A Population Study of Northern Madtom in the St. Clair—Detroit River System, Michigan

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Abstract

The northern madtom (*Noturus stigmosus*) is a small Ictalurid catfish historically found in isolated populations throughout Western Lake Erie and the Ohio River Basin. Until recently, northern madtom were considered extirpated from most of their historic range in Michigan; however, monitoring of constructed spawning reefs in the St. Clair - Detroit River System revealed northern madtom on and near these new reefs. Northern madtom are vulnerable to extinction due to their rare occurrence and lack of knowledge about their habitat requirements. I investigated selected reefs and rocky substrate sites in the Detroit River and the St. Clair River Delta to determine the presence and abundance of northern madtom. Overall, I collected thirty-seven northern madtoms in 2013 and 2014, and was also able to use data from another twenty-six fish collected in a previous study in 2011. Northern madtom abundance and occurrence was highly correlated (Pearson, r = 0.803) to preferred locations based on a habitat suitability index using bathymetry and surface current velocity. There was no correlation between age of reef and abundance of northern madtom. However, northern madtom were only observed in close proximity to rocky substrate which supports the notion that they prefer rocky substrate and constructed spawning reefs are helping their populations to recover. I also aged otoliths, pectoral spines, and dorsal spines from northern madtom; ages observed ranged from one to five years. A Von Bertalanffy growth curve was fit to the estimated ages and measured total lengths (mm); results were an asymptotic length (L_∞) equal to 142mm and growth rate (K) equal to 0.4025. I collected five northern madtom that were not aged; these were smaller than the estimated at age one total length (67mm), which shows evidence of natural reproduction occurring in these waters.

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Introduction

The northern madtom (*Noturus stigmosus*) is a small Ictalurid catfish found in isolated populations in Western Lake Erie and the Ohio River Basin (Taylor 1969; Scott and Crossman 1985; Bailey et al. 2004). Within Michigan, its historical range included the Huron River, Detroit River, St. Clair River, and Lake St. Clair (Latta 2005; Manny et al. 2014). Today, northern madtom still occur in these locations in Michigan, but populations are estimated to be much less abundant than they were historically (Dextrase et al. 2003; Latta 2005; DFO 2012; Manny et al. 2014). Northern madtom has also disappeared from portions of its native range outside of Michigan. For example, it is well documented that northern madtom have been extirpated from the Syndeham River in Ontario (Dextrase et al. 2003). This species was thought to be extirpated from its historic range within Michigan; however, northern madtom were recently observed in the St. Clair River (French and Jude 2001), Detroit River (Dextrase et al. 2003; Latta 2005; McCulloch and Mandrak 2012; DFO 2012; Manny et al. 2014), and Huron River (unpublished data from University of Michigan ichthyology class Fall 2012). Since northern madtom is a small, cryptic catfish that lacks economic value, there has not been extensive documentation of habitat preferences or population status in U.S. waters.

The northern madtom has different species status designations for within the nations and states of its range. Its global status is Vulnerable. Its federal status in the United States is Vulnerable, and in Canada it is Endangered. Within the United States, it is designated as a Species of Concern, Vulnerable, and Endangered in different states (Table 1). In the province of Ontario, northern madtom research has been proactive in updating its species status which recently downgraded it to Endangered in May 2014 (COSSARO 2014).

Habitat modifications have altered many aquatic environments where northern madtom were historically found in Michigan. Dredging to keep waterways open for freight shipping has occurred since the 1880s in the Great Lakes and connecting waters. The St. Clair River, Lake St. Clair, and Detroit River are major connecting waterways with freight shipping channels. Removal of gravel and boulders during dredging of shipping channels destroyed critical habitat which previously provided spawning grounds and protection for eggs and larval fish (Caswell et al. 2004; Bennion and Manny 2011). Northern madtom have been documented spawning on and near gravel and boulder substrates in fast flowing waters (Taylor 1969; MacInnis 1998; Tzilkowski and Stauffer 2004; Latta 2005; Scheibly et al. 2008; McCulloch and Mandrak 2012; Manny et al. 2014), and their diet includes aquatic macroinvertebrates that prefer rocks and gravel rather than barren, sandy patches (French and Jude 2001; Burkett 2013).

Beginning in 2003, artificial spawning reefs were constructed in the Detroit and St. Clair rivers to provide crucial spawning habitat for fish. Prior to construction, northern madtom were not commonly found in standardized fish samples, but following construction, northern madtom have been routinely observed (Manny et al. 2015). Restoration of these spawning habitats brings up many questions relating to northern madtom habitat preferences and abundances in these waterways.

Northern madtom have recently been captured in trawls (French and Jude 2001), gillnets (Manny et al. 2014), and minnow traps (Manny et al. 2014) in the Detroit and St. Clair rivers. A post-construction monitoring study of an artificial reef (Belle Isle) from 2003 to 2011 targeted benthic fish with baited minnow traps and was found to be effective at capturing northern madtom in depths of 7m with high current velocities (Manny et al. 2014). Gillnets were also used but proved to be lethal for northern madtom while minnow traps were non-lethal if checked frequently. Two other studies targeting round gobies and native benthic fishes captured northern madtom while conducting night trawls in the St. Clair River near Algonac State Park (French and Jude 2001; Burkett 2013). Based on this background information, I used minnow traps as a passive, effective, and non-lethal method to target northern madtom.

Habitat suitability indices (HSI) analyze habitat quality for a particular species' biological requirements and can predict the likelihood of that species being present in a given location. HSIs can be made for species ranges, spawning habitat, migration corridors, and any other habitat characteristics. In an aquatic ecosystem habitat, parameters often include bathymetry, current velocity, vegetation type, substrate composition, water chemistry, and food availability. Maps produced using HSIs indicate locations with strong or weak suitability based on the combination of these factors (Terrell 1984).

Age structure of northern madtom in the Detroit and St. Clair rivers has not been well documented. Manny et al. (2014) looked at population age structure of northern madtom in the Detroit River from data collected on seven individuals. There are three commonly used aging structures (sagittal otoliths, dorsal spines, and pectoral spines) in catfish (Buckmeier et al. 2002). Manny et al. (2014) found pectoral spines had 75% agreement with otolith estimates; dorsal spines had 66% agreement with otolith estimates; and dorsal spines had 60% agreement with pectoral spines. Pectoral spine removals are not lethal for catfish (Colombo et al. 2011; Weber and Brown 2011), so I decided to use spines for aging fish collected in this study.

The purpose of this study was to evaluate northern madtom in the St. Clair- Detroit River System. To understand this objective better, this study aimed to: (1) Create a northern madtom habitat suitability index model and determine whether this model accurately predicted northern madtom presence; (2) Determine the relationship between abundance of northern madtom and age of reefs; (3) Determine the presence and abundance of northern madtom at selected sites in the Detroit and St. Clair rivers; and (4) Create a growth curve from aged northern madtom based on average length associated with each age class. My hypotheses were: (1) The habitat suitability index will accurately predict northern madtom presence and abundance for selected sample sites; (2) Northern madtom abundance will be greater on older reefs than younger reefs; (3) Rocky habitats similar in substrate composition to constructed reefs will have abundances similar to constructed reefs; and (4) Sites farther from rocky substrate will not have detectable numbers of northern madtom.

Study Site

The Detroit River is a 51.5 kilometer international waterway connecting Lake St. Clair to Lake Erie. The Detroit River watershed includes large metropolitan areas and is sometimes referred to as a "sewershed" (US EPA 2014). The St. Clair River is 64.4 km long, connecting Lake Huron to Lake St. Clair. It branches into several channels at its mouth near Lake St. Clair producing a large delta region. Shoreline along the St. Clair River is not as developed as the Detroit River, and much of its watershed is agricultural (US EPA 2014).

The Detroit River is home to two constructed reefs. The Belle Isle Reef located at the juncture of Lake St. Clair and the Detroit River (Figure 1), was constructed in 2004 and is $1100m^2$ in total reef area (Manny et al. 2015). Fighting Island reef, located further downstream in the Detroit River (Figure 1), was constructed in 2008 and is $3300m^2$ (Roseman et al. 2011, Manny et al. 2015). Further yet down the Detroit River and slightly south of the Ambassador Bridge is a site where the Fort Wayne reef was slated for construction in 2014 (Figure 1). This reef would have been approximately one acre in size (~$4000m^2$) but was cancelled due to concerns with freighters coming too close to the reef, potentially filling interstitial spaces with sediments over time (Manny et al. 2015).

The St. Clair River delta has one constructed spawning reef, one historic spawning reef, and at least one rocky shoreline site potentially used by rock spawners. The Middle Channel reef, constructed in 2012, is located just south of where the Middle Channel splits from the North Channel (Figure 2) and is $4005 m^2$ (Manny et al. 2015). The Mazlinkas Reef, located in the North Channel (Figure 2), was created in the late 1800s when coal burning vessels deposited coal cinders (Thomas and Haas 2004). Algonac State Park is located further upstream in the St. Clair River (Figure 2) and has a riverfront beach that is protected by a rocky riprap that extends into the river. This state park was established in 1994; so it is likely that this rocky substrate was built in the intervening years to protect this riverfront beach from erosion. Since this study began, two additional reefs were constructed in the St. Clair River in 2014, and one reef in the Detroit River is projected for construction in 2015.

Three sites in the Detroit River were sampled: the Belle Isle Reef, the proposed Fort Wayne reef site, and a near-shore rocky site in the Detroit River west of Grosse Isle near the Wyandotte Shores Golf Course (Figure 1). All sites were sampled in 2013, and Belle Isle reef was again sampled in 2014. In the St. Clair River, three sites were sampled: the Middle Channel Reef, Mazlinkas Reef, and a rocky shore site near Algonac State Park (Figure 2). All the St. Clair River sites were sampled in 2013 and 2014. At the end of the 2014 sampling season, additional sites were sampled once for two consecutive nights to detect whether northern madtom were found in close proximity to reefs but in areas of different substrate types, depths, or current velocities.

Methods

I created a habitat suitability index (HSI) in ArcGIS 10.2.2 following the 2013 sampling season to identify regions of the Detroit and St. Clair rivers where northern madtom would mostly likely be found. This type of modeling has not been done for northern madtom in U.S. waters previously though it is common for many other threatened species (Rubec et al. 1998). The layers included bathymetry and surface current velocity (Figure 3 and 4). The bathymetry layer was obtained from the NOAA National Geophysical Data Center as created by the NOAA Great Lakes Environmental Research Laboratory (NGDC 1999). The surface current velocity layer was obtained from the Great Lakes Observing System's Huron-Erie Corridor Waterways Forecast System (GLOS 2013).

I estimated habitat preferences for northern madtom through a literature search; and I confirmed these through conversations with St. Clair - Detroit River System fishery biologists. Northern madtom prefer deeper depths with less light penetration and areas of faster current velocities. I developed an HSI model with these parameters. The bathymetry layer came in ASCII format and was converted to raster then resampled using cubic cell shapes (Figure 3A). Depths were binned based on suitability with depths between 0 and 3m ranked as "fair" (0.5/1), 3 and 7m as "optimum" (1/1), and greater than 7m as "good" (0.8/1) (Figure 3B). One study in the St. Clair River suggested that northern madtom had high abundances in water depths around 3m (French and Jude 2001), and another suggested that adult northern madtom were frequently observed at 7m (Holm and Mandrak 1998). Depths greater than 7m were given a "good" ranking (0.8/1) because northern madtom could occur at these depths, although literature suggests they prefer depths between 3 and 7m. Conversations with St. Clair- Detroit River System fishery biologists confirmed that northern madtom adults prefer moderate water depths where there is relatively low light penetration during the day.

The surface current velocity source layer was a shapefile which was converted to a raster for resampling using the same cubic cell transformation as the bathymetry layer (Figure 4A). Northern madtom are frequently found in areas of swift current velocities (MacInnis 1998, Holm and Mandrak 2001, Manny et al. 2014). Surface current velocity values varied from 0 to 1.8 m/s.; they were scaled into quartiles between 0 and 1. This resulted in the highest surface flow velocity rank to be 1 and the lowest surface flow velocity rank to be 0 (Figure 4B). The HSI was created using a Raster Calculator with equal weighing for bathymetry and current velocity (Figure 5). Presence and absence of northern madtom from sampling sites can be compared to this predictive HSI model to test the model's validity.

Monthly assessments were conducted using standardized minnow traps at each sampling site. Three gangs of five minnow traps were considered to be a standard assessment. Minnow traps had two openings, one on each end, either 3mm or 6mm metal mesh, and were baited with cheese cubes and dog food. Each minnow trap gang consisted of five minnow traps with ten feet between each attachment point on a fifty foot setline. There were anchors attached to the two setline ends, and the downstream anchor had a fifty foot buoy line attached to a large surface buoy for retrieval.

Assessments were conducted for two consecutive nights each month, and traps were checked at least once every 24 hours. During the 2013 sampling season, assessments were conducted once a month at each site. During the 2014 sampling season, they were conducted twice a month at each site. All northern madtom were identified, counted, and total length measured to the nearest millimeter. For statistical analysis, catch per unit effort (CPUE) was calculated for all sites. Effort was defined as the number of days fished multiplied by the number of minnow traps per location per day. The number of madtom caught at each site was divided by this effort, resulting in a CPUE that is equivalent to madtom per minnow trap per day (Table 3). Individuals from all species were released alive and unharmed with the exception of round gobies (*Neogobius melanostomus*), an invasive species; these were destroyed.

Pearson's correlation was estimated between CPUE and HSI score for northern madtom presence at all sampling sites, including those with no northern madtom catches, to determine whether the model was a good fit. If there was a significant correlation ($\alpha < 0.05$) between observed CPUE and the HSI output, this means the HSI model was a good predictor of northern madtom abundance. Either a low or non-statistically significant correlation between observed CPUE and the HSI output would mean the HSI model was a poor predictor of northern madtom abundance and further data layers may be needed for this model in the future. A Pearson's correlation was used to determine the relationship between the abundance of northern madtom and the age of reefs on which they were caught. The ages of the reefs are as follows: Mazlinkas reef was estimated to be 125 years old, Algonac State Park riprap was estimated to be 25 years old, Belle Isle reef is 12 years old, and Middle Channel reef is 3 years old. The Fort Wayne proposed reef site consists of scattered rocky substrate and was not considered a reef due to its patchy nature and was given an age estimation of 0. The age of the Detroit near-shore rocky site could not be estimated and it was left out of the Pearson's correlation which estimated the relationship between reef age and northern madtom abundance. One-way ANOVAs for mean CPUE across sites, mean CPUE across months, and mean water temperature across months were performed to look for significant geographical (between sites) or temporal (across time) differences. All statistical analyses were performed in IBM SPSS Statistics, with α set at 0.05.

Pectoral spine samples for aging were removed from twenty-one northern madtom caught during the 2013 sampling season. These spines were collected by separating the pectoral fin from the pectoral spine, then cutting close to the base of the spine. Thirty northern madtom collected from the St. Clair River in 2011 were donated from another study at the University of Michigan (Burkett 2013). For these thirty individuals, I removed the dorsal spine, sagittal otoliths, and one pectoral spine. Spines were cleaned and embedded in Spurr Low Viscosity Embedding Media. Using a low speed Isomet saw, spines were cut into approximately 0.3mm slices. These segments were attached to microscope slides and sanded down for optimal viewing of annuli rings (Buckmeier et al. 2002). Spines were aged independently three times or until a consensus was reached.

Otoliths were prepared using a similar technique in which they were attached to microscope slides with epoxy to be sanded. Following sanding, light burning of the otolith surface and side lighting were essential to visualizing otolith annuli (Buckmeier et al. 2002). Otoliths are generally considered to be the most accurate structure when age is unknown (Buckmeier et al. 2002), but it would be helpful to know whether the pectoral spine or dorsal spine is also accurate in estimating ages in northern madtom because it is non-lethal to remove one of these structures.

Aging accuracy across sagittal otoliths, pectoral spines, and dorsal spines was compared for these donated specimen using methods similar to Manny et al. (2014). Percent agreement was calculated to compare the accuracy between otolith and pectoral spine, otolith and dorsal spine, and pectoral spine and dorsal spine age estimates. The percent agreement equation (Equation 1) was:

$$= \frac{|Structure\ 1\ Age\ Estimate - Structure\ 2\ Age\ Estimate|}{True\ Age} \times 100\%$$

True age was the otolith age estimation when comparing otolith to pectoral spine and dorsal spine; however, the true age was the pectoral spine estimate when comparing pectoral spines to dorsal spines since pectoral spines were believed to be more accurate than dorsal spines (Manny et al. 2014).

Mean length at each age was calculated using estimated ages from otolith, when available, and pectoral spines, when otolith readings were not available. Mean age plotted against mean total length at each age was used to estimate an annual growth curve for northern madtom. The general Von Bertalanffy growth equation is: $L_t = L_\infty\left(1 - e^{(-K\times(t+t_0))}\right)$. This equation for northern madtom was calculated in two stages. The first stage was finding an estimation of the equation variables and the second stage was using these estimated starting points for the variables to run in R to find more accurate variable values. The first stage utilizes the Ford-Walford calculation method (Quinn and Deriso 1999). The second stage used the package 'fishmethods' in R, took the estimated values of L_∞, K, and t_0 from stage one as starting parameters, and calculated more accurate values for these variables (Nelson 2014).

Results

The Habitat Suitability Index (HSI) created shows regions of high (red), medium (yellow), and low (green) probabilities for northern madtom to occur throughout the St. Clair-Detroit River System (Figure 5). The highest HSI score was 0.841 and the lowest HSI score was 0.250 throughout the entire St. Clair - Detroit River System. The CPUE and HSI score were significantly correlated (Pearson r=0.803; p=0.005). This shows a very strong, positive correlation between CPUE and HSI prediction.

Northern madtom, found in low abundance at the study sites, were the fourth most abundant species, comprising 2.30% of total catch. Species more abundant than northern madtom included round goby (67.72%), spottail shiner (*Notropis hudsonius*) (19.68%), and rock bass (*Ambloplites rupestris*) (2.79%) (Table 2). Thirty-seven northern madtom were caught in the Detroit and St. Clair Rivers during this study. They were collected at half of the sampling sites; total catch varied from 0 to 14 at a site (Table 3). CPUE varied from 0 to 0.062 per minnow trap per day (Table 3). The lowest CPUEs were at sites located at least 100m away from known spawning reefs or rocky habitats. The highest CPUE (0.062 per minnow trap per day) was at the constructed reef near Belle Isle in the Detroit River. Belle Isle had the highest CPUE of the five targeted reef sites sampled (0.062 northern madtom per minnow trap night) and the Middle Channel Reef had the lowest (0.009 northern madtom per minnow trap night) (Figure 6). The CPUE at Belle Isle was significantly higher than the CPUE at the Middle Channel (ANOVA, $p=0.019$). Comparisons of mean CPUE at other reefs were not significant. There were no significant differences for mean CPUE across depths, mean CPUE across months (Figure 7), or mean temperatures across months (Figure 8) (ANOVA, $\alpha > 0.05$). Results showed no significant correlation between CPUE and age of reef (Pearson $r= -0.394$, $p=0.511$).

Of the thirty-seven northern madtom caught during this study, twenty-one had a pectoral spine removed and aged. Thirty northern madtom caught in the St. Clair River in a prior study had been preserved in ethanol. Of these, twenty-six had one pectoral spine, one dorsal spine, and one sagittal otolith removed and aged. Percent agreement was highest between the pectoral spine and otolith (85%) which was followed by the dorsal spine and otolith (81%) with pectoral spine and dorsal spine having the lowest correlation (71%). Total length for collected northern madtom observed ranged between 32 and 140mm (Figure 9), and age ranged between one and five years (Figure 10). Growth in length appeared to slow after three years of age, and length had a significant linear relationship with age ($r= 0.729$, $p=0.000$).The Von Bertalanffy growth curve

(Equation 2) included the asymptotic total length for northern madtom to be 142mm and growth rate variable (K) to be 0.4025. This growth curve along with average total length for each age class is shown in Figure 11. Based on this growth curve, any northern madtom less than 67mm in total length can be estimated to be less than a year old. I did collect five individual northern madtom less than 67mm in total length (Figure 10), suggesting that there is reproduction occurring in the St. Clair – Detroit River System. Young fish, less than one year of age, often do not travel far, so it can be assumed that these observed fish are less than one year in age and were spawned in the St. Clair- Detroit River System.

Discussion

I expected the Habitat Suitability Index (HSI), including bathymetry and surface current velocity, would accurately predict northern madtom presence throughout the St. Clair – Detroit River System. Indeed, it did; HSI output scores had a high correlation with observed CPUE of northern madtom at selected sites. This study is the first to create an HSI model for northern madtom in U.S. waters. Northern madtom prefer fast flowing waters (Holm and Mandrak 2001; Dextrase et al. 2003; DFO 2012; McCulloch and Mandrak 2012; COSSARO 2014; Manny et al. 2014;), depths between 3 and 7m (Holm and Mandrak 1998; French and Jude 2001; Holm and Mandrak 2001), and rocky substrate (MacInnis 1998; Tzilkowski and Stauffer 2004; Scheibly 2008; Manny et al. 2014). Unfortunately, substrate data for the entire St. Clair- Detroit River System were not available at the time of this study. To increase the accuracy of this HSI model, a substrate data layer should be added. Proximity to rocky substrate should help predict northern madtom locations better since they utilize rocky substrate for spawning (MacInnis 1998; Tzilkowski and Stauffer 2004; Schiebly 2008;) and feeding on aquatic macroinvertebrates (Holm and Mandrak 1998; French and Jude 2001; Holm and Mandrak 2001; Tzilkowski and Stauffer

2004; Burkett 2013). I was unable to sample throughout all parts of the St. Clair and Detroit Rivers, and additional sampling at more sites for longer periods of time would further test accuracy of this HSI model and where northern madtom are located throughout the entire St. Clair - Detroit River System.

On reefs and rocky sites, I hypothesized that northern madtom abundances would be greater on older reefs than younger ones. If this were true, I would have seen the highest CPUE rates at the Mazlinkas Reef, followed by Algonac State Park, Belle Isle Reef, Middle Channel Reef, and the Fort Wayne site. This expected trend did not exist, as there was no significant correlation between observed CPUE and age of reefs. The oldest constructed reef, Belle Isle Reef, had the highest CPUE most likely due to its location at the junction of the Detroit River and Lake St. Clair. In a similar study, Manny et al. (2014) looked at northern madtom distribution throughout the Detroit River from 2003 to 2011, and it was found that northern madtom were most abundant at the mouth of the Detroit River near Lake St. Clair. This geographical location is a hot spot for northern madtom and it is not well understood why. My results support the findings of Manny et al. (2014) that northern madtom are most highly concentrated around Belle Isle. The reappearance of northern madtom occurred at the same time as the construction of these spawning reefs, specifically Belle Isle. While it is likely that reefs have benefited northern madtom, reefs may not be the sole reason for their population numbers to be increasing.

Rocky habitats had similar abundances to constructed reefs, supporting my third hypothesis. Of the six main sites sampled, three were reefs sites (Belle Isle, Mazlinkas, and Middle Channel) and three were rocky sites (Algonac State Park, Fort Wayne, and Detroit Near-Shore). CPUE across these sites varied; Belle Isle Reef had the highest followed by Fort Wayne, Algonac State Park, Mazlinkas Reef, Middle Channel Reef, and Detroit Near-Shore (Figure 6). There were no significant differences found in CPUE between reef and rocky sites. Therefore, rocky habitat sites appear to have similar abundances to constructed reef sites. However, there are limitations to how far the conclusions in this study reach. More details on the existence of rocky substrate, as well as more extensive sampling of the St. Clair- Detroit River System is needed to fully conclude northern madtom are found throughout the system on any rocky substrate, not just reefs. It would also be important to know the size of rocky locations to better define use of this habitat by northern madtom.

I found that northern madtom were not collected at sites away from selected reef and rocky substrate sites, which is consistent with my fourth hypothesis. To further test this, I sampled at sites approximately 100m away (Mazlinkas and Middle Channel reefs) to see if I would collect northern madtom and none were collected. To date, no studies have found northern madtom in locations with absolutely no rocky substrate nearby. This suggests that northern madtom do have a habitat preference for rocky substrate. However, more extensive sampling is needed to confirm northern madtom do not occur at sites without rocky substrate as this study focused most of its efforts on sampling at rocky substrate sites. Within the St. Clair- Detroit River system, sampling needs to be conducted further upstream in the St. Clair River, in tributaries directly connecting to the Detroit and St. Clair rivers, in nearby wetlands, and in Lake St. Clair to determine the total extent of northern madtom presence throughout these rivers and confirm what types of substrates and habitats northern madtom utilize.

This study supports the findings of Manny et al. (2014) that pectoral spines are more accurate than dorsal spines for aging northern madtom. Percent agreement for estimated ages in both pectoral and dorsal spines compared to estimated ages from otoliths was high. As expected, there was a high correlation between total length and estimated age. The slow growth observed after year three matches literature suggesting northern madtom sexually mature between years three and four (Tzilkowski and Stauffer 2004). The Von Bertalanffy growth equation calculated in this study is the first attempt to do so for northern madtom. This growth curve can be used in future studies to estimate age from total length and avoid the unnecessary sacrifice of an already rare fish. Previous studies suggest northern madtom live to age three (Holm and Mandrak 2001) but I aged nine fish over three and some fish up to five years old, as did Manny et al. (2014).

There were a few limitations in this study. The size of minnow traps were a potential source of biased sampling as larger northern madtom were less likely to be able to escape compared to smaller northern madtom. A normal recruitment curve would have younger fish being most abundant with fewer fish at each subsequent age due to mortality. Figure 10 shows a bell shaped curve for the age distribution observed for northern madtom. This means younger fish were not as likely to be caught in the minnow traps since three year-olds observed were much more abundant than one or two year-olds. I was unable to sample within shipping channels due to strict rules not allowing buoys within these channels, so it is possible that northern madtom are in the shipping channels at deeper depths than I was able to sample. Northern madtom were believed to be reduced to very low abundance in the 1970s and 1980s (Holm and Mandrak 1998, Latta 2005, Manny et al. 2014) but it is unclear if this was actual or a result of data gaps due to lack of sampling in the appropriate locations during these years. Since there is no way to go back and determine the status of northern madtom back then, this is a potentially biased assumption. However, it is important to note that absolutely no documented records of northern madtom occurred during this time frame. Power plants along the Detroit River typically report a variety of fish they accidentally kill through their water intake systems and no northern madtom were reported during this time (Bruce Manny, USGS, 2015).

Overall, I can conclude that (1) The habitat suitability index created did accurately predict northern madtom presence; (2) Northern madtom abundance was not correlated with age of reefs; (3) Rocky habitats did have abundances similar to constructed reefs; and (4) Sites farther from rocky substrate did not have detectable levels of northern madtom.

The northern madtom is a species of concern throughout the different countries, states, and provinces of its range. They are rare throughout their limited range, and their largest documented population to date is in the St. Clair - Detroit River System. In general, we lack knowledge concerning its habitat requirements in order to protect it. This species is vulnerable to extinction due to its rare occurrence and low abundance where it does occur. The findings of this study add to the literature of northern madtom; perhaps sufficient data on this species will lead to its proper population designation in the U.S. if that differs from its current status.

Tables

Region	Designation	Rank
Global	Vulnerable	Not Applicable
Canada	Endangered	Not Applicable
United States	Vulnerable	Not Applicable
Arkansas	Under Review	Under Review
Illinois	Endangered	Presumed Extinct (SX)
Indiana	Species of Concern	Critically Imperiled (S1)
Kentucky	Species of Concern	Imperiled (S2) / Vulnerable (S3)
Ohio	Endangered	Critically Imperiled (S1)
Michigan	Endangered	Critically Imperiled (S1)
Mississippi	Endangered	Critically Imperiled (S1)
Pennsylvania	Endangered	Critically Imperiled (S1)

Table 1: Current status of northern madtom (*Noturus stigmosus*) in different governmental regions throughout its range (COSSARO 2014; NatureServe 2014).

Common Name	**Scientific Name**	**Total Abundance**	**Proportion**
Round Goby	*Neogobius melanostomus*	1091	0.6772
Spottail Shiner	*Notropis hudsonius*	317	0.1968
Rock Bass	*Ambloplites rupestris*	45	0.0279
Northern Madtom	*Noturus stigmosus*	37	0.0230
Bluntnose Minnow	*Pimephales notatus*	34	0.0211
Yellow Perch	*Perca flavescens*	31	0.0192
Sand Shiner	*Notropis stramineus*	28	0.0174
Northern Logperch	*Percina caprodes*	10	0.0062
Smallmouth Bass	*Micropterus dolomieu*	4	0.0025
Largemouth Bass	*Micropterus salmoides*	4	0.0025
Emerald Shiner	*Notropis atherinoides*	4	0.0025
Walleye	*Sander vitreus*	2	0.0012
Burbot	*Lota lota*	1	0.0006
Tubenose Goby	*Proterorhinus semilunaris*	1	0.0006
Yellow Bullhead	*Ameiurus natalis*	1	0.0006
Bluegill	*Lepomis macrochirus*	1	0.0006

Table 2: The number and relative proportion of each species collected by minnow traps in 2013 and 2014 in both the Detroit and St. Clair Rivers combined.

Site	Days fished	Minnow traps fished	Effort	Northern Madtom Catch	CPUE	HSI Score
Fort Wayne*	6	10	60	3	0.050	0.62370
Detroit Near-shore +	4	15	60	0	0.000	0.42848
Belle Isle Reef*	15	15	225	14	0.062	0.67504
Mazlinkas Reef*	22	15	330	6	0.018	0.61306
Upstream Mazinkas Reef +	2	15	30	0	0.000	0.37483
Downstream Mazlinkas Reef +	2	15	30	0	0.000	0.37125
Middle Channel Reef*	22	15	330	3	0.009	0.60141
Downstream Middle Channel Reef +	4	15	60	0	0.000	0.40135
Algonac State Park*	18	15	270	10	0.037	0.50288
Algonac Near-shore +	4	15	60	0	0.000	0.41275

Table 3: Total effort, catch, and CPUE for northern madtom at each sampling location for 2013 and 2014. * designates a reef or rocky substrate site; + designates a site at least 100m away from a known reef or rocky substrate

Figures

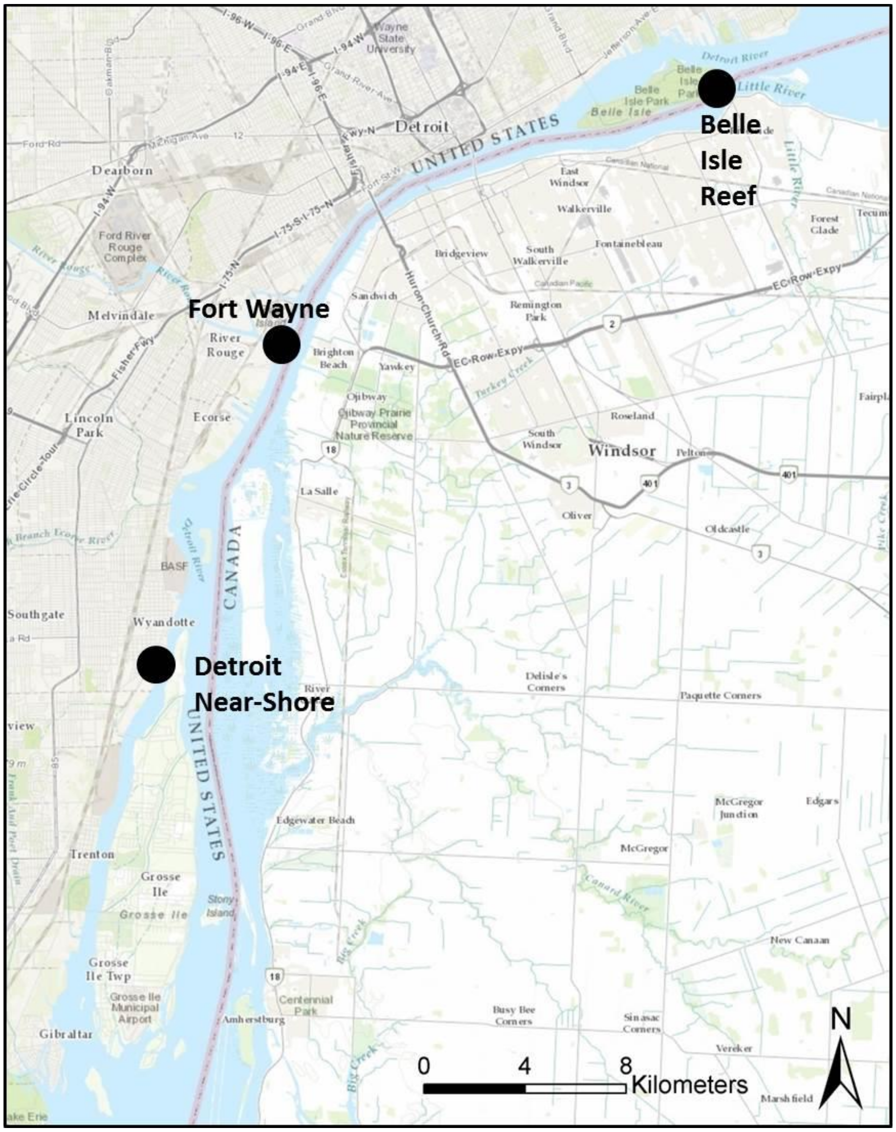

Figure 1: Sampling locations in the Detroit River where standardized minnow trap collections were done in 2013 and 2014.

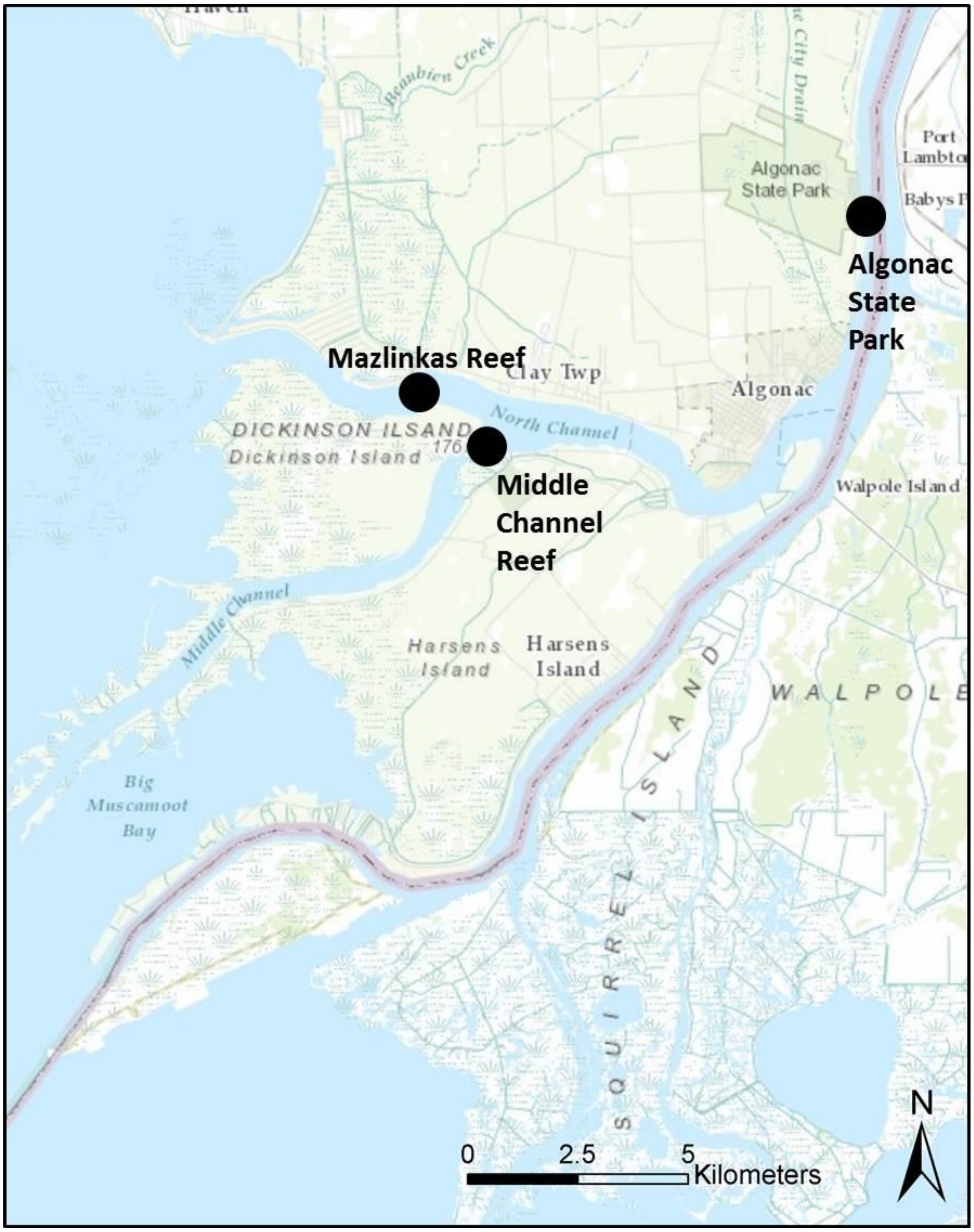

Figure 2: Sampling locations in the St. Clair River where standardized minnow trap collections were done in 2013 and 2014.

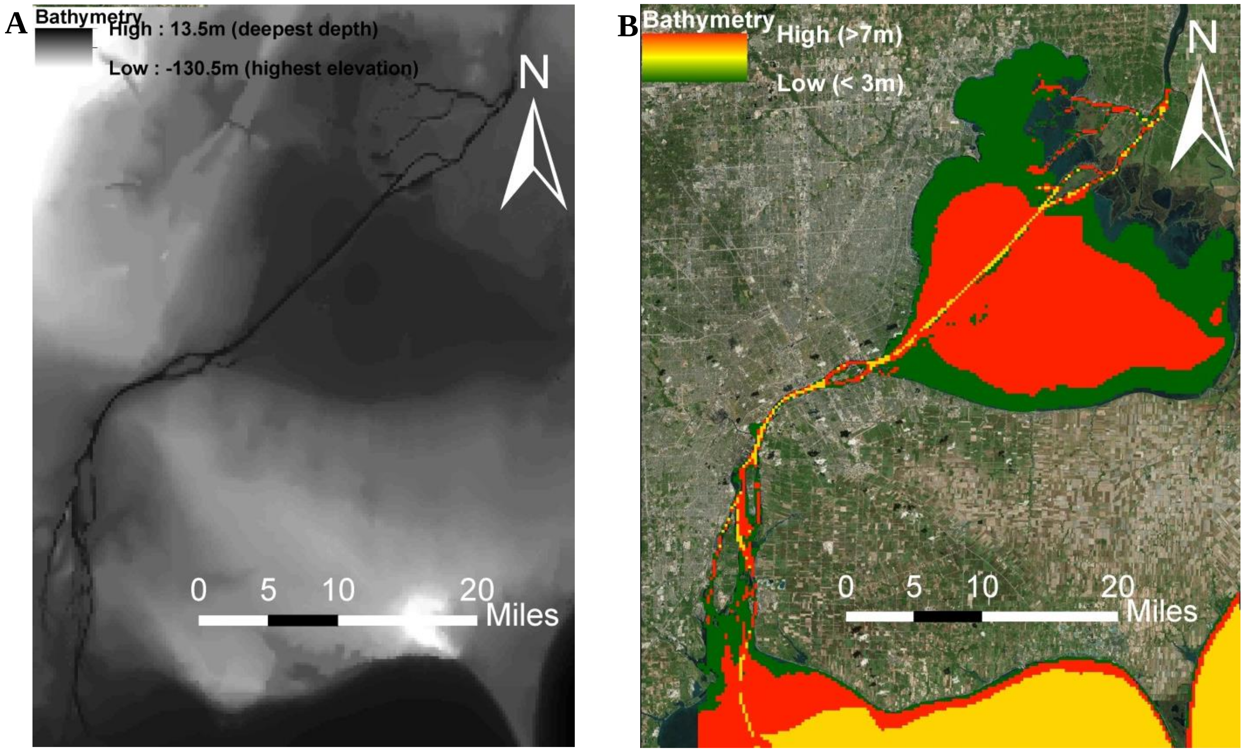

Figure 3: Bathymetry data layers (A) prior to modification (unit=m) and (B) after depths were ranked. B was used as input for the HSI model shown in Figure 5.

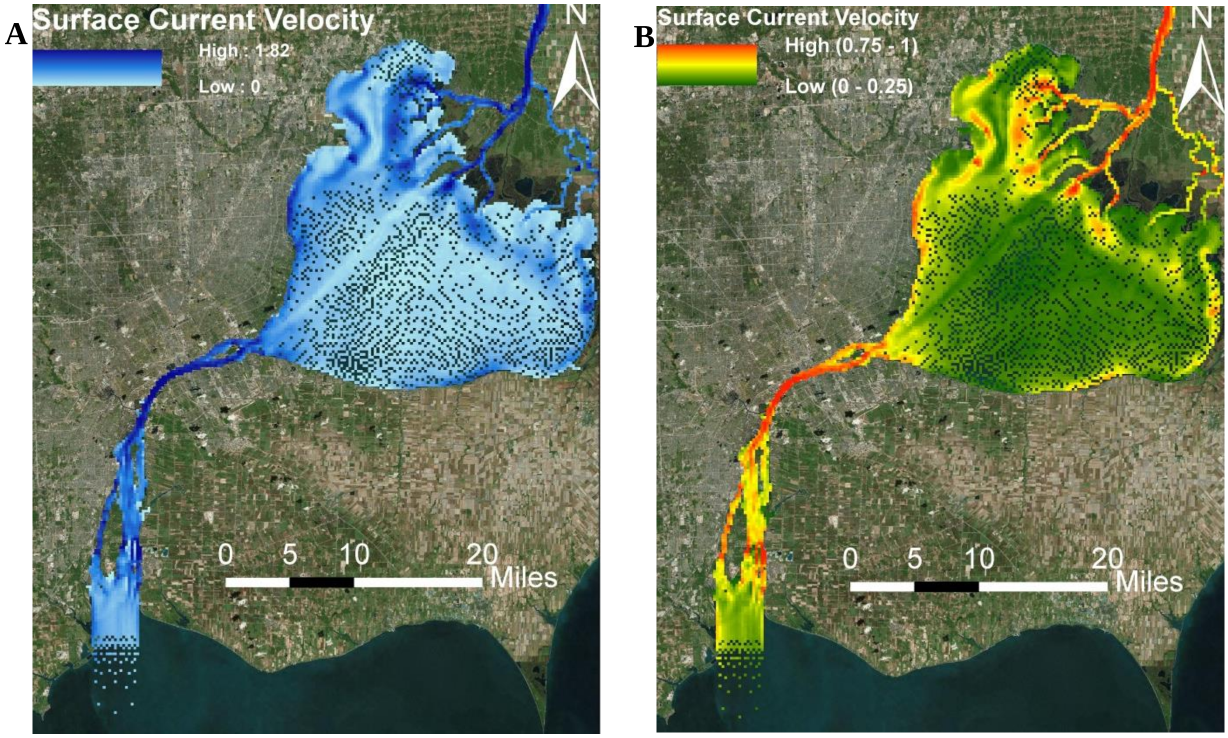

Figure 4: Surface current velocity layers (A) prior to modification (unit=m/s) and (B) after scaled to be between 0 and 1. B was used as input for the HSI model shown in Figure 5.

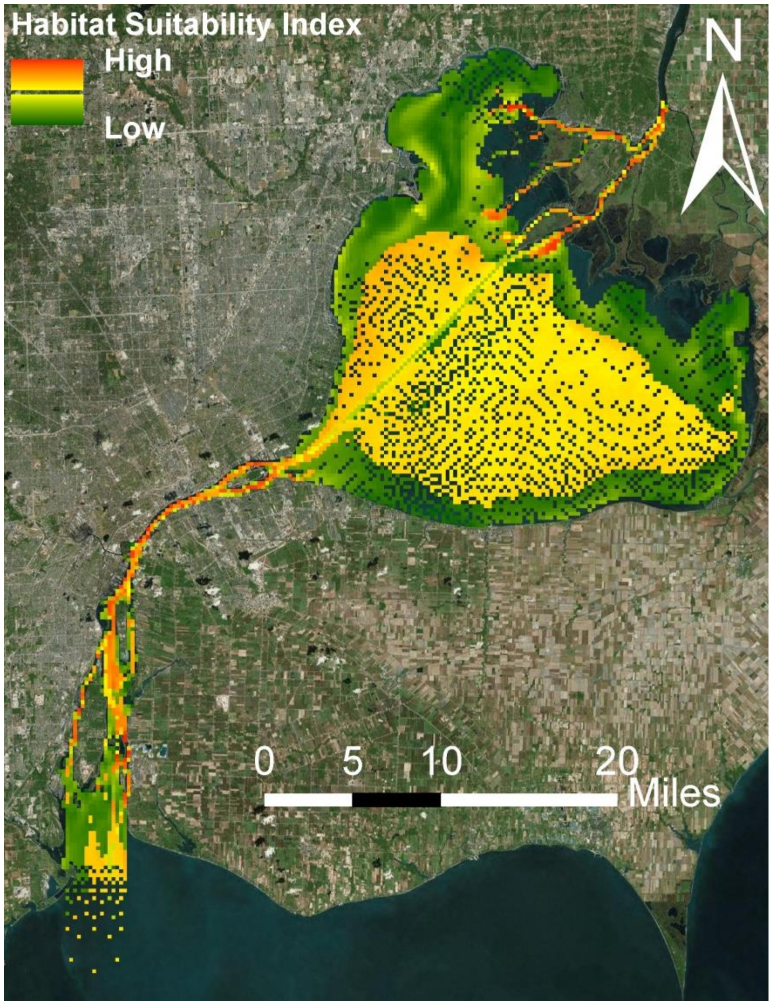

Figure 5: HSI model prediction northern madtom occurrence within the St. Clair- Detroit River system. Map shows regions of high (> 0.75; red), medium (0.5 – 0.75; yellow), and low (0.25 – 0.5; green) probabilities for northern madtom to occur.

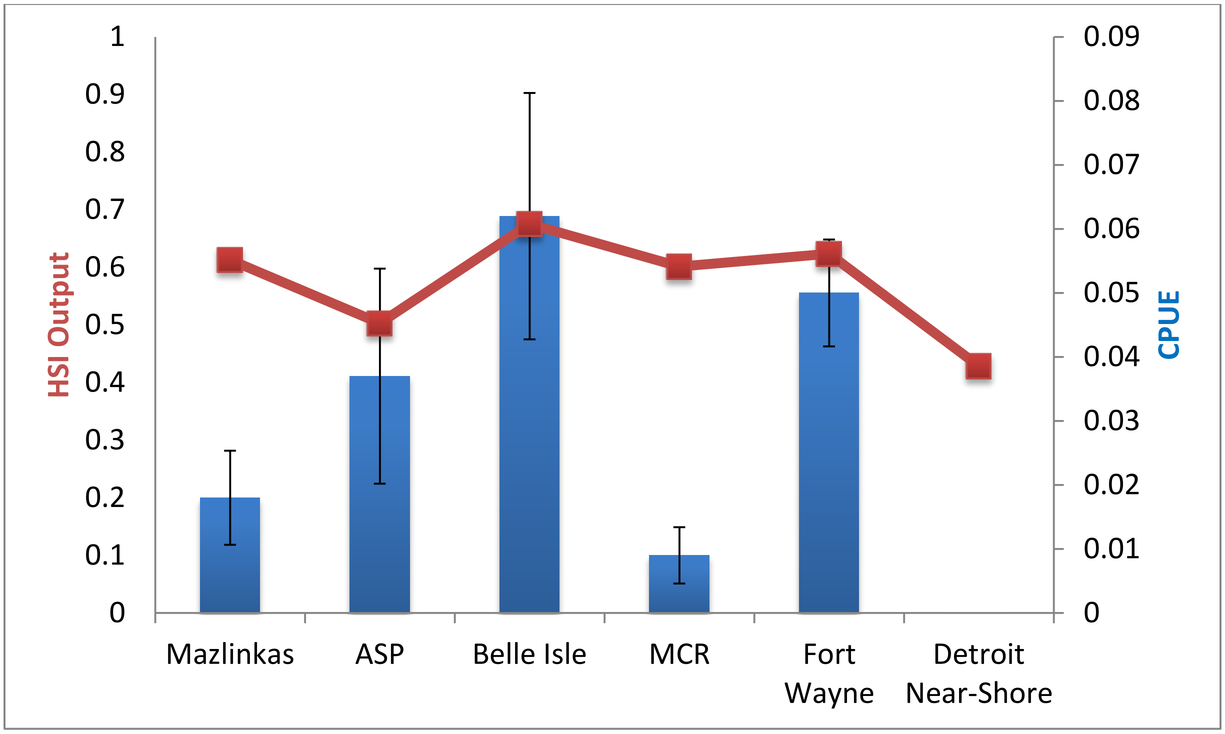

Figure 6: Catch per unit effort (bars; mean ± SE) (northern madtom per minnow trap per night) and HSI output (line) for each sampled site listed in order from oldest (left) to newest (right).

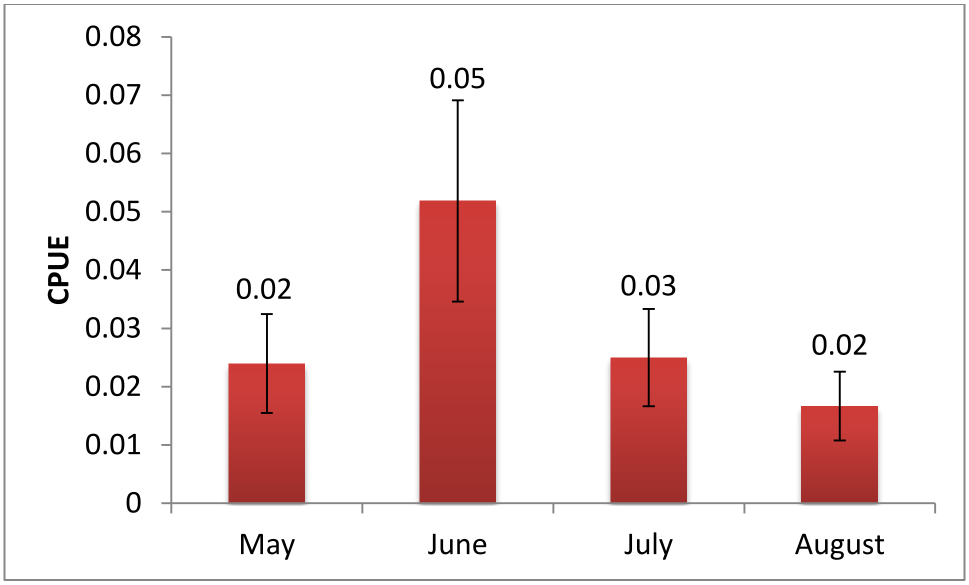

Figure 7: Mean (± SE) Catch per Unit Effort (northern madtom per minnow trap per night) for each summer month in 2013-2014.

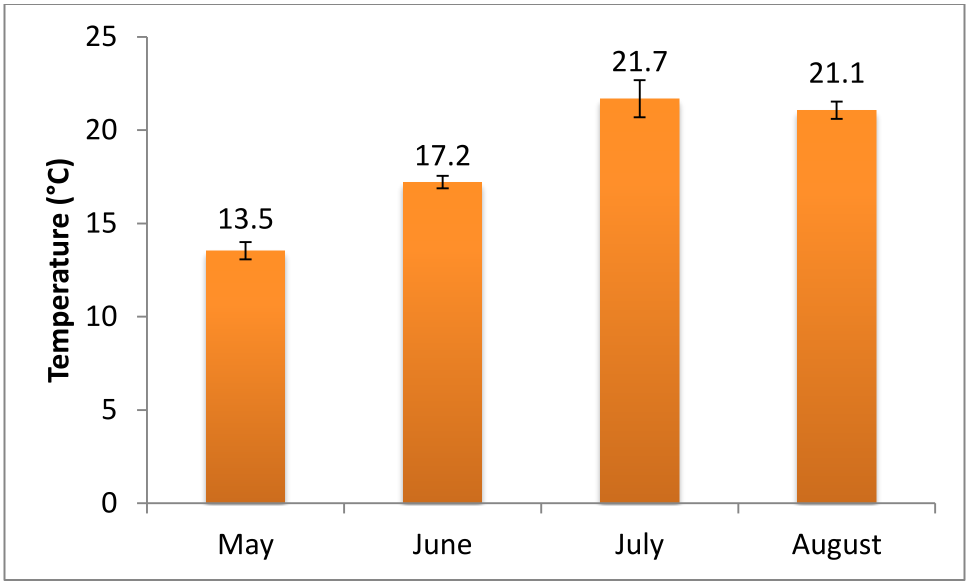

Figure 8: Mean (± SE) surface water temperature (°C) for all sampling sites combined during each month sampled in 2013 and 2014.

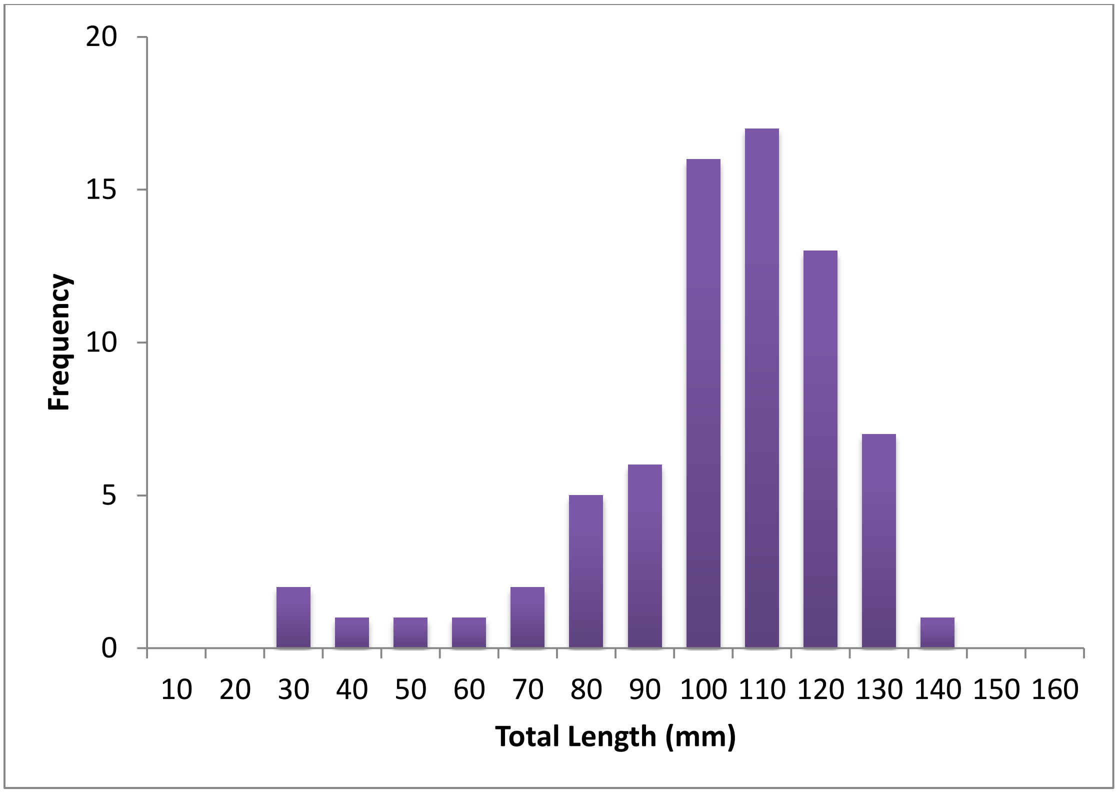

Figure 9: Length distribution for all northern madtom observed during this study (N=67).

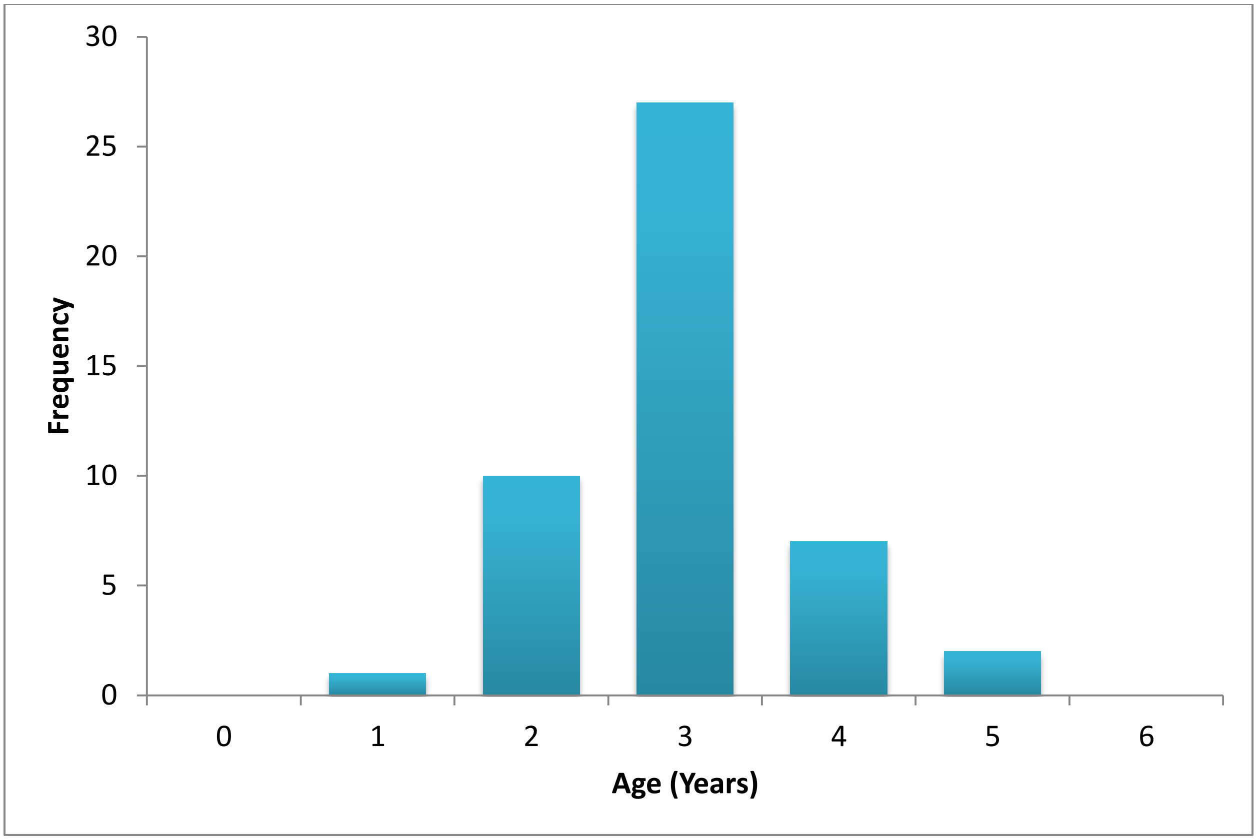

Figure 10: Age distribution for all northern madtom aged during this study (N=47).

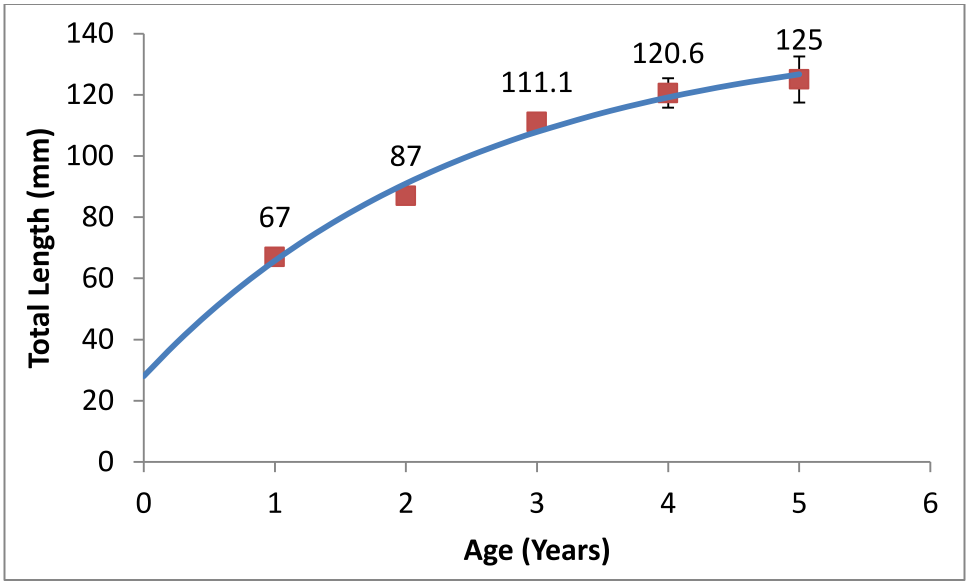

Figure 11: Mean (± SE) total length of northern madtom for each age class (red points) and Von Bertlanffy Growth Curve (blue line).

Equations

Equation 1: Percent agreement equation to compare two aging structures. True age is the otolith age for otolith–pectoral spine and otolith–dorsal spine comparisons; however, true age is the pectoral spine age estimation for pectoral spine–dorsal spine comparisons.

$$= \frac{|Structure\ 1\ Age\ Estimate - Structure\ 2\ Age\ Estimate|}{True\ Age} \times 100\%$$

Equation 2: Von Bertalanffy growth equation for northern madtom calculated from mean total length found for each age class (Quinn and Deriso 1999).

$$L_t = 141.9382\left(1 - e^{(-0.4025\times(t+0.5476)\,)}\right.$$

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