UTILITY OF MACROPHYTE HABITAT FOR JUVENILE FISHES: CONTRASTING USE IN TURBID AND CLEARWATER CONDITIONS OF MAUMEE BAY, LAKE ERIE

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ABSTRACT

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Many of the lake-dwelling fish species of Lake Erie rely on shallow, heavily vegetated bays as spawning grounds to increase offspring probability of survival during early life stages. Multiple complex abiotic and biotic factors can affect mortality especially during early life stages; the loss or absence of suitable habitat is one of these key factors leading to poor recruitment of fish species. Submerged aquatic vegetation (SAV)/macrophyte beds in clearwater systems act as refuges for juvenile fish decreasing mortality from predation while foraging on prey resources. However, it also has been shown that river discharge "plumes" (areas of high turbidity) may act as habitat/refuge for young-of-the-year fishes. The Maumee River and Maumee Bay, once with abundant macrophyte beds, have experienced substantive increases in suspended solids over the last century. Historical introduction of benthivorous feeding carp (especially *Cyprinus carpio*), sediment pollution from surface runoff in the surrounding watershed and relatively high wave energy further increases the levels of turbidity in bays and decrease the amount of SAV habitat. The potential colonization of western Lake Erie by Grass Carp (*Ctenopharyngodon idella*) could further reduce the distribution of the SAV that may serve as a crucial habitat for economically and ecologically important Lake Erie fish species.

I mapped the distribution of macrophytes in the northern section of Maumee Bay to quantify the utilization of SAV by juvenile fishes and the current distribution of SAV. In summer 2014 I used side scan sonar images processed in Quester Tangent™ computer programs in order to provide this baseline distribution. The 300-hectare mapped area was primarily inhabited by two SAV species, eel grass (*Vallisneria americana*) and variable pondweed

(*Potamogeton gramineus*), and this SAV was distributed over 43.7% of the area (131.2 hectares). The distribution of SAV seemed to be more related to the influx of sediments (increased turbidity) from the Ottawa and Maumee Rivers than depth, since the depth was fairly consistent throughout the surveyed area.

Using an active capture gear (neuston net, 9.5 mm mesh), I sampled the communities of juvenile fish utilizing the open (turbid) and SAV habitat areas. The areas of SAV contained a greater species richness than the surrounding turbid habitat (averaging 8.6 species vs. 5 species), and was dominated by juvenile centrarchids including Largemouth Bass (*Micropterus salmoides*), Bluegill (*Lepomis macrochirus*) and Black Crappie (*Pomoxis nigromaculatus*) (3,334 individuals vs 99 individuals). The ecologically valuable fish species Western Banded Killifish (*Fundulus diaphanus menona*), Logperch (*Percina caprodes*) and Bluntnose Minnow (*Pimephales notatus*) serve as important food resource for larger piscivorous games fish species and preferred SAV habitat.

This evidence suggests that SAV still serves as a crucial habitat for juvenile fish species even when the surrounding water column is turbid. SAV distributions should be preserved and enhanced in the western bays of Lake Erie to maintain/expand a crucial nursery habitat for economically and ecologically valuable fish species.

I dedicate this thesis work to the loving memory of my uncle, William D. Koehler, he inspired me to take pride in my work, always dedicate myself to my goals, but, to always put my interests aside when a friend or even a complete stranger needs help. He was always an outstanding role model, I aspire to become a great man by making choices that will honor his memory.

"A prudent man should always follow in the footsteps of great men and imitate those who have been outstanding. If his own prowess fails to compare with theirs, at least it has an air of greatness about it." –Niccolo Machiavelli

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INTRODUCTION

Submerged aquatic vegetation (SAV) in shallow bays and estuaries serves as habitat for invertebrates and fishes, provides food and nesting material for waterfowl, lessens bank erosion by buffering wave energy and increases water clarity by reducing flow which allows suspended sediments to settle out of the water column (Hasler and Jones 1949, Orth and Moore 1984, Carpenter and Lodge 1986, Perrow et al. 1999, Herring et al. 2006). SAV also serves as nursery habitat for juvenile fishes until they attain the size and swimming speed necessary to lessen the chance of predation while foraging for prey (Boesch and Turner 1984, Werner and Gilliam 1984). Because SAV serves numerous crucial roles in the aquatic ecosystem that many fish species rely upon, it is valuable for resource managers to monitor the expansion or decline of this important aquatic habitat.

Extensive research has been conducted to find and protect areas that exhibit large amounts of productivity and support a wide range of diversity, like vegetated estuaries and wetlands. Conservation of vegetation in estuaries is an important focal point of fisheries conservation because estuaries are some of the most degraded environments on earth due to the changes brought about by human activities such as increases in sedimentation from agriculture and changes in depth due to dredging for shipping channels (Edgar et al. 2000). Other human activities, such as overexploitation of resources and pollution of these estuarine areas, have forced restoration efforts to be undertaken; however, the majority of these restoration efforts focused on providing a temporary boost to the upper trophic levels, all but ignoring historic ecosystem structure and trophic relationships (Lotze et al. 2006).

The intentional or accidental introduction of nonindigenous organisms into these estuarine habitats has also caused further alteration from the historic ecosystem structure and in some cases threaten native aquatic species. For example, SAV abundance and species richness was greatly reduced leading to a shift to turbid water conditions in the shallow areas of a lake in Spain after the introduction of the freshwater crayfish (*Procambarus clarkii*) (Marchi et al. 2011). One of the greatest threats to SAV habitat across the continental United States is the accidental and intentional spread of the herbivorous Grass Carp (*Ctenopharyngodon idella*) through the Mississippi River system into midwestern lakes, reservoirs and even the Laurentian Great Lakes. Grass carp have been known to consume numerous taxa of SAV across many continents, and given enough time, can eradicate SAV in the littoral zones of lakes (Van Dyke et al. 1984). Thus, any habitat restoration efforts of wetlands that include linkage/connection of larger bodies of water need to take into account the potential effects of invasive species on the likelihood of restoration effectiveness.

Methods for quantifying SAV distribution or density may be summarized into three main categories; physical (generally requiring a SCUBA diver to conduct quadrat sampling of SAV), off-water remote (the use of airborne or space-borne sensors and interpretation of the imagery obtained) and on-water remote (the interpretation of sonar images) (Sabol et al. 2002). Even though the physical approach to sampling SAV allows the researcher to obtain a high level of accuracy for density and species composition, this approach requires a large amount of effort and will not allow the researcher to estimate the extent of SAV distribution over a large area (Sabol et al. 2002). Off-water remote approaches, such as the use of remote sensing techniques, can be impractical for the mapping of SAV due to its relatively high cost, unpredictable water conditions (water clarity) that reduce the quality of images and the limited availability of quality images in coastal estuarine areas (Wolter et al. 2005). Thus, an on-water remote approach of interpreting images produced by sonar equipment to generate a map of SAV distribution seems to be most labor efficient and allows for estimation over a larger area than the physical sampling approach (Preston 2009). Vertically aimed echo sounders can be effective for estimating plant density in a timely manner, but they may lead to misinterpretation of the bottom lake bed as short plants, and the narrow beam width of the echo sounder in shallow estuarine areas requires a large amount of interpolation in order to generate a distribution map (Sabol et al. 2002). The use of side-scan sonar images has been shown to provide a clear image of the physical characteristics of a sea or lake bed that serves as important fish habitat, allowing organizations to locate and protect these habitats for either commercially exploited species, threatened and endangered species or both (Collins and McConnaughey 1998, Ellingsen et al. 2002). Because many aquatic vegetation taxa have a distinct reflectivity produced by the gases contained within the structure of the plant (Sabol and Burcizinski 1998), the acoustic classification of signals, along with ground truthing, allows for the distribution of SAV to be mapped efficiently over large survey areas with side scan sonar images and image processing software (Preston 2009).

The largest tributary to Lake Erie is the Maumee River, and its confluence with Lake Erie produces the large (5,441 hectares) freshwater estuary, Maumee Bay (Brant and Herdendorf 1972). The once heavily vegetated shallow bays/estuaries of western Lake Erie served as refuges or “nurseries” for economically important fishes and invertebrates, providing protection from predation during critical life history stages (Boesch and Turner 1984), aiding in the recruitment of top predator piscivorous fish species that are commercially and recreationally harvested. However, this important habitat resource for Lake Erie fish species has been altered over the last century primarily due to man-made disturbances to the shoreline and the surrounding watershed, leading to degraded water quality and cultural eutrophication from non-point source pollution (Moorhead et al. 2007). Levels of suspended sediments have been increasing in the water-ways from agricultural and urban run off over the last century (Herdendorf 1987), and the levels of suspended sediments discharged into Lake Erie's tributaries is expected to increase or remain at relatively high levels in the near future (Richards 2008). Channelization and dredging of the Maumee River/Bay and other Lake Erie rivers may also contribute to the loss of aquatic vegetation in the bays/estuaries; the mean depth of these bays and rivers changes from 2-3 meters to a depth of 8-9 meters, so that commercial freight ships can navigate the bays and rivers, reducing the amount of littoral areas for vegetation growth. The channelization of rivers also increases the amount of suspended sediments being transported into the adjoining bays/estuaries, increasing light attenuation in the water column and thereby reducing aquatic vegetation (Nakamura et al. 1997).

The arrival of invasive species into Lake Erie has also had a substantial impact on water quality conditions and vegetation. The Common Carp (*Cyprinus carpio*) can increase turbidity in bays/estuaries by re-suspending sediments via their benthic feeding habits (Chow-Fraser 1999, Nieocyzm and Kloskowski 2014). The successful colonization of western Lake Erie bays by the invasive, herbivorous Grass Carp would further reduce SAV populations that are already in decline. Numerous tributary rivers of Lake Erie and other Great Lakes have the potential to support successful reproduction based on the flow rates and temperatures needed for successful incubation of Grass Carp eggs (Kocovsky et al. 2012). The discovery of four diploid Grass Carp in a western Lake Erie bay has provided evidence that this species has the potential to successfully reproduce and potentially colonize Lake Erie bays and tributaries (Chapman et al. 2013).

Numerous agencies are making efforts to reduce pollution, sediment runoff, eutrophication and the impacts of invasive aquatic organisms, creating evaluation indices to communicate with the public where restoration efforts are needed. These areas are referred to as Areas of Concern (AOC) (Hartig 1993). The U.S.-Canada Great Lakes Water Quality Agreement defines AOCs as geographic areas that fail to meet the general or specific objectives of the agreement where such failure has caused or is likely to cause impairment of beneficial use of the area's ability to support aquatic life; Maumee Bay along with the lower Maumee River is classified as an AOC (Hartig 1993). Impaired bay regions in the past were aided through the construction of diked wetlands with the primary interest of managing waterfowl, but these systems have been shown to increase nutrient loads due to the loss of nutrient exchange processes, support invasive plant species and possess a lower species diversity of fishes than the surrounding non-diked wetlands, most likely due to the separation from the natural hydrological regime of the adjacent lake (Prince et al. 1992, Johnson et al. 1997, Herrick and Wolf 2005). Present and future restoration efforts appear to focus on using dikes to create open water wetlands, to reduce sediment transfer, excessive nutrient influx and wave energy, and to increase water clarity, but maintain a connection to the lake for natural water level changes and connectivity for fish migration (Fredrickson and Taylor 1982, Mitsch and Wang 2000, Bouvier et al. 2009). If open water wetlands are to be constructed or if diked wetlands are to be altered in order to create a connection with the lake, preliminary (base-line) data pertaining to the current status of the aquatic ecosystem are crucial for future determination of the changes that restoration or invasive species will have in the bays/estuaries of western Lake Erie.

I used side scan sonar and the post-processing of the images to create a profile of SAV distribution in a 300-ha section in northern Maumee Bay where SAV is present, but sparse, and restoration efforts are planned (Personal communication with Chris May – The Nature Conservancy). These data provide base-line information on the SAV composition and distribution in the summer of 2014. I also sampled for juvenile fishes and community composition in two distinct habitat types in the bay, turbid open water regions devoid of vegetation and vegetated habitat. Turbid areas caused by river discharge of sediments may act as a refuge for juvenile fish by concealing the juvenile fish from predators (Reichert et al. 2010). However, SAV also serves as important habitat for juvenile fish to use as a refuge from predation in lakes and bays with relatively high water clarity (Werner and Gilliam 1984). Therefore, I determined the differences in juvenile fish abundance and community composition between areas of high turbidity that are devoid of SAV and habitat with SAV present.

METHODS

North Maumee Bay

Maumee Bay receives water from the Maumee River (17,114 km^2), and Ottawa River (388 km^2) watersheds (Shindel et al. 2002, Figure 1). Surface runoff from row crop agriculture and urban areas in the Maumee River watershed supplies the largest contribution of sediment pollution into Lake Erie contributing to the relatively shallow Maumee Bay (average depth = 1.7m, Herdendorf and Krieger 1989). Even though the bay is shallow, increased light attenuation from high sediment loading has contributed to the decline of native SAV abundance over the last century (Herdendorf 1987). To compare fish community differences in turbid areas versus SAV habitat, I conducted sampling in the northern section of Maumee Bay, which contains a remnant community of SAV. All of the sampling took place in spring/summer 2014 in the northern section of Maumee Bay, near Indian Island (41.749073 N, -83.453541 W), approximately 12 km northeast of Toledo, Ohio (Figure 1).

Characterizing Submerged Aquatic Vegetation (SAV)

In late June 2014, a large quadrant of North Maumee Bay was surveyed using side scan sonar with a Humminbird 798 ci side imaging depth finder (Humminbird, Eufala, AL). Images were recorded at a frequency of 455 kHz at a ping rate of 10 pings/second. An east-to-west transect/perimeter of the research area was paired with a perpendicular north-to-south transect to cover the majority of surveyed area. Recordings were loaded into the software HumViewer™ to dissect the recordings into smaller segments and then into the program SON2XTF™ to convert the file type to XTF (eXtended Triton Format) for later analysis with MWS SWATHVIEW™.

Analysis of acoustic signatures recorded by the side scan sonar was processed by Maritime Way Scientific (1420 Youville Drive, Ottawa, ON) using MWS SWATHVIEW™ to generate a map showing SAV distribution. Signals that returned to the transducer from an incident angle less than 2 degrees and signals that were unable to accurately extend to the full 29-meter distance from the transducer due to obstruction from high densities of SAV were eliminated. This truncation of the side-scan sonar information allowed for the amount of misclassification of areas in the Northern Maumee Bay to be reduced. See Preston (2009) for details regarding, image processing, image compensation, bottom picking and the principal components analysis used for feature/class identification in SWATHVIEW. The feature/class identification regions created by SWATHVIEW in the sampled area were analyzed in CLAMS™ in order to conduct interpolation of the classes into the areas missed during the side scan survey, creating a SAV distribution map in the surveyed area. Parameters in CLAMS were adjusted as follows: the search radius was set to 60 meters, the search size was set to 16 classes, the number of sectors was set to 12 and the number of required sectors was set to 5. Depth (m) measurements recorded along the transects of the side scan survey were loaded into ArcMap 10.2™ in order to conduct Inverse Distance Weighted (IDW) interpolation of depth (m) into the areas not surveyed in the transects in order to generate a bathymetry map of the sampled area.

SAV Ground-Truthing

In late June 2014, SAV samples were collected in the surveyed area of Maumee Bay at 20 locations to serve as ground-truthing information for classification with side scan sonar imaging. SAV was collected by SCUBA diving with a 0.36 m^2 square quadrat sampler; three haphazard samples were taken at each location. Vegetation was identified, separated by taxon, dried for 72 hours at 60 C to achieve a constant dry weight (Hengst et al. 2010) and then weighed to the nearest 0.01 gram. An error matrix was used to compare the SAV distribution map generated by the side scan sonar and the groundtruthed data, and overall accuracy was calculated along with a kappa coefficient to determine the level of accuracy and the chance-corrected proportional agreement of this on-water remote sensing approach (Agyemang et al. 2011).

Physical and Biological Sampling

During late June and early July 2014, juvenile fish were collected in the surveyed area of North Maumee Bay from either the turbid open water or SAV habitats (n = 16 from each) using a surface-sampling metal-framed neuston net (1m deep x 2m wide, 61m head rope, 9.5-mm bar mesh body and 1-mm mesh cod end, Sea-Gear Corporation, Melbourne, FL). Tows were made with a benchmark time of 150 seconds at a maintained speed of approximately 2.2 m/s in order to reduce gear avoidance by the juvenile fish (Meerbeek et al. 2002). Some tows in the SAV habitat had a shorter distance and time duration due to clogging of the net with debris (i.e., tows were terminated when a speed of 2.2 m/s was no longer possible). Juvenile fish samples were euthanized using tricaine methanesulfonate (MS-222) and then immediately frozen for preservation (BGSU IACUC Protocol 14-008). Juvenile fish were identified to species level, total length was measured to the nearest 0.1 mm, and biomass was measured to the nearest 0.01 grams. Catch per Unit Effort (CPUE) was calculated as the number of fish per 100m. CPUE, species richness and species diversity values were compared among habitats using t-tests (α= 0.05). Jaccard's community difference index was used to determine the similarity of the juvenile fish communities in the two habitats (Birks 1987, Real and Vargas 1996).

In early July 2014, benthic macroinvertebrate samples (n=15) were collected in the surveyed area of North Maumee Bay. Samples were collected in three habitat types: areas dominated by eel-grass (*Vallisneria Americana*, n=5), areas dominated by variable pondweed (*Potamogeton gramineus*, n=5), and turbid areas devoid of SAV (n=5). Samples were collected with a Petite PONAR 6" sampler (Wildco, Saginaw, MI) and immediately preserved in 85%

ethanol with Rose Bengal Disodium Salt (Fisher Scientific, Fair Lawn, NJ) to stain the specimens. Samples were rinsed in a 500-µm standard sieve (U.S. Standard Sieve Series, Chicago, IL) before specimens were counted and identified to the family level. Densities of macroinvertebrates were converted to number per m^2 and compared among habitats using a one-way analysis of variance (ANOVA $\alpha=0.05$) and Tukey's HSD post hoc test.

Environmental variables, such as water temperature and dissolved oxygen, were collected with a sensor (YSI Pro 20, Yellow Springs, OH), while turbidity was assessed with Secchi depths at each of the 32 fish sampling locations to determine if there was spatial variability among the areas with submerged aquatic vegetation (SAV) and the turbid areas devoid of SAV. A t-test for each of these water sample variables (temperature, D.O. and secchi depths) was conducted to detect differences between the two habitats ($\alpha=0.05$).

RESULTS

Characterizing SAV

Analysis of the side scan images in SWATHVIEW and CLAMS generated eight distinct acoustic classes in the surveyed area of Maumee Bay. Of the 300 hectare research area, 242.8 hectares was sampled with the side scan survey, two of the eight acoustic classes made up 94% of the area sampled. Ground-truthing information containing SAV and open lakebed locations allowed for the two dominant acoustic classes to be classified as SAV habitat 40.8% and areas of open lakebed, turbid open water habitat devoid of SAV 53.1% (Figure 2). All eight acoustic classes making up the 242.8 hectares of area sampled in the side scan survey were then transferred to CLAMS, in order to conduct distance-weighted interpolation of the class assignments and create a map of SAV distribution in the rest of the approximately 300-hectare survey area. The resulting interpolation allowed for the areas missed (57.2 ha) by the side scan survey to be classified in order to estimate the complete extent of SAV habitat (Figure 3).

Analysis of the interpolated map in ArcMap 10.2 resulted in the following areal estimation of the two major classifications (Figure 4): SAV, heavily comprised of eel grass and variable pondweed, made up 131.2 hectares (43.7%), while 156.5 hectares (52.2%) of the surveyed area consisted of turbid open water area devoid of vegetation.

The side-scan sonar map achieved an overall accuracy of 75% when compared to ground-truthing SCUBA diving locations (15 out of the 20 sites were correctly classified by the SWATHVIEW generated map) and achieved a moderate kappa coefficient of 0.519 (a measure of the proportional improvement by the classifier over a purely random assignment to classes). All locations inside the SAV beds and outside in the turbid open water achieved a 100%

accuracy, while sites located at the interface between the two habitats exhibited errors in accuracy, which is expected. There was very little variation in depth within the research area, with the majority of the area between 1 to 1.75m in depth (Figure 5).

Submerged Aquatic Vegetation (SAV)

Quadrat sampling at the 20 ground truthing locations yielded 5 species of SAV; eel grass, variable pondweed, leafy pondweed (*Potamogeton foliosus*), muskgrass (*Chara vulgaris*) and sago pondweed (*Potamogeton pectinatus*). Of the 14 quadrat sites with SAV, eel grass was the most abundant species, making up 73.4% of the total biomass, followed by variable pondweed (21.8%). Species composition from 20 sampling sites aided Maritime Way Scientific Ltd. in identifying unique acoustic classes belonging to the SAV in the side-scan sonar lakebed classification (see appendix A for information on quadrat sampling site locations and SAV densities).

Physical and Biological Sampling

Secchi depths for water clarity in the two habitats (SAV and turbid area devoid of SAV) differed significantly; Secchi depths were significantly greater inside the SAV habitat (mean = 103 cm, ± 7.4 S.E.) than the open water (mean = 50.3 cm ± 3.2 S.E.),($t = -6.55$, d.f. = 31, $p < 0.0001$). Neither water temperatures nor dissolved oxygen levels between the two habitats were significantly different ($t = 0.35$, $p = 0.64$ and $t = 0.93$, $p = 0.82$, respectively with d.f. = 31 for both tests).

Even though catch per unit effort of juvenile fishes in SAV habitat was 60% higher than in open water (turbid) habitat, there was no significant difference in CPUE between the two habitats ($t = -1.94$, d.f. = 31, $p = 0.06$), thus trending toward higher juvenile fish abundance inside SAV habitat. Species richness was significantly higher in SAV with on average 8.6 species present versus 5 species in open habitat (t = -4.23, d.f. = 31, p < 0.0001; Table 1). While turbid open water habitat was dominated by Spottail Shiners (*Notropis hudsonius*; 65.3%), invasive White Perch (*Morone americana*; 7.4%), and Gizzard Shad (*Dorosoma cepedianum*; 4.6%), SAV habitat supported mostly Bluegill (*Lepomis macrochirus*; 71.4%), Black Crappie (*Pomoxis nigromaculatus*; 0.65%) and Largemouth Bass (*Micropterus salmoides*; 3.1%), with abundant invasive Goldfish (*Carassius auratus*; 9.3%), Spottail Shiners (8.1%), Western Banded Killifish (*Fundulus diaphanous menona*; 1.9%) and Logperch (*Percina caprodes*) (1.5%). With such extensive dominance by single species, Shannon-Weiner diversity between habitats was not significantly different (t = -0.87, d.f. = 31, p = 0.19). As a measure of community similarity, the Jaccard's Index of 34% (p = 0.016, Real and Vargas 1996) reinforces the point that the fish communities in the two habitats are significantly different (Rahel 2002). The location of the neuston net trawls for juvenile fish appears in Appendix B.

In the three habitats (dominated by variable pondweed, eel grass and areas devoid of SAV) dominant macroinvertebrate taxa were chironomids and oligochaetes, comprising, on average, 60.4% and 26.3%, respectively, of the total macroinvertebrate community (Figure 6). However, no significant difference was detected among habitats for each taxon (F = 0.63, d.f. = 2, 14, p = 0.55, F = 3.05, d.f. = 2, 14, p = 0.08), implying that there was no difference in available benthic food resources for the juvenile fish species that were occupying either the SAV or turbid habitats.

DISCUSSION

The use of side-scan sonar data from commercially available "fish finders", provides low cost and detailed information to managers and conservation biologists for mapping distribution of SAV, which can serve as baseline data for 1) restoration, 2) assessing impacts of invasive aquatic organisms (e.g., Grass Carp introduction into western Lake Erie), 3) classifying SAV distribution, and 4) demonstrating the projected fish community shifts from turbid open water habitat to SAV-dominated habitat. All of this information can aid in guiding restoration efforts to remove the Maumee River/Bay from the list of Great Lake's AOC.

The use of side-scan sonar analysis is part of a new shift in the conservation field, allowing for new metrics, such as the pattern and distribution of physical fish habitat, to be used along with traditional size and growth metrics to make a better assessment of the overall health and status of fisheries (Minns and Wichert 2005). This acoustic mapping technique has been shown to be effective and is now being used for showing the pattern of SAV distribution aimed at mapping the distribution of SAV in southwestern Florida estuaries (Locker and Wright 2003, Dunn 2007). This technique is also useful for mapping the sediment/substrate types that serve as important habitat for commercially harvested fish species like Atlantic Cod (*Gadus morhua*) (Collins and McConnaughey 1998) and to gain insight into the amount of available ideal spawning substrates for threatened fish species like Atlantic Sturgeon (*Acipenser oxyrhynchus oxyrchynchus*) and Lake Trout (*Salvelinus namaycush*),(Edsall et al. 1989, Hook 2011).

The use of low cost, commercially available side-scan sonar provides sufficiently accurate, high resolution data of underwater aquatic physical features in shallow areas in which the use of large and expensive towed transducers is not feasible (Kaeser and Litts 2008).

Although it would be ideal for side-scan surveys to thoroughly scan all of the area with overlap for greater accuracy of identifying aquatic physical features, surveys conducted on large sections of water can maintain classification accuracy while increasing cost and time effectiveness by implementing interpolation methods, such as we used with CLAMS software (Tamsett 1993, Preston 2009, Shumchenia and King 2010). Even though side-scan information can exhibit errors in correctly identifying classifications due to environmental factors, such as distortions of the return angle, geometric error and obstructions (Cobra et al. 1992, Blondel 2009), the use of programs like SWATHVIEW, along with groundtruthing information and the overlapping of multiple transects allows for accurate identification of SAV habitat (Preston et al. 2000, Preston et al. 2006, Preston 2009). Utilization of these processes and truncation of the unsuitable side-scan data in SWATHVIEW (Maritime Way Inc.) allowed us to generate a SAV distribution map with a 75% overall accuracy and moderate (Kappa coefficient = 0.519) chance-corrected proportional agreement in northern Maumee Bay, an accuracy similar to other on-water and off-water (remote sensing) mapping approaches (Kaeser and Litts 2008, Agyemang et al. 2011).

Vegetation sampling and analysis of the side scan sonar images in the study area of northern Maumee Bay indicated that the area is dominated by eel grass (42.6%) with sparse amounts of *Potamogeton* (likely variable pondweed, 1.51%) and trace amounts of muskgrass, *Chara*, a community make up that is common in the open water/larger bays of Lake Erie (Herdendorf 1987). The dominance of many Lake Erie bays by eel grass is most likely due to this species' elongated and floating leaf structure which allows it to reach the water surface and aid its survival in areas with decreased light penetration due to increased turbidity (Lowden 1982, French and Moore 2003). Bathymetrically, this region of northern Maumee Bay is consistently shallow with most of the entire surveyed area between 1 and 1.75m deep.

Additionally, habitat devoid of SAV was significantly more turbid than the vegetated habitat. The depth that SAV can survive increases as the amount of light penetration increases (Dennison et al. 1993), and declines in SAV have been shown to be related to decreasing light penetration due to decreases in water quality from sediment pollution (Orth et al. 2009). Restoration efforts in this area of northern Maumee Bay thus appear to need a focus on reducing suspended sediment loadings and turbidity. One promising restoration effort could be the implementation of a low lying dike between the surveyed area and Lake Erie that would be intended to reduce sediments that are suspended into this area's water column by the relatively high wave energy created in western Lake Erie wetlands and the influx from the Ottawa and Maumee Rivers (Herdendorf 1987).

The overall abundance of juvenile fish (CPUE measured as # of juvenile fish per 100 meters trawl distance), and species diversity (Shannon Weiner index scores) were not significantly different in SAV habitat compared to surrounding turbid open water habitat, but species richness was significantly higher in the SAV habitat and there was a pronounced community shift. Differences in CPUE and diversity were likely not detected because of the large amount of variability among neuston net samples. Schooling species in open water habitat (e.g., Spottail Shiners) and aggregations of centrarchids, such as Bluegills, in vegetation along with variable distributions of SAV in trawls made it difficult to detect differences in these metrics. As many as 112 North American fish species utilize SAV habitat in the turbid upper Mississippi River system (Janecek 1988), and the overall fish abundance measured by CPUE has been shown to be higher in this habitat over surrounding areas (Killgore et al. 1989, Ye et al. 2006) even when the SAV habitat is comprised of non-native aquatic plant species (e.g., Eurasion water-milfoil *Myriophyllum spicatum*; Borawa et al. 1979). Limited similarity between juvenile fish communities in the two habitats (measured by Jaccard's index) and greater juvenile fish species richness in the SAV habitat implies that this habitat is crucial for fish species that have adapted to utilizing it. Further loss of SAV habitat in the coastal wetland areas of western Lake Erie will increase biotic homogeneity (decreasing richness of juvenile fish species) allowing invading sediment tolerant species to thrive, and lead to the decline of native fish species in the bays of western Lake Erie (Scott and Helfman 2001, Rahel 2002).

Juvenile centrarchids like Largemouth Bass, Bluegill and Black Crappie continue to have a strong association with SAV habitat, even when the surrounding turbid water is an available nursery habitat. Submerged aquatic vegetation (SAV) is an important habitat for numerous juvenile fish species and it can act as a critical determinant of recruitment success of these and other economically important sport fish species in Midwestern lakes and the western bays of Lake Erie (Wilcox and Meeker 1992, Hayes et al. 2009). Even though areas of high turbidity caused by eutrophication (suspended sediment or high phytoplankton abundance) serve as nursery habitat by increasing ability to avoid predation during early life stages (Fiksen et al. 2002, Reichert et al. 2010), many fish species have adapted to inhabiting and foraging inside macrophyte beds (Diehl 1988). Many centrarchids rely upon SAV habitat (Dibble 1997), and the species richness of this family can be directly related to the vegetation diversity that serves as a complex habitat (Tonn and Magnuson 1982). Year class strength of Black Crappie is positively affected by the presence of macrophytes (Maceina and Shireman 1982). Experiments with Bluegills have shown that juvenile centrarchids tend to rely upon SAV habitat as a refuge until the fish have grown to a sufficient size and developed a swimming ability that is adequate for them to avoid predation while they reduce intraspecific competition by venturing into the open waters to feed upon large zooplankton prey (Werner and Hall 1974, Werner et al. 1983). Savino and Stein (1989) have shown that Largemouth Bass prefer to inhabit SAV habitat over the surrounding open water in order to ambush their prey.

Even though an insufficient sample size of Yellow Perch was collected here to make conclusions on their habitat preference for SAV, past research has shown that Yellow Perch and the closely related European Perch (*Perca fluviatillis*) exhibit a strong relationship with SAV habitat during all of their life stages (Diehl and Eklov 1995, Hayes et al 2009). SAV serves as ideal structure for spawning females to deposit eggs, allowing the eggs to stay suspended above the sediment that can suffocate a large proportion of the eggs if they were laid directly on the lake bed (Smith et al. 2001). SAV also serves as an important foraging area for Yellow Perch as they go through diet shifts with increased body size, consuming plankton and benthic invertebrates between 40 – 60mm in total length and then shifting to small fishes and benthic invertebrates generally at sizes greater than 80mm in total length (Persson 1986,Graeb et al 2006). Restoration and preservation of littoral zones with abundant SAV habitat could aid the recruitment of the Yellow Perch, an economically important species that attracted 1.27 million angling hours by private sport fishermen on the Ohio waters of Lake Erie in 2011 (ODW 2012). Yellow Perch also serves as an important prey species for other economically game fish species such as the Walleye (Forney 1974, Knight and Vondracek 1993).

SAV in Maumee Bay also serves as habitat for small benthic fish species like Logperch, Western Banded Killifish and Bluntnose Minnows. These three fish species also rely upon SAV habitat for refuge and foraging for either their early life stages or all of their life stages (Rozas and Odum 1988, Brazner 1997). These three small fish species have been shown to serve as a food resource for Walleye and other top predator species (Godin and Morgan 1985, Lyons 1987, Liao et al. 2001). Protection of SAV habitat for these small epi-benthic species may be important for preserving their populations because the nonindigenous round goby (*Neogobius melanostomus*) and tubenose goby (*Proterorhinus semilunaris*) have led to the decline of native benthic fish species by competing for the same food resources during the juvenile life stage and preying upon the juvenile life stages of these species as adults (French and Jude 2001, Bergstrom and Mensinger 2009, Kocovsky et al. 2011).

Northern pike (*Esox lucius*) also exhibited a decline in Lake Erie over the last 150 years, associated with changes to the lake shoreline after European settlement, primarily the loss of SAV habitat and the increase in turbidity (Hartman 1973). Increases in pike populations are related to the presence of abundant SAV (used as a spawning location and as habitat for juveniles and adults), and this species would likely benefit from proliferation of SAV habitat (Casselman and Lewis 1996). The restoration/expansion of available SAV habitat in Maumee Bay and other bays in Lake Erie will likely enhance numerous native fish species and will reduce the amount of available habitat for invasive nuisance species, such as the White Perch, which have been shown to have less dependence on nearshore tributary wetland habitat (Koonce et al. 1996).

Recent evidence of the successful reproduction of herbivorous Grass Carp has the potential to cause additional reductions of SAV habitat due to the fact that these fish have substantial abilities to reduce SAV abundance and distribution (Madsen 2000). When Grass Carp are used as a biological method for removing nuisance SAV (aquaculture and pond management) they are seen as an “all or nothing” approach to vegetation removal because of the inability to control feeding sites and they are difficult to contain in the water body (Madsen 2000). Mitzner (1978) reported that the first introduction of Grass Carp in an Iowa reservoir caused the reduction of SAV by 91%. Similarly, the removal of 3,600 hectares of SAV from a Texas reservoir in 1981 by Grass Carp in one year also resulted in a substantial decline in the biomass of several sport fish species, including Bluegill and Black Crappie along with the decline of age-1-and-older Largemouth Bass (Bettoli et al. 1993). Thus, ecological changes caused by Grass Carp could also lead to reductions of some indigenous fish (Taylor et al. 1984). Even though the Great Lakes has received a reported 139 non-indigenous aquatic organisms (Mills et al. 1993), more information on the ecological impacts of invasive species are needed to assess the damage that can occur and provide evidence that intervention is needed to prevent/reduce the damage. Using the 14 ground-truthed sights containing SAV, average wet weight biomass was determined (172.31 grams wet weight/m^2). When this average is used with the overall area containing SAV in the research area of northern Maumee Bay (Figure 4, 131.26 hectares), I estimated that there was an overall SAV biomass greater than 226,000 kilograms.

Young Grass Carp smaller than 1 kg prefer to consume eel grass (Bonar et al. 1993), the dominant species found in northern Maumee Bay and many other areas in western Lake Erie. Ignoring the correction factors (Wiley and Wike 1986, Stewart and Boyd 1999), I estimated that Grass Carp around 1 kg in weight could consume around 71% of their body weight per day in the summer months. A population of only 1,000 Grass Carp of this size could consume 710 kg/day of SAV. Over a 90-day summer, approximately 28% of the SAV biomass could be consumed. Side-scan sonar mapping of the northern section of Maumee Bay may serve as baseline information that could be used to measure changes to SAV distribution over the next decade in order to detect ecosystem damage that may be caused by the invading Grass carp in the form of SAV habitat reduction.

Anthropogenic impacts to coastal wetland/estuaries, like northern Maumee Bay, have lead to an altered ecosystem susceptible to successful invasion by an exotic plant species such as *Phragmites australis* (Hershner and Havens 2008). The native SAV plants in this area of northern Maumee Bay may be safe from the detrimental effects that *Phragmites australis* has on plant communities because this emergent plant is restricted from growing in this habitat due to an inability to supply oxygen to its roots in deep waters (Weisner and Graneli 1989). The 1 – 1.75 meters of depth throughout this bay makes this area ideal for restoration efforts aimed at increasing abundance of the native plant species which clearly is an effective nursery habitat for numerous fish species native to Lake Erie. Restoration efforts aimed at decreasing turbidity in northern Maumee Bay should have a substantive effect on the expansion of the native SAV plants.

The use of low cost commercially available, high resolution side-scan sonar like that used here can provide adequate habitat data when paired with a third party software for analysis and the comparison of groundtruthing data. This SAV distribution in northern Maumee Bay in 2014 serves as a baseline for gauging the success of future restoration projects aimed at reducing turbidity levels, like the one proposed near the survey area by the Michigan TNC. The presence of SAV is a main determinant of Lake Qualitative Habitat Evaluation Index (L-QHEI) scores (Thoma 2006) and it effects the Index of Biotic Integrity scores (Karr 1981), both metrics are used to assess restoration success. Restoration efforts to expand SAV distribution will lead to reducing the beneficial use impairment to aquatic life in the region and may aid in the delisting of the Maumee River/Bay as an AOC. Given that this area already has established SAV, relatively minor restoration efforts (and cost) could lead to extensive expansion of SAV in this highly altered ecosystem. However, it is critical to recognize the threat that an expanding population of herbivorous Grass Carp could have on many of the restored wetlands with linkages to the Great Lakes.

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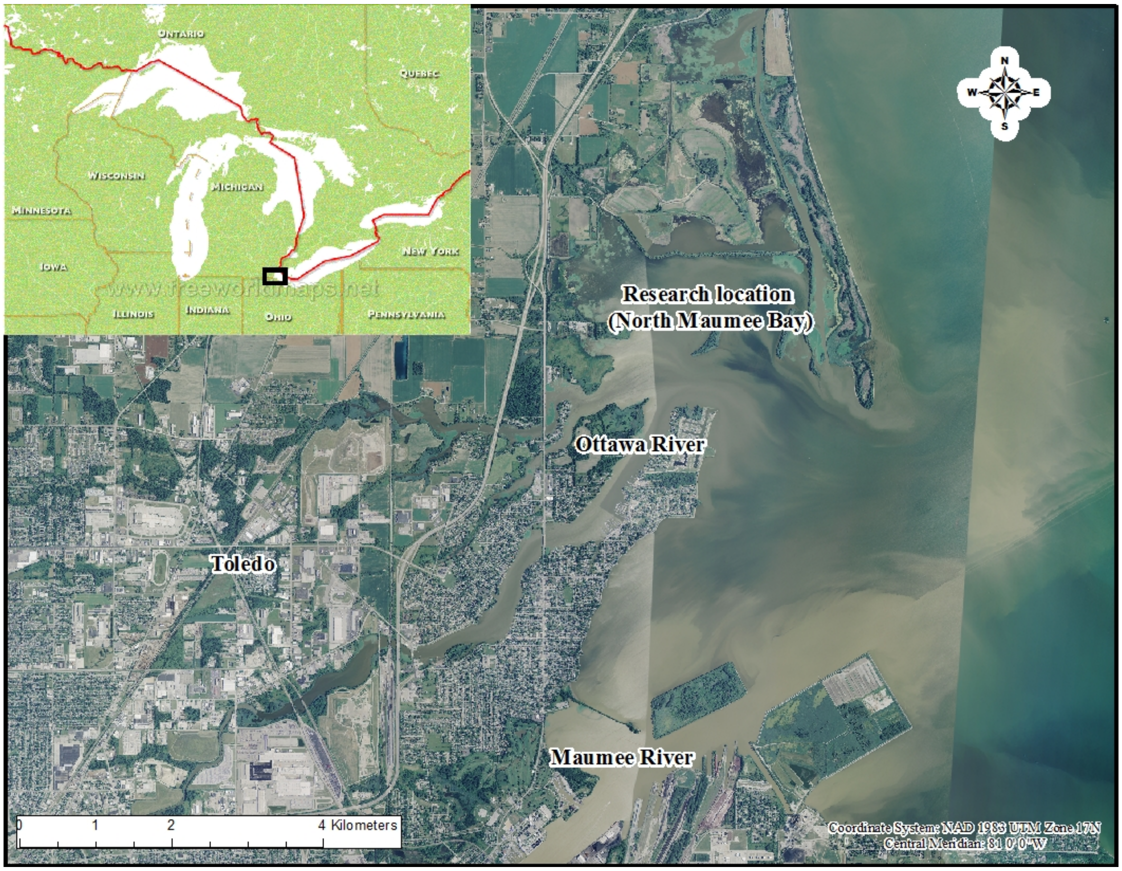


Figure 1. Maumee Bay in western Lake Erie, the location of the study location in North Maumee Bay, and where juvenile fish sampling and side scan sonar mapping took place in a 300-hectare quadrant of the bay.

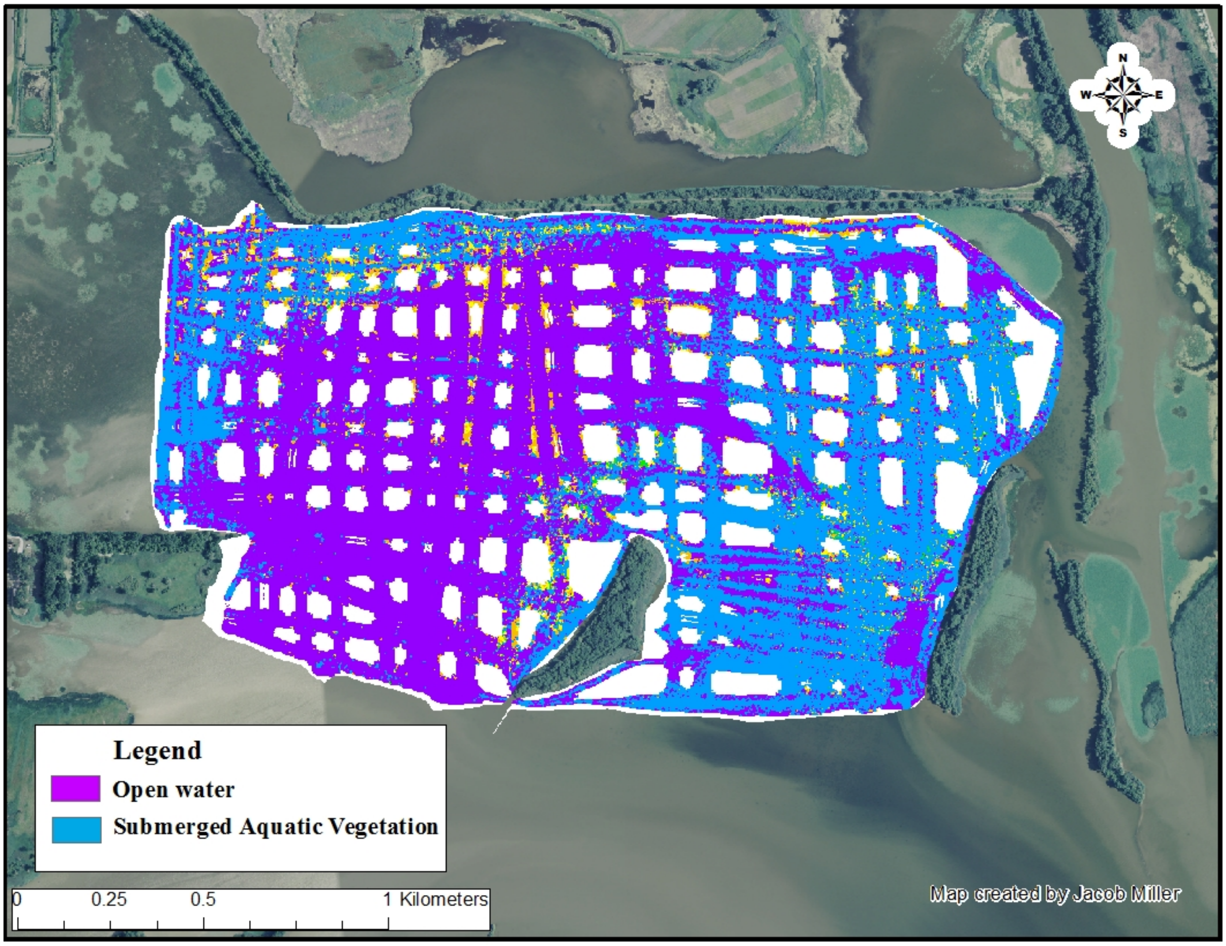


Figure 2. Acoustic classifications identified with the computer program SWATHVIEW using side-scan sonar data. Areas denoted by colors not shown in the legend were unable to be identified by groundtruthing.

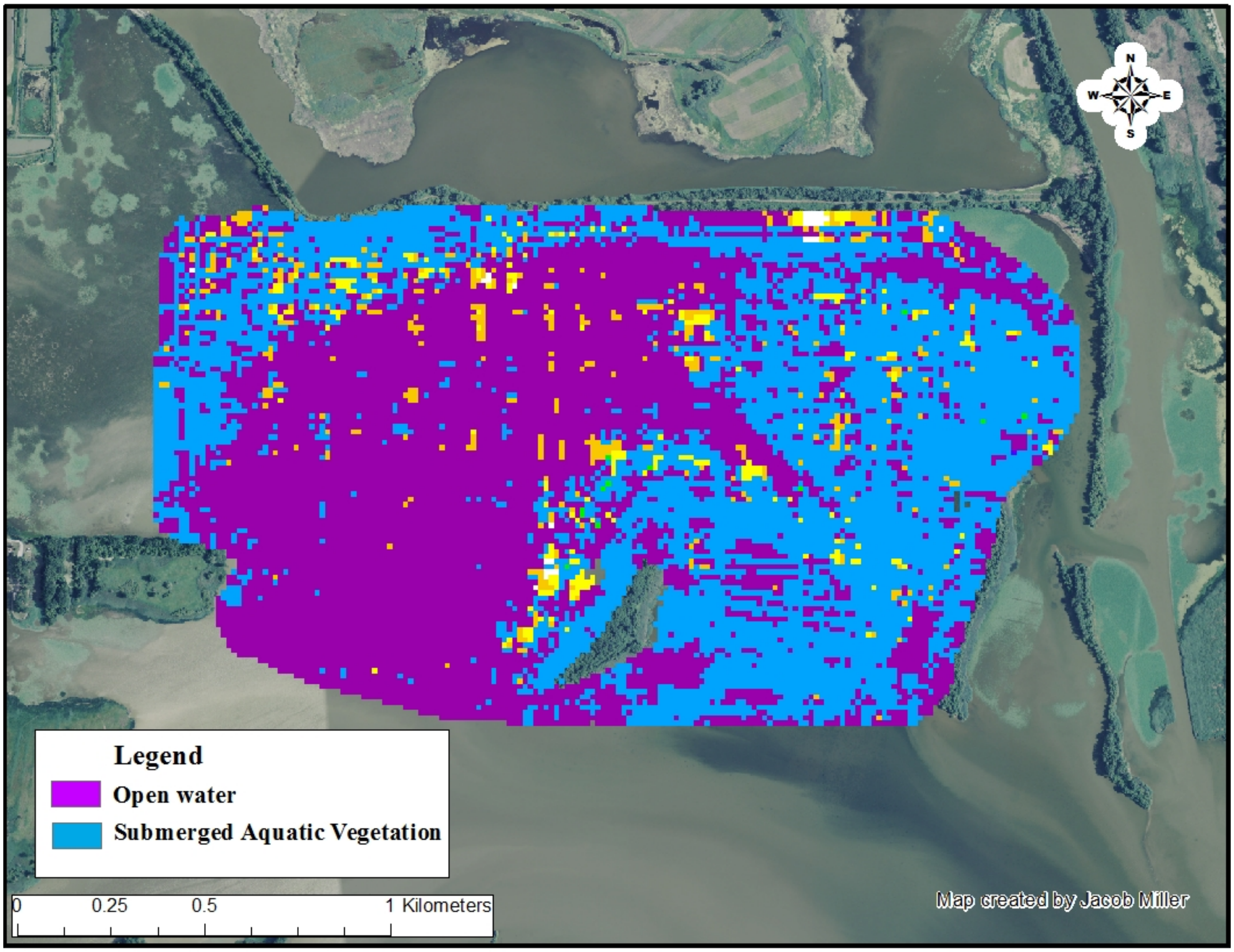


Figure 3. Acoustic classifications after classification interpolation was conducted with the computer program CLAMS. Areas denoted by colors not shown in the legend were unable to be identified by groundtruthing.

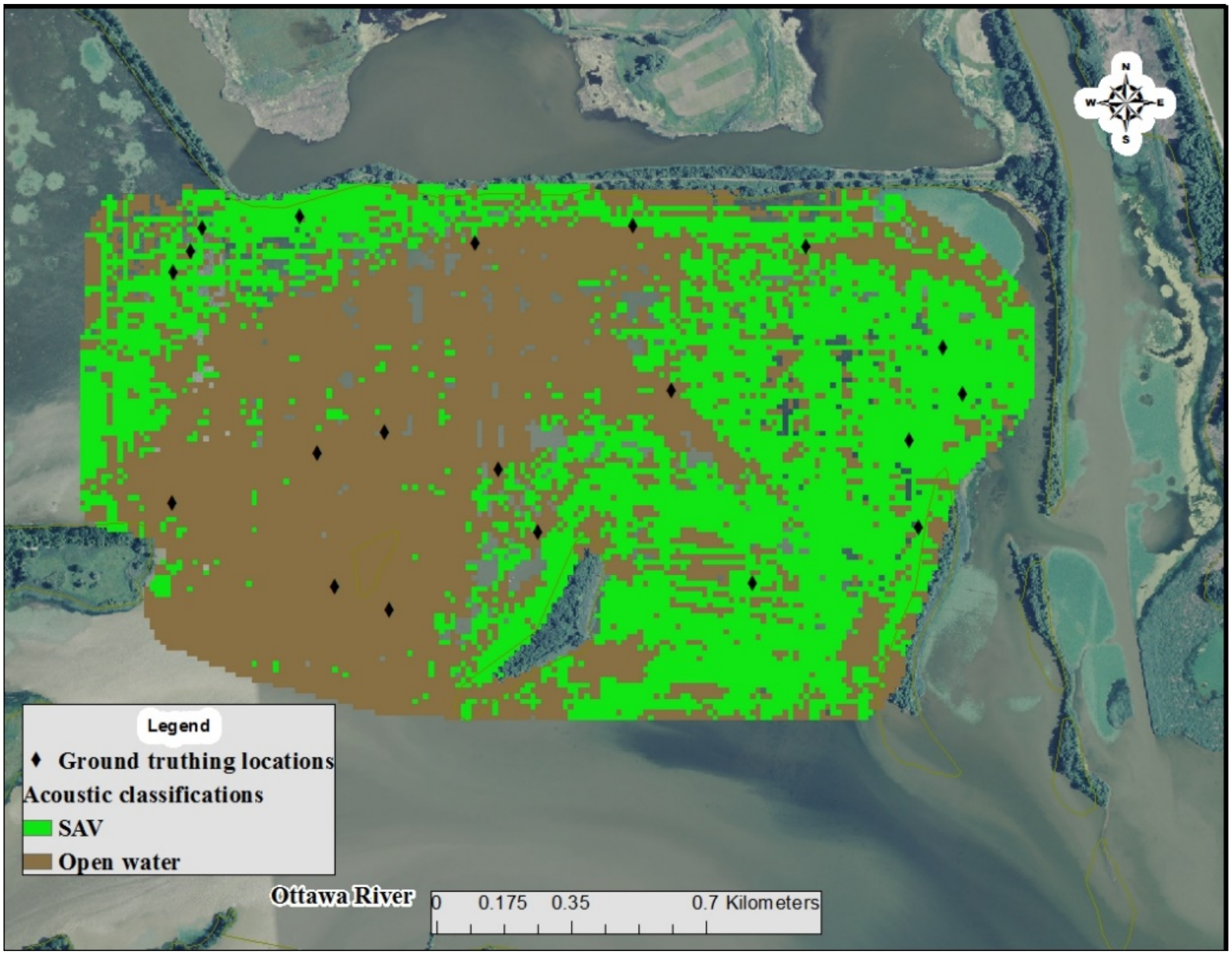


Figure 4. Spatial distribution of submerged aquatic vegetation (SAV) in northern Maumee Bay, generated by analyzing the 2 dominant acoustic classes identified in the side scan survey that made up approximately 96.8% of the research area.

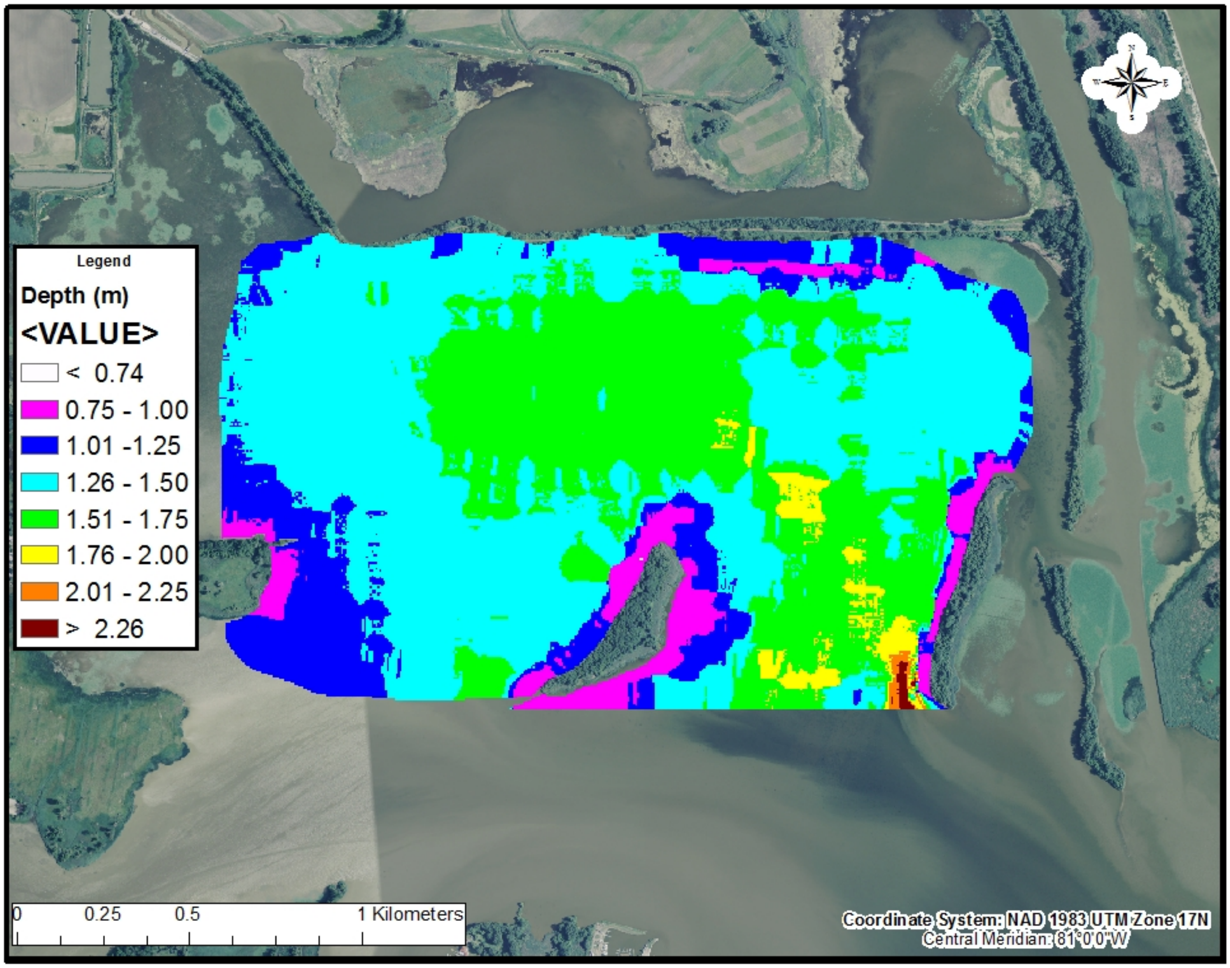


Figure 5. Bathymetry map showing depths in meters inside the research area in northern Maumee Bay in summer 2014.

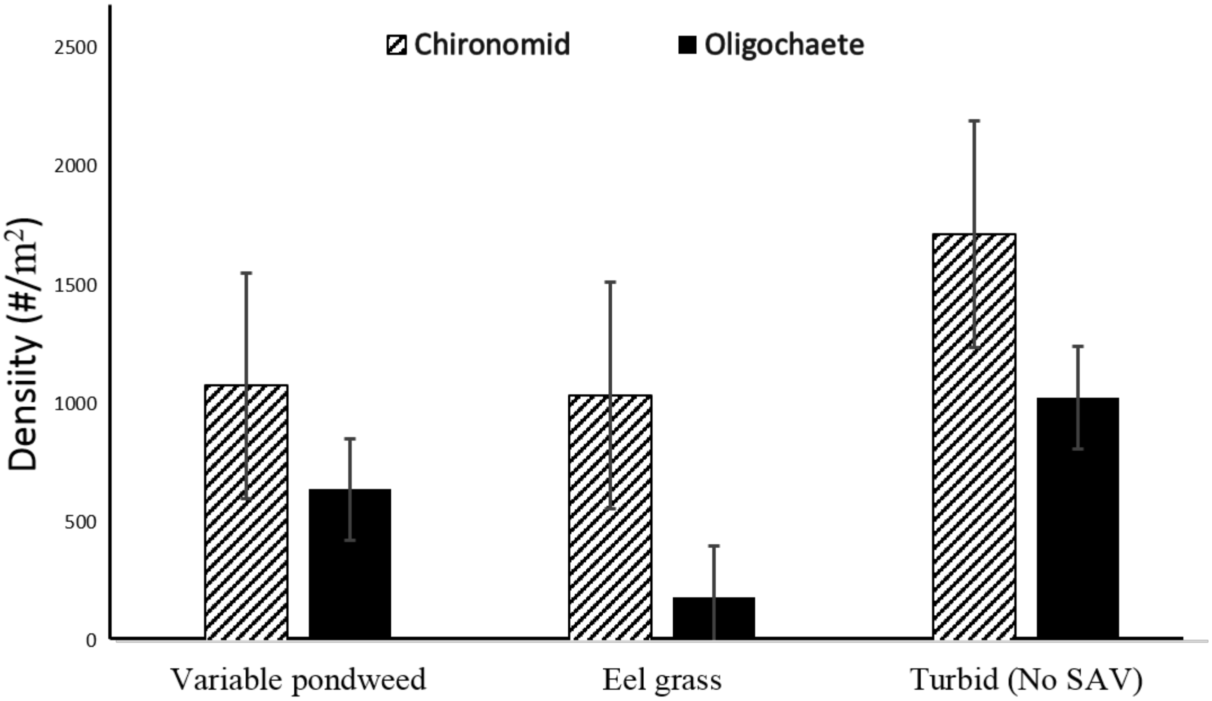


Figure 6. Mean density (± SE) of dominant taxa (chironomids and oligochaetes) in the three dominant habitat types in the study area of Maumee Bay, from PONAR samples (n = 5).

Species	% Composition of sample Turbid(open water)	 Submersed Aquatic Vegetation
Rock Bass (*Ambloplites rupestris*)	nc	0.02
Yellow Bullhead (*Ameiurus natalis*)	nc	0.02
Freshwater Drum (*Aplodinotus grunniens*)	0.03	nc
Goldfish (*Carassius auratus*)	0.14	9.29
Quillback (*Carpiodes cyprinus*)	0.03	nc
White Sucker (*Catastomus commersoni*)	0.24	0.38
Gizzard Shad (*Dorosoma cepedianum*)	21.6	0.54
Western Banded Killifish (*Fundulus diaphanus menona*)	nc	1.94
Channel Catfish (*Ictalurus punctatus*)	0.10	0.02
Brook Silverside (*Labidesthes sicculus*)	0.45	nc
Longnose Gar (*Lepisosteus osseus*)	nc	0.02
Orangespotted Sunfish (*Lepomis humilis*)	0.03	0.18
Bluegill (*Lepomis macrochirus*)	3.38	71.4
Redfin Shiner (*Lythrurus umbratilis*)	0.03	0.00
Large Mouth Bass (*Micropterus salmoides*)	0.07	3.07
White Perch (*Morone americana*)	7.42	0.90
Round Goby (*Neogobius melanostomus*)	nc	0.06
Golden Shiner (*Notemigonus crysoleucas*)	0.03	0.04
Emerald Shiner (*Notropis atherinoides*)	0.83	0.63
Spottail Shiner (*Notropis hudsonius*)	65.3	8.05
Rosyface Shiner (*Notropis rubellus*)	0.21	nc
Stonecat (*Noturus flavus*)	nc	0.02
Tadpole Madtom (*Noturus gyrinus*)	nc	0.07
Yellow Perch (*Perca flavescens*)	0.03	0.18
LogPerch (*Percina caprodes*)	0.03	1.49
Bluntnose Minnow (*Pimephales notatus*)	nc	0.90
Fathead Minnow (*Pimephales promelas*)	nc	0.02
Black Crappie (*Pomoxis nigromaculatus*)	nc	0.65
Total number of fish	2871	4435
Distance sampled with neuston net (km)	3.465	3.165
Average CPUE (# fish/100 m) ± S.E.	81.0 ± 15.4	133.8 ± 29.6
Average Species Richness ± S.E.	5 ± 0.5	8.6 ± 0.6

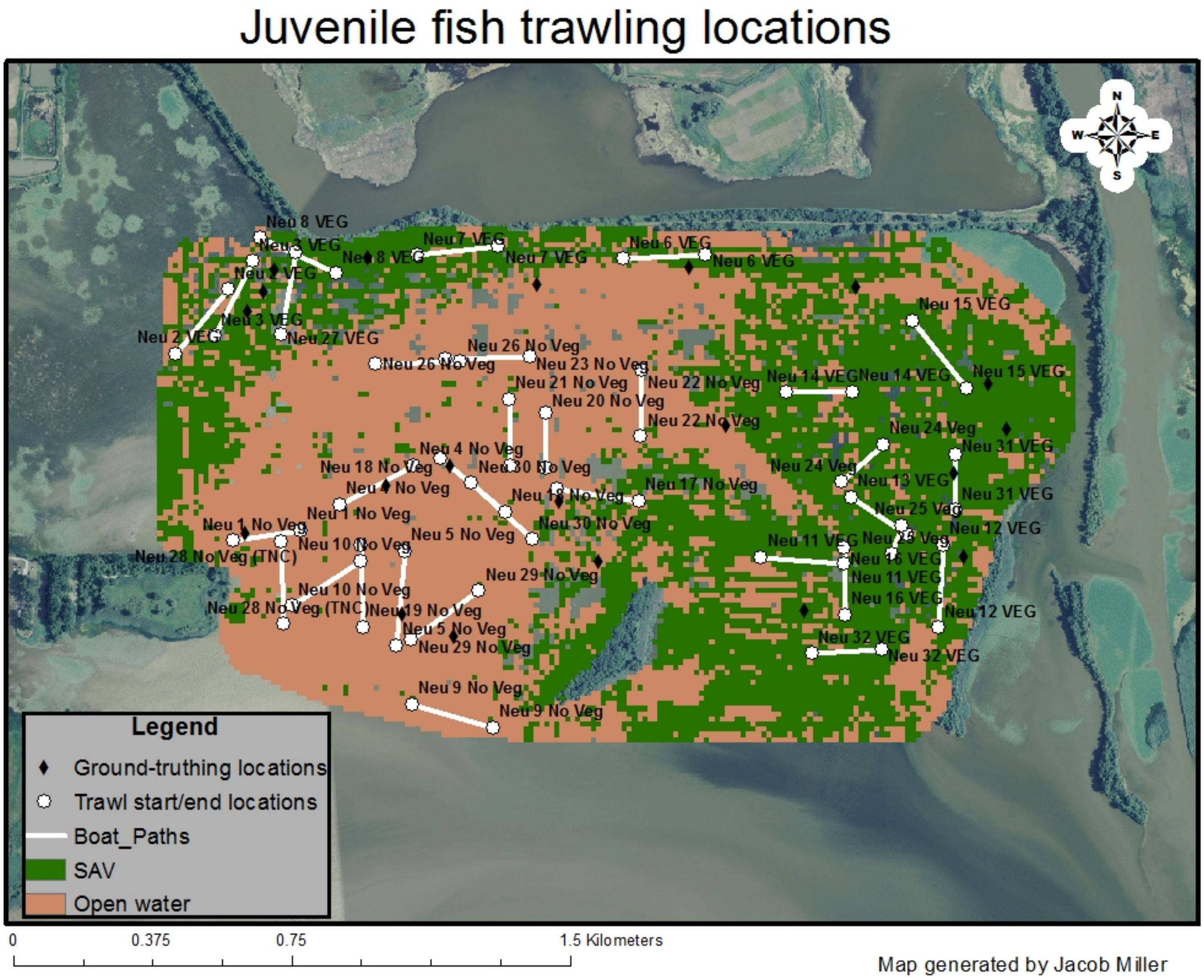
Table 1. Juvenile fish caught with neuston net in two habitat types (turbid (open water) and SAV). Percent composition of each species to the total number caught in each habitat and the average catch per unit effort (CPUE) values measured in number of juvenile fish per 100m (n = 16 trawls per habitat, nc = not collected).

APPENDIX A: GROUND-TRUTH SAV DATA

UTM coordinates		Dry weight (grams) per m^2					
X	Y	Eel grass	Variable pondweed	Leafy pondweed	Musk grass	Sago Pondweed	Total mean SAV biomass
294984.82	4625675.44	0.95	79.81	3.53	12.58	nc	96.87
295031.06	4625730.97	4.05	15.11	1.19	8.22	nc	28.58
295060.71	4625789.47	58.22	0.27	1.16	8.30	nc	67.94
295312.12	4625821.10	13.47	0.40	nc	0.66	nc	14.47
294980.13	4625076.81	nc	nc	nc	nc	nc	nc
295359.59	4625206.14	nc	nc	nc	nc	nc	nc
295531.80	4625259.18	nc	nc	nc	nc	nc	nc
295827.30	4625165.19	nc	2.89	nc	nc	nc	2.89
295932.19	4625001.41	nc	20.12	nc	nc	nc	20.12
295543.62	4624799.52	nc	nc	nc	nc	nc	nc
295403.85	4624859.08	nc	nc	nc	nc	nc	nc
295767.75	4625750.66	86.05	nc	nc	nc	4.14	90.19
296894.59	4625240.71	69.74	nc	nc	nc	nc	69.74
297035.25	4625358.95	83.98	0.3	nc	0.18	0.09	84.56
296984.62	4625480.78	65.4	nc	nc	nc	nc	65.40
296627.34	4625742.82	0.09	39.65	nc	nc	nc	39.75
296176.77	4625796.40	43.43	0.69	nc	nc	nc	43.50
296276.93	4625369.41	nc	nc	nc	nc	nc	nc
296490.13	4624868.83	129.42	3.47	nc	nc	nc	132.90
296918.66	4625014.07	19.34	8.01	nc	nc	nc	25.34

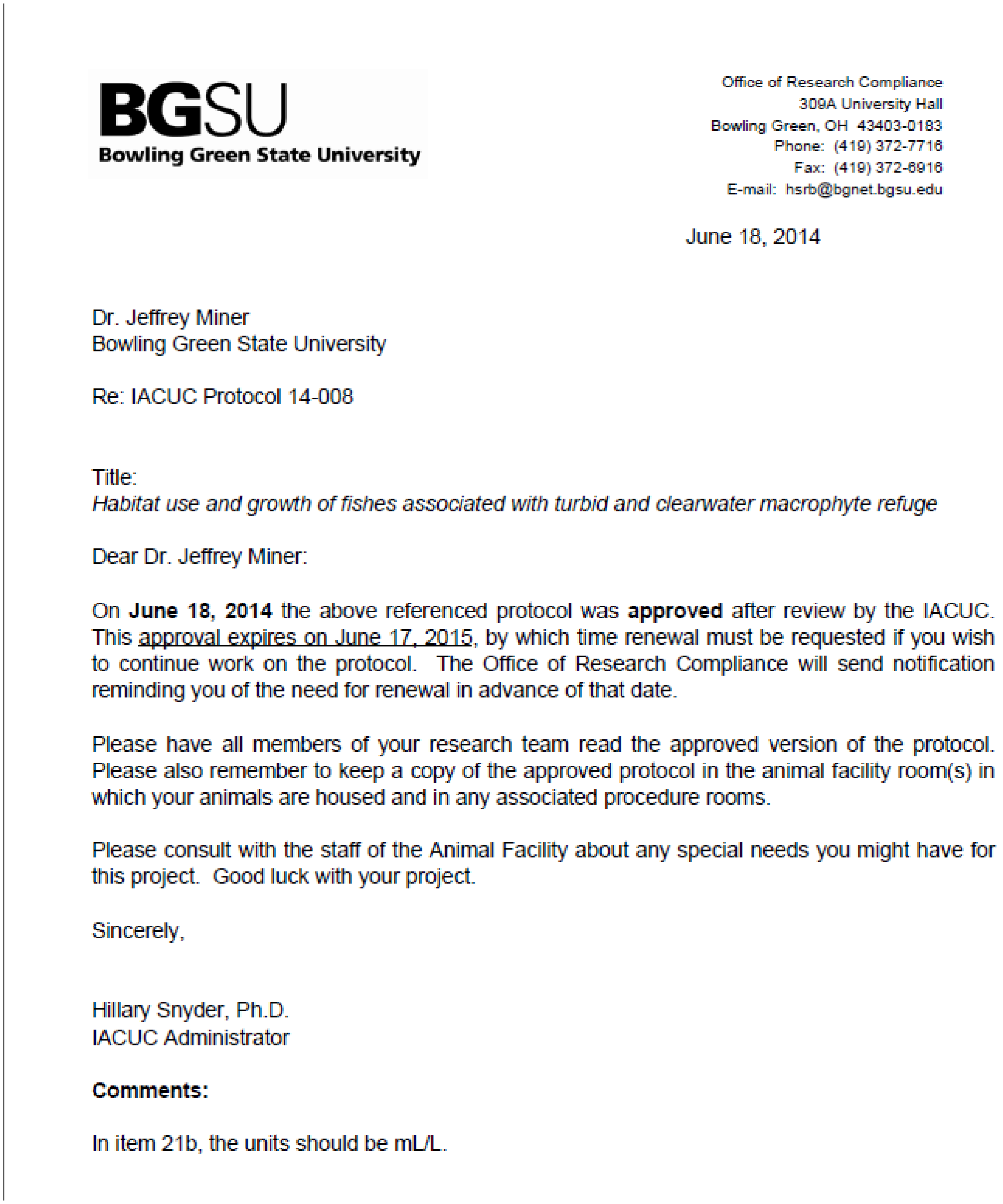
Appendix A. Coordinates and SAV composition/abundances at the 20 ground-truthing locations in north Maumee Bay research area.

APPENDIX B: JUVENILE FISH TRAWLING LOCATIONS



Appendix B. Juvenile fish neuston net trawling locations inside SAV habitat (n = 16) and in turbid, open water habitat (n = 16).

APPENDIX C: IACUC PROTOCOL 14-008



BGSU
Bowling Green State University

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June 18, 2014

Dr. Jeffrey Miner
Bowling Green State University

Re: IACUC Protocol 14-008

Title:
Habitat use and growth of fishes associated with turbid and clearwater macrophyte refuge

Dear Dr. Jeffrey Miner:

On **June 18, 2014** the above referenced protocol was **approved** after review by the IACUC. This approval expires on June 17, 2015, by which time renewal must be requested if you wish to continue work on the protocol. The Office of Research Compliance will send notification reminding you of the need for renewal in advance of that date.

Please have all members of your research team read the approved version of the protocol. Please also remember to keep a copy of the approved protocol in the animal facility room(s) in which your animals are housed and in any associated procedure rooms.

Please consult with the staff of the Animal Facility about any special needs you might have for this project. Good luck with your project.

Sincerely,

Hillary Snyder, Ph.D.
IACUC Administrator

Comments:

In item 21b, the units should be mL/L.