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[Management Brief]

Precision of Hard Structures Used to Estimate Age of Bowfin in the Upper Mississippi River

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Abstract.—The bowfin *Amia calva* has traditionally been considered a nuisance species that competes for resources with more desirable fish species. However, an emerging market for bowfin roe has increased the species' economic importance and raised awareness associated with the lack of information on its ecology and population dynamics. Furthermore, few studies have investigated the utility and precision of hard structures used to estimate bowfin age. The objective of this study was to examine the precision of age estimates obtained from sectioned pectoral fin rays, otoliths, scales, gular plates, and branchiostegal rays of bowfin collected from the upper Mississippi River. Structures from 255 bowfin were examined. Otoliths, scales, and branchiostegal rays were excluded from analyses because of poor readability. Sectioned pectoral fin rays provided the highest between-reader agreement and lowest variation between age estimates.

The bowfin *Amia calva* is native to the eastern half of the United States and is the sole extant species in the family Amiidae (Pflieger 1997). Historically, the bowfin was considered an undesirable species that competes with more popular sport fish species (Coker 1930; Scarnecchia 1992). Forbes and Richardson (1920) stated that bowfin are "as useless and destructive to our productive waters as wolves and foxes were in our pastures and poultry yards." Similarly, Coker (1930) commented that bowfin are "called by a dozen names, none of which is intended to be complimentary." Because of this negative perception, much of the biological focus on bowfin has been associated with depleting or eliminating bowfin from water bodies. Bowfin have previously been of limited commercial importance, but the value of bowfin roe has recently increased due to declining sturgeon (family Acipenseridae) and paddlefish *Polyodon spathula* populations (Davis 2003). For example, commercial harvesters in Tennessee sold processed bowfin roe for US$15 per kilogram in 2005, but by 2008 the price had increased to $80 per kilogram (G. Scholten, Tennessee Wildlife Resources Agency, personal communication).

Age and growth information is important in the management of exploited species. Calculation of dynamic rate functions, such as growth, recruitment, and mortality, depends on accurate and precise age and growth data (DeVries and Frie 1996). Many structures are used to estimate age of fishes. However, age estimation is often accompanied by several sources of error that can have significant effects on many population parameter estimates (Campana 2001). Validation refers to the accuracy of age estimates and is generally examined using known-age fish (DeVries and Frie 1996). Although understanding the accuracy of different methods of age estimation is important, data required for assessing accuracy are often limited. In contrast, verification refers to the precision of age estimates obtained from hard structures. Although age estimates that are precise may not necessarily be accurate (Maceina et al. 2007), understanding the precision of structures used for age estimation can reduce variation and increase the utility of age and growth information (DeVries and Frie 1996). Research suggests that the preferred structure for age estimation varies by species and geographic location. For example, scales and otoliths provided equally precise age estimates for black crappies *Pomoxis nigromaculatus* in South Dakota waters (Cruse et al. 1993), whereas in Kentucky waters black crappie age estimates obtained from otoliths were more precise than those obtained from scales (Ross et al. 2005). Fin rays are generally the preferred structure for estimating age of sturgeons (Brennan and Cailliet 1989; Jackson et al. 2007), and skeletal or cranial bones (e.g., vertebrae and cleithra) provide the most precise age estimates for Colorado pikeminnow *Ptychocheilus lucius* (Hawkins et al. 2004) and muskellunge *Esox masquinongy* (Casselman 1979). In the limited literature regarding age and growth of bowfin, suggestions regarding the preferred age estimation structure are inconsistent. Mundahl et al. (1988) and Schiavone

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(1982) used scales to age bowfin in Minnesota and New York populations, whereas Holland (1964) and Davis (2003) used gular plates in Missouri and Louisiana populations.

In light of the recent increase in bowfin harvest, precise age and growth information is needed to better understand and manage bowfin populations. Our objective was to assess the precision of age estimates obtained from scales, otoliths, pectoral fin rays, gular plates, and branchiostegal rays of bowfin sampled from the upper Mississippi River. Ideally, we would have also validated the accuracy of age estimates obtained from those structures, but known-age bowfin were unavailable.

Methods

Bowfin were collected from Pools 11 and 13 of the upper Mississippi River in April 2007 by use of modified fyke nets (0.75- × 1.5-m frame, 19-mm bar mesh, 12-m lead, and two throats) and boat-mounted electrofishers (pulsed DC). Fish were measured for total length (TL; mm), and weighed (g), euthanized, and transported to the laboratory for processing. Scales, pectoral fin rays, gular plates, branchiostegal rays, and all three pairs of otoliths (i.e., sagittae, lapilli, and asterisci) were extracted from each fish and placed in an individually numbered scale envelope. Gular plates were only collected from bowfin sampled from Pool 13. Scales were collected from the area immediately posterior to the pectoral fin. Scales were allowed to air dry and then were pressed onto acetate slides. The resulting impressions were viewed with a microfiche reader. Fin rays were clipped from the fish as close to the pectoral girdle as possible. Fin rays were air dried and mounted in epoxy following methods outlined by Koch and Quist (2007). Three 0.6-mm sections were cut from the proximal end of the encapsulated ray with a Buehler Isomet low-speed saw (Buehler, Lake Bluff, Illinois). Similar to fin rays, otoliths were mounted in epoxy and sectioned through the nucleus along the dorsoventral plane. Fin ray and otolith sections were examined using an image analysis system (computer linked to a stereoscope). Gular plates and branchiostegal rays were air dried, briefly immersed in hot water, and then scrubbed with a nylon brush to remove residual tissue. Gular plates and branchiostegal rays were viewed whole via transmitted light from an adjustable light source.

Three readers independently estimated age from all structures. In addition to the presumptive number of annuli, a rating indicating the individual reader's confidence in their age estimate was assigned to each structure. Confidence ratings were integers varying from 0 (i.e., no confidence) to 3 (i.e., absolute confidence), as used in other studies assessing precision of age estimates (Fitzgerald et al. 1997; Koch et al. 2008). When age estimates from all three readers did not agree, the structure was viewed by all readers and a consensus age was assigned. In some cases, no consensus age was reached because of poor readability or discrepancies in the interpretation of annuli. Age was estimated for each structure without prior knowledge of fish length or weight. Between-reader agreement and agreement of an individual reader with the consensus age were quantified as percent agreement (i.e., exact agreement and agreement within 1 year). The precision of age estimates was also evaluated via the coefficient of variation (100 × [SD/mean]; Campana et al. 1995). Age estimates were examined by confidence level to evaluate the relationship between reader confidence and precision of age estimates.

TABLE 1.—Precision of age estimates between readers (R1–R3; percent exact agreement and percent agreement within 1 year; coefficient of variation [CV] is given in parentheses) for sectioned pectoral fin rays ($N = 255$) and gular plates ($N = 137$) of bowfin sampled from Pools 11 and 13 of the upper Mississippi River in 2007.

Comparison	Fin ray	Gular plate
Percent exact agreement (CV)		
R1 versus R2	72.3 (2.6)	45.5 (6.1)
R1 versus R3	71.9 (2.6)	48.0 (6.0)
R2 versus R3	70.7 (3.0)	45.5 (6.6)
Percent agreement within 1 year		
R1 versus R2	93.8	81.3
R1 versus R3	96.7	81.3
R2 versus R3	92.2	78.0

Results

Structures from 255 bowfin (118 fish from Pool 11; 137 fish from Pool 13) were examined. Bowfin varied from 392 to 807 mm TL. After examination of all structures, only sectioned pectoral fin rays and gular plates were deemed useful for estimating age of bowfin. Sectioned and whole otoliths, scales, and branchiostegal rays were not useful for interpretation of annuli. We attempted to age these structures but did not assign ages because of extremely poor readability. Branchiostegal rays, whether examined whole or sectioned, produced no discernible annuli.

Reader agreement was higher for sectioned pectoral fin rays than for gular plates (Table 1). Exact agreement between readers varied from 70.7% to 72.3% for fin rays and from 45.5% to 48.0% for gular plates. Age estimates from gular plates were nearly twice as variable as those from fin rays. Reader agreement within 1 year was 78.0–81.3% for gular

TABLE 2.—Precision of initial age estimates from three readers (R1–R3) in relation to the consensus age (CA; percent exact agreement and percent agreement within 1 year; coefficient of variation [CV] is given in parentheses) determined from fin rays (N = 255) and gular plates (N = 137) of bowfin sampled from Pools 11 and 13 of the upper Mississippi River in 2007.

Comparison	Fin ray	Gular plate
Percent exact agreement (CV)		
R1 versus CA	91.6 (0.9)	79.4 (3.3)
R2 versus CA	85.4 (1.6)	65.7 (4.5)
R3 versus CA	83.6 (1.8)	75.5 (3.0)
Percent agreement within 1 year		
R1 versus CA	99.1	94.1
R2 versus CA	97.8	92.2
R3 versus CA	98.2	96.1

plates and 92.2–96.7% for fin rays. Agreement between initial ages and consensus ages was also higher and less variable for fin rays than for gular plates (Table 2). Most discrepancies between individual age estimates and consensus age were within 1 year, and agreement within 1 year of the consensus age exceeded 92% for fin rays and gular plates for all readers.

Consensus age estimates from gular plates and fin rays were unrelated to structure age. Percent exact agreement of age estimates from the two structures was only 27.9%, but agreement of estimates within 1 year was 72.1% (Figure 1). The maximum disparity in consensus age estimates of two structures was 5 years, where the gular plate consensus age estimate was 2 years and the fin ray consensus age estimate was 7 years for the same fish. Mean difference between age estimates from gular plates and estimates from fin rays was −0.09 years and was evenly distributed above and below exact agreement.

Confidence in age estimates was generally higher for fin rays than for gular plates (Figure 2). No gular plate was given the maximum confidence rating of 3 by all readers, and only nine gular plates received a confidence ranking of 3 by any reader. For fin rays and gular plates, readers tended to agree more when confidence ratings were high (Figure 2). For example, when all three readers assigned a confidence rating of 3 to a structure, individual age estimates agreed 100% of the time. The maximum confidence rating of 3 was assigned by all three readers on 18 fin ray sections. When at least one individual reader assigned a confidence ranking of 0 to a fin ray section ($N = 70$), exact agreement of all readers

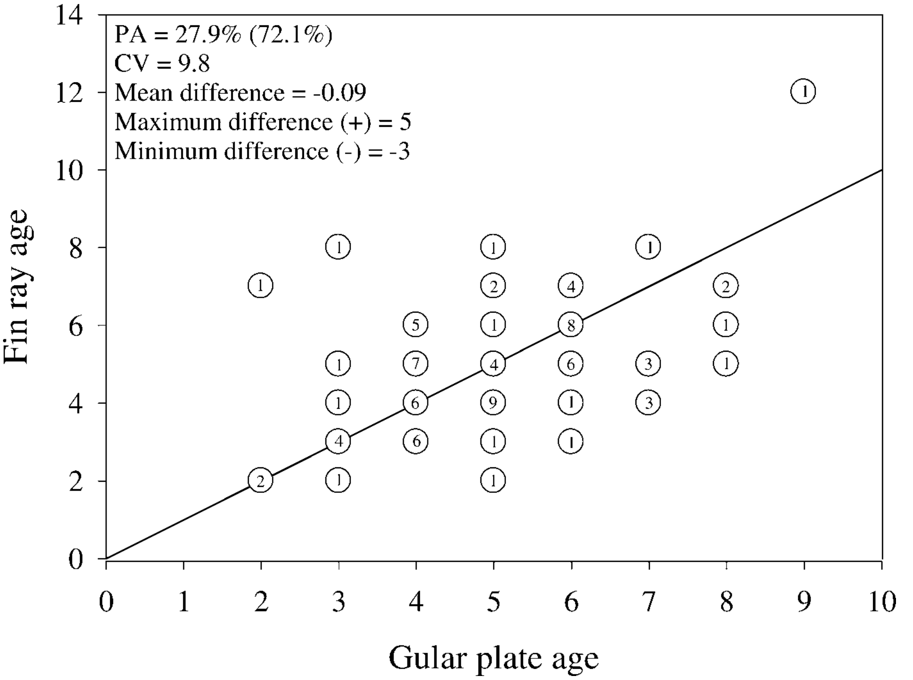

FIGURE 1.—Age bias plots for consensus ages estimated from sectioned fin rays and gular plates of bowfin sampled from Pools 11 and 13 of the upper Mississippi River, in 2007. Precision between structures was measured as percent exact agreement (PA; value outside parentheses), percent agreement within 1 year (value inside parentheses), and mean coefficient of variation (CV). Numbers in circles indicate the number of bowfin at each age.

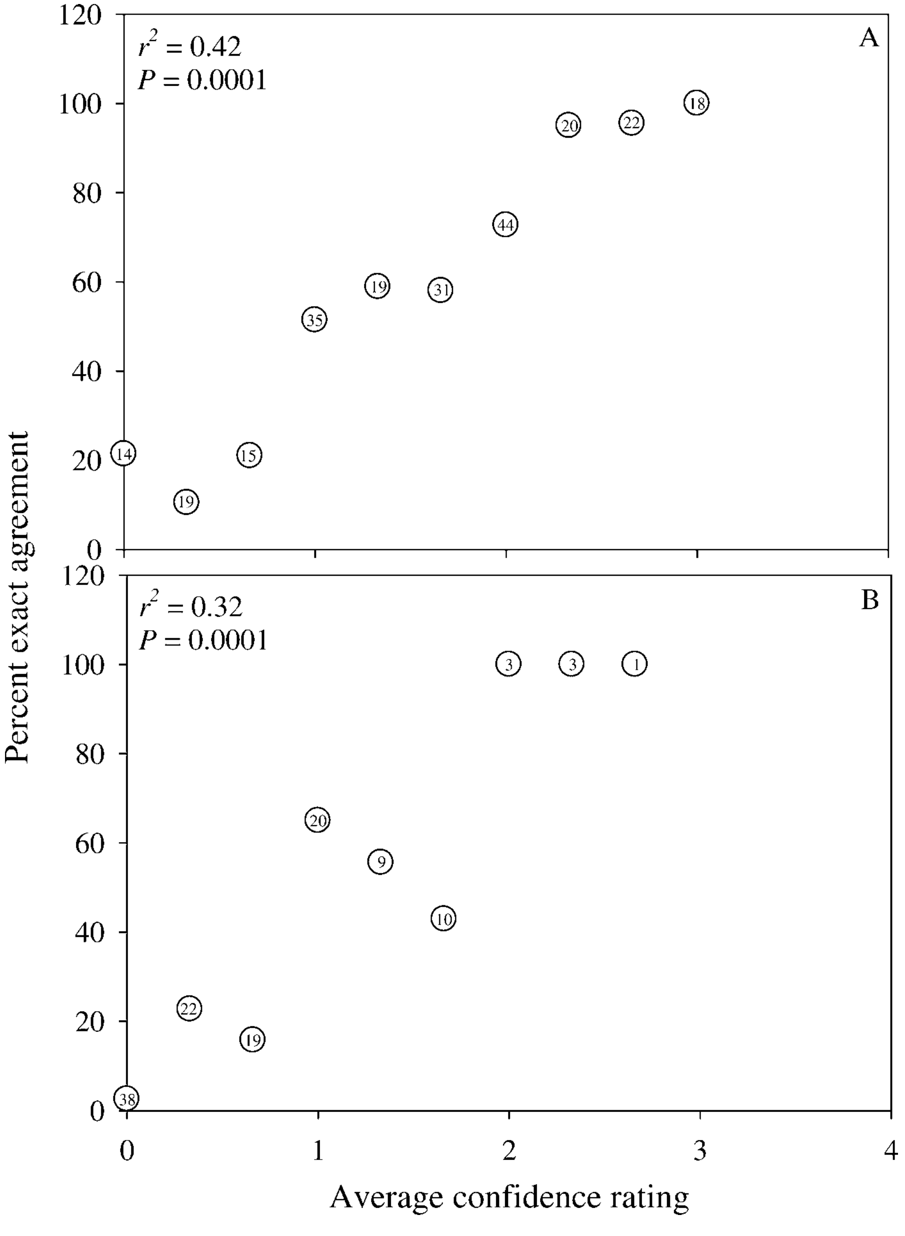

FIGURE 2.—Percent exact agreement of initial age estimates from three independent readers presented in relation to the readers' confidence ratings (0 = no confidence in age estimate; 3 = absolute confidence) for ages determined from **(A)** sectioned pectoral fin rays and **(B)** gular plates of bowfin sampled from pools 11 and 13 of the upper Mississippi River in 2007. Numbers in circles indicate the number of structures examined for each agreement value and confidence ranking.

was only 24%. However, when no reader assigned a confidence rating of 0 ($N = 185$), exact agreement among all readers increased to 77%.

Discussion

Age estimates obtained from sectioned pectoral fin rays were more precise than those obtained from gular plates. Branchiostegal rays, scales, and otoliths exhibited poor readability and did not appear to have potential as aging structures for bowfin in the upper Mississippi River basin. In the limited literature describing age and growth of bowfin, only Holland (1964) attempted to estimate age of bowfin via sectioned pectoral fin rays, and he suggested that cross sections of pectoral and pelvic fin rays were not useful for estimating bowfin ages because they did not exhibit annuli. Although fin rays were not a useful structure in that study, current technology (e.g., mounting mediums, low-speed saws, and optics) may increase the readability of sectioned fin rays from bowfin. Holland (1964) also examined scales, vertebrae, opercles, branchiostegal rays, and gular plates from bowfin and suggested that only gular plates were useful for estimating bowfin ages. Davis (2003) used gular plates to age bowfin from Louisiana after no annuli were observed on whole otoliths. Mundahl et al. (1998) and Schiavone (1982) used scales to estimate age of bowfin from Minnesota and New York, but results of our study and the study by Holland (1964) indicate that scales do not exhibit consistently interpretable annuli.

Our study suggests that otoliths, branchiostegal rays, and scales are not useful structures for estimating age of bowfin in the upper Mississippi River. Although otoliths are the preferred structure used to estimate age for many species (Maceina et al. 2007; but see Walsh et al. 2008), annuli were difficult to distinguish in sectioned otoliths. Similar to otoliths, scales were of limited use in estimating bowfin age because they showed no evident signs of annuli and were obscured by a high number of apparent accessory checks. Finally, branchiostegal rays proved difficult to interpret. In addition to poor readability, branchiostegal rays exhibited thickening of the proximal portion of the structure, thereby obscuring potential annuli from early years of life.

Age estimates obtained from structures with high confidence rankings were more precise than those with low ratings; this result corroborates previous research by Koch et al. (2008), who found that age estimates obtained with high confidence from fin rays of shovelnose sturgeon *Scaphirhynchus platorynchus* were more precise than those with low confidence ratings. Conversely, Fitzgerald et al. (1997) found that confidence rankings had no effect on accuracy of age estimates from muskellunge scales. Although we cannot attest to the relationship between confidence ratings and the accuracy of our age estimates, we contend that confidence rankings have the potential to improve age and growth data by enabling scientists to only use information obtained from structures with the highest readability and precision (i.e., high confidence ratings).

Our results suggest that fisheries scientists should use sectioned pectoral fin rays for age and growth analysis of bowfin. Precision of age estimates was maximized for sectioned pectoral fin rays, and collection of this structure is not lethal. Unfortunately, we could not examine the accuracy of any bowfin age estimation structure, so further research on validating age estimates for bowfin is needed.

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