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Comparison of Lapilli Otoliths and Pectoral Fin Rays for Estimating Age of Northern Pikeminnow

Running footer: Structures for estimating age of Northern Pikeminnow

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1 table, 2 figures

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Abstract

Northern Pikeminnow *Ptychocheilus oregonensis* is a piscivorous cyprinid native to western North America. Information on the best structure for estimating age of Northern Pikeminnow is a key knowledge gap that may limit inquiries on management efforts. Thus, the objective of this study was to evaluate between-reader precision and concordance between age estimates for lapilli otoliths and pectoral fin rays from Northern Pikeminnow. Age estimates from lapilli otoliths were compared to those from pectoral fin rays of 150 Northern Pikeminnow captured from Lake Cascade, Idaho, in April-May 2022. Exact percent-agreement of estimated ages between the readers was higher for fin rays (75.3%) than otoliths (50.0%), with a mean coefficient of variation of 3.5 and 8.7, respectively. Readers also assigned a confidence rating (0-3; higher value reflects higher confidence in age estimate) to each structure. Confidence ratings were higher for fin ray age estimates (mean ± SD; 1.6 ± 0.6) than otolith estimates (1.1 ± 0.7) across readers. A consensus age was estimated for each structure and fish. Agreement between consensus age estimates for otoliths and fin rays was 26.7% with a coefficient of variation of 14.0. Our findings suggest that fin rays were easier to collect, process, and read than otoliths, and resulted in more precise age estimates than otoliths. Results from our study provide guidance on the best structures for estimating the age of Northern Pikeminnow that can be used to inform management efforts.

Introduction

Northern Pikeminnow is a native cyprinid common throughout western North America. The native distribution of Northern Pikeminnow extends from Nevada, United States, to British Columbia, Canada, and from the Pacific coast to the Rocky Mountains of western Montana, United States (Wydoski and Whitney 2003). Northern Pikeminnow typically inhabit low-velocity habitats in large rivers and lakes. However, the construction of dams has provided novel lentic habitat for Northern Pikeminnow across its distribution and has resulted in increased abundance of Northern Pikeminnow in many systems (Simpson and Wallace 1982; Wydoski and Whitney 2003; Wallace and Zaroban 2013). The same dams have created poor conditions for out-migrating juvenile salmon *Oncorhynchus* spp. and steelhead *Oncorhynchus mykiss* (Wydoski and Whitney 2003; Wallace and Zaroban 2013). In reservoir systems, Northern Pikeminnow take advantage of adverse salmonid habitat and consume salmon and steelhead smolts (Knutsen and Ward 1999; Petersen and Ward 1999; Wydoski and Whitney 2003). As a result of their influence on juvenile salmonids, Northern Pikeminnow has been the focus of numerous removal efforts (Scott and Crossman 1973; Simpson and Wallace 1982; Wydoski and Whitney 2003). For example, a sport reward program was established on the Columbia and lower Snake rivers in 1990 where anglers receive a monetary reward for every Northern Pikeminnow they return to the program. The goal of the Northern Pikeminnow sport reward program is to exploit 10-20% of Northern Pikeminnow ≥ 275 mm total length annually (Beamesderfer et al. 1996; Winther et al. 2024). Due to the cultural, ecological, and economic importance of salmonids and the fisheries they support, understanding the ecology of Northern Pikeminnow is a high priority. However, the lack of information of the precision and readability of structures for ageing Northern Pikeminnow hinders our understanding of their population dynamics.

Growth, mortality, and recruitment are the primary functions that regulate fish population dynamics and influence the management of fishes (Ricker 1975). Age data are particularly important because they can provide insight on the characteristics of individual fishes (e.g., age at maturity) as well as information on the age structure of a population (Quist et al. 2012). Age structure data have a variety of important uses, including providing information on recruitment dynamics and forming the basis of mortality estimates (e.g., Smith et al. 2012). Age data are also central to age-structured models focused on population dynamics and bioenergetics (e.g., Peterson and Ward 1999; Caswell 2001).

Examination of hard structures (i.e., scales, fin rays, otoliths) is the most common technique for estimating the age of fishes, and obtaining reliable age data is dependent on the selection of the best structure (Quist and Isermann 2017). Most studies that have estimated the age of Northern Pikeminnow have used scales (e.g., Jeppson and Platts 1959; Hill 1962; Knutsen and Ward 1999; Gray 2001). Scales are notorious for providing inaccurate age estimates compared to otoliths or fin rays, particularly for fish that live more than a few years (e.g., Schill et al. 2010; McInerny 2017; Quist et al. 2022). Sagittal otoliths are a common structure used to estimate age for many freshwater fishes (Quist et al. 2012; Whitledge 2017). However, Northern Pikeminnow and other ostariophysian fishes have small, irregularly shaped, and fragile sagittal otoliths compared to other taxa (Long and Grabowski 2017; Vilizzi 2018). Instead, lapilli otoliths are often used to estimate age of ostariophysian fishes (Long and Grabowski 2017; Phelps et al. 2017). Pectoral fin rays are also commonly used to provide accurate and precise age estimates for ostariophysian fishes and do not require fish sacrifice (Fischer and Koch 2017; Phelps et al. 2017). Despite the importance of Northern Pikeminnow, no research has been conducted on the precision and readability of ageing structures for the species. Thus, the objective of this study was to compare precision of age estimates and readability of lapilli otoliths and pectoral fin rays for Northern Pikeminnow.

Methods

Northern Pikeminnow were collected from Lake Cascade, Idaho, during April-May 2022. Fish were sampled using a combination of floating and sinking gill nets (45 m long, 2 m tall; 19, 25, 32, 28, 51, and 64 cm bar measure mesh). Total length was measured to the nearest millimeter for all fish. Lapilli otoliths and pectoral fin rays were removed from five individuals per 1-cm length bin. Otoliths were extracted following Schneidervin and Hubert (1986), and the leading right pectoral fin ray was removed at the body wall with side-cutting pliers (Koch et al. 2008). Both structures were placed into coin envelopes and allowed to air dry (~3 months) before processing.

Otoliths and fin rays were mounted separately in 2-mL microcentrifuge tubes with epoxy following Koch and Quist (2007). Transverse sections (0.6-0.8 mm) of otoliths were taken by cutting on either side of the nucleus with a low-speed saw (Buehler Inc., Lake Bluff, IL). Cross sections (0.8-1.0 mm) of pectoral fin rays were cut close to the base of the fin ray. Structures were sanded and polished with sandpaper and then viewed under a dissecting microscope with transmitted light. Immersion oil was used as necessary to enhance clarity.

Each structure was independently assigned an age by two readers without knowledge of the length of individual fish. One reader was a novice (Reader 1) and the other (Reader 2) had approximately one year of experience ageing fishes. Both readers received extensive training by an experienced reader (~30 years of experience ageing fishes) prior to the study. Estimated ages were compared between readers. If readers disagreed, there was deliberation until a consensus age was reached. A consensus age was reached for all fish. Readers assigned a confidence rating between 0 and 3 to each age estimate where a rating of 0 reflected no confidence and a rating of 3 indicated nearly complete confidence in a reader's age estimate (Koch et al. 2008; Spiegel et al. 2010).

Age-bias plots were used to examine precision of structures between readers and between structures (Campana et al. 1995). Specifically, we plotted the age estimates of readers for each structure to evaluate between-reader precision. The consensus age of fin rays was compared to the consensus age of otoliths to evaluate between-structure precision. Precision of age estimates was summarized by calculating percent exact agreement (PA-0). Many techniques that rely on age structure data (e.g., mortality estimates) are robust to small errors in age estimates (Ricker 1975; Smith et al. 2012). As such, we also calculated percent agreement with 1 year (PA-1) to provide additional insight on the use of each structure. The coefficient of variation (CV) was also calculated to further assess precision (Campana et al. 1995):

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

X_{ij} is the ith age estimation for the jth fish, X_j is the mean age of the jth fish, and R is the number of times each fish was aged (Campana et al. 1995).

Results

In total, 150 Northern Pikeminnow varying from 174 mm to 520 mm (mean ± SD = 348.9 ± 91.9 mm) were sampled. Age estimates from otoliths varied from 2-21 years and from 2-18 years for fin rays. Exact agreement between readers was 50.0% for otoliths and 75.3% for fin rays (Figure 1). Percent agreement within 1 year was 84.6% for otoliths and 95.3% for fin rays.

Otoliths had a higher mean CV (8.7) than fin rays (3.5; Figure 1). Reader 2 typically provided an older age estimate than Reader 1 and the difference between readers increased with fish age. Specifically, the average difference in age estimates using otoliths between readers was 1.3 years (± 0.8) for age-9 and younger fish (i.e., based on the consensus age) and 2.4 years (±2.1) for age-10 and older Northern Pikeminnow. Similar patterns were observed for fin rays, but the magnitude was lower for fish < age 9 (0.2 ± 0.4) and ≥ age 10 (1.2 ± 1.0). Exact agreement of the consensus age between structures was low (26.7%) but much higher within 1 year (80.0%; Figure 2). Fin rays were easier to read due to having more visible, clearly defined annuli. Consequently, deliberations to reach a consensus took considerably longer for otoliths (~5-10 minutes) than for fin rays (< 2 minutes). Relatively high confidence ratings also reflected the ease with which fin rays were aged (Table 1). Differences in confidence ratings between readers were minimal, but we did observe a pattern associated with the age of fish. For fin rays, the average confidence rating was 1.5 (±0.6) for age-9 and younger Northern Pikeminnow and slightly lower for age-10 and older fish (1.1 ± 0.7). However, confidence in age estimates using otoliths were much lower for age-10 and older fish (0.7 ± 0.6) than fish < age 9 (1.5 ±0.6).

Discussion

Ages estimated from otoliths have been validated for a variety of fishes and are typically considered the best structure for estimating the age of fishes (Long and Grabowski 2017; Phelps et al. 2017). Precision of ages estimated from lapilli otoliths have been evaluated for multiple ostariophysian fishes (Sylvester and Berry 2006; Quist et al. 2007; Seibert and Phelps 2013). Quist et al. (2007) recommended using lapilli otoliths for Creek Chubs *Semotilus atromaculatus* as they were more precise than fin rays and other ageing structures. Sylvester and Berry (2006) recommended lapilli otoliths as the preferred structure for ageing White Suckers *Catostomus commersonii*. Similarly, Seibert and Phelps (2013) deemed lapilli otoliths as the most precise structure for ageing Silver Carp *Hypophthalmichthys molitrix*. Hawkins et al. (2004) found that lapilli otoliths from Colorado Pikeminnow *Ptychocheilus lucius* were the second most precise ageing structure after vertebrae. The results of these studies have generally shown that otoliths provide more precise age estimates than other structures. In our study, we expected otoliths to perform better than fin rays but we observed the opposite pattern. Otoliths had low between-reader precision and readers had little confidence in their age estimates for otoliths. Readers found that the otoliths were difficult to read, largely because most of the otoliths lacked contrast, particularly on the outer third of the otolith.

In recent years, fin rays have become a popular, non-lethal ageing structure for many fishes (Quist et al. 2012; Koch and Fischer 2017). Our results showed that Northern Pikeminnow fin rays provided more precise age estimates than otoliths. Griffin et al. (2017) evaluated precision of lapilli otoliths and pectoral fin rays of Utah Chubs *Gila atraria*. They found that fin rays had higher percent agreement (PA-0 = 74.0%) than otoliths (48.2%). Quist et al. (2007) reported that pectoral fin rays and otoliths from Roundtail Chub *Gila robusta* had similar between-reader precision. Both structures were more precise than scales, opercles, and cleithra. Though not an ostariophysian fish, Mountain Whitefish *Prosopium williamsoni* showed similar patterns where pectoral fin rays provided more precise age estimates than otoliths (Watkins et al. 2015). We acknowledge that our study focused on precision in age estimates and not accuracy. Most studies that have evaluated accuracy of otoliths have found that they provide accurate age estimates (e.g., Schill et al. 2010; Long and Grabowski 2017; Phelps et al. 2017). Similarly, age estimates from fin rays are often concordant with otolith ages, thereby suggesting that fin rays can also provide accurate age estimates (e.g., Quist et al. 2007; Koch and Fischer 2017). Future research focused on the accuracy of age estimates from Northern Pikeminnow fin rays would contribute to the broader understanding of the use of fin rays to estimate age.

Otoliths often provide precise and accurate age estimates, but our results suggest pectoral fin rays are the preferred ageing structure for Northern Pikeminnow. Fin rays were easy to collect in the field, simple to process in the laboratory, easier to read than otoliths, and provided precise age estimates. In contrast, otoliths required sacrificing fish, were difficult and time consuming to remove in the field, difficult to mount and section in the laboratory, and difficult to read. Information on age is important for understanding fish population dynamics. Our results provide insight on improved techniques that can be used to describe the population ecology and guide management of Northern Pikeminnow across its distribution.

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Table 1. Percentage of age estimates from lapilli otoliths and pectoral fin rays given a confidence rating (0 = low confidence; 3 = high confidence) by reader from Northern Pikeminnow collected in Lake Cascade, Idaho, during April-May 2022.

	Otoliths		Fin ray	
Confidence rating	Reader 1	Reader 2	Reader 1	Reader 2
0	16.7%	20.0%	2.0%	2.7%
1	64.6%	50.0%	47.3%	41.3%
2	18.7%	30.0%	48.7%	54.7%
3	0.0%	0.0%	2.0%	1.3%

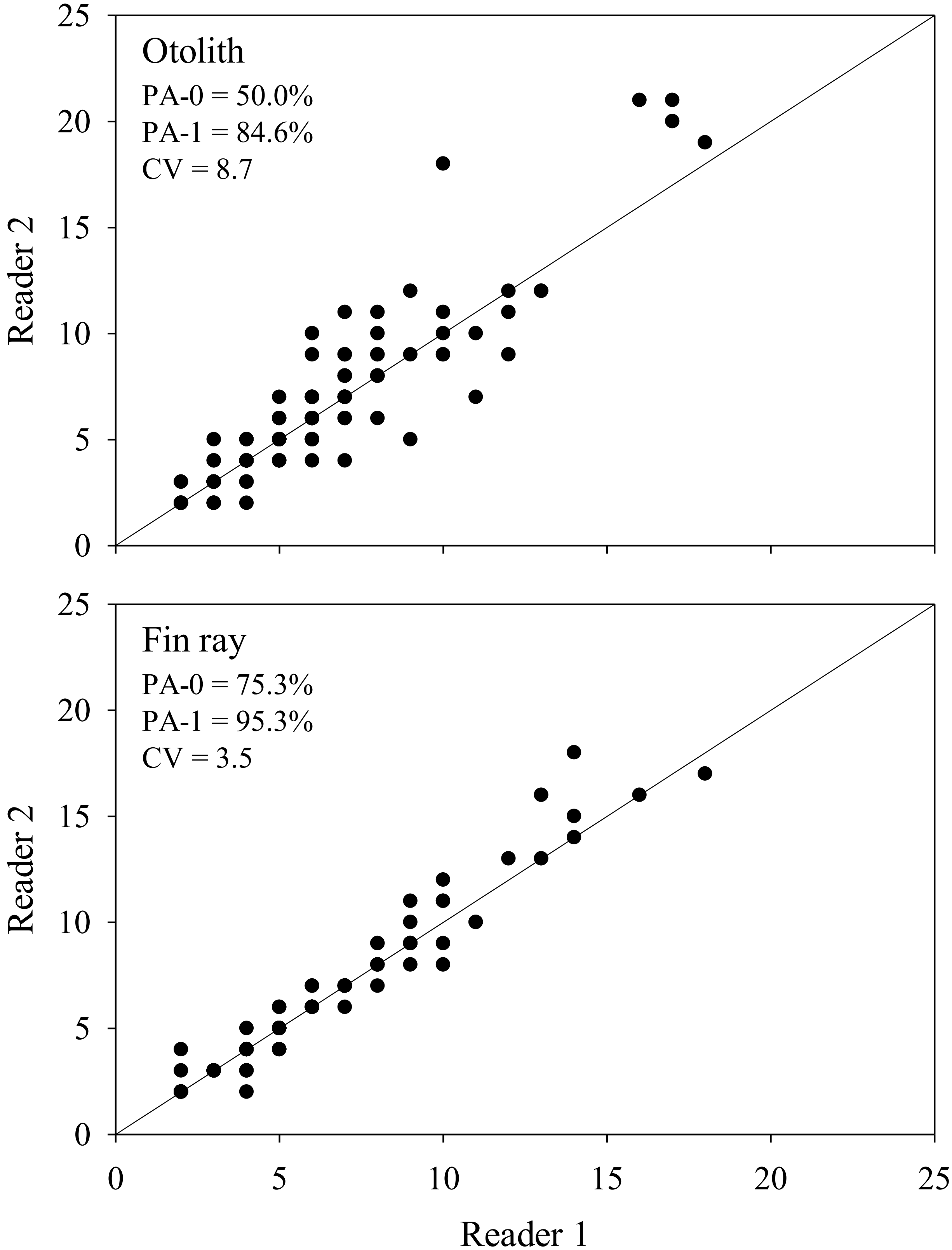

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Figure 1. Between-reader agreement in age estimates from sectioned lapilli otoliths and pectoral fin rays from Northern Pikeminnow sampled in Lake Cascade, Idaho in April and May 2022. Precision between the two readers is shown using exact agreement (PA-0) and within 1-year agreement (PA-1). Mean coefficient of variation (CV) was also used to assess precision. The 1:1 line is presented for reference.

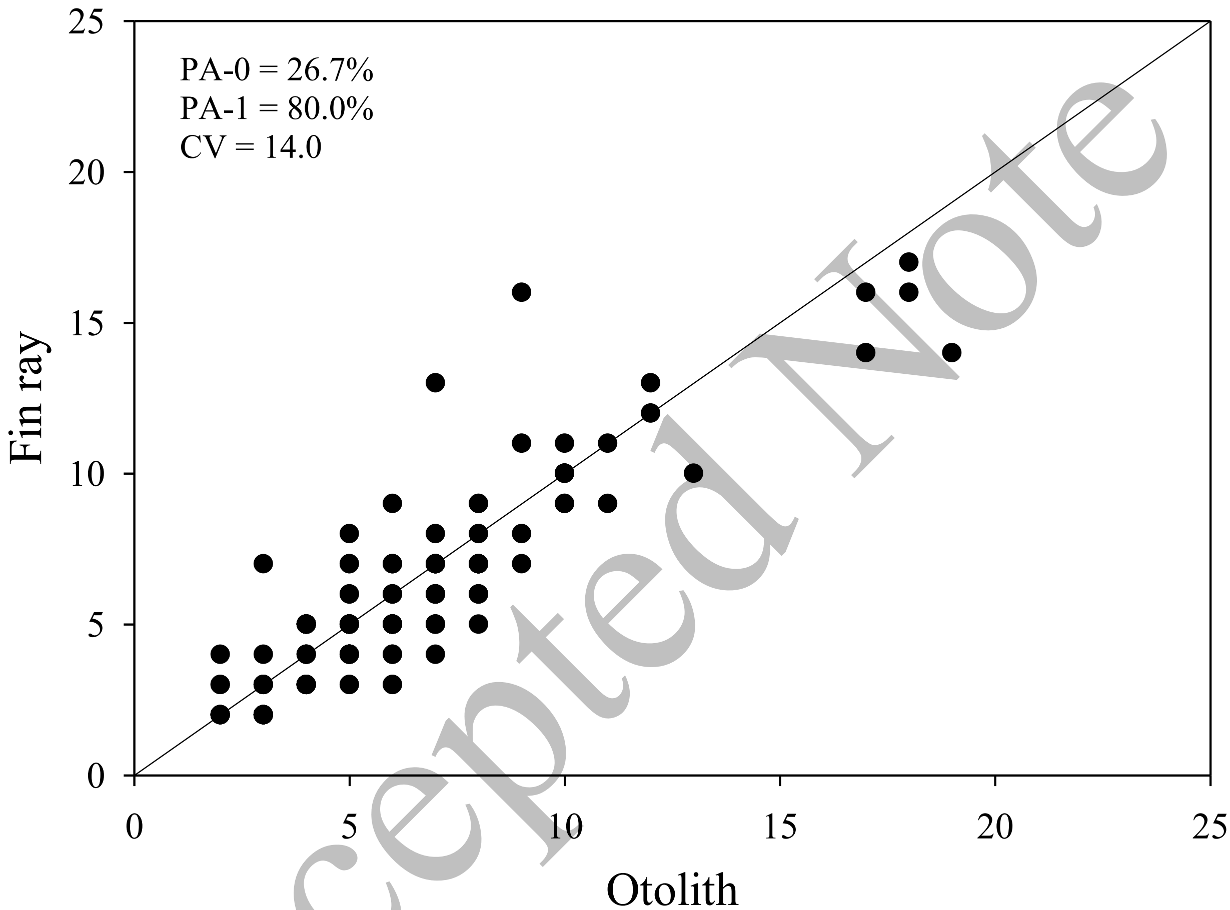

Figure 2. Age-bias plot representing the precision between the consensus ages assigned to pectoral fin rays and lapilli otoliths from Northern Pikeminnow in Lake Cascade, Idaho in April and May 2022. Precision between the two structures is shown using exact agreement (PA-0) and within 1-year (PA-1). Mean coefficient of variation (CV) was also used to assess precision. The 1:1 line is presented for reference.