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Evaluation of Hard Structures Used to Estimate Age of Common Carp

Abstract

Understanding age distributions and dynamic rate functions is critical for effective management of Common Carp (*Cyprinus carpio*) populations, but requires the use of readable hard structures that produce precise age estimates. Various non-lethal hard structures for estimating age of Common Carp have been evaluated, but a comprehensive evaluation of the precision of age estimates and relative readability among widely-used hard structures is lacking. We verified age estimates obtained from asteriscus otoliths, scales, pectoral fin rays, and dorsal fin spines of 207 Common Carp from Crane Creek Reservoir and Lake Lowell in southwestern Idaho. Between-reader precision, readability, and differences in age estimates among hard structures were evaluated. Percent agreement (PA) was lower and the coefficient of variation (CV) was higher for otoliths (PA = 18.4%; CV = 17.6) and scales (PA = 29.7%; CV = 15.4) compared with pectoral fin rays (PA= 51.7%; CV = 4.9) and dorsal fin spines (PA = 65.2%; CV = 3.0). Both readers displayed higher confidence in estimating age using dorsal fin spines than pectoral fin rays. In general, age estimates from scales and otoliths were lower than both pectoral fin rays and dorsal fin spines. Between-reader analysis showed high exact and within-1 year agreement, low CV, and higher confidence ratings for age estimates obtained from dorsal fin spines when compared with the other hard structures. Dorsal fin spines provide the most repeatable estimates of Common Carp age and annuli formed on dorsal fin spines were easily read. Thus, understanding Common Carp population age structure and growth can be achieved using dorsal fin spines.

Keywords: Common carp, dorsal fin spine, pectoral fin ray, scale, otolith

Introduction

Common Carp *Cyprinus carpio* have become a widespread non-native species in North America following their introduction in the mid-1800s. Originally introduced in the U.S. to serve as a food source for an expanding country (Baird 1874), Common Carp quickly become ubiquitous throughout waters of North America. Common Carp is native to Europe where it supports many important recreational fisheries (Panek 1987), but outside their native distribution, Common Carp have the potential to negatively influence the integrity of aquatic ecosystems and fish assemblage structure (Parkos et al. 2003, Weber and Brown 2009, Jackson et al. 2010). Where Common Carp have been introduced, habitat conditions are often degraded and very few Common Carp populations are of commercial or recreational value (Lougheed et al. 1998, Zambrano et al. 1999). Common Carp feed by rummaging through sediments and then expelling particles into the water column (Breukelaar et al. 1994), and as a result, can reduce the diversity and abundance of benthic invertebrate communities (Miller and Crowl 2006, Fischer et al. 2012). The manner in which Common Carp forage can also cause a lake to transition from a clear to a turbid state, thereby deteriorating habitat for sight-feeding fishes (Jackson et al. 2010, Weber and Brown 2011). Such changes can alter food web structure and, because most sport fishes are sight-feeding piscivores (e.g., black basses

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Micropterus spp., Bluegill *Lempomis macrochirus*, and Walleye *Sander vitreus*), Common Carp-mediated changes in the water quality can negatively influence local economies that depend on income from recreational angling (Jackson et al. 2010). Due to negative effects on water quality, food web structure, and economically-important fishes, considerable effort has been directed at reducing Common Carp abundance to minimize deleterious effects on aquatic ecosystems (Schrage and Downing 2004, Jackson et al. 2010).

Understanding age distributions and dynamic rate functions (i.e., growth, recruitment, and mortality) are critical components of effectively managing fish populations (Ricker 1975). Fisheries biologists routinely use age and growth information to manage sport fisheries, species of conservation concern, and even nuisance species such as Common Carp. In many freshwater systems, Common Carp make up the majority of the vertebrate biomass and are an important component of both lentic (Schrage and Downing 2004) and lotic (Verrill and Berry 1995) fish assemblages. Thus, information on Common Carp age and growth is important for formulating proper management decisions such as those that include optimal removal and suppression of populations that negatively influence important sport and commercial fisheries (Wichers 1975, Jackson et al. 2007, Weber and Brown 2011).

Reliable estimates of fish age are needed for accurate and precise estimates of growth. Obtaining reliable age estimates is dependent on selecting the best hard structure that is also the most practical given various limitations (e.g., logistic constraints, time, inability to sacrifice fish). The accuracy and precision of age estimates is variable among hard structures depending on species and geographic region (Quist et al. 2012). For instance, Schramm and Doerzbacher (1985) reported that Black Crappie *Pomoxis nigromaculatus* scales in the southeastern U.S. provided unreliable age estimates and suggested the use of otoliths. In contrast, Kruse et al. (1993) found that scales from Black Crappie in northern waters (i.e., South Dakota) provided higher age estimate precision than otoliths. Therefore, evaluating hard structures across regions is important for meeting research and management objectives.

Hard structures from Common Carp have been extensively evaluated and early studies reported confounding results regarding the precision of age estimates from different hard structures (Jackson et al. 2007), but with a variety of comparison criteria. McConnell (1952) and Lubinski et al. (1984) reported contradictory results regarding the utility of Common Carp scales. McConnell suggested the use of opercles compared to scales, whereas Lubinski et al. (1984) reported that scales provided superior age estimates to opercles. Asteriscus otoliths have been validated using known-age Common Carp from Australian waters (Brown et al. 2004), but otoliths are often undesirable because extraction requires sacrificing fish. Although sacrificing Common Carp in waters where they are not native is generally not a concern, sacrificing fish may be impractical in certain situations, such as for mark-recapture projects. Phelps et al. (2007) compared age estimates derived from scales, opercles, vertebrae, and pectoral fin rays relative to otoliths. They found that pectoral fin rays provided the most concordance relative to otoliths, with an average percent error of 1.2%. Jackson et al. (2007) examined the precision of scales and dorsal fin spines and found that agreement between two readers was 90.6% for dorsal fin spines, whereas age estimates from scales lacked precision beyond age 1. Weber and Brown (2011) compared the precision of dorsal fin spines and pectoral fin rays and found that both had high percent agreement (~ 95%) and low coefficient of variation (0.3%) following a joint examination by two readers. These results suggest that dorsal fin spines may provide a reliable non-lethal hard structure for age estimation.

Dorsal fin spines and pectoral fin rays are favorable because they can easily be removed without sacrificing fish and often provide more precise estimates of age than other hard structures (Jackson et al. 2007, Weber and Brown 2011). However, age estimates from dorsal fin spines have not been compared with otoliths and the only previous study comparing pectoral fin rays with otoliths (Phelps et al. 2007) failed to evaluate the between-reader precision of both hard structures. While otoliths have been used to estimate age of a variety of species they are often less practical and less precise than alternative hard structures for some species (Walsh et al. 2008). Recently, we have observed poor readability and difficulty in estimating age of Common Carp using otoliths. Due to the inconsistencies among studies regarding agreement between hard structures for estimating age of Common Carp and perceived issues with using otoliths, we compared the precision of age estimates obtained from multiple hard structures that are widely-used for estimating age of Common Carp. We were unable to evaluate the accuracy of age estimates because estimating accuracy requires the use of known-age fish (Beamish and McFarlane 1983, Quist et al. 2012). While knowledge of the accuracy of age estimation is important, identifying hard structures with the highest precision is also important for guiding efforts associated with estimating age and growth of fishes. Therefore, the objective of this study was to compare the precision and readability of otoliths, scales, pectoral fin rays, and dorsal fin spines from Common Carp.

Methods

Common Carp were collected in October 2012 from Crane Creek Reservoir and Lake Lowell in southwestern Idaho using experimental gill nets and daytime boat-mounted electrofishing. All individuals were measured to the nearest millimeter (total length), euthanized, and stored in a freezer for later processing. Asteriscus otoliths, scales, pectoral fin rays, and dorsal fin spines were removed from each individual. Otoliths were removed via the "up-through-the-gills" method according to Schneidervin and Hubert (1986). Roughly 5–10 scales were removed from the area directly ventral to the lateral line and posterior to the insertion of the pectoral fin on the left side of each individual (Isermann et al. 2003; Jackson et al. 2007). Pectoral fin rays were removed at the proximal end of the ray by cutting the left leading fin ray at the insertion of the articulating process (Koch et al. 2008). The right fin ray was used in place of a damaged or deformed left fin ray. Dorsal fin spines were removed in a similar fashion to that of pectoral fin rays by cutting into the tissue and rotating the spine until it was pulled free.

All structures were allowed to air dry in coin envelopes for at least two weeks. After air drying, damaged or regenerated scales were discarded. Remaining scales were pressed onto acetate slides and read using a microfiche projector. Each spine and fin ray was mounted in epoxy in either a 2 ml or 5 ml microcentrifuge tube following Koch and Quist (2007). Generally, 5 ml centrifuge tubes were needed due to the large diameter of the proximal end of the spines and fin rays. Cross-sections (0.8 mm thick) were cut near the base of the fin ray or spine using a Buehler Isomet low-speed saw (Buehler, Lake Bluff, IL). Whole otoliths were examined but quickly deemed unreadable. Therefore, otoliths were mounted in epoxy using 2 ml microcentrifuge tubes. Transverse sections were cut using a low-speed saw; sections bracketed the nucleus (Brown et al. 2004). Right and left otoliths were used interchangeably because previous studies have found no difference in age estimates obtained from non-deformed otoliths of the same individual for other species (e.g., White Crappie *Pomoxis annularus*; Boxrucker 1986). Otolith, pectoral fin ray, and dorsal fin spine sections were examined using a dissecting microscope with transmitted light and an image analysis system (Image ProPlus; Media Cybernetics, Silver Springs, MD).

Annuli were enumerated on all hard structures independently by two readers. One of the readers had substantial experience estimating age of fishes with otoliths and scales, whereas the other reader had minimal experience. Neither reader had much experience estimating age of fishes using fin rays or spines. However, both readers received training on age estimation from a highly experienced scientist and spent considerable time examining fin rays and spines from a variety of species prior to the study. Age was estimated for one hard structure before proceeding to the next. Knowledge of fish size and age estimates from other hard structures was unknown to readers during the age estimation process. In addition to the presumptive number of annuli, a rating

TABLE 1. Study site, surface area (ha), sample size, and total length (mm) statistics of Common Carp sampled for age estimation from Crane Creek Reservoir and Lake Lowell, Idaho (2012). Mean, standard deviation (SD), minimum (min), and maximum (max) lengths are provided (mm).

			Total length			
Study site	Surface area	*n*	Mean	SD	Min	Max
Crane Creek Reservoir	1,497	125	365	84	198	642
Lake Lowell	3,642	82	495	39	401	635

indicating the individual reader's confidence in their age estimates was assigned to each hard structure (Fitzgerald et al. 1997, Koch et al. 2008, Spiegel et al. 2010). We followed the rating criteria provided by Spiegel et al. (2010) where confidence ratings were integers between 0 and 3. A confidence rating of 0 corresponded to no confidence, whereas a rating of 3 corresponded to complete confidence in the reader's age estimate. Age-bias plots were used to evaluate between-reader precision for each hard structure (Campana et al. 1995). Age-bias plots were created for each hard structure by plotting age estimates from reader 1 against age estimates from reader 2. Variation in age estimates between readers was assessed by calculating the percent agreement (i.e., exact and within-1 year agreement) in age estimates for each hard structure. The coefficient of variation (CV) was used as another measure of precision in age estimates and was calculated as:

$$CV_j = 100 \times \frac{\sqrt{\sum_{i=1}^{R} \frac{(X_{ij}-X_j)^2}{R-1}}}{X_j},$$

where X_{ij} is the *i*th age determination for the *j*th fish, X_j is the mean age of the *j*th fish, and *R* is the number of times age was estimated for each fish (Campana et al. 1995). The CV was estimated for individual fish and hard structure, and then averaged across individuals to provide an estimate of between-reader precision by hard structure. Confidence ratings for each hard structure were pooled for both readers. A Kruskal-Wallis test was used to evaluate whether median confidence ratings differed among hard structures. A post-hoc Wilcoxon rank-sum test for pairwise comparisons was then used to evaluate differences in estimated age among pairs of hard structures. A type I error rate of $\alpha = 0.05$ was used for all statistical tests.

Results

We estimated age of 207 Common Carp varying in length from 198 to 642 mm (Table 1). Common Carp sampled from Lake Lowell exhibited a narrow distribution of lengths (401–635 mm) compared with fish from Crane Creek Reservoir (198–642 mm). Age estimates varied from 1 to 19 years for otoliths, 0 to 17 years for scales, 1 to 17 years for pectoral fin rays, and 1 to 18 years for dorsal fin spines.

Exact age estimate agreement between readers was lowest for otoliths and highest for dorsal fin spines (Table 2). Exact age estimate agreement was 18% for otoliths, 30% for scales, 52% for pectoral fin rays, and 65% for dorsal fin spines. Percent agreement within 1 year increased to 54% for otoliths, 67% for scales, 88% for pectoral fin rays, and 94% for dorsal fin spines. Pectoral fin rays and dorsal fin spine age estimates also displayed the lowest between-reader CVs (Table 2). Mean CV of age estimates was highest for otoliths. Examination of age-bias plots showed high concordance between readers for dorsal fin spines and low concordance for scales and otoliths (Figures 1–4). Using scales and otoliths,

TABLE 2. Precision in age estimates between two readers for otoliths, scales, pectoral fin rays, and dorsal fin spines from Common Carp sampled in Crane Creek Reservoir and Lake Lowell, Idaho (2012). Measures of precision include exact percent agreement (PA-0), percent agreement within 1 year (PA-1), and mean coefficient of variation (CV).

Hard structure	PA-0	PA-1	CV
Otoliths	18.4	54.1	17.6
Scales	29.7	66.6	15.4
Pectoral fin rays	51.7	88.4	4.9
Dorsal fin spines	65.2	93.7	3.0

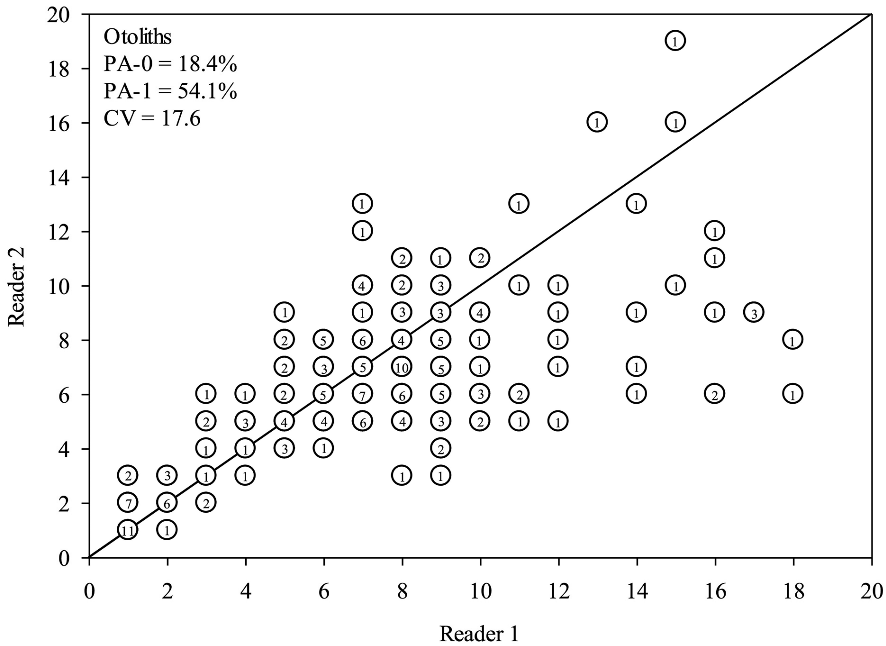

Figure 1. Age-bias plot for ages assigned to sectioned otoliths from Common Carp sampled from Crane Creek Reservoir and Lake Lowell, Idaho in 2012 (n = 207). Precision between readers is indicated as exact (PA-0) and within-1 year (PA-1) agreement and mean coefficient of variation (CV). Numbers inside circles represent the number of observations.

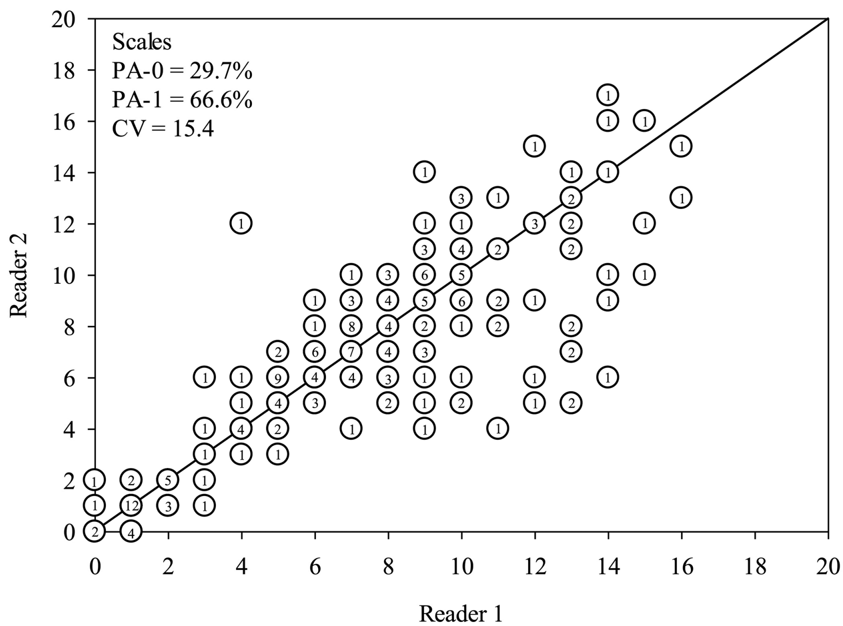

Figure 2. Age-bias plot for ages assigned to scales from Common Carp sampled from Crane Creek Reservoir and Lake Lowell, Idaho in 2012 (n = 207). Precision between readers is indicated as exact (PA-0) and within-1 year (PA-1) agreement and mean coefficient of variation (CV). Numbers inside circles represent the number of observations.

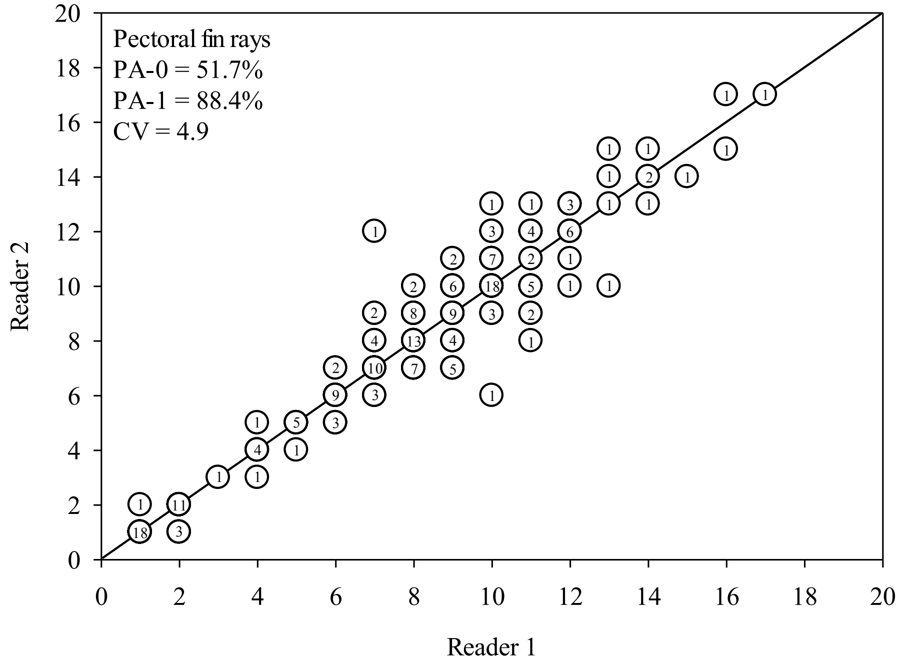

Figure 3. Age-bias plot for ages assigned to sectioned pectoral fin rays from Common Carp sampled from Crane Creek Reservoir and Lake Lowell, Idaho in 2012 (n = 207). Precision between readers is indicated as exact (PA-0) and within-1 year (PA-1) agreement and mean coefficient of variation (CV). Numbers inside circles represent the number observations.

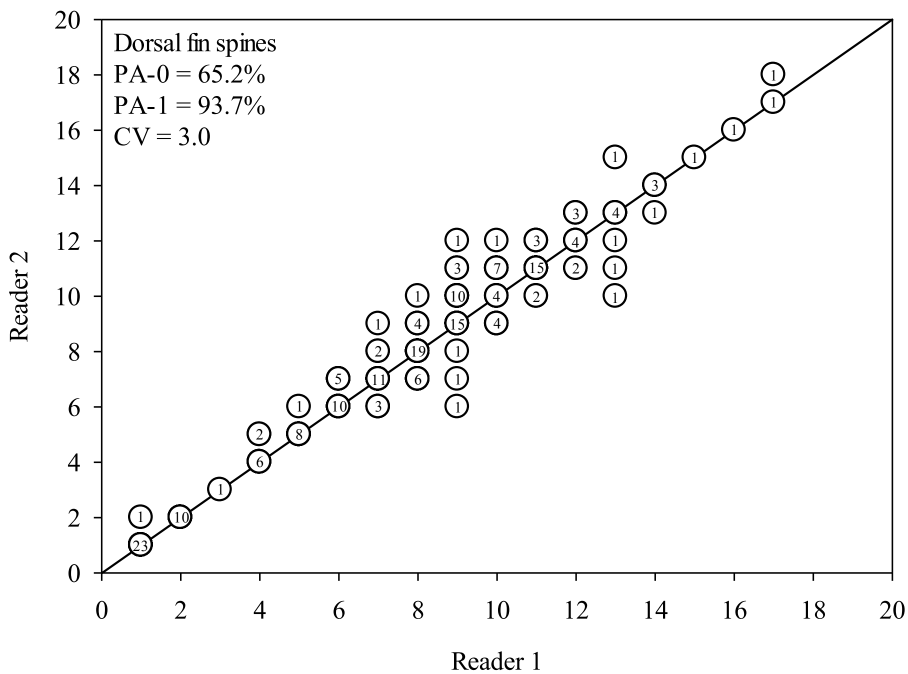

Figure 4. Age-bias plot for ages assigned to sectioned dorsal fin spines from Common Carp sampled from Crane Creek Reservoir and Lake Lowell, Idaho in 2012 (n = 207). Precision between readers is indicated as exact (PA-0) and within-1 year (PA-1) agreement and mean coefficient of variation (CV). Numbers inside circles represent the number of observations.

reader 2 tended to underestimate age of Common Carp relative to ages assigned by reader 1. Age estimates from scales and otoliths displayed the most variation, particularly for older fish (Figures 1 and 2). Pectoral fin rays and dorsal fin spines provided similar age estimates (Figures 3 and 4).

Median confidence ratings assigned by both readers were similar for all hard structures; however, confidence ratings showed a decreasing trend with age for both readers among all hard structures. No otolith was assigned a confidence rating higher than 1, and the majority of otoliths were given a rating of 0. No scale was assigned a confidence rating of 3. Most scales (91%) received a rating of 0 or 1. Median confidence ratings assigned by readers were significantly different for all hard structures (order from lowest to highest confidence rating: otoliths, scales, pectoral fin rays, dorsal fin spines; $P < 0.001$).

Age estimates obtained from non-lethal hard structures tended to disagree with sectioned otoliths for both readers (Table 3). Age estimates from otoliths and pectoral fin rays were significantly different, as were differences from otoliths and dorsal fin spines ($P < 0.001$). When compared with otoliths, mean exact agreement was lowest for scales (13.9%) and highest for dorsal fin spines (19.7%).

TABLE 3. Percent exact agreement of various hard structures with otoliths for both readers for Common Carp sampled in Crane Creek Reservoir and Lake Lowell, Idaho (2012).

	Agreement with sectioned otolith age (%)		
Hard structure	Reader 1	Reader 2	Mean
Scales	14.1	13.6	13.9
Pectoral fin rays	18.1	18.3	18.2
Dorsal fin spines	21.6	17.8	19.7

Discussion

Understanding age distributions and dynamic rate functions is critical for effective management of systems influenced by Common Carp. Several different hard structures have been used to estimate age of Common Carp (Table 4); however, a comprehensive evaluation of the precision and relative readability among hard structures for Common Carp is lacking. When compared with otoliths, age estimates obtained from all three alternative hard structures (i.e., scales, pectoral fin rays, dorsal fin spines) rarely agreed with age estimates from otoliths. Phelps et al. (2007) found that percent error of age estimates, relative to otoliths, was lowest for scales and pectoral fin rays from Common Carp. Brown et al. (2004) found low (5%) percent error in age estimates

TABLE 4. Summarization of peer-reviewed studies that have evaluated hard structures for estimating age of Common Carp. Included is the citation, hard structure evaluated, and major finding of the study. Complete references to each study can be found in the Literature Cited section.

	Hard structure					
Study	Otoliths	Scales	Pectoral fin rays	Dorsal fin spines	Other	Major finding
Brown et al. (2004)	X†					Otoliths: APE* = 4.56%, CV = 6.41
Jackson et al. (2007)		X		X†		Dorsal fin spines: PA-0 = 95.8%, CV = 1.6; Scales: PA-0 = 32.7%, CV = 33.6
Lubinski et al. (1984)	X	X†		X	X	Scales and opercles: 100% readability; Dorsal fin spines = 95% readability
McConnell (1952)					X†	Lowest processing time and highest readability for opercles
Phelps et al. (2007)		X	X†		X	Pectoral fin rays: 1.2% APE* relative to otoliths
Weber and Brown (2011)			X	X†		Dorsal fin spines: PA-0 = 57.9%, CV = 6.6; Pectoral fin rays: PA-0 = 43.5%, CV = 9.9

*Average percent error

†Indicates best hard structure selected in each study

between readers when measuring precision of Common Carp otoliths. However, low between-reader agreement and high variance among age estimates for otoliths in our study suggests that they likely lack the high accuracy and precision that has previously been reported (Brown et al. 2004). Comparisons relative to otoliths may not be useful for comparing age estimation structures for Common Carp. Both readers in our study reported difficulty identifying annuli on otoliths and no individual otolith received a confidence rating greater than one (i.e., low confidence due to undefined annular growth rings [Spiegel et al. 2010]). Oftentimes, agreement between our readers differed by 10 years or more. Every attempt was made to improve the clarity of otolith sections (lighting, various filters, immersion liquids to decrease light refraction), but otoliths remained difficult to read. Although difficulty reading otoliths may be limited to our study populations, we have experienced the same difficulties with Common Carp otoliths (asteriscus and lapillus) from Iowa, Kansas, Oregon, and Utah.

Scales are commonly used to estimate age of a variety of fishes because they can be easily collected and fish can be released in good condition (Quist et al. 2012). Scales are especially common for estimating ages of many short-lived fishes, including many cyprinids (Kamilov 1984, Quist and Guy 2001). Scales are also advantageous to use for estimating age of short-lived species (e.g., Chinook Salmon *Oncorhynchus tshawytscha* [Copeland et al. 2011]) because they provide adequate precision and accuracy, and large samples can be processed quickly. However, like all hard structures, accuracy and precision of age estimates from scales varies among species, but many previous studies have concluded that scales provide imprecise estimates of age (Schramm and Doerzbacher 1985, Marwitz and Hubert 1995, Sylvester and Berry 2006, Quist et al. 2007). In our study, age estimates from scales lacked precision and readers had low confidence in assigning ages, which is consistent with prior research on Common Carp (Jackson et al. 2007). In fact, exact and within-1 year agreement rates of age estimates obtained from scales in our study were nearly identical to those reported by Jackson et al. (2007). Exact agreement between readers in our study was 29.7% and within-1 year agreement was 66.6%, and many disagreements between readers differed by 5–8 years. Scales typically required less processing time than other hard structures used in this study, but consistently produced imprecise age estimates and rarely agreed with pectoral fin rays or dorsal fin spines.

Pectoral fin rays and dorsal fin spines often produce similar age estimates in many fish species and have become a common alternative to otoliths and other lethal hard structures (Koch and Quist 2007, Weber and Brown 2011). We found that age estimates from dorsal fin spines and pectoral fin rays had the highest precision between readers and the least amount of variation. In general, it is desirable for hard structures to yield a CV of less that 8% to provide reliable age estimates (Campana 2001). We found that mean CVs for pectoral fin rays and dorsal fin spines were well below this threshold, whereas scales and otoliths produced mean CVs greater than 15%. One potential issue is that erosion of early annuli in spines due to expansion of the central lumen can cause errors in age estimates (Patton and Hubert 1996, Kwak et al. 2006). We did not observe any erosion of annuli in Common Carp spines. Although mean estimated age for pectoral fin rays and dorsal fin spines was similar, readers had higher confidence in estimating age using dorsal fin spines. Both readers noted better clarity of annuli for dorsal fin spines compared with pectoral fin rays, particularly for older age classes. Readers also observed that early annuli were difficult to distinguish on pectoral fin rays because of their morphological irregularity, whereas the shape of dorsal fin spines allowed for easy identification of early annuli. Although there are inconsistencies in the literature as to whether dorsal fin spines produce the most precise estimates of age for Common Carp (Lubinski et al. 1984), our results are consistent with more recent studies that have found high between-reader agreement in age estimates for dorsal fin spines (Jackson et al. 2007, Weber and Brown 2011).

Our results suggest that dorsal fin spines are a non-lethal hard structure that will provide precise estimates of Common Carp age. With an increasing interest in understanding Common Carp population dynamics, biologists may need to obtain age and growth information in conjunction with other project objectives that require fish to be released (e.g., mark-recapture techniques). Dorsal fin spines provide this option in addition to being quick and easy to process and analyze. Future age and growth studies on Common Carp using otoliths or scales should be approached with caution given the low precision and poor readability of these hard structures. Future research should focus on validating age estimates from dorsal fin spines of Common Carp and evaluating techniques (e.g., sectioning locations) for standardization. Validation of the accuracy of age estimates from dorsal fin spines will provide fisheries scientists with a more complete understanding of the utility of age-based data from Common Carp populations and provide confidence in age-based analyses that require estimates of true age.

Common Carp populations in North America are of increasing concern due to the deleterious effects on more desirable fish populations and communities, therefore reliable age estimates that can be obtained in the most cost and time efficient fashion are of high importance (Isermann et al. 2003). Reliable age estimates are likely to elicit better estimates of dynamics rate functions and consequently more effective management (Ricker 1975, Quist et al. 2012). Our results suggest that estimates of Common Carp age using dorsal fin spines will facilitate achievement of management goals.

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