A GUIDE TO OTOLITHS OF MINNESOTA FISHES

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Abstract—**Investigations into the diet patterns of piscivores can provide crucial information on predator-prey relationships, population dynamics, and responses to changing ecosystems. However, digestive processes often remove or alter physical characteristics that are traditionally used to identify consumed fish. This problem has been addressed to some degree with advances in molecular technologies, although these methods can be costly and require specific training and equipment to do so. In contrast, bony structures such as otoliths, vertebrae, cleithra, and others frequently have morphologies that are unique among families, genera, and species. Because these structures are resistant to digestion, they can be used to identify prey fishes effectively and efficiently in varying states of digestion, if the investigator has access to reference specimens or photos from identified taxa. Although some reference materials for identifying bony structures are available, many are specific to a small number of species. This is especially true for otoliths, which are often more difficult to differentiate among species. To address this issue, we have compiled a photographic atlas of sagittal and astericus otoliths for fishes of Minnesota that have been identified in previous diet studies and during summer sampling within the state. In addition to photographs, this guide will provide insights on distinct morphological characteristics and key differences among similar species, making this a useful resource for investigations of piscivore diets in Minnesota and the surrounding area.**

I. INTRODUCTION

Fisheries managers often use diet studies from piscivores to quantify prey abundance, feeding interactions, habitat use and niche overlap between species (Chipps et al. 2007, Pierce et al. 1991). Identifying the contents of those diets can be very time consuming especially when fully intact specimens are not found, due to the quick digestion of soft tissue. As a result, hard structures such as otoliths, cleithra, vertebrae, scales, and pharyngeal teeth are often the only items left inside the stomachs. These structures consist of traits that aid in identification of the prey (Garman 1982; Holland-Bartels et al. 1990; Traynor et al. 2010).

Otolith shape and size vary heavily by species depending on body shape, habitat, and spawning practices, allowing for species identification, and making them especially beneficial to diet studies (Youssef. et al 2016). In a study in southern Georgia, otoliths proved helpful in the identification of species in predators' diets (Reid et al. 1996). Otoliths are hard calcium carbonate structures found in bony fishes (class Osteichthyes). These structures aid in the fish's ability to balance and hear. There are three pairs, sagittate (often the largest and main focus of this study), lapilli, and asterisci (certain sets extracted and photographed), that are found suspended inside a fluid filled sac near the inner ear (Secor et al. 1992). Otoliths are most commonly used as an ageing structure for fish as their annuli tend to be more accurate than other structures (e.g., scales or fin rays; Haglund et al. 2017). These accurate age estimates can influence management practices like stocking, size limits and harvest limits (Allen et al. 2010). Another concept otoliths are used for is microchemistry. Otolith microchemistry looks at the chemical composition and mineral accumulation inside the otolith. Often otoliths develop distinct trace elements to allow for analyses. This allows researchers to gauge environmental histories, diet, pollution exposer, movements, and habitat changes (Sturrock et al. 2015).

As the 21st century continues, otoliths are still being used for ageing, past history, movements and identification. Small photo inventories of otoliths exist, like the Lackman Labs online inventory of otoliths from mid-western species (bigmouthbuffalo.org/otolith/), but references for marine species are generally more common (Campana 2004). Recent studies have revealed morphological differences in shape and size of otoliths depending on geographic location of the species, which could provide difficulties for using them worldwide (Capoccioni et al. 2010). The objective of this study is to produce a photographic atlas of otoliths of Minnesota fishes to provide insight to future diet analyses and other research centered around otoliths.

II. METHODS

In this study, fish were collected by the Minnesota Department of Natural Resources (MNDNR), Minnesota Pollution Control Agency (MPCA), and by anglers. Fish were collected across the entire state of

Minnesota, including border waters Lake Superior and the Red River of the North. Fish captured by the MNDNR and MPCA were collected using standard surveying practices. These practices included gill netting, electrofishing (boat, mini-boom, and backpack), seining, and angling. Collected fish that were 300 mm total length (TL) or smaller were placed in voucher containers filled with 10% formalin until voucher containers could be washed with deionized water and then refilled with 70% ethanol. All fish over 300 mm TL were placed in bags and frozen until otoliths could be extracted.

Otolith extraction was the most time consuming and tedious part of this study. Representative fish were selected based on two main criteria: (1) specimens looked to have no abnormalities which could affect growth of hard structures and (2) specimens were older than age-0. Otoliths were extracted using the "through-the-gills" method for fish 100 mm TL or larger and the "between-the-eyes" method for fish smaller than 100 mm TL (Long and Grabowski 2017).

Extracted otoliths were placed into a scintillation vial filled with distilled water to ensure they would not dry out and crack or deteriorate prior to being photographed. Otoliths were photographed using an Olympus EP 50 digital microscope camera paired with an Olympus SZX10 microscope (Olympus Corporation, Tokyo). They were placed on their distal surface with their anterior end facing down, oriented to match their original location in the fish (i.e., the otolith to the left in the photo is the otolith from the left side of the fish; Campana 2004). A scale bar (2 mm long) was included on all photos to show relative size. Photos of otoliths were sorted into families and are placed accordingly in the guide.

III. RESULTS

Otoliths were collected from individuals representing 11 families, 37 genera, and 46 species. Similar to other structures, there were patterns in otolith morphology that were consistent within families and genera. Brief descriptions of the overall morphology for families and genera are listed below. Differences in morphology became more subtle with higher taxonomic resolution, but certain genera and species could still be differentiated. The descriptions and photographs below will provide a resource to identify specimens based on otolith morphology. Figure 1 shows general positioning of otolith inside a fishes head.

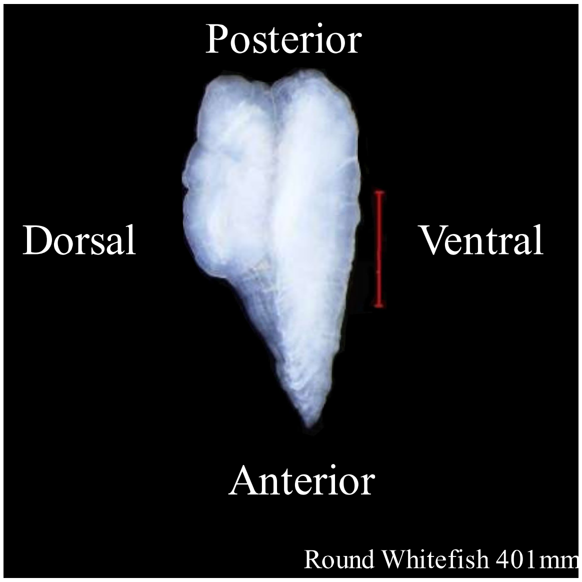

Figure 1. Positioning of otoliths inside the fish.

Amiidae

Otoliths can be characterized with an oval shape, with a wider posterior end and a narrower ventral end. Serrated edges surround the entire circumference of the otolith with deeper serrations on the posrior end. Only the bowfin *Amia ocellicauda* belongs to this family (Figure 2).

Catostomidae

Otoliths can be characterized by a circular to oval shape. Unlike the Amiidae, the circumference is much smoother along the edges of most species in the family, except for the white sucker *Catostomus commersonii,* where light serrations can be found. There are one to three projections extending from the ventral side of the otoliths depending on species (Figures 3-4).

Centrarchidae

Centrarchidae otoliths have two main shapes. Otoliths from *Ambloplites, Lepomis*, and *Pomoxis* generally have a wider oval shape with two lobes on the anterior end of the otoliths. The dorsal half is smoother and contains less severe serrations than the ventral half, and these three genera have relatively large otoliths compared to the size of the fish. *Micropterus* have a thinner, longer oval shape with visually sharper lobes compared to the other three genera. Serrations are found along most of the circumference, but smaller serrations are noted on the posterior end (Figures 5-8).

Cottidae

Cottidae otoliths have very smooth circumference with a unique oval shape. At the posterior end it is wide and there are two small lobes that appear very rounded. As you go farther to the anterior end it narrows down and comes to a rounded point. The two species collected within the Cottidae family are very similar in both shape and size (Figure 9).

Leuciscidae

This family was the largest sampled and recorded in this study. Luesciscidae otoliths are all very similar in shape and size. They appear to have a very round shape and rigid along the entire circumference. Certain genera have larger projections than others and the photos below will be very helpful in identification of species (Figures 10-15).

Esocidae

Of the two species collected from Esocidae both are from the genus *Esox* (Northern Pike *Esox lucius*, Muskellunge, *Esox masquinongy*). These otoliths have a very unique shape, unlike the other families. These otoliths have a wider, almost squared posterior end, narrowing down to a curved anterior end that comes to a point. Although both are very similar in shape and size both have unique attributes to allow for identification (Figures 16-17).

Gadiddae

Gadidae is another family that have otoliths with a unique shape. They are very large for the size of fish and are longer than they are wide. They have a very straight and smooth dorsal side, with a large gradually lobed and rigid ventral side. Both the posterior and anterior ends are rounded with the anterior end slightly sharper (Figure 18).

Hiodontidae

Only one species was collected in the study. The otoliths had a robust build to them with a unique shape. The shape resembles a heart with the dorsal side containing two rounded lobes, with a deep triangular cut in between them. The ventral side came down to a rounded point, with a small secondary lobe on the posterior edge of the otolith (photo from Long et al. 2021 was used for interpretation of otolith).

Ictaluridae

Two genera (*Amerius, Ictaluris*) were gathered from the Ictaluridae family. Both sets of otoliths recovered had a very round shape. *Amerius* otoliths seemed to have more and deeper serrations along circumference, with a small projection at the anterior end. *Ictaluris* had a smoother circumference although small serrations were noted, and the projection at the anterior end was larger and had a deeper ident (Figure 19).

Percidae

Four genera were collected in the family Pericdae, (*Ethostoma, Perca, Percina, Sander*) totaling six species. Overall, all have a relatively similar shape, looking like a compressed oval with a rounded anterior end and a lobe on the ventral side. *Etheostoma* and *Percina* have a smooth circumference, where *Perca* and *Sander* have a serrated circumference. *Percina* has a larger indent on the anterior side before the lobe, where *Etheostoma* is much more gradual and less noticed. Overall size will also help differentiate between genera (photo from Lackmann Otolith Lab used to interpret walleye otolith) (Figures 20-23).

Salmonidae

Three genera were collected in the family Salmonidae (*Coregonus, Onchorhyncus, Salvelinus*), all with a similar general shape. Consisting of a wider posterior end, narrowing down to pointed or rounded anterior end. *Coregonus* otoliths were very large for the size of fish and had a sharper point at the anterior end compared to other genera. *Onchorhyncus* otoliths varied the most in their genus ranging from very small to large and robust. *Salvelinus* otoliths had a much more gradually rounded posterior end than other genera in this family (Figures 24-34).

IV. DISCUSSION

In this study, a photographic inventory was created that documented morphological variations in the otoliths of the several families, genera and species present in Minnesota. Differences between morphology of otoliths are greatest at the family and genus levels, although differences between species are noted but less extreme. Even though differences at species level are not as drastic in certain species, the photographs should prove useful to differentiate between species of similar morphology that may be in question. Although otoliths can often be used for identification to species, their small size hinders their ability to be useful in all instances. In these cases, other structures such as otoliths, clithera, or pharyngeal teeth (Garmin 1982, Traynor et al. 2010) are likely more practical.

In the instance of extra specimens' additional sets of otoliths were pulled to see if there was variation amongst morphology. Although slight differences were noted, overall size was the biggest variation between the sets recovered. During the study, total length of the specimen that otoliths were recovered from was the only statistic recorded. Only measuring the total length of the specimen brought to question if there would be a difference in otolith morphology from male to females in the species. Many fish species are known to have sexual dimorphism. In a study looking at one species, *Oryzias dancena* (Indian Ricefish) it found a significant difference in many characteristics between sexes (Im et al. 2016).

Overall, otoliths are still and will continue to be a reliable asset to diet studies. Having the ability to identify partially digested prey inside stomachs down to families, genera, and species is beneficial to managers and researchers looking at predator-prey relationships and niche overlap. Although, additional studies are needed to see if there are variations in otolith morphology based on sex, geographical isolation and other factors that might influence difference in species.

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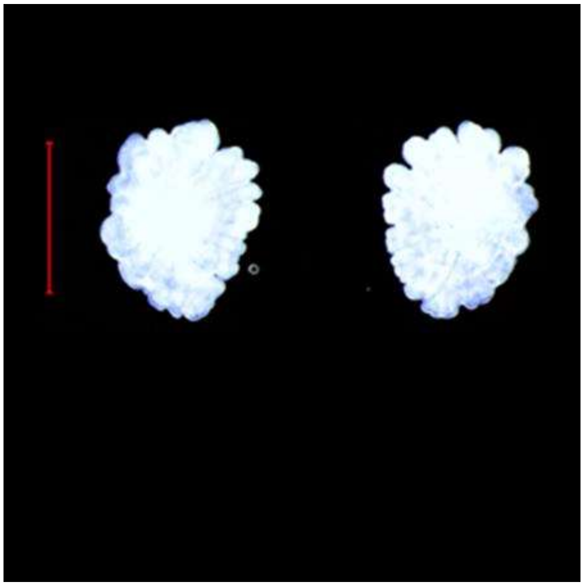

Figure 2: Bowfin (*Amia ocellicauda*) TL 220mm

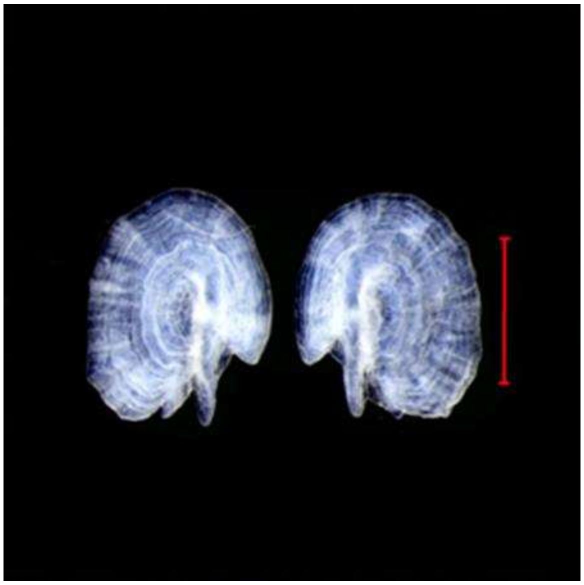

Figure 3: Longnose Sucker (*Catostomus catostomus*) TL 287mm

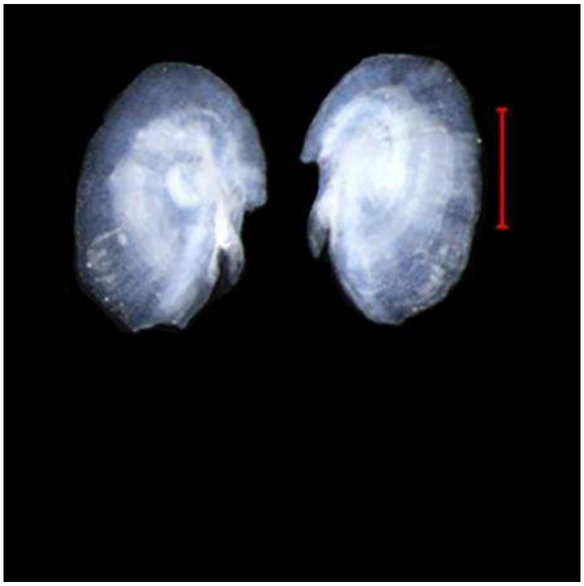

Figure 4: Shorthead Redhorse (*Moxostoma macrolepidotom)* TL 343mm

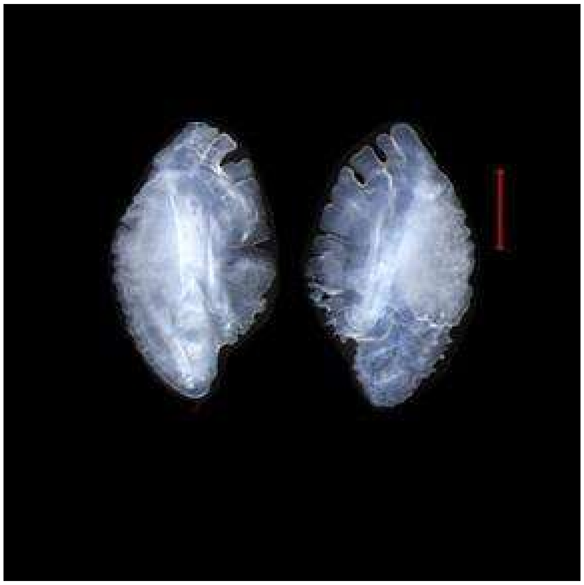

Figure 5: Rock Bass (*Ambloplites rupestris*) TL 197mm

Figure 6: Bluegill (*Lepomis macrochirus*) TL 221mm

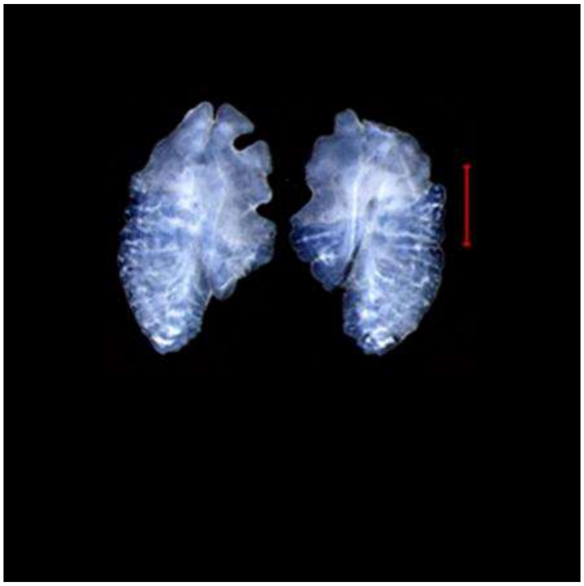

Figure 8: Pumpkinseed (*Lepomis gibbosus*) TL 177mm

Figure 7: Green Sunfish (*Lepomis cyanellus*) TL 87mm

Figure 9: Mottled Sculpin (*Cottus bairdii*) TL 120mm

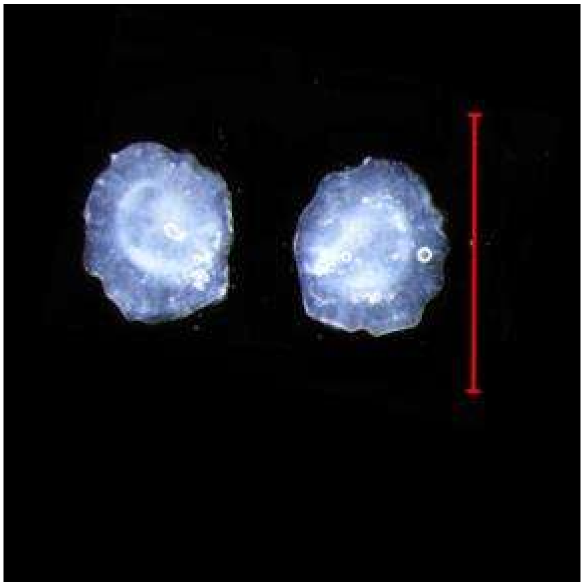

Figure 10: Central Stoneroller (*Campostoma anomalum*) TL 114mm

Figure 12: Common Shiner (*Luxilus cornutus*) TL 157mm

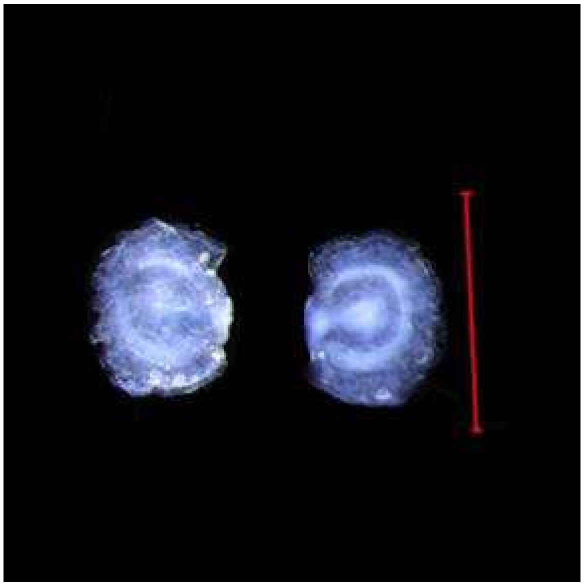

Figure 11: Spottail Shiner (*Notropis hudsonius*) TL 81mm

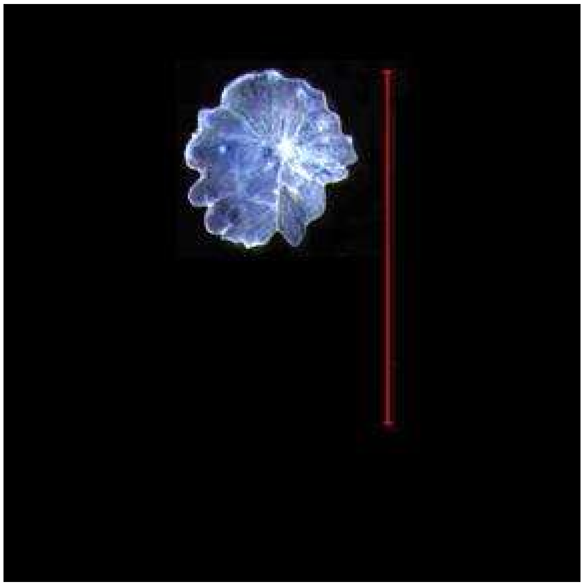

Figure 13: Blackchin Shiner (*Notropis heterodon*) TL 46mm

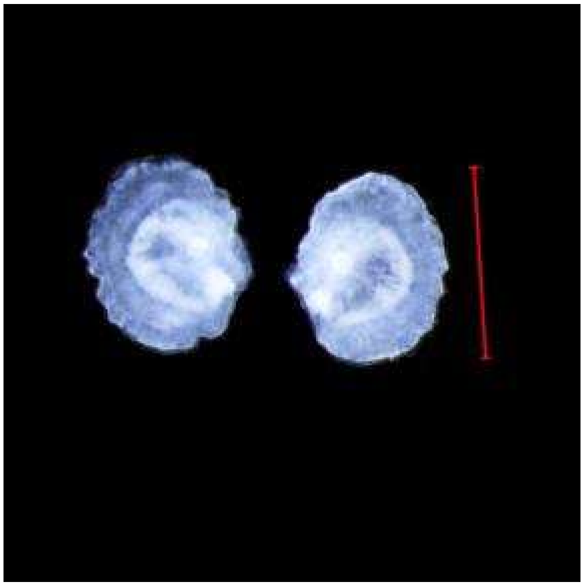

Figure 14: Hornyhead Chub (*Nocomis biguttatus*) TL 141mm

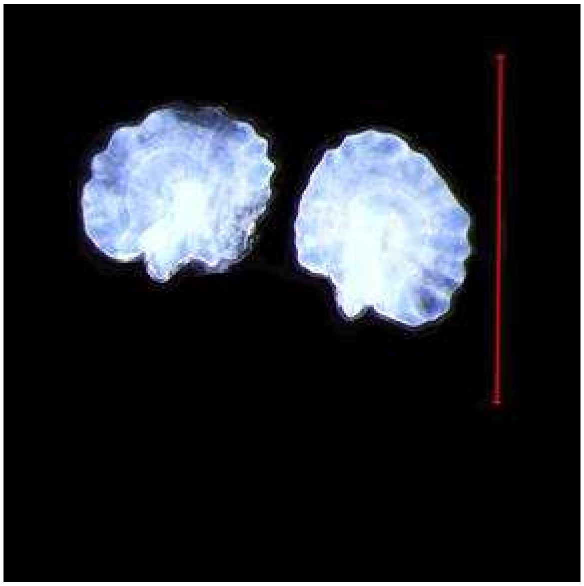

Figure 16: Longnose Dace (*Rhinichthys cataractae*) TL 93mm

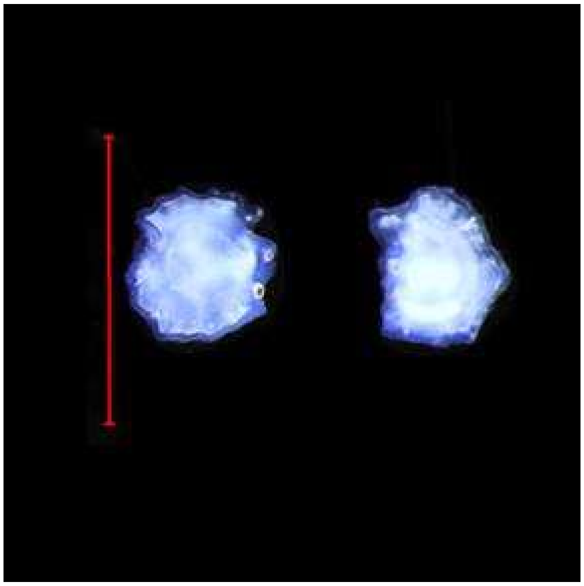

Figure 15: Bluntnose Minnow (*Pimephales notatus*) TL 81mm

Figure 17: Muskellunge (*Esox masquinongy*) TL 701mm

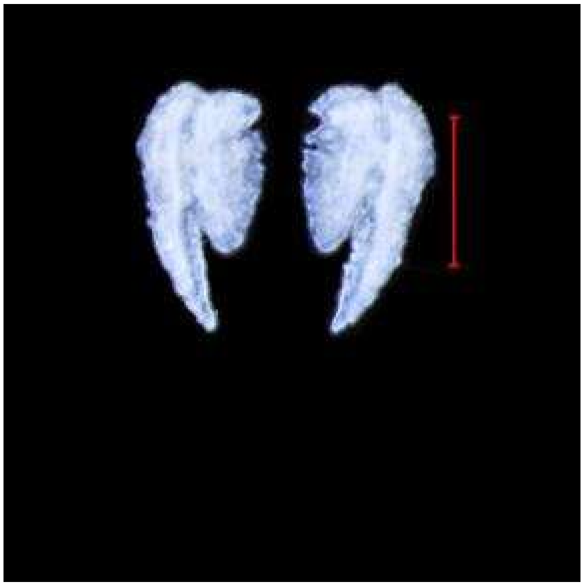

Figure 18: Northern Pike (*Esox lucius*) TL 171mm

Figure 20: Yellow Bullhead (*Ameiurus natalis*) TL 228mm

Figure 19: Burbot (*Lota lota*) TL 488

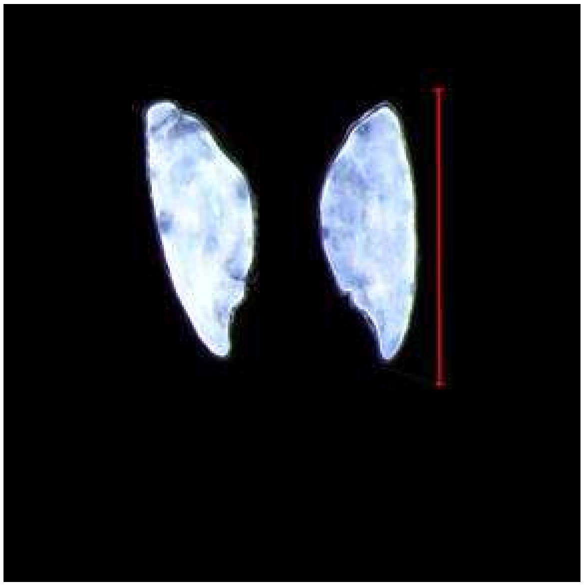

Figure 21: Johnny Darter (*Etheostoma nigrum*) TL 70mm

Figure 22: Rainbow Darter (*Etheostoma caeruleum*) TL 55mm

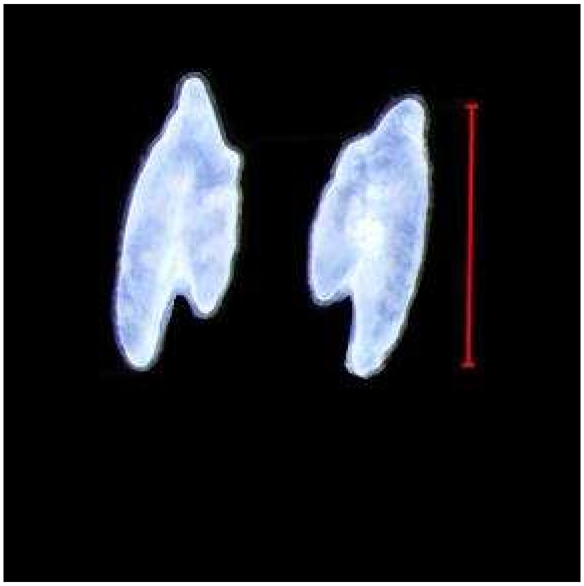

Figure 23: Blackside Darter (*Percina maculata*) TL 87mm

Figure 24: Logperch (*Percina caprodes*) TL 119mm

Figure 25: Bloater (*Coregonus hoyi*) TL 299mm

Figure 26: Kiyi (*Coregonus kiyi*) TL 205mm

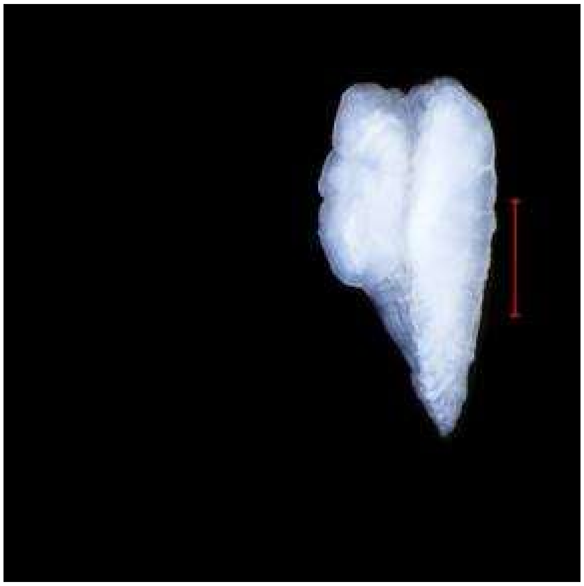

Figure 28: Round Whitefish (*Prosopium cylindraceum*) TL 401mm

Figure 27: Lake Whitefish *(Coregonus clupeaformis*) TL 584mm

Figure 29: Tulibee Cisco (*Coregonus artedi*) TL 391mm

Figure 30: Chinook Salmon (*Oncorhynchus tshawytscha*) TL 698mm

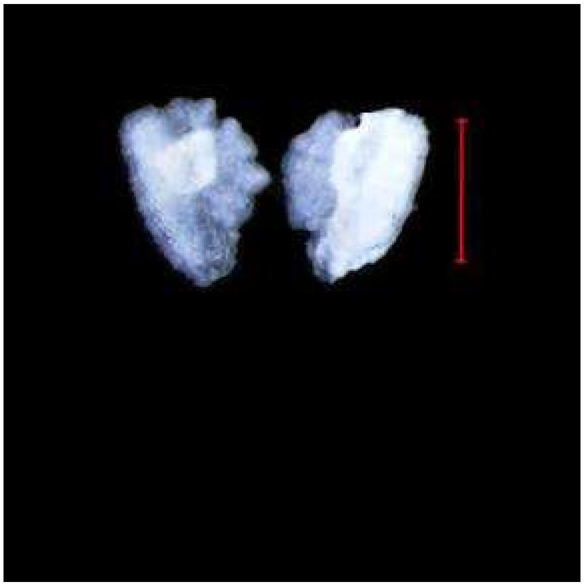

Figure 32: Pink Salmon (*Oncorhynchus gorbuscha)* TL 368mm

Figure 31: Coho Salmon (*Oncorhynchus kisutch*) TL 426mm

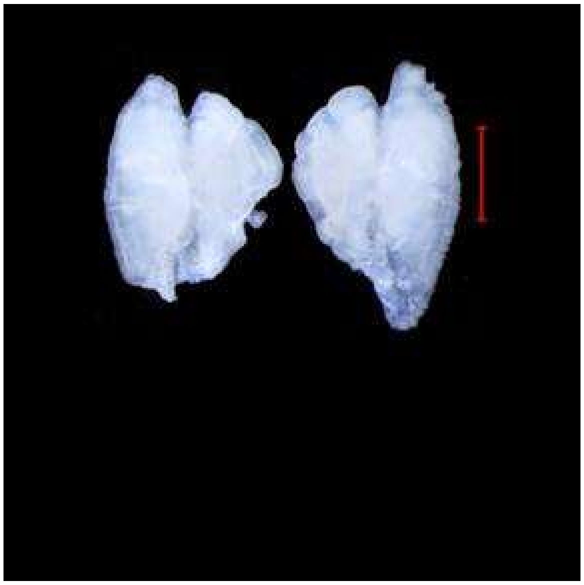

Figure 33: Rainbow Trout (*Oncorhynchus mykiss*) TL 377mm

Figure 34: Lake Trout (*Salvelinus namaycush*) TL 597mm

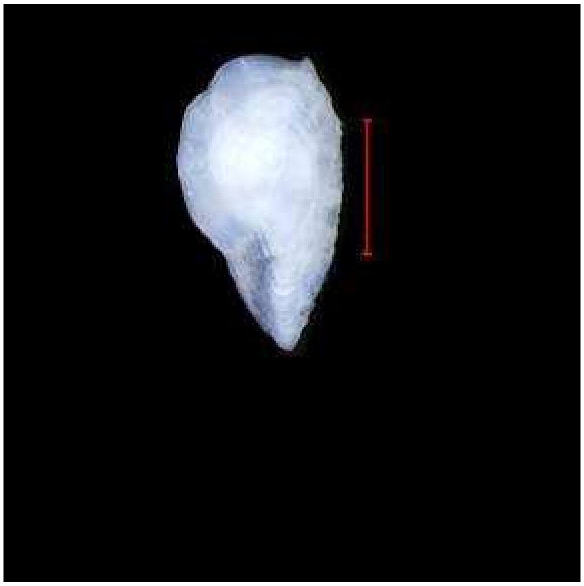

Figure 35: Siscowet Lake Trout TL 467mm