruitment. Channel catfish (*Ictalurus punctatus*) are commonly aged using the lapilli otolith or the articular process of the pectoral spine. Many fisheries managers prefer to use pectoral spines because the process does not require the sacrifice of the fish, but this method may produce biased age estimates. To compare precision of the two methods, we used pectoral spines and lapilli otoliths to age 649 channel catfish collected from five Oklahoma impoundments during 2018 to 2020. Additionally, we compared von Bertalanffy growth parameters and mortality estimates derived using our pectoral spine and otolith age estimates. Finally, we compared processing times for both structures. Agreement and precision between readers were higher with otoliths (percent agreement = 80%–82.6%; mean CV = 1.5%–4.4%; average percent error = 2.1%–9.3%) than with spines (percent agreement = 37%–50.5%; mean CV = 8.5%–15.1%; average percent error = 12%–21.3%). Reader-specific bias was not observed in otolith age estimates but was observed in spine age estimates in fish ≥7 years old. Age-bias plots comparing consensus ages between structures indicated that using spines overestimated ages of younger fish but underestimated ages of fish age 6 and older. Due to low sample size in three of the five reservoirs, growth parameters and mortality were only calculated for Carl Blackwell and Meeker reservoirs. Disparities in aging precision between the two methods resulted in differences in estimates of growth parameters and mortality from Carl Blackwell but not Meeker. Further, processing spines was three times more labor intensive than processing otoliths. Our results indicate that use of spines produces imprecise age estimates for channel catfish and may result in biased growth estimates. However, managers may be able to use spines to estimate ages of channel catfish in short-lived populations where older fish are rare or nonexistent.

Key words: Ictaluridae, precision, structure, preparation, age and growth

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In many aquatic systems throughout the United States, channel catfish (*Ictalurus punctatus*) populations create popular recreational fisheries (Michaletz and Dillard 1999). In Oklahoma, channel catfish ranked as the third most pursued species since 1985 (York 2019). Due to this popularity, many state agencies have implemented stocking programs to create or supplement channel catfish populations and others have instituted regulations to protect these populations (Hubert 1999). In order to manage these channel catfish populations, it is essential to attain accurate and precise age estimates for calculation of population metrics (e.g., growth, mortality, recruitment, age, and size at maturity; Buckmeier et al. 2002, Colombo et al. 2010, Barada et al. 2011).

The basal recess of the pectoral spine had been the preferred structure for age estimation of channel catfish (Hubert 1999). However, Nash and Irwin (1999) found that the central lumen of the pectoral spine expands over time, resulting in the loss of annular marks. Crumpton et al. (1984) suggested that the articular process of the pectoral spine should be used to age catfish due to the difficulty of discerning annual marks on otoliths. Advances in processing techniques and improved ability to estimate catfish age from otoliths resulted in otoliths becoming the preferred aging technique for catfish. In particular, Buckmeier et al. (2002) showed that interpretation of annular marks was more variable using pectoral spines than otoliths, thus the authors suggested that otoliths were more reliable than spines for aging channel catfish.

Most studies have found that annular marks on otoliths are easily interpreted and provide a more accurate and precise age estimate of ictalurids (Nash and Irwin 1999, Buckmeier et al. 2002, Barada et al. 2011, Waters et al. 2019). However, Colombo et al. (2010) found no systematic difference between age estimates from

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otoliths and the articular process of pectoral spines of channel catfish, and both structures produced similar population metrics. Buckmeier et al. (2002) found that accessory growth rings contributed to the over estimation of channel catfish ages when using articular process. Barada et al. (2011) suggested that neither otoliths nor pectoral spines are ideal for aging channel catfish and recommended that fisheries managers choose structures on a case-by-case basis.

The process of collecting lapilli otoliths samples requires mortality of the fish, whereas pectoral spine removal is non-lethal resulting in widespread use among fisheries managers (Stevenson and Day 1987). Pectoral spines are detached from the fish by pulling outward and twisting clockwise (Sneed 1951, Mayhew 1969). Stevenson and Day (1987) reported that wounds created by disarticulated pectoral spines healed quickly with no infection; however, despite observing no mortality, there appeared to be a slight growth difference between fish that had pectoral spines disarticulated compared to those that did not.

Studies evaluating aging precision between the articular process of pectoral spines and otoliths have produced inconsistent results. However, Oklahoma Department of Wildlife Conservation management biologists age channel catfish from numerous populations each year, making it advantageous to further evaluate the use of a non-lethal method of aging this species. Additionally, if precision is comparable between structures, then differences in processing time for each structure should be considered. Therefore, the objective of this study was to compare reader agreement, precision of age estimates, and processing times between aging using the articular process of pectoral spines and aging using the lapilli otoliths of channel catfish from five Oklahoma impoundments. Further, because differences in age estimates between structures could result in disparities in age-based population parameters, we compared von Bertalanffy growth parameters and mortality between structures for two of the five populations.

Methods

Channel catfish were collected for age estimation from five Oklahoma impoundments between 2018 and 2020 using electrofishing, gillnets, and hoop nets (Table 1). Fish were placed into a 1:1 ice water slurry to be euthanized (Blessing et al. 2010) and returned to the lab, where they were measured (TL; mm), had the left pectoral spine disarticulated (Sneed 1951, Mayhew1969), and had lapilli otoliths extracted (Buckmeier et al. 2002, Long and Stewart 2010). Otoliths were cleaned and placed into individually numbered envelopes and allowed to dry for at least 24 h prior to processing (Secor et al. 1992); pectoral spines were boiled to remove organic material (Puchala et al. 2018), placed into individually numbered envelopes, and allowed to dry for at least three weeks before processing.

Table 1. Summary data for reservoirs in Oklahoma where channel catfish were collected between 2018–2020, including size of reservoirs (ha), gear type used for sampling (EF = Electrofishing, GN = gillnets, and HP = hoop nets), sample size (*n*), TL range (mm), and range of age estimates (years).

Reservoir	ha	Gears	*n*	TL (mm)	Age (yrs)
Canton	3201.1	EF, GN	54	275–685	2–18
Carl Blackwell	1363.8	HP	234	228–643	1–16
Jap Beaver	16.2	EF, HP	23	401–691	2–8
Meeker	85.4	HP	285	86–451	0–11
Sooner	2185.3	EF, GN, HP	50	322–719	2–14

We used methodology outlined in Mauck and Boxrucker (2004) to process otoliths and the articular process of the pectoral spine. However, otoliths were not browned, because Waters et al. (2019) found that precision of age estimates between browned and standard methods was similar for channel catfish. Both structures were cut using a low-speed saw with a 127-mm diameter x 0.4-mm thickness blade (Model 11-1280-160; Buehler Ltd., Lake Bluff, Illinois) and then polished with wet 2000-grit sandpaper until annuli became clear and distinguishable. Otoliths were viewed for age estimation by placing the polished side up in a dish containing black modeling clay, submerged in water, and viewed with a dissecting microscope (4x–90x). The articular process of the pectoral spine was viewed by placing the distal end of the spine into clay with the polished side facing up, leveled, and coated with mineral oil to improve clarity of annuli. Additionally, annular marks for both structures were illuminated using a fiber optic filament attached to an external light source (Buckmeier et al. 2002). When illuminated, annular marks of otoliths appeared as opaque bands on a lighted background and as dark bands on a light background for spines (Figure 1).

Two readers independently estimated the age of all channel catfish using both structures. Each structure was evaluated separately and in random order (Hoff et al. 1997). Aging experience varied between readers in this study. Reader 1 had 14 years of experience aging various freshwater fish with several structures, including channel catfish. Conversely, reader 2 had little fish aging experience and had never aged channel catfish prior to this study. If readers disagreed on the number of annular marks estimated for a structure, a concert reading was conducted by both readers to reach agreement (Hoff et al. 1997). If a structure was deemed unreadable, then that individual structure was removed from the study and structures from that fish were not compared with a final consensus reading.

Preparation times for both pectoral spines and otoliths were recorded in minutes. This was achieved by using a timer to record

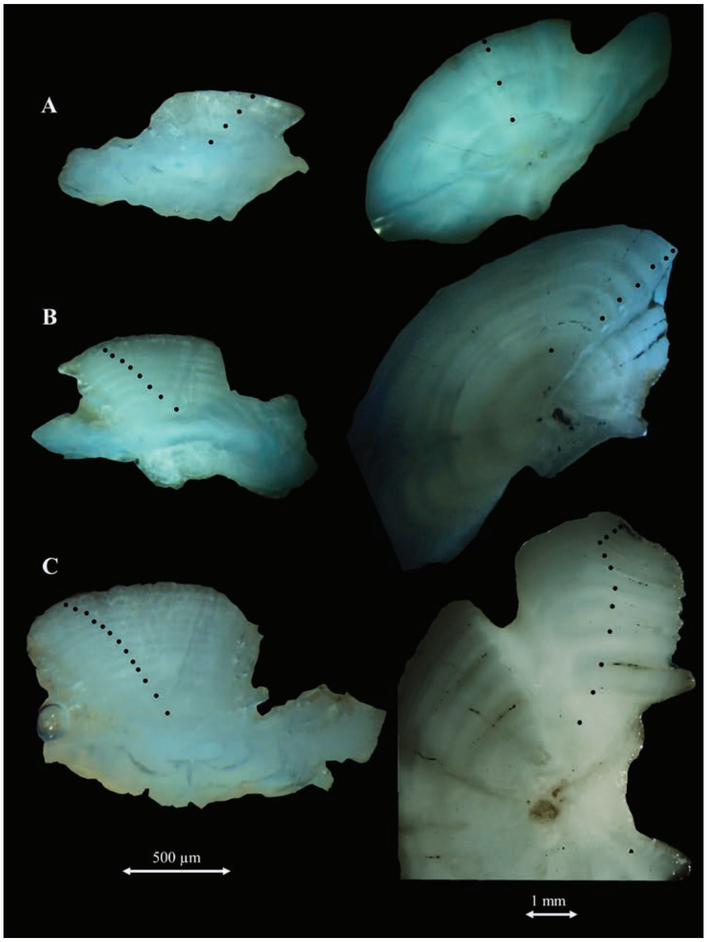

Figure 1. Photographs of the otolith (left) and articular process of the pectoral spines (right) from an estimated age 4 (A; 361 mm TL), age 8 (B; 497 mm TL), and age 13 (C; 657 mm TL) channel catfish. Black dots indicate annuli counted for final consensus ages.

start and stop times for each of eight timed trials for both structures (eight replicates). A single timed trial consisted of the time needed for preparing either otoliths or spines prior to aging. A total of 486 fish comprised the eight timed trials (60.75 fish per trial on average). For each trial with otoliths we recorded the total time in min needed to remove otoliths from envelopes, place into a silicon mold, orient otoliths, apply epoxy to the cells, and cut and polish each otolith. For each trial with pectoral spines we recorded the total time needed to boil, remove excess organic material, cut the articular process, and polish. After completion, the total number of structures processed was divided by the time (min) to achieve a number of structures processed min–1 for each trial. Differences in the two processing rates were assessed using a two-sample *t*-test (Waters et al. 2019).

Between reader precision of otolith and spine age estimates was evaluated for each reservoir using 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). Further, paired *t*-tests were used to compare the consensus ages between structures from each reservoir. Age-bias plots were constructed to compare age estimates between readers to the final consensus age estimates for each structure. Additionally, age-bias plots were used to compare final consensus ages between structures for each reservoir, and 95% confidence intervals were calculated for each of the reported age classes by each reader (Campana et al. 1995). Paired and two-sample *t*-tests were conducted using XLSTAT 2020 (Addinsoft, Inc., New York City, New York).

Growth and mortality of channel catfish was described with a von Bertalanffy growth model using mean TL at age and catch-curve analysis between structures. Models were compared for Carl Blackwell and Meeker reservoirs using a likelihood ratio test (Kimura 1980, Cerrato 1990, Ogle 2016, Porta et al. 2017). Weighted catch curves were used to estimate instantaneous mortality (Z) of each species derived using estimated ages from each of the five structures. Total annual mortality (A) was calculated as $1–e^{-Z}$ (Ricker 1975). Growth and mortality analyses were calculated using the Fisheries Stock Analysis R package (Ogle 2017) within the Oklahoma Fisheries Analysis App (OFAA 2018) and the Fishery Science Methods and Models R package (Nelson 2019). Slopes of the catch curves (Z) were compared among structures using ANCOVA in XLSTAT (Addinsoft, Inc., New York City, New York). All statistical results were considered significant at $P < 0.05$.

Results

A total of 649 channel catfish was collected for age estimation. Of these, ages of 646 individuals were estimated using otoliths and 632 using spines. Because some samples could not be read and were removed from the evaluation, 631 individuals were used to compare final consensus age estimates between structures. Channel catfish used for age estimation ranged 86–719 mm TL (Table 1). Age estimates ranged from 0 to 18 for otoliths and 0 to 14 for spines. The mean processing rate for otoliths was 1.7 otoliths min–1 (range = 1.6–1.8), which was significantly faster ($t = 2.098$, df = 6, $P < 0.01$) than the mean processing rate for pectoral spines which was 0.6 spines min–1 (range = 0.3–0.9).

Between-reader precision was high for otoliths from each reservoir (CV range = 2.1%–9.3%; Table 2). Conversely, between-reader precision using spines was two to three-fold lower, with a mean CV ranging from 12.0%–21.3% among reservoirs (Table 2). Similarly, low APE values among reservoirs suggest precision was high between readers for otoliths (APE = 1.5%–4.4%) compared to spines (APE = 8.5%–15.1%; Table 2). Between-reader agreement using otoliths ranged 80.0%–82.6% among reservoirs; conversely, between-reader agreement for spines ranged 37.0%–50.0% among reservoirs. Age estimates between the two readers were similar for three reservoirs when using otoliths, and for two reservoirs when using spines, but otherwise differed between readers (Table 2).

Given the high precision between reader age estimates for otoliths, age-bias plots suggested no systematic differences between the two readers for all age classes (Figure 2). Conversely, reader bias was observed for spines, particularly for older fish. Age-bias plots showed limited bias for channel catfish <7 years old using spines, but for older ages reader 1 overestimated ages while reader 2 underestimated ages. Age-bias plots comparing final consensus ages showed that spines overestimated ages in younger fish and underestimated ages starting at age 6 compared to otoliths (Figure 3). Mean age estimates and final consensus estimates were

Table 2. Percent reader agreement, average percent error (APE), mean CV, and outcomes of paired *t*-tests comparing readers for ages from otoliths and spines of channel catfish collected in five Oklahoma reservoirs between 2018–2020.

Reservoir	Structure	*n*	% Agreement	APE	Mean CV (%)	*t*	df	*P*
Canton	Otolith	54	81.5	2.1	2.9	–1.00	53	0.32
	Spine	54	37.0	11.3	15.9	6.84	53	0.01
Carl Blackwell	Otolith	234	81.2	3.1	4.3	–4.56	233	0.01
	Spine	220	50.5	9.8	13.9	9.46	219	0.01
Jap Beaver	Otolith	23	82.6	2.5	3.5	2.07	22	1.00
	Spine	23	47.8	8.5	12.0	2.06	22	0.84
Meeker	Otolith	285	81.4	4.4	9.3	6.69	284	0.01
	Spine	285	37.9	15.1	21.3	–1.85	284	0.06
Sooner	Otolith	50	80.0	1.5	2.1	–0.82	49	0.41
	Spine	50	37.5	12.3	17.4	6.30	49	0.01

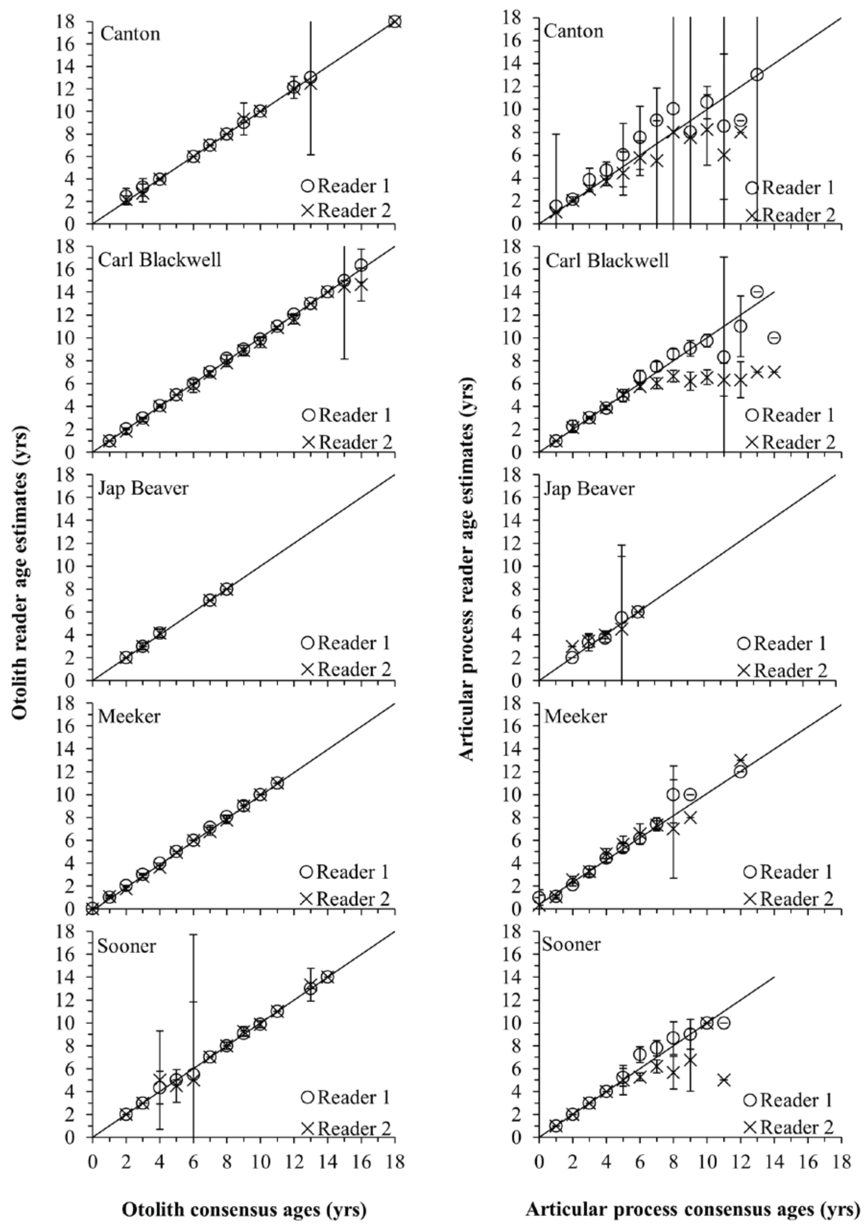

Figure 2. Age-bias plots comparing reader 1 and reader 2 age estimates from otoliths and articular process to final consensus age estimates from each structure for channel catfish from each of five Oklahoma reservoirs. Error bars represent the 95% confidence interval. The diagonal line represents 1:1 relationship between consensus ages and reader 1 and 2 estimated ages.

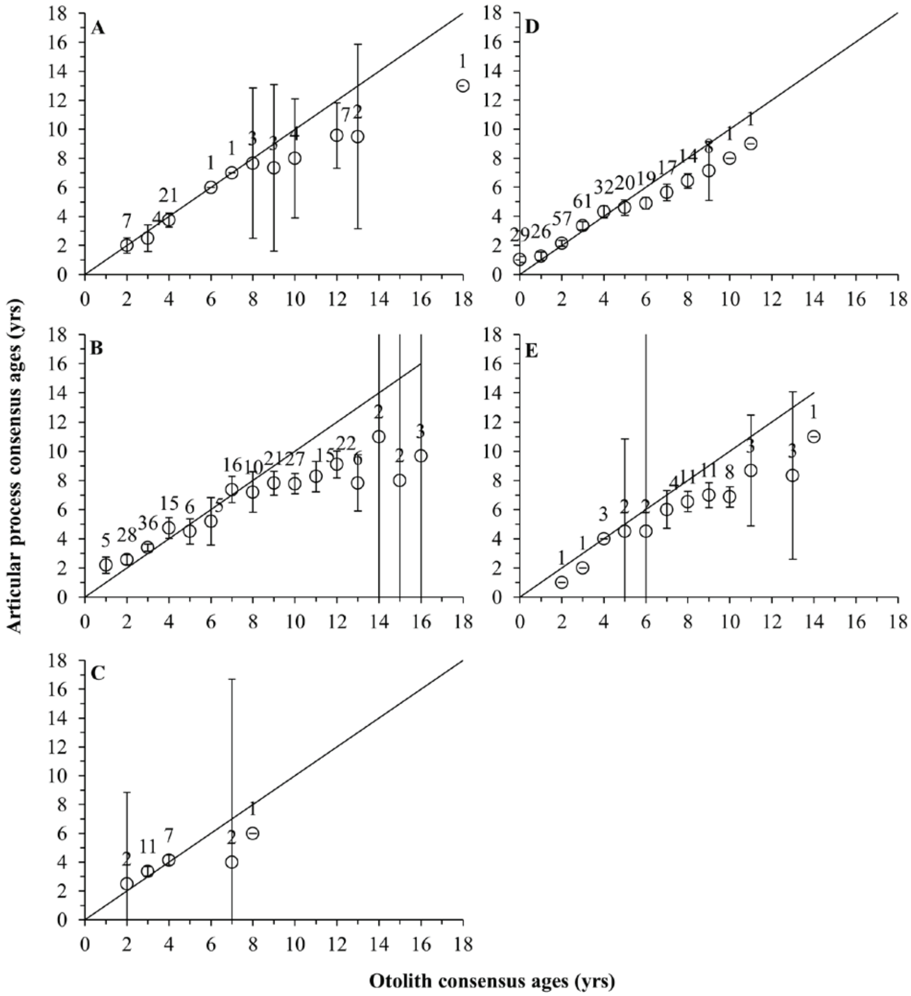

Figure 3. Final consensus age estimates (years) of otoliths compared to articular processes of channel catfish collected during 2018–2020 from five Oklahoma reservoirs: (A) Canton, (B) Carl Blackwell, (C) Jap Beaver, (D) Meeker, (E) Sooner. The diagonal line represents a 1:1 relationship between structures. Numbers above each point represent sample size of that age group.

Table 3. Mean consensus age estimates and outcomes of paired *t*-test comparing ages of otoliths and spines of channel catfish collected from five Oklahoma reservoirs between 2018–2020.

Reservoir	*n*	Otolith	Spine	*t*	df	*P*
Canton	54	6.33	5.42	3.44	53	0.01
Carl Blackwell	219	7.21	6.07	6.55	218	0.01
Jap Beaver	23	3.78	3.69	0.35	22	0.72
Meeker	285	3.47	3.41	0.8	284	0.42
Sooner	50	8.4	6.46	9.04	49	0.01

Table 4. Growth parameters, likelihood ratio test statistics used to compare von Bertalanffy growth models, instantaneous total mortality (*Z*), total annual mortality (*A*), and ANCOVA results comparing slopes of catch curves (*Z*) calculated using age estimates from otoliths and articular processes of channel catfish from two Oklahoma reservoirs.

		Growth Parameters			Likelihood Ratio Test			Mortality		ANCOVA	
Reservoir	Structure	L∞	K	t_0	X^2	df	*P*	*Z*	*A*	F	*P*
Carl Blackwell	Otolith	617	0.49	–0.27	–	–	–	0.135	0.13	–	–
	Spine	531	0.43	–0.91	15.38	3	<0.01	0.304	0.26	22.518	<0.01
Meeker	Otolith	367	0.29	–1.67	–	–	–	0.444	0.36	–	–
	Spine	399	0.35	–1.83	6.84	3	0.07	0.449	0.36	0.698	0.41

similar between aging structures in two reservoirs (Table 3). For the remaining populations, mean age estimates and final consensus estimates were lower using spines than otoliths.

Growth models using otolith age estimates predicted channel catfish would reach larger L_∞ compared to spines for Carl Blackwell (Table 4). As a result, Carl Blackwell von Bertalanffy model parameters (L_∞, *k, and* t_0) differed significantly between structures. The L_∞ predicted using spines was larger than that predicted using otolith age estimates for the Meeker Reservoir population; however, the von Bertalanffy parameters did not differ between structures. Catch-curve analysis using otoliths from channel catfish from Carl Blackwell resulted in a 50% lower annual mortality estimate compared to spines (Table 2), and slopes of the catch-curve (i.e., Z) were significantly different between structures. Conversely, less difference was observed between otoliths and spines of channel catfish from Meeker Reservoir, and slopes of the catch curves were similar between structures.

Discussion

We found that age estimates produced by lapilli otoliths of channel catfish were more precise than those produced by spines, similar to findings reported by Buckmeier et al. (2002) and Barada et al. (2011) for this species. Buckmeier et al. (2002) found that spines typically overestimated channel catfish ages; whereas Barada et al. (2011) observed that pectoral spines tended to underestimate ages for fish younger than age 11. Similarly, Nash and Irwin (1999) found that otoliths were more accurate and precise than pectoral spines for flathead catfish (*Pylodictis olivaris*). Conversely, Colombo et al. (2010) found high agreement and detected no bias between otoliths and spines in channel catfish. Olive et al. (2011) determined that channel catfish age estimates were no different between spines and otoliths up to age 6 and estimates between structures were within 1 year for fish up to age 16. Conversely, although we found little bias for channel catfish <7 years old, ages of older channel catfish were underestimated using spines compared to otoliths.

Experience level differed between readers in this study. Reader 1 was considered an experienced reader having examined different aging structures of many fish species, while reader 2 was considered a novice with little to no aging experience. This was evident in the age-bias plot for spine estimates which show the inconsistency of ages derived from spines due to misinterpretation of annuli. Although more experienced, reader 1 interpreted partial and accessory marks as annuli, leading to an overestimation of ages in the Canton and Sooner populations. Reader 2 could not discern annuli crowded on the edge in some spines, which resulted in underestimated ages. However, age estimates were similar between readers using otoliths for fish younger than age 13 among reservoirs. For older fish variability increased, but no bias was observed. High agreement of age estimates between readers of differing experience demonstrates the greater readability of channel catfish otoliths compared to spines. Both readers noted that annuli were easier to interpret when using otoliths, leading to high agreement between readers. Buckmeier et al. (2002) and Nash and Irwin (1999) found that annuli were easier to interpret in otoliths compared to spines for catfishes. However, our results indicated that it may be possible to use spines to successfully age channel catfish in populations where older fish are rare or nonexistent, as demonstrated in the populations from Jap Beaver and Meeker reservoirs.

Using pectoral spines for aging channel catfish may be challenging for populations of channel catfish living in stressful environments. Several factors such as handling stress, spawning, low dissolved oxygen, starvation, water temperature, and water-level fluctuations can lead to accessory marks or crowding of annuli in aging structures (Ottaway and Simkiss 1977, Weyl and Booth 1999). For example, Snow et al. (2018) reported a formation of a second annulus (false annulus) in saugeye (female walleye [*Sander vitreus*] and male sauger [*S. canadensis*]) dorsal spines during summer when fish contained a high percentage of empty stomachs and water temperatures were at their highest. In contrast, otoliths are generally considered to be more accurate than external aging structures because they are easier to interpret and material is not reabsorbed (Isely and Grabowski 2007).

Most age-based population metrics that guide management decisions assume that fish ages are measured without error (Beamish and McFarlane 1983). Since pectoral spines can be impacted by biotic and abiotic factors that compromise the precision of the structure, fisheries managers should be aware of interpretation error associated with using spines of channel catfish if no other option is available. To combat aging errors, fisheries managers should develop a reference collection to aid in training inexperienced readers and to provide experienced readers with a guide for establishing quality control (Campana 2001). Additionally, reference collections would provide stable referencing tools for comparison among multiple readers in concert. For example, adding an additional reader when one of the two independent readers lacks experience can limit errors and provide a tool to gauge one's experience level.

Otolith preparation times in our study were almost three times faster than processing times for the spines. Although Buckmeier et al. (2002) did not measure processing times for each structure, they suggested that otoliths and the basal recess of spines were faster to prepare than the articular process. Barada et al. (2011) found processing pectoral spines was slightly faster than otoliths of channel catfish, with the most time-consuming step being boiling and removing the spine abductor and arrector dorsalis tissues (Miano et al. 2013) from the pectoral spines. Along with differences in the precision of data and potential effects of bias on age-based population characteristics, the time needed to process each structure should be considered by fisheries managers prior to choosing a structure for estimating ages of channel catfish. Although not measured in this study, future work should record and compare the time needed to remove otoliths and spines.

Differences in age estimates between structures were significant enough to produce different estimates of growth parameters and mortality for the population of channel catfish in Carl Blackwell Reservoir. Conversely, we did not observe differences in either growth parameters or mortality estimates for the Meeker Reservoir population, but this was likely driven by slow growth and a truncated age structure. Contrary to our findings, Colombo et al. (2010) found no difference in growth models or mortality estimates produced using age estimates from otoliths and spines for channel catfish up to age 9. Olive et al. (2011) suggested that age estimates from pectoral spines within 1 year of otolith age estimates would produce acceptable population parameters, but they caution that this may not apply to every population. Further, Nash and Irwin (1999) suggested that age estimates with relatively low bias may provide acceptable data for most management purposes. Based on the results of this study we found that differences in growth parameters and mortality estimates between structures existed in only one of reservoirs. However, managers would need to sacrifice fish in order to understand the possible limitation of using spines to describe age-based population metrics. For this reason and the lack of precision between structures we recommend fisheries managers use otoliths when calculating age-based population metrics for management of channel catfish populations.

Overall, these findings support the use of lapilli otoliths as an aging structure for channel catfish because annular marks are distinguished easily with high precision. Although this method involves sacrificing the fish, otoliths provide the most reliable approach for age determination of channel catfish, can be processed more efficiently, and likely produce the most accurate description of population characteristics. As such, fisheries managers can combat concerns from recreational anglers regarding killing fish with an explanation of the importance of obtaining accurate age data for managing channel catfish populations. It is important to note that in this study aging error was not based on known age but on consensus age of otoliths versus articular process of the pectoral spine. The precision or subsequent error could change if the study was completed with known age fish (Buckmeier and Howells 2003). Because otoliths are generally considered the most accurate aging structure, otoliths should be compared to ages estimated from spines for other channel catfish populations, as ability to reliably estimate ages from spines appears population specific.

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