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MANAGEMENT BRIEF

Influence of Sectioning Location on Age Estimates from Common Carp Dorsal Spines

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Abstract

Dorsal spines have been shown to provide precise age estimates for Common Carp *Cyprinus carpio* and are commonly used by management agencies to gain information on Common Carp populations. However, no previous studies have evaluated variation in the precision of age estimates obtained from different sectioning locations along Common Carp dorsal spines. We evaluated the precision, relative readability, and distribution of age estimates obtained from various sectioning locations along Common Carp dorsal spines. Dorsal spines from 192 Common Carp were sectioned at the base (section 1), immediately distal to the basal section (section 2), and at 25% (section 3), 50% (section 4), and 75% (section 5) of the total length of the dorsal spine. The exact agreement and within-1-year agreement among readers was highest and the coefficient of variation lowest for section 2. In general, age estimates derived from sections 2 and 3 had similar age distributions and displayed the highest concordance in age estimates with section 1. Our results indicate that sections taken at ≤ 25% of the total length of the dorsal spine can be easily interpreted and provide precise estimates of Common Carp age. The greater consistency in age estimates obtained from section 2 indicates that by using a standard sectioning location, fisheries scientists can expect age-based estimates of population metrics to be more comparable and thus more useful for understanding Common Carp population dynamics.

Understanding fish population demographics (e.g., age structure, longevity) and dynamics (i.e., growth, recruitment, mortality) is central to fisheries management (Ricker 1975; Allen and Hightower 2010). Hard-structure-based age estimation is commonly used to evaluate population rate functions (i.e., growth, recruitment, mortality); thus, obtaining precise age estimates is important for understanding how populations function and respond to management actions. Common Carp *Cyprinus carpio* is an important fish species throughout the world. Within its native distribution, Common Carp is a popular sport fish (Hickley and Chare 2004; Arlinghaus 2008). However, throughout much of its distribution Common Carp is largely regarded as a nuisance species due to its deleterious

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effects on aquatic systems (e.g., decreased water clarity, reductions in aquatic vegetation; Miller and Crowl 2006; Weber and Brown 2009). Therefore, considerable effort has focused on decreasing the abundance or complete removal of unwanted Common Carp populations (Koehn et al. 2000). Predicting the effects of Common Carp removal and measuring progress toward that management goal requires an understanding of population rate functions. Previous studies have examined population metrics from single, age-based samples to inform the management of nuisance Common Carp populations. Specifically, an understanding of how removal efforts act to influence population rate functions is central to predicting maturity schedules, length structure, and extinction rates (Brown and Walker 2003; Weber et al. 2011). Regardless of the management purpose (e.g., removal, recreational fishery), successful management of Common Carp relies on accurately estimating dynamic rate functions and population characteristics (Weber and Brown 2011; Weber et al. 2011).

Age and growth data are commonly obtained by biologists to evaluate management activities (e.g., harvest regulations) and formulate management objectives. For example, Cucherousset et al. (2009) used age-at-maturity and growth information of Pumpkinseed *Lepomis gibbosus* to identify systems that were more susceptible to invasion by this species in northern Europe. Similarly, Syslo et al. (2011) used population metrics (e.g., growth, age at maturity) to evaluate the efficacy of a suppression program for Lake Trout *Salvelinus namaycush* implemented in Yellowstone Lake, Montana. With regard to Common Carp, Weber et al. (2011) used age data from Common Carp populations in South Dakota lakes to understand the influence of commercial exploitation on population dynamics. Likewise, Brown and Walker (2003) measured the response of multiple Common Carp populations to various levels of mortality estimated from age-based data. Additionally, age and growth data provide insight on regulatory mechanisms influencing fish populations and allow scientists to gain insight on multiple years with a single sample. As such, proper evaluation of dynamic rate functions necessitates precise estimations of fish age.

Quantifying dynamic rate functions generally requires the use of calcified structures (e.g., otoliths, fin rays). As such, obtaining the most useful population information requires the selection of a hard structure that yields both accurate and precise age estimates (Quist et al. 2012). Standardized techniques for removing and processing hard structures are necessary for attaining consistent age data that are comparable across populations (Koch et al. 2008). Therefore, developing standardized methods to acquire age information is necessary for ensuring the usefulness of data collected by management agencies.

Asteriscus otoliths have been validated for estimating the age of Common Carp (Brown et al. 2004). However, the use of otoliths requires sacrificing the fish. In certain circumstances sacrificing fish is undesirable (e.g., mark–recapture studies). Furthermore, removing and processing Common Carp otoliths is labor intensive. Therefore, identifying age estimation structures that are nonlethal and require less processing time is desirable. The most common nonlethal structure used in age and growth projects has historically been scales (Quist et al. 2012). However, the use of other nonlethal hard structures, such as fin rays and spines, has increased (Jackson et al. 2007; Koch et al. 2008; Weber and Brown 2011). Fin rays and spines are often advantageous over scales because they do not regenerate and are rarely lost or damaged. Scales are particularly difficult to interpret for older fish, and several studies have shown that fin rays and spines provide more precise age estimates than scales for a variety of species (Mills and Beamish 1980; Jackson et al. 2007; Phelps et al. 2007).

Recent research has reported that dorsal spines are the most precise nonlethal hard structure for estimating the age of Common Carp (Jackson et al. 2007; Weber and Brown 2011). However, removal of the entire dorsal spine is generally injurious to the fish, which may negatively influence growth (Saunders and Allen 1967; Johnsen and Ugedal 1988) and survival (Vincent-Lang 1993; Champagne et al. 2008). Removing the entire dorsal spine is more intrusive than fin-clipping and damages and exposes additional dermal tissue. Therefore, managers concerned with injuring fish may be less likely to remove the entire dorsal spine, thereby influencing which sectioning location may be used.

Descriptions of the removal locations of dorsal spines are generally vague and rarely mention exact measurements. For example, Weber and Brown (2011) removed the dorsal spine at the base of the structure near the body of the fish, whereas Jackson et al. (2007) described removing the dorsal spine by cutting the structure at the surface of the fish's body. Without standardized removal methods, there may be inconsistent patterns of removal and resulting sectioning locations. Inconsistencies in removal and the resulting sectioning location can produce age data that are not meaningful or comparable across samples (Koch et al. 2008). Due to the increased use of dorsal spines for estimating the age of Common Carp, establishing standardized methodology for removing and sectioning dorsal spines for age and growth analysis is needed. The objective of this study was to evaluate the precision, readability, and relative age estimates obtained from different sectioning locations of dorsal spines from Common Carp.

METHODS

Common Carp were collected in October 2012 from Crane Creek Reservoir and Lake Lowell in southwestern Idaho using experimental-mesh gill nets (46 m × 1.8 m with panels of 25-, 32-, 38-, 44-, and 50-mm bar-measure mesh) and daytime boat-mounted electrofishing. Electrofishing power output was standardized to 2,750–3,200 W (Miranda 2009). All individuals were measured to the nearest millimeter (total length), euthanized, and stored in a freezer for later processing. Dorsal spines were removed at the base of the structure by cutting

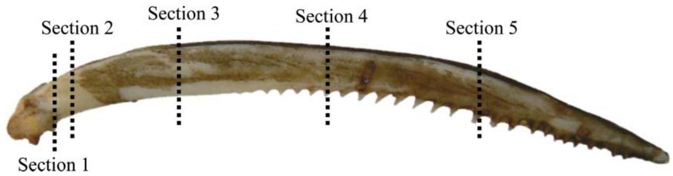

FIGURE 1. Common Carp dorsal spine showing the approximate locations of the five sections that were removed from each dorsal spine to investigate precision and readability in age estimates.

into the surrounding tissue and rotating the dorsal spine until it was pulled free from the body.

Dorsal spines were allowed to air-dry in coin envelopes for at least 2 weeks. After air-drying, each dorsal spine was measured and marked at 25, 50, and 75% of its total length. Each dorsal spine was mounted in epoxy in either a 2- or 5-mL centrifuge tube following Koch and Quist (2007). Generally, 5-mL centrifuge tubes were needed due to the large diameter of the proximal end of the dorsal spines. For larger dorsal spines, several molds were needed to encapsulate the entire structure in epoxy. The first cross section was cut where the dorsal spine curves to form the articulating process (section 1; Figure 1). Section 2 was cut immediately distal to section 1 to represent the sectioning location for dorsal spines that would result from removal at the body surface. To represent variations in removal location, sections 3, 4, and 5 were cut at 25, 50, and 75% of the total length of each dorsal spine, respectively (Figure 1). All cross sections were cut to 0.8 mm in thickness using a Buehler Isomet low-speed saw (Buehler, Lake Bluff, Illinois). Dorsal spine sections were individually examined using a dissecting microscope with transmitted light and an image analysis system (Image-Pro Plus; Media Cybernetics, Silver Springs, Maryland).

Annuli were enumerated on all sections independently by three readers without knowledge of section, fish length, water body, or age estimates from other readers. One of the readers had substantial (i.e., >3 years) experience estimating the age of Common Carp using dorsal spines, whereas the other two readers had minimal (i.e., <1 year) experience estimating the age of Common Carp. After each reader assigned an age, the estimates were compared and discrepancies between age estimates were discussed. A consensus age was then assigned based on agreement between the three readers during a mutual reading.

In addition to the number of annuli, a rating indicating reader confidence in each age estimate was assigned following Spiegel et al. (2010), for which 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 (Fitzgerald et al. 1997; Koch et al. 2008). Age-bias plots were used to evaluate between-section precision for dorsal spines (Campana et al. 1995). Age-bias plots were created by plotting the consensus Age estimates from sections 2, 3, 4, and 5 against section 1. Precision in age estimates among readers was assessed by calculating the exact percent agreement and the percent agreement within 1 year for each section. The coefficient of variation (CV; $100 \times$ SD/mean) was used as a measure of variation in age estimates (Campana et al. 1995). The CV was estimated for individual sectioning locations and then averaged across sectioning locations to provide an estimate of among-reader precision. In addition, the exact percent agreement, percent agreement within 1 year, and CV were calculated for all sections paired with section 1 to evaluate between-section precision and identify trends in precision along dorsal spines using consensus ages. Age estimates were summarized by confidence rating to evaluate readability. Confidence ratings for each section were pooled for all readers, and a Kruskal–Wallis test was used to determine whether median confidence ratings differed among sectioning locations. A post hoc Wilcoxon rank-sum test for pairwise comparisons was then used to evaluate specific differences in confidence ratings among sectioning locations.

Multinomial logistic regression was used to evaluate the relationship between reader, water body, section, and consensus age with confidence rating (Fox 2008). Ten a priori candidate models were fitted using various combinations of covariates that were hypothesized to influence confidence rating. Akaike's information criterion corrected for small sample size (AIC_c) was used to rank candidate multiple regression models (Akaike 1973; Burnham and Anderson 2002). Also, AIC_c weights (w_i) were used to compare competing multiple regression models and assess the relative importance of each model. All analyses were conducted using R statistical computing language (R Development Core Team 2012), and a type I error rate of $\alpha = 0.05$ was used for all statistical tests.

Multicolinearity among explanatory variables was assessed prior to creating candidate models. Pearson's correlation coefficient was used to evaluate the correlation among all possible pairs of covariates. When two covariates were significantly correlated (Pearson's $r \geq |0.70|$, $P \leq 0.05$), the variable with the most logical relevance of a significantly correlated pair was retained for further analysis. For instance, fish length and consensus age were significantly correlated ($r = 0.81$, $P = 0.003$); therefore, we retained consensus age in the candidate model suite and excluded fish length.

RESULTS

We aged 192 Common Carp varying from 198 to 642 mm in total length (Table 1). Age estimates varied from 1 to 18 for section 1, from 1 to 17 for sections 2 and 3, from 0 to 22 for section 4, and from 0 to 16 for section 5, with sections 4 and 5 providing statistically significant differences in age estimates from section 1. The exact percent agreement among readers was highest for section 2 (54%), followed by section 3 (52%), section 5 (50%), section 1 (48%), and section 4 (42%). The percent agreement within 1 year among readers increased

TABLE 1. Surface area (ha) of study sites, the sample size (n), and total length (mm) of Common Carp sampled for age estimation from Crane Creek Reservoir and Lake Lowell, Idaho, in 2012. Mean (SD in parentheses), minimum (Min), and maximum (Max) lengths are provided.

Water body	Surface area	n	Total length	
			Mean	Min–Max
Crane Creek Reservoir	1,497	114	365 (84)	198–642
Lake Lowell	3,642	78	495 (39)	401–635

markedly for all sections. Within-1-year agreement was highest for section 1 (83%), followed by sections 2 and 5 (82%), section 3 (81%), and section 4 (75%). We did not observe an increasing pattern of variation in age estimates moving distally along dorsal spines but instead found that section 2 (CV = 4.9) and 3 (5.0) provided the lowest CVs, followed by section 1 (5.7), section 5 (8.3), and section 4 (8.4).

Between-section agreement decreased moving distally along the dorsal spines. Exact and within-1-year agreement with section 1 for consensus ages was highest for section 2 (53% and 84%, respectively) and lowest for section 5 (6% and 43%, respectively; Figure 2). Age-bias plots indicated that section 2 had the highest concordance with section 1. Older age-classes were consistently underestimated when section 2 was compared with section 1, with the highest concordance observed among younger Common Carp (i.e., ≤ 5 years old). Sections 3, 4, and 5 displayed low concordance with section 1, particularly for older age-classes. In general, sections 3, 4, and 5 tended to underestimate age compared with section 1.

Readers were less confident in assigning ages to the most distal sections of Common Carp dorsal spines (Figure 3). Individual reader confidence was highest for age estimates

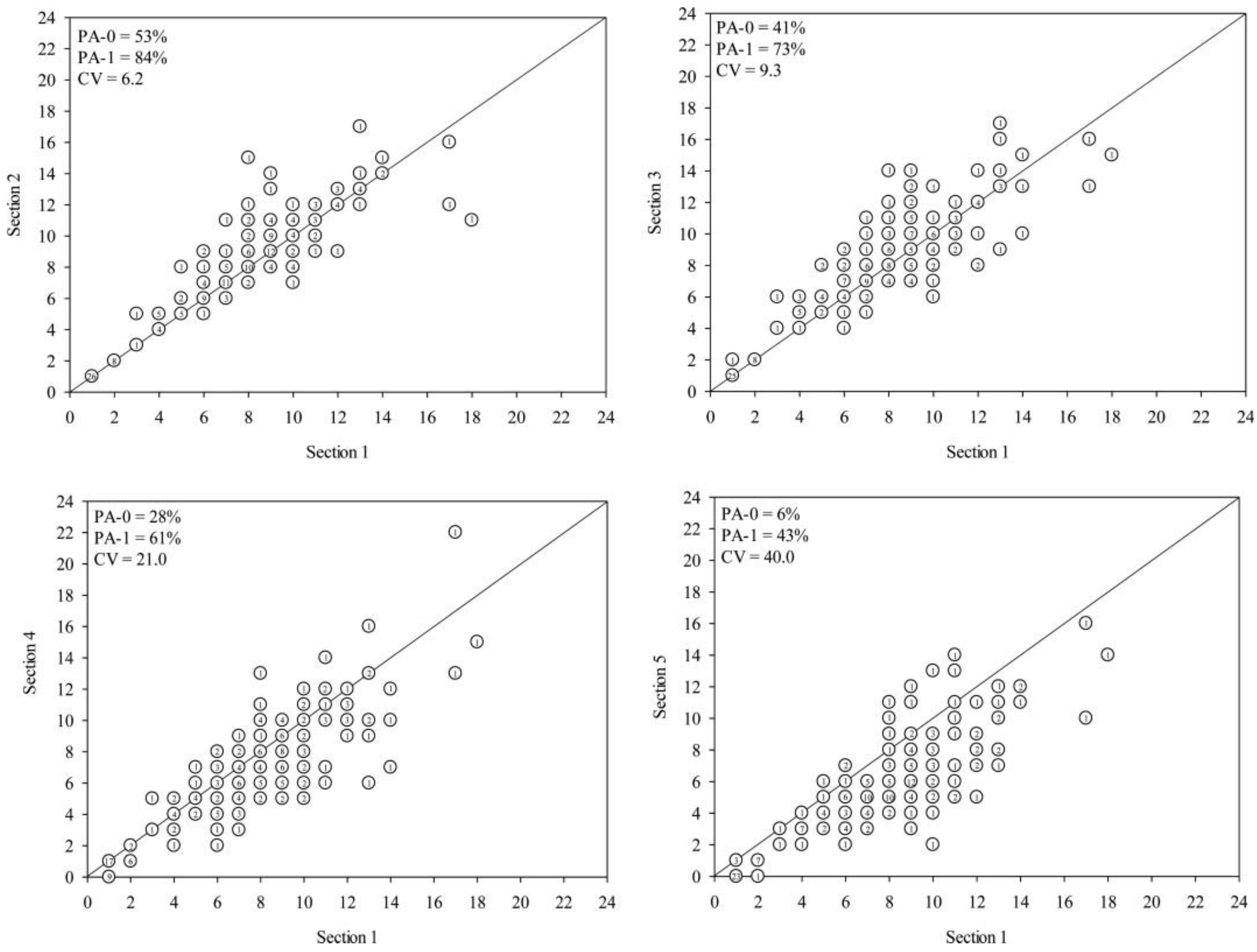

FIGURE 2. Age-bias plots for ages assigned to Common Carp dorsal spines between section 1 and sections 2, 3, 4, and 5 for Common Carp sampled from Crane Creek Reservoir and Lake Lowell, Idaho, in 2012 (n = 192). The precision between sections is indicated as the exact percent agreement (PA-0), the within-1-year agreement (PA-1), and the mean coefficient of variation (CV). The numbers inside the circles represent the number of observations.

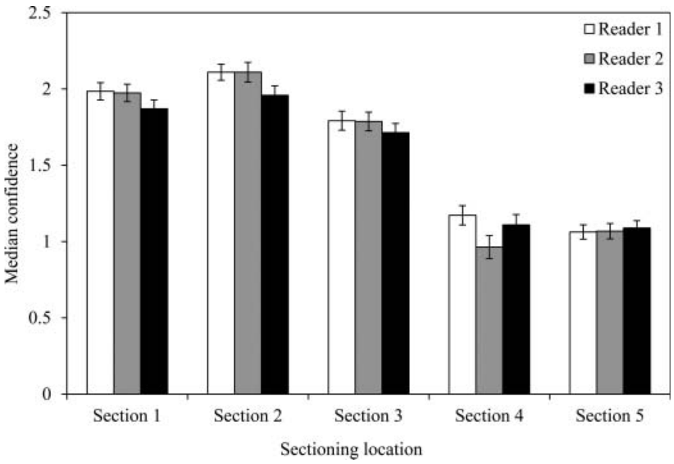

FIGURE 3. Median confidence rating (higher values indicate more confidence) for each reader and sectioning location (i.e., sections 1, 2, 3, 4, and 5) along dorsal spines from Common Carp sampled from Crane Creek Reservoir and Lake Lowell, Idaho, in 2012. Error bars represent ± 1 standard error of the mean.

assigned to section 2 and lowest for section 5. The median confidence ratings were significantly different among all sections. The most parsimonious model predicting reader confidence was the model including the additive effects of consensus age, reader, section, and water body (Table 2). This model accounted for 99% of the total w_i out of the candidate suite of models. The only other model accounting for additional w_i was the model including the covariates of consensus age, reader, and section. The probability of an increase in confidence rating was negatively related to consensus age for the top model (Table 3). Compared with reader 1, readers 2 and 3 were less likely to assign an equivalent confidence rating, suggesting that reader 1 was more confident overall in their age estimations. All readers were less confident assigning ages to sections 3, 4, and 5. However, readers were more confident assigning ages to section 2 than to section 1 (Figure 3). Readers were less confident assigning ages to Common Carp from Lake Lowell than to those from Crane Creek Reservoir.

The distributions of consensus age varied among sectioning location. Section 4 and 5 each included age-0 fish that were not present in sections 1, 2, and 3. Consensus age estimates were consistently lower for sections 4 and 5 than for section 1. The majority of Common Carp identified as age 1 from section 1 were estimated as age 0 with sections 4 and 5. In addition, section 4 displayed the most variability in age estimates (Figure 4). The maximum ages of sections 1, 2, 3, and 5 were all within 2 years of one another.

DISCUSSION

Fish age has been estimated from a variety of hard structures in various species. However, because precision and accuracy are critical for obtaining meaningful age and growth data, the identification of structures that provide replicable age estimates among species is important (Campana 2001). Traditionally, otoliths have been regarded as the most precise and accurate hard structure to age fish, including Common Carp (Brown et al. 2004). Support for otoliths as the premier age estimation structure has waned as more efficient, nonlethal structures are verified (Jackson et al. 2007; Weber and Brown 2011; Weber et al. 2011). A number of studies have been conducted in an attempt to identify viable nonlethal age estimation structures for Common Carp. For example, Phelps et al. (2007) reported 94%

TABLE 2. Comparison of multinomial logistic regression models developed to predict the confidence rating of age estimates obtained from the dorsal spines of Common Carp sampled from Crane Creek Reservoir and Lake Lowell, Idaho, in 2012. The Akaike information criterion corrected for small sample sizes (AIC_c) was used as an indication of model rank. The total number of model parameters (K), the negative log likelihood [Log(l)], and the model weight (w_i) are included.

Model	K	AIC_c	ΔAIC_c	Log(l)	w_i
Consensus age + reader + water body + section	27	4,742.53	0.00	−2,344.27	0.99
Consensus age + reader + section	24	4,752.40	9.87	−2,352.20	0.01
Consensus age + water body + section	21	4,762.56	20.03	−2,360.28	0.00
Reader + water body + section	24	5,990.93	1,248.40	−2,971.46	0.00
Reader + section	21	6,361.54	1,619.01	−3,159.77	0.00
Section	15	6,376.04	1,633.51	−3,173.02	0.00
Consensus age + reader + water body	15	6,259.99	1,517.46	−3,114.99	0.00
Consensus age + reader	12	6,291.96	1,549.43	−3,133.98	0.00
Reader + water body	12	6,929.27	2,186.74	−3,452.64	0.00
Consensus age + water body	9	6,274.11	1,531.58	−3,128.06	0.00
Water body	6	6,941.94	2,199.41	−3,464.97	0.00
Reader	9	7,240.49	2,497.96	−3,611.25	0.00
Consensus age	6	6,306.01	1,563.48	−3,147.00	0.00
Intercept only	3	7,252.75	2,510.21	−3,623.37	0.00

TABLE 3. Parameter estimates and 95% confidence limits for the top multinomial logistic regression model that estimated confidence ratings for age estimates obtained from Common Carp sampled from Crane Creek Reservoir and Lake Lowell, Idaho, in 2012. Coefficients are interpreted as the odds ratio relative to a confidence rating of 0 (i.e., reference category).

Variable	Estimate	Confidence limits Lower	Confidence limits Upper
Confidence level 1			
Intercept	37.205	14.955	92.562
Consensus age	1.008	0.960	1.058
Reader 2	0.962	0.673	1.376
Reader 3	0.525	0.374	0.738
Lake Lowell	0.719	0.530	0.977
Section 2	187,875.100	150,146.300	235,084.300
Section 3	0.400	0.167	0.960
Section 4	0.070	0.032	0.153
Section 5	0.174	0.077	0.392
Confidence level 2			
Intercept	1,219.600	457.100	3,254.300
Consensus age	0.725	0.681	0.772
Reader 2	0.671	0.444	1.014
Reader 3	0.527	0.356	0.781
Lake Lowell	0.527	0.368	0.755
Section 2	296,087.000	247,998.200	353,500.600
Section 3	0.255	0.106	0.615
Section 4	0.003	0.001	0.006
Section 5	0.006	0.002	0.001
Confidence level 3			
Intercept	24,369.400	8,449.600	70,283.200
Consensus age	0.398	0.365	0.433
Reader 2	0.572	0.348	0.940
Reader 3	0.579	0.360	0.932
Lake Lowell	0.442	0.275	0.711
Section 2	423,601.500	325,595.400	551,107.900
Section 3	0.218	0.084	0.564
Section 4	0.001	0.001	0.003
Section 5	0.002	0.001	0.001

agreement between pectoral fin rays and otoliths collected from Common Carp from five South Dakota lakes. Similarly, in a comparison between dorsal spines and pectoral fin rays of Common Carp, Weber and Brown (2011) reported similar age estimates and high precision with both structures. Dorsal spines were reported to be much more precise than scales for estimating the age of Common Carp from 28 Iowa lakes (Jackson et al. 2007). In addition, anecdotal evidence exists suggesting that dorsal spines tend to have the highest readability (i.e., higher reader confidence) compared with pectoral fin rays and otoliths and are the most precise nonlethal age estimation structure for Common Carp. Although the results of this study show that there are

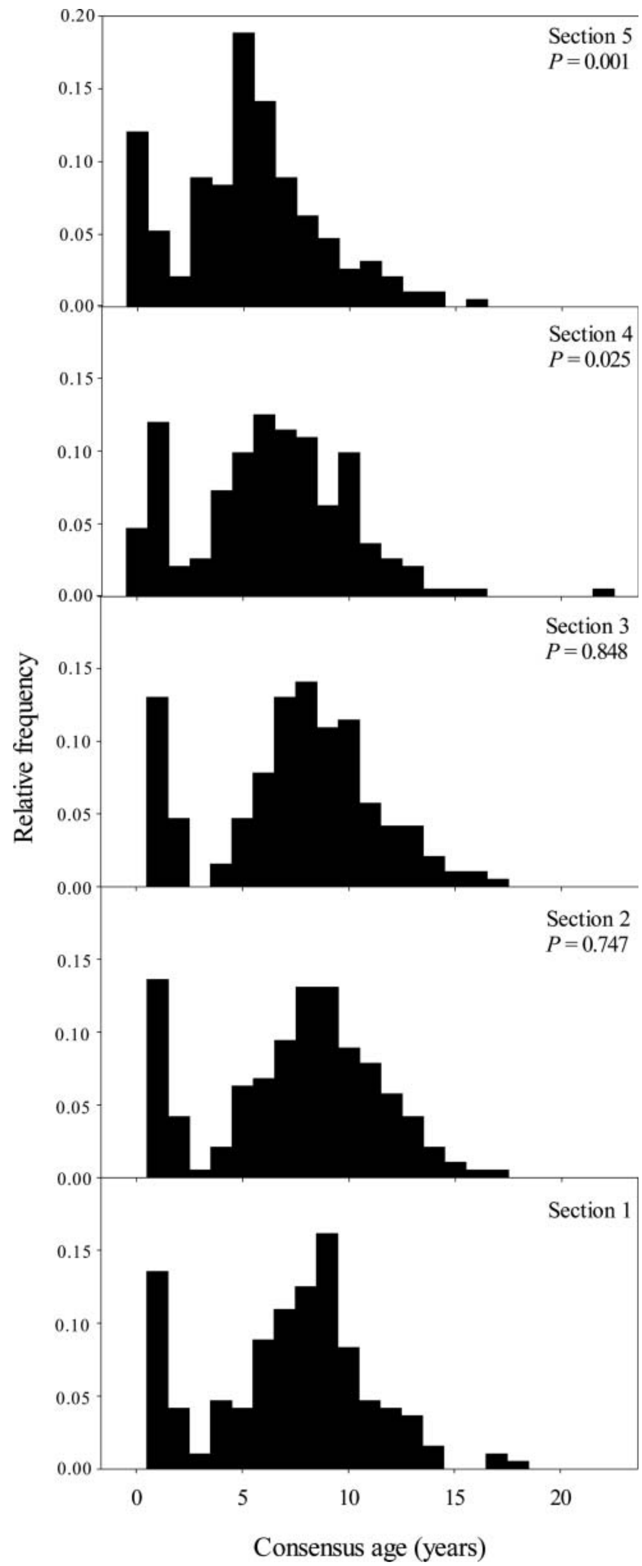

FIGURE 4. Age-frequency distributions for sectioning locations (i.e., sections 1, 2, 3, 4, and 5) along dorsal spines from Common Carp sampled from Crane Creek Reservoir and Lake Lowell, Idaho. The P-values are from Kolmogorov–Smirnov tests comparing the section locations (i.e., sections 2, 3, 4, and 5) with section 1.

differences in age estimates along the longitudinal gradient of a Common Carp dorsal spine, dorsal spines appear to be a fairly forgiving structure for estimating the age of Common Carp. For instance, sections 1, 2, and 3 provided similar age distributions and mean confidence ratings. The relatively high precision and readability of sections 1, 2, and 3 may quell the uncertainty surrounding the accuracy and precision associated with the sectioning locations of Common Carp dorsal spines.

Decreased precision and readability of cross sections near the distal end of a structure have been reported for other fishes. Koch et al. (2008) compared sectioning locations along pectoral fin rays from Shovelnose Sturgeon *Scaphirhynchus platorynchus* and found that sections cut from the proximal end of the pectoral fin ray were more precise than those cut from more distal sections. Similarly, Kopf and Davie (2001) concluded that proximal sections cut along dorsal and anal spines of Striped Marlin *Kajikia audax* displayed a greater number of annuli and had a lower average percent error than sections cut more distally. For Channel Catfish *Ictalurus punctatus*, capturing the highest number of annuli in pectoral spines was best achieved near the base of the structure (Sneed 1951). Our results support previous research in that higher precision and readability were associated with sections taken near the proximal end of the dorsal spine. Annuli towards the outer edge of sections 4 and 5 were "clumped" and difficult to distinguish from one another, resulting in poor readability. Sneed (1951) reported complete loss of early annuli on cross sections taken near the distal end of pectoral spines of Channel Catfish. This is consistent with our findings that sections 4 and 5 consistently lacked early annuli. Additionally, our results indicate that annuli from sections taken at the base of a structure were more difficult to identify. For example, section 1 had a lower exact percent agreement and a higher CV than sections 2 and 3. The annuli of section 1 were consistently obscured by the structural morphology of the articulating process creating difficulty distinguishing annuli.

Age distributions varied among sectioning locations but also between water bodies. Differences in age distribution were dramatic; the sample from Crane Creek Reservoir contained 48 individuals younger than 5 years old, and the sample from Lake Lowell only contained 3 individuals younger than 5 years old. Results from this study indicated that readability decreased in relation to fish age as younger age-classes were consistently assigned the highest confidence ratings. Our top model predicting confidence ratings indicated that water body was important in explaining variability in the model. However, this is likely an artifact of differences in the catchability of Common Carp between study sites or the age structure of each population. Therefore, reader confidence ratings were likely not influenced by variability in growth or annulus formation between water bodies.

Nearly all aspects of fisheries techniques have undergone standardization. The standardization of fish collection and processing methods not only ensures efficiency, it also facilitates effective and meaningful comparisons of population parameters among fish populations (Bonar et al. 2009). Although standardization of sampling methods is common, few agencies have adopted standard removal and sectioning locations of hard structures for estimating the age of fish. Due to the decreased precision and readability of distal cross sections, the standardization of removal, and thus sectioning locations, is warranted. In addition to the poor precision and readability associated with the distal portions of the dorsal spines evaluated in our study, early annuli were often completely absent. Although dorsal spine removal location will likely vary depending on the species, our results indicate that the removal of the entire dorsal spine of Common Carp is likely not necessary because section 2 will encompass the total number of annuli and provide precise age estimates. Although previous studies with other species have suggested obtaining cross sections close to the "conspicuous curve" of the fin ray or spine, our results suggest that this is not necessary for Common Carp. In fact, sections including the articulating process will result in age estimates that lack precision. Based on our findings, Common Carp dorsal spines need not be disarticulated but rather removed close to the body wall. This will result in precise age estimates, quick removal, and less injury to the fish. By using a standard sectioning location, fishery scientists can better understand Common Carp population dynamics and make informed management decisions with age-based data from dorsal spines.

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