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Accuracy and Precision of Age Estimation of Crappies

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Abstract.—A collection of known-age black crappies *Pomoxis nigromaculatus* and white crappies *P. annularis* (ages 1–5) was used to evaluate the accuracy and precision of ages estimated from otoliths and scales by readers of varying experience levels. Age estimation accuracy for black crappie otoliths averaged 99.6%, whereas accuracy for scales was 77.6%. Accuracy of age estimates from white crappie otoliths averaged 98.5%, whereas accuracy of estimates from scales averaged 80.4%. For both species, age estimation precision was higher for otoliths than for scales. Reader bias (e.g., difference between true age and estimated age) tended to be greater for scales than otoliths in both species. Bias in otolith age estimation was minimal and only apparent for age-5 crappies, which were consistently underaged. Bias in scale age estimation was most apparent for age-4 and age-5 crappies, which were also typically underaged. Reader experience influenced the degree of precision and bias; experienced readers produced more precise and less biased age estimates. The use of otoliths to improve crappie age estimate precision and bias has been well documented. Through the use of known-age fish, we provide evidence that age estimate accuracy can also be improved.

Age structure in freshwater fish populations is frequently estimated by examination of scales or otoliths (Jearld 1983; Summerfelt and Hall 1987). Several studies have demonstrated that ages estimated from scales can be inaccurate, especially for older fish (Erickson 1983; Casselman 1990; Hammers and Miranda 1991). As fish growth becomes asymptotic, scale growth becomes negligible, resulting in underestimation of age for older fish (Beamish and McFarlane 1987). Age estimation errors associated with scales can also result from resorption, erosion, and decremental changes in the scale itself (Casselman 1990). Generally, accuracy of age estimates derived from otoliths has been relatively high (Williams and Bedford 1974; Taubert and Tranquilli 1982; Erickson 1983). Despite the increased accuracy associated with the use of otoliths, scales continue to be used due to the ease of collection and the ability to ''live-release'' fish.

Several studies have shown that in crappies *Pomoxis* spp. age estimates derived from otoliths are more precise than those obtained from scales (Boxrucker 1986; Crumpton et al. 1988; Hammers and Miranda 1991). In addition, Maceina and Betsill (1987) and Schramm and Doerzbacher (1984) used marginal increment analysis to confirm that distinct annuli are laid down once each spring on otoliths of black crappies *P. nigromaculatus* and white crappies *P. annularis*. Because known-age fish were not used in these studies, the authors were unable to conclude that crappie otoliths are valid for accurate age estimation. Known-age fish provide the best method of age validation, but difficulty in obtaining known-age reference collections precludes their use (Beamish and McFarlane 1983). Validation of age estimation accuracy is critical to any study that utilizes age data to describe population dynamics (Buckmeier 2002). Beamish and McFarlane (1987) called for increased efforts to assess the accuracy of ages estimated from calcified structures.

Hammers and Miranda (1991) examined a limited number of scales and otoliths from known-age white crappies in Mississippi and suggested that age estimates from scales may not be as accurate as those made from otoliths. Because the work by Hammers and Miranda (1991) was not intended as a validation study, few known-age fish were examined.

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Crappies represent important sport fishes across their range, and further validation regarding the accuracy of crappie age estimates derived from scales and otoliths would be useful for biologists who utilize age structure information in managing crappie fisheries. Objectives of our study were (1) to validate and compare accuracy of age estimates determined from scales and otoliths of black and white crappies and (2) to compare the precision and bias of age estimates for both structures in both species. This study provided an ideal comparison between the two species because all fish were known age and were raised under similar conditions.

Methods

Black and white crappies were spawned in 0.4-ha ponds at the Minor Clark Fish Hatchery, Morehead, Kentucky, in 1991. Starting in 1992, 50 juveniles of each species were electrofished from the hatchery ponds in September of each year. Crappies were collected for 5 years, producing a sample of 250 fish (ages 1–5) of each species.

After fish collection, a sample of scales was taken from each fish below the lateral line at the tip of the posteriorly extended pectoral fin. In addition, both sagittal otoliths were extracted. Scales and otoliths were dry-stored in scale envelopes prior to examination. Although 250 fish of each species were sampled, the number of scales and otoliths available for age estimation varied from 239 to 249 due to deformation or breakage.

All scales and otoliths were examined independently by four readers (two experienced and two inexperienced). Both inexperienced readers had less than 1 year of professional experience in age estimation, whereas the experienced readers had each spent over 10 years examining scales and otoliths. Because all crappies were collected in the fall, the age assigned to each fish equaled the number of opaque bands counted.

Whole otoliths were placed in a black dish, covered with diluted glycerine, and examined under a dissecting microscope. No preference was given to the use of the right or left otolith, and readers had the option of examining both otoliths if necessary. Scales were initially pressed between glass slides and read on a microfiche projector. To estimate age by use of the most current scale method, we also pressed scales onto acetate slides. This decision was made several years after the glass-pressed readings were made. As a result, acetate-pressed scales were only examined by the two experienced readers.

To determine whether age estimation accuracy was improved by teamwork, both experienced readers also reexamined any scales (glass and acetate pressed) whose age they disagreed upon. Acting together, the readers attempted to come to a consensus. If an agreement could not be reached, the scale was not used for consensus age estimation analysis.

Accuracy was calculated as the percentage of fish that were aged correctly. Reader age estimation precision was calculated based on the coefficient of variation (CV = 100 $\times$ SD/mean) as presented by Chang (1982). Differences in precision between scales and otoliths within a species were tested by use of Wilcoxon's paired signed rank test (SAS Institute 1988). Differences in precision between species were examined by use of the Wilcoxon rank-sum test (SAS Institute 1988). All statistical tests were considered significant at the 0.05 level. Reader bias was assessed for both magnitude and direction, and was calculated as the mean difference between the estimated age and true age of each fish.

Results

For all readers combined, age estimation accuracy was 99% (range, 98–100%) for both black and white crappie otoliths (Table 1). The greatest discrepancy in accuracy among readers was at age 5 for otoliths of both species (range, 92–100%). Accuracy for glass-pressed scales was 80% (range, 60–94%) for white crappies and 78% (range: 54–94%) for black crappies; accuracy decreased with increasing age (Table 1). Acetate-pressed scales were only read by the two experienced readers; overall accuracy was 89% (86% and 93%) for white crappies and 80% (70% and 90%) for black crappies (Table 1). Accuracy of estimates based on acetate-pressed scales declined with fish age for both species (Table 1).

Consensus reading (the two experienced readers together) produced an accuracy of 91% for glass-pressed white crappie scales, 87% for glass-pressed black crappie scales, 94% for acetate-pressed white crappie scales, and 91% for acetate-pressed black crappie scales (Table 1).

For all readers combined, age estimation precision was greater for otoliths of black (Wilcoxon's paired signed rank test: $S = -5{,}662.5$, $P < 0.01$) and white crappies ($S = -3{,}417.5$, $P < 0.01$) than for glass-pressed scales (Table 2). Differences between species were also evident (Table 2). Black crappie otoliths produced more precise age estimates than white crappie otoliths (Wilcoxon rank-

TABLE 1.—Accuracy of age estimates (%) based on otoliths and scales from known-age crappies. Readers 1 and 2 (R1, R2) were considered inexperienced, whereas 3 and 4 (R3, R4) were experienced. ''All'' represents the mean of all readers combined, ''Paired'' represents the consensus reading between R3 and R4.

	Otoliths						Glass-pressed scales							Acetate-pressed scales				
Age	*N*	R1	R2	R3	R4	All	*N*	R1	R2	R3	R4	All	Paired	*N*	R3	R4	All	Paired
								White crappies										
1	46	96	100	100	100	99	47	92	96	100	96	96	96	47	100	100	100	100
2	48	98	100	100	100	99	48	88	92	92	81	88	94	48	96	94	95	98
3	49	98	98	100	100	99	49	74	96	92	82	86	94	49	96	98	97	98
4	47	98	98	98	100	98	48	27	96	77	75	69	88	48	73	92	82	94
5	49	98	92	98	100	97	49	22	92	69	74	64	62	49	63	82	72	82
Total	239	98	96	99	100	99	241	60	94	86	81	80	91	241	86	93	89	94
								Black crappies										
1	50	100	100	100	100	100	49	88	100	90	100	94	92	49	100	98	99	100
2	50	100	100	100	100	100	50	70	100	76	92	85	82	50	86	88	87	88
3	49	100	98	100	100	99	50	52	100	80	84	79	96	50	62	92	77	90
4	50	100	100	100	100	100	50	40	96	66	64	67	70	50	48	88	68	88
5	50	96	98	100	100	99	49	18	74	69	94	64	94	49	55	82	66	88
Total	249	99	99	100	100	99	248	54	94	76	87	78	87	248	70	90	80	91

sum test: $Z = 2.2551$, $P = 0.02$). Glass-pressed scales yielded more precise estimates for white crappies than for black crappies ($Z = -2.4748$, $P = 0.01$).

Acetate-pressed scales (read by experienced readers only) produced more precise age estimates than glass-pressed scales for white crappies ($S = -404.5$, $P < 0.01$) but not for black crappies ($S = -206.5$, $P = 0.46$) (Table 2). Ages estimated from acetate-pressed scales, however, were not as precise as ages estimated from otoliths for black ($S = 266.5$, $P < 0.01$) or white ($S = -1{,}501.5$, $P < 0.01$) crappies.

A difference in age estimation precision by reader experience level was evident for glass-pressed scales of both black ($S = -824.0$, $P = 0.04$) and white crappies ($S = -996.5$, $P < 0.01$); experienced readers exhibited better precision (Table 2). Although experience level was not a significant factor in age estimation precision for black crappie otoliths ($S = -1.5$, $P = 0.50$), white crappie otoliths were aged with more precision by experienced readers ($S = -21.5$, $P = 0.03$) (Table 2). Age estimation precision across ages varied by species and aging structure as well as by reader experience level (Table 2).

For both scale age estimation methods and for both crappie species, the magnitude of reader bias tended to increase with increasing fish age (Table 3). Directional bias results for scales indicated that readers generally overestimated the age of age-1 crappies and underestimated ages for age-4 and

TABLE 2.—Age estimation precision, calculated as mean CV, for scales and otoliths from known-age black and white crappies. ''All'' represents all readers combined (two inexperienced readers [IR] and two experienced readers [ER]).

	Glass-pressed scales			Acetate-pressed scales (ER)	Otoliths		
Age	All	IR	ER		All	IR	ER
				White crappies			
1	5.0421	6.0179	2.0060	0.0000	1.7391	2.0496	0.0000
2	10.4658	7.4639	8.3478	3.3391	0.5952	0.9821	0.0000
3	7.8220	6.1548	6.1640	1.8760	0.7421	1.1545	0.0000
4	12.0147	15.6831	6.2480	5.6868	0.6013	0.0000	0.0000
5	11.0853	13.9612	5.5318	3.9284	0.8846	0.9621	0.3207
Total	9.3050	9.8738	5.6762	2.9778	0.9060	1.0257	0.1315
				Black crappies			
1	6.4382	5.7723	4.8103	0.9621	0.0000	0.0000	0.0000
2	12.3132	8.4853	8.6738	6.5997	0.0000	0.0000	0.0000
3	12.1928	11.1723	8.6806	8.1239	0.3140	0.4123	0.0000
4	13.9260	11.7514	12.1443	12.0769	0.0000	0.0000	0.0000
5	12.7018	15.1408	5.9441	9.1738	0.4671	0.3143	0.0000
Total	11.5301	10.4645	8.0722	7.4060	0.1556	0.1442	0.0000

TABLE 3.—Reader bias, reported as the mean difference between estimated age and true age, for scales and otoliths of known-age black and white crappies. Readers 1 and 2 were inexperienced, whereas readers 3 and 4 were experienced.

Method	Species	Reader	Age 1	2	3	4	5
Otoliths	White crappie	1	0.04	−0.02	−0.02	−0.02	−0.02
		2	0.00	0.00	−0.02	−0.02	−0.08
		3	0.00	0.00	0.00	0.02	−0.02
		4	0.00	0.00	0.00	0.00	0.00
	Black crappie	1	0.00	0.00	0.00	0.00	−0.04
		2	0.00	0.00	0.02	0.00	−0.02
		3	0.00	0.00	0.00	0.00	0.00
		4	0.00	0.00	0.00	0.00	0.00
Glass-pressed scales	White crappie	1	0.09	0.04	0.04	−0.50	−0.90
		2	0.04	0.08	0.06	0.00	−0.08
		3	0.00	0.00	0.06	−0.10	−0.35
		4	0.04	−0.02	−0.18	−0.10	−0.29
	Black crappie	1	0.12	0.30	0.54	−0.12	−1.04
		2	0.00	0.00	0.00	0.00	−0.26
		3	0.10	0.22	0.18	−0.08	−0.33
		4	0.00	0.00	−0.08	−0.02	−0.08
Acetate-pressed scales	White crappie	3	0.00	0.00	0.02	−0.25	−0.39
		4	0.00	0.06	−0.02	−0.02	−0.18
	Black crappie	3	0.00	−0.08	−0.18	−0.06	−0.57
		4	0.02	0.08	0.10	−0.06	−0.20

age-5 crappies. Most differences in directional bias between readers occurred for crappies aged 2 and 3. Bias in age estimation of otoliths was generally low across all ages (Table 3).

Discussion

Although differences in age estimation precision between crappie scales and otoliths have been documented (Schramm and Doerzbacher 1984; Boxrucker 1986; Hammers and Miranda 1991), differences in accuracy have so far only been assumed. Validation techniques like marginal increment analysis can confirm that distinct annuli are laid down at approximately the same time each year, but cannot validate whether these annuli can be accurately identified by a variety of readers. Absolute validation is only possible through the use of known-age fish. The intent of this study was to validate the findings and assumptions of previous studies through the use of known-age fish.

Otoliths of both black and white crappies were found to provide highly accurate estimates of true fish age. In addition, age estimate accuracy was higher for otoliths than for scales; this was true for white and black crappies and for inexperienced and experienced readers. Although this study did not address age validation through marginal increment analysis, it does provide confirmation that accuracy assumptions drawn from such studies were correct.

Although readers did not know the maximum age of crappies in our reference collection, it appears that all were able to deduce this information through the otolith age estimation process. Because otoliths were aged first as a group and accuracy was high, it became evident to readers that the maximum age was 5 years. As a result, bias was introduced into their estimation of scale ages. Unfortunately, older fish were not mixed into the sample when the fish were aged in 1997 to prevent this from happening. Although such bias does affect our results, we believe that it should have only improved reader accuracy at the older ages, and therefore our results are a best-case scenario.

The inability of one of the inexperienced readers (reader 1) to accurately age scales contrasts with the almost perfect accuracy produced when estimating otolith ages. The fourth and fifth annuli of both black and white crappies were closely spaced and were located very near the edge in both scales and otoliths. Only on scales did this result in significant missed annuli in age estimates. The discrepancy in age estimation accuracy between otoliths and scales for inexperienced readers shows that otoliths become even more beneficial when reader experience level is low.

Check marks and false annuli appeared on both the scales and otoliths of black and white crappies, but were more easily distinguishable from true annuli on otoliths. Therefore, precision in general was much better for otoliths than for scales. Slight differences in age estimation precision between black crappie and white crappie otoliths did exist, but precision was high for both species. Experience level affected precision, and therefore more precise age estimates were produced by experienced readers. This was the case for both scales and otoliths.

Close spacing of the outer annuli on both the otoliths and scales of black and white crappies was the most likely cause of consistent underestimation of age. The inability of readers to decipher check marks on scales, however, produced a higher magnitude of bias in scales than in otoliths.

The utility of glass-pressed scales for age estimation purposes is limited. Acetate slides are preferred and are assumed to provide a more clear depiction of the scale. Our study assessed differences between the two scale mounting methods. The use of acetate impressions improved overall age estimation accuracy somewhat (<10% for either species). Although acetate impressions provide the potential to improve individual reader accuracy, variability associated with scales still existed. If 90% accuracy is used as a guideline for minimal bias effects on rate function estimation (Buckmeier 2002), then acetate impressions only helped to limit the effects of bias for one of the readers.

Consensus reading increased accuracy levels of age estimates based on acetate-pressed scales for both species. Collaboration between the two experienced readers reduced the difference between otolith and scale accuracy to less than 10% for both species. Improvements may not have been as substantial for two inexperienced readers or for readers with a combination of experience levels. Our results do indicate that consensus age estimation of acetate impressions may provide sufficient accuracy to offer an alternative to otoliths in some cases.

The fact that such high variability existed between our inexperienced readers brings up an important issue pertaining to consensus age estimation. Reader personality may have a major impact on the accuracy obtained by consensus age estimation. The nature of personality and behavior within a hierarchy may prevent the inexperienced reader from successfully correcting a superior. In the case of our study, accuracy would have been sacrificed if inexperienced reader 2 had been paired with either experienced reader. It is crucial that both readers have an open mind when using the consensus age estimation method.

Our results provide findings similar to those of other studies and support the fact that otoliths generally offer more precise and less biased age estimation results. Through the use of known-age fish, we have demonstrated that otoliths also provide the benefit of improved accuracy. In certain cases, accuracy requirements, fish disposition, need for a nonlethal method, and reader experience may dictate the use of scales instead of otoliths. In such instances, we recommend the use of paired-reader consensus age estimation to improve overall accuracy.

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References

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.

Beamish, R. J., and G. A. McFarlane. 1987. Current trends in age determination methodology. Pages 15–42 *in* R. C. Summerfelt and G. E. Hall, editors. Age and growth of fish. Iowa State University Press, Ames.

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

Buckmeier, D. L. 2002. Assessment of reader accuracy and recommendations to reduce subjectivity in age estimation. Fisheries 27(1):10–14.

Casselman, J. M. 1990. Growth and relative size of calcified structures of fish. Transactions of the American Fisheries Society 119:673–688.

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

Crumpton, J. E., M. M. Hale, and D. J. Renfro. 1988. Bias from age-grouping black crappie by length-frequency as compared to otolith aging. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 40(1986): 65–71.

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

Hammers, B. E., and L. E. Miranda. 1991. Comparison of methods for estimating age, growth, and related population characteristics of white crappies. North American Journal of Fisheries Management 11: 492–498.

Jearld, A., Jr. 1983. Age determination. Pages 301–324 *in* L. A. Nielsen and D. L. Johnson, editors. Fisheries techniques. American Fisheries Society, Bethesda, Maryland.

Maceina, M. J., 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.

SAS Institute. 1988. SAS/STAT user's guide, release 6.03. SAS Institute, Cary, North Carolina.

Schramm, H. L., Jr., and J. F. Doerzbacher. 1984. Use of otoliths to age black crappie from Florida. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 36(1982):95–105.

Summerfelt, R. C., and G. E. Hall, editors. 1987. Age and growth of fish. Iowa State University Press, Ames.

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.

Williams, T., and B. C. Bedford. 1974. The use of otoliths for age determination. Pages 114–223 *in* T. B. Bagenal, editor. Aging of fish. Unwin Brothers, Old Woking, UK.