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For

GREAT LAKES SPOTTED MUSKELLUNGE RESTORATION NATURAL SPAWNING EFFORT AND RECRUITMENT EVALUATION (30181-9-G028)

Submitted by

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Executive Summary

The identification, and ultimately protection, of critical spawning habitat for muskellunge (*Esox masquinongy)* in Green Bay is a vital step for re-establishing a self sustaining population in the Green Bay system. This study was designed to document the extent of natural reproduction and locate spawning areas by oviduct insertion of radio transmitters into mature females prior to spawning. Expelled transmitters were later located using radio telemetry to identify spawning sites. Between 2009 and 2010 twenty-six of thirty-seven implanted transmitters were located as deposited. Time constraints prevented modeling of all research areas (Fox River, lower Green Bay, Little Sturgeon, and Menominee River). Menominee River data was chosen as the area to be modeled because it had the most documented successful reproduction in Green Bay and spawning muskellunge exhibited preferential selection of certain habitats.

Menominee River muskellunge preferred spawning in areas with low to moderate bottom slopes, where woody debris was present, where there was medium vegetative coverage, and in substrates containing silt. Based on electivity and model results, muskellunge were preferentially selecting specific habitat as spawning areas. Utilizing these identified habitat preferences allowed successful modeling of spawning areas that effectively identified known spawning locations. Two modeling types were utilized, Maxent and classification trees. The Maxent model proved most effective at predicting additional potential spawning locations and correctly classifying known spawning sites. Classification tree models present a useful management tool to guide habitat restoration in rehabilitation areas to increase muskellunge spawning habitat potential.

Several potential factors that could be limiting natural reproduction were identified during this study. Fish community dynamics present in spawning and nursery habitat could be one factor decreasing natural reproduction through potential predator prey interactions. Low dissolved oxygen levels within specific spawning areas could be causing site specific egg and larval mortality. In addition, limited physical area of suitable spawning habitat may be resulting in use of marginal habitat, thus reducing natural reproductive success in Green Bay.

Potential management implications of this project and model results include identification of suitable stocking locations, critical habitat designation to protect important spawning locations, as well as targeting areas for projects designed to rehabilitate muskellunge spawning habitat. Habitat preferences identified by classification tree models can serve as important guidelines during future restoration projects.

INTRODUCTION

Muskellunge (*Esox masquinongy*) are an important ecological and economic resource throughout their range of existence. They serve as top predators in aquatic ecosystems where they persist (Bozek et al. 1999) and their large size and the overall difficulty associated with catching a single fish, let alone a trophy, help drive the multi-million dollar sport fishery that surrounds muskellunge (Menz and Wilton 1983, Younk and Cook 1992, Farrell et al. 2007). Despite their ecological and economical importance, the future of muskellunge remains uncertain as many populations are limited by low levels of natural recruitment (Dombeck et al. 1986, Inskip 1986).

Historically, muskellunge were an important native species supporting a local near-shore fishery and serving as an important predator in the ecosystem of Green Bay (Smith and Snell 1891, Greene 1935). Muskellunge were known to use several areas throughout the bay as spawning habitat including Peats Lake in the southern bay along with Sturgeon Bay on the eastern shore (Goodyear et al. 1982). However, due to ecosystem changes caused by pollution, habitat destruction, over-exploitation, and exotic species introductions many native fish species, including muskellunge, were extirpated by the mid-1900s (Lake Michigan Fisheries Team 2004, Kapuscinski 2007).

The passage of the Clean Water Act in 1972 led to improved water quality and as a result a response was seen in the local fishery as well, with game species increasing in overall numbers and diversity (Kapuscinski 2007). Several planning efforts including the Lake Michigan Integrated Fisheries Management Plan (Lake Michigan Fisheries Team 2004) and the Lower Green Bay Remedial Action Plan (WDNR 1986) expressed the need to re-establish the once-native muskellunge in order to improve the fishery in Green Bay and the overall stability of the fish community (WDNR 1986, Lake Michigan Fisheries Team 2004, Kapuscinski 2007).

A plan was constructed by Wisconsin Department of Natural Resources (WDNR) biologists to reintroduce and re-establish a self-sustaining population of Great Lakes strain muskellunge (Kapuscinski 2007). In 1989 the reintroduction plan began with strong support from Musky Clubs Alliance of Wisconsin. Initially the Indian River Chain of Lakes in the Southern Peninsula of Michigan was chosen as a genetically appropriate source population. Gametes were collected for 5 years. Fertilized eggs were also imported from Lake St Clair in 1996. All fertilized eggs were brought to Wisconsin, hatched and raised at Wild Rose State Fish Hatchery, and stocked into Green Bay and an inland brood lake. The inland brood lake was used for gamete collection from 1995 until 2001, then gametes were collected from the established Fox River population. From 1995 to 2001 an average of 2,875 muskellunge were stocked each year; this number increased dramatically to average 20,324 muskellunge annually from 2002 to 2006.

Adult muskellunge populations have responded positively to the increased stocking efforts over the past twenty-two years. Spring netting and fall electrofishing data show increasing catch-per-unit-effort, total abundance, and mean size for adult fish (Rowe 2010). As this re-established population has continued to mature and increase in size, the muskellunge fishery in Green Bay has rapidly increased as well (Rowe 2010). In 2008 the Lake Michigan creel survey estimated the directed effort toward muskellunge was 35,638 hours (Rowe 2010).

Although Green Bay currently supports a trophy muskellunge fishery, with significant numbers of fish larger than 1270 mm, the population has been solely dependent on stocking. It was hypothesized that insufficient populations of adults present in the bay limit natural recruitment (Kapuscinski 2007). However, the increasing population of adults along with observations of spawning muskellunge throughout the bay (Rowe 2010) has provided evidence that the population may be past this critical threshold even though there has been no natural reproduction documented in the lower bay or Fox River (Rowe and Lange 2008). In 2008, two young-of-the-year muskellunge were captured from lower Menominee River and genetic analysis confirmed these fish consistent with the stocked strain of Great Lakes spotted muskellunge (B. Sloss, University of Wisconsin-Stevens Point, personal communication), marking the first evidence of natural reproduction in the bay. From 2009 to 2010 two additional naturally reproduced muskellunge were captured in the Menominee River and one in Sturgeon Bay. To date the documented levels of natural reproduction are significantly below levels needed for a self sustaining muskellunge fishery even though population levels have drastically increased since 2000. Therefore it is important to consider alternative hypotheses of potential factors that could be limiting natural recruitment.

It has been well documented that lack of spawning habitat can limit natural reproduction in muskellunge populations (Dombeck et al. 1984, Dombeck et al.1986, Zorn et al. 1998, Rust et al. 2002, Nohner 2009). Muskellunge are broadcast spawners and provide no parental care to their young with the average female producing 120,000 non-adhesive eggs that are laid over hundreds of yards (Scott and Crossman 1973, Oehmcke et al. 1974, Hess and Hartwell 1978, Becker 1983, Nohner 2009). Dombeck et al. 1984 concluded that different populations of muskellunge utilize different spawning habitat and that spawning habitat can be critical to the developing embryos. The inland form of barred muskellunge have been observed spawning in shallow bays less than 1 m in depth with vegetation, woody debris, and silt/muck bottoms (Scott and Crossman 1973, Oehmcke et al. 1974, Dombeck 1979, Becker 1983, Zorn et al. 1998, Pierce et al. 2007, Nohner 2009). However, other inland lake populations preferred deeper water, between 1-2m, composed of mostly *Chara* spp. (Strand 1986). Studies on Great Lakes form of spotted muskellunge have documented fish in Lake St. Clair to the St. Lawrence River spawning from shallow (<1 m) to deep water (>3 m) with no vegetation or moderate to high vegetation, respectively (Haas 1978, Farrell et al. 1996). Habitat locations have ranged from open water to vegetated marshes, shoals in main river channels, and shallow backwaters along river margins. Substrates consisted of rock, gravel, sand, and silt (Haas 1978, Harrison and Hadley 1978, Farrell et al. 1996, Younk et al. 1996). However, much of the current literature on muskellunge, with the exception of a few recent studies, only qualitatively described muskellunge spawning habitat and failed to compare background, or available, habitat to spawning habitat. As a result they were unable to identify muskellunge preferences and can only discuss usage of particular habitat types (Nohner 2009).

Previous studies attempting to model spawning habitat for muskellunge (Dombeck et al. 1986, Rust et al. 2002) were limited in that they predicted spawning success at the whole-lake level and failed to predict specific areas within an individual lake where spawning was likely to occur (Nohner 2009). Farmer and Chow-Fraser (2004) built a conceptual model using temperature, dissolved oxygen (DO), and spatial separation of eggs as primary variables for predicting spawning habitat. However, this model did not directly address other variables, such as substrate and vegetation, which have been noted by many other researchers as being key variables in defining muskellunge spawning habitat. Nohner (2009) attempted to address many of these shortcomings but also lacked fine scale resolution of percent substrate composition and percent vegetative coverage that may be important drivers in determining preferred muskellunge spawning habitat. Nohner also relied on his own determination of categorical variables to quantify spawning habitat that may not have biological and ecological relevance in classifying spawning habitat.

With the extreme variation in spawning habitat utilized by muskellunge, it is imperative that spawning sites be identified and preferred spawning habitat be defined for Green Bay muskellunge to allow for the prediction of additional possible spawning areas. Several methods have been used to identify muskellunge spawning locations, including direct observation (Zorn et al. 1998, Nohner 2009), radio tracking (Strand 1986), and extensive egg sampling (Farrell et al. 1996). These are all very labor intensive methods, especially for a large and extensive system such as Green Bay. More recently, muskellunge spawning locations have been identified by insertion of miniature radio transmitters into oviducts of mature females prior to spawning, which are then located using telemetry after fish had expelled the transmitter while spawning (Pierce 2004, Pierce et al. 2007). Although still time intensive, oviduct implantation and telemetry are more feasible and applicable methods for a system like Green Bay where it is impossible to effectively sample any substantial area using any of the other methods.

Crossman (1990) and Farrell et al. (2007) have shown evidence supporting spawning site fidelity in muskellunge. As a result, fisheries managers have begun site specific stocking efforts targeting areas with suitable habitat characteristics as stocking sites (Werner et al. 1996, Farrell and Werner 1999, Rowe and Lange 2008). However, this approach is limited by the ability of managers to identify areas with suitable habitat. The first step to addressing this issue is to identify spawning locations in Green Bay that will allow for more efficient habitat protection and enhancement efforts along with the selection of more effective stocking locations (Rowe and Lange 2008). In addition to identifying spawning locations, the ability to understand and model specific finely resolved habitat parameters preferred by spawning muskellunge, and the ability to predict areas with suitable spawning habitat that will support successful recruitment, are critical to the success of stocking programs (Farrell et al. 2007) and re-establishment of muskellunge in Green Bay.

Since the muskellunge population in Green Bay is limited by lack of natural recruitment and reliance on stocking, this study was designed to better understand these relationships and to assess spawning habitat and natural recruitment in Green Bay muskellunge. This study addressed other shortcomings in the muskellunge literature by quantitatively describing muskellunge spawning habitat preference at a finer resolution than has previously been documented and by testing models' predictive abilities using both human defined variable categories as well as continuous variables, allowing models to determine natural breaks in continuous predictor variables. The specific objectives of this study were to (1) Identify locations in Green Bay and its tributary rivers where muskellunge spawn. (2) Document egg deposition at identified spawning locations. (3) Quantify physical habitat of the identified spawning locations. (4) Build a spatial model to predict potential spawning locations based on physical habitat characteristics. (5) Identify potential causes of mortality to eggs. (6) Document if spawning locations also act as nursery habitats and whether they continue to be utilized by age-0 muskellunge. (7) Identify relationships between young-of-the-year muskellunge and the fish community and habitat where they are found.

METHODS:

Study Site

This study was conducted in Green Bay, an extension of northwestern Lake Michigan that can be classified as a freshwater estuary (Smith et al. 1988, Herdendorf 1990) (Figure 1). Green Bay, encompassed by Wisconsin and Michigan, is 193 km long and up to 30 km wide; the watershed covers 40,000 km^2 and is fed by eleven rivers and streams (Bertrand et al. 1976). The southern waters are considered hyper-eutrophic while the northern waters are meso-oligotrophic (Smith et al. 1988, Sager and Richman 1991).

Based on netting and angler reported recaptures of tagged muskellunge, the WDNR recognizes three distinct populations of muskellunge within the bay with a minimal degree of mixing despite no physical barriers separating them (Rowe and Lange 2008). These populations closely mirror stocking efforts of the WDNR; with one population inhabiting the lower portion of the bay and the Fox River, a second population on the west shore concentrated around the Menominee and Peshtigo rivers, and a third population on the east shore in the area around Sturgeon Bay and Little Sturgeon Bay (Rowe and Lange 2008).

Spawning Site Identification

For the purposes of this study, muskellunge spawning sites were identified by inserting radio transmitters into the oviducts of mature female muskellunge (>100 cm) prior to spawning and then locating the transmitters using radio telemetry after they had been expelled by the female during a spawning event. Past studies have shown radio transmitters were expelled by the muskellunge along with eggs during spawning, allowing for identification of spawning locations (Pierce 2004, Pierce et al. 2007). Fish for implantation were captured during April and May, 2009 and 2010, using fyke nets with 1.5m diameter hoops and leads varying from 15 to 30 m in length. Data collected from each implanted fish included length, weight, frequency of transmitter implanted, sex, and reproductive condition. Sex was determined by stripping; if no gametes were yielded, urogenital pores were examined to determine sex of the muskellunge (Lebeau and Pageau 1989). Reproductive condition was classified as "ripe" if eggs were produced when the fish was stripped by hand, or "hard" if eggs were not produced when stripped.

Female muskellunge were implanted with Advanced Telemetry Systems (ATS) model F1420 miniature radio transmitters. Each transmitter was 8 mm wide and 16 mm long, weighed 1.3 g, had a 25 cm long wire antennae, with a guaranteed battery life of 29 days. Transmitters were inserted through the oviduct into the egg masses, allowing antennae to trail out through the oviduct (Pierce et al. 2007). Transmitter frequencies ranged between 49.004 and 49.366 mHz.

In 2009, transmitters were implanted into mature female muskellunge from the Fox River and lower bay. The lower bay is defined as the area from the mouth of the Fox River to Little Tail Point. In 2010, muskellunge were implanted from the Menominee River and Little Sturgeon Bay (Figure 1). Implanted fish were located using a four element ATS yagi mast mounted radio telemetry antenna and an ATS R2000 receiver programmed to cycle through transmitter frequencies on a 4 second delay. When a transmitter was found a handheld square antenna was used to pinpoint the transmitter and the location was recorded using a handheld Garmin eTrex Venture HC geographic positioning system (GPS). Date, time, water temperature, depth, and physical habitat were noted in addition to location. If a transmitter was stationary for consecutive tracking trips, it was assumed to be expelled and hereafter is referred to as a "deposited" transmitter. The location of the deposited transmitter was then pinpointed based on signal strength and direction using an underwater antenna (Fellers and Kleeman 2003) and a GPS waypoint was taken.

After a deposited transmitter was identified, egg searches were used to verify these locations as spawning sites. Egg searches were conducted using D-frame nets to sample bottom sediments which were visually sorted for eggs. Searches were conducted until an egg was found or a standardized search effort of 1.5 person hours had been expended (Zorn et al. 1998).

Assessing Natural Recruitment

Two rounds of seining, one in July and one in August, were completed at each location a transmitter was deposited to assess natural recruitment of muskellunge and fish community structure following sampling guidelines in Farrell (2001). A 7.6 m long by 1.2 m high seine with a 1.2 m by 1.2 m bag and 3.2 mm mesh was used in July, and a 22.9 m long by 2.4 m high seine with a 1.8 m by 1.8 m bag and 9.5 mm mesh was used in August. All fish collected were identified to species and released.

Spawning Habitat Characteristics

Eight major variables were measured within all identified spawning sites to characterize spawning habitat: (1) depth, (2) bottom slope, (3) shoreline development, (4) shoreline habitat, (5) substrate composition, (6) percent of total vegetative coverage, (7) percent vegetative species composition, and (8) coarse woody debris. Habitat parameters were measured within a 10x20 m (200 m^2) grid centered over the recovered transmitter. This 200m^2 grid was considered the "spawning site." The grid was broken into 1 m^2 quadrats and measurements were taken within these quadrats. Five measurements were taken along a transect parallel to shore, centered over the deposited transmitter and 10 measurements were taken in random squares throughout the grid, resulting in a total of 15 quadrats sampled within a spawning area (Figure 2).

Bottom slope was measured by taking depth readings 5 m toward shore (perpendicular to shore) from the deposited transmitter and 5 m away from shore from the deposited transmitter (Figure 2). Slope was also classified into categories of 0-3.0%, 3.1-6.0%, 6.1-9.0%, 9.1-12.0%, and greater than 12% to be tested in addition to continuous slope percentages (Nohner 2009). Shoreline development was assessed as a percent of the 20 m of shoreline parallel to the spawning site that was developed. Distance from shoreline to the development and type of development were also recorded. Shoreline habitat was also assessed at two levels, immediate (at the water's edge) and environmental (habitat type away from water's edge). Immediate and environmental shoreline habitat categories included: wooded, shrub, lawn, wetland, rip rap, grasses, exposed rock, sand. The remaining physical habitat characteristics were measured in each of the 15 quadrats within every spawning site.

Inorganic substrate composition was determined by feel or by visual observation, after a sample was taken with a dip net. It was recorded as percent (to the nearest 5%) of each category with the following classification criteria defining categories: bedrock (solid slab), boulder (261 mm - 4.1 m), cobble (65 – 260 mm), gravel (2 – 64 mm), sand (0.062 – 1.9 mm), silt (0.004 – 0.061 mm), and clay (0 - 0.003 mm) (Simonson et al. 1993). If present, percent coverage of leaf litter, woody debris, and shells were also visually estimated to the nearest 5% in each sampled quadrat. A final category of sand silt mix was created as an additional substrate category to be tested. In order for a location to be classified as having a sand-silt mix there had to be at least 10% sand and silt present and the location was not to include greater than 10% of any other substrate type. Several techniques were tested to measure aquatic vegetation, including visual estimation, a viewing tube, and rake samples. Limited visibility due to high turbidity prevented visual estimation and the use of a viewing tube to measure percent coverage of submersed aquatic vegetation (SAV). Therefore, the standard use of a vegetation rake was chosen as the method to sample SAV abundance. This is a proven method especially in areas where visibility is limited (Kenow et al. 2007). SAV and emergent vegetative coverage were estimated by taking a rake of the bottom within each $1m^2$ quadrat. Percent total coverage (0-100%) of vegetation was estimated and broken into percent submergent and percent emergent. These total percents were then broken into percent composition by individual species, yielding an overall percent coverage (percent SAV and percent emergent vegetation), percent coverage by species, and number of species present. Total vegetative coverage was also broken down into categories of low (0-33%), medium (34-66%), and high (67-100%).

Coarse woody debris (CWD) was estimated by walking two transects, 2.5m to either side of the deposited transmitter transect and parallel to the shoreline. The number of individual pieces of CWD were counted and the diameter of each piece was estimated as 5cm, 10cm, or >20cm.

Spawning habitat characteristics were determined for each spawning area by averaging data for each variable from all 15 quadrats.

Dissolved Oxygen (DO) was also measured on two separate mornings within each spawning area using a YSI 55 dissolved oxygen meter mounted to a staff to ensure readings were collected at a consistent distance (0.5 cm) above the water-substrate interface (Zorn et al. 1998). Readings were taken at 5 randomly chosen locations within each spawning area, between the hours of 0400 – 0600, and within 14 days of locating the deposited transmitter. Three readings were taken at each of the 5 random locations within each spawning area. The meter was allowed to stabilize before the first reading was taken, followed by a reading a minute after stabilization, and a third reading another minute later (two minutes after stabilization), giving a total of 15 measurements per location per morning measured.

In order to test whether muskellunge preferentially selected for or against certain characteristics as spawning habitat, the available habitat was also quantified. Eighty background sites were measured within each of the 4 individual research areas (Fox River, lower bay, Little Sturgeon Bay, and the Menominee River). All background habitat measures were collected within the spawning season (determined by deposition dates of transmitters) during the 2010 field season. At each background site, shoreline development, shoreline habitat, depth, bottom slope, substrate composition, abundance of total vegetative coverage, percent vegetative species composition, number of vegetative species, and coarse woody debris were measured using the same methods previously described. Location of background sites were randomly selected but depth of random sampling was stratified based on spawning site depths observed in 2009. Random sampling was constrained based on landmarks that provided a substantial buffer beyond spawning areas identified by deposited transmitters. In the lower bay background sampling was conducted in areas between Little Tail Point on the west shore and Point Sable on the east shore (Figure 1). Background habitat was confined to the Menominee River on the west shore, as all deposited transmitters were located within the river boundaries. On the east shore background habitat was measured within Little Sturgeon Bay.

Ivlev's index of electivity (1961) was successfully used by Nohner (2009) to determine muskellunge spawning habitat preference and was, therefore, also used for this study. The index estimates electivity, E = (r-p)/(r+p), with "r" representing the proportion of known spawning sites with a given categorical habitat characteristic and "p" being the proportion of background habitat sharing the same categorical habitat variable. Habitat preference is dependent upon a comparison between prevalence of a habitat characteristic within spawning locations compared to overall habitat available. When using Ivlev's index the sign of the electivity number shows if a habitat category is being selected for (positive values) or against (negative values) and the magnitude of that number gives an indication of the strength of selection from 0-1. Electivity was determined separately for each variable by comparing spawning habitat to background habitat. Chi-square tests could not be used to test for statistically significant differences between spawning and background habitat as several of the categories failed to meet the assumption of the test that each category tested must contain five or more observations (Zar 1999).

A t-test was used to test for significant differences in means of continuous variables between spawning and background locations with the null hypothesis that mean values were equal between spawning sites and background sites (R Development Core Team 2010). If variances between spawning and background habitat were determined to be equal (less than 0.5) then a 2 sample t-test was used but if this assumption was not met then a Welch's t-test was applied. For all statistical tests, alpha was set at 0.05.

Variables used for modeling were selected using the results from the Ivlev Electivity Index and t-test. Categorical variables with at least two observations and an electivity of greater than 0.3 or less than -0.3 in any category were included in the model. Continuous variables resulting in significant differences between means as measured by t-tests were also included in the model. The goal of these tests is to limit the number of variables included in modeling because having a high ratio of model variables to number of occurrence observations can lead to overfitting of Maxent models (Harrell 2001, Burnham and Anderson 2002).

Modeling Muskellunge Spawning Habitat

Muskellunge spawning habitat suitability was modeled using two different approaches, Maxent and tree regression analysis. Maxent was chosen because it has been proven to outperform other modeling techniques when sample sizes are low (Hernandez et al. 2006, Pearson et al. 2007), requires only presence data (Phillips et al. 2006), and has already been effectively utilized to predict muskellunge spawning habitat (Nohner 2009). It is a machine learning program that predicts a probability distribution of a species that maximizes entropy, or is closest to uniform (Phillips et al. 2006, Phillips et al. 2008). Similar to Nohner 2009 muskellunge spawning habitat was considered a species and the distribution of this "species" was modeled. In this case Maxent used spawning sites identified by deposited transmitters as known presence locations and environmental data from background habitat as available habitat. The predicted distribution Maxent outputs is a map where each cell has a probability between 0 and 1 representing the likelihood of the species (spawning site) occurring in that cell. A cell with a predicted probability close to 1 represents the most suitable habitat (best spawning) habitat, within the study area while cells with predicted probabilities close to 0 represent areas of lowest suitability (Phillips et al. 2004).

Typically data sets will be divided into training and test sets where a given percentage of the data (often 75%) will be used to train the Maxent model and the remaining (25%) will be withheld to test the model's predictions (Pearson et al. 2007). However, with small sample sizes this technique is not applicable as training and test data sets become too small (Pearson et al. 2007). To address this problem, a bootstrapping replication technique was applied to the dataset which uses all occurrence data to build the model. The model is then tested against a user defined percentage of the dataset. Bootstrapping is sampling with replacement, meaning that individual occurrence points can be used more than once in the testing dataset for any particular model run (Phillips et al. 2008). By allowing all data to be included in building the Maxent model, bootstrapping makes the most out of small data sets when removing a single data point would result in a substantial amount of data being removed. Bootstrapping provides a practical approximation of the model's ability to make predictions and has been shown to be better than cross-validation at estimating model performance (Wintle et al. 2005). Models were tested with varying numbers of replicates (1, 5, 10, 25, 50, 100, 250, and 500) to test the effects of the number of bootstrapped replicates on the results. Using a high number of replicates in a bootstrapped model ensures that all occurrence locations are used to test the model and is another way to make best use of small data sets (Phillips et al. 2008). For this study the user defined test percentage was set at 22%, meaning the constructed model is tested against 22% of the known spawning sites to determine its classification ability. All other model parameters were set to Maxent defaults.

Performances of the model's results were tested using a threshold-independent analysis by computing a receiver operating characteristic (ROC) curve. A ROC plot is created by plotting sensitivity values, the true-positive fraction against 1-specificity, the false positive fraction for all available probability thresholds (Hernandez et al. 2006). For each model run the area under the ROC curve (AUC) was calculated allowing the user to see variation as well as minimum and maximum AUC values between replicate runs. An average AUC was also computed across all replicate model runs. AUC indicates that for any x-y point on the plot, the x value represents percent of the available area that has been included to predict y percent of spawning sites (Phillips et al. 2004). An AUC value of 0.5 represents a model that is no better than random at predicting spawning habitat and a value of 1.0 represents a model that can discriminate perfectly. However, maximum AUC is less than one when modeling species that use a wide array of habitat (Phillips et al. 2004) and is further decreased when only using presence-only data to create models (Wiley et al. 2003).

The contribution of each habitat parameter to the model was estimated using a jackknife test of variable importance (Yost 2008). This jackknife test provides two separate measures.

First, it tests the gain of a model based solely on each single habitat variable and then tests the gain of a model that excludes only that particular variable. This allows the user to determine overall improvement in gain and loss of gain in a model when each individual variable is included or excluded (Phillips et al. 2008).

Effect of each environmental variable on the Maxent model was also tested by plotting the logistic prediction against the range of each environmental variable while all other environmental variables were held at their average sample value (Phillips et al. 2008). In other words, during this test all variables were held at their average value while the probability of spawning habitat was plotted as a single variable was allowed to vary across its range. Logistic predictions near one represent a high probability of spawning, while predictions near zero indicate low likelihood of spawning (Nohner 2009). Locations with a predicted value of 0.5 or less indicate that these areas have a less than random chance of containing spawning habitat while sites with a predicted probability of greater than 0.5 are considered to have spawning habitat present. The closer the value is to 1 the greater the probability and the more suited the location is as a spawning area.

Each habitat layer used for Maxent modeling had to be created from raw data gathered at each individual background location. Background data was first interpolated using ordinary kriging in ArcMap 10 (ESRI 2011). Kriging specifications were tested to determine which combination resulted in the lowest root mean square error rates. The kriging specifications that lowered error rates utilized 7 lags and 5 nearest neighbors. Kriged layers were then converted to raster layers which were masked to include data only within the specified research area boundaries. Masked raster layers were then converted to ASCII files which are the required file type for Maxent input layers.

Muskellunge spawning habitat was also modeled using a classification tree approach in R based on the recursive partitioning package (Therneau and Atkinson 2010). Classification trees can be used to explain a single response variable by using environmental data, categorical and/or numerical, to create splits that result in more homogenous groups (De'ath and Fabricius 2000). In this case, the recursive binary partitioning analysis was used to discover differences in habitat characteristics between spawning and background locations. The model divides a dataset by selecting the single habitat variable that accounts for the most variability between the two groups and makes a split in the dataset using that particular variable. This process is then repeated on each of the two groups created from the previous split with each variable being assessed at every split whether the variable was previously used or not (Rejwan et al. 1999). The groups are continually split into more homogeneous groups until only a single location remains as a group or until there is no variation between locations in a group (Clark and Pregibon 1992).

The classification tree model is represented graphically with the undivided data set at the top (the root) followed by each of the nodes (a binary split), which are further split until the final undivided groups (the leaves) remain at the bottom of the tree (De'ath and Fabricius 2000).

Splits near the top of the classification tree are more likely to properly represent actual differences in habitat characteristics between known spawning and background locations. Near the bottom of a tree, splits are performed on such small sample sizes that the precision of each split is weakened, making results less generally applicable and less effective in modeling (De'ath and Fabricius 2000). Therefore, large classification trees are often "pruned" to eliminate bottom splits, thereby decreasing overall tree size and maximizing precision of the model.

The rpart package provides several error outputs that are used in evaluating overall ability of the classification tree to accurately identify differences between spawning and background locations. The relative error (rel error) identifies the number of incorrectly classified sites at each split and can also be used to calculate r-squared values (1-relative error). The model also provides a "xerror" which is calculated by splitting the dataset into training and testing sets. The model is then built using training data and testing data that was not used to train the model. Each of these error rates are standardized to the maximum error, which is the error that exists with no splits in the dataset (Kevin Wehrly, Michigan Department of Natural Resources, personal communication). Since the variable of interest for the spawning habitat model is categorical (spawning or background habitat) the "class" mode of classification was used. The rpart parameters used in this study were: minsplit = 3 (minimum number of observations in a node that the model will try to split; minbucket = 2 (minimum number of observations in a leaf); xval = 9 (controls the number of cross-validations to be performed); cp = 0.01 (default setting, cp is the complexity parameter which controls pruning of the classification tree) (Atkinson and Therneau 2000).

RESULTS:

Identifying Spawning Locations

In 2009, transmitters were implanted into mature female muskellunge from lower Green Bay, 10 fish from the Fox River and 10 from the bay itself. In 2010, 13 mature female muskellunge were implanted from the Menominee River and 4 females from Little Sturgeon Bay. Female muskellunge used for oviduct implantation of radio transmitters were 101-133 cm total length (TL) and averaged 122 cm (Table 1).

Eight of 10 transmitters implanted in the Fox River and 5 of 10 implanted in the lower bay were located as deposited (Figure 3). In 2010, 9 of 13 transmitters implanted in the Menominee River were located as deposited (Figure 4). All 4 transmitters that were implanted in Little Sturgeon Bay were deposited (Figure 5); however, one transmitter was located in the same area where it was implanted, and egg searches were not able to verify the location as a spawning site. Therefore, that location was not considered a spawning site. Over the 2 year study 37 transmitters were implanted and 25 were found as deposited, yielding a 68% deposition and discovery rate. There was no significant difference in size of muskellunge that expelled their transmitter (121 cm TL, SD=9.5) compared to those whose transmitters were not found as deposited (122 cm TL, SD=7; 2-sample t-test; P>0.50). Reproductive condition of fish at implantation was also tested to determine whether it had an impact on likelihood of deposition. However, there was no correlation between condition of fish and likelihood of transmitter deposition (Yates corrected chi-square, n=36, v=1, P>0.05).

Deposited radio tags continued to transmit signals for more than 50 days. Implanted muskellunge carried transmitters between 1 and 26 days while traveling distances from 0.2 km to 19 km before expulsion (Table 1). Signals from deposited transmitters were located within 2 m^2 using an underwater antennae (based on signal strength and direction) but could not be visually located or physically extracted due to water turbidity and algal growth. Transmitter signal strength and range were tested by sinking a transmitter in a known location and testing the maximum distance of detection. Effective range varied from 20 to 870 m depending on type of antenna, depth of water, density of vegetation, and water conductivity (Table 2).

Egg Searches and Natural Recruitment

Egg searches were completed at 12 of the 13 deposited transmitter locations in 2009. One transmitter was expelled near Little Tail Point in water that was too deep for wading and cold water temperatures that were present when the transmitter was found prevented swimming to conduct egg searches. Of the remaining 12 deposited transmitter sites (6 in the Fox River and 6 in the lower bay) 6 sites were confirmed to have eggs present. However, no young-of-the-year (YOY) muskellunge were captured during summer seining in the Fox River or lower bay. July seining results showed that the three most dominant species present in lower bay spawning areas were yellow perch (*Perca flavescens*), round goby (*Neogobius melanostomus*), and gizzard shad (*Dorosoma cepadianum*), which respectively represented 82%, 5%, and 4% of total catch determined by number individuals (Figure 6).

In 2010, only 1 of 3 deposited transmitter locations in Little Sturgeon Bay for eggs. Again, water depth and cold temperatures prevented wading and swimming to conduct surveys at two locations. Summer seining efforts in Little Sturgeon Bay failed to capture any YOY muskellunge. Nine deposited transmitter locations were searched in the Menominee River, and 5 searches found muskellunge eggs. No YOY muskellunge were found during the first round of seining in July. The three most abundant species in the Menominee River were pumpkinseed (*Lepomis gibbosus*), largemouth bass (*Micropterus salmoides*), and round goby (*Neogobius melanostomus*), accounting for 26%, 25%, and 16% of total catch (Figure 6). During August seining one YOY muskellunge was captured at a deposited transmitter location just downstream of Strawberry Island. The fish was 172mm, weighed 18g, and represents the sixth naturally reproduced muskellunge discovered to date in the Menominee River system.

Due to extreme time commitment required to develop spatial models and the fact that natural reproduction was only documented in the Menominee River, the Menominee River was the area chosen to assess for spawning habitat preference and to build spatial predictive models in order to predict additional spawning habitat.

Spawning Habitat

Menominee River muskellunge utilized a wide range of habitat for spawning. Depths of deposited transmitters varied from 25-157 cm (averaged 83 cm). Vegetative coverage within spawning areas ranged from no vegetation to completely covered and dominant substrates included cobble, gravel, sand, and silt.

Average DO levels within Menominee River spawning areas ranged from 3.81 to 8.46 mg/L. The average across all spawning areas was 5.7 mg/L but varied based on location measured and individual days. Two of the spawning areas had measured daily averages below 4 mg/L on one of two days DO was measured. When averaged over the two days measured DO levels within a given spawning area never fell below 4.2 mg/L.

Spawning muskellunge preferentially utilized areas with high levels of total vegetative coverage; 66% of spawning areas had 34-100% vegetative coverage, compared to only 25% for the abundance of such available habitat (Table 3). Areas with medium vegetative coverage (34-66%) were preferred most by spawning muskellunge as seen by an electivity value of 0.8. Locations with 67-100% vegetative coverage were also selected for more often than they were available in the Menominee River (Table 3). Both of these variables, and others that contained at least 2 spawning sites and an $E > 0.3$ or < -0.3 were included in models of spawning habitat. This criterion was utilized in order to limit the number of variables to prevent model overfitting while still including the most influential variables.

Importance of vegetation was also evaluated by analyzing number of vegetative species present in background and spawning locations. Sites containing zero vegetative species were selected against (no spawning sites fell into this category), while 38% of available habitat lacked vegetative species (Table 3). The strongest selection was for locations containing an intermediate number of species (3). Sixty-six percent of spawning locations contained 3 different vegetative species whereas only 6% of background locations fell within this category resulting in an electivity of 0.75. Areas with greater than 3 vegetative species present could not effectively be analyzed as no spawning sites and only a few background sites fell into these categories.

Locations with shallow bottom slopes (0-3%) were strongly selected for by spawning muskellunge ($E = 0.44$, Table 3). All slope categories greater than 3% had negative electivity values suggesting that these categories were selected against for spawning.

The index of electivity indicated that Menominee River locations where coarse woody debris was present were preferred as spawning habitat, as evidenced by an electivity of 0.55 (Table 3). River locations lacking coarse woody debris were still used as spawning areas 22% of the time, but this was less than random as 77% of available habitat lacked woody debris (Table 3).

All other categorical variables failed to exhibit strong enough preferences or did not contain enough spawning locations to be included in model building. Slight, but not significant, preferences were shown for areas with sand/silt bottom substrate mixes and sand shorelines (Table 3).

Individual t-tests showed that the only continuous variable showing significant differences between mean values of background and spawning locations was percent silt of the bottom substrate. Means of all other continuous variables (sediment types, percent bottom slope, and percent vegetative coverage) did not show significant differences between background and spawning locations. However, because total vegetative coverage category and bottom slope category variables showed significant differences in the index of electivity, percent bottom slope and total percent vegetative coverage were utilized in modeling to investigate possible effects between representing these variables as continuous or categorical in modeling.

Variables that showed significant differences between background and spawning locations and were therefore used in modeling included: total percent vegetative coverage, vegetative coverage category, number of vegetative species, bottom slope, bottom slope category, presence and absence of coarse woody debris, and percent silt composition of bottom substrate.

Modeling Muskellunge Spawning Habitat

Maxent:

Three model runs were completed at each replicate value of 1, 5, 10, 25, 50, 100, 250, and 500 utilizing a bootstrapped approach. Relative percent contribution of each habitat variable was consistent regardless of number of replicates run but did become more stable as replicate numbers increased. Vegetative coverage category contributed most to overall training gain of the model at 23% (Figure 7). Percent silt and presence of coarse woody debris both accounted for 20% of overall gain. Both percent bottom slope and bottom slope category increased training gain of the model by 18%. Overall these five variables accounted for nearly all training gain during the building of the Maxent model. Number of vegetative species and percent total vegetative coverage contributed minimally to training gain of the model, 1% and 0% respectively.

Consistent patterns developed with higher number of replicates within the habitat preference analysis and probability of spawning. Habitat preference graphs indicate probability of spawning plotted against the range of each variable. If probability does not change over the range of the variable it shows the variable has little predictive ability. Locations classified with a higher vegetative coverage category, meaning more vegetative coverage, were more likely to provide spawning habitat, shown by the increase in probability as vegetative coverage class increases (Figure 8). Similarly, areas predicted as having coarse woody debris present resulted in a higher probability of having spawning habitat present. In general, locations with high amounts of silt were predicted to have a lower probability of being classified as spawning habitat. Both percent bottom slope and bottom slope category showed consistent results indicating that areas with shallower slopes resulted in greater spawning habitat probabilities. In contrast, there was little difference in predicted probability of spawning habitat with varying number of vegetative species and no difference in probability across the range of percent vegetative coverage suggesting that the model does not rely on these two variables to determine likelihood of spawning habitat presence or absence.

The jackknife analysis showed that the slope category variable resulted in greatest training gain, 0.38, when used exclusively (Figure 9). In other words, the slope category variable had the greatest amount of useful model building information by itself. Slope category was closely followed by vegetative coverage category (0.37) and bottom slope (0.33) suggesting that each of these variables contain a great deal of predictive power alone. Training gain was decreased the most when woody debris was left out of model building process (Figure 9). This suggests that woody debris contained the greatest amount of information to the Maxent model that cannot be explained by any other variables.

AUC values indicated that the model performed well. With 500 replicates the bootstrapped Maxent model had an average AUC value of 0.931 (Figure 10). AUC values stabilized around 0.930 when models were run with 25 replicates or more indicating that the Maxent model could correctly predict a random point for presence or absence of spawning 93% of the time. When only 10% of the fractional predicted area (x-axis) is included in the model, over 80% of spawning locations were accounted for (sensitivity). This demonstrates that the model can efficiently distinguish between spawning habitat and background habitat.

An analysis of area predicted as containing spawning habitat (output value greater than 0.5) versus area not containing spawning habitat (output value less than or equal to 0.5) shows relatively consistent results in models with more than 10 replicates (Figure 11). Ten percent of available habitat, waters less than 1.5 m deep, was predicted to contain habitat characteristics that spawning muskellunge prefer (Figure 11). Model outputs identify three distinct spawning areas; the largest is between the Wisconsin shoreline and Stephenson Island, the second is just downstream of Strawberry Island (the site where a YOY muskellunge was captured) and the final spawning area lies near the turning basin and encompasses two known spawning locations (Figure 12).

Classification Tree:

When all seven habitat parameters were used as input variables to the classification tree the model that was produced contained only splits based on bottom slope. This model accounted for greatest amount of dataset variance explained (56%, Figure 13) and resulted in 3 terminal nodes (Figure 14). The first split at 1.95 included 67% of spawning sites with slopes less than 1.95 while only 15% of background sites fit this criteria. The next split resulted in two leaves one of which was defined as locations with slopes between 1.45 and 1.95. This leaf contained 56% of spawning locations and 0% of background locations. These model results showed that areas with moderate bottom slopes were being used with greater frequency as spawning habitat than they were available. According to the classification tree bottom slope was the most important variable in predicting Menominee River muskellunge spawning habitat.

A model was then built excluding bottom slope but using the other 6 habitat variables in order to test what other variables could be important in defining muskellunge spawning habitat. The resulting model contained 3 breaks and produced an r^2 value of 0.33333 (Figures 13 and 15). The variable explaining the greatest amount of variance was presence or absence of woody debris. Twenty-three percent of background areas contained woody debris while 77% of spawning areas had woody debris present. Locations containing woody debris were then split based on the number of vegetative species present. Forty-four percent of spawning locations had woody debris and at least two vegetative species present while only 3% of the available habitat met this criteria. The final split was based on total vegetative coverage, areas with less than or greater than 91.5%. Thirty-three percent of spawning locations contained woody debris, had 2 or more vegetative species present, and had less than 91.5% total vegetative coverage present; however, there were no measured background sites that fit this criteria. This model did not classify spawning sites as well as a model based on bottom slope but did outperform all other models based on only a single variable (Figure 13).

An analysis of area predicted by these models as spawning habitat is dependent on the individual model considered. Area results are the same for models built using only the bottom slope variable and all variables, as bottom slope was the only variable utilized when all variables were used an inputs. When only considering area predicted by the first split in this model (slopes less than 1.95), 7% of available habitat was predicted as spawning habitat (Figure 16). When the second split was added, areas between 1.45 and 1.95, no habitat that was predicted to fall into this category. Based on the first split of 1.95 the areas with suitable muskellunge spawning habitat were concentrated near Stephenson Island and the 6th Street Slip (Figure 17).

The classification model that was built excluding bottom slope classified 19% of water less than 1.5 m deep in the Memoninee River to contain habitat suitable for spawning muskellunge if analyzed after the first split, woody debris presence or absence (Figure 16). Predictions based on the two splits after the woody debris split result in less than 1% of habitat being suitable for muskellunge spawning. Utilizing the first split predicted spawning habitat in the Menominee River to be spread throughout the river with concentrations near the turning basin, Strawberry Island, and downstream of the 6th Street Slip (Figure 18).

When tested individually, several variables were capable of distinguishing between background habitat locations and spawning locations of muskellunge in the Menominee River. Variables that could be exclusively used to classify spawning habitat included percent total vegetative coverage, percent silt of substrate composition, and bottom slope. Other variables (woody debris, bottom slope category, vegetative coverage category, and number of vegetative species) could not define differences between background and spawning locations when used exclusively.

The bottom slope model resulted in the identical model described above when all variables were included. It had the greatest r^2 value, 0.5556 (Figure 13), and contained two splits resulting in 3 terminal nodes (Figure 14) as outlined above

A classification tree model utilizing only percent silt of bottom substrate resulted in an r^2 value of 0.2222 and contained two splits, the first being at 34.5%, with locations containing greater than 34.5% silt not being used as spawning habitat. The next split occurred at 11.33% and showed that areas with greater than 11.33% but less than 34.5% silt were utilized as spawning habitat (44% of locations) more than they were present in background habitat (8% of locations). These results suggest that muskellunge spawning in the Menominee River preferentially selected areas containing an intermediate amount of silt, specifically locations containing between 11.33 and 34.5%.

Percent total vegetative coverage could also be used exclusively to create a classification tree model. The resulting model produced an r^2 value of 0.1111 and contained two splits which produced three leaves. Model splits were at 37.5% and 91.5% total vegetative coverage. Locations with greater than 37.5% vegetative coverage included 67% of spawning locations but only 28% of background habitat locations. The next split occurred at 91.5% vegetative coverage. Forty-five percent of spawning areas fell into the terminal group containing between 37.5 and 91.5% vegetative coverage but only 4% of the background sites met this criteria.

Model Comparison:

A comparison between models shows similar predictions regarding what variables are important to defining muskellunge spawning habitat, amount of area predicted as containing suitable habitat, as well as where these predicted areas are located. In terms of variables that were important, Maxent results suggested that vegetative coverage category was the variable that had greatest relative contribution to defining spawning habitat (Figure 7). However, only 6% or less separates vegetative coverage category, percent silt, woody debris, bottom slope, and bottom slope category in overall percent contribution (Figure 7). Meanwhile jackknife test results indicated that bottom slope category, vegetative coverage category, and bottom slope all resulted in high levels of training gain when used exclusively to build a Maxent model (Figure 9). Although not necessarily at the top of any Maxent measure of variable importance, bottom slope was always included as an important variable. Likewise, bottom slope was the single most important variable in classification tree models distinguishing differences between background and spawning habitat locations.

Woody debris accounted for 20% of relative contribution of regular gain during Maxent model building and was also the variable that decreased training gain the most when left out of model building as tested by the jackknife analysis (Figures 7 and 9). Woody debris was also important in the classification model and resulted in the first split, explaining the greatest amount of variance between spawning and background locations, when bottom slope was excluded from model building (Figure 13).

Amount of area predicted by the best Maxent and tree models corresponded relatively well. The 500 replicate Maxent model runs predicted an average of only 10% of available habitat in the Menominee River to be muskellunge spawning habitat (Figure 11). The classification tree model based on bottom slope was the most conservative model and predicted only 7% of available habitat in the Menominee River to be suitable for muskellunge spawning (Figure 16). The next best classification model, bottom slope excluded, predicted slightly more suitable habitat, 19%, based on the first model split (Figure 16). There is, however, some discrepancy in actual locations predicted to have spawning habitat present between models. The Maxent model predicts spawning habitat to be located between Stephenson Island and the Wisconsin shoreline, around Strawberry Island, and in the turning basin (Figure 12). The bottom slope tree model predicted muskellunge spawning habitat to be concentrated around Stephenson Island and near the 6th Street Slip (Figure 17). The model with bottom slope excluded predicted a greater area in general but still had Stephenson Island and Strawberry Island as well as downstream of the 6th Street Slip to be preferred habitat for spawning muskellunge (Figure 18). Every model predicted the area around Stephenson Island to contain spawning habitat as well as some area around the turning basin or the 6th Street Slip and 2 of 3 models suggest Strawberry Island to have spawning habitat present.

Overall, the bottom slope classification tree model performed poorly. It predicted 7% of the available area as spawning habitat but only included 1 of 9 known spawning areas within the predicted 10%. The Maxent and classification tree model excluding bottom slope both correctly predicted 67% of deposited transmitter sites as spawning areas. Since, the Maxent model used only 10%, compared to 19% as predicted by the bottom slope excluded tree model, it appears that the Maxent model performed best in predicting known spawning locations while minimizing predicted spatial area.

DISCUSSION

The results of this study support past findings concerning muskellunge spawning. Menominee River muskellunge preferred spawning in areas with low to moderate bottom slopes, where woody debris was present, where there was medium vegetative coverage, and in substrates containing silt. Muskellunge showed no preference between developed and undeveloped shoreline or type of shoreline habitat. Based on electivity and model results, muskellunge were preferentially selecting specific habitat as spawning areas. Utilizing these identified habitat preferences allowed successful modeling of spawning areas that effectively identified known spawning locations.

Spawning Habitat

Muskellunge preferred area exhibiting low to moderate bottom slopes as spawning habitat. Habitat containing bottom slopes less than 3% were utilized as spawning habitat in greater proportion than they were available. All other slope categories showed negative electivity values. This result was contrary to Nohner (2009) who described the inland form of barred muskellunge spawning habitat as areas with moderate to high slopes (>9.1%). Muskellunge in this study were Great Lakes strain spotted muskellunge which may partially explain differences in preferred habitat. Nohner (2009) hypothesized that although steep slopes do not directly impact egg survival, areas with steep slopes meant increased mixing with limnetic zone water, leading to more stable water temperatures. It is unlikely that bottom slope was directly impacting egg survival in the Menominee River either. However, slope could be a regulating factor affecting other habitat characteristics such as substrate type, presence of woody debris, and amount of vegetative coverage, all of which were preferred by spawning muskellunge. Areas with steep slope are more prone to erosion of bottom substrate, particularly silt substrates. Riverine areas with high bottom slopes may be less likely to have persistent submergent aquatic vegetation, which was a defining characteristic between spawning and background habitat. Locations with low to moderate slopes may also retain woody debris as opposed to high slope environments where river currents may be more likely to transport woody debris.

Areas containing coarse woody debris were strongly preferred as spawning habitat by Menominee River muskellunge. Previous studies have found presence of woody debris to be important in spawning habitat, egg survival, overall natural recruitment, and success of stocked muskellunge. Several studies found muskellunge preferred spawning areas containing submerged wood, stumps, or driftwood (Nevin 1901, Leach 1927, MacGregor et al. 1960, Shrouder 1974, Dombeck et al. 1984). Presence of woody debris has also been shown to increase egg survival (Dombeck et al. 1984, Zorn et al. 1998), by preventing eggs from sinking into bottom substrates (Schneberger 1936) where anoxic conditions may be fatal to developing eggs or newly hatched larvae (Zorn et al. 1998). Zorn et al. (1998) and Rust et al. (2002) found self-sustaining muskellunge lakes had a higher percentage of available spawning area covered in woody debris than stocked lakes (Zorn et al. 1998, Rust et al. 2002). Even in stocked lakes, Hanson and Margenau (1992) concluded that stocked muskellunge preferentially utilized areas with woody debris, likely as cover from predators.

Spawning muskellunge showed a selection against locations with little vegetative coverage (0-33%, E=-0.38). The strongest selection (E=0.80) was for moderate levels of vegetative coverage (34-66%), followed by high vegetative coverage (67-100%, E=0.33). These results are consistent with other studies. Murry and Farrell (2007) found moderate vegetative densities (20-60% coverage) to be strongly and positively related with abundance of YOY muskellunge in St. Lawrence River nursery areas. A study of survival of muskellunge stocked in inland Wisconsin lakes concluded that stocked muskellunge utilized areas with heavy vegetative coverage after being stocked and hypothesized that vegetation may provide a refuge from predators (Hanson and Margenau 1992). *Chara* spp. has been documented as muskellunge spawning habitat by several studies (Dombeck et al. 1984, Craig and Black 1986, Werner et al. 1996, Murry and Farrell 2007, Pierce et al. 2007) but it was not present in Menominee River locations sampled during this study. However, *Chara* spp. was found in Little Sturgeon Bay. Thirty of eighty (38%) background locations contained *Chara* spp. but it was not documented at any spawning locations. These findings contradict previous studies and suggest a negative correlation between spawning habitat and *Chara* spp. presence.

The range of depths utilized as spawning habitat was consistent with depths described by previous studies. Depths at Menominee River locations with deposited transmitters ranged from 0.49 to 1.03 m (averaged 0.71 m). Both Dombeck et al. (1984) and Oehmcke et al. (1974) also found that muskies utilized areas with depths less than 1 m. Nursery habitat of age-0 muskellunge has been described as shallow habitat, typically less than 1.5 m deep (Craig and Black 1986, Farrell and Werner 1999, Murry and Farrell 2007). Farrell and Werner (1999) along with Murry and Farrell (2007) found negative associations between YOY presence and increased depth. The exception is a Lake St. Clair study that suggested muskellunge were spawning in open water areas with depths greater than 3 m (Haas 1978).

Spawning muskellunge did not display any selection for developed areas as spawning locations. This variable has not previously been tested as a characteristic defining muskellunge spawning habitat at individual spawning sites, as past studies used shoreline development as a variable to describe natural reproductive success for entire lakes. Trautman (1981) and Dombeck et al. (1984) suggested that lakes with increasing human shoreline development resulted in decreased muskellunge recruitment and thus required stocking. Rust et al. (2002) found the most important variable in determining whether or not a lake had good natural reproduction was percentage of developed shoreline (Rust et al. 2002). A large portion of highly developed areas in the Menominee River include docking slips (for large freighters) that have steel walls and are over 6 m deep which were not considered as potential background habitat in this study. Although no selection for undeveloped shoreline was observed during this study, shoreline development and the resulting habitat degradation, was likely an important factor contributing to the extirpation of muskellunge from Green Bay during the 1920s and 1930s.

Muskellunge also did not preferentially utilize a particular land cover type. Several studies have described muskellunge spawning habitat as having an association with wetland areas (Scott and Crossman 1973, Craig and Black 1986, Nohner 2009). Wetland land cover is not prevalent in the Menominee River, only 11% of available habitat, and no spawning areas were located in wetland areas.

Dissolved oxygen levels were measured to determine the potential of egg and larval mortality caused by hypoxic conditions. Average daily average DO levels within spawning areas in the Menominee River ranged from 3.81 to 8.46 mg/L. Dombeck et al. (1984) observed increased mortality in larvae exposed to 4 mg/L for greater than 8 hours. Two Menominee River and two lower Green Bay spawning locations had average daily DO levels below 4 mg/L which could be causing localized egg and larval mortality. An analysis of DO levels in self-sustaining lakes found average levels between 6.0 to 8.4 mg/L (Dombeck et al. 1984). Eighteen of twenty-five (72%) spawning locations identified during this study had daily DO levels below 6.0 mg/L. Zorn et al. (1998) described one difference between stocked lakes and self-sustaining lakes they analyzed was increased levels of DO in lakes with successful natural reproduction.

Modeling Muskellunge Spawning Habitat

Several models were built in an attempt to predict spawning areas in the Menominee River utilizing results from analyses identifying preferred spawning habitat. Three models were built and tested with the Maxent model proving to be most effective at predicting and classifying spawning areas. Classification tree models did not predict spawning habitat as well and were not as accurate at classifying known spawning sites.

Maxent

The Maxent model performed well and effectively classified known spawning locations as spawning habitat. AUC values stabilized around 0.93 after 25 replicates. AUC values higher than “0.9 indicate very good discrimination” as sensitivity rate is high compared to fractional predicted area (false positive rate) (Pearce and Ferrier 2000). Coverage category, percent silt of bottom substrate, woody debris, percent bottom slope, and bottom slope category accounted for 98% of the increase in gain during model building. Percent bottom slope and bottom slope category accounted for similar increases in gain (18.1 and 17.8% respectively), as expected since these variables provide similar information. Vegetative coverage category was expected to have a large contribution to model gain because it had the largest electivity value. However, percent vegetative coverage accounted for 0% model gain. This is likely because there was not a significant difference in means of percent vegetative coverage between background and spawning sites. It is hypothesized that because vegetative coverage was only important when represented as a categorical variable that estimating percent total coverage to the nearest 5% may be too fine a scale to be important in modeling muskellunge spawning habitat and a more coarse scale (low, medium, high) may be more appropriate to define habitat preferences.

Jackknife analysis showed training gain was decreased greatest when woody debris was omitted. This result suggested that woody debris contained the greatest amount of information that cannot be extracted from another variable. This is expected because all other variables, except for silt which showed the second largest decrease in gain when excluded, are also correlated to another variable. For example, the model would not be expected to lose much gain when percent bottom slope was withheld because bottom slope category was still used in model building. Slope category, vegetative coverage category, and bottom slope showed high training gains when used exclusively to build Maxent models. These three variables in particular contained a great deal of information defining spawning habitat and are the best variables to measure if time or resources limit the amount of data that can be collected in the field.

Classification Trees

The classification model was effective at identifying splits in habitat variables to differentiate between spawning and background locations. Inputting all modeling variables resulted in a model with 3 terminal nodes with 2 splits based on percent bottom slope. The first split was at a percent bottom slope of 1.95% and the second break was at 1.45%. Bottom slope was likely affecting other habitat variables, as described above, that were being preferentially selected for. However, it is unclear as to the affect a 0.5% change in bottom slope would have on other environmental variables. Yet, over 50% of spawning locations had bottom slopes between 1.45 and 1.95% while no background sites had this characteristic. This strong selection was likely correlated to changes in other habitat characteristics although the correlations are not clear.

Percent total vegetative coverage and percent silt could be modeled exclusively to differentiate between background and spawning habitat. Classification tree models predict that moderate to high levels of vegetative coverage (37.5 – 91.5%) were important. These results coincide with electivity and Maxent results as well as findings of Murry and Farrel (1997) along with Hanson and Margenau (2002) as described above. The large range predicted by the model (37.5 - 91.5%) provides additional support for the theory that coarse definitions of vegetative coverage may be adequate for defining muskellunge spawning habitat. Model results based exclusively on percent silt show low to moderate levels to be preferred for spawning. This finding was consistent with results from t-tests that showed significant differences between means of percent silt in spawning and background locations. Dombeck et al. (1984) found high levels of silt substrate to have very low DO levels and increased egg mortality. Low to moderate levels of silt may maintain higher DO levels while still providing favorable conditions for vegetation, making such locations preferred spawning areas.

Woody debris was an important variable in the Maxent model and was also used as the first split (variable that explained the most variation) when percent bottom slope was excluded from the classification tree model. The finding that woody debris was used as the first split, with bottom slope excluded, suggested that it was the second most important variable in defining muskellunge spawning habitat in the Menominee River. This was expected because of the strong positive electivity shown for presence of woody debris, Maxent model results, and the strong support in the literature (discussed above) pertaining to the importance of woody debris. Woody debris was not expected to be able to model muskellunge habitat when used exclusively because it was a binary variable and would only allow a single split, presence or absence.

Model Comparison

Models differed in their ability to model and predict Menominee River spawning habitat. However, consistent results were identified between all three models with regards to what habitat variables were important in defining spawning habitat. Low bottom slope percentages, presence of woody debris, and intermediate vegetative coverage were important identifiers in all models. The Maxent model was more conservative in area prediction than the classification model when excluding bottom slope but predicted 3% more spawning habitat than the classification tree using all variables. However, because the "all variables" tree model correctly predicted only 1 of 9 known spawning locations, the Maxent model (67% correctly classified spawning sites) was the best option for modeling and predicting Menominee River muskellunge spawning habitat.

The ability of the Maxent model to accurately and precisely predict muskellunge spawning habitat can prove influential in designating areas as critical spawning habitat which will be a crucial step in preserving the limited amount of remaining available spawning habitat and the overall continued restoration of Green Bay muskellunge. However, the classification models provide biologically significant thresholds with respect to variables such as percent bottom slope and percent total vegetative coverage that are hard to interpret from Maxent models. Thus, the use of classification models can prove extremely useful in habitat restoration projects. Using guidelines established at splits in classification models can make restoration efforts more efficient and effective.

Study Limitations

A critical aspect of the research process is to identify limitations associated with each study so such limitations can be improved on in future projects if possible. Addressing potential shortcomings is also critical to thorough analysis.

One potential limitation was the low success rate of egg searches during this study (11/22 or 50%) compared to Nohner (2009), where 67% of spawning sites were verified with eggs. Both the Fox and Menominee Rivers produce high sediment loads that could have quickly and easily covered eggs, especially demersal non-adhesive muskellunge eggs. This habitat condition along with water movement, including river/lake currents, seiche, and wave action can resuspend bottom sediments and quickly transport eggs leading to decreased egg search success rates. Despite decreased egg confirmation rates, the fact that 22 of 26 deposited transmitters (85%) were located at least once (many were located multiple times) still implanted in swimming fish prior to egg deposition gives increased confidence that fish were not randomly dropping transmitters, outside of spawning events. Oviduct implantation is further supported by the length of time fish retained their transmitters and distance traveled before expulsion. Implanted muskellunge retained their transmitter for an average of 14 ± 2.5 days and average distance between implantation and deposition location was 3.2 km (Table 1) providing evidence that it was unlikely transmitters were deposited without spawning activity.

A potential weakness that could have implications on overall analysis was the method of measuring woody debris. Within a spawning area, woody debris was assessed by walking two 20 m transects parallel to shore. However, due to time constraints woody debris at background locations was measured by counting coarse woody debris as a point measurement within each background location. This potentially biased woody debris counts making it less likely to include woody debris near background locations. Yet, close to 25% of background sites contained woody debris, showing that point measurements were effective, although potentially less effective, at capturing presence of woody debris.

Another shortcoming was the transmitters themselves. Transmitters performed up to specifications but tests of signal strength showed an inverse relationship between signal strength and depth. If a muskellunge did spawn in a deep offshore area it is unlikely that its transmitter would have been found as deposited. However, since the majority of transmitters were deposited in shallow water the potential implication of this potential shortcoming is minimal.

Study results could have also been improved with an increased number of known spawning locations. Funding limitations prevented additional transmitters from being purchased for implantation which could have led to an increased number of spawning locations. Having only nine deposited transmitters in the Menominee River limits overall power of analyses and was one reason for low r^2 values in classification tree models. With only nine known spawning locations a heavy emphasis was put on each site during modeling, exacerbating differences between locations and decreasing model performance. Six additional spawning locations were located in the Fox River in 2009 and although they represented six additional river spawning sites they were not included in the dataset that was used to build the model. Several cases of successful natural reproduction have been documented in the Menominee River while no YOY muskellunge have been discovered anywhere in the lower bay. Thus, Menominee River results represented the best dataset to model likely spawning habitat variables important in successful natural reproduction. Another reason to exclude Fox River data from modeling was overall habitat differences between locations. Menominee River electivity results suggested low to moderate bottom slopes, medium vegetative coverage, and presence of woody debris to be most important in terms of spawning habitat preferences. Fox River electivity data showed no preference between bottom slopes and habitat surveys showed an overall lack of vegetation (2 of

80 of background sites and 0 of 6 spawning sites contained greater than 33% vegetative coverage) and woody debris (0 of 80 background sites and 2 of 6 spawning sites). If added to model analysis overall lack of similar available habitat between the two rivers would have altered habitat preferences identified in Menominee River models.

Limitations to Natural Reproduction

Documented muskellunge natural recruitment is limited throughout Green Bay. The Menominee River represents the most productive water in terms of natural reproduction with four YOY muskellunge being captured over the past three years. Two naturally reproduced muskellunge have been found in Little Sturgeon Bay along with one naturally reproduced tiger muskellunge. No natural reproduction has been documented in lower Green Bay or Fox River. A number of potential causes are likely contributing to these low levels of natural reproduction.

Fish community dynamics in nursery areas can be an important variable to consider with regards to success of natural reproduction and stocking. Predation as well as lack of appropriate prey can be causes of mortality to all stages of muskellunge development. July seining results showed that yellow perch were the most dominant fish species in lower bay spawning areas (82% of total catch) whereas yellow perch were rarely found in the Menominee River (2% of total catch). Presence of and predation by yellow perch may be one factor that can help explain why successful natural reproduction is being observed in the Menominee River but not in the lower portion of the bay. Becker (1983) speculated that yellow perch and northern pike predation could be a limiting factor in muskellunge natural recruitment. Increasing yellow perch abundance was found to be negatively associated with YOY muskellunge abundance (Murry and Farrell 2007). Fish community dynamics are not only important in terms of natural reproduction but must also be considered in determining potential stocking locations. Hanson and Margenau (1992) stressed the importance of considering fish community dynamics when choosing muskellunge stocking locations as resident predator populations can have severe detrimental effects on survival and recruitment of stocked individuals. A study by Craig and Black (1986) in South Georgian Bay, Lake Huron found a positive correlation between pumpkinseed abundance and presence of YOY muskellunge. Ninety percent of their seine hauls with YOY muskellunge had pumpkinseed (a potential prey species) as the dominant species present (Craig and Black 1986). Pumpkinseeds were the overall dominant species present during July seining efforts in the Menominee River and were present in 7 of 9 deposited transmitter locations. However, in the lower bay pumpkinseeds accounted for 0% of average catch during July and were present at only 3 of 13 spawning locations. This evidence further supports the theory that fish community composition in the lower bay may be negatively affecting muskellunge recruitment.

Round goby represented the second most common species during seining efforts in the lower bay and the third most common species in the Menominee River. The invasive round goby could be another potential source of egg mortality as they have been documented to prey on eggs of lake trout (*Salvelinus namaycush*) (Chotkowski and Marsden 1999) and could be preying on muskellunge eggs when present.

Another possible cause of egg mortality in Green Bay is high sediment loads and nutrients carried in the Fox and Menominee Rivers. The high biological oxygen demand created by elevated nutrient levels could serve as yet another stressor to muskellunge eggs and larval survival. Dissolved oxygen levels are low compared to previous associations made between DO and successful natural reproduction. Sixteen percent of spawning locations were shown to have potentially fatal DO levels for muskellunge larvae (less than 4 mg/L) and 72% had levels below those consistent with successful muskellunge recruitment (6.0 – 8.4 mg/L, Dombeck et al. 1984). Even in areas where DO levels are sufficient, resultant sediment deposition in the Fox River and southern portion of Green Bay could be covering eggs with sediment shortly after they are expelled. In this case DO levels at the water substrate interface could be sufficient but eggs would still be experiencing anoxic conditions under deposited sediments.

A final problem that may potentially be limiting natural reproduction in Green Bay is limited amounts of suitable spawning habitat. It has been observed that lack of suitable spawning habitat can limit reproductive success in muskellunge populations (Dombeck et al. 1984, Dombeck et al. 1986, Zorn et al. 1998, Rust et al. 2002). The Maxent model predicts that only 10% of available Menominee River habitat is suited for muskellunge spawning. Netting results indicated a large increase in muskellunge presence within the river during spawning season. With a limited amount of available habitat, overlap in spawning areas is likely inevitable and could be a cause of egg mortality. Dombeck et al. (1984) hypothesized that repeated intense activity in a single spawning area could cause previously deposited eggs to be pushed deeper into soft substrates or entirely covered, causing increased egg mortality by suffocation. Competition for preferred spawning areas is also likely when suitable habitat is limited and scars on many netted fish may provide evidence of spawning competition (Nohner 2009). Competition could result in some fish having to use marginal habitat which could explain some variation in spawning habitat preferences.

Areas predicted as suitable habitat in the Menominee River are concentrated in three main areas, Stephenson Island, Strawberry Island, and turning basin. However, the entire area throughout the turning basin and 6th St. Slip will be dredged in 2012 due to high levels of arsenic in bottom sediments. This is particularly concerning because the end result is that a portion of the 10% of available spawning habitat will be substantially disrupted and altered. However, it is unknown whether the arsenic contaminated sediment was negatively affecting muskellunge reproduction efforts. Regardless, these efforts could open a door for restoration activity to modify the dredged area and improve habitat conditions to make them more suitable for muskellunge reproduction.

There is no single factor limiting natural reproduction in Green Bay. Limitations can be specific to a given region of the bay (lack of spawning habitat in the lower bay) or even to individual spawning areas (low DO levels). Even in self-sustaining populations muskellunge recruitment is extremely low. Limited recruitment observed in Green Bay is likely the result of a combination of factors.

Management Guidelines and Implications

Results from this study will be useful in developing future muskellunge management guidelines. Key steps to increase the success of muskellunge restoration in Green Bay are effective stocking, adding new and/or improving existing spawning habitat, and protecting suitable spawning areas.

Maxent model output results in the form of maps clearly show areas predicted to have suitable spawning habitat. These maps can be used to guide site specific stocking efforts. By stocking fish in areas known to contain suitable habitat survival should be increased. Although it is unknown when muskellunge natal imprinting occurs, if it does, (Werner and Farrel 1999), the potential is to seed areas with suitable spawning habitat with stocked YOY muskellunge. The hope is that these stocked fish will then return to these areas in the future to spawn, thus increasing future spawning success.

Another key aspect of continued muskellunge management in Green Bay is improvement of existing spawning habitat and the addition of new areas with suitable habitat. Potential funding through Great Lakes Fish and Wildlife Restoration Act, National Resource Damage Assessment, and Great Lakes Restoration Initiative has the potential to provide money for restoration in areas like the Fox and Menominee Rivers, which have been designated as Areas of Concern, by the Environmental Protection Agency (EPA). Current and proposed dredging projects in both the Fox and Menominee Rivers will remove contaminated sediments and create opportunities to restore these areas with suitable muskellunge spawning habitat. The proposed Cat Island Restoration will try to return the Peats Lake area of the lower bay to a marsh environment that historically supported muskellunge spawning. Classification tree models can be instrumental in guiding these restoration efforts to ensure these new areas contain habitat suitable for spawning muskellunge.

As fisheries managers, the ability to predict and improve spawning habitat will be vital to the success of fish populations such as muskellunge where so many populations depend on supplemental stocking. If managers are unable to protect existing critical habitat and possibly create new habitat, their reliance on stocking will only increase in areas where natural reproduction currently exists, and in areas where it does not they will never overcome this barrier. The easily interpreted binary results of the Maxent output map can be a powerful management tool in designating and protecting critical areas.

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References

Atkinson, E.J., and T.M. Therneau. An introduction to recursive partitioning. Technical report, Mayo Foundation, Feb 2000.

Becker, G.C. 1983. Fishes of Wisconsin. University of Wisconsin Press, Madison, Wisconsin

Bertrand, G., J. Lang, and J. Ross. 1976. The Green Bay watershed past/present/future. University of Wisconsin Sea Grant Tech. Report No. 229. Madison, Wisconsin.

Bozek, M.A., T.M. Burri, and R.V. Frie. 1999. Diets of muskellunge in northern Wisconsin lakes. North American Journal of Fisheries Management 19:258-270.

Burnham, K.P., and D.R. Anderson. 2002. Model selection and multimodel inference. A practical information-theoretic approach, 2nd edn. Springer, New York.

Clark, L.A., and D. Pregibon. 1992. Tree-based models. Pages 377-419 in J.M. Chambers and T.J. Hastie, editors. Statistical models in S. Wadsworth and Brooks, Pacific Grove, California, USA.

Craig R.E., Black R.M. 1986. Nursery habitat of muskellunge in southern Georgian Bay, Lake Huron, Canada. American Fisheries Society Special Publication 15:79-86.

Crossman, E.J. 1990. Reproductive homing in muskellunge, *Esox masquinongy*. Canadian Journal of Fisheries and Aquatic Sciences 47:1803-1812.

De'ath, G., and K.E. Fabricius. 2000. Classification and regression trees: A powerful yet simple technique for ecological data analysis. Ecology 81:3178-3192.

Dombeck, M. P. 1979. Movement and behavior of the muskellunge determined by radio-telemetry. Wisconsin Department of Natural Resources, Technical Bulletin 113, Madison.

Dombeck, M.P., B.W. Menzel, and P.N. Hinz. 1984. Muskellunge spawning habitat and reproductive success. Transactions of the American Fisheries Society 113:205-216.

Dombeck, M.P., B.W. Menzel, and P.N. Hinz. 1986. Natural muskellunge reproduction in Midwestern lakes. American Fisheries Society Special Publication 15:122-134.

ESRI 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

Farmer, B., and P. Chow-Fraser. 2004. A conceptual model of muskellunge spawning habitat. Undergraduate thesis. McMaster University, Hamilton, Ontario, Canada.

Farrell, J.M. 2001. Reproductive success of sympatric northern pike and muskellunge in an upper St. Lawrence River bay. Transactions of the American Fisheries Society 130:796-808.

Farrell, J.M., R.M. Klindt, J.M. Casselman, S.R. LaPan, R.G. Werner, A. Schiavone. 2007. Development, implementation, and evaluation of an international muskellunge management strategy for the upper St Lawrence River. Enivronmental Biology of Fishes, 79:111-123.

Farrell, J.M., R.G. Werner, S.R. LaPan, and K.A. Claypool.1996. Egg distribution and spawning habitat of northern pike and muskellunge in a St. Lawrence River marsh, New York. Transactions of the American Fisheries Society 125:127-131.

Farrell, J.M. and R.G. Werner. 1999. Distribution, abundance, and survival of age-0 muskellunge in Upper St. Lawrence River nursery bays. North American Journal of Fisheries Management. 19:310-321.

Fellers, G.M., and P. Kleeman. 2003. A technique for locating and recovering radiotransmitters at close range. Herpetological Review 34:123.

Goodyear, C.S., T.A. Edsall, D.M. Ormsby Dempsey, G.D. Moss, and P.E. Polanski.1982. Atlas of the spawning and nursery areas of Great Lakes fishes.Volume IV. U.S. Fish and Wildlife Service, Washington, DC FWS/OBS-82/52.

Greene, C.W. 1935. The distribution of Wisconsin fishes. Wisconsin Conservation Commission. Wisconsin, USA, p 235.

Hanson, D. A., and T. L. Margenau. 1992. Movement, habitat selection, behavior, and survival of stocked muskellunge. North American Journal of Fisheries Management 12:474-483.

Harrell, F.E. 2001. Regression modelling with applications to linear models, logistic regression and survival analysis. Springer Series in Statistics. Springer-Verlag, New York.

Harrison, E.J., and W.F. Hadley. 1978. Ecological separation of sympatric muskellunge and northern pike. American Fisheries Society Special Publication 11:129-134.

Haas, R.C. 1978. The muskellunge in Lake St. Clair. A symposium on selected coolwater fishes of North America. American Fisheries Society, Special Publication 11, Bethesda, Maryland.

Herdendorf, C.E. 1987. The ecology of the coastal marshes of western Lake Erie: a community profile. U.S. Fish and Wildlife Service, Biological Report 85(7.9). Washington, D.C.

Hernandez, P. A., C. H. Graham, L. L. Master, and D. L. Albert. 2006. The effect of sample size and species characteristics on performance of different species distribution modeling methods. Ecography 29:773-785.

Hess, L. and C. Hartwell. 1978. Literature review of large esocids (muskellunge, northern pike, hybrid tiger muskellunge). Pages 139-175 in J. Dube and Y. Gravel editors. Proceedings of the 10th Warm Water Workshop. Northeastern Division, American Fisheries Society, Bethesda, MD.

Inskip, P. D. 1986. Negative associations between abundances of muskellunge and northern pike: evidence and possible explanations. Pages 135-150 *in* Hall, G. E., editor. Managing muskies. American Fisheries Society, Special Publication 15, Bethesda, Maryland.

Ivlev, V. S. 1961. Experimental ecology of the feeding of fishes. Yale University Press, New Haven, Connecticut.

Kapuscinski, K.L., B.J. Belonger, S.Fajfer, and T.J. Lychwick. 2007. Population dynamics of muskellunge in Wisconsin waters of Green Bay, Lake Michigan, 1989-2005. Environmental Biology of Fishes, 79:27-36.

Kenow, K.P., J.E. Lyon, R.K. Hines, and A. Elfessi. 2007. Estimating biomass of submersed vegetation using a simple rake sampling technique. Hydrobiologia 575:447-454.

Lake Michigan Fisheries Team. 2004. Lake Michigan Integrated Fisheries Management Plan 2003 -2013. Wisconsin Department of Natural Resources, Bureau of Fisheries and Habitat Management, Admin. Report No. 56, Madison, WI.

Lebeau, B. and P. Gerard. 1989. Comparative urogenital morphology and external sex determination in muskellunge, *Esox masquinongy* Mitchill. Canadian Journal of Zoology 67:1053-1060.

Menz, F.C. and D.P. Wilton. 1983. An economic study of the muskellunge fishery in New York. New York Fish and Game Journal 30:12-29.

Murry, B.A. and J.M. Farrell. 2007. Quantification of native muskellunge nursery habitat: influence of body size, fish community composition, and vegetation structure. Environmental Biology of Fishes 79:37-47.

Nevin, J. 1901. The propagation of muskellunge in Wisconsin. Transactions of the American Fisheries Society 30:90-93.

Nohner, J. 2009. Development of a GIS model to predict muskellunge spawning habitat in northern Wisconsin lakes. M.S. Thesis, University of Michigan, Ann Arbor.

Oehmke, A.A., L. Johnson, J. Klingbiel, and C. Winstrom. 1974. The Wisconsin Muskellunge. Its life history, ecology, and management. Wisconsin Department of Natural Resources Publication 8-3600(74).

Pearce, J., and S. Ferrier. 2000. Evaluating the predictive performance of habitat models developed using logistic regression. Ecological Modeling 133:225-245.

Phillips, S. J., and M. Dudik. 2008. Modeling species distributions with Maxent: new extensions and a comprehensive evaluation. Ecography 31:161-175.

Phillips, S.J., M. Dudik, and R. Schapire. 2008. A Brief Tutorial on Maxent. Museum 107-135. Retrieved from http://www-2.cs.cmu.edu/afs/cs/user/aberger/www/html/tutorial/tutorial.html

Phillips, S. J., R. P. Anderson, and R. E. Schapire. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modeling 190:231-259.

Pierce, R.B. 2004. Oviduct insertion of radio transmitters as a means of locating northern pike spawning habitat. North American Journal of Fisheries Management 24:244-248.

Pierce, R.B., J.A. Younk, and C.M. Tomcko. 2007. Expulsion of miniature radio transmitters along with eggs of muskellunge and northern pike – a new method for locating critical spawning habitat. Environmental Biology of Fishes 79:99-109.

Pearson, R.G., C.J. Raxworthy, M. Nakamura, and A.T. Peterson. 2007. Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. Journal of Biogeography 34:102-117.

R Development Core Team. 2010. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Rejwan, C., Collins N.C., Brunner L.J., B.J. Shuter, M.S. Ridgway. 1999. Tree Regression Analysis on the Nesting Habitat of Smallmouth Bass. Ecology 80:341-348.

Rowe, D.C. 2010. Status of great lakes muskellunge in Wisconsin waters of Green Bay, Lake Michigan. Great Lakes Fisheries Commission Report. Wisconsin Department of Natural Resources. Green Bay, Wisconsin.

Rust, A.J., J.S. Diana, T.L. Margenau, and C.J. Edwards. 2002. Lake characteristics influencing spawning success of muskellunge in Northern Wisconsin lakes. North American Journal of Fisheries Management 22:834-841.

Sager, P.E., and S. Richman. 1991. Functional interaction of phytoplankton and zooplankton along the trophic gradient in Green Bay, Lake Michigan. Canadian Journal of Fisheries and Aquatic Sciences 48:116-122.

Scott, W.B., and E.J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada, Bulletin 184.

Shrouder, J. D. 1975. The muskellunge in Michigan. Michigan Department of Natural Resources Fisheries Division Pamphlet 45, Lansing, Michigan, USA.

Simonson, T.D., J. Lyons, P.D. Kanehl. 1993. Guidelines for evaluating fish habitat in Wisconsin streams. Gen. Tech. Rep. NC-164. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station.

Smith, P. L., R.A. Ragotzkie, A.W., Andren, and H.J. Harris. 1988. Estuary rehabilitation: the Green Bay History. Oceanus 31:12-30.

Smith, H.H, and M. Snell. 1891. Review of the fisheries of the Great Lakes in 1885, with introduction and description of fishing vessels and boats by J. W. Collins. Report of Commissioner of Fish and Fisheries, p 333.

Strand, R.F. 1986. Identification of principal spawning areas and seasonal distribution and movements of muskellunge in Leech lake Minnesota. American Fisheries Society Special Publication 15:62-73.

Therneau, T.M., and B. Atkinson. R port by Brian Ripley. (2010). rpart: Recursive Partitioning. R package verion 3.1-46. http://CRAN.R-project.org/package=rpart.

Ware, D.M. 1975. Relation between egg size, growth, and natural mortality of larval fish. Journal of the Fisheries Research Board of Canada 32:2503-2512.

Wehrly, Kevin. Michigan Department of Natural Resources. May 6th, 2011. Ann Arbor, Michigan.

Werner, R.G., R Klindt, and B.V. Jonckheere. 1996. Vegetative characteristics of muskellunge (Esox masquinongy) spawning and nursery habitat in the 1000 Islands section of the St. Lawrence River. Great Lakes Res Rev 2:29-35.

Wiley, E. O., K. M. McNyset, A. T. Peterson, C. R. Robins, and A. M. Stewart. 2003. Niche modeling and geographic range predictions in the marine environment using a machine-learning algorithm. Oceanography 16(3):120-127.

Wintle, B.A., J. Elith, and J.M. Potts. 2005. Fauna habitat modeling and mapping: A review and case study in the Lower Hunter Central Coast region of NSW. Austral Ecology 30:719-738.

Wisconsin Department of Natural Resources. 1986. Lower Green Bay remedial action plan. Wisconsin Department of Natural Resources, Bureau of Fisheries Management and Habitat Protection, Madison, Wisconsin.

Yost, A. C., S. L. Peterson, M. Gregg, and R. Miller. 2008. Predictive modeling and mapping sage grouse (*Centrocercus urophasianus*) nesting habitat using Maximum Entropy and a long-term dataset from Southern Oregon. Ecological Informatics 3:375-386.

Younk, J.A. and M.F. Cook. 1992. Applications of an angler diary for muskellunge Esox masquinongy. Minnesota Department of Natural Resources, Investigational Report 420, St. Paul.

Younk, J.A., M.F. Cook, T.J. Goeman, and P.D. Spencer. 1996. Seasonal habitat use and movements of muskellunge in the Mississippi River. Minnesota Department of Natural Resources, Investigational Report 449, Minneapolis, MN.

Zar, J. H. 1999. Biostatistical analysis. Prentice-Hall, Inc., New York.

Zorn, S.A., T.L. Margenau, J.S. Diana, and C.J. Edwards. 1998. The influence of spawning habitat on natural reproduction of muskellunge in Wisconsin. Transactions of the American Fisheries Society 127:995-1005.

Table 1: Data from female muskellunge implanted with transmitters in their oviducts and tracked for egg deposition locations.

Location Implanted	Date Implanted	Length (cm)	Reproductive Condition	Estimated H_2O temp. (°C) when deposited (±1 SE)	Estimated # days between implantation and deposition (±1 SE)	Minimum distance traveled with transmitter (km)
Fox River	4/28/2009	125	Hard	14.8 ± 0.1	18 ± 2	8
	4/28/2009	125	Hard	12.9 ± 2.9	11 ± 11	16.5
	4/28/2009	126	Hard	15.6 ± 0.8	12 ± 2	14.1
	4/28/2009	123	Hard	15.0 ± 0.3	18 ± 2	1
	4/29/2009	119	Hard	17.5 ± 2.2	21 ± 2	2.7
	4/29/2009	119	Hard		Not located as deposited	
	5/1/2009	126	Hard	19.3 ± 0.4	22 ± 1.5	5.2
	5/1/2009	121	Ripe	13.3 ± 0.3	4 ± 0.5	0.5
	5/1/2009	128	Hard		Not located as deposited	
	5/4/2009	103	Ripe	15.0 ± 0.3	12 ± 2	5.6
Green Bay	5/4/2009	127	Hard	17.6 ± 0.9	33 ± 3	0.2
	5/4/2009	127	Hard		Not located as deposited	
	5/5/2009	101	Ripe	14.6 ± 1.1	7 ± 7	13.2
	5/5/2009	105	Ripe	16.7 ± 1.1	26 ± 2	4.5
	5/6/2009	124	Ripe	15.8 ± 1.4	3 ± 2	0.3
	5/6/2009	119	Hard	15.6 ± 1.1	13 ± 8.5	0.4
	5/6/2009	106	Hard		Not located as deposited	
	5/7/2009	124	Ripe		Not located as deposited	
	5/8/2009	128	Hard		Not located as deposited	
	5/8/2009	113	Ripe		Not located as deposited	
Little Sturgeon Bay	4/29/2010	128	Ripe	Transmitter fell out upon release of the fish		
	5/5/2010	102	Ripe	17.6 ± 2.8	20 ± 2	0.4
	5/17/2010	115	Ripe	17.4 ± 4.5	8 ± 2	0.7
	5/17/2010	114	Ripe	17.3 ± 0.4	11 ± 5	1
Menominee River	4/28/2010	128	Ripe	13.8 ± 0.0	21 ± 2	0.3
	4/29/2010	121	Ripe	12.7 ± 0.4	12 ± 0.5	0.4
	4/30/2010	127	Ripe	12.6 ± 0.5	16 ± 1.5	0.3
	4/30/2010	133	Ripe	12.4 ± 0.0	11 ± 0.5	0.3
	5/1/2010	128	Ripe		Not located as deposited	
	5/1/2010	123	Ripe		Not located as deposited	
	5/1/2010	133	Ripe	12.4 ± 0.3	11 ± 0.5	0.7
	5/3/2010	131	Ripe	12.4 ± 0.0	14 ± 0.5	0.6
	5/3/2010	131	Ripe	13.8 ± 0.0	14 ± 0.5	1.2
	5/4/2010	127	Ripe	12.2 ± 0.5	7 ± 0.5	1.3
	5/5/2010	125	Ripe	12.4 ± 0.4	10 ± 1.5	0.7
	5/5/2010	124	Ripe		Not located as deposited	
	5/6/2010	121	Ripe		Not located as deposited	
Averages	5/3	122		14.8 ± 1.1	14 ± 2.5	3.2

Table 2: Transmitter Detection Characteristics

Conductivity (μS)	Depth (m)	Detection Distance (m)	% Vegetative Coverage	Antenna
400	0.5	590	0	Boat
	1.5	220	0	
	3.0	20	0	
	0.5	199	0	Handheld Square
	1.5	99	0	
	3.0	30	0	
320	0.5	870	0	Boat
	0.5	300	100	
	1.5	108	60	
	3.0	62	100	
	0.5	390	0	Handheld Square
	0.5	190	100	
	1.5	80	60	
	3.0	55	100	

Table 3: Summary of available habitat, background levels, and the index of electivity for each Menominee River variable.

Variable	Category	Proportion of Spawning Habitat	Proportion of Background Habitat	Index of Electivity (E)
*Total Vegetative Coverage	0-33%	33.3	75	-0.38
	34-66%	22.2	2.5	0.80
	67-100%	44.4	22.5	0.33
*# of Vegetative Species	0	0	38	-1
	1	33.3	20	0.25
	2	22.2	31	-0.17
	3	44.4	6	0.75
	4	0	4	-1
	5	0	1	-1
*Slope	0-3.0	67	26	0.44
	3.1-6.0	11	18	-0.23
	6.1-9.0	0	12	-1
	9.1-12.0	0	8	-1
	12+	22	36	-0.23
*Coarse Woody Debris	Absent	22	77	-0.55
	Present	78	23	0.55
Development	Developed	44	44	0.01
	Undeveloped	56	56	-0.01
Sand/Silt Mix	Absent	70	30	-0.12
	Present	56	44	0.2
Immediate	Grass/Shrub	11	14	-0.12
	Riprap/Rock	44	49	-0.05
	Sand	44	25	0.27
	Wetland	0	11	-1
Environmental	Boulder/Cobble	0	8	-1
	Concrete/Riprap	11	4	0.45
	Natural Grasses	33	35	-0.03
	Lawn	11	0	1
	Phragmites	0	4	-1
	Shrub	44	48	-0.04

*Variables used in modeling (categories must have contained at least 2 spawning sites, or 22% of the proportion of spawning sites, and had an electivity > 0.3 or electivity < -0.3)

Figure 1: Map of Green Bay with research areas highlighted

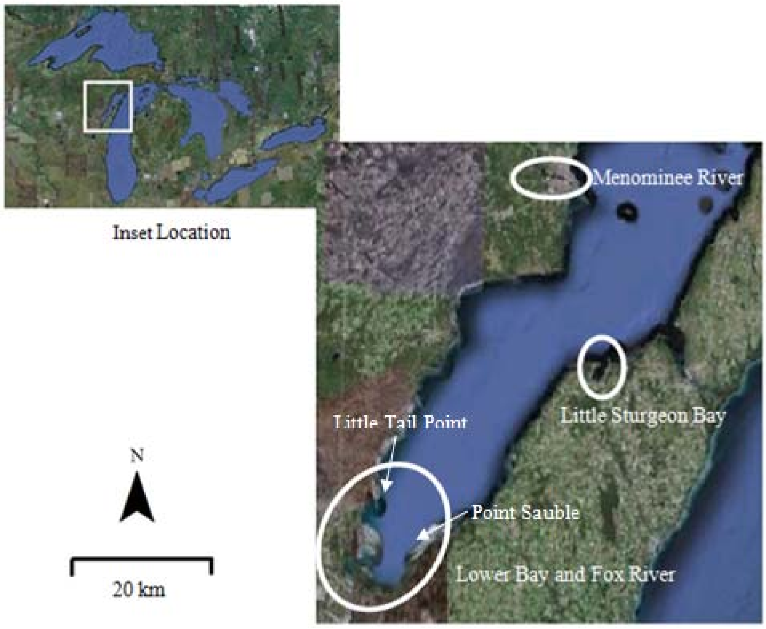


Figure 2: Example of the grid used to sample habitat within a spawning area.

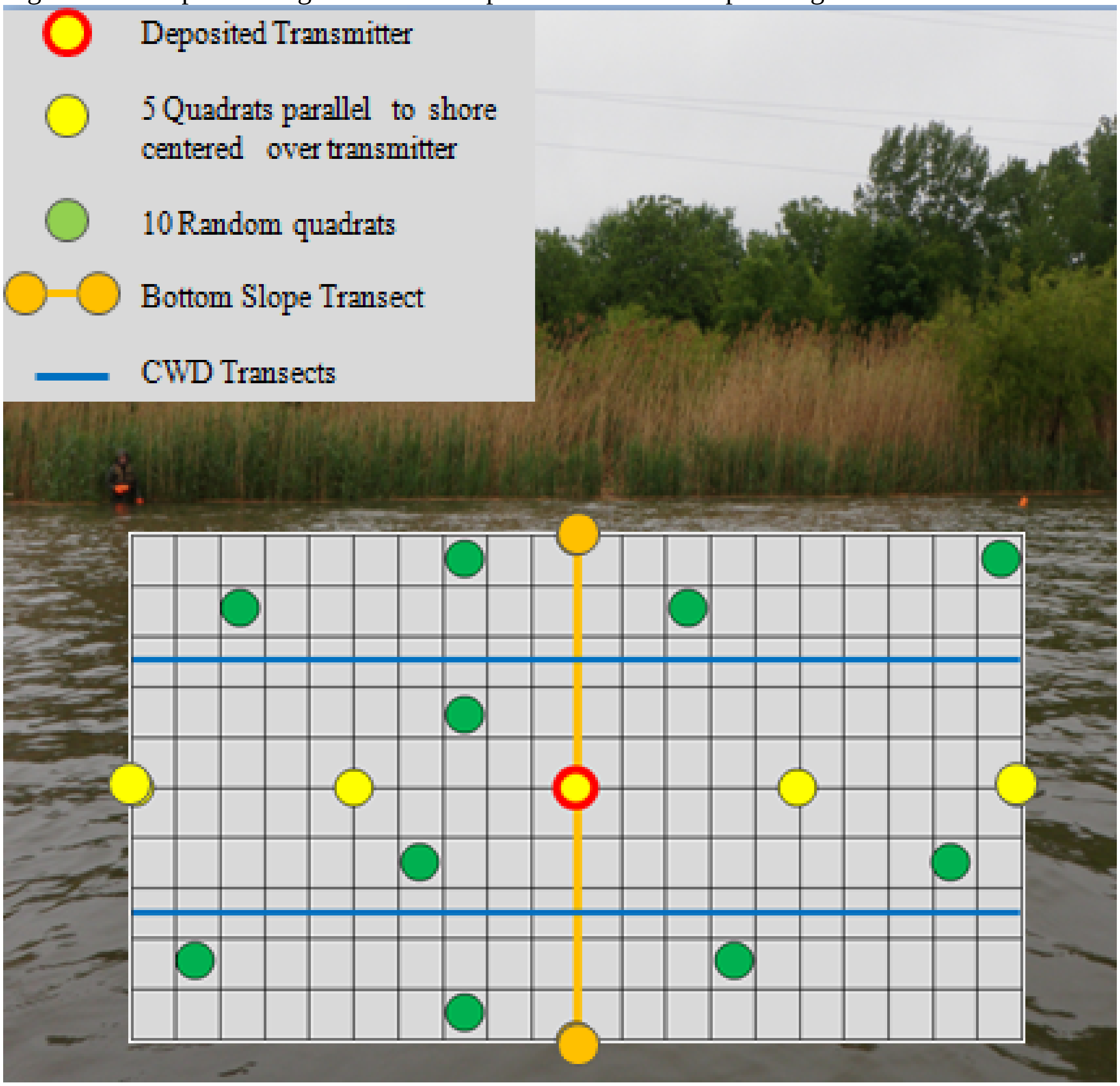
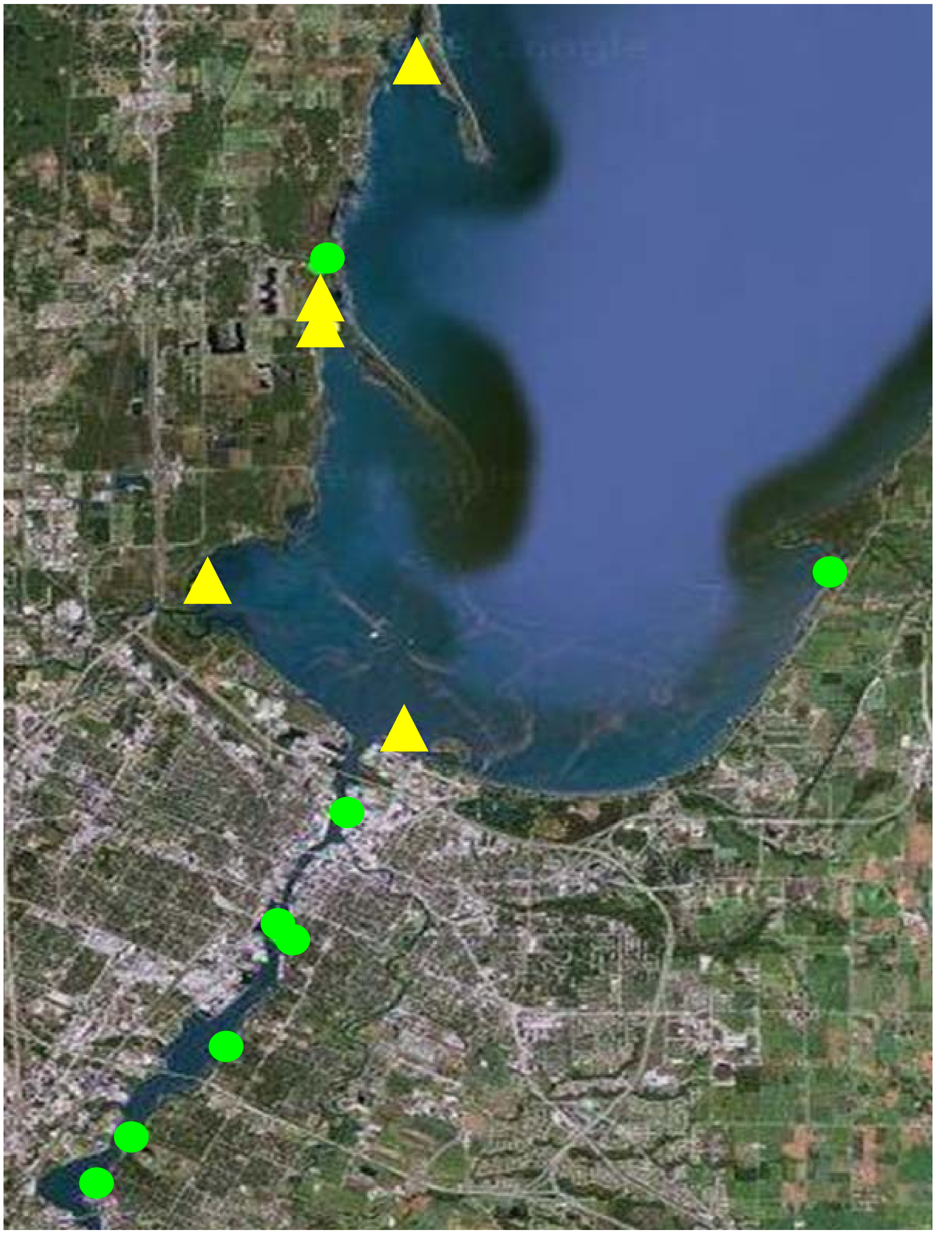


Figure 3: Image of 13 deposited transmitter locations in the Fox River and lower Green Bay in 2009.



Transmitter implanted in the Fox River (n=8)

Transmitter implanted in the lower bay (n=5)

Figure 4: Image of 9 deposited transmitter locations in the Menominee River in 2010.

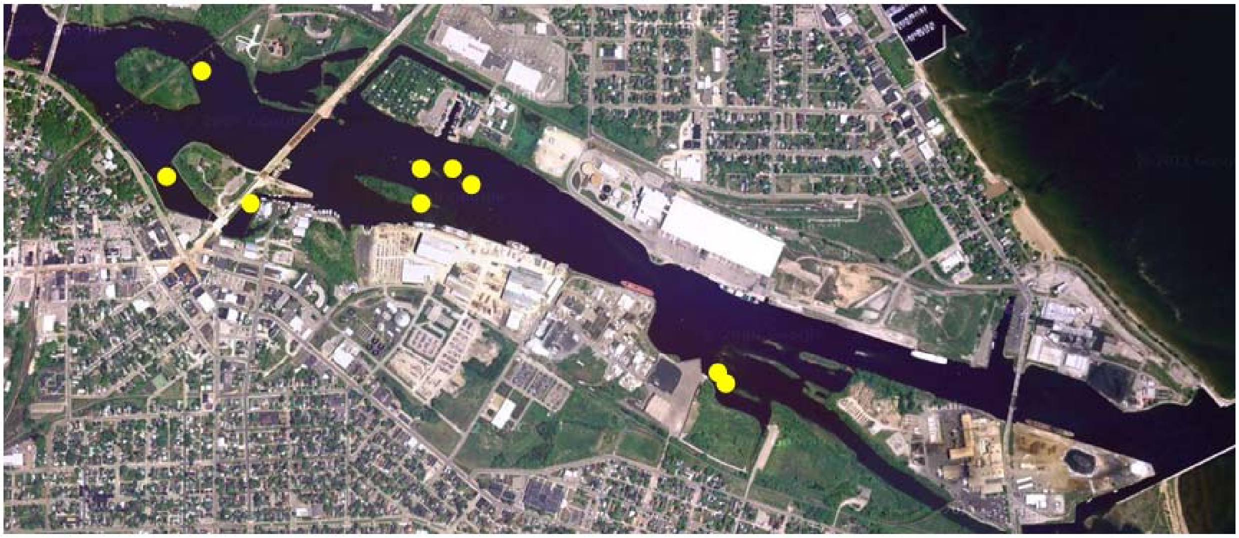


Figure 5: Image of 3 deposited transmitter locations in Little Sturgeon Bay in 2010.

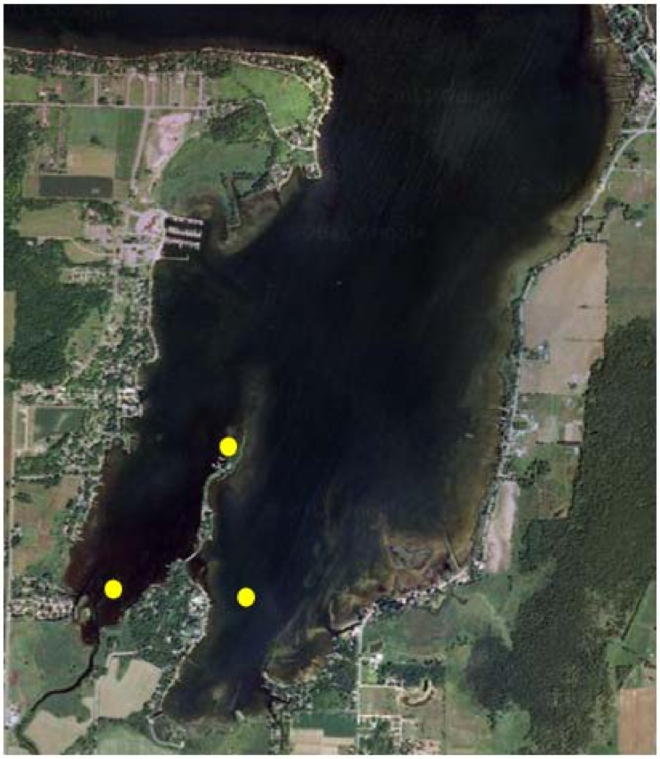


Figure 6: July seining results for the lower bay (Fox River and lower bay combined) and the Menominee River. Percent of total catch of three most abundant species is given for each location. Dominant species in the lower bay included yellow perch, round goby, and gizzard shad. Menominee River dominant species were pumpkinseed, largemouth bass, and round goby.

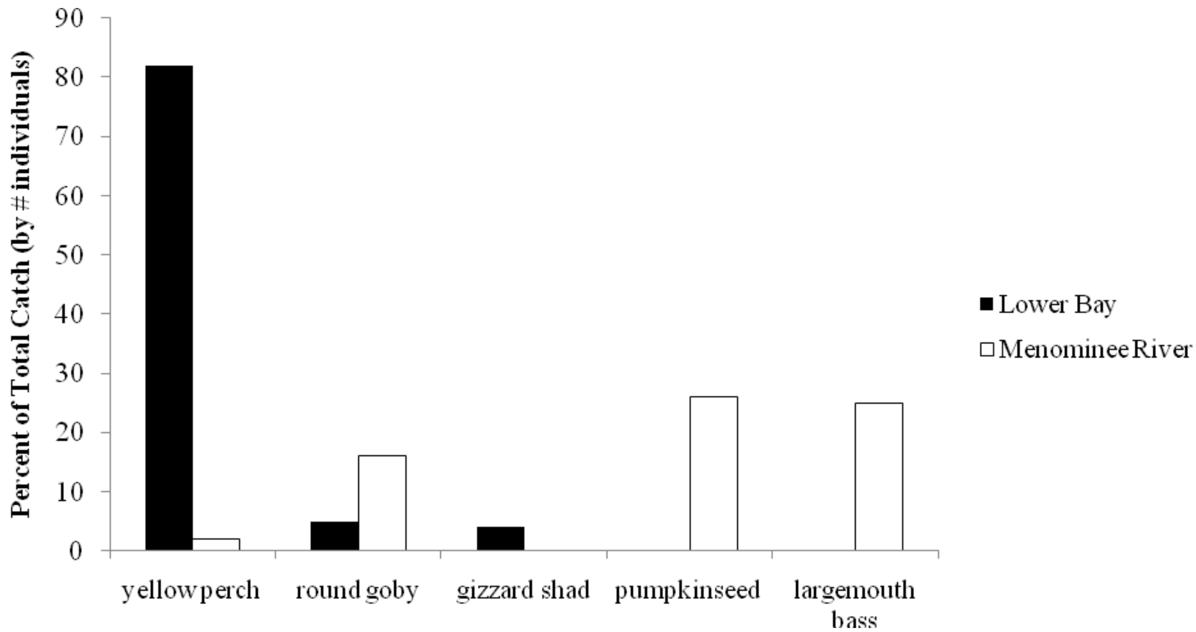


Figure 7: Relative percent contribution of each habitat variable to the Maxent model. Contributions were averaged over the three 500 replicate model runs. Percent contribution is represented by the increase or decrease in regular gain during each iteration of the model training.

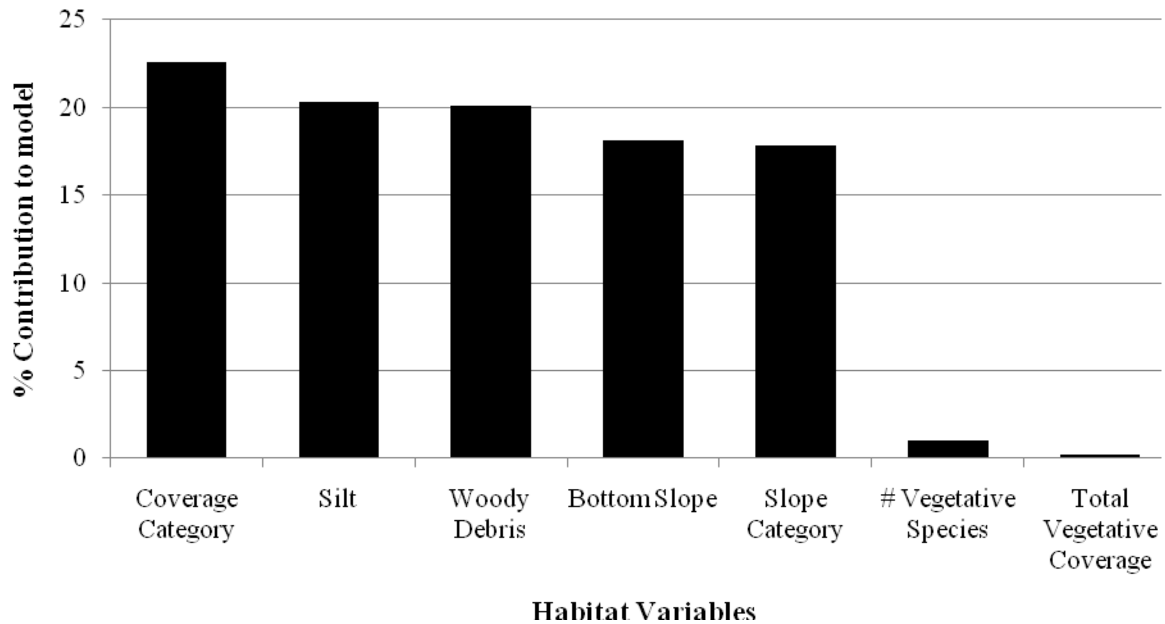


Figure 8: Analysis of the logistic prediction (probability of spawning habitat presence) plotted over the range of each habitat variable while all other variables are kept at their average value. The curves show the mean response over the 500 replicate runs in red and ± one standard deviation in blue.

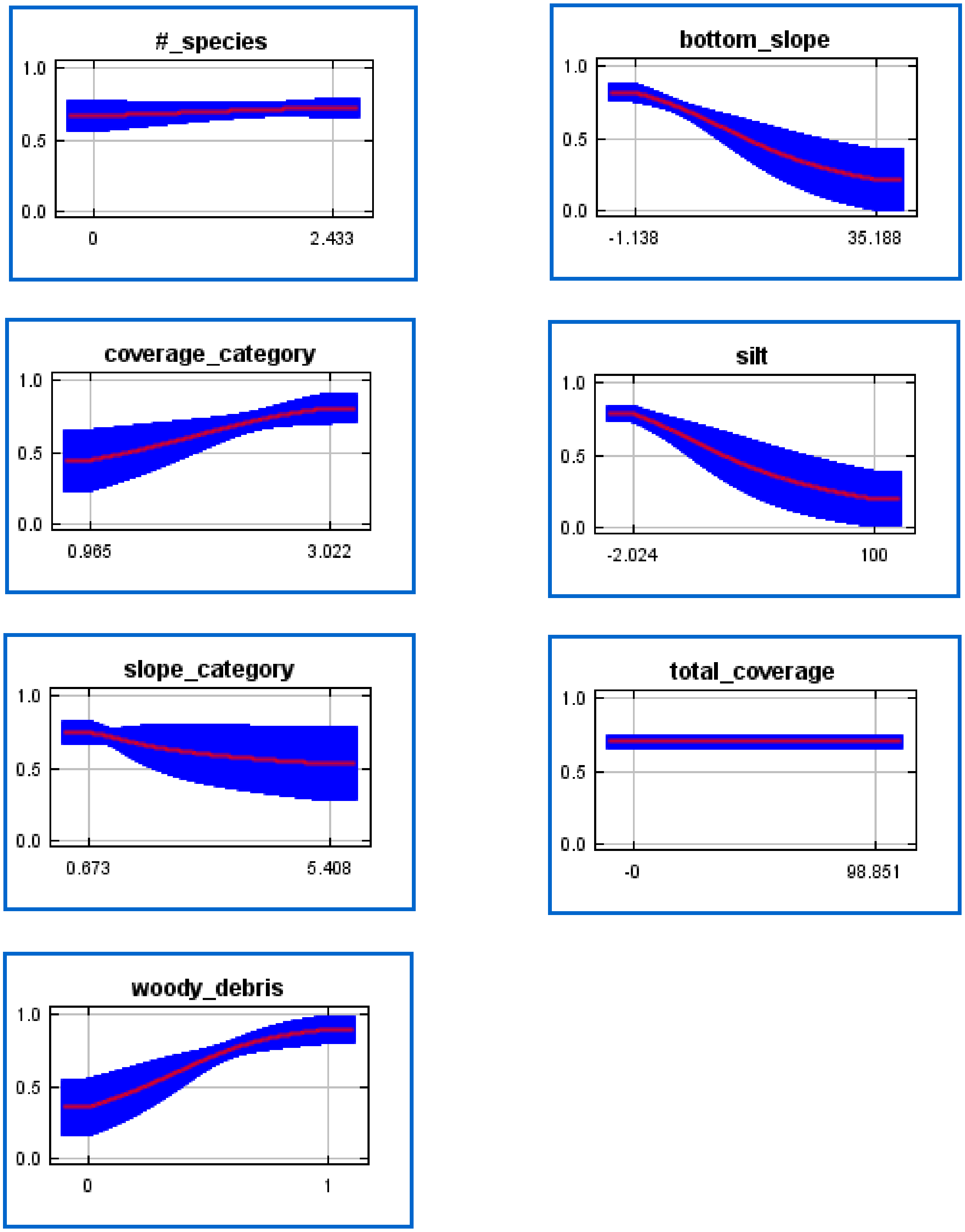


Figure 9: Jackknife test results for training gain for the three Maxent model runs of 500 replicates each. The training gain of a model "with only variable" (white) represents the gain of a model built using only that single variable. The training gain of a model "without variable" (black) represents the gain of a model built using all other variables while excluding the variable of interest. Dashed line indicates the training gain of a model constructed using all variables.

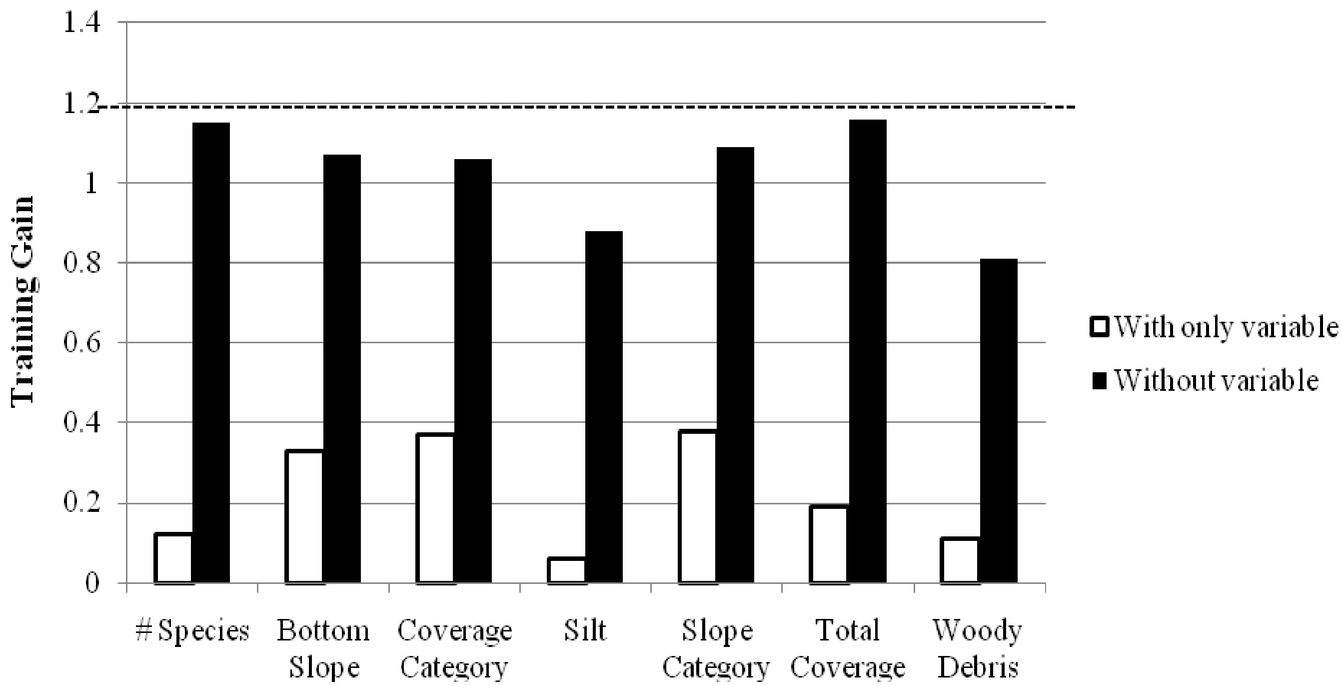


Figure 10: Area under the curve analysis for a 500 replicate Maxent model run. A mean AUC value of 0.931 indicates a strong ability of the model to predict muskellunge spawning habitat.

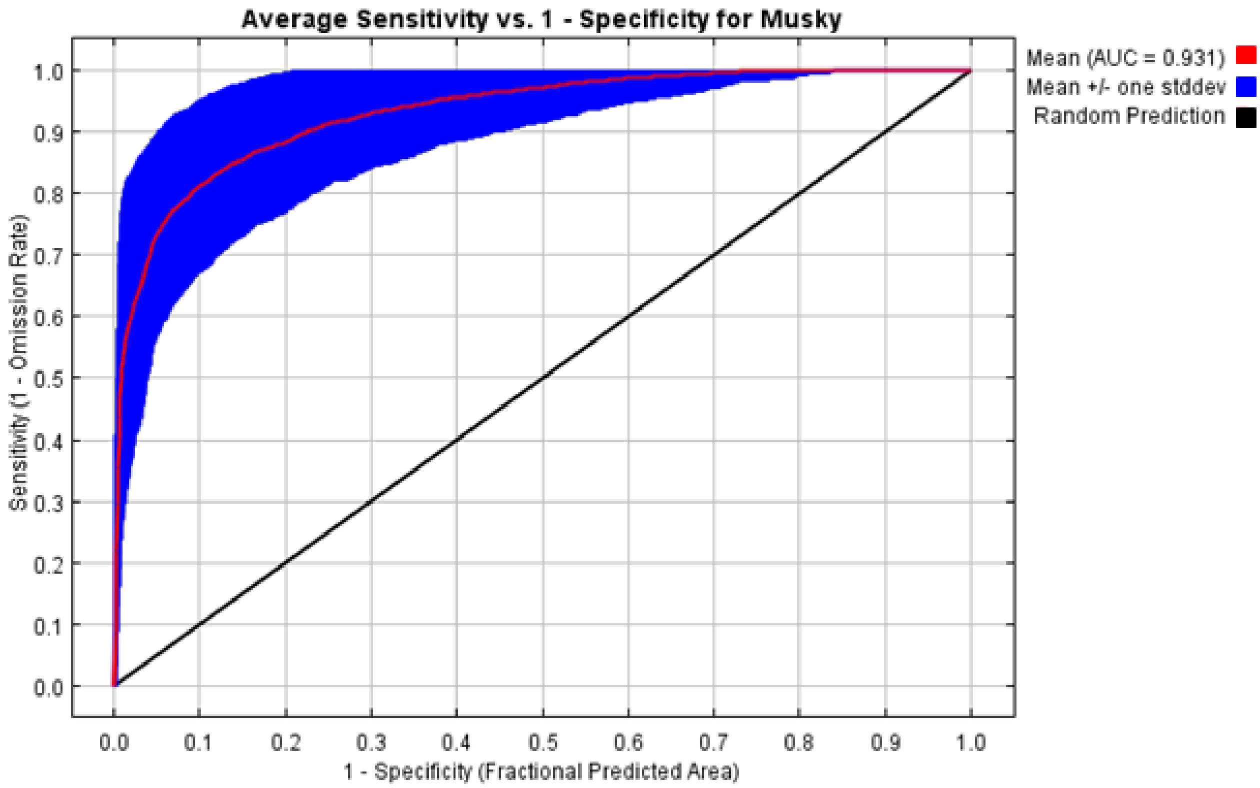


Figure 11: Area analysis of Maxent model results showing the percent of the available spawning habitat (<1.5m depth) in the Menominee River that was predicted as having habitat characteristics suitable for spawning muskellunge.

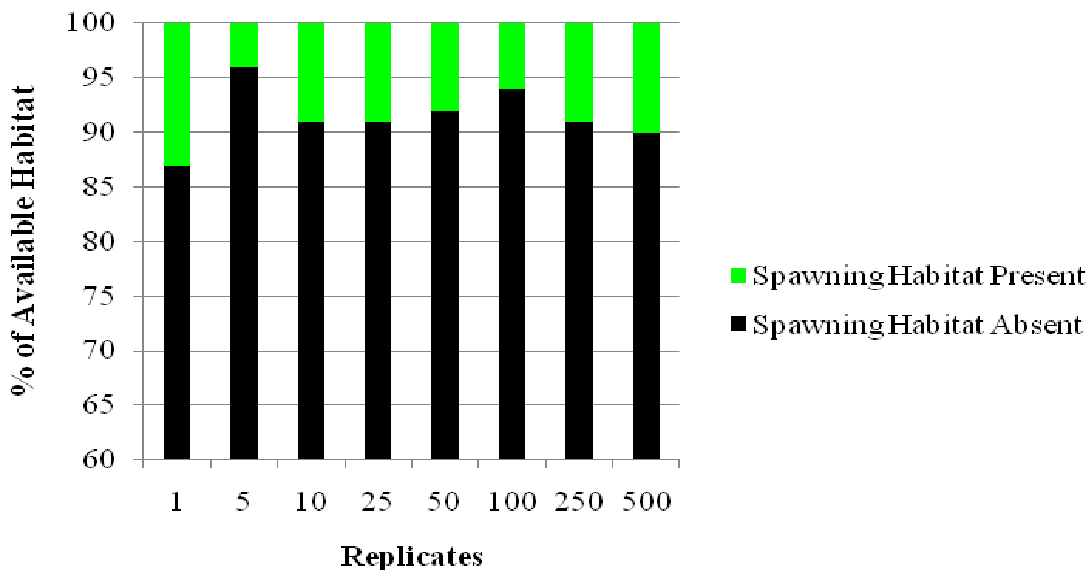


Figure 12: Maxent model predictions of muskellunge spawning with 500 bootstrapped replicates. Black areas indicate locations that are not predicted to have habitat characteristics suitable for spawning muskellunge while green areas represent locations predicted to contain suitable spawning habitat.

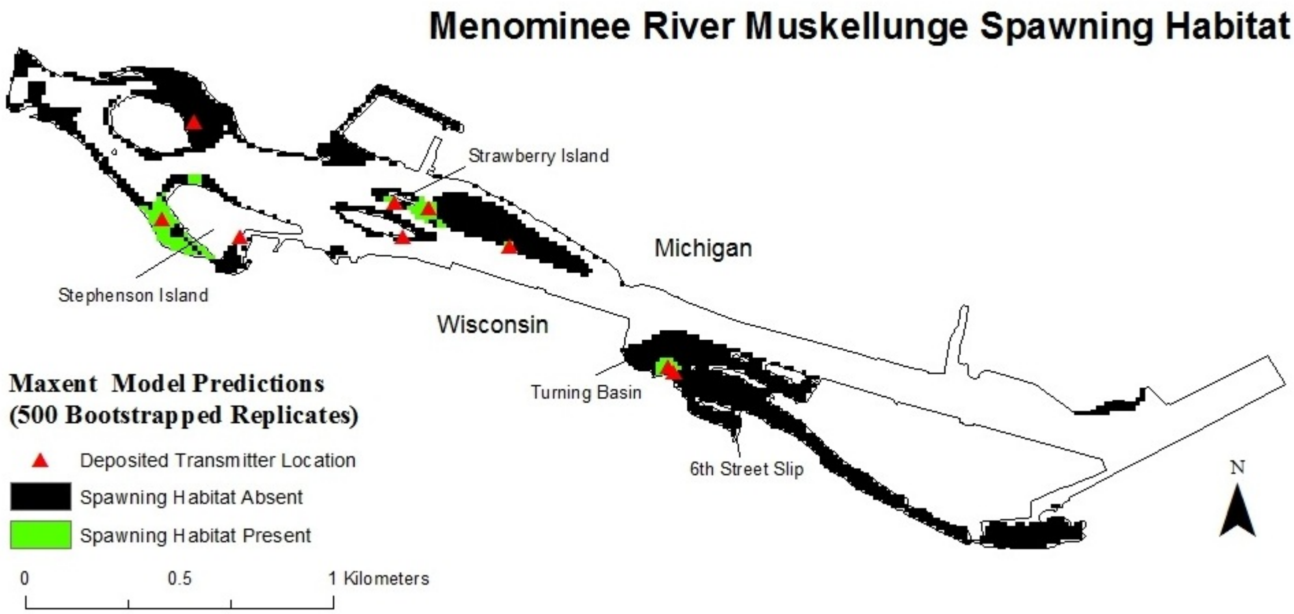


Figure 13: Analyses of variance explained by classification tree models. Model type refers to variables including in model building.

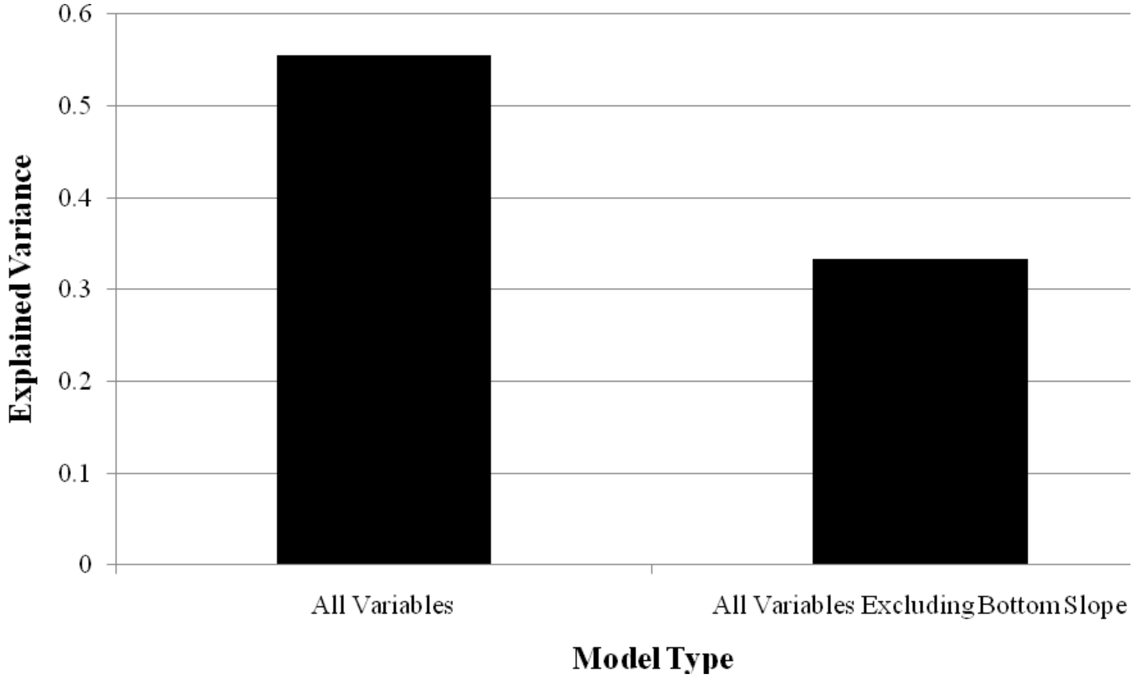


Figure 14: Classification tree model generated from using all habitat variables which resulted in 3 terminal groups (leaves). Horizontal bars define the criteria each split was based upon. Green bars represent the remaining percent of spawning locations after each split and black represents the remaining percent of background locations.

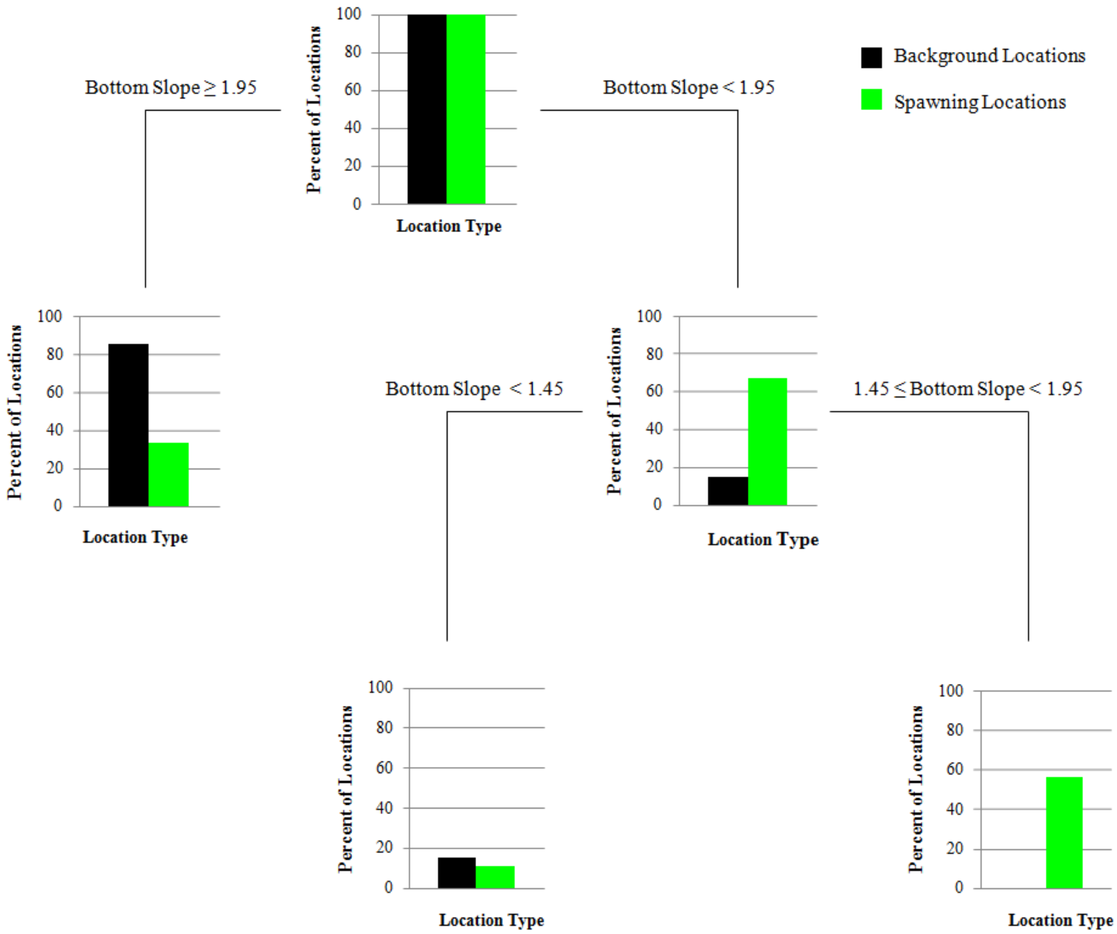


Figure 15: Classification tree model generated from excluding bottom slope but using all other variables, which resulted in 4 terminal groups (leaves). Horizontal bars define the criteria each split was based upon. Green bars represent the remaining percent of spawning locations after each split and black represents the remaining percent of background locations.

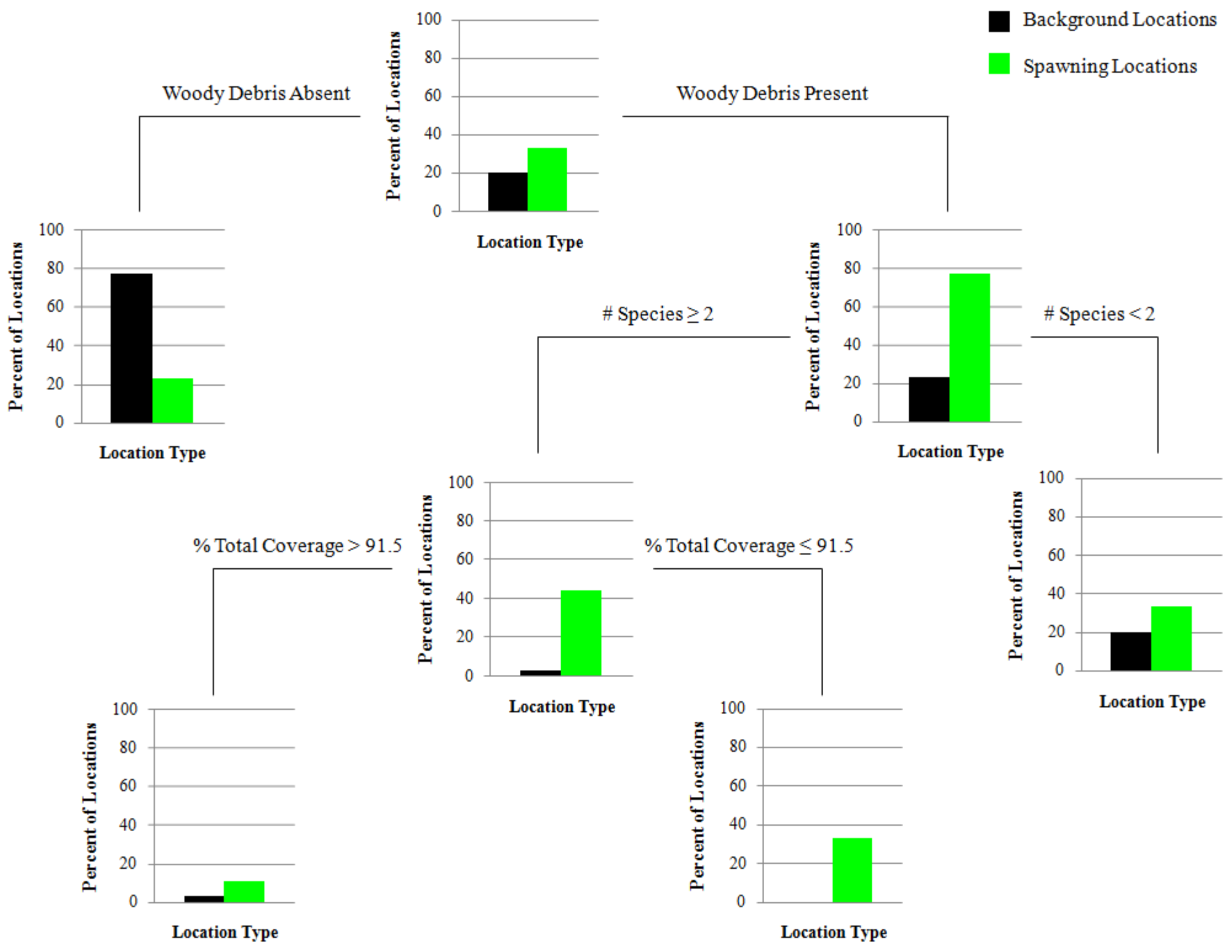


Figure 16: Figure 9: Area analysis of classification tree model results showing the percent of the available spawning habitat (<1.5m depth) in the Menominee River that was predicted to have habitat characteristics suitable for spawning muskellunge.

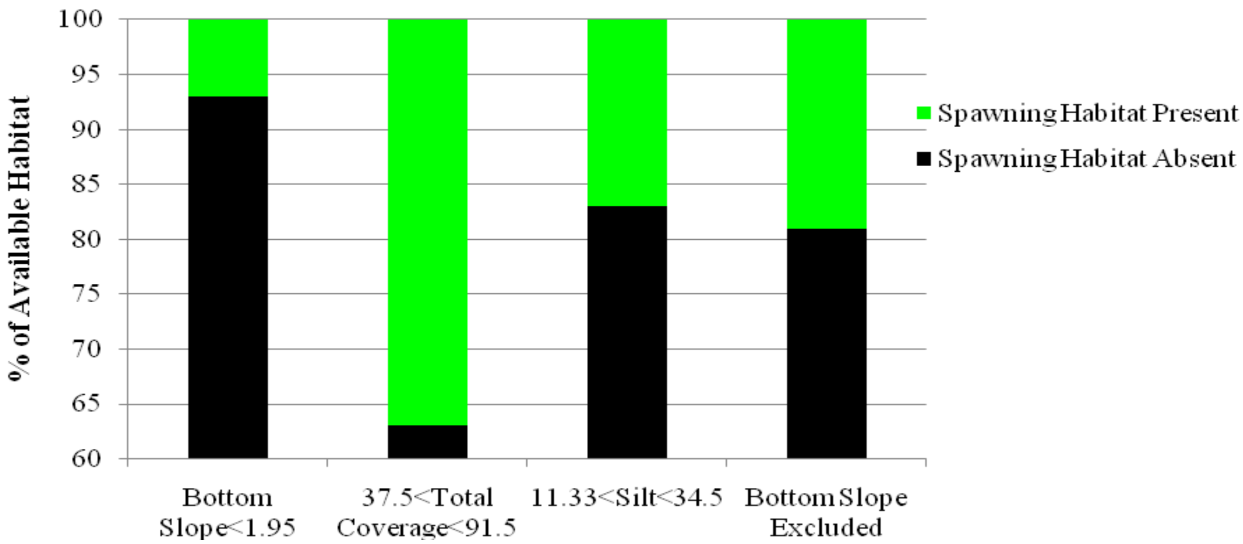


Figure 18: Classification tree model predictions of muskellunge spawning using all variables. Black areas indicate locations that are not predicted to have habitat characteristics suitable for spawning muskellunge while green areas represent locations predicted to contain suitable spawning habitat.

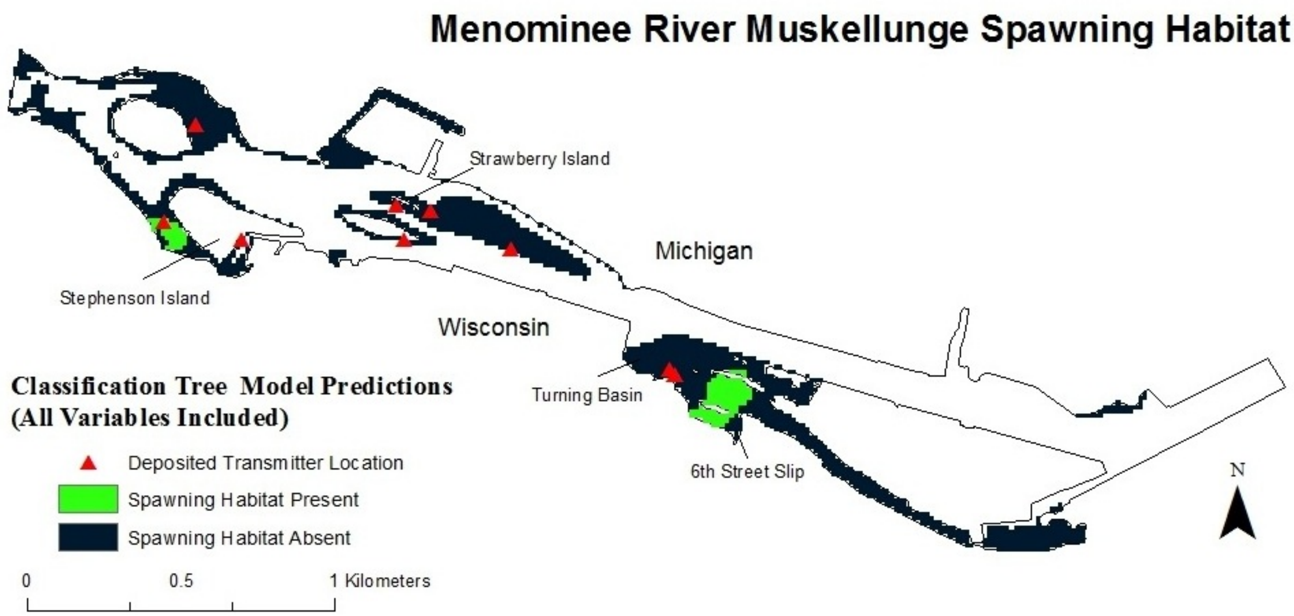
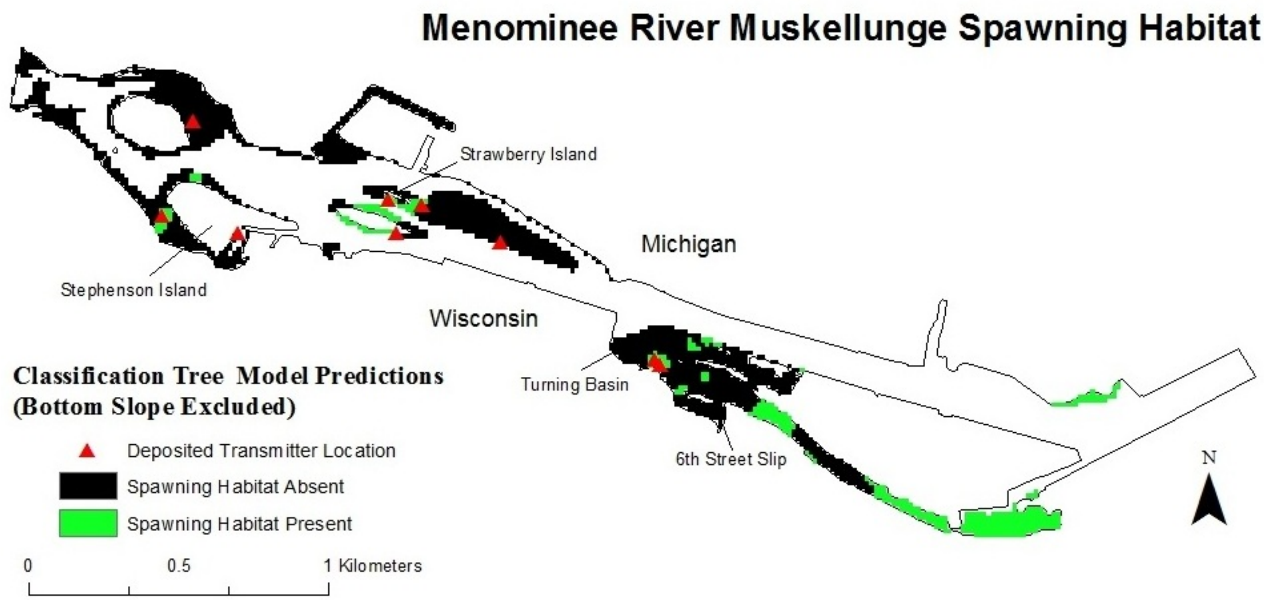


Figure 19: Classification tree model predictions of muskellunge spawning excluding bottom slope but using all other variables. Black areas indicate locations that are not predicted to have habitat characteristics suitable for spawning muskellunge while green areas represent locations predicted to contain suitable spawning habitat.



Appendix 1: 2009 Fox River and lower Green Bay telemetry data.

Waypoint	Date	Latitude	Longitude
004 Dt	28-May-09	44.634483	-88.029717
014 5-11	11-May-09	44.617267	-88.0134
014 Dt	29-May-09	44.617267	-88.0134
024 5-28	29-May-09	44.667533	-87.990633
024 5-29	29-May-09	44.66635	-87.99075
024 Dt	9-Jun-09	44.667017	-87.990533
034 5-21	21-May-09	44.5721	-88.03685
034 5-21 2	21-May-09	44.571567	-88.037817
034 5-7	7-May-09	44.576133	-88.033733
034 Dt	19-Jun-09	44.571783	-88.038183
044 5-18	18-May-09	44.504417	-88.0223
044 5-18 2	18-May-09	44.504817	-88.023333
044 5-4	4-May-09	44.4709	-88.051033
044 5-4 2	4-May-09	44.473467	-88.04985
044 5-5	5-May-09	44.473717	-88.051183
044 5-5 2	5-May-09	44.47355	-88.051417
044 Dt	24-May-09	44.503783	-88.02215
054 5-18	18-May-09	44.456317	-88.060733
054 5-22	22-May-09	44.455367	-88.061383
054 5-25	25-May-09	44.45505	-88.062183
054 5-27	27-May-09	44.455283	-88.062167
054 6-1	1-Jun-09	44.45565	-88.06175
054 6-1 2	1-Jun-09	44.455033	-88.061833
054 Dt	3-Jun-09	44.455033	-88.061833
074 5-29	29-May-09	44.618217	-88.013
074 5-29 2	29-May-09	44.61815	-88.012917
074 5-7	7-May-09	44.61425	-88.0071
074 5-7 2	7-May-09	44.612967	-88.008317
074 5-7 3	7-May-09	44.605583	-88.009917

Appendix 1: 2009 Fox River and lower Green Bay telemetry data.

Waypoint	Date	Latitude	Longitude
074 Dt	8-Jun-09	44.617933	-88.013483
084 5-18	18-May-09	44.525267	-88.0099
084 5-18 2	18-May-09	44.524467	-88.009883
084 Dt	1-Jun-09	44.5242	-88.009867
095 6-10	10-Jun-09	44.559883	-87.909833
095 6-22	22-Jun-09	44.619017	-87.859417
114 5-14	14-May-09	44.50185	-88.021717
114 6-10	10-Jun-09	44.540183	-87.998183
114 6-10 2	10-Jun-09	44.540217	-87.998267
114 6-17	17-Jun-09	44.54015	-87.998183
114 Dt	21-Jun-09	44.540167	-87.998167
124 5-12	12-May-09	44.571267	-87.900833
124 Dt	15-May-09	44.5713	-87.900617
154 5-22	22-May-09	44.482133	-88.0335
154 5-25	25-May-09	44.482117	-88.033767
154 5-25 2	25-May-09	44.482217	-88.033083
154 5-27	27-May-09	44.482217	-88.033383
154 6-1	1-Jun-09	44.482367	-88.033367
154 Dt	3-Jun-09	44.482483	-88.032533
164 5-18	18-May-09	44.5014	-88.021667
164 5-4	4-May-09	44.53465	-88.008417
164 5-5	5-May-09	44.5377	-88.006817
164 Dt	25-May-09	44.5017	-88.020667
174 5-4	4-May-09	44.469517	-88.052633
174 5-4 2	4-May-09	44.46455	-88.05395
174 5-5	5-May-09	44.46455	-88.054033
174 5-5 2	5-May-09	44.464467	-88.0541
174 Dt	24-May-09	44.464117	-88.054067
184 5-5	5-May-09	44.529317	-88.008517
184 5-7	7-May-09	44.553383	-88.013767

Appendix 1: 2009 Fox River and lower Green Bay telemetry data.

Waypoint	Date	Latitude	Longitude
194 5-18	18-May-09	44.480383	-88.0351
194 5-22	22-May-09	44.473117	-88.042983
194 5-5	5-May-09	44.47305	-88.044233
194 6-1	1-Jun-09	44.5351	-88.008283

Appendix 2: 2010 Menominee River telemetry data.

Waypoint	Date	Latitude	Longitude
004 05-10-10	10-May-10	45.09807	-87.6093
004 5-24-10	24-May-10	45.10592	-87.60172
024 5-16-10	16-May-10	45.10233	-87.62295
024 5-21-10	21-May-10	45.10242	-87.62187
024 Dt	21-May-10	45.10242	-87.6218
033 05-10-10	10-May-10	45.10232	-87.6226
033 5-10-10	10-May-10	45.10137	-87.62213
033 5-12-10	12-May-10	45.10163	-87.62108
033 5-16-10	16-May-10	45.10217	-87.62153
033 5-21-10 1	21-May-10	45.10215	-87.62115
033 Dt	21-May-10	45.10223	-87.62037
044 05-10-10	10-May-10	45.09763	-87.6059
044 5-12-10	12-May-10	45.0973	-87.60312
064 05-10-10	10-May-10	45.09768	-87.60515
064 5-11-10	11-May-10	45.09698	-87.6103
064 5-12-10	12-May-10	45.09725	-87.60997
064 5-16-10	16-May-10	45.09747	-87.61025
064 5-17-10	17-May-10	45.09717	-87.61035
064 Dt	21-May-10	45.09737	-87.61073
094 05-10-10	10-May-10	45.10197	-87.61723
094 5-11-10	11-May-10	45.1016	-87.61703
094 5-12-10	12-May-10	45.10133	-87.61782
094 5-13-10	13-May-10	45.10142	-87.61812
094 5-16-10	16-May-10	45.10143	-87.6184
094 5-21-10	21-May-10	45.10088	-87.61698
094 Dt	21-May-10	45.10103	-87.61705
124 5-10-10	10-May-10	45.1043	-87.62948
124 5-12-10	12-May-10	45.10412	-87.62945
124 5-10-10	10-May-10	45.10367	-87.63115
124 5-16-10	16-May-10	45.10435	-87.6287

Appendix 2 continued

Waypoint	Date	Latitude	Longitude
124 5-17-10	17-May-10	45.10532	-87.6306
124 Dt	21-May-10	45.10495	-87.62998
154 5-16-10	16-May-10	45.09973	-87.61452
336 5-10-10	10-May-10	45.10163	-87.62815
336 Dt	11-May-10	45.10155	-87.62823
344 5-10-10	10-May-10	45.10205	-87.63137
344 5-12-10	12-May-10	45.10217	-87.63143
344 Dt	13-May-10	45.10215	-87.63137
357 5-10-10	10-May-10	45.10178	-87.62062
357 5-10-10 2	10-May-10	45.10123	-87.62373
357 5-12-10	12-May-10	45.10133	-87.62157
357 5-12-10 1	12-May-10	45.10135	-87.62118
357 Dt	13-May-10	45.10142	87.62145
366 05-10-10	10-May-10	45.09758	-87.61043
366 5-11-10	11-May-10	45.09733	-87.61013
366 5-12-10	12-May-10	45.09698	-87.60992
366 5-16-10	16-May-10	45.09735	-87.61005
366 Dt	17-May-10	45.09722	-87.61045
378 5-24-10	24-May-10	45.09208	-87.58822
378 5-24-10 1	24-May-10	45.092	-87.58843
378 6-9-10	9-Jun-10	45.09697	-87.58873
378 6-13-10	13-Jun-10	45.08983	-87.58717
378 6-21-10	21-Jun-10	45.09478	-87.59198
378 6-22-10	22-Jun-10	45.0937	-87.59015

Appendix 3: 2010 Little Sturgeon Bay telemetry data.

Waypoint	Date	Latitude	Longitude
084 Dt	20-May-10	44.825717	-87.55302
104 5-13-10	14-May-10	44.837383	-87.55402
104 5-20-10	20-May-10	44.838183	-87.5534
104 5-23-10	23-May-10	44.83825	-87.55347
104 5-27-10	27-May-10	44.8377	-87.55562
104 Dt	17-Jun-10	44.8377	-87.55557
133 5-20-10	20-May-10	44.833183	-87.54737
133 5-23-10	23-May-10	44.8607	-87.52763
133 5-27-10	27-May-10	44.832017	-87.56095
133 Dt	27-May-10	44.831817	-87.56115
194 5-20-10	20-May-10	44.832583	-87.56123
194 5-23-10	23-May-10	44.83795	-87.55533
194 6-14-10	14-Jun-10	44.829633	-87.55407
194 Dt	17-Jun-10	44.82995	-87.55432

Appendix 4: Fox River habitat survey data.

Waypoint	**Spawn**	**Development**	**Immediate Shoreline**	**Environmental Shoreline**	**Date**	**Latitude**	**Longitude**
044 Dt	1	0	sand	lawn	24-May-09	44.50378	-88.0222
054 Dt	1	0	wetland	shrub	3-Jun-09	44.45503	-88.0618
084 Dt	1	1	riprap	shrub	1-Jun-09	44.5242	-88.0099
154 Dt	1	1	riprap	shrub	3-Jun-09	44.48248	-88.0325
164 Dt	1	0	wetland	shrub	25-May-09	44.5017	-88.0207
174 Dt	1	1	riprap	shrub	24-May-09	44.46412	-88.0541
Spawning Habitat Averages (SHA)							
Background Habitat Averages (BHA)							
1	0	1	riprap	concrete	2-Jun-10	44.46393	-88.0543
2	0	1	sand	rip rap	2-Jun-10	44.46857	-88.0504
3	0	0	sand	shrub	2-Jun-10	44.46932	-88.0497
4	0	0	grass_shrub	grasses	2-Jun-10	44.47235	-88.0465
5	0	1	riprap	shrub	2-Jun-10	44.47178	-88.0441
6	0	1	riprap	shrub	2-Jun-10	44.4737	-88.0408
7	0	1	grass_shrub	rip rap	2-Jun-10	44.47802	-88.0369
8	0	1	sand	shrub	2-Jun-10	44.47822	-88.0363
9	0	1	rock	rip rap	2-Jun-10	44.47965	-88.0343
10	0	1	riprap	concrete	2-Jun-10	44.48013	-88.034
11	0	1	sand	rip rap	2-Jun-10	44.48585	-88.031
12	0	1	riprap	shrub	2-Jun-10	44.48857	-88.0276
13	0	0	wetland	shrub	2-Jun-10	44.4903	-88.0263
14	0	0	wetland	shrub	2-Jun-10	44.4906	-88.0262
15	0	1	riprap	shrub	2-Jun-10	44.49303	-88.0227
16	0	1	riprap	shrub	2-Jun-10	44.49703	-88.0226
17	0	1	rock	shrub	2-Jun-10	44.49882	-88.022
18	0	1	riprap	concrete	2-Jun-10	44.49957	-88.022

Appendix 4: Fox River habitat survey data.

Waypoint	Spawn	Development	Immediate Shoreline	Environmental Shoreline	Date	Latitude	Longitude
19	0	1	riprap	shrub	2-Jun-10	44.50095	-88.0207
20	0	1	riprap	shrub	2-Jun-10	44.50175	-88.0207
21	0	0	grass_shrub	shrub	2-Jun-10	44.5026	-88.0212
22	0	1	riprap	shrub	2-Jun-10	44.50615	-88.0208
23	0	1	riprap	shrub	2-Jun-10	44.50775	-88.0205
24	0	1	riprap	grasses	2-Jun-10	44.50872	-88.0202
25	0	1	riprap	concrete	2-Jun-10	44.51367	-88.0181
26	0	1	riprap	lawn	2-Jun-10	44.52032	-88.0089
27	0	1	riprap	lawn	2-Jun-10	44.5293	-88.0078
28	0	1	riprap	lawn	2-Jun-10	44.5298	-88.008
29	0	1	riprap	lawn	2-Jun-10	44.53092	-88.0077
30	0	0	wetland	phrag	2-Jun-10	44.53582	-88.0048
31	0	1	riprap	concrete	2-Jun-10	44.53728	-88.0041
32	0	1	riprap	concrete	2-Jun-10	44.5377	-88.0038
33	0	1	riprap	shrub	2-Jun-10	44.5391	-88.0065
34	0	1	rock	shrub	2-Jun-10	44.53175	-88.0097
35	0	1	rock	shrub	2-Jun-10	44.5315	-88.0098
36	0	1	sand	shrub	2-Jun-10	44.53128	-88.0099
37	0	1	riprap	concrete	2-Jun-10	44.52977	-88.01
38	0	1	rock	boul	2-Jun-10	44.51877	-88.0168
39	0	1	riprap	rip rap	2-Jun-10	44.51127	-88.0234
40	0	1	riprap	rip rap	2-Jun-10	44.50452	-88.0243
41	0	1	riprap	shrub	2-Jun-10	44.50397	-88.0246
42	0	1	riprap	shrub	2-Jun-10	44.50368	-88.0248
43	0	1	rock	cobb	2-Jun-10	44.50203	-88.0257
44	0	1	rock	shrub	2-Jun-10	44.50075	-88.0256
45	0	1	riprap	shrub	2-Jun-10	44.49803	-88.0249
46	0	1	rock	shrub	2-Jun-10	44.49658	-88.0264
47	0	1	rock	concrete	2-Jun-10	44.49275	-88.0287

Appendix 4: Fox River habitat survey data.

Waypoint	Spawn	Development	Immediate Shoreline	Environmental Shoreline	Date	Latitude	Longitude
48	0	1	riprap	concrete	2-Jun-10	44.49172	-88.03
49	0	1	riprap	concrete	2-Jun-10	44.49108	-88.0307
50	0	1	rock	boul	2-Jun-10	44.48913	-88.0331
51	0	1	sand	phrag	8-Jun-10	44.45853	-88.0592
52	0	1	sand	phrag	8-Jun-10	44.45622	-88.0615
53	0	1	riprap	concrete	8-Jun-10	44.45082	-88.0638
54	0	1	rock	lawn	8-Jun-10	44.45042	-88.063
55	0	1	riprap	shrub	8-Jun-10	44.45073	-88.0715
56	0	1	rock	shrub	8-Jun-10	44.45185	-88.074
57	0	1	rock	san	8-Jun-10	44.45552	-88.0745
58	0	1	sand	rip rap	8-Jun-10	44.45653	-88.0736
59	0	1	sand	rip rap	8-Jun-10	44.45535	-88.0689
60	0	1	riprap	trees	8-Jun-10	44.45573	-88.068
61	0	1	riprap	lawn	8-Jun-10	44.4574	-88.0681
62	0	1	riprap	shrub	8-Jun-10	44.46002	-88.0634
63	0	1	riprap	lawn	8-Jun-10	44.46088	-88.0613
64	0	0	wetland	trees	8-Jun-10	44.46547	-88.0576
65	0	0	wetland	trees	8-Jun-10	44.46558	-88.0573
66	0	0	wetland	trees	8-Jun-10	44.46597	-88.0567
67	0	0	wetland	lawn	8-Jun-10	44.46698	-88.0552
68	0	0	sand	phrag	8-Jun-10	44.46942	-88.056
69	0	1	wetland	rip rap	8-Jun-10	44.46915	-88.0536
70	0	0	wetland	trees	8-Jun-10	44.47138	-88.0519
71	0	0	rock	trees	8-Jun-10	44.4749	-88.0502
72	0	0	sand	phrag	8-Jun-10	44.47513	-88.0497
73	0	0	sand	phrag	8-Jun-10	44.47567	-88.0488
74	0	1	riprap	concrete	8-Jun-10	44.47725	-88.0488
75	0	1	riprap	concrete	8-Jun-10	44.47713	-88.0484
76	0	1	riprap	concrete	8-Jun-10	44.47858	-88.0486

Appendix 4: Fox River habitat survey data.

Waypoint	Spawn	Development	Immediate Shoreline	Environmental Shoreline	Date	Latitude	Longitude
77	0	1	riprap	concrete	8-Jun-10	44.4788	-88.0477
78	0	0	wetland	trees	8-Jun-10	44.47892	-88.046
79	0	1	sand	rip rap	8-Jun-10	44.48308	-88.0439
80	0	1	riprap	shrub	8-Jun-10	44.48587	-88.0399

Appendix 4: Fox River habitat survey data.

Waypoint	**Bedrock**	**Boulder**	**Cobble**	**Gravel**	**Sand**	**Silt**	**Clay**	**Concrete**	**Litter**	**Depth**
044 Dt	0	3.462	3.077	22.31	47.31	15.38	0	0	1.154	85
054 Dt	0	0	0.667	20.67	26	52.67	0	0	0.333	93
084 Dt	0	27.5	57.5	15	0	0	0	0	0	116
154 Dt	0	0	0.667	44.667	39.667	15	0	0	0	112
164 Dt	0	0.667	7.333	14	37	41	0	0	3.667	86
174 Dt	0	0	11	12	26	51	0	0	0	75
SHA	0	5.2715	13.374	21.44667	29.3295	29.175	**0**	**0**	**0.859**	**94.5**
BHA	0	12.1875	8.4375	21.75	28.875	22.3125	**5.1875**	**1.25**	**0.375**	**77.4875**
1	0	0	75	25	0	0	0	0	0	115
2	0	0	0	5	90	5	0	0	0	117
3	0	0	20	80	0	0	0	0	0	53
4	0	0	0	20	70	10	0	0	0	135
5	0	0	100	0	0	0	0	0	0	63
6	0	0	40	60	0	0	0	0	0	37
7	0	0	0	10	35	5	50	0	0	66
8	0	0	0	20	10	0	70	0	0	74
9	0	0	0	95	5	0	0	0	0	68
10	0	0	0	100	0	0	0	0	0	57
11	0	0	0	5	90	5	0	0	0	123
12	0	0	0	55	40	5	0	0	0	86
13	0	0	0	0	95	5	0	0	0	81
14	0	0	0	0	95	5	0	0	0	84
15	0	0	0	0	80	20	0	0	0	82
16	0	0	0	20	75	5	0	0	0	99
17	0	0	0	10	85	5	0	0	0	60
18	0	0	0	0	0	100	0	0	0	97

Appendix 4: Fox River habitat survey data.

Waypoint	Bedrock	Boulder	Cobble	Gravel	Sand	Silt	Clay	Concrete	Litter	Depth
19	0	0	80	20	0	0	0	0	0	79
20	0	0	40	25	30	5	0	0	0	98
21	0	0	0	60	40	0	0	0	0	38
22	0	70	30	0	0	0	0	0	0	56
23	0	100	0	0	0	0	0	0	0	99
24	0	100	0	0	0	0	0	0	0	55
25	0	75	25	0	0	0	0	0	0	70
26	0	50	0	50	0	0	0	0	0	36
27	0	0	0	100	0	0	0	0	0	54
28	0	100	0	0	0	0	0	0	0	26
29	0	0	50	50	0	0	0	0	0	58
30	0	0	0	0	0	100	0	0	0	100
31	0	0	0	0	0	0	0	100	0	123
32	0	0	0	100	0	0	0	0	0	94
33	0	0	0	50	0	0	50	0	0	102
34	0	0	0	0	100	0	0	0	0	100
35	0	0	0	0	75	25	0	0	0	34
36	0	0	0	0	80	20	0	0	0	35
37	0	0	0	0	20	80	0	0	0	51
38	0	0	50	50	0	0	0	0	0	88
39	0	0	0	10	0	0	90	0	0	115
40	0	50	25	25	0	0	0	0	0	85
41	0	0	0	50	40	10	0	0	0	95
42	0	0	0	50	50	0	0	0	0	103
43	0	0	25	75	0	0	0	0	0	129
44	0	0	0	10	85	5	0	0	0	60
45	0	0	0	90	10	0	0	0	0	85
46	0	0	0	50	40	10	0	0	0	130
47	0	0	0	70	15	15	0	0	0	38

Appendix 4: Fox River habitat survey data.

Waypoint	Bedrock	Boulder	Cobble	Gravel	Sand	Silt	Clay	Concrete	Litter	Depth
48	0	100	0	0	0	0	0	0	0	47
49	0	0	25	75	0	0	0	0	0	29
50	0	0	50	50	0	0	0	0	0	30
51	0	0	0	0	90	10	0	0	0	54
52	0	0	0	0	50	50	0	0	0	51
53	0	0	40	60	0	0	0	0	0	95
54	0	100	0	0	0	0	0	0	0	54
55	0	0	0	0	0	100	0	0	5	75
56	0	0	0	40	60	0	0	0	0	55
57	0	0	0	5	0	15	80	0	0	74
58	0	0	0	0	80	10	10	0	0	77
59	0	0	0	0	50	50	0	0	0	88
60	0	0	0	0	90	10	0	0	0	73
61	0	0	0	0	0	100	0	0	0	55
62	0	0	0	0	85	15	0	0	5	37
63	0	0	0	0	90	10	0	0	0	77
64	0	0	0	0	30	70	0	0	0	69
65	0	0	0	0	20	80	0	0	0	52
66	0	0	0	0	30	70	0	0	5	53
67	0	0	0	0	40	60	0	0	0	57
68	0	0	0	0	10	30	60	0	5	117
69	0	0	0	0	30	70	0	0	5	98
70	0	0	0	0	10	90	0	0	0	92
71	0	0	0	0	40	60	0	0	0	125
72	0	0	0	0	25	75	0	0	5	78
73	0	0	0	0	0	95	5	0	0	86
74	0	100	0	0	0	0	0	0	0	50
75	0	90	0	10	0	0	0	0	0	72
76	0	40	0	60	0	0	0	0	0	150

Appendix 4: Fox River habitat survey data.

Waypoint	Bedrock	Boulder	Cobble	Gravel	Sand	Silt	Clay	Concrete	Litter	Depth
77	0	0	0	0	20	80	0	0	0	83
78	0	0	0	0	25	75	0	0	0	67
79	0	0	0	0	80	20	0	0	0	94
80	0	0	0	0	0	100	0	0	0	152

Appendix 4: Fox River habitat survey data.

Waypoint	Bottom Slope	Slope Category	Woody Debris	Total Coverage	Coverage Category	# Species
044 Dt	16	5	1	2	1	0
054 Dt	1	1	0	29	1	1
084 Dt	0	1	0	0	1	0
154 Dt	5.1	2	0	0	1	0
164 Dt	1.5	1	1	6	1	1
174 Dt	1.4	1	0	6	1	1
SHA	4.166666667	1.833333	0.333333	7.166667	1	0.5
BHA	3.962059733	1.625	0	4.5	1.025	0.375
1	11.6	4	0	0	1	0
2	2	1	0	15	1	1
3	12.92682927	5	0	5	1	1
4	1.5	1	0	0	1	0
5	10.6779661	4	0	0	1	0
6	12.33333333	5	0	0	1	0
7	13.2	5	0	0	1	0
8	4	2	0	5	1	1
9	5.8	2	0	5	1	1
10	5.263157895	2	0	0	1	0
11	0.75	1	0	0	1	0
12	5.2	2	0	25	1	1
13	1.8	1	0	5	1	1
14	1.2	1	0	5	1	1
15	2.2	1	0	30	1	1
16	5.8	2	0	5	1	1
17	1	1	0	30	1	1
18	4.8	2	0	0	1	0

Appendix 4: Fox River habitat survey data.

Waypoint	Bottom Slope	Slope Category	Woody Debris	Total Coverage	Coverage Category	# Species
19	4.8	2	0	0	1	0
20	0.2	1	0	0	1	0
21	2.8	1	0	5	1	1
22	0.6	1	0	0	1	0
23	0.6	1	0	0	1	0
24	0.4	1	0	0	1	0
25	0	1	0	0	1	0
26	0.2	1	0	0	1	0
27	0.6	1	0	0	1	0
28	4.6	2	0	0	1	0
29	0.4	1	0	0	1	0
30	0.8	1	0	10	1	1
31	1.75	1	0	0	1	0
32	0.2	1	0	5	1	1
33	1.2	1	0	0	1	0
34	1	1	0	0	1	0
35	0	1	0	5	1	1
36	0.2	1	0	15	1	1
37	2.2	1	0	35	2	1
38	0	1	0	0	1	0
39	9	3	0	0	1	0
40	0.8	1	0	0	1	0
41	1	1	0	0	1	0
42	7.6	3	0	5	1	1
43	1	1	0	0	1	0
44	0.4	1	0	0	1	0
45	3.4	2	0	0	1	0
46	0.444444444	1	0	0	1	0
47	2	1	0	0	1	0

Appendix 4: Fox River habitat survey data.

Waypoint	Bottom Slope	Slope Category	Woody Debris	Total Coverage	Coverage Category	# Species
48	2	1	0	0	1	0
49	2	1	0	0	1	0
50	0.2	1	0	0	1	0
51	4.8	2	0	5	1	1
52	0.2	1	0	0	1	0
53	0.4	1	0	0	1	0
54	2.8	1	0	0	1	0
55	1	1	0	0	1	0
56	1	1	0	0	1	0
57	1.6	1	0	5	1	2
58	1.4	1	0	60	2	1
59	4.2	2	0	0	1	0
60	3.6	2	0	0	1	0
61	4	2	0	0	1	0
62	1.4	1	0	0	1	0
63	5.2	2	0	5	1	1
64	3	1	0	0	1	0
65	2.8	1	0	10	1	1
66	2.2	1	0	10	1	1
67	1.2	1	0	0	1	0
68	0.6	1	0	0	1	0
69	0.2	1	0	5	1	1
70	1.2	1	0	0	1	0
71	4.8	2	0	0	1	0
72	5.2	2	0	25	1	1
73	2.6	1	0	0	1	0
74	0.8	1	0	0	1	0
75	0.4	1	0	0	1	0
76	0.2	1	0	0	1	0

Appendix 4: Fox River habitat survey data.

Waypoint	Bottom Slope	Slope Category	Woody Debris	Total Coverage	Coverage Category	# Species
77	1.5	1	0	10	1	2
78	15.95238095	5	0	5	1	1
79	37.6	5	0	10	1	1
80	50.66666667	5	0	0	1	0

Appendix 5: Lower Green Bay habitat survey data

Waypoint	Spawn	Development	Immediate Shoreline	Environmental Shoreline	Date	Latitude	Longitude	Bedrock	Boulder
004 Dt	1	1	riprap	lawn	28-May-09	44.63448	-88.0297	0	0
014 Dt	1	0	wetland	phrag	29-May-09	44.61727	-88.0134	0	0
024 Dt	1	0	wetland	wetland	9-Jun-09	44.66702	-87.9905	0	0
034 Dt	1	0	wetland	wetland	19-Jun-09	44.57178	-88.0382	0	0
074 Dt	1	0	wetland	grasses	8-Jun-09	44.61793	-88.0135	0	0
114 Dt	1	1	riprap	shrub	21-Jun-09	44.54017	-87.9982	0	13.33
124 Dt	1	1	sand	lawn	15-May-09	44.5713	-87.9006	0	5.33
Spawning Habitat Averages (SHA)								0	2.6657143
Background Habitat Averages (BHA)								0	1.25
1	0	0	sand	phrag	3-Jun-10	44.57543	-87.9052	0	0
2	0	1	rock	shrub	3-Jun-10	44.56492	-87.9055	0	0
3	0	1	dock	cobb	3-Jun-10	44.56457	-87.9058	0	0
4	0	1	rock	gravel	3-Jun-10	44.56247	-87.9069	0	0
5	0	1	rock	gravel	3-Jun-10	44.54607	-87.92	0	0
6	0	0	rock	grasses	3-Jun-10	44.5439	-87.9241	0	0
7	0	1	rock	boul	3-Jun-10	44.53382	-87.9419	0	0
8	0	0	wetland	phrag	3-Jun-10	44.53228	-87.9494	0	0
9	0	1	sand	phrag	3-Jun-10	44.532	-87.9723	0	0
10	0	1	sand	san	3-Jun-10	44.53265	-87.9757	0	0
11	0	1	wetland	grasses	3-Jun-10	44.53433	-87.9808	0	0
12	0	0	rock	phrag	3-Jun-10	44.53583	-87.9841	0	0
13	0	1	rock	shrub	3-Jun-10	44.5408	-88.006	0	0
14	0	1	rock	shrub	3-Jun-10	44.54248	-88.0071	0	0
15	0	1	rock	shrub	3-Jun-10	44.54477	-88.0096	0	0
16	0	1	rock	shrub	3-Jun-10	44.54492	-88.0101	0	0
17	0	1	wetland	phrag	3-Jun-10	44.5492	-88.0163	0	0
18	0	0	wetland	phrag	3-Jun-10	44.55168	-88.0205	0	0
19	0	0	wetland	phrag	3-Jun-10	44.55187	-88.0208	0	0

Appendix 5: Lower Green Bay habitat survey data

Waypoint	Spawn	Development	Immediate Shoreline	Environmental Shoreline	Date	Latitude	Longitude	Bedrock	Boulder
20	0	0	wetland	phrag	3-Jun-10	44.55343	-88.0219	0	0
21	0	0	wetland	phrag	3-Jun-10	44.55992	-88.0272	0	0
22	0	0	wetland	phrag	3-Jun-10	44.56242	-88.0263	0	0
23	0	0	wetland	phrag	3-Jun-10	44.56733	-88.0255	0	0
24	0	0	wetland	phrag	3-Jun-10	44.57645	-88.0345	0	0
25	0	0	wetland	phrag	3-Jun-10	44.57495	-88.0196	0	0
26	0	0	wetland	phrag	3-Jun-10	44.5813	-88.0167	0	0
27	0	0	wetland	phrag	3-Jun-10	44.58218	-88.0149	0	0
28	0	0	wetland	phrag	3-Jun-10	44.58633	-88.0139	0	0
29	0	0	wetland	phrag	3-Jun-10	44.58913	-88.0135	0	0
30	0	0	wetland	phrag	3-Jun-10	44.59232	-88.0089	0	0
31	0	0	wetland	phrag	3-Jun-10	44.5952	-88.0084	0	0
32	0	1	riprap	lawn	3-Jun-10	44.61207	-88.0099	0	0
33	0	0	wetland	phrag	3-Jun-10	44.61525	-88.0109	0	0
34	0	0	wetland	phrag	3-Jun-10	44.61723	-88.0114	0	0
35	0	0	wetland	phrag	3-Jun-10	44.62298	-88.0112	0	0
36	0	0	wetland	phrag	3-Jun-10	44.62412	-88.01	0	0
37	0	0	wetland	phrag	3-Jun-10	44.62217	-88.0111	0	0
38	0	0	wetland	phrag	3-Jun-10	44.61817	-88.0107	0	0
39	0	0	wetland	phrag	3-Jun-10	44.60927	-88.0049	0	0
40	0	0	wetland	phrag	3-Jun-10	44.60122	-87.9941	0	0
41	0	0	wetland	phrag	3-Jun-10	44.59338	-87.9862	0	0
42	0	0	sand	phrag	3-Jun-10	44.58115	-87.9819	0	0
43	0	0	wetland	phrag	7-Jun-10	44.66337	-87.9885	0	0
44	0	0	wetland	phrag	7-Jun-10	44.66447	-87.9885	0	0
45	0	0	wetland	phrag	7-Jun-10	44.6648	-87.9887	0	0
46	0	0	wetland	phrag	7-Jun-10	44.66582	-87.9896	0	0
47	0	0	wetland	phrag	7-Jun-10	44.6737	-87.9935	0	0
48	0	0	wetland	phrag	7-Jun-10	44.67472	-87.9931	0	0
49	0	0	wetland	phrag	7-Jun-10	44.67677	-87.9919	0	0
50	0	0	wetland	phrag	7-Jun-10	44.67668	-87.9925	0	0

Appendix 5: Lower Green Bay habitat survey data

Waypoint	Spawn	Development	Immediate Shoreline	Environmental Shoreline	Date	Latitude	Longitude	Bedrock	Boulder
20	0	0	wetland	phrag	3-Jun-10	44.55343	-88.0219	0	0
21	0	0	wetland	phrag	3-Jun-10	44.55992	-88.0272	0	0
22	0	0	wetland	phrag	3-Jun-10	44.56242	-88.0263	0	0
23	0	0	wetland	phrag	3-Jun-10	44.56733	-88.0255	0	0
24	0	0	wetland	phrag	3-Jun-10	44.57645	-88.0345	0	0
25	0	0	wetland	phrag	3-Jun-10	44.57495	-88.0196	0	0
26	0	0	wetland	phrag	3-Jun-10	44.5813	-88.0167	0	0
27	0	0	wetland	phrag	3-Jun-10	44.58218	-88.0149	0	0
28	0	0	wetland	phrag	3-Jun-10	44.58633	-88.0139	0	0
29	0	0	wetland	phrag	3-Jun-10	44.58913	-88.0135	0	0
30	0	0	wetland	phrag	3-Jun-10	44.59232	-88.0089	0	0
31	0	0	wetland	phrag	3-Jun-10	44.5952	-88.0084	0	0
32	0	1	riprap	lawn	3-Jun-10	44.61207	-88.0099	0	0
33	0	0	wetland	phrag	3-Jun-10	44.61525	-88.0109	0	0
34	0	0	wetland	phrag	3-Jun-10	44.61723	-88.0114	0	0
35	0	0	wetland	phrag	3-Jun-10	44.62298	-88.0112	0	0
36	0	0	wetland	phrag	3-Jun-10	44.62412	-88.01	0	0
37	0	0	wetland	phrag	3-Jun-10	44.62217	-88.0111	0	0
38	0	0	wetland	phrag	3-Jun-10	44.61817	-88.0107	0	0
39	0	0	wetland	phrag	3-Jun-10	44.60927	-88.0049	0	0
40	0	0	wetland	phrag	3-Jun-10	44.60122	-87.9941	0	0
41	0	0	wetland	phrag	3-Jun-10	44.59338	-87.9862	0	0
42	0	0	sand	phrag	3-Jun-10	44.58115	-87.9819	0	0
43	0	0	wetland	phrag	7-Jun-10	44.66337	-87.9885	0	0
44	0	0	wetland	phrag	7-Jun-10	44.66447	-87.9885	0	0
45	0	0	wetland	phrag	7-Jun-10	44.6648	-87.9887	0	0
46	0	0	wetland	phrag	7-Jun-10	44.66582	-87.9896	0	0
47	0	0	wetland	phrag	7-Jun-10	44.6737	-87.9935	0	0
48	0	0	wetland	phrag	7-Jun-10	44.67472	-87.9931	0	0
49	0	0	wetland	phrag	7-Jun-10	44.67677	-87.9919	0	0
50	0	0	wetland	phrag	7-Jun-10	44.67668	-87.9925	0	0

Appendix 5: Lower Green Bay habitat survey data

Waypoint	**Cobble**	**Gravel**	**Sand**	**Silt**	**Clay**	**Concrete**	**Litter**	**Depth**	**Bottom Slope**	**Slope Category**
004 Dt	0	0	0	100	0	0	13	70	16	5
014 Dt	0	0	53.33	46.67	0	0	0	90	0.8	1
024 Dt	0	0	78	22	0	0	0	157	0.9	1
034 Dt	0	0	0	100	0	0	0	76	0.4	1
074 Dt	0	0	75.67	24.33	0	0	0	89	1	1
114 Dt	0	0	85.667	1	0	0	0	110	9.5	4
124 Dt	26	16.667	45.33	6.667	0	0	0	25	1.2	1
(SHA)	3.7142857	2.381	48.285286	42.952429	0	0	1.8571429	88.142857	4.257142	2
(BHA)	3.5	4	73.375	17.875	0	0	0	78.3625	4.295585	1.4875
1	0	0	100	0	0	0	0	92	0.2	1
2	50	50	0	0	0	0	0	94	5.2	2
3	0	100	0	0	0	0	0	110	2.4	1
4	0	0	100	0	0	0	0	68	2	1
5	0	50	50	0	0	0	0	92	1.6	1
6	0	50	50	0	0	0	0	20	3.4	2
7	0	0	100	0	0	0	0	124	2.8	1
8	0	0	100	0	0	0	0	97	0.6	1
9	0	0	100	0	0	0	0	81	-1	1
10	0	0	100	0	0	0	0	80	1	1
11	0	0	100	0	0	0	0	94	2.2	1
12	0	0	0	100	0	0	0	135	0	1
13	0	0	100	0	0	0	0	89	1.2	1
14	0	0	100	0	0	0	0	87	1	1
15	0	0	100	0	0	0	0	87	3.2	2
16	0	0	100	0	0	0	0	60	0.4	1
17	0	0	100	0	0	0	0	60	1	1
18	0	0	80	20	0	0	0	97	4.8	2
19	0	0	90	10	0	0	0	79	4.8	2

Appendix 5: Lower Green Bay habitat survey data

Waypoint	Cobble	Gravel	Sand	Silt	Clay	Concrete	Litter	Depth	Bottom Slope	Slope Category
20	0	0	50	50	0	0	0	98	0.2	1
21	0	0	20	80	0	0	0	38	2.8	1
22	0	0	80	20	0	0	0	56	0.6	1
23	0	0	85	15	0	0	0	99	0.6	1
24	0	0	10	90	0	0	0	55	0.4	1
25	0	0	90	10	0	0	0	70	0	1
26	0	0	90	10	0	0	0	36	-0.2	1
27	0	0	90	10	0	0	0	54	0.6	1
28	0	0	95	5	0	0	0	26	4.6	2
29	0	0	100	0	0	0	0	58	0.4	1
30	0	0	100	0	0	0	0	100	0.8	1
31	0	0	100	0	0	0	0	123	1.75	2
32	0	0	60	40	0	0	0	94	-0.2	1
33	0	0	40	60	0	0	0	102	1.2	1
34	0	0	30	70	0	0	0	100	1	1
35	0	0	30	70	0	0	0	34	0	1
36	0	0	0	100	0	0	0	35	0.2	1
37	0	0	40	60	0	0	0	51	2.2	1
38	0	0	5	95	0	0	0	88	0	1
39	0	0	95	5	0	0	0	115	9	3
40	0	0	100	0	0	0	0	85	0.8	1
41	0	0	100	0	0	0	0	95	1	1
42	0	0	100	0	0	0	0	103	7.6	3
43	0	0	40	60	0	0	0	129	-1	1
44	0	0	100	0	0	0	0	60	-0.4	1
45	0	0	100	0	0	0	0	85	3.4	2
46	0	0	40	60	0	0	0	130	0.444444	1
47	0	0	70	30	0	0	0	38	2	1
48	0	0	70	30	0	0	0	47	2	1
49	0	0	0	100	0	0	0	29	2	1
50	0	0	10	90	0	0	0	30	0.2	1

Appendix 5: Lower Green Bay habitat survey data

Waypoint	Cobble	Gravel	Sand	Silt	Clay	Concrete	Litter	Depth	Bottom Slope	Slope Category
51	0	0	70	30	0	0	0	54	4.8	2
52	0	0	90	10	0	0	0	51	0.2	1
53	0	0	95	5	0	0	0	95	0.4	1
54	0	0	90	10	0	0	0	54	2.8	1
55	0	0	85	15	0	0	0	75	1	1
56	0	0	90	10	0	0	0	55	1	1
57	0	0	90	10	0	0	0	74	1.6	1
58	0	0	90	10	0	0	0	77	1.4	1
59	0	0	100	0	0	0	0	88	4.2	2
60	0	0	95	5	0	0	0	73	3.6	2
61	0	0	100	0	0	0	0	55	4	2
62	0	0	100	0	0	0	0	37	1.4	1
63	0	0	100	0	0	0	0	77	5.2	2
64	0	0	100	0	0	0	0	69	3	1
65	0	0	100	0	0	0	0	52	2.8	1
66	0	0	100	0	0	0	0	53	2.2	1
67	80	0	20	0	0	0	0	57	-1.2	1
68	0	0	100	0	0	0	0	117	0.6	1
69	0	0	100	0	0	0	0	98	0.2	1
70	0	0	100	0	0	0	0	92	-1.2	1
71	0	0	100	0	0	0	0	125	4.8	2
72	0	0	100	0	0	0	0	78	-5.2	2
73	0	0	100	0	0	0	0	86	2.6	1
74	0	0	0	0	0	0	0	50	62.5	5
75	0	0	95	5	0	0	0	72	0.4	1
76	0	0	95	5	0	0	0	150	0.2	1
77	100	0	0	0	0	0	0	83	55.33333	5
78	0	5	80	15	0	0	0	67	15.95235	5
79	50	25	25	0	0	0	0	94	37.6	5
80	0	40	50	10	0	0	0	152	50.66667	5

Appendix 5: Lower Green Bay habitat survey data

Waypoint	Woody Debris	Total Coverage	Coverage Category	# Species
004 Dt	1	87	3	6
014 Dt	0	5	1	1
024 Dt	0	47	2	3
034 Dt	0	39	2	1
074 Dt	0	78	3	1
114 Dt	0	1	1	1
124 Dt	0	0	1	0
(SHA)	0.142857143	36.71428571	1.857142857	1.857142857
(BHA)	0.0375	16.625	1.3125	0.525
1	0	0	1	0
2	0	0	1	0
3	0	0	1	0
4	0	0	1	0
5	0	0	1	0
6	0	0	1	0
7	0	0	1	0
8	0	5	1	1
9	0	0	1	0
10	0	0	1	0
11	0	0	1	0
12	0	0	1	0
13	0	0	1	0
14	0	0	1	0
15	0	0	1	0
16	0	0	1	0
17	0	0	1	0
18	0	0	1	0
19	0	0	1	0

Appendix 5: Lower Green Bay habitat survey data

Waypoint	Woody Debris	Total Coverage	Coverage Category	# Species
20	0	0	1	0
21	0	10	1	1
22	0	5	1	1
23	0	0	1	0
24	0	0	1	0
25	0	30	1	1
26	0	10	1	1
27	0	5	1	1
28	0	30	1	1
29	0	0	1	0
30	0	0	1	0
31	0	0	1	0
32	0	0	1	0
33	0	0	1	0
34	0	0	1	0
35	0	70	3	1
36	0	100	3	1
37	0	25	1	1
38	0	0	1	0
39	0	5	1	1
40	0	0	1	0
41	0	0	1	0
42	0	0	1	0
43	0	75	3	2
44	0	5	1	2
45	0	50	2	1
46	0	75	3	2
47	0	100	3	1
48	0	50	2	2
49	0	100	3	1
50	0	100	3	1

Appendix 5: Lower Green Bay habitat survey data

Waypoint	Woody Debris	Total Coverage	Coverage Category	# Species
51	0	100	3	2
52	0	60	2	2
53	0	5	1	1
54	0	75	3	1
55	0	20	1	2
56	0	5	1	2
57	0	5	1	1
58	0	5	1	2
59	0	0	1	0
60	0	0	1	0
61	0	0	1	0
62	0	0	1	0
63	0	0	1	0
64	0	0	1	0
65	0	0	1	0
66	1	0	1	0
67	0	0	1	0
68	0	0	1	0
69	0	0	1	0
70	0	0	1	0
71	1	0	1	0
72	1	0	1	0
73	0	0	1	0
74	0	0	1	0
75	0	100	3	1
76	0	0	1	0
77	0	5	1	1
78	0	100	3	4
79	0	0	1	0
80	0	0	1	0

Appendix 6: Menominee River habitat survey data.

Waypoint	Spawn	Development	Immediate Shoreline	Environmental Shoreline	Date	Latitude	Longitude
024 Dt	1	0	sand	shrub	21-May-10	45.10242	-87.6218
033 Dt	1	0	sand	shrub	21-May-10	45.10223	-87.6204
064 Dt	1	1	riprap	concrete	21-May-10	45.09737	-87.6107
094 Dt	1	1	riprap	shrub	21-May-10	45.10103	-87.6171
124 Dt	1	0	grass_shrub	shrub	21-May-10	45.10495	-87.63
336 Dt	1	1	riprap	grasses	11-May-10	45.10155	-87.6282
344 Dt	1	1	riprap	lawn	13-May-10	45.10215	-87.6314
357 Dt	1	0	sand	grasses	13-May-10	45.10142	-87.6215
366 Dt	1	0	sand	grasses	17-May-10	45.09722	-87.6105
Spawning Habitat Averages (SHA)							
Background Habitat Averages (BHA)							
3	0	1	riprap	shrub	19-May-10	45.09197	-87.5945
4	0	1	rock	grasses	19-May-10	45.0918	-87.5972
5	0	1	riprap	grasses	19-May-10	45.09252	-87.598
13	0	1	rock	shrub	19-May-10	45.09722	-87.6056
15	0	0	grass_shrub	grasses	19-May-10	45.09535	-87.6055
16	0	0	wetland	phrag	19-May-10	45.09252	-87.5997
17	0	0	wetland	grasses	19-May-10	45.093	-87.6011
19	0	0	grass_shrub	shrub	19-May-10	45.09528	-87.6081
20	0	0	grass_shrub	shrub	19-May-10	45.09607	-87.6087
21	0	0	grass_shrub	shrub	19-May-10	45.09612	-87.6093
22	0	0	sand	shrub	19-May-10	45.09642	-87.6096
23	0	0	sand	shrub	19-May-10	45.09675	-87.6098
24	0	0	grass_shrub	shrub	19-May-10	45.09732	-87.6093
25	0	0	wetland	phrag	19-May-10	45.09687	-87.6085
26	0	0	sand	shrub	19-May-10	45.09737	-87.6084
27	0	0	sand	shrub	19-May-10	45.09717	-87.6074
28	0	0	grass_shrub	shrub	19-May-10	45.09755	-87.6073

Appendix 6: Menominee River habitat survey data.

Waypoint	Spawn	Development	Immediate Shoreline	Environmental Shoreline	Date	Latitude	Longitude
29	0	0	sand	shrub	19-May-10	45.09775	-87.608
30	0	0	sand	shrub	19-May-10	45.09743	-87.608
32	0	1	riprap	shrub	26-May-10	45.09732	-87.6117
33	0	1	riprap	grasses	26-May-10	45.09837	-87.6124
35	0	1	riprap	shrub	26-May-10	45.10108	-87.6169
36	0	1	riprap	shrub	26-May-10	45.10122	-87.6181
37	0	0	sand	grasses	26-May-10	45.10142	-87.6219
38	0	0	sand	grasses	26-May-10	45.10142	-87.6221
39	0	0	dock	shrub	26-May-10	45.10195	-87.6237
40	0	0	dock	shrub	26-May-10	45.10203	-87.6237
41	0	0	grass_shrub	shrub	26-May-10	45.10225	-87.6238
42	0	0	rock	boul	26-May-10	45.10262	-87.6227
43	0	0	riprap	shrub	26-May-10	45.10253	-87.6222
44	0	0	sand	shrub	26-May-10	45.10233	-87.6216
45	0	0	riprap	shrub	26-May-10	45.10235	-87.6215
46	0	0	sand	shrub	26-May-10	45.1021	-87.6208
47	0	0	riprap	shrub	26-May-10	45.10198	-87.6203
48	0	0	sand	shrub	26-May-10	45.10262	-87.6213
49	0	0	sand	grasses	26-May-10	45.10377	-87.6226
50	0	1	rock	gravel	26-May-10	45.1057	-87.6219
51	0	1	sand	grasses	26-May-10	45.10488	-87.6202
52	0	0	wetland	shrub	26-May-10	45.10363	-87.6245
53	0	0	sand	grasses	26-May-10	45.10372	-87.6241
54	0	0	sand	grasses	26-May-10	45.10388	-87.6246
55	0	0	rock	shrub	26-May-10	45.10365	-87.6249
56	0	0	sand	shrub	26-May-10	45.10207	-87.6226
57	0	0	sand	shrub	26-May-10	45.10202	-87.6222
58	0	0	sand	grasses	26-May-10	45.10157	-87.6211
59	0	0	grass_shrub	grasses	1-Jun-10	45.10525	-87.6286
60	0	0	rock	grasses	1-Jun-10	45.1064	-87.6312
61	0	0	rock	grasses	1-Jun-10	45.10628	-87.6321

Appendix 6: Menominee River habitat survey data.

Waypoint	Spawn	Development	Immediate Shoreline	Environmental Shoreline	Date	Latitude	Longitude
62	0	0	rock	grasses	1-Jun-10	45.10612	-87.633
63	0	1	rock	grasses	1-Jun-10	45.10627	-87.6341
64	0	0	rock	grasses	1-Jun-10	45.10592	-87.6324
65	0	0	grass_shrub	grasses	1-Jun-10	45.10452	-87.633
66	0	1	rock	shrub	1-Jun-10	45.10425	-87.6324
67	0	0	grass_shrub	grasses	1-Jun-10	45.10503	-87.6303
68	0	0	rock	shrub	1-Jun-10	45.10337	-87.633
69	0	1	rock	rr	1-Jun-10	45.10245	-87.632
70	0	1	rock	grasses	1-Jun-10	45.10175	-87.6307
71	0	1	rock	grasses	1-Jun-10	45.10252	-87.6316
72	0	1	rock	grasses	1-Jun-10	45.10252	-87.6318
73	0	1	rock	grasses	1-Jun-10	45.10317	-87.6299
74	0	1	rock	shrub	1-Jun-10	45.10327	-87.6271
75	0	1	rock	concrete	1-Jun-10	45.10235	-87.6277
76	0	1	riprap	grasses	1-Jun-10	45.10213	-87.6268
77	0	1	rock	shrub	1-Jun-10	45.1012	-87.6281
78	0	1	riprap	grasses	1-Jun-10	45.10087	-87.6243
79	0	1	riprap	concrete	1-Jun-10	45.10075	-87.6235
80	0	1	riprap	shrub	1-Jun-10	45.10288	-87.6186
81	0	0	grass_shrub	shrub	1-Jun-10	45.10287	-87.6184
82	0	1	riprap	shrub	1-Jun-10	45.10237	-87.6171
83	0	1	riprap	shrub	1-Jun-10	45.10225	-87.6168
84	0	1	riprap	cobb	1-Jun-10	45.10148	-87.6151
85	0	1	riprap	cobb	1-Jun-10	45.10128	-87.6149
86	0	1	riprap	cobb	1-Jun-10	45.10043	-87.6131
87	0	1	riprap	gravel	1-Jun-10	45.10008	-87.6126
88	0	1	riprap	shrub	1-Jun-10	45.09843	-87.5987
89	0	1	riprap	shrub	1-Jun-10	45.09597	-87.5924
90	0	1	riprap	shrub	1-Jun-10	45.09598	-87.5921

Appendix 6: Menominee River habitat survey data.

Waypoint	**Bedrock**	**Boulder**	**Cobble**	**Gravel**	**Sand**	**Silt**	**Clay**	**Concrete**	**Litter**	**Depth**	**Bottom Slope**
024 Dt	0	0	0	3	74.3	22	0	0	6	68	5.5
033 Dt	0	0	0	6.66	81	12.667	0	0	36.7	58	1.8
064 Dt	0	0	0	0	91.667	8.333	0	0	0	83	1.8
094 Dt	0	0	2.667	0.333	84.333	12.667	0	0	0	76	1.6
124 Dt	0	14	54.33	31.667	0	0	0	0	0	68	0.9
336 Dt	0	4.17	91.67	4.1667	0	0	0	0	0	69	16.15384
344 Dt	0	0	0	67	30	3	0	0	0	65	-1.5
357 Dt	0	0	70.36	13.929	15.714	0	0	0	0	49	22.5
366 Dt	0	0	0	0	66	34	0	0	0	103	-1.9
(SHA)	0	2.01889	24.3363	14.0837	49.2238	10.2963	0	0	4.74444	71	5.2059806
(BHA)	0	12.5324	15.1948	18.8964	33.0548	19.0254	0	0.32463	6.94809	82.4936	14.956111
3	0	0	0	25	75	0	0	0	0	80	20.51251
4	0	0	100	0	0	0	0	0	0	80	72.77273
5	0	0	50	50	0	0	0	0	0	118	118
13	0	0	0	75	25	0	0	0	0	88	24.44444
15	0	0	0	0	0	100	0	0	0	92	4.6
16	0	0	0	0	0	100	0	0	0	75	4
17	0	0	0	0	0	100	0	0	0	91	4.6
19	0	0	0	0	0	100	0	0	0	60	6.6
20	0	0	0	0	40	60	0	0	0	17	6.078571
21	0	0	0	0	90	10	0	0	0	90	-6.25
22	0	0	0	0	0	100	0	20	0	110	9.2
23	0	0	0	0	0	100	0	0	0	77	3.6
24	0	0	0	0	70	30	0	0	0	35	2.8
25	0	0	0	0	0	100	0	0	0	40	1.4
26	0	0	0	0	40	60	0	0	0	55	2
27	0	0	0	0	0	100	0	0	0	84	1
28	0	0	0	0	100	0	0	0	0	47	3

Appendix 6: Menominee River habitat survey data.

Waypoint	Bedrock	Boulder	Cobble	Gravel	Sand	Silt	Clay	Concrete	Litter	Depth	Bottom Slope
29	0	0	0	0	100	0	0	0	0	77	8.4
30	0	0	0	0	15	85	0	0	0	69	0.6
32	0	0	25	70	5	0	0	0	0	44	16.92307
33	0	0	0	80	20	0	0	0	0	93	27.3529
35	0	0	0	0	85	15	0	0	0	74	1
36	0	0	0	0	90	10	0	0	0	154	9.8
37	0	0	0	40	60	0	0	0	0	84	11.2
38	0	0	0	50	50	0	0	0	0	124	19.6
39	0	0	0	0	90	10	0	0	60	81	18.4090
40	0	0	0	10	85	5	0	0	80	86	21.5
41	0	0	0	15	80	5	0	0	0	79	13.8
42	0	0	0	0	85	15	0	0	0	96	5.2
43	0	0	0	0	65	35	0	0	0	73	4.2
44	0	0	0	0	65	35	0	0	50	117	8.2
45	0	0	0	0	90	10	0	0	30	60	3.8
46	0	0	0	0	90	10	0	0	10	74	5
47	0	0	0	0	85	15	0	0	0	78	2.4
48	0	0	0	0	20	80	0	0	0	107	12.4
49	0	0	0	0	35	65	0	0	0	76	8.8
50	0	0	0	100	0	0	0	0	0	72	37.89473
51	0	0	0	0	90	10	0	0	0	87	21.75
52	0	0	50	0	50	0	0	0	0	58	7.4
53	0	0	0	0	90	10	0	0	0	54	0.6
54	0	0	0	0	70	30	0	0	0	76	7.2
55	0	0	0	100	0	0	0	0	0	130	9.2
56	0	0	0	0	90	10	0	0	0	87	18.125
57	0	0	0	35	60	5	0	0	40	108	22.040633
58	0	0	0	0	95	5	0	0	80	88	9.6
59	0	0	20	75	5	0	0	0	0	104	2.4
60	0	75	0	25	0	0	0	0	0	97	5.8
61	0	80	20	0	0	0	0	0	0	69	13.8

Appendix 6: Menominee River habitat survey data.

Waypoint	**Bedrock**	**Boulder**	**Cobble**	**Gravel**	**Sand**	**Silt**	**Clay**	**Concrete**	**Litter**	**Depth**	**Bottom Slope**
62	0	0	90	10	0	0	0	0	0	103	5.6
63	0	100	0	0	0	0	0	0	0	79	15.19230
64	0	0	100	0	0	0	0	0	0	72	6.4
65	0	50	0	0	40	10	0	0	50	90	15.78943
66	0	0	90	10	0	0	0	5	0	58	12.08333
67	0	0	10	20	70	0	0	0	0	54	3
68	0	0	95	5	0	0	0	0	0	106	0.6
69	0	50	25	25	0	0	0	0	0	66	2.8
70	0	0	40	35	20	5	0	0	0	39	0.4
71	0	10	0	80	10	0	0	0	40	70	2
72	0	0	0	100	0	0	0	0	0	110	3.4
73	0	0	0	0	80	20	0	0	20	77	8.8
74	0	0	50	50	0	0	0	0	0	178	1
75	0	100	0	0	0	0	0	0	0	75	17.85714
76	0	100	0	0	0	0	0	0	0	130	39.39393
77	0	0	100	0	0	0	0	0	0	80	4.4
78	0	0	20	80	0	0	0	0	0	61	15.6410
79	0	0	0	0	0	0	0	0	0	61	10
80	0	0	30	10	60	0	0	0	0	99	22
81	0	0	50	50	0	0	0	0	0	65	19.6969
82	0	100	0	0	0	0	0	0	0	81	67.5
83	0	100	0	0	0	0	0	0	0	57	31.66666
84	0	0	100	0	0	0	0	0	0	54	15.42857
85	0	0	100	0	0	0	0	0	0	120	35.29411
86	0	0	5	60	30	5	0	0	0	108	31.76470
87	0	0	0	90	10	0	0	0	0	126	38.18181
88	0	0	0	80	20	0	0	0	75	98	28
89	0	100	0	0	0	0	0	0	0	64	35.5555
90	0	100	0	0	0	0	0	0	0	56	29.47368

Appendix 6: Menominee River habitat survey data.

Waypoint	**Slope Category**	**Woody Debris**	**Total Coverage**	**Coverage Category**	**# Species**
024 Dt	2	1	79	3	3
033 Dt	1	1	51	2	2
064 Dt	1	1	83	3	3
094 Dt	1	0	100	3	3
124 Dt	1	0	0	1	0
336 Dt	5	1	0	1	0
344 Dt	1	1	40	2	0
357 Dt	5	1	0	1	1
366 Dt	1	1	100	3	2
SHA	2	0.777777778	50.33333333	2.111111111	1.55555556
BHA	3.176470588	0.220779221	29.02597403	1.506493506	0.71428571
3	5	1	0	1	0
4	5	0	0	1	0
5	5	0	25	1	1
13	5	0	0	1	0
15	2	1	100	3	1
16	2	1	100	3	1
17	2	1	5	1	1
19	3	0	10	1	0
20	2	1	25	1	1
21	3	0	5	1	2
22	4	1	100	3	3
23	2	0	100	3	1
24	1	0	5	1	1
25	1	1	25	1	1
26	1	0	15	1	1
27	1	0	100	3	0
28	1	0	0	1	0

Appendix 6: Menominee River habitat survey data.

Waypoint	Slope Category	Woody Debris	Total Coverage	Coverage Category	# Species
29	3	1	0	1	1
30	1	0	100	3	0
32	5	0	0	1	0
33	5	0	5	1	0
35	1	0	100	3	1
36	4	0	100	3	4
37	4	0	0	1	0
38	5	1	0	1	0
39	5	1	0	1	0
40	5	1	0	1	0
41	5	0	15	1	1
42	2	0	100	3	1
43	2	0	100	3	2
44	3	1	25	1	1
45	2	0	5	1	1
46	2	1	100	3	2
47	1	0	100	3	2
48	5	0	100	3	3
49	3	0	35	2	1
50	5	0	10	1	2
51	5	0	30	1	3
52	3	0	80	3	0
53	1	0	5	1	0
54	3	0	100	3	3
55	4	0	0	1	0
56	5	1	5	1	1
57	5	1	5	1	1
58	4	0	5	1	0
59	1	0	0	1	0
60	2	0	0	1	1
61	5	0	0	1	0

Appendix 6: Menominee River habitat survey data.

Waypoint	Slope Category	Woody Debris	Total Coverage	Coverage Category	# Species
62	2	0	0	1	0
63	5	0	0	1	0
64	3	0	0	1	0
65	5	0	5	1	0
66	5	0	0	1	0
67	1	0	0	1	0
68	1	0	0	1	0
69	1	0	100	3	0
70	1	0	20	1	1
71	1	0	60	2	2
72	2	0	5	1	0
73	3	1	100	3	1
74	1	0	0	1	0
75	5	0	0	1	0
76	5	0	0	1	0
77	2	0	0	1	0
78	5	0	100	3	1
79	4	0	0	1	0
80	5	0	40	2	1
81	5	0	30	1	1
82	5	0	0	1	0
83	5	0	0	1	0
84	5	0	0	1	0
85	5	0	5	1	1
86	5	0	0	1	0
87	5	0	5	1	1
88	5	0	25	1	1
89	5	1	0	1	0
90	5	0	0	1	0

Appendix 7: Little Sturgeon Bay habitat survey data.

Waypoint	Spawn	Development	Immediate Shoreline	Environmental Shoreline	Date	Latitude	Longitude
104 Dt	1	0	Rock	Shrub	17-Jun-10	44.8377	-87.5556
133 Dt	1	1	Rip Rap	Lawn	27-May-10	44.83182	-87.5612
194 Dt	1	Too far from shore	Too far from shore	Too far from shore	17-Jun-10	44.82995	-87.5543
Spawning Habitat Averages (SHA)							
Background Habitat Averages (BHA)							
1	0	1	Shrub	Shrub	10-Jun-10	44.85002	-87.5499
2	0	1	Rock	Rock	10-Jun-10	44.8482	-87.5504
3	0	1	Rock	Grasses	10-Jun-10	44.84668	-87.5533
4	0	0	Wetland	Shrub	10-Jun-10	44.84602	-87.555
5	0	0	Wetland	Rock	10-Jun-10	44.84508	-87.5537
6	0	1	Rock	Rock	10-Jun-10	44.84192	-87.5604
7	0	1	Rock	Rock	10-Jun-10	44.84165	-87.5604
8	0	1	Rock	Rock	10-Jun-10	44.84132	-87.5605
9	0	1	Rock	Rock	10-Jun-10	44.83787	-87.5545
10	0	0	Rock	Rock	10-Jun-10	44.83652	-87.5554
11	0	1	Rock	Rock	10-Jun-10	44.83548	-87.5562
12	0	1	Rock	Shrub	10-Jun-10	44.83426	-87.5577
13	0	0	Rock	Shrub	10-Jun-10	44.83288	-87.5582
14	0	1	Rock	Trees	10-Jun-10	44.83092	-87.5593
15	0	0	Rock	Shrub	10-Jun-10	44.83	-87.5611
16	0	0	Wetland	Grasses	10-Jun-10	44.83165	-87.5641
17	0	1	Rock	Lawn	10-Jun-10	44.8322	-87.5636
18	0	1	Rock	Lawn	10-Jun-10	44.83243	-87.5637
19	0	1	Rip Rap	Lawn	10-Jun-10	44.83338	-87.5635
20	0	1	Rock	Lawn	10-Jun-10	44.8341	-87.5631
21	0	1	sand	Lawn	10-Jun-10	44.83562	-87.5621
22	0	0	Rock	Grasses	10-Jun-10	44.83617	-87.5614
23	0	0	Rock	Grasses	10-Jun-10	44.83647	-87.5611

Appendix 7: Little Sturgeon Bay habitat survey data.

Waypoint	Spawn	Development	Immediate Shoreline	Environmental Shoreline	Date	Latitude	Longitude
24	0	0	Rock	Trees	10-Jun-10	44.83677	-87.5617
25	0	0	Rock	Trees	10-Jun-10	44.83698	-87.562
26	0	0	Rock	Grasses	14-Jun-10	44.83613	-87.5542
27	0	1	Rock	Rock	14-Jun-10	44.83332	-87.5565
28	0	1	Rock	Shrub	14-Jun-10	44.83278	-87.5568
29	0	1	Rock	Dock	14-Jun-10	44.83227	-87.5567
30	0	1	Rock	Shrub	14-Jun-10	44.83073	-87.5578
31	0	0	Wetland	Shrub	14-Jun-10	44.82538	-87.5575
32	0	0	Rock	Shrub	14-Jun-10	44.8263	-87.5566
33	0	0	Rock	Shrub	14-Jun-10	44.8261	-87.5565
34	0	0	Wetland	Trees	14-Jun-10	44.82532	-87.5578
35	0	0	Wetland	Trees	14-Jun-10	44.8269	-87.5581
36	0	1	Rock	Concrete	14-Jun-10	44.82785	-87.5567
37	0	1	Rock	Lawn	14-Jun-10	44.82442	-87.5527
38	0	1	Rip Rap	Lawn	14-Jun-10	44.82475	-87.5531
39	0	0	Rock	Grasses	14-Jun-10	44.825	-87.5526
40	0	1	Rock	Lawn	14-Jun-10	44.8254	-87.5535
41	0	1	Rip Rap	Grasses	14-Jun-10	44.82567	-87.5528
42	0	1	Rip Rap	Shrub	14-Jun-10	44.82547	-87.5525
43	0	1	Rip Rap	Lawn	14-Jun-10	44.82715	-87.5539
44	0	1	Sand	Lawn	14-Jun-10	44.82818	-87.5528
45	0	1	Wetland	Lawn	14-Jun-10	44.82797	-87.5521
46	0	1	Wetland	Rock	14-Jun-10	44.8285	-87.5501
47	0	0	Wetland	Lawn	14-Jun-10	44.83103	-87.5494
48	0	0	Rock	Shrub	14-Jun-10	44.83177	-87.5475
49	0	0	Wetland	Trees	14-Jun-10	44.83115	-87.5473
50	0	0	Wetland	Trees	14-Jun-10	44.83087	-87.5469
51	0	1	Wetland	Lawn	14-Jun-10	44.83073	-87.5449
52	0	0	Wetland	Shrub	14-Jun-10	44.83242	-87.5457
53	0	0	Wetland	Shrub	14-Jun-10	44.83207	-87.5445
54	0	0	Wetland	Grasses	14-Jun-10	44.83307	-87.5434

Appendix 7: Little Sturgeon Bay habitat survey data.

Waypoint	Spawn	Development	Immediate Shoreline	Environmental Shoreline	Date	Latitude	Longitude
55	0	0	Wetland	Wetland	15-Jun-10	44.83312	-87.5416
56	0	0	Wetland	Wetland	15-Jun-10	44.83438	-87.5437
57	0	1	Rock	Dock	15-Jun-10	44.83625	-87.5417
58	0	0	Wetland	Wetland	15-Jun-10	44.83868	-87.5414
59	0	0	Wetland	Shrub	15-Jun-10	44.84368	-87.5399
60	0	0	Wetland	Shrub	15-Jun-10	44.84373	-87.5383
61	0	0	Wetland	Shrub	15-Jun-10	44.8441	-87.5376
62	0	0	Wetland	Shrub	15-Jun-10	44.84445	-87.5379
63	0	0	Rock	Shrub	15-Jun-10	44.84483	-87.5366
64	0	0	Rock	Shrub	15-Jun-10	44.846	-87.5366
65	0	1	Rock	Shrub	15-Jun-10	44.8469	-87.5348
66	0	1	Rock	Grasses	15-Jun-10	44.85047	-87.5337
67	0	1	Rock	Dock	15-Jun-10	44.85048	-87.5341
68	0	0	Rock	Grasses	15-Jun-10	44.85263	-87.5345
69	0	0	Rock	Rock	15-Jun-10	44.85272	-87.5347
70	0	1	Sand	Grasses	15-Jun-10	44.85493	-87.5349
71	0	0	Wetland	Rip Rap	16-Jun-10	44.83068	-87.5643
72	0	1	Rip Rap	Concrete	16-Jun-10	44.8295	-87.5648
73	0	1	Rock	Shrub	16-Jun-10	44.82915	-87.5651
74	0	0	Wetland	Grasses	16-Jun-10	44.82892	-87.5665
75	0	1	Rock	Lawn	16-Jun-10	44.82917	-87.5681
76	0	0	Wetland	Grasses	16-Jun-10	44.82817	-87.5639
77	0	0	Wetland	Wetland	16-Jun-10	44.8278	-87.5638
78	0	0	Grasses	Grasses	16-Jun-10	44.82687	-87.5641
79	0	0	Grasses	Grasses	16-Jun-10	44.82608	-87.5651
80	0	1	Wetland	Wetland	16-Jun-10	44.84553	-87.5581

Appendix 7: Little Sturgeon Bay habitat survey data.

Waypoint	**Bedrock**	**Boulder**	**Cobble**	**Gravel**	**Sand**	**Silt**	**Clay**	**Concrete**	**Litter**	**Depth**
104 Dt	0	0	0	0	40	60	0	0	0	241
133 Dt	0	0	0	0	0	100	0	0	0	96
194 Dt	0	0	0	0	10	90	0	0	0	301
(SHA)	0	0	0	0	16.667	83.33333	0	0	0	212.667
(BHA)	0	2.875	13.75	26.8125	21.5	33.8125	0	0	0	79.7875
1	0	50	50	0	0	0	0	0	0	90
2	0	0	75	15	10	0	0	0	0	77
3	0	0	0	5	0	95	0	0	0	67
4	0	0	0	40	0	60	0	0	0	56
5	0	0	0	80	20	0	0	0	0	97
6	0	0	0	70	30	0	0	0	0	68
7	0	0	10	80	10	0	0	0	0	58
8	0	0	20	45	35	0	0	0	0	65
9	0	0	0	95	0	5	0	0	0	85
10	0	0	0	0	15	85	0	0	0	154
11	0	0	50	0	0	50	0	0	0	74
12	0	0	0	100	0	0	0	0	0	87
13	0	0	0	0	0	100	0	0	0	100
14	0	0	0	0	60	40	0	0	0	53
15	0	0	0	0	0	100	0	0	0	66
16	0	0	0	0	0	100	0	0	0	67
17	0	0	0	0	20	80	0	0	0	81
18	0	0	0	0	20	80	0	0	0	75
19	0	0	0	0	20	80	0	0	0	82
20	0	0	0	0	10	90	0	0	0	91
21	0	0	0	0	5	95	0	0	0	83
22	0	0	10	80	10	0	0	0	0	68
23	0	30	20	50	0	0	0	0	0	86

Appendix 7: Little Sturgeon Bay habitat survey data.

Waypoint	Bedrock	Boulder	Cobble	Gravel	Sand	Silt	Clay	Concrete	Litter	Depth
24	0	0	0	60	0	40	0	0	0	74
25	0	0	0	30	0	70	0	0	0	121
26	0	0	80	20	0	0	0	0	0	89
27	0	0	50	50	0	0	0	0	0	114
28	0	0	25	25	50	0	0	0	0	60
29	0	0	85	15	0	0	0	0	0	88
30	0	0	0	20	50	30	0	0	0	71
31	0	0	0	0	15	85	0	0	0	92
32	0	0	0	70	30	0	0	0	0	131
33	0	0	0	90	0	10	0	0	0	37
34	0	0	0	0	30	70	0	0	0	94
35	0	0	0	0	20	80	0	0	0	101
36	0	0	0	0	95	5	0	0	0	152
37	0	0	0	0	15	85	0	0	0	83
38	0	0	0	0	0	100	0	0	0	85
39	0	0	0	85	10	5	0	0	0	44
40	0	0	0	0	0	100	0	0	0	80
41	0	50	0	0	0	50	0	0	0	100
42	0	0	0	0	15	85	0	0	0	86
43	0	0	0	0	60	40	0	0	0	74
44	0	0	0	0	0	0	0	0	0	108
45	0	0	0	0	90	10	0	0	0	113
46	0	0	0	0	80	20	0	0	0	59
47	0	0	0	0	95	5	0	0	0	132
48	0	0	0	0	95	5	0	0	0	87
49	0	0	0	0	95	5	0	0	0	68
50	0	0	60	25	10	5	0	0	0	36
51	0	0	0	0	20	80	0	0	0	27
52	0	0	20	70	10	0	0	0	0	67
53	0	0	0	45	50	5	0	0	0	40
54	0	0	30	0	65	5	0	0	0	97

Appendix 7: Little Sturgeon Bay habitat survey data.

Waypoint	Bedrock	Boulder	Cobble	Gravel	Sand	Silt	Clay	Concrete	Litter	Depth
55	0	0	10	15	75	0	0	0	0	54
56	0	0	0	20	80	0	0	0	0	123
57	0	0	0	50	20	30	0	0	0	99
58	0	0	0	75	15	10	0	0	0	56
59	0	0	50	25	25	0	0	0	0	119
60	0	0	0	75	15	10	0	0	0	60
61	0	0	25	50	15	10	0	0	0	58
62	0	0	0	75	10	15	0	0	0	107
63	0	0	100	0	0	0	0	0	0	18
64	0	0	80	0	10	10	0	0	0	123
65	0	0	25	65	0	10	0	0	0	87
66	0	0	15	60	10	15	0	0	0	72
67	0	25	30	30	10	5	0	0	0	107
68	0	0	20	70	10	0	0	0	0	55
69	0	0	15	70	10	5	0	0	0	53
70	0	0	50	45	0	5	0	0	0	90
71	0	0	0	0	5	95	0	0	0	67
72	0	75	0	0	0	25	0	0	0	87
73	0	0	0	85	10	5	0	0	0	95
74	0	0	95	0	0	5	0	0	0	40
75	0	0	0	0	0	100	0	0	0	86
76	0	0	0	0	10	90	0	0	0	52
77	0	0	0	0	0	100	0	0	0	15
78	0	0	0	0	40	60	0	0	0	52
79	0	0	0	0	85	15	0	0	0	54
80	0	0	0	70	0	30	0	0	0	114

Appendix 7: Little Sturgeon Bay habitat survey data.

Waypoint	**Bottom Slope**	**Slope Category**	**Woody Debris**	**Total Coverage**	**Coverage Category**	**# Species**
104 Dt	2.2	1	0	95	3	3
133 Dt	0.1	1	1	86	3	3
194 Dt	0.2	1	0	49	2	1
(SHA)	0.833	1	0.333	76.667	2.667	2.3333
(BHA)	6.858	2	0.025	31.875	1.575	1.3875
1	1.6	1	0	0	1	0
2	3.2	2	0	0	1	0
3	19.14285714	5	0	5	1	2
4	2.2	1	0	5	1	1
5	8	3	0	45	2	1
6	18.88888889	5	0	5	1	1
7	11.83673469	4	0	5	1	1
8	13.82978723	5	0	5	1	2
9	1.8	1	0	5	1	1
10	1.75	1	0	75	3	3
11	49.33333333	5	0	5	1	1
12	6.6	3	0	5	1	1
13	1.25	1	0	40	2	4
14	9.4	4	0	30	1	4
15	1.8	1	0	10	1	2
16	1.4	1	0	70	3	3
17	0.8	1	0	40	2	1
18	0.2	1	0	100	3	3
19	1.4	1	0	80	3	2
20	-0.6	1	0	80	3	2
21	0.8	1	0	100	3	2
22	0.4	1	0	0	1	0
23	5.2	2	0	0	1	0

Appendix 7: Little Sturgeon Bay habitat survey data.

Waypoint	Bottom Slope	Slope Category	Woody Debris	Total Coverage	Coverage Category	# Species
24	-10.25	4	0	60	2	1
25	44.81481481	5	0	50	2	1
26	2.2	1	0	0	1	0
27	5	2	0	50	2	3
28	15.78947368	5	0	10	1	1
29	2.6	1	0	0	1	0
30	2.6	1	0	15	1	2
31	1.6	1	0	100	3	2
32	5.2	2	0	50	2	2
33	2.2	1	0	0	1	0
34	0.2	1	0	100	3	1
35	1.4	1	0	30	1	3
36	4.473684211	2	0	40	2	1
37	18.44444444	5	0	100	3	1
38	8.2	3	0	30	1	2
39	40	5	0	10	1	1
40	1.2	1	0	70	3	6
41	100	5	0	100	3	1
42	16.2	5	0	75	3	2
43	2.2	1	0	0	1	0
44	0.2	1	0	30	1	2
45	1	1	0	100	3	1
46	1.8	1	0	50	2	1
47	1.75	1	0	5	1	1
48	1.4	1	0	20	1	2
49	0.6	1	1	0	1	0
50	0.4	1	0	0	1	0
51	1.2	1	0	20	1	1
52	1	1	0	5	1	1
53	0.2	1	0	5	1	1
54	0.6	1	0	5	1	1

Appendix 7: Little Sturgeon Bay habitat survey data.

Waypoint	Bottom Slope	Slope Category	Woody Debris	Total Coverage	Coverage Category	# Species
55	0.4	1	0	25	1	1
56	-3.4	2	0	10	1	2
57	0.6	1	0	20	1	1
58	2.8	1	0	20	1	1
59	0.444444444	1	0	0	1	0
60	2.6	1	0	0	1	0
61	1.4	1	0	5	1	1
62	2.2	1	0	40	2	1
63	1.6	1	0	0	1	0
64	3.75	2	0	20	1	1
65	1	1	0	50	2	1
66	1.6	1	0	80	3	1
67	0.75	1	0	20	1	1
68	6	1	0	0	1	0
69	0.8	1	0	0	1	0
70	2.2	1	0	5	1	1
71	0.8	1	0	30	1	2
72	10.6	4	0	5	1	1
73	2.6	1	0	15	1	2
74	25	5	0	5	1	2
75	23.88888889	5	0	40	2	1
76	1.4	1	0	100	3	3
77	-3	1	0	100	3	2
78	10.6122449	4	0	10	1	2
79	2	1	0	10	1	2
80	15.6	5	1	100	3	4