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Precision of Northern Pike Age Estimates Using Four Calcified Structures

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Abstract

Age and growth data provide valuable information for the management of fish populations. However, the quality of data is often a function of the choice of structure used to evaluate age and growth. Here, we compared ages of Northern Pike *Esox lucius* estimated using four calcified structures: sagittal otoliths, cleithra, pelvic fin rays, and pectoral fin rays. Northern Pike were sampled from Lake Pend Oreille, Idaho, using experimental gill nets. Northern Pike varied in length from 320 mm to 1,173 mm and estimated ages varied from 1-7 years. We found high levels of precision and agreement across all readers and structures. Percent exact agreement between readers varied from 90.0 to 95.3% and coefficients of variation varied from 1.3 to 3.0%. Percent exact agreement in consensus age estimates varied from 92.9 to 98.2% and coefficients of variation varied from 0.5 to 1.9% between structures. Otoliths generally had the lowest precision and required more intensive processing than other structures. Pelvic fin rays typically provided the same ages as pectoral fin rays but had higher average confidence. Pelvic fin rays are likely the best structure for ageing Northern Pike as they can be removed without sacrificing the fish, provide age estimates concordant with structures known to provide accurate ages, and are easy to read with moderate preparation.

Introduction

Northern Pike *Esox lucius* is a non-native species that has become increasingly common in the western United States following a suite of legal and illegal introductions (Carim et al. 2022). Northern Pike can quickly establish robust populations in new waterbodies as they tolerate a wide range of abiotic conditions (e.g., temperature, oxygen, pH), consume a variety of prey, mature early, and have plastic spawning requirements (Raat 1988; Billard 1996; Craig 1996; Crane et al. 2015; Dunker et al. 2018; Jacobsen and Engström-Öst 2018). Additionally, Northern Pike have been known to disperse long distances (Skov et al. 2018), and dispersal frequency and distance are often aided by illegal human intervention (Carim et al. 2022). Introduced Northern Pike can disrupt the existing community structure through predation (He and Kitchell 1990; Dunker et al. 2018; Mayer and Garrett 2023). The influence of Northern Pike can transcend trophic levels and affect plankton abundances and assemblages (Findlay et al. 2000; Byström et al. 2007). In habitats where they have been introduced, Northern Pike have been documented to seasonally consume large quantities of native salmonids that have high ecological and economic value (Rutz et al. 1996; Byström et al. 2007; Muhlfeld et al. 2008; Sepulveda et al. 2013; Walrath et al. 2015a). The presence of Northern Pike has been shown to be a predictor of the absence of salmonids in otherwise suitable lakes due to the effects of predation (Spens and Ball 2008). A better understanding of Northern Pike populations is important as fisheries managers identify ways to manage non-native populations, particularly in western North America.

Accurate age and growth data can be used to estimate dynamic rates functions that are vital to management of fish populations (e.g., growth, recruitment, mortality; Quist et al. 2012). The quality of estimated ages is dependent on the choice of structure used and the species of interest (Phelps et al. 2017). Northern Pike was among the first species to be aged using calcified structures when Hans Hederström proposed in 1759 that rings found on Northern Pike vertebrae corresponded with the fish's age (Jackson 2011). Contemporary ageing studies seek to evaluate the accuracy (i.e., whether the age estimate reflects the true age) or the precision (i.e., reproducibility of an age estimate) of various hard structures (Campana 2001). Several studies have shown that cleithra can provide accurate age estimates in Northern Pike (e.g., Casselman 1978; Laine et al. 1991). Babaluk and Craig (1990) used chemically marked fish to demonstrate that both cleithra and pelvic fin rays from Northern Pike can be used to accurately estimate ages. With regard to precision, studies have shown that scales, otoliths, fin rays, opercula, and metapterygoid bones provide precise age estimates for Northern Pike (Frost and Kipling 1959; Faust et al. 2013; Oele et al. 2015; Blackwell et al. 2016).

Although the cleithrum provides accurate age estimates for Northern Pike, removal requires sacrificing fish which may not be desirable or feasible (Phelps et al. 2017). Scales and fin rays are commonly used to age esocids and do not require sacrificing the fish (Maceina et al. 2007). Scales have been shown to be less precise than cleithra and often underestimate ages of old fish and overestimate ages of young fish (Casselman 1979; Laine et al. 1991; Oele et al. 2015; Blackwell et al. 2016). Babaluk and Craig (1990) showed that pelvic fin rays can provide accurate and precise age estimates. Oele et al. (2015) demonstrated that anal fin rays provided precise age estimates for Northern Pike. Despite the long history of ageing Northern Pike, only one study has compared age estimates from two different fin rays from Northern Pike (Dembkowski et al. 2020). Furthermore, the precision of ages estimated using pectoral fin rays from Northern Pike has not yet been evaluated. The primary objective of our study was to assess the between-reader and between-structure precision of ages derived from cleithra, otoliths, pelvic fin rays, and pectoral fin rays. Additionally, we sought to compare the readability of each structure.

Methods

Lake Pend Oreille is a large, oligotrophic lake located in northern Idaho with a total surface area of 38,300 ha and a maximum depth of 357 m (McCubbins et al. 2016; Dux et al. 2019). The lake can be divided into northern and southern basins, each with distinct morphology. The northern basin of Lake Pend Oreille is characterized by gently sloping shorelines, extensive littoral habitat, and relatively shallow depths (i.e., <100 m), contrasted by the southern basin which is deep (i.e., >200 m), has steep shorelines, and little to no littoral habitat (Dux et al. 2019). The two major tributaries to Lake Pend Oreille, the Clark Fork and Pack rivers, flow into the northern basin and have relatively shallow deltas.

Northern Pike were sampled monthly from March to November 2025 using experimental gill nets. Gill nets were 45.7 m long × 1.8 m deep with five 9.1 m panels made up of 51, 64, 76, 89, or 102 mm stretch mesh. Captured Northern Pike were measured for total length to the nearest millimeter. The leading pectoral and pelvic fins rays from captured Northern Pike were removed, placed into individually numbered coin envelopes, and air dried. Sagittal otoliths (hereafter, otoliths) were removed and cleaned of any tissue then placed into individually numbered plastic tubes. Cleithra were removed, cleaned of as much tissue as possible, placed into individually numbered coin envelopes, and frozen until further processing. Northern Pike structures were removed opportunistically from fish sampled for a concurrent study which required releasing the fish. As such, all four structures were only removed from incidental mortalities, whereas pectoral and pelvic fin rays were removed from the majority of fish.

Fin rays were mounted in epoxy and sectioned (~0.9 mm thick) using a low-speed saw following the protocol described in Koch and Quist (2007). Otoliths were mounted in epoxy and sectioned (~0.8 mm thick) along the transverse plane to include the nucleus. The resulting sections were lightly sanded using 400, 600, and 1000 grit sandpaper to improve readability (Fischer and Koch 2017; Long and Grabowski 2017). Cleithra were submerged in boiling water for 5-10 seconds and cleaned of any remaining tissue before being air dried (Faust and Scholten 2017).

Fin rays and otoliths were aged under a microscope using transmitted light. Cleithra were aged using reflected light (Casselman 1979). Two readers independently aged each structure without knowledge of the length of the fish. Reader 1 had extensive experience ageing fishes (~25 years) using various structures; Reader 2 had less experience (~2 years) ageing fishes, but received extensive training prior to the study. Readers were provided with the date of each sample to inform whether the most recent annulus would not be visible (i.e., in the spring). Each reader assigned a confidence rating to their age estimate varying from zero, indicating low confidence, to three, indicating high confidence (Koch et al. 2008; Spiegel et al. 2010). Estimated ages between readers were compared for each structure. If there was a discrepancy in age, the readers identified a consensus age.

Age-bias plots were used to assess precision between readers for each structure by plotting ages assigned by Reader 1 against ages assigned by Reader 2 (Campana et al. 1995). Precision between readers was further assessed by calculating the percent exact agreement of estimated ages for each structure. Coefficient of variation (CV) was calculated for each structure:

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

where X_{ij} is the i^{th} age estimation of the j^{th} fish, X_j is the average estimated age of the j^{th} fish, and R is the number of times each fish was aged (Campana et al. 1995). Percent agreement, CV, and reader confidences were averaged across all fish for each structure. Precision between different structures was assessed by calculating percent exact agreement and CV using consensus ages for all possible combinations of structures. Precision was only evaluated for fish that had all four structures removed.

Results

Structures were collected from 111 Northern Pike varying in total length from 320 mm to 1,173 mm. All fish except one were aged with pectoral fin rays, 80 were aged with otoliths, 84 were aged with cleithra, and 85 were aged with pelvic fin rays. Estimated ages varied from 1 to 7 years for pectoral and pelvic fin rays and 1 to 6 years for otoliths and cleithra. Exact agreement between readers was high for all structures but lowest for otoliths (90.0%), followed by cleithra (91.7%), pectoral fin rays (91.8%), and pelvic fin rays (95.3%; Table 1). Ages assigned by both readers were within one year for all structures (Figure 1). Coefficient of variation was highest for otoliths (3.0%; SE 1.1) and lowest for pelvic fin rays (1.3%; SE 0.6; Table 1). Fifty-six Northern Pike had all four structures removed and varied in length from 320 mm to 1095 mm. Exact agreement in consensus age estimates among structures varied from 92.9 to 98.2% (Table 2). Consensus ages were within one year for all structures (Figure 2). Coefficients of variation varied from 0.5 to 1.9% among consensus ages (Table 2).

Discussion

Many studies have investigated the usefulness of different calcified structures to provide precise age estimates for a suite of fish species. Results of that research have shown how precision is dependent on the structure used, age of the fish, and the species of interest (Quist et al. 2007; Phelps et al. 2017; Lindelien et al. 2024). We documented high concordance among all four structures used to age Northern Pike. Additionally, all four structures had a CV within the 5% CV threshold that many consider precise (Laine et al. 1991; Campana et al. 1995). Due to the absence of known-age fish, we were unable to assess accuracy of each structure, but cleithra and pelvic fin rays have been validated as accurate for Northern Pike (Casselman 1978; Babaluk and Craig 1990; Laine et al. 1991) and otoliths have been validated as accurate for a diversity of fishes (Phelps et al. 2017). Pectoral fins have not been previously investigated, but our results indicate that ages assigned using pectoral fin rays are typically the same as those assigned using cleithra, otoliths, and pelvic fin rays, thereby suggesting that pectoral fin rays from Northern Pike are likely to produce accurate ages.

Cleithra are often considered to be the best structure to age esocids since they produce accurate age estimates and are generally precise (Laine et al. 1991; Faust et al. 2013; Oele et al. 2015). Our results are consistent with Faust et al. (2013) and Oele et al. (2015) as we had high between-reader agreement for cleithra. Otoliths are widely used to age fishes and are frequently considered the most accurate structure for many taxa (Maceina et al. 2007; Long and Grabowski 2017). In our study, otoliths had the highest CV, lowest percent agreement, and lowest reader confidence in assigned ages. Otoliths were typically opaque and the annuli were often difficult to discern despite extensive sanding, polishing, and application of immersion oil. Nevertheless, ages estimated with otoliths had high agreement between readers and structures. Removal of cleithra and(or) otoliths requires sacrificing fish. However, lethal sampling is not always acceptable by the public or because sacrificing fish is not appropriate for meeting study objectives (e.g., mark-recapture efforts, movement studies; Pollock and Mann 1983; Coggins et al. 2006; Unsworth et al. 2025). However, the benefits of non-lethal sampling are only as valuable as the precision and accuracy of age estimates. Scales and fin rays are the two primary non-lethal alternatives to otoliths or cleithra. Scales are often precise for a variety of taxa, such as salmonids (Watkins et al. 2015; Reinhardt et al. 2022) and centrarchids (Ross et al. 2005). However, scales are often less precise than other calcified structures (McInerny 2017). Though we did not evaluate the precision of scales in this study, Oele et al. (2013) and Blackwell et al. (2016) reported that scales were among the least precise structures used to age Northern Pike. Similar trends have been found in other taxa (Phelps et al. 2017). Only 12% of ages assigned to known-age Alligator Gar *Atractosteus spatula* using scales were accurate compared to 96% of ages assigned using otoliths (Buckmeier et al. 2012). Herbst and Marsden (2011) noted that scales had the lowest precision and highest uncertainty of three structures used to age Lake Whitefish *Coregonus clupeaformis*. Morehouse et al. (2013) reported that ages estimated using scales from Largemouth Bass *Micropterus salmoides* were less precise and more biased than those using dorsal fin spines and pectoral fin rays.

Fin rays have shown promise as an accurate and precise structure when non-lethal samples are needed, but the quality of age estimates can depend on the species and specific fin ray. Research has demonstrated that fin rays can provide precise ages in a variety of taxa, including salmonids (Watkins et al. 2015), catostomids (Quist et al. 2007; Spiegel et al. 2010), and cyprinids (Phelps et al. 2007; Griffin et al. 2017). Anal and pelvic fin rays have been the primary fins rays used for esocids and tend to produce the same age estimates as cleithra (Brenden et al. 2006; Oele et al. 2015; Crane et al. 2020). Dembkowski et al. (2020) found that pelvic fin rays were the preferred nonlethal structure to age Northern Pike in Wisconsin because ages estimated with pelvic fin rays corresponded with those estimated with cleithra for fish less than 483 mm. Ages estimated using anal fin rays frequently underestimated ages obtained from pelvic fin rays and cleithra. Babaluk and Craig (1990) validated pelvic fin rays from Northern Pike as accurate, and Johnson (1971) reported that pectoral fin rays from Muskellunge *E. masquinongy* provided accurate age estimates for fish up to age 11. Our study is the first to assess age estimates from pectoral fin rays in Northern Pike. We found that ages estimated using pectoral fin rays had high concurrence with the other structures. Beamish (1981) compared dorsal, caudal, and pelvic fin rays from Alaska Pollock *Gadus chalcogrammus*, Pacific Cod *G. macrocephalus*, and Pacific Albacore *Thunnus alalunga* and found that different fin rays provided similar age estimates. Weber and Brown (2010) compared dorsal fin spines and pectoral fin rays from Common Carp *Cyprinus carpio* and reported similar ages estimated from both structures. Additionally, Bauerlien et al. (2018) found that pectoral fin rays from Chain Pickerel *E. niger* had the second highest percent exact agreement (52%) of eight structures.

We observed higher levels of precision across all structures than other comparable Northern Pike studies (e.g., Faust et al. 2013; Oele et al. 2015; Blackwell et al. 2016). Although one reader had extensive experience ageing fishes, experience was not likely the primary reason for high precision. Fast growth rates and younger fish ages have been suggested as factors that can improve the precision of age estimates (Hoxmeier et al. 2001; Koenigs et al. 2015). Thus, the young age structure and fast growth rates experienced by Northern Pike in Lake Pend Oreille and other systems across the region may contribute to the high levels of precision (Bean et al. 2011; Walrath et al. 2015b). Nevertheless, we documented high concordance in age estimates among all structures. Though not explicitly recorded, we noted that much less time was required to process fin rays after sectioning compared to otoliths as the fin rays could be easily read with little to no sanding or polishing. Furthermore, pelvic fin rays had high rates of agreement with cleithra and did not require sacrificing the fish. Our results suggest that all structures evaluated in this study are likely to provide precise age estimates for Northern Pike, but pelvic fin rays had the highest agreement between readers, lowest CV, and high reader confidence.

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Figures

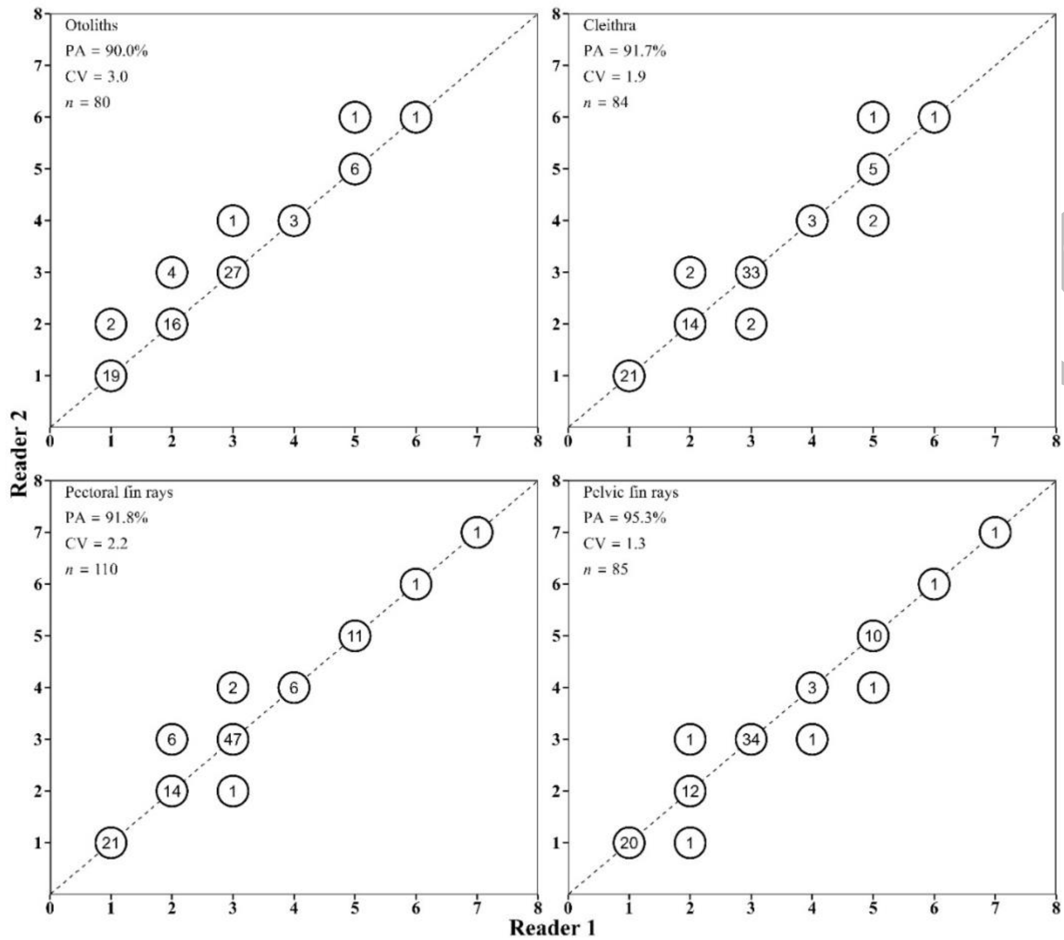
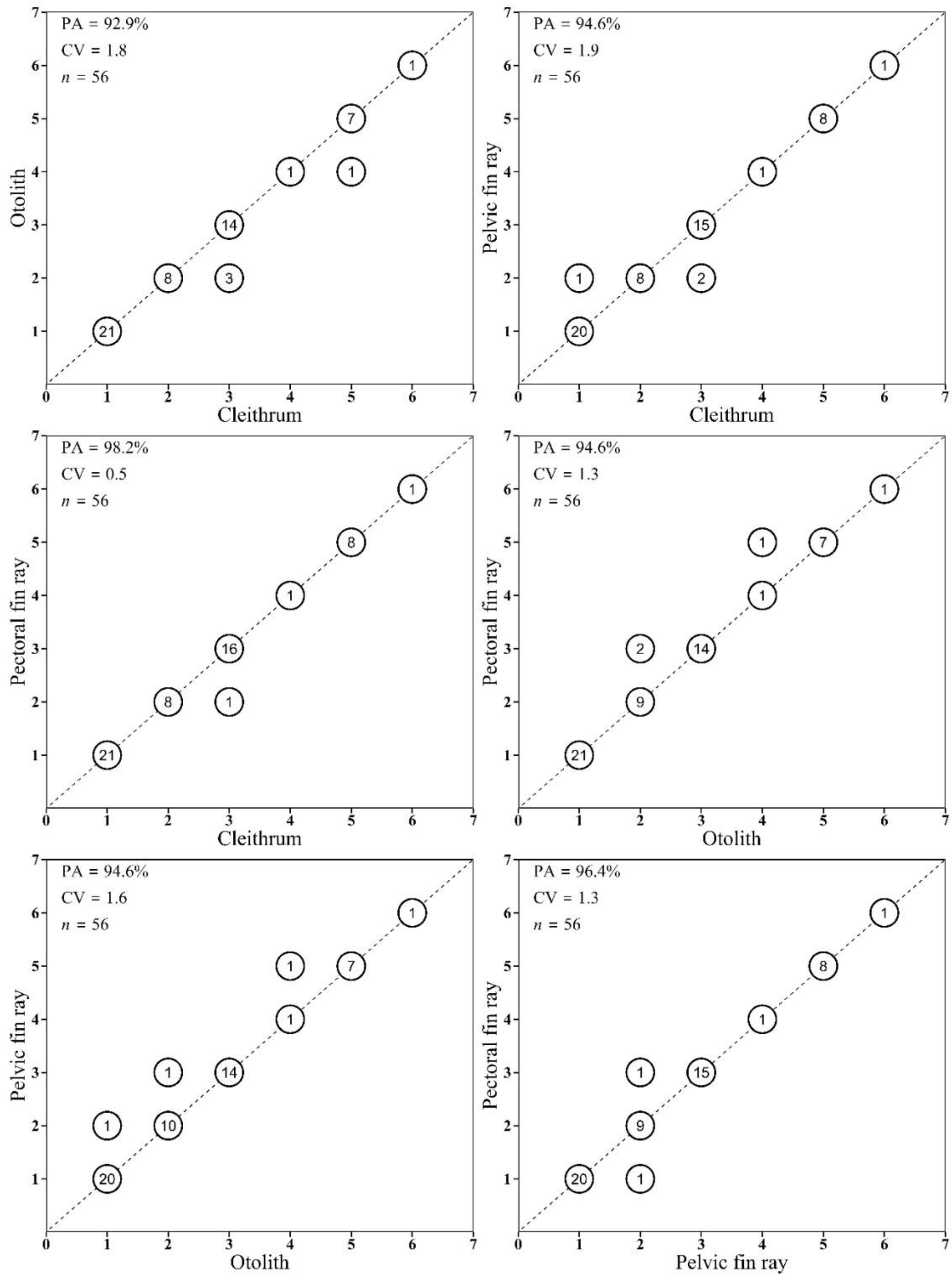


Figure 1. Age-bias plots for ages assigned by two readers using various calcified structures from Northern Pike. Percent exact agreement (PA) between structures, coefficient of variation (CV), and sample size are provided for each structure. Numbers inside circles indicate the number of observations.



486
487 Figure 2. Consensus ages among structures used to estimate ages of Northern Pike. Percent exact
488 agreement (PA) between structures, coefficient of variation (CV), and sample size are provided
489 for each combination of structures. Numbers inside circles indicate the number of observations.

Tables

Table 1. Summary of all Northern Pike structures aged from Lake Pend Oreille, Idaho. Mean confidence ratings are listed with the standard error in parentheses.

Structure	*n*	Agreement (%)	CV (%)	Confidence
Otolith	80	90.0	3.0 (1.1)	1.0 (0.06)
Cleithrum	84	91.7	1.9 (0.7)	1.9 (0.06)
Pectoral fin ray	110	91.8	2.2 (0.7)	2.0 (0.05)
Pelvic fin ray	85	95.3	1.3 (0.6)	2.2 (0.06)

Table 2. Summary of all Northern Pike structure combinations compared from Lake Pend Oreille, Idaho. Mean coefficient of variation (CV) is listed with the standard error in parentheses.

Structure Combination	*n*	Agreement (%)	CV (%)
Otolith-Cleithrum	56	92.9	1.8 (0.9)
Otolith-Pectoral fin ray	56	94.6	1.3 (0.8)
Otolith-Pelvic fin ray	56	94.6	1.6 (1.0)
Cleithrum-Pectoral fin ray	56	98.2	0.5 (0.5)
Cleithrum-Pelvic fin ray	56	94.6	1.9 (1.1)
Pelvic fin ray-Pectoral fin ray	56	96.4	1.3 (1.0)