Minnesota F25AF00867
R29G60F29RP37
Area F111
July 17, 2026

MINNESOTA DEPARTMENT OF NATURAL RESOURCES

DIVISION OF FISH AND WILDLIFE

SECTION OF FISHERIES

SPECIAL PUBLICATION 195

Comparison of Channel Catfish Age Structure Estimation and Processing Techniques for Three Northern Populations

By

Tanner Carlson & Nicholas Kludt, Ph.D.

Approved by:  (7.17.2026)
Marc Bacigalupi, Regional Fisheries Manager

Abstract

Consistent and reliable age estimation is foundational to quantitative fisheries science, yet commonly used aging structures may differ in performance. We compared age estimates from Channel Catfish (*Ictalurus punctatus*) pectoral spines and otoliths collected from three tributaries of the Red River of the North in northwestern Minnesota. We evaluated age estimate agreement, bias, and implications of these for management. Agreement of age estimates between structures was high, with most estimates differing by ≤1 year and overall precision indicating acceptable consistency between structures. Age estimation bias was low between structures across observed ages (2-20 years), although divergence in age estimates between structures increased with age. Growth models derived from both structures were similar through approximately age 14, after which pectoral spine underestimation was increasingly observed relative to otoliths, suggesting pectoral spines are suitable for monitoring of younger age classes in northern populations. The observed increasing uncertainty with age highlights a need for caution when interpreting pectoral spine derived age data for older individuals. Additionally, observed differences in growth among tributaries indicate that uniform length-based sampling thresholds may not be appropriate across systems. This study supports continued use of pectoral spines as an efficient, non-lethal, and reliable aging structure for Channel Catfish in the Red River Basin, and likely broadly across northern populations.

Introduction

Consistent and reliable fish age estimates are important for evaluating fish population status (Kerns & Lombardi-Carlson 2013). Age data are used to inform stock assessments, growth models, and mortality estimates, and inaccurate ages can result in biased estimates (Quinn & Deriso 1999). Various studies have demonstrated that commonly used calcified aging structures may not always be suitable for age estimation, necessitating regional validation (Campana 2001, Buckmeier et al. 2002). Otoliths are considered the most accurate aging structure across many fish species (Campana & Thorrold 2001) yet require the fish to be sacrificed and take more time to extract relative to other structures (Phelps et al. 2007).

Generally, managers prefer to use nonlethally obtained aging structures when possible to avoid the negative public perceptions that may occur when sacrificing large numbers of fish (Olive et al. 2011). Nonlethal aging structure collection also tends to be faster. Pectoral spines have historically been the primary aging structure used to evaluate Channel Catfish (*Ictalurus punctatus*) populations (Sneed 1951; Colombo et al. 2010, Goble 2011, Stevens 2013). Pectoral spine removal has generally not increased mortality (Stevenson and Day 1987, Michaletz 2005) and is therefore assumed to be

nonlethal, although this has not been rigorously evaluated for large (> 24 inch) individuals. While potential mortality increases remain a concern due to the large wounds that occur when spines are removed from large catfish (e.g. Goble 2011), the technique nevertheless remains a widespread approach for obtaining aging structures from Channel Catfish while allowing live release. Age estimate comparisons of Channel Catfish pectoral spines and otoliths have demonstrated potential underestimation of older ages when using pectoral spines, particularly in long-lived populations (Buckmeier et al. 2002; Olive et al. 2011; Hull et al. 2022). Case-specific evaluation of the approach can address these concerns.

As structure development is a function of growth and age, it is important to note that Channel Catfish exhibit latitudinal variation in growth and longevity (Hubert 1999; Michaletz & Travnichek 2011), with northern populations usually experiencing shorter growing seasons, reduced annual growth, and longer-lived fish (Quist et al. 2003). Paradoxically, the growth rate of Channel Catfish (and northern-latitude Ictalurid populations generally) tends to be seasonally faster than southern populations when standardized for temperature regime (Rypel 2011), despite being nominally slower than annual rates of southern populations (e.g. Hubert 1999). On a regional scale, resource availability (Dettmers et al. 2001), temperature variance (Stevens 2013) and habitat differences (Goble 2011) all contribute to variance in growth. These environmental and latitudinal differences may impact annulus formation and the readability of aging structures (Casselman 1987; Campana 2001).

Many aging structure comparisons for Channel Catfish have occurred in the southern portion of their large range (Nash et al. 2009; Olive et al. 2011). While these studies are informative, the latitudinal variation of longevity and growth observed in Channel Catfish suggests the performance of aging structures in southern populations may not be generalizable to more northern populations. Aging structure comparative performance remains understudied near the northern extent of the Channel Catfish native range.

The Red River of the North (hereafter “Red River”) and its tributaries are a northern stronghold for Channel Catfish, containing trophy-sized fish in a high relative abundance (Kludt 2023). Historically, managers with the Minnesota Department of Natural Resources (MNDNR) have used pectoral spines to collect aging data to inform management decisions within the Red River basin (Kludt 2023). To minimize the potential for underestimating the ages of older fish and potential additive mortality in larger fish, only individuals below 25 inches in total length are included in the length-stratified age structure collections. The sampling protocols for the Red River and its tributaries are being evaluated as part of continuous improvement efforts, necessitating a concurrent evaluation of age structure choice. The Channel Catfish aging structure comparison from Siddons (2015), which used samples from the

Lockport, Manitoba, reach of the Red River, represents the only prior Channel Catfish aging structure comparison near or at the northern extent of the species' range. Because the Red River and associated tributary age and mortality estimates inform management decisions including harvest regulations, a comparison of aging structures' relative performance was warranted. Our objectives were to (1) compare age estimates derived from Channel Catfish pectoral spines and otoliths from three tributaries of the Red River, (2) quantify precision and age bias between aging structures, (3) evaluate implications for growth parameter estimation, and (4) determine if the current protocols for taking aging structures on the Red River and its tributaries are appropriate.

Study Area

Channel Catfish were collected from three Red River tributaries, the Red Lake, Roseau, and Thief Rivers, during the summer of 2025 as part of standard stream survey efforts (Fig. 1). The study rivers' diversity of scale, flow regime, and habitat availability are generally representative of Minnesota's Red River tributaries.

The Red Lake River below the Thief River Falls hydroelectric dam in Thief River Falls, MN has a diverse Channel Catfish size structure, with site-specific habitat occupancy and relative abundance dependent on river conditions (i.e. increasing water levels tend to cue upstream movement from downstream habitats). The Thief River lacked historical MNDNR Channel Catfish records; however, a potential source population was identified when multiple individuals were detected in the Red Lake River Reservoir in 2019 and 2024. The reservoir is upstream of the high-head Thief River Falls hydroelectric dam, which is a complete fish barrier at the confluence of the Thief and Red Lake Rivers. Any population in the Thief River was suspected to be low abundance and a possible historic reestablishment of species' range upstream from the dam. The Roseau River has a low-density Channel Catfish population with quality-sized fish.

The three study area rivers vary in system scale and flow regime, as demonstrated by the mean 2025 discharge (cubic feet per second [cfs] ± standard deviation) measured at the downstream-most gauge station on each river: Red Lake River (USGS-05080000), 721.1 ± 298.7 cfs, Roseau River (USGS-05112000) 406.5 ± 387.9 cfs and Thief River (USGS-05076000), 110.7 ± 131.2 cfs. The Red Lake River population characteristics outlined above are generally reflective of the more stable hydrologic conditions and greater habitat availability, as opposed to the low-flow and limited habitat challenges facing the Roseau and Thief River populations.

Methods

Field Sampling

Channel Catfish sampling intended to capture a variety of fish sizes in each river for age structure comparison, using a variety of sampling gears that are commonly used to target catfish in mid-size rivers in Minnesota. A combination of hoop nets (seven fiberglass hoops, 1.1–1.2 m diameters, 4.8 m long, and constructed of 2.5-cm nylon bar mesh; HN), trap nets (19 mm mesh, double framed; TN), and 25-hook baited trot lines (ATL) were used in all three rivers. Hoop nets were set in deeper pools with increased current (when possible), parallel to the river edge with the opening facing downstream. Trap nets were set with the rear (pot end) of the net secured to the riverbank and the lead drifting with the current (set at a ~45-degree angle from the shore angled downstream). Trot lines were set perpendicular to shore in deeper pools with current and baited with cut suckers (*Catostomidae*), but nightcrawlers (*Lumbricus terrestris*) were also used in the Roseau River. Roseau River sampling occurred at four locations between the City of Roseau and the town of Caribou (Carlson 2026a; Figure 1). Thief River sampling occurred on the lower 2.5 miles of the river near the Red Lake River Reservoir (Carlson 2026b; Figure 1). Red Lake River sampling occurred near the town of St. Hilaire, approximately 12 miles downstream of the dam in Thief River Falls, MN (Carlson 2026c; Figure 1).

Sampled Channel Catfish were measured for total length (TL) and weighed to the nearest gram. Due to the low catch rates expected in the Thief and Roseau Rivers, all sampled catfish were sacrificed and had both lapillus otoliths and pectoral spines removed for aging structure comparisons. Gonads were visually evaluated to determine sex. On Red Lake River below the Thief River Falls dam, all sampled Channel Catfish were measured for total length, weighed, had at least one pectoral spine taken for aging, and the first two individuals in each 25 mm (~1 in) length group were sacrificed, sexed via gonads, and lapillus otoliths were extracted for aging structure comparisons.

Aging Structure Lab Processing

Each otolith was mounted in a hard epoxy resin (West System 105/205 epoxy/hardener) using a silicone well mold (Figure 2). Otoliths were cut using a Buehler ISOMET low-speed saw with two, four-inch diameter cutting blades, separated by a three-inch diameter spacer that was the width of one cutting blade (~350 micrometers; Figure 3). This allowed for a thinner cut section than possible with a single blade, and reduced the risk of cracking. The otolith section was lightly sanded on both sides using P600 grit sandpaper, submerged in mineral oil, and viewed through a microscope with a top light on a black background (top view) and alternately with a bottom light on a clear background plate (bottom view; Figure 4). Channel Catfish pectoral spines were cut using the same low-speed saw using

only a single cutting blade, cutting along the line marked in Figure 5 similar to methods used by Buckmeier et al. (2002). This is the standard cross sectioning location used by the MNDNR (Hoxmeier et al. 2018), albeit with the cut angled through the articulating process, as opposed to perpendicular to the long axis of the spine, which MNDNR Region 1 staff feel tends to produce clearer annuli. The cut spine section was submerged in mineral oil and viewed through a microscope with a top light on a black background. Both aging structures were aged independently by two experienced agers (Campana 2001). Where there was disagreement on otolith or spine age estimates between the primary readers, a third reader reviewed the structure to determine a consensus age.

Analysis

Age Agreement and Precision

Age estimates derived from otoliths and pectoral spines were compared for fish (n=66) that had both aging structures taken. For each fish, age bias was calculated between viewers for each structure (otolith top view, otolith bottom view, and pectoral spines) as well as between consensus age estimates for otoliths and pectoral spines. Age bias was calculated by taking the difference of age estimates between either agers or structures. Exact agreement (%), agreement within ±1 year, and agreement within ±2 years were calculated for estimates between agers and structures to quantify reader concordance (Beamish & Fournier 1981). An age–age agreement plot between consensus ages for otoliths and pectoral spines was constructed relative to a 1:1 reference line (Figure 6). Precision between structures was quantified using the coefficient of variation (CV) following Campana (2001) where:

$$CV = \frac{\sqrt{\sum\left(Age_{spine} - Age_{otolith}\right)^2/(\mathrm{2n})}}{Age_{otolith}}$$

Age-specific CV was also calculated to evaluate precision changes between structures as age increases. Lower CV values indicate higher precision between aging structure estimates.

Growth Modeling

Length-at-age relationships were modeled separately for otolith and pectoral spine derived age estimates using a nonlinear Gompertz growth function:

$$L(a) = L_{\infty}\exp\left[-\mathrm{k}\exp(-\mathrm{g} * \mathrm{Age})\right]$$

Where *L(a)* is total length at age a_i, L_∞ is asymptotic length, *k* is the scaling coefficient, and *g* is the growth-rate coefficient. The Gompertz growth model was selected because it often provides improved fit for species exhibiting early rapid growth followed by gradual asymptotic deceleration, such as in Channel Catfish (Quinn & Deriso 1999; Ricker 1975). For otolith data, both population-specific and combined models were evaluated. In the population model, L_∞, *k*, and t_g were modeled as functions of population for growth comparisons of Channel Catfish between rivers. Due to low sample size, and the use of paired fish for aging structure comparisons, a combined growth model was fit for otoliths and pectoral spines for aging structure comparisons for "Northwestern Minnesota" Channel Catfish as growth rate differences between rivers would not have an impact on age comparisons between structures. All growth models were fit in a Bayesian framework using Hamiltonian Monte Carlo sampling using program R (R Core Team 2022) with the *brms* package (Bürkner 2017), which interfaces with Stan (Carpenter et al., 2017). Four Markov chains were run for 4,000 iterations each. Weakly informative priors were specified for growth parameters:

$$L_\infty \sim Normal(31,10), \text{constrained} > 0$$

$$k \sim Normal(2,2), \text{constrained} > 0$$

$$\text{g} \sim Normal(0,1)$$

$$\sigma \sim Exponential(1)$$

Model fit was evaluated by running posterior predictive checks and considered the model to be properly converged if rank-normalized $\hat{R}$ values were less than 1.01 (Vehtari et al. 2021).

Growth Curve Comparison

Posterior predicted length-at-age values were generated across a continuous age grid for both structures. For each posterior draw and age:

$$\Delta\,(a) = L_{spine}(a) - L_{otolith}(a)$$

Posterior summaries included the mean predicted difference in predicted length between structures with 90% credible intervals, and the posterior probability that spine-predicted length exceeded otolith-predicted length at each age. Ninety percent credible intervals were reported to reflect posterior uncertainty while maintaining interpretability for management-relevant effect sizes. To evaluate growth curve divergence between structures at older ages, posterior differences were summarized for ages 12 years and older. Age 12 was selected as the breakpoint because other studies comparing Channel Catfish aging structures showed divergence around age 12 (Barada & Pegg 2011;

Olive et al. 2011) and visual inspections of length at age curves in this study appeared to show divergence beginning around age 12.

Posterior Probability of Structural Divergence

For each age, the probability of spine derived length being larger than otolith derived length was calculated. Structural divergence was defined as significant posterior evidence when probability exceeded 0.95. A 0.95 posterior probability threshold was used as a conventional benchmark for strong evidence in Bayesian inference (McElreath 2020). The earliest age that met this threshold was identified as the divergence onset between spine and otolith age estimates.

Estimation of Under-Aging in Years

To quantify the expected under-aging of spine derived age estimates, posterior spine derived lengths were converted to otolith-equivalent ages by inverting the otolith Gompertz function. Under-aging by pectoral spines relative to otoliths at age a was calculated as:

$$a = -\frac{1}{g}\ln\left[\frac{-\ln\left(L/L_{\infty}\right)}{k}\right]$$

L represents posterior spine predicted length at age *a.* Ratios approaching 0 or 1 were constrained to the open interval (0,1) to ensure numerical stability near the asymptote. Posterior summaries of mean under-aging, 90% credible intervals, and posterior probability of under-aging (> 0) were calculated for ages ≥ 12 years.

Results

Age Agreement and Precision

A total of 66 Channel Catfish were sampled and had both otoliths and pectoral spines taken for aging structure analysis (33 in the Red Lake River, 28 in the Roseau River, and 5 in the Thief River; Table 1). Size ranged from 11.2 to 28.8 inches across the three sampled rivers with an average of 21.5 inches (Figure 7). One ager had exact age estimate agreement for pectoral spines and top view otoliths on 33% of sampled catfish (n=22) with an average difference of 0.20 years and exact agreement between pectoral spines and bottom view otoliths on 29% of sampled catfish (n=19) with an average difference of 0.12 years (Table 2). The other ager had exact agreement between pectoral spines and top view otoliths for 42% of sampled catfish (n=28) with an average difference of 0.02 years and the

same age estimate between pectoral spines and bottom view otoliths for 30% of sampled catfish (n=20) with an average difference of 0.49 years (Table 2). Since top view otolith age estimates had less average difference and higher agreement between agers than the bottom view otoliths, top view otolith consensus aging was used for all modeling and comparisons. Otolith age estimate agreement between agers was 29% (n=19), with 79% (n=52) of estimates within one year of each other, and 95% (n=63) of estimates within two years (Table 2). Pectoral spine age estimate agreement between agers was 39% (n=26), with 77% (n=51) of estimates within one year of each other, and 95% (n=63) of estimates within two years (Table 2). Consensus age bias (pec spine estimates- otolith estimates) was -0.2 years (ager one, -0.02 years; ager two, -0.2 years) with a maximum observed bias of four years (Figure 8).

The coefficient of variation (CV) between structures was 0.0788, indicating that estimates differed by 7.9% relative to their mean, suggesting moderate to good precision between structures. CV values were higher in ages 5-7 (CV 19-42%) due to low sample sizes of those ages (n=11). CV values also increased after age 15 (4%), however, CV did not exceed 10% at most ages (Table 3).

Growth Modeling

The Gompertz growth model provided an adequate fit to length-at-age data for both otolith and spine derived age estimates. Posterior predictive distributions closely tracked observed length trajectories across the sampled age range, with no systematic bias evident in residual diagnostics. $\hat{R}$ values were less than 1.01 for each parameter in both the otolith and pectoral spine models indicating that chains had converged in both models. Parameter estimates for otolith-based ages were L_∞ =31.4 in (95% credible interval [CrI]: 27.4 to 38.6), k = 1.64 (95% CrI: 1.34 to 2.09), and g = 0.14(95% CrI: 0.08 to 0.20; Table 4). Parameter estimates for pectoral spine-based ages were L_∞ =36.3 in (95% CrI: 29.5 to 47.1), k = 1.69 (95% CrI: 1.47 to 1.98), and g = 0.11 (95% CrI: 0.07 to 0.17; Table 4). Asymptotic length (L_∞) estimates were slightly higher in pectoral spines, whereas the growth coefficient g was slightly lower for spine-based ages, indicating slower early growth under pectoral spine aging compared to otoliths (Figure 9).

The otolith derived Gompertz growth model with population effects, used only to compare growth rates between river systems, showed a visual difference in growth rates between the Roseau and Red Lake Rivers, though not statistically significant as 95% CrI overlap. $\hat{R}$ values were less than 1.01 for each parameter in the model indicating that chains had converged. Model parameters for each river can be found in Table 5.

Growth Curve Comparison

Posterior draws of differences in predicted length at age between pectoral spine and otolith derived ages did not vary significantly. Mean predicted differences in length showed pectoral spines predicted slightly smaller fish between ages 2-12 when compared to otoliths (mean difference between 0-0.5 in; Figure 10). Mean difference in predicted length between structures was zero at age 12 and continuously increased (spine derived predicted length > otolith derived predicted length) as age increased (Figure 10). Across all observed ages 95% credible intervals include zero, indicating there is no significant difference in predicted length between structures from 2-20 years old.

Posterior Probability of Structural Divergence

Posterior draws of predicted length differences revealed minimal differences between structures at younger ages (< age 12) with increasing divergence with age. Between ages 5-10 the probability pectoral spine length was greater than otolith derived length at age was low (<0.3; Figure 11), indicating pectoral spines were assigning higher ages when compared to otoliths in smaller fish. At age 12, the probability that pectoral spine length was greater than otolith derived length at age was 0.5, indicating both structures were predicting the same lengths. As age increased past age 12 the probability pectoral spine derived length was greater than otolith derived length at age increased to 0.88 at age 17, below the 0.95 threshold for statistical significance (Figure 11). However, the 88% probability pectoral spines predict higher lengths after age 15 suggest moderate evidence of structural divergence at older ages (15+ years).

Estimation of Under-Aging in Years

Analytical inversion of the otolith Gompertz function was used to convert spine-predicted lengths to otolith-equivalent ages. Across posterior draws, spine based assigned ages began to underestimate otolith equivalent ages after consensus (otolith) age 12 (Figure 12). For fish aged ≥12 years, the mean under-aging (otolith-equivalent age − spine age) was 6.84 years (95% CrI: -0.33 to 35.66 years) with a median of 1.6 years. Maximum mean expected under-aging reached 5 years at the upper observed age range (age 20). Under-aging increased nonlinearly with age and was most pronounced near the asymptotic region of the growth curve (Figure 12). Uncertainty also increased near the asymptotic region of the growth curve, as seen by the wide 95% credible intervals of the mean prediction in Figure 12.

Differences between aging structures were minimal at younger ages (<12 years). While 95% credible intervals overlapped zero across all observed ages, mean predicted difference between

structures increased starting at age 12. At age 14.3 years, mean bias was 0.5 years (pectoral spines over aged by 0.5 years compared to otoliths). Because fish are aged in whole years, this represents the point at which divergence between structures becomes practically meaningful for age assignment. At the maximum observed age (20 years), mean under-aging was 4 years.

Discussion and Management Implications

This study compared Channel Catfish age estimates derived from pectoral spines and otoliths. Overall, results indicate that pectoral spines provided age estimates similar to otoliths through approximately age 14, with pectoral spine derived estimates gradually increasing in underestimation thereafter. While differences in estimates between aging structures were not statistically significant, the data provided biological thresholds where manager confidence in pectoral spines' age estimate accuracy should begin to decline. Aging structure estimate divergence was previously reported at age 18 for Red River mainstem individuals (Siddons 2015); however, this was based on visual assessment of departure from a 1:1 estimate relationship as opposed to the more quantitatively rigorous assessment herein. These findings are consistent with previous evaluations of Channel Catfish aging structures elsewhere, which documented increasing underestimation of ages derived from pectoral spines for older fish compared with otoliths (Barada et al. 2011; Olive et al. 2011; Buckmeier et al. 2002).

Reader agreement between aging structures was moderate to high, with most estimates within 1 year (82%) and coefficient of variation (CV) values generally below 10% across ages. Consensus age bias between structures was low overall (0.2 years), and the maximum observed bias between structures was 4 years. Divergence between age estimates by structure was not strongly supported under the 0.95 posterior probability threshold. However, posterior probabilities did suggest moderate divergence beginning near age 15 (max probability =0.88 at age 17), which has biological and management implications, even though 95% credible intervals overlapped zero at all observed ages. Generally, these results align with previous literature showing that pectoral spines can underestimate age relative to otoliths in older Channel Catfish, particularly beyond approximately age 12 (Barada et al. 2011; Olive et al. 2011). However, in this study there was no statistically significant difference between structures at any observed age and the magnitude of divergence observed was gradual. Practical differences in whole year age assignment did not become meaningful until around age 14.

Growth curve parameter estimates were similar between structures. Posterior predictive comparisons demonstrated minimal differences in predicted length at age through age 12 (< 0.5 in).

Divergence between growth curves increased gradually after age 12, consistent with under-aging at older ages when using spine-derived estimates. As fish approach L_{∞}, small differences in assigned ages translate to larger discrepancies in inferred growth due to the flattening of the Gompertz growth curve. This pattern explains the nonlinear increase in expected under-aging of pectoral spines observed at older ages and the widening credible intervals as age increases (Figure 12).

The relative performance of aging structures presented herein is an important confirmatory finding for current MNDNR monitoring practices; in particular, that spine derived ages are reliable through age 12 and likely remain so through age 14. On the Red River mainstem, MNDNR managers only collect Channel Catfish pectoral spines from fish up to 25 inches in total length for long-term growth rate monitoring. The intent of this monitoring approach is surveillance of somatic growth rates prior to sexual maturity, with an assumption that sex-specific growth rate divergence is less likely during this period. Monitoring is therefore focused on individuals less than age 10, which is the typical recruitment age observed in the system (Stewart and Watkinson 2004); this age informs the field protocol. Based on long-term length-at-age data trends, a 10-year-old individual is predicted to have a mean total length slightly greater than 20 inches and is not expected to exceed 25 inches (Kludt 2023; Figure 13), thus justifying the length-defined sampling frame. As this study and Siddon (2015) both suggest spine-derived aging is reasonable for individuals up to age 14, present Red River protocols likely yield reliable inferences about long-term immature Channel Catfish growth rate stability.

However, while sample size was limited, results from the upper Red Lake River provide a cautionary note for population assessment in the relatively smaller, lower productivity upper reaches of tributaries. In smaller, less productive upper stream reaches, growth may be assumed *a-priori* to be relatively slower following the resource availability predictions of the river continuum concept (Vannote et al. 1980). This was observed in the Upper Red Lake River sample, where a 25-inch catfish was estimated to be approximately 20 years old, as opposed to the approximately 14 years old expected for a fish of similar length in the Red River (Figure 13). If we assume this is representative of the Upper Red Lake River population's length-at-age structure and further imagine aging this length-age cohort using spines, we might expect to serially under-age these older fish (Figure 6, 12). This under-aging would then propagate through subsequent analyses, manifesting as an over-estimation of growth (e.g. Figure 11). When headwaters-to-confluence or upper-reach-specific age structure data are an assessment goal, the use of spines should be carefully considered relative to otoliths for data quality reasons.

We acknowledge a limited focus on larger, old-aged fish, and that these were not well-represented in our assessment. Generally, sample sizes of old-age large fish tend to be small when

sampled in proportion to population abundance. This contributes to wide credibility intervals near growth curve asymptotes, as seen here beyond age 15. Additional sampling of large, old individuals would improve precision in estimating divergence magnitude between structures if we wished to extend our inferences to those age classes. However, this increased precision would come at the cost of sacrificing angler-coveted larger individuals and would likely have a minimal impact on the current management goal of maintaining consistent growth from ages 3-10.

Overall, this study supports continued use of pectoral spines as an efficient, reliable and practical aging structure for Channel Catfish in the Red River Basin and likely across northern populations more broadly. Cautions regarding pectoral spine underestimation of large, old-age individuals continue to be relevant, so care should be taken when designing or interpreting assessments if using this structure for age assignment. Locally, if the Red River protocol and its maximum total length threshold for structure collection are going to be applied in tributary surveys inclusive of upper or headwaters reaches, prior analyses should assess system-specific growth patterns.

Literature Cited

Barada, T. J., & Pegg, M. A. (2011). Population characteristics of Channel Catfish in the Platte River, Nebraska. *American Fisheries Society Symposium*, 77, 81-94.

Barada, T. J., Blank, A. J., & Pegg, M. A. (2011). Bias, precision, and processing time of otoliths and pectoral spines used for age estimation of channel catfish. In P. H. Michaletz & V. H. Travnichek (Eds.), *Conservation, Ecology, and Management of Catfish: The Second International Symposium* (pp. 723–731).

Beamish, R. J., & Fournier, D. A. (1981). A method for comparing the precision of a set of age determinations. *Canadian Journal of Fisheries and Aquatic Sciences*, *38*(8), 982-983.

Bürkner, P.-C. (2017). brms: An R package for Bayesian multilevel models using Stan. *Journal of Statistical Software, 80*(1), 1–28.

Buckmeier, D. L., Irwin, E. R., Betsill, R. K., & Prentice, J. A. (2002). Validity of otoliths and pectoral spines for estimating ages of channel catfish. *North American Journal of Fisheries Management*, *22*(3), 934-942.

Campana, S. E. (2001). Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation methods. *Journal of Fish Biology*, 59(2), 197–242.

Campana, S. E., & Thorrold, S. R. (2001). Otoliths, increments, and elements: Keys to a comprehensive understanding of fish populations? *Canadian Journal of Fisheries and Aquatic Sciences, 58*(1), 30–38. https://doi.org/10.1139/f00-177

Carlson, T. (2026a). Roseau River (H-024) 2025 Stream Survey. Completion Report. *Minnesota Department of Natural Resources. Division of Fish and Wildlife. Baudette, MN.*

Carlson, T. (2026b). Thief River (H-026-030-033) Initial Stream Survey. Completion Report. *Minnesota Department of Natural Resources. Division of Fish and Wildlife. Baudette, MN.*

Carlson, T. (2026c). Red Lake River (H-026-030) 2025 Targeted Channel Catfish Survey. Completion Report. *Minnesota Department of Natural Resources. Division of Fish and Wildlife. Baudette, MN.*

Carpenter, B., A. Gelman, M.D. Hoffman, D. Lee, B. Goodrich, M. Betancourt, and A. Riddell. (2017). Stan: A probabilistic programming language. *Journal of Statistical Software, 76*(1), 1–32.

Casselman, J. M. (1987). Determination of age and growth. In A. H. Weatherley & H. S. Gill (Eds.), *The biology of fish growth* (pp. 209–242). Academic Press.

Colombo, R. E., Phelps, Q. E., Miller, C. M., Garvey, J. E., Heidinger, R. C., & Richards, N. S. (2010). Comparison of channel catfish age estimates and resulting population demographics using two common structures. *North American Journal of Fisheries Management, 30*(1), 305–308.

Dettmers, J.M., Wahl, D.H., Soluk, D.A., & Gutreauter, S. (2001). Life in the fast lane: fish and foodweb structure in the main channel of large rivers. *Journal of the North American Benthological Society* 20(2):255-265.

Goble, C.W. (2011). Ecology and management of Channel catfish and Flathead catfish populations in the Missouri River, NE. *Thesis, University of Nebraska-Lincoln.*

Hoxmeier, J., McInerny, M., Habrat, M., Hodgins, N., Katzenmeyer, E., & Stewig., J. (2018). Division of Fish and Wildlife guidelines for age and growth estimation of Minnesota fishes, ver.1.01. *Minnesota Department of Natural Resources Division of Fish and Wildlife. St. Paul, MN.*

Hubert, W. A. (1999). Biology and management of channel catfish. In E. R. Irwin et al. (Eds.), Catfish 2000: Proceedings of the International Ictalurid Symposium. *American Fisheries Society.*

Hull, N. J., Olson, C. M., Snow, R. A., & Porta, M. J. (2022). Using pectoral spines and otoliths for estimating ages of channel catfish and effects on estimating population parameters. *Southeastern Association of Fish and Wildlife Agencies Journal, 9*, 39–46.

Kerns, J. A., & Lombardi-Carlson, L. A. (2013). Chapter 1: Introduction to age and growth. In M. D. Quist & D. A. Isermann (Eds.), Age and growth of fishes: Principles and techniques (pp. 1–12). *American Fisheries Society.*

Kludt, N.B. (2023). Red River of the North Channel Catfish Population Assessment, Summer 2022. *Minnesota Department of Natural Resources, Division of Fish and Wildlife, Detroit Lakes, MN.*

Kludt, N.B. (2026). Red River of the North Channel Catfish gear and survey methods evaluation, and recommendations for survey standardization, summer 2025. *Minnesota Department of Natural Resources, Division of Fish and Wildlife, Detroit Lakes, MN.*

McElreath, R. (2020). rethinking: Statistical Rethinking book package, 2016. *R package version*, *1*.

Michaletz, P. H. (2005). Does pectoral spine extraction cause mortality to Channel Catfish? *North American Journal of Fisheries Management* 25, 533-535.

Michaletz, P. H., & Travnichek, V. H. (2011). Conservation, ecology, and management of catfish: The second international symposium. *American Fisheries Society.*

Nash, M. K., Irwin, E. R., & Quist, M. C. (2009). Age and growth of channel catfish in the Tombigbee River system, Alabama and Mississippi. *North American Journal of Fisheries Management, 29*(3), 845–853.

Olive, J. A., Schramm, H., Gerard, P. D., & Irwin, E. (2011). An evaluation of agreement between pectoral spines and otoliths for estimating ages of catfishes. *American Fisheries Society Symposium,* 77, 679–688.

Phelps, Q. E., Edwards, K. R., & Willis, D. W. (2007). Precision of five structures for estimating age of common carp. *North American Journal of Fisheries Management, 27*(3), 103–105. https://doi.org/10.1577/M06-076.1

Quinn, T. J., & Deriso, R. B. (1999). Quantitative fish dynamics. *Oxford University Press.*

Quist, M. C., Pegg, M. A., & DeBoer, J. A. (2003). Age and growth of channel catfish in the upper Mississippi River basin. *North American Journal of Fisheries Management, 23*(2), 451–463.

R Core Team. (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Ricker, W. E. (1975). Computation and interpretation of biological statistics of fish populations. *Fish. Res. Board Can. Bull.*, *191*, 1-382.

Rypel, A.L. (2011). Meta-analysis of growth for five North American catfishes: effects of climate, hydrologic habitat, and latitudinal counter gradients. *American Fisheries Society Symposium* 77:661-677.

Siddons, S.F (2015). Population dynamics and movement of Channel Catfish in the Red River of the North. *Thesis, University of Nebraska-Lincoln.*

Sneed, K. E. (1951). A method for calculating the growth of channel catfish, *Ictalurus lacustris punctatus*. *Transactions of the American Fisheries Society, 80*(1), 174–183.

Stewart, K., & Watkinson, D (2004). Freshwater Fishes of Manitoba. *University of Manitoba Free Press, Winnipeg.*

Stevens, T.M (2013). Feeding ecology and factors influencing growth and recruitment of Channel Catfish in South Dakota reservoirs. *Thesis, South Dakota State University*.

Stevenson, F., & Day, R.E. (1987). Mortality and growth of channel catfish following extraction of a pectoral spine. *North American Journal of Fisheries Management* 7:443-443.

Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R., & Cushing, C.E. (1980). The river continuum concept. *Canadian Journal of Fisheries and Aquatic Science*, 37, 130-137.

Vehtari, A., Gelman, A., Simpson, D., Carpenter, B., & Bürkner, P. C. (2021). Rank-normalization, folding, and localization: An improved Rˆfor assessing convergence of MCMC (with discussion). *Bayesian analysis*, *16*(2), 667-718.

Tables

Table 1. Channel Catfish catch by river and gear type used in aging structure comparisons. The number in parentheses represents the number of nets/trotlines deployed in the waterbody.

	Trap Nets	Hoop Nets	Trot Lines
Red Lake River	4 (n=9)	103 (n=9)	11 (n=2)
Roseau River	0 (n=3)	5 (n=39)	23 (n=12)
Thief River	1 (n=9)	2 (n=9)	2 (n=3)

Table 2. Percentage of agreement (number of fish) for various structural and reader aging comparisons evaluated in this study. Average difference of disagreement in years is listed for each comparison, respectively.

	Pectoral Spines	Top View Otoliths	Bottom View Otoliths	Pectoral Spines/Top View Otoliths	Pectoral Spines/Bottom View Otoliths
Ager One					
Same Estimate	NA	NA	NA	42%	30%
±1 Year	NA	NA	NA	77%	67%
±2 Years	NA	NA	NA	89%	88%
Avg Difference (Years)	NA	NA	NA	0.02	0.49
Ager Two					
Same Estimate	NA	NA	NA	33%	29%
±1 Year	NA	NA	NA	64%	64%
±2 Years	NA	NA	NA	80%	82%
Avg Difference (Years)	NA	NA	NA	0.20	0.12
	Between Reader Age Comparisons			Consensus Ages Between Structures	
Same Estimate	39%	29%	28%	61%	NA
±1 Year	77%	79%	61%	82%	NA
±2 Years	95%	95%	83%	88%	NA
Avg Difference (Years)	0.26	0.44	1.14	0.20	NA

Table 3. Coefficient of Variation (CV) percentage by age and combined CV for precision age estimate evaluations. Ages with "NA" did not have a large enough sample size to calculate CV.

Otolith Age	CV	*n*	Mean Bias Between Structures
3	NA	1	NA
4	NA	1	NA
5	42%	2	1.50
6	20%	6	0.17
7	21%	4	0.75
8	0%	2	0.00
9	5%	5	0.20
10	6%	3	0.33
11	7%	9	0.44
12	9%	8	0.38
13	4%	3	0.67
14	3%	6	0.17
15	4%	4	0.50
16	4%	3	0.33
17	11%	4	1.00
18	4%	2	2.50
19	NA	1	4.00
20	0%	2	3.00
Combined	8%	66	0.73

Table 4. Parameter estimates, estimated error, and 90% credible intervals for both the otolith and pectoral spine derived Gompertz nonlinear growth models (Red Lake, Roseau, and Thief Rivers combined).

Regression Coefficients	Parameter Estimate	Estimated Error	90% Credible Interval Lower	90% Credible Interval Upper	R Hat Value
Otolith L_{inf}	31.44	2.86	27.42	38.55	1.00
Otolith K	1.64	0.19	1.34	2.09	1.00
Otolith G	0.14	0.03	0.08	0.20	1.00
Otolith Sigma	2.03	0.18	1.72	2.41	1.00
Pec Spine L_{inf}	36.31	4.61	29.51	47.12	1.00
Pec Spine K	1.69	0.13	1.47	1.98	1.00
Pec Spine G	0.11	0.03	0.07	0.17	1.00
Pec Spine Sigma	1.94	0.17	1.63	2.31	1.00

Table 5. Parameter estimates, estimated error, and 90% credible intervals for an otolith derived Gompertz nonlinear growth model with population effects for the Roseau and Red Lake Rivers.

Regression Coefficients	Parameter Estimate	Estimated Error	90% Credible Interval Lower	90% Credible Interval Upper	R Hat Value
Roseau L_{inf}	40.71	7.80	25.96	56.76	1.00
Roseau K	0.09	0.08	0.00	0.28	1.00
Roseau G	-0.08	0.02	-0.12	-0.04	1.00
Red Lake River L_{inf}	33.22	4.49	26.71	44.24	1.00
Red Lake River K	1.46	0.10	1.26	1.67	1.00
Red Lake River G	0.10	0.02	0.06	0.15	1.00
Sigma	1.57	0.15	1.31	1.91	1.00

Figures

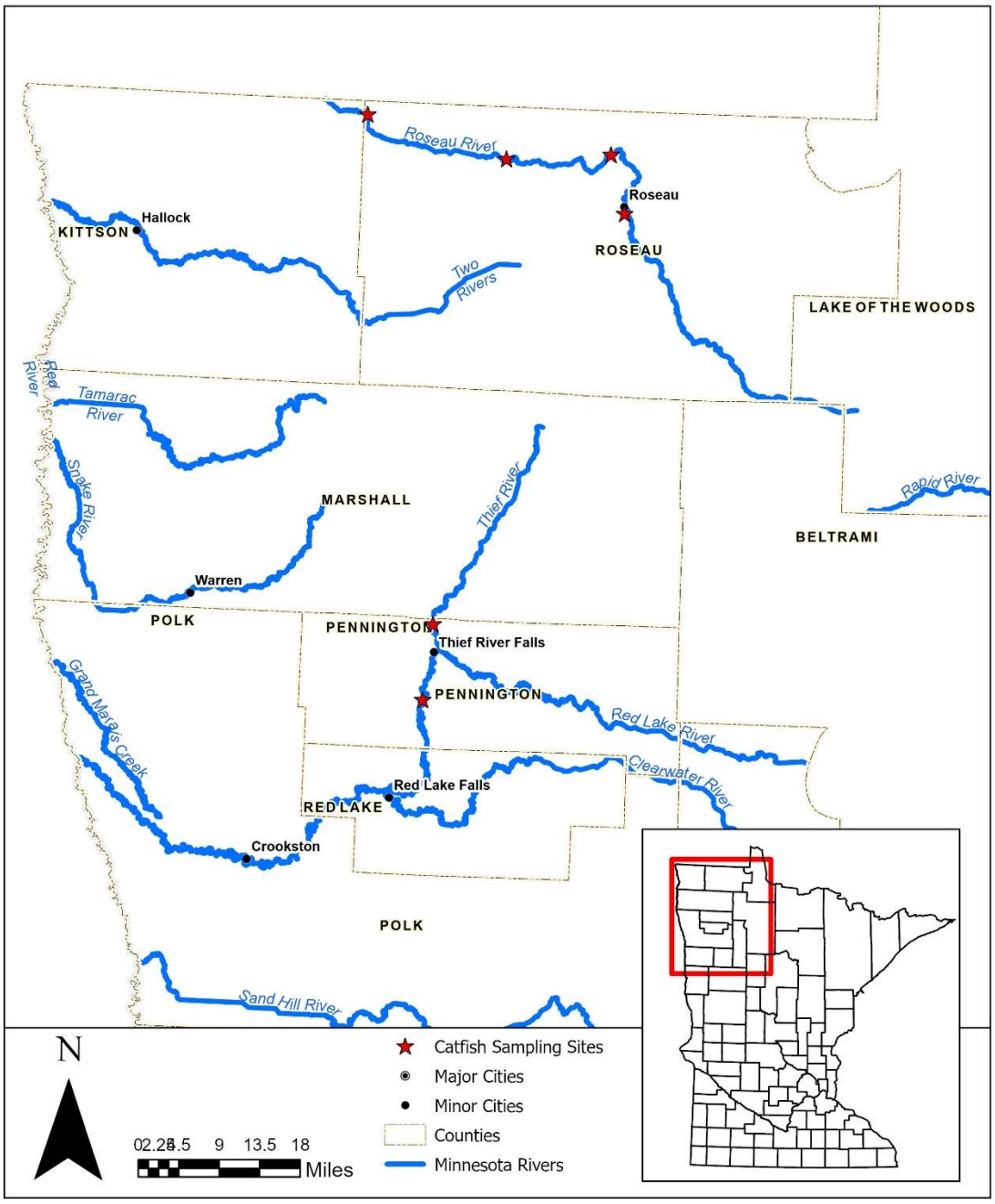


Figure 1. Northwest Minnesota Rivers with Channel Catfish sampling locations used in this study.

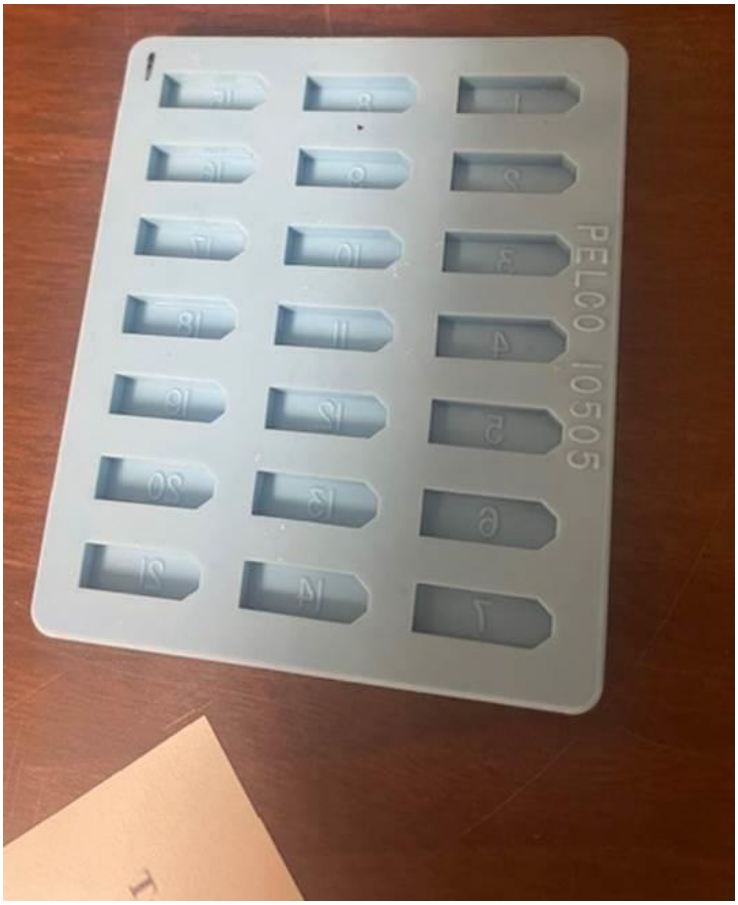


Figure 2. Silicone epoxy tray used to mount Channel Catfish otoliths for processing.

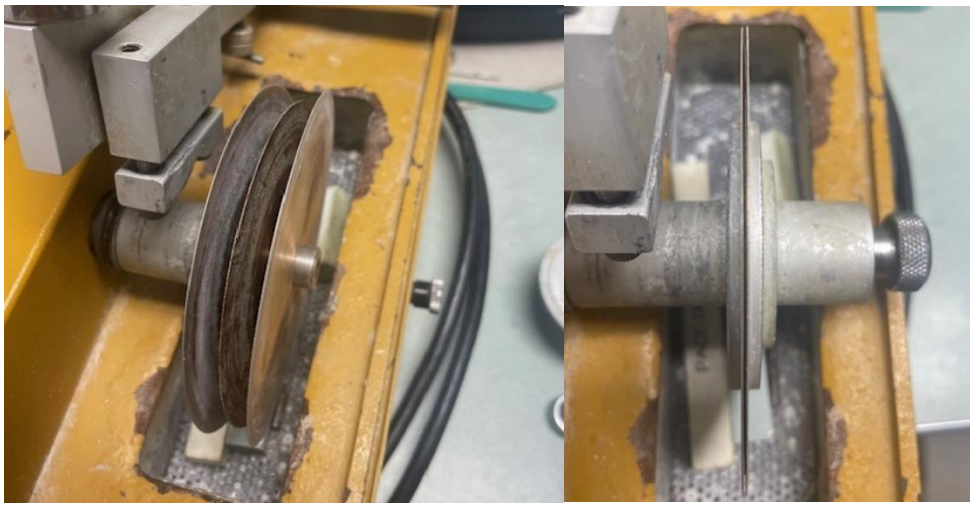


Figure 3. Loose blades on the low speed saw to show blade order (left) and properly tightened blades showing cutting width for otolith cross sections (right).

Figure 4. Top light “top view” (left) and a bottom light “bottom view” (right) of the same otolith cross section under a dissection microscope.

Figure 5. Pectoral spine cut line (blue line) used for obtaining an aging cross section.

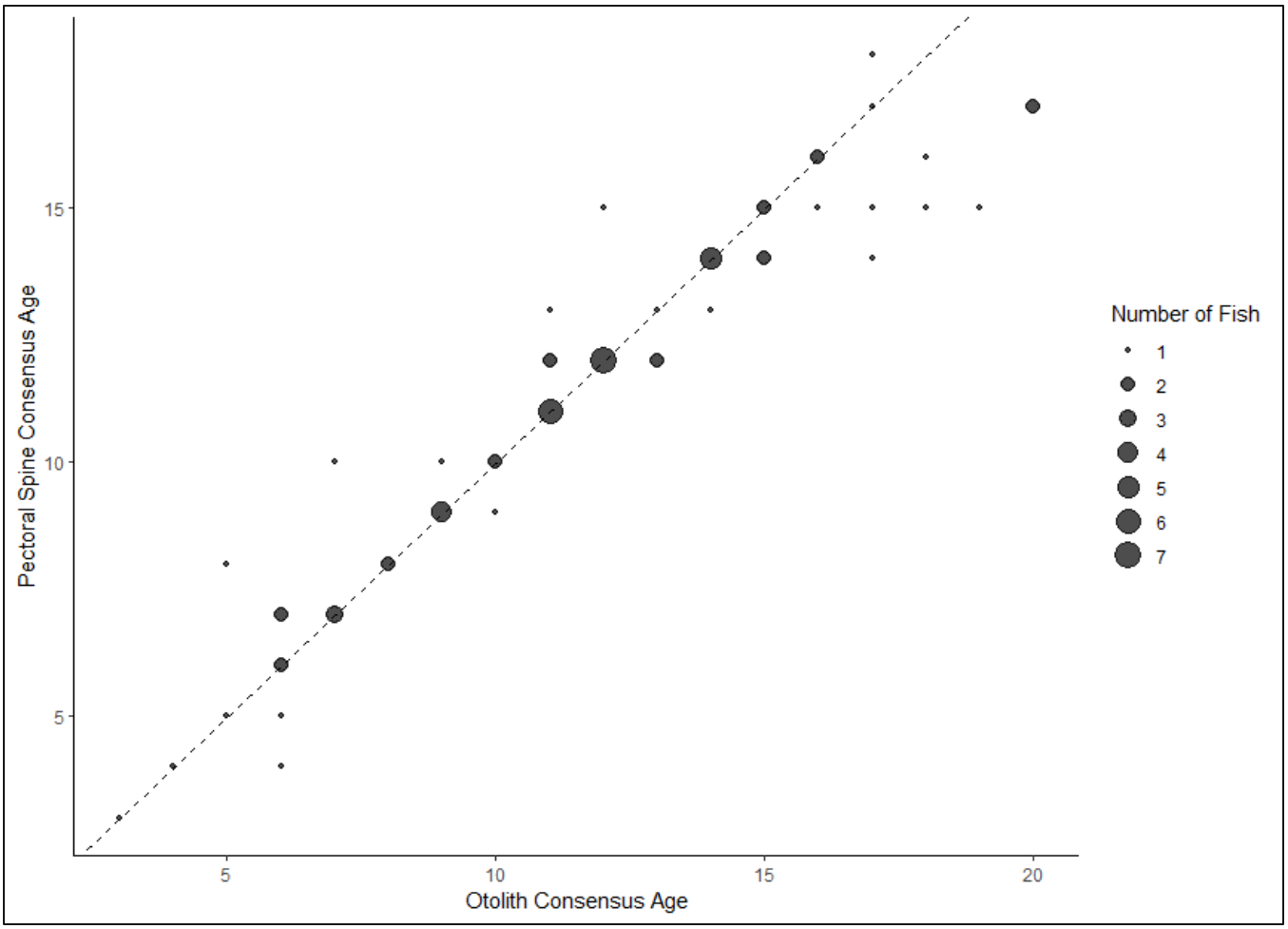


Figure 6. Otolith and pectoral spine consensus aging estimate comparisons (black points) with the ideal 1:1 ratio line (dashed black line) marked. Larger points indicate multiple individual fish in the same location.

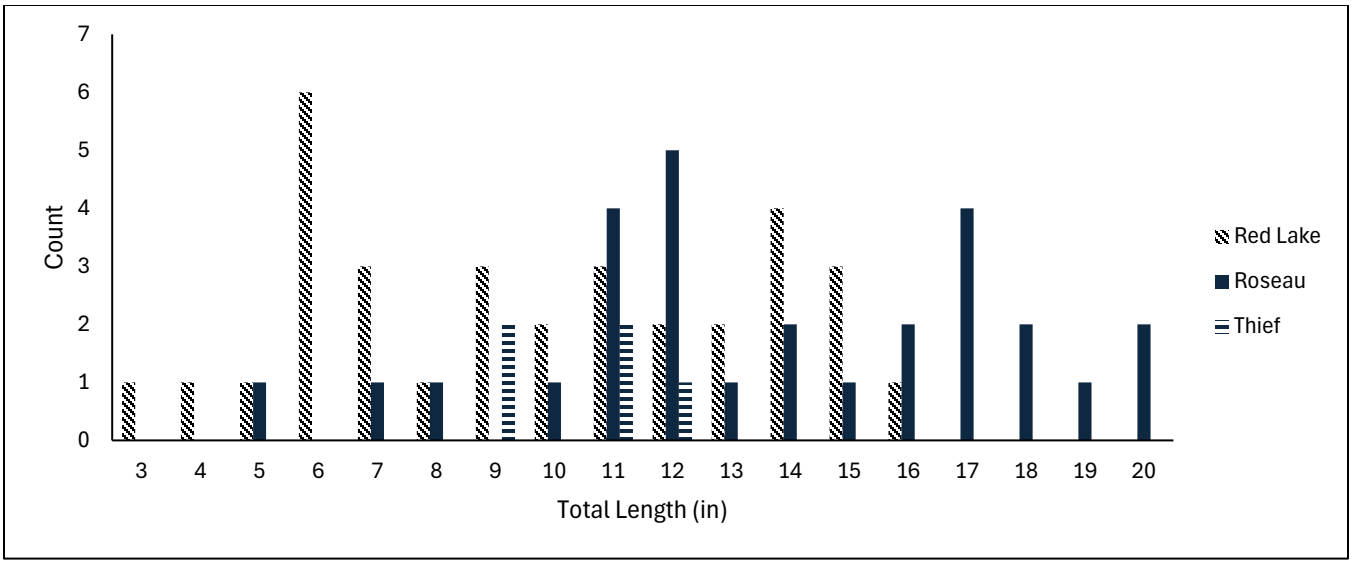


Figure 7. Length distribution of sampled Channel Catfish used in this study, separated by waterbody.

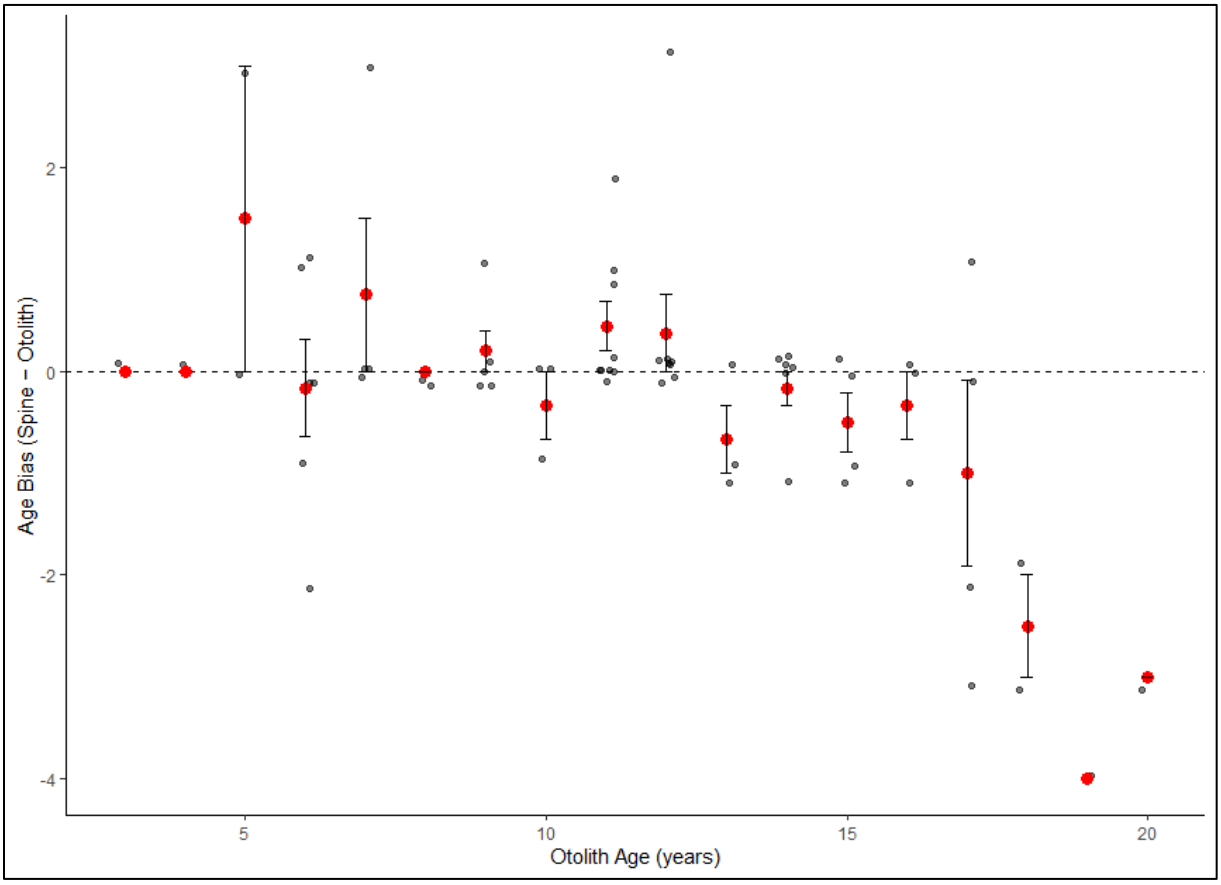


Figure 8. Age bias plot with consensus age estimate differences between pectoral spines and otoliths for individual fish (black dots), mean age bias at each otolith age (red dots) and 95% confidence intervals (black bars) of the mean.

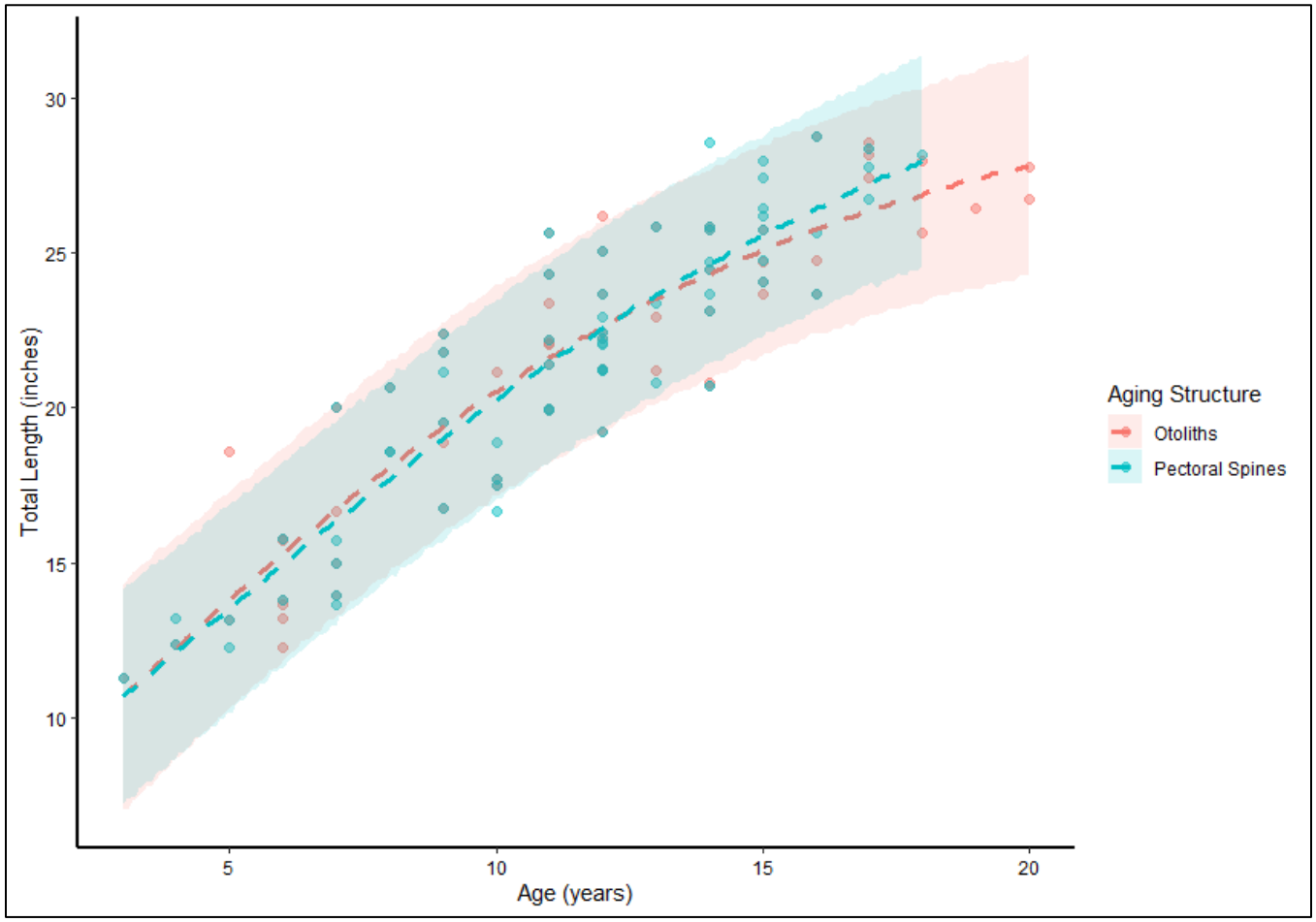


Figure 9. Gompertz growth curves for otolith derived ages (red line; 90% CrI, red shaded area) and pectoral spine derived ages (blue line; 90% CrI, blue shaded area) from fish collected from the Red Lake, Roseau, and Thief Rivers. Individual fish used in the models are marked with points and color coded by aging structure.

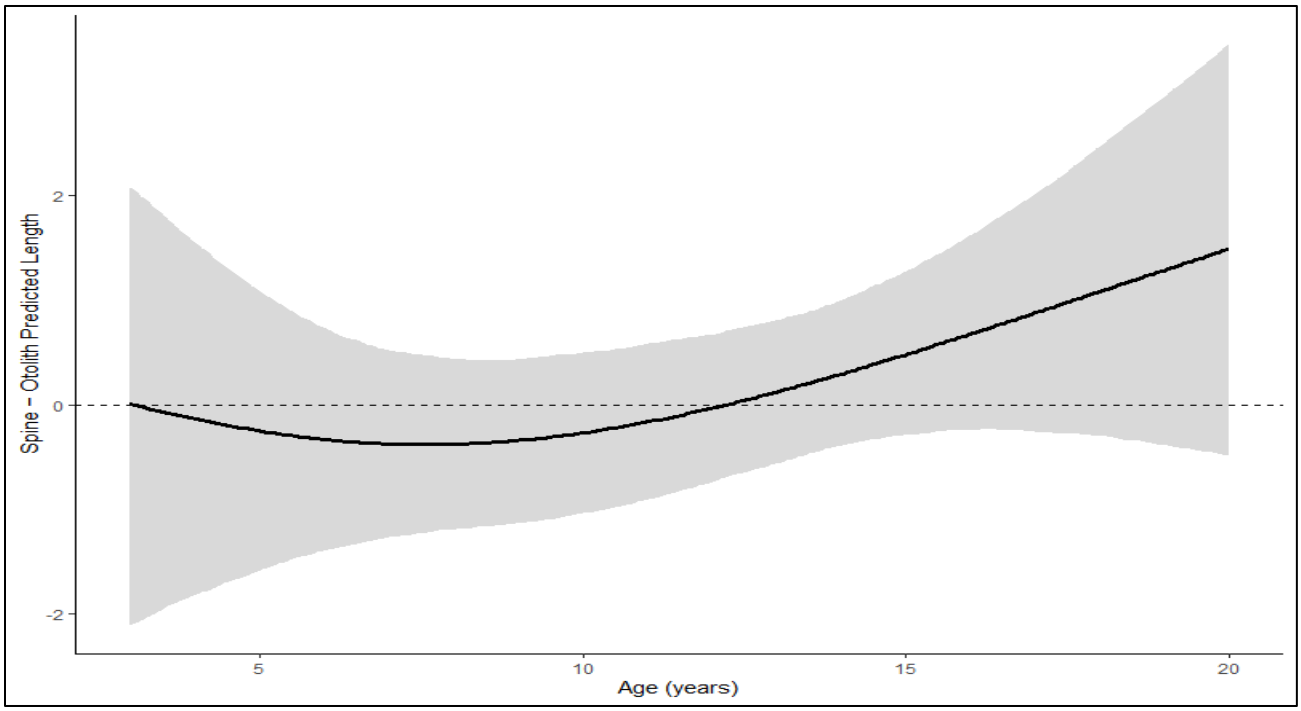


Figure 10. Mean predicted total length difference (pectoral spine – Otolith predicted length) at age (black line) with 90% CrI of the mean estimate (Grey shaded area).

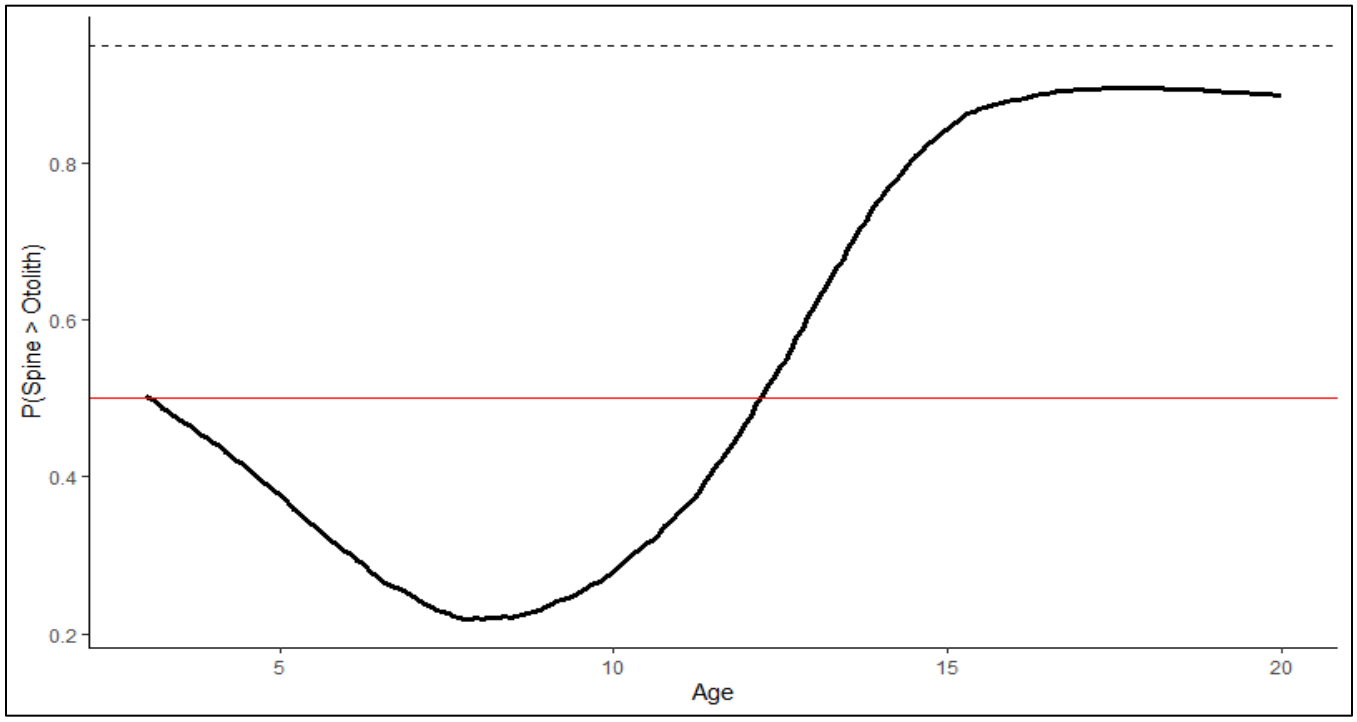


Figure 11. The probability of pectoral spine derived length at age being greater than otolith derived length at age (black line) with P=0.95 threshold for statistical significance labeled (dashed line). The red line represents P=0.5 where otolith and pectoral spine derived ages are predicted to be identical.

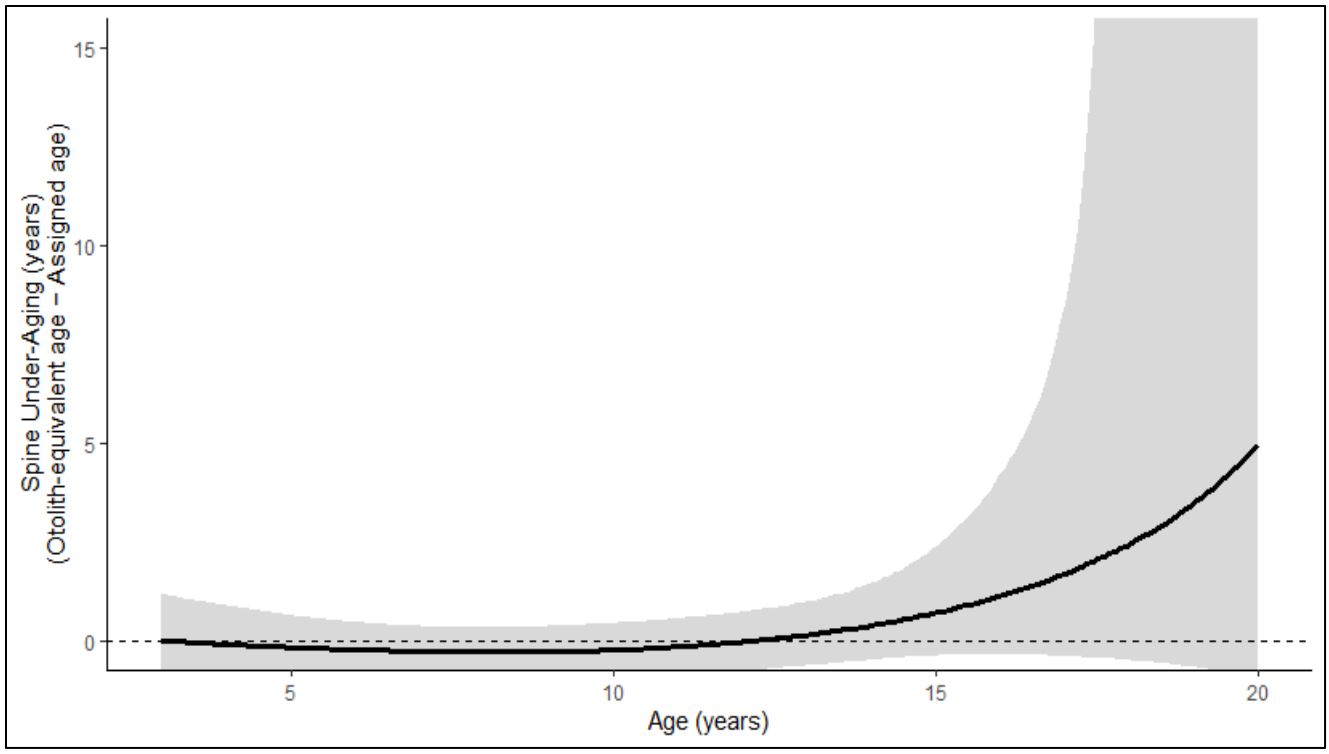


Figure 12. Mean predicted otolith-equivalent pectoral spine age minus pectoral spine assigned age (black line) to estimate under-aging at a given age. 90% CrI (grey shaded area) is labeled.

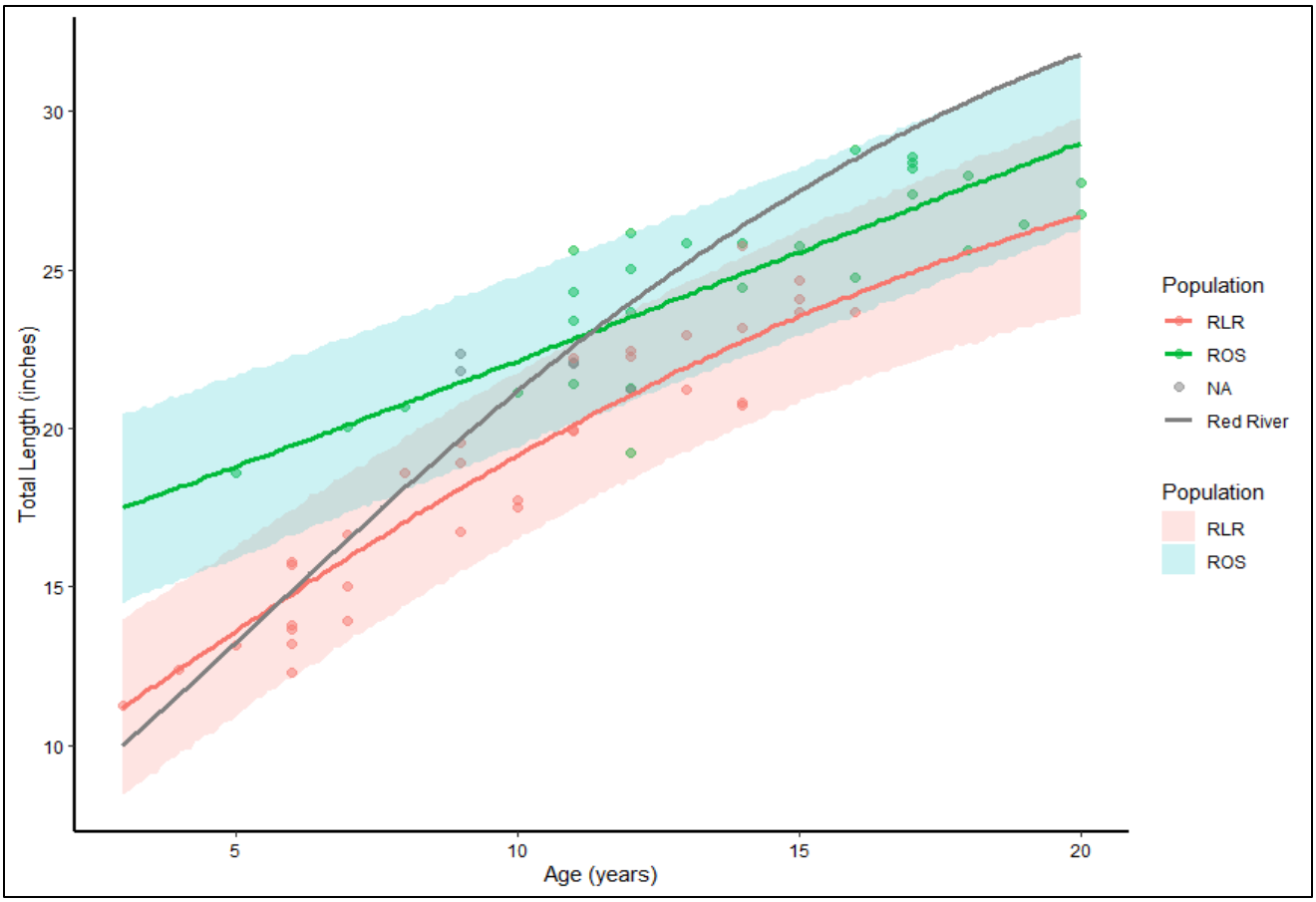
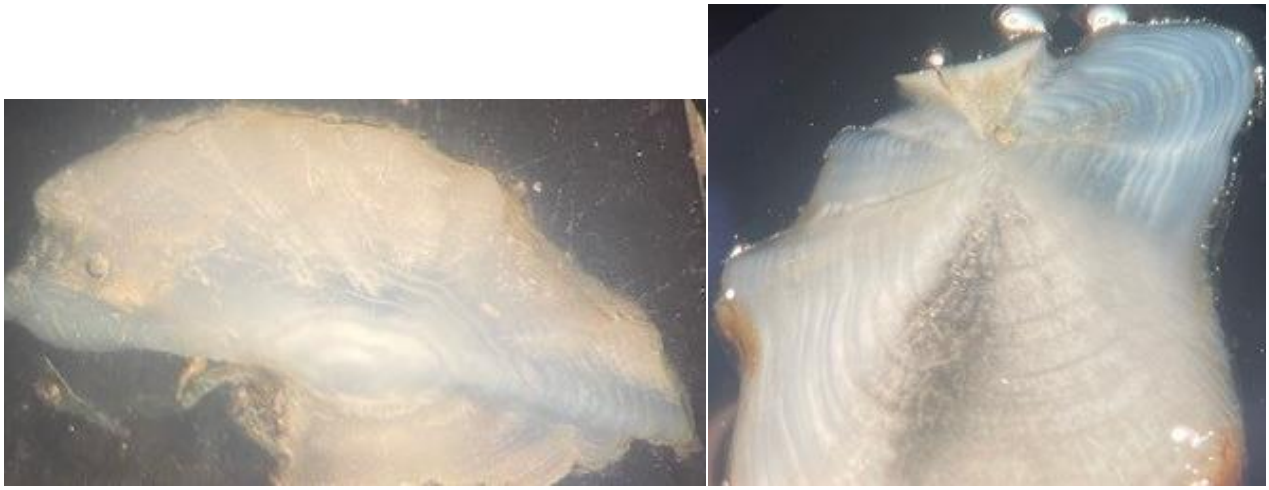


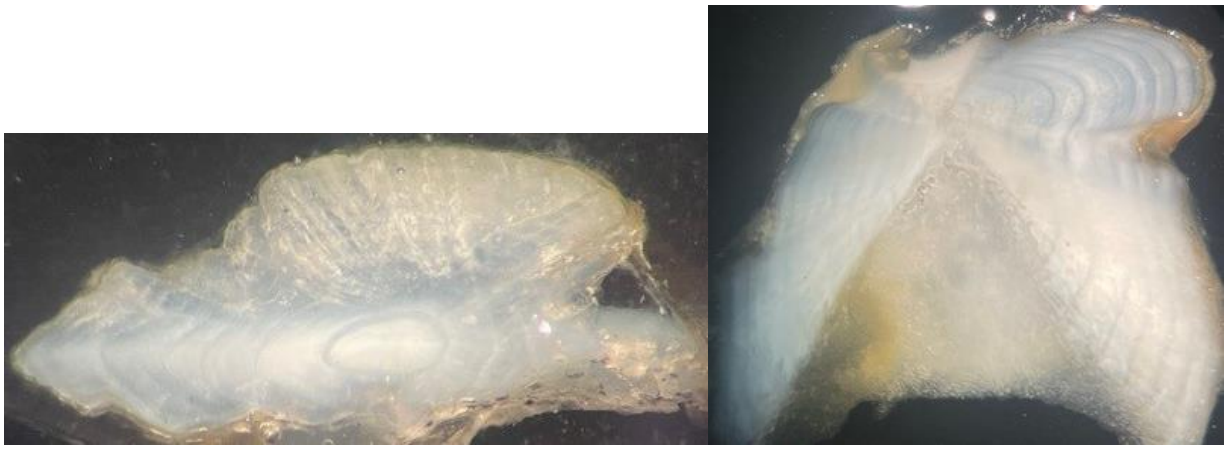
Figure 13. Gompertz length at age curves for the Red River of the North (Grey line; Kludt 2023), Roseau River (Green line; 90%CrI green shaded), and Red Lake River (Red line; 90% CrI red shaded). Individuals used in the growth models are labeled (Roseau, green points; Red Lake River, red points). Grey points (n=5) represent fish sampled in the Thief River that did not have enough sampled individuals to build a growth model.

Appendix

Appendix A. Otolith (left) and pectoral spine (right) cross sections used in aging estimates. Both structures were consensus aged at 15 years.



Appendix B. Otolith (left) and pectoral spine (right) cross sections used in aging estimates. Both structures were consensus aged at 8 years.



Appendix C. Otolith (left) and pectoral spine (right) cross sections used in aging estimates. The otolith cross section was consensus aged at 18 years, and the pectoral spine was consensus aged at 16 years.