Great Lakes Spotted Muskellunge Restoration: Evaluating Natural Recruitment and Modeling Spawning Habitat in Green Bay, Lake Michigan

by

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ABSTRACT

The identification and protection of critical spawning habitat for muskellunge (*Esox masquinongy)* in Green Bay of Lake Michigan is a vital step for re-establishing a self sustaining population. This study was designed to document the extent of natural reproduction and locate spawning areas using 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 (70%) implanted transmitters were located as deposited at spawning sites. Using identified spawning locations, habitat selection was estimated for key environmental variables, and spatial models were built to predict muskellunge spawning habitat in Green Bay. Menominee River data were utilized in modeling because it had the most documented successful reproduction in Green Bay. Menominee River muskellunge showed a significant preference for spawning in areas with low to moderate bottom slopes (0-3%), medium percent vegetative coverage (34-66%), where woody debris was present, and in substrates containing silt. Utilizing these identified habitat preferences allowed successful modeling of location and characteristics of spawning areas. Two modeling approaches were used, classification tree and Maxent (maximum entropy). Classification tree models predicted areas to be spawning habitat based mainly on bottom slope, woody debris, and submerged vegetation. Maxent models proved most effective at predicting limited areas as potential spawning locations and correctly classifying most known spawning sites. Maxent models used habitat variables of vegetative cover, bottom slope, percent silt, and presence of woody debris as the main variables to identify spawning habitat. Dissolved oxygen levels averaged 5.7 mg/L over all Menominee River spawning sites but levels as low as 3.8 mg/L were observed within specific spawning areas and may cause site specific egg and larval mortality. In the future, habitat preferences and model results could be used to locate suitable locations for stocking muskellunge, guide designations of critical habitat to protect important spawning habitat, and identify areas for rehabilitation projects to enhance muskellunge spawning success.

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 Lake Michigan's Green Bay (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 et al. 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 et al. 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 (Wisconsin Department of Natural Resources 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 (Wisconsin Department of Natural Resources 1986, Lake Michigan Fisheries Team 2004, Kapuscinski et al. 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 et al. 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, and 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 et al. 2007). However, the increasing population of adults along with observations of spawning muskellunge throughout the bay 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 2010). In 2008, two young-of-the-year muskellunge were captured from the lower Menominee River and genetic analysis confirmed these fish consistent with the stocked strain of Great Lakes spotted muskellunge (Rowe 2010), 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 has 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 1-2 m, 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) addressed many of these shortcomings by modeling spawning habitat within individual lakes using a robust dataset. Due to the large sample size involved in measuring habitat variables for 247 confirmed spawning sites, Nohner 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 2010). 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 2010). 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 as well as 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) Identify potential causes of mortality to eggs. (4) Quantify physical habitat within identified spawning locations. (5) Build a spatial model to predict potential spawning locations based on physical habitat characteristics. (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 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 1987) (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 2010). These populations closely mirror stocking efforts of the WDNR; with one population inhabiting the lower portion of the bay and Fox River, a second population on the west shore concentrated around the Menominee and Peshtigo rivers, and a third population on the east shore around Sturgeon Bay and Little Sturgeon Bay (Rowe 2010).

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 1.5-m 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 global 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 where 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 200 m^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, and 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 1-m^2 quadrat. Percent total coverage (0-100%) of vegetation was estimated (to the nearest 5%) 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 percent 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 (Figure 2). The number of individual pieces of CWD were counted and the diameter of each piece was estimated as 5 cm, 10 cm, or >20 cm.

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 (Ivlev 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 categories failed to meet the assumption 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 regression tree 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 using a maximum likelihood algorithm to maximize entropy (Phillips et al. 2006, Phillips et al. 2008). Maxent starts with a probability distribution that is uniform across the area of interest and weights each environmental variable, or feature. It then adjusts each feature in turn in order to optimize the probability of the occurrence dataset (Hernandez et al. 2006, 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 and Dudik 2008).

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 (Nohner 2009). 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 and Dudik 2008) 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 et al. 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 (rpart) 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, $n = 36$, $v = 1$, $P > 0.75$).

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 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 were searched for eggs. Again, water depth and cold temperatures prevented 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 172 mm, weighed 18 g, 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 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 sites with no spawning and only a few background sites fell into these categories.

Locations with shallow bottom slopes (0-3%) were strongly selected 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, percent 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 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). On average about ten percent of available habitat (area with water 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), produced an r^2 value of 0.56, 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 0.33 (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 criterion. 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 (Figure 14), no habitat 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 Menominee 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, 0.56 (Figure 13), and contained two splits resulting in 3 terminal nodes (Figure 14).

A classification tree model utilizing only percent silt of bottom substrate resulted in an r^2 value of 0.22 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% coverage with silt substrate.

Percent total vegetative coverage could also be used exclusively to create a classification tree model. The resulting model produced an r^2 value of 0.11 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 separated 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 tree 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 15).

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 area. Both, the classification tree model excluding bottom slope and the Maxent model correctly predicted 67% of deposited transmitter sites as spawning areas. Since the Maxent model included only 10%, compared to 19% 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

Menominee River muskellunge preferred spawning in areas with low to moderate bottom slopes, where woody debris was present, and medium vegetative coverage. These findings are consistent with other studies that have shown woody debris (Dombeck et al. 1984, Zorn et al. 1998, Rust et al. 2002) and vegetative coverage (Hanson and Margenau 1992, Murry and Farrell 2007) to be important to successful natural reproduction. Muskellunge showed no preference between developed and undeveloped shoreline or types of shoreline habitat. Utilizing these habitat preferences allowed successful modeling of spawning areas that effectively identified known spawning locations.

Spawning Habitat

Muskellunge preferred areas exhibiting low to moderate bottom slopes (less than 3%) as spawning habitat. All other slope categories showed negative electivity values which was contrary to Nohner (2009) who described spawning habitat in lakes for inland barred muskellunge 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 relative to bottom slope. 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. 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. River 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 difference between spawning and background habitat. Locations with low to moderate slopes may also retain woody debris as opposed to high slope environments where accompanying river currents may be more capable of transporting 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 1975, 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. Even in stocked lakes, Hanson and Margenau (1992) concluded that stocked muskellunge fingerlings 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 preferred 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 was not present in any Menominee River locations sampled during this study.

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 a negative correlation between YOY presence and increased depth. The exception to this trend is a study that suggested muskellunge in Lake St. Clair spawned in open water areas with depths greater than 3 m (Haas 1978).

Spawning muskellunge did not display any selectivity for or against developed areas as spawning locations. Shoreline development has not previously been tested as a characteristic defining muskellunge spawning habitat at the scale of individual spawning sites. Past studies have 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 supplemental stocking. Rust et al. (2002) found the most important variable in determining whether a lake had good natural reproduction was percentage of developed shoreline. 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, so they were not considered as potential background habitat in this study. Although selection for undeveloped shoreline was not 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.

Shoreline land cover type was not preferentially utilized by spawning muskellunge. Several studies have described muskellunge spawning habitat as being associated with wetland areas (Scott and Crossman 1973, Craig and Black 1986, Nohner 2009). Although wetland land cover is present in the Menominee River, representing 11% of available habitat, no spawning areas were located in wetland areas.

Dissolved oxygen levels at the sediment-water interface were measured to determine the potential of egg and larval mortality caused by hypoxic conditions. Average daily 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 cause 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. The Maxent model proved to be most effective at predicting and classifying spawning areas. Classification tree models did not predict spawning habitat as well or included larger areas in order to encompass known spawning sites.

Maxent

The Maxent model effectively classified known spawning locations as spawning habitat while 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). Vegetative 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 probably occurred because there was not a significant difference in means of percent vegetative coverage between background and spawning sites. Since vegetative coverage was only important to Maxent models when represented as a categorical variable, estimating percent total coverage to the nearest 5% may be too fine a scale to be important in modeling muskellunge spawning habitat and a coarser scale (low, medium, high) may be more appropriate.

Jackknife analysis showed training gain decreased most when woody debris was omitted from model building. This suggested woody debris contained the greatest amount of information that could not 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, were correlated with 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 included in model building. Slope category, vegetative coverage category, and bottom slope percent 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 tree 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 and 2 splits based solely 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 likely affected other habitat variables, as described above, that were actually being selected for. However, it is unclear how a 0.5% change in bottom slope would affect other environmental variables. Yet, over 50% of spawning locations had bottom slopes between 1.45 and 1.95% while no background sites fell into this category. 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 predicted that moderate to high levels of vegetative coverage (37.5 – 91.5%) were important. These results were consistent with electivity and Maxent results as well as findings of Murry and Farrell (2007) and Hanson and Margenau (1992). The large range for percent vegetative coverage (37.5 - 91.5%) predicted by the model provides additional support for coarse definitions of vegetative coverage to be adequate for defining muskellunge spawning habitat.

Model results based exclusively on percent silt showed low to moderate levels were 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 than locations with high silt substrates while still providing favorable conditions for vegetation, making such locations preferred spawning areas. It is also possible that eggs may be less exposed and less vulnerable to predation in substrates containing silt as opposed to sand substrates.

Woody debris was an important variable in the Maxent model and produced the first split (explained the most variance) 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 pertaining to the importance of woody debris. However, woody debris could not be used exclusively to model muskellunge spawning habitat because it was modeled as a binary variable (presence or absence) and would only allow a single split.

Model Comparison

Models differed in the extent of area included as spawning habitat and the fraction of known Menominee River spawning locations predicted as spawning habitat. However, consistent results were obtained for all models on what 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 and "all variables" tree model predicted similar percentages of spawning habitat, 10% and 7% respectively, compared to 19% predicted by the tree model excluding bottom slope. However, because the "all variables" tree model correctly predicted only 1 of 9 known spawning locations, the Maxent model (with 67% of spawning sites correctly classified) was the best option for modeling and predicting Menominee River muskellunge spawning habitat.

Study Limitations

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 egg searches. Both the Fox and Menominee rivers produce high sediment loads that could quickly and easily cover eggs, especially muskellunge eggs that are demersal and non-adhesive. This habitat condition, along with river and lake currents, seiche, or wave action can re-suspend bottom sediments and quickly transport eggs leading to lower egg densities in searched locations. Despite decreased egg confirmation rates, the fact that 22 of 26 deposited transmitters (85%) were located at least once (many were located multiple times) while still implanted in moving fish gives increased confidence that fish were not randomly dropping transmitters outside of spawning events. The success of oviduct implantation was 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 transmitters were not deposited randomly but during spawning activity.

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 probably makes the woody debris counts lower near background locations. Yet close to 25% of background sites contained woody debris, showing that point measurements were effective at capturing presence of woody debris, but probably were biased towards lower frequencies of positive locations.

Another possible shortcoming was the transmitters themselves. Transmitters performed up to specifications but showed an inverse relationship between signal strength and depth. If a muskellunge did spawn and deposit a transmitter in a deep offshore area, it is unlikely that its transmitter would have been found. However, Pierce et al. (2007) observed a 50% deposition rate of transmitters implanted in muskellunge, yet 70% of transmitters implanted during this study were deposited in shallow water, suggesting the potential implication of this shortcoming is minimal.

Funding limitations prevented additional transmitters from being purchased for implantation which would have led to an increased number of spawning locations. With only nine deposited transmitters in the Menominee River, overall power of analyses was limited and this was one reason for low r^2 values in classification tree models. With only nine known spawning locations the models relied heavily on each spawning site, exacerbating any differences between locations and decreasing model performance. Having additional spawning sites could have helped to distinguish a consistent pattern in habitat characteristics preferred by spawning muskellunge and led to a stronger model. Six additional spawning locations were located in the Fox River in 2009 but they were not included in the dataset that was used to build the model. Several YOY muskellunge have been collected 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 and rearing habitat variables important to successful natural reproduction. Another reason to exclude Fox River data from modeling was the major 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 while habitat surveys showed an overall lack of vegetation (only 2 of 80 of background sites and no spawning sites contained greater than 33% vegetative coverage) and woody debris (no background sites and only 2 of 6 spawning sites). If added to model analysis, lack of similar available habitat between the two rivers could have altered habitat preferences utilized in Menominee River models.

Limitations to Natural Reproduction

Documented muskellunge natural recruitment is limited throughout Green Bay. Four naturally reproduced YOY muskellunge have been found in the Menominee River and two 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 may be important to success of natural reproduction and stocking. Predation, as well as lack of appropriate prey, can cause mortality to all life stages of muskellunge. 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). Predation by yellow perch may be one factor resulting in successful natural reproduction in the Menominee River but not in the lower bay. Becker (1983) speculated that yellow perch and northern pike predation could be a limiting factor to muskellunge natural recruitment, while Murry and Farrell (2007) found yellow perch abundance was negatively associated with YOY muskellunge abundance. 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. Round gobies have been documented to prey on eggs of lake trout (*Salvelinus namaycush*) (Chotkowski and Marsden 1999) as well as smallmouth bass (Steinhart et al. 2004) and could be preying on muskellunge eggs when present.

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 ninety percent of seine hauls with YOY muskellunge had pumpkinseed (a potential prey species) as the dominant species present. In this study, 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, pumpkinseeds accounted for 0% of average catch during July in the lower bay and were present at only 3 of 13 spawning locations.

Another possible cause of egg mortality in Green Bay is high sediment and nutrient loads carried in the Fox and Menominee rivers. The high biological oxygen demand created by sediments and nutrients could serve as yet another stressor to muskellunge egg and larval survival. Dissolved oxygen levels of sediments in this study were low compared to other studies; sixteen percent of spawning locations had potentially fatal DO levels for muskellunge larvae (less than 4 mg/L) while 72% had levels lower than Dombeck et al. (1984) associated with successful muskellunge recruitment (6.0 – 8.4 mg/L).

Areas predicted as suitable habitat in the Menominee River are concentrated in three main areas: Stephenson Island, Strawberry Island, and the turning basin. The entire turning basin area will be dredged in 2012 to remediate high levels of arsenic in bottom sediments. A portion of the observed spawning habitat in the Menominee River will be substantially disrupted and altered at that time. While sediments may damage muskellunge spawning during remediation, high arsenic levels may have already caused egg and larval mortality. Although lethal arsenic levels pertaining to muskellunge are unknown, exposure to high levels of arsenic has been shown to be lethal to many fish species (Schaperclaus 1992). These efforts may open a door for restoration activity to modify the dredged area and improve habitat conditions to make them more suitable for muskellunge reproduction.

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 to or improving existing spawning habitat, and protecting current suitable spawning areas.

Maxent model maps clearly show areas predicted to contain suitable spawning habitat. These maps can be used to guide site stocking efforts. By stocking fish in areas known to contain suitable habitat, survival should be increased. Although it is unknown when or if muskellunge natal imprinting occurs (Farrell and Werner 1999), it is possible to seed suitable spawning habitat with stocked YOY muskellunge. If these stocked fish later return to their natal area to spawn, this may increase future spawning success.

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.

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. Possible 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. Current and proposed dredging projects in both the Fox and Menominee rivers will remove contaminated sediments and could create areas with suitable muskellunge spawning habitat. The proposed Cat Island Restoration is planned to return the Peats Lake area of the lower bay to a marsh environment that historically supported muskellunge spawning (Goodyear et al. 1982). Classification tree models could guide these actions to help ensure that restored 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.

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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: Distances transmitters were detected based on conductivity, depth of water, antenna type, and vegetative cover. Detection distances represent a single measurement using a single transmitter tested in 2010.

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 habitat variable at muskellunge spawning locations in the Menominee River. Asterisk indicates 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)

Variable	**Category**	**Percentage of Spawning Habitat**	**Percentage 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
*Number 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

Figure 1: Map of Green Bay, Lake Michigan with research areas highlighted

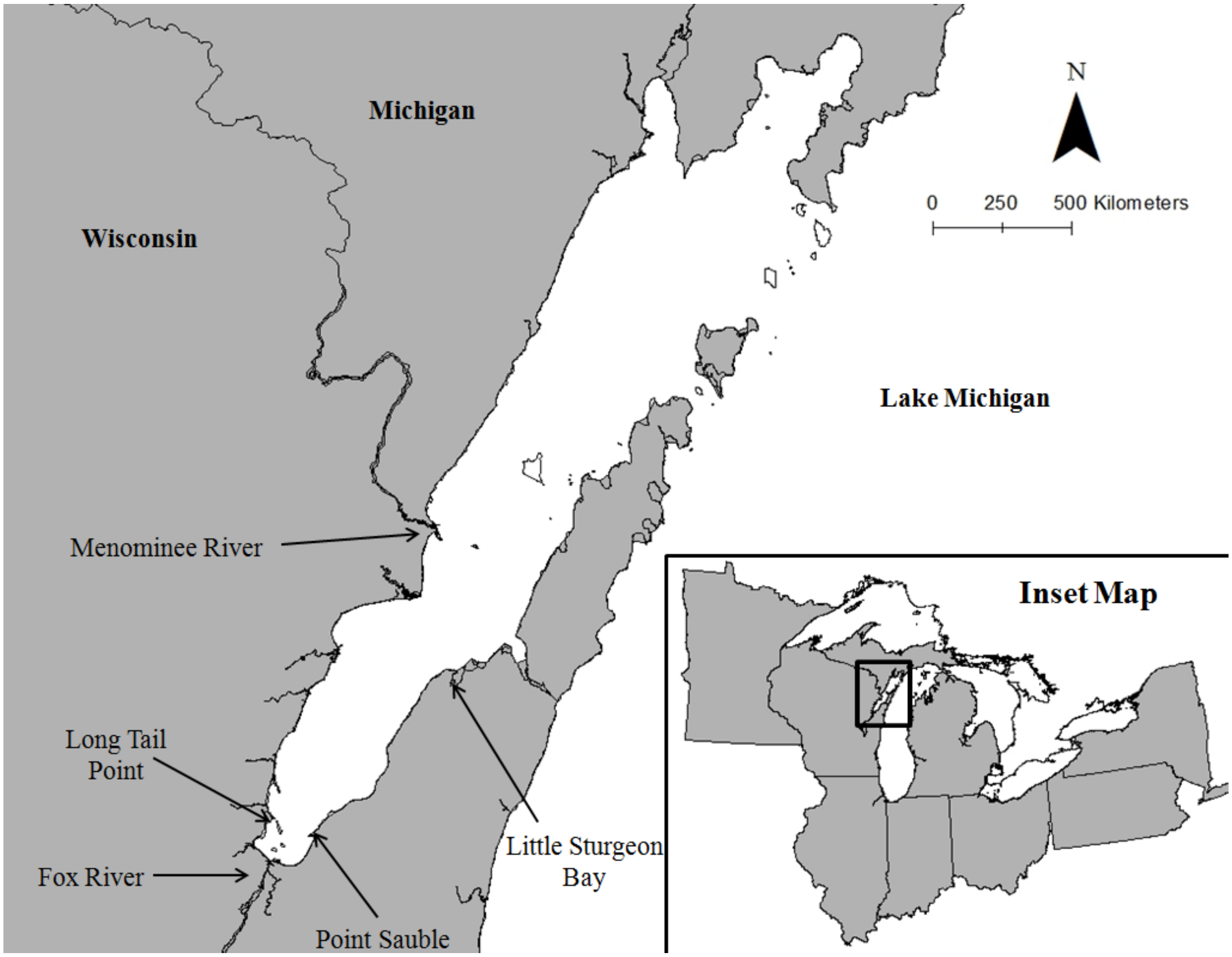


Figure 2: Example of the grid used to sample habitat within a spawning area.

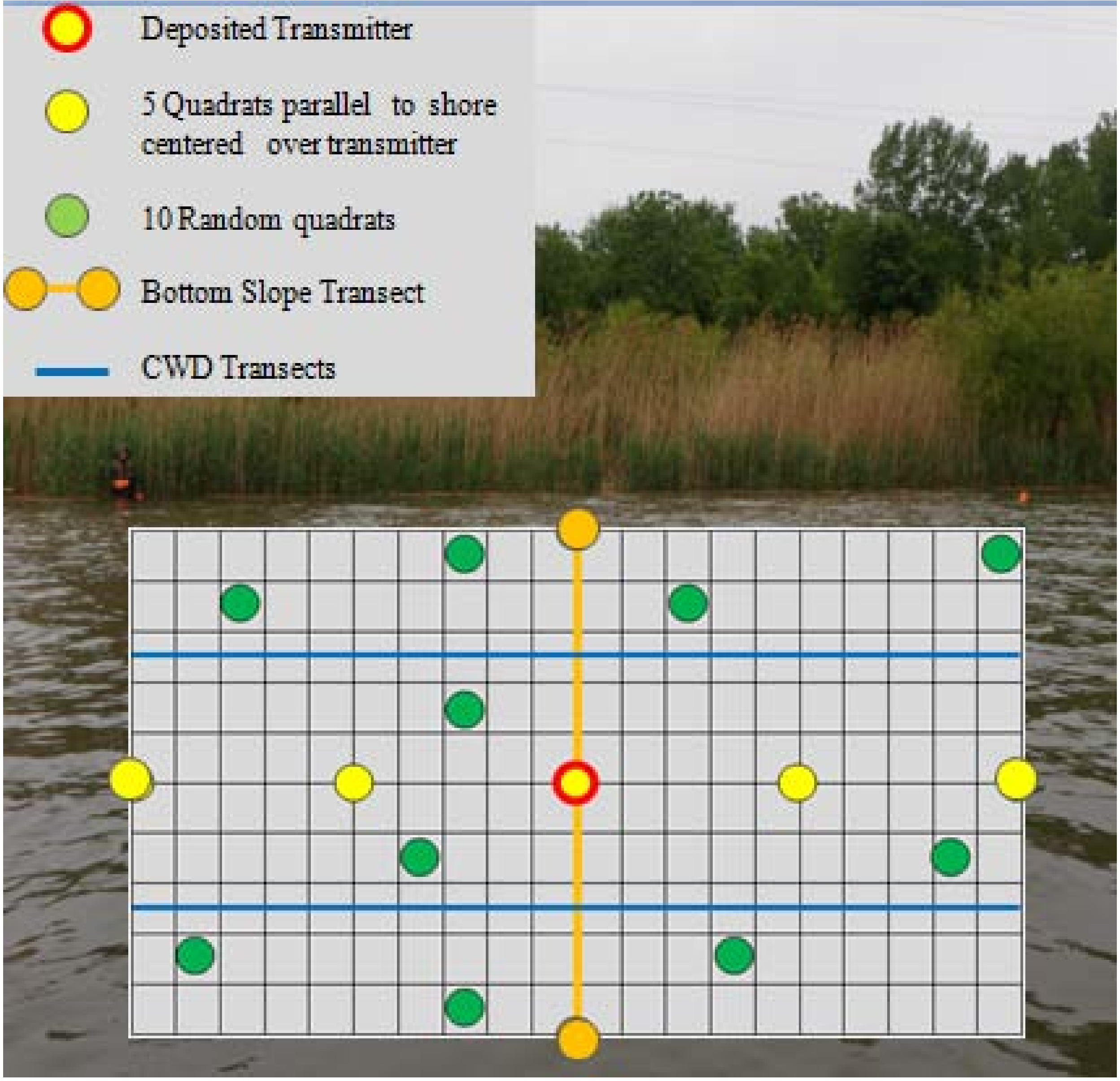


Figure 3: Image of 13 deposited transmitter locations in the Fox River and lower Green Bay in 2009.

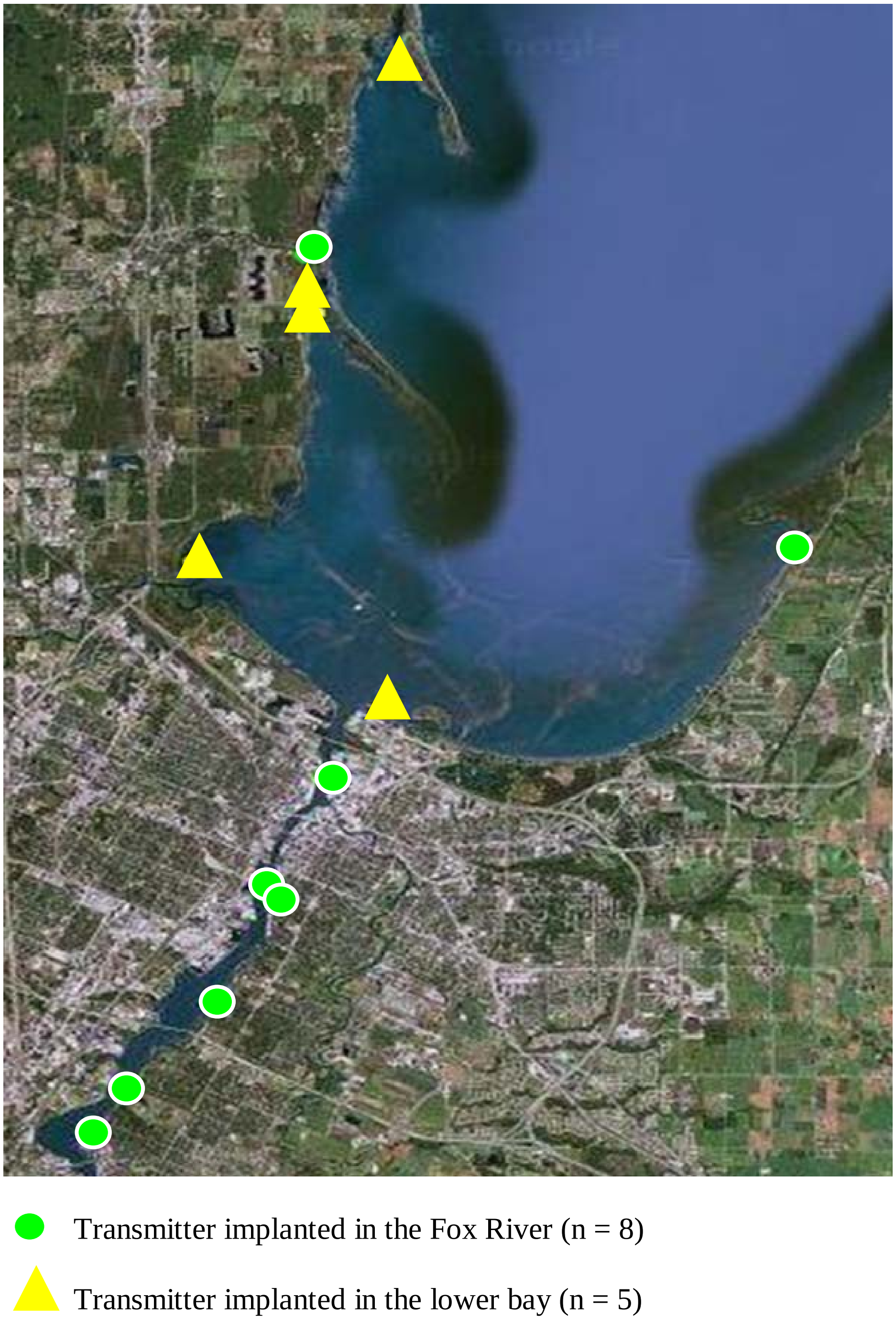


Figure 4: Image of 9 deposited transmitter locations in the Menominee River in 2010.

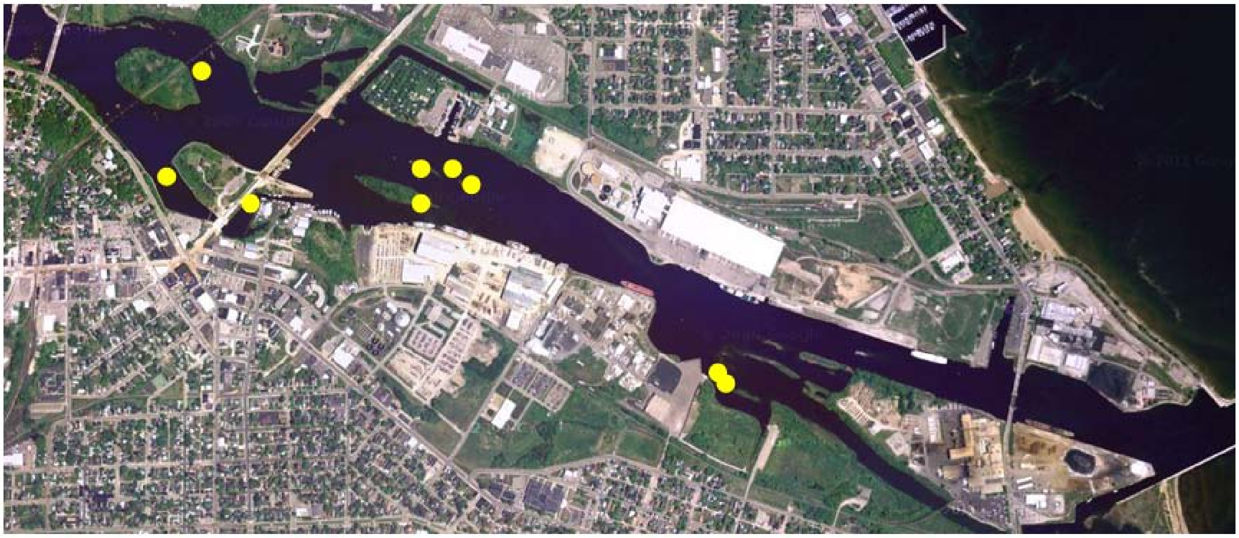


Figure 5: Image of 3 deposited transmitter locations in Little Sturgeon Bay in 2010.

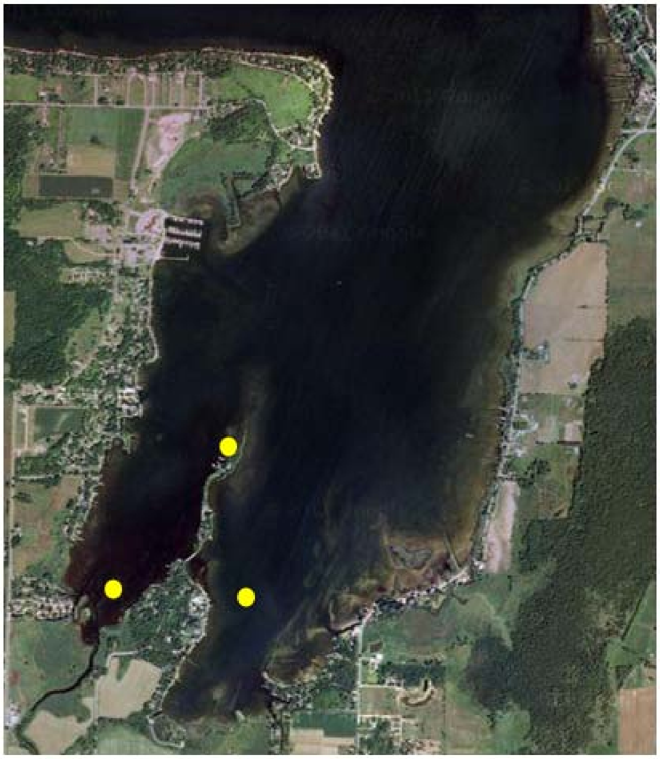


Figure 6: July seining results for the lower bay (Fox River and lower bay combined) and the Menominee River. Percent of total catch of three most abundant species is given for each location. Dominant species in the lower bay included yellow perch, round goby, and gizzard shad. Menominee River dominant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

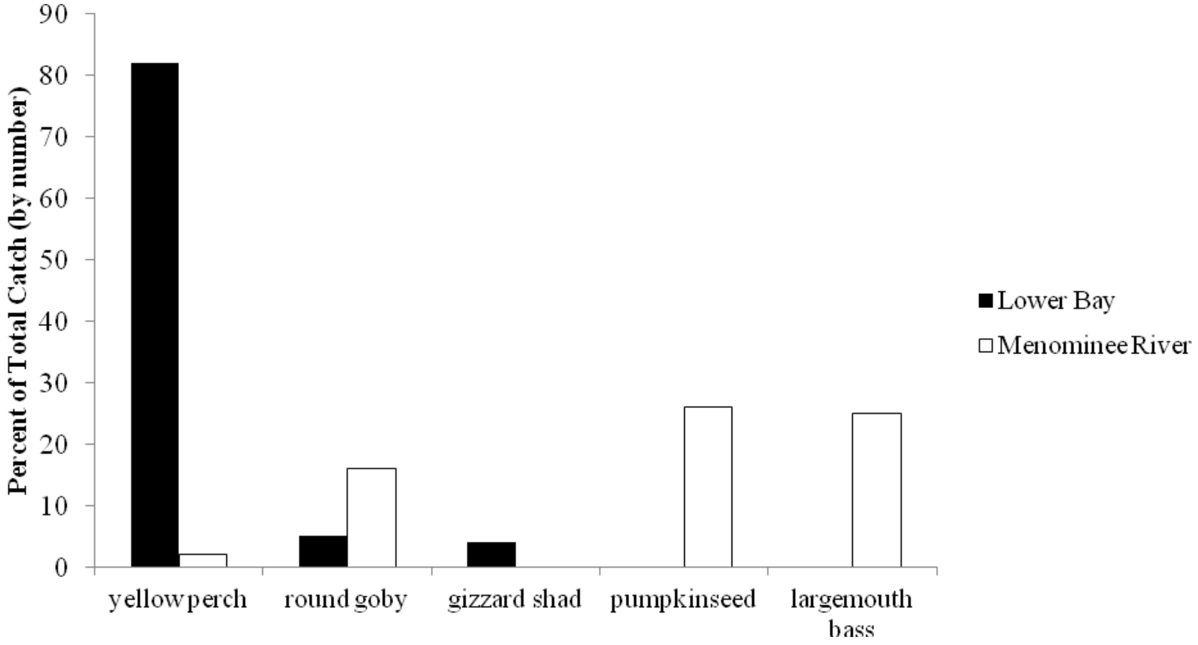


Figure 7: Relative percent contribution of each habitat variable to the Maxent model. Contributions were averaged over the three 500 replicate model runs. Percent contribution is represented by the increase or decrease in regular gain during each iteration of the model training.

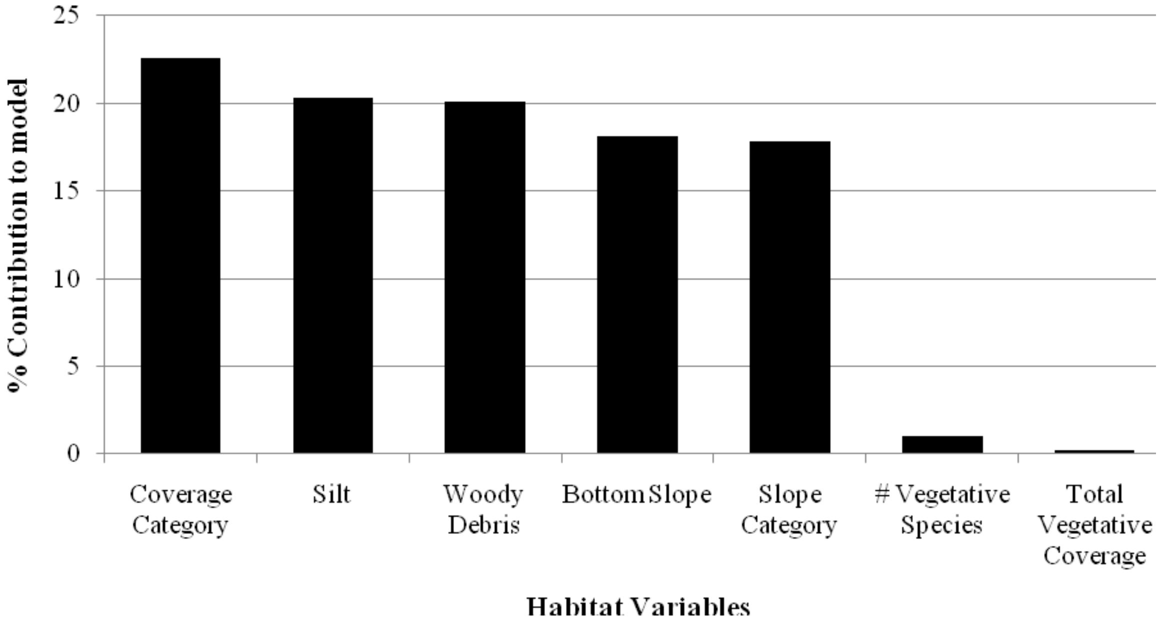


Figure 8: Analysis of probability of spawning habitat presence in the Menominee River plotted over the range of each habitat variable while all other variables are kept at their average value. The curves show the mean response over 500 Maxent model replicate runs in red and ± one standard deviation in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

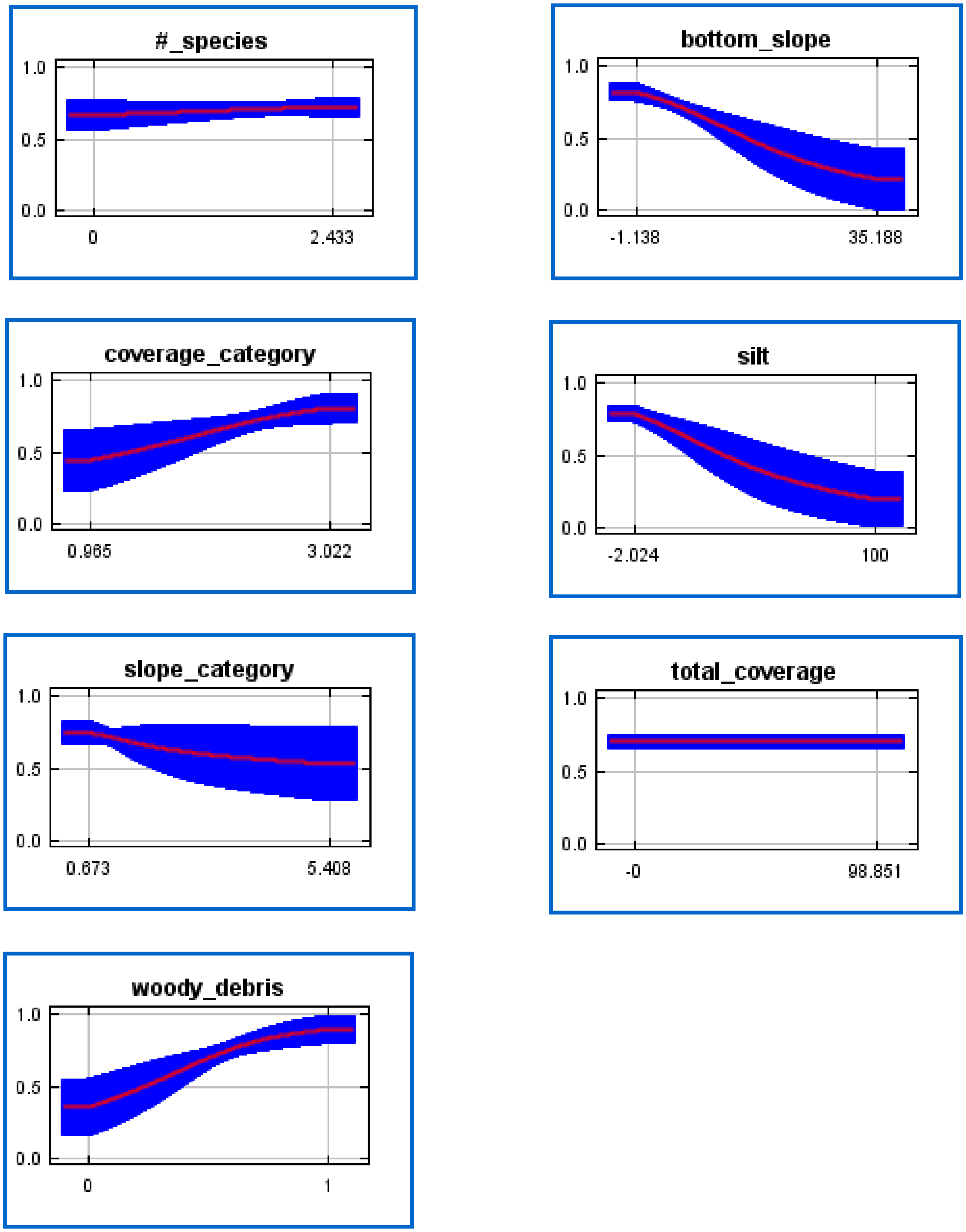


Figure 9: Jackknife test results for training gain averaged over three Maxent model runs of 500 replicates each for spawning habitat in the Menominee River. The training gain of a model "with only variable" (white) represents the gain of a model built using only that single variable. The training gain 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.

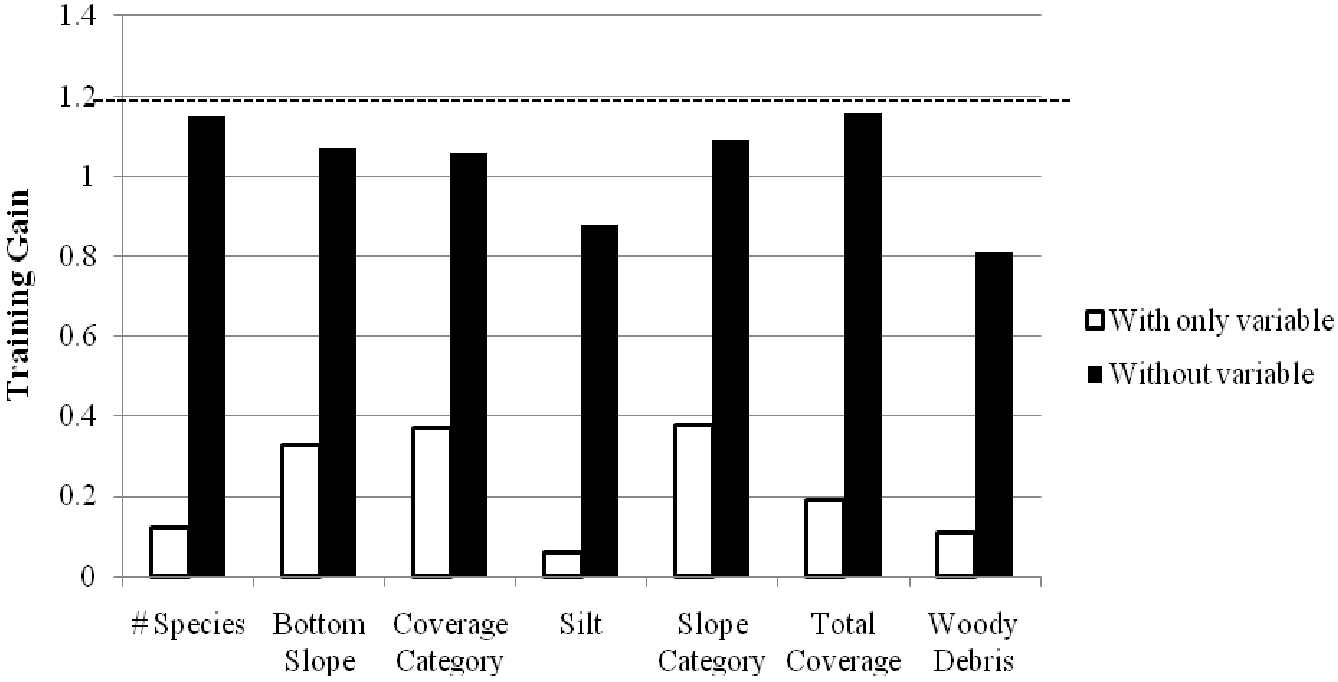


Figure 10: Area under the curve analysis for a 500 replicate Maxent model run. A mean AUC value of 0.931 indicates a strong ability of the model to predict muskellunge spawning habitat in the Menominee River.

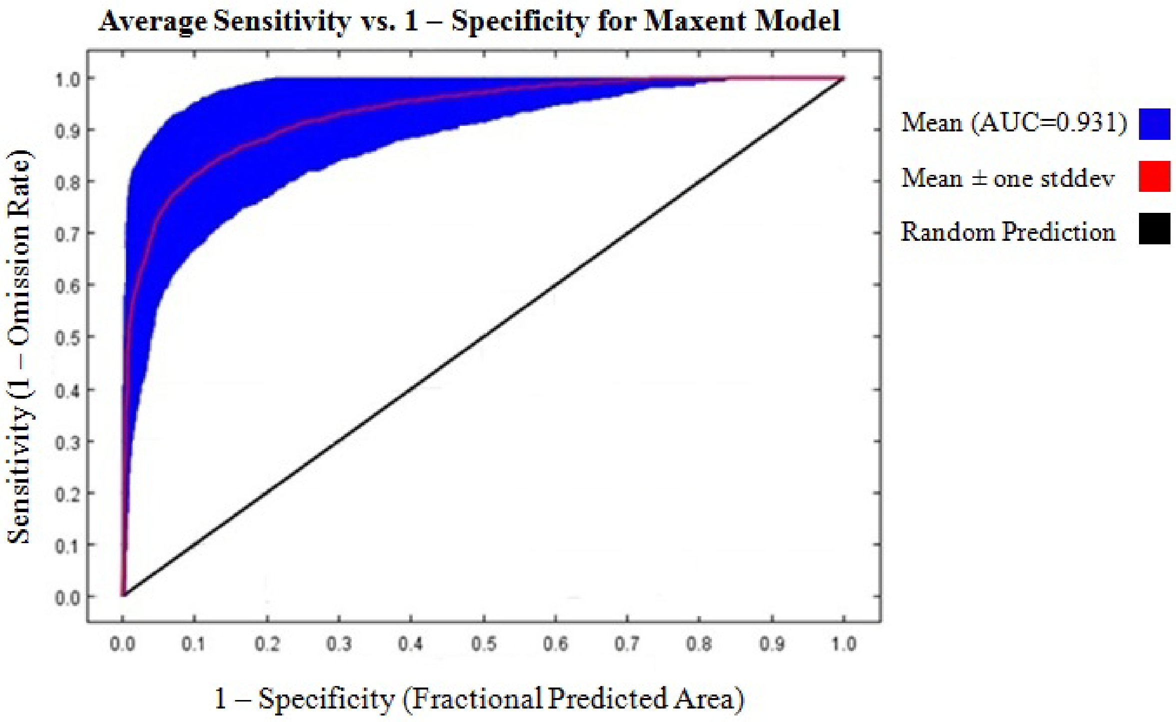


Figure 11: Area analysis of Maxent model results showing the percent of water < 1.5 m deep in the Menominee River that was predicted to have habitat characteristics suitable for spawning muskellunge.

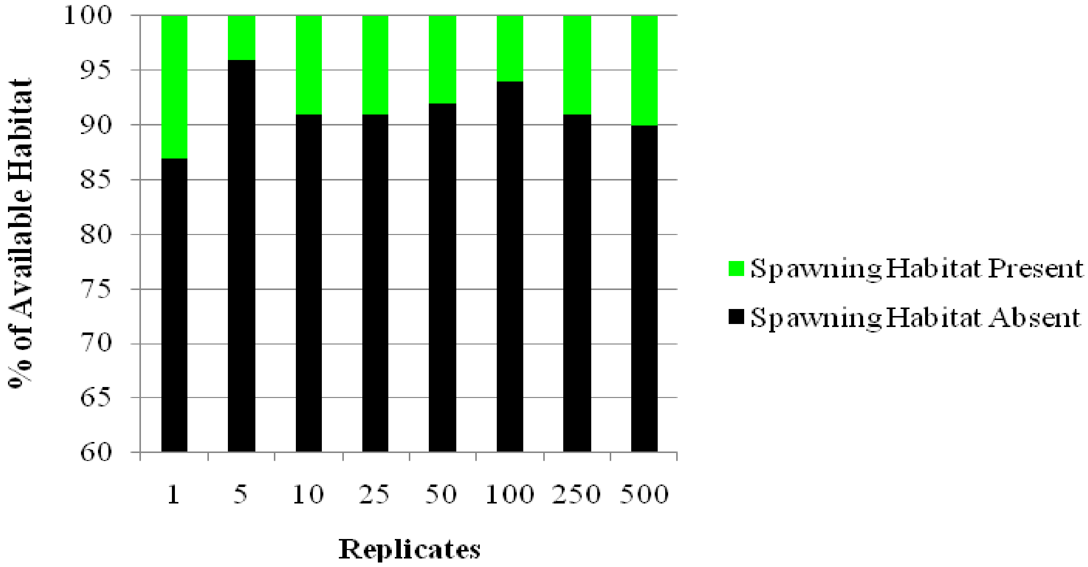


Figure 12: Maxent model predictions of muskellunge spawning with 500 bootstrapped replicates. Black areas indicate locations that are not predicted to have habitat characteristics suitable for spawning muskellunge whereas green areas represent locations predicted to contain suitable spawning habitat. Model results show 6 of 9 spawning locations (red triangles) being located in areas predicted to contain spawning habitat. Cell size for model predictions is 14.5 x 14.5.

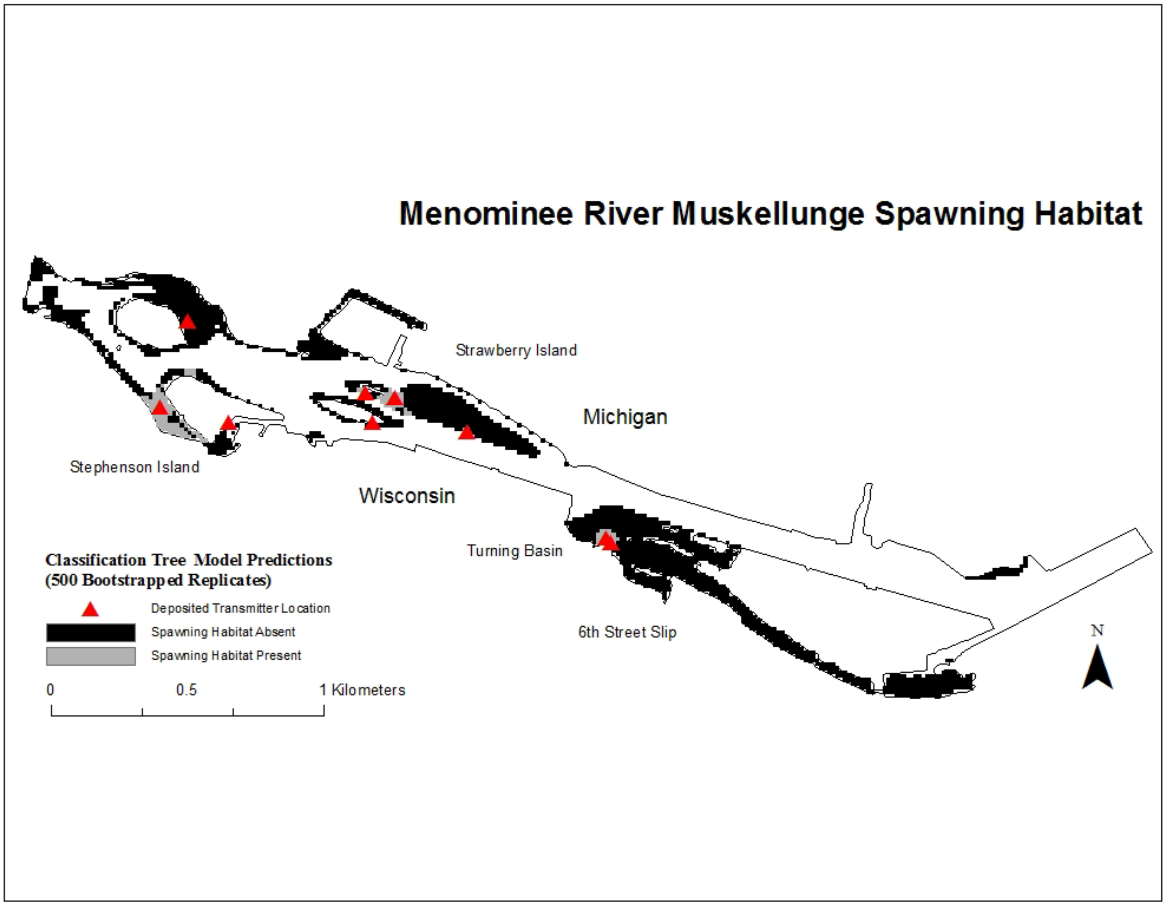


Figure 13: Analyses of variance explained by classification tree models. Model type refers to variables included in model building.

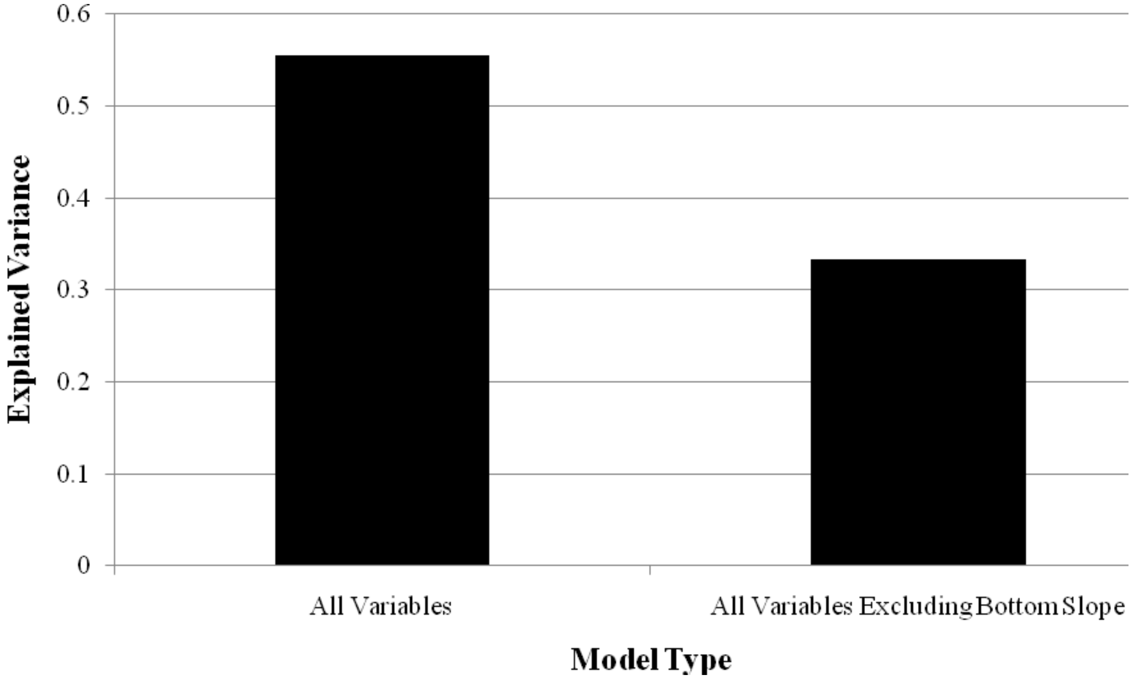


Figure 14: Classification tree model generated from using all habitat variables (although percent bottom slope was the only variable utilized in modeling) which resulted in 3 terminal groups (leaves). Horizontal bars define the criteria each split was based upon. Green bars represent the remaining percent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

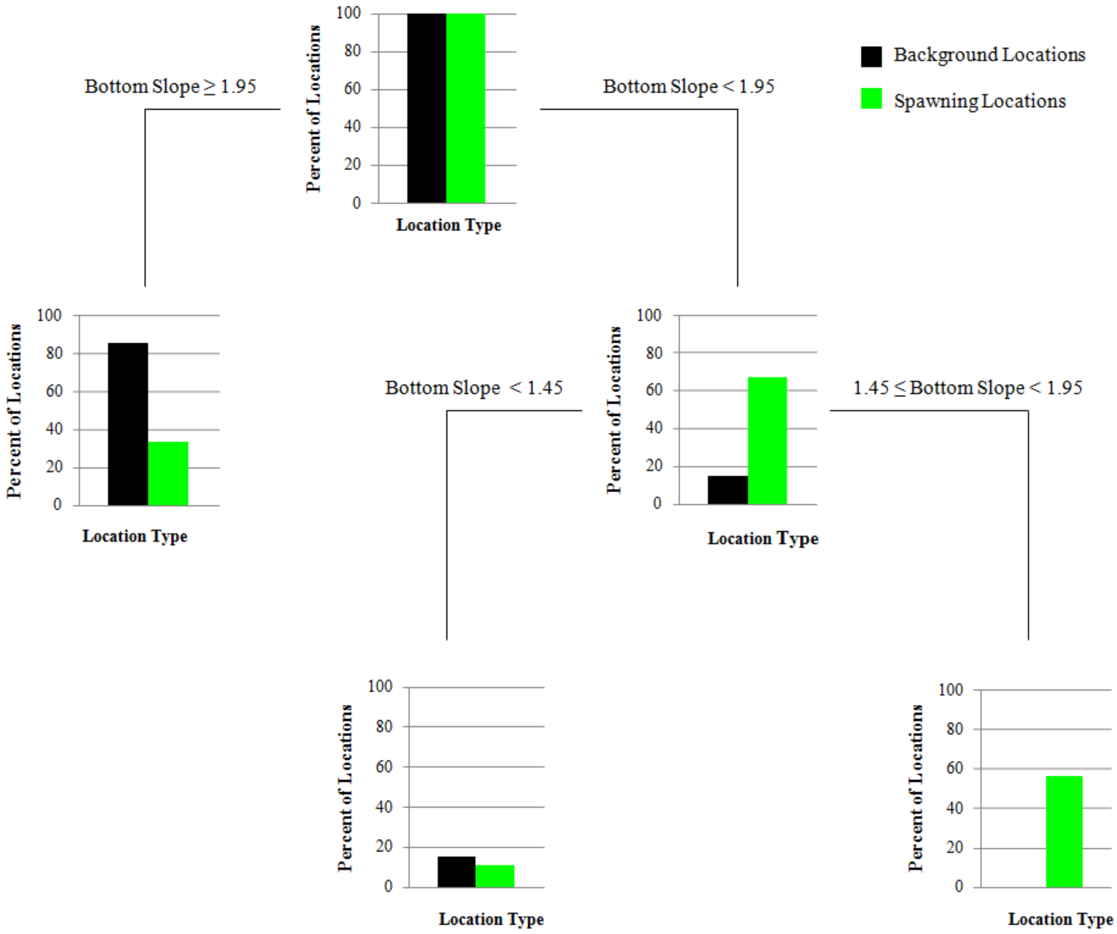


Figure 15: Classification tree model generated from excluding bottom slope but using all other variables, which resulted in 4 terminal groups (leaves). Horizontal bars define the criteria each split was based upon. Green bars represent the remaining percent of spawning locations after each split and black represents the remaining percent of background locations. Number of species refers to the number of vegetative species present within a location. Percent total coverage refers to the percent of bottom substrate covered by vegetation.

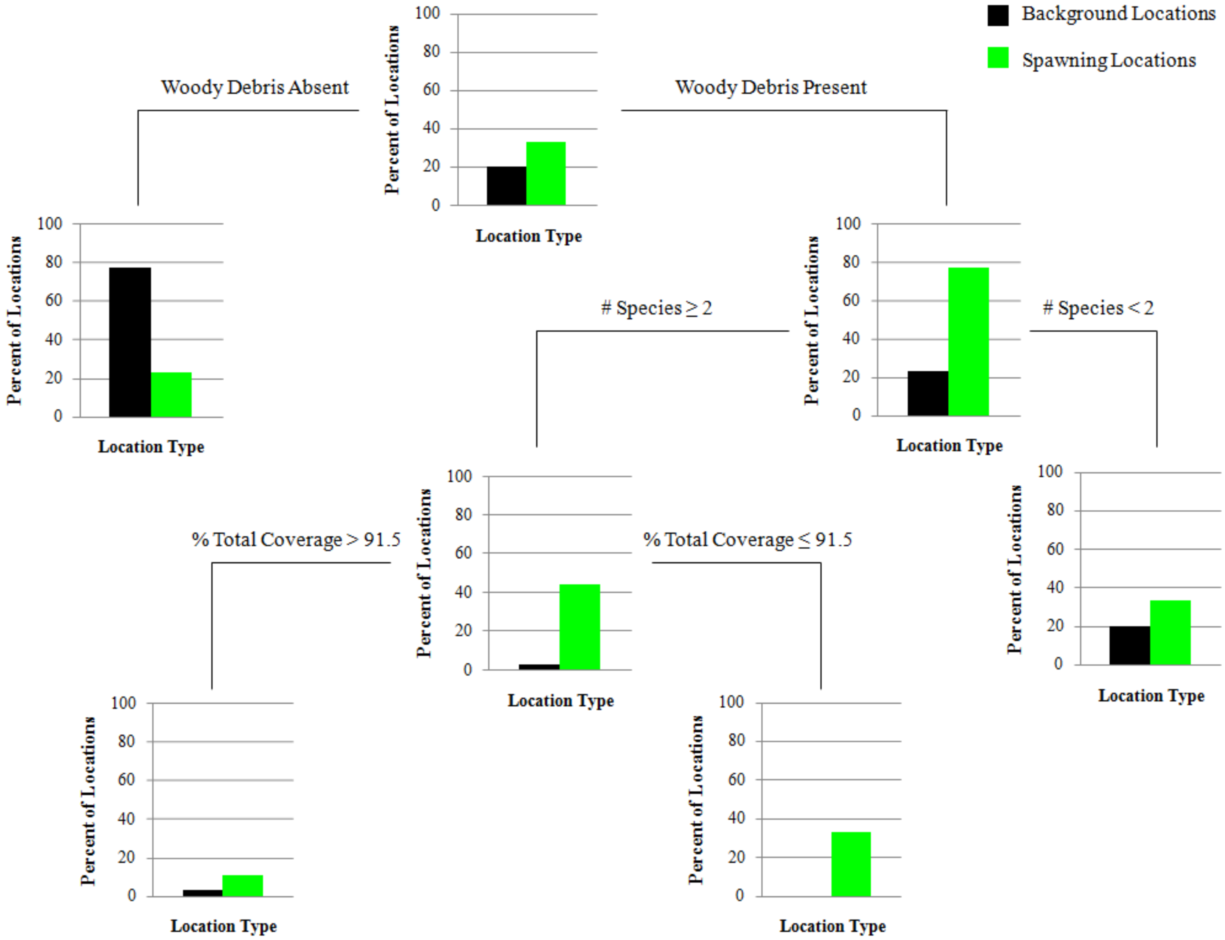


Figure 16: Area analysis of classification tree models after the first split showing the percent of water < 1.5 m deep in the Menominee River predicted to have habitat characteristics suitable for spawning muskellunge.

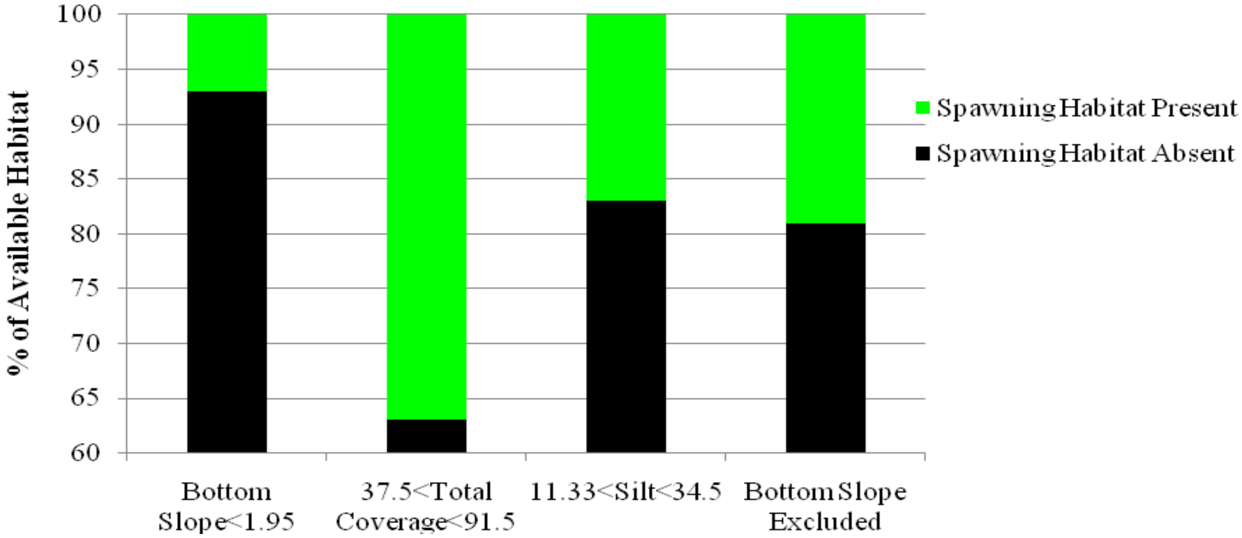


Figure 17: Classification tree model predictions of muskellunge spawning using all variables. Black areas indicate locations that are not predicted to have habitat characteristics suitable for spawning muskellunge whereas green areas represent locations predicted to contain suitable spawning habitat. Model results show 1 of 9 spawning locations (red triangles) being located in areas predicted to contain spawning habitat. Cell size for model predictions is 14.5 x 14.5.

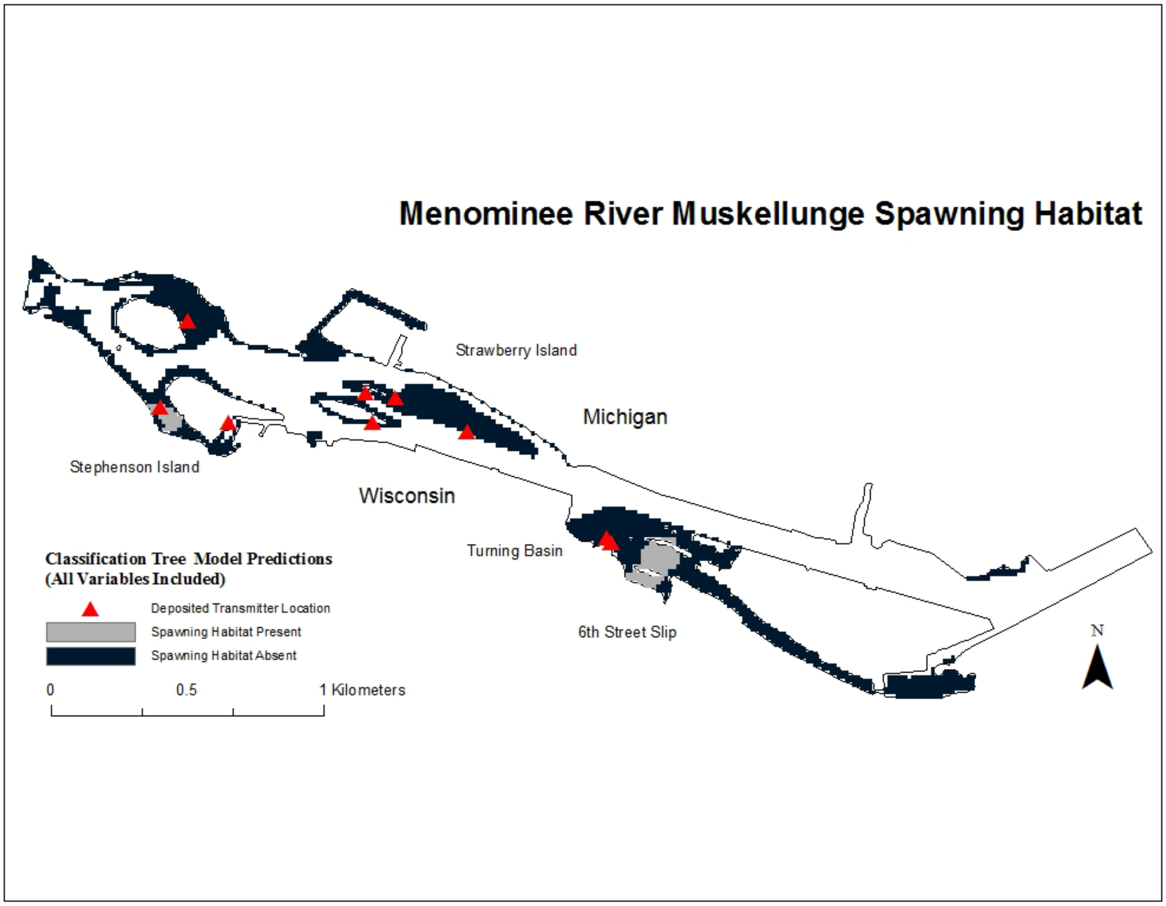
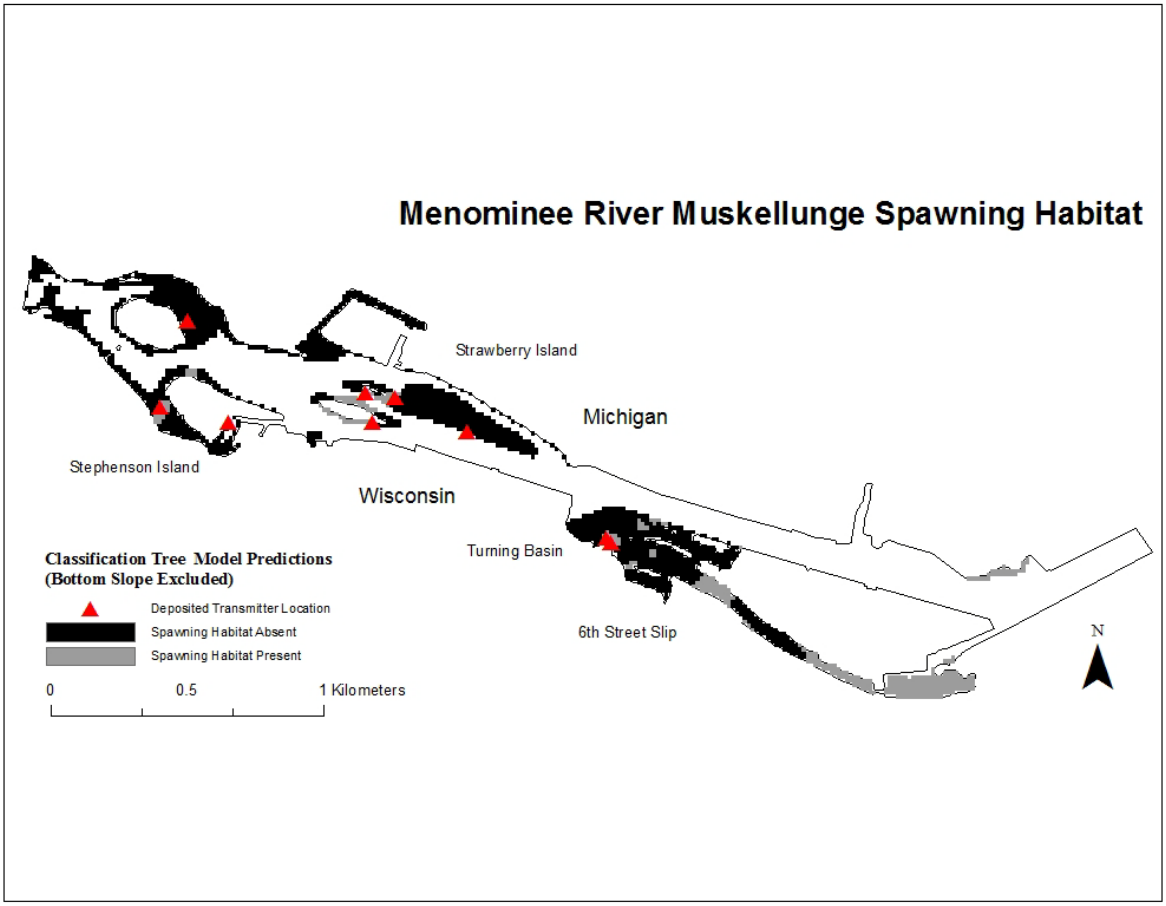


Figure 18: Classification tree model predictions of muskellunge spawning excluding bottom slope but using all other variables. Black areas indicate locations that are not predicted to have habitat characteristics suitable for spawning muskellunge whereas green areas represent locations predicted to contain suitable spawning habitat. Model results show 6 of 9 spawning locations (red triangles) being located in areas predicted to contain spawning habitat. Cell size for model predictions is 14.5 x 14.5.



Appendix 1: Description of column headers used for location and habitat data in the appendix tables.

Location Data (Appendices 2 – 4):

Waypoint	Individual name assigned to a GPS point taken to mark a transmitter. Waypoints were labeled using the transmitter frequency followed by the date or "Dt" if the transmitter was deposited.
Date	Date the waypoint was recorded onto the GPS.

Habitat Data (Appendices 5 – 8): Deposited transmitter data are averages of all 15 measurements taken within each spawning area while background habitat data are single point measurements.

Waypoint	Individual name assigned to a GPS point taken to mark a deposited transmitter or background sample location.
Date	Date the transmitter was confirmed as deposited (Dt) or date the background sample was taken.
Spawn	Binary code used in modeling to distinguish between spawning locations (1) and background locations (0).
Development	Binary code used in modeling to determine whether the shoreline along the sampled location was developed (1) or undeveloped (0).
Immediate Shoreline	Description of habitat at the water's edge. Categories include: rock, riprap, grass-shrub, wetland, sand.
Environmental Shoreline	Description of shoreline habitat away from water's edge. Categories include: shrub, lawn, rock, grasses (natural grasses), trees, dock, concrete, wetland, phrag (*Phragmites*), cobb (cobble), boul (boulder), and riprap.
Bedrock	Percent of substrate (to the nearest 5%) classified as bedrock (solid slab).
Boulder	Percent of substrate (to the nearest 5%) classified as boulder (261 mm - 4.1 m).
Cobble	Percent of substrate (to the nearest 5%) classified as cobble (65 – 260 mm).
Gravel	Percent of substrate classified as gravel (2 – 64 mm).

Appendix 1 (continued): Description of column headers used for location and habitat data in the appendix tables.

Habitat Data (Appendices 5 – 8): Deposited transmitter data are averages of all 15 measurements taken within each spawning area while background habitat data are single point measurements.	
Sand	Percent of substrate (to the nearest 5%) classified as sand (0.062 – 1.9 mm).
Silt	Percent of substrate (to the nearest 5%) classified as silt (0.004 – 0.061 mm).
Clay	Percent of substrate (to the nearest 5%) classified as clay (0 - 0.003 mm).
Concrete	Percent of substrate (to the nearest 5%) classified as concrete.
Litter	Percent of substrate (to the nearest 5%) classified as detritus or coarse benthic organic matter (included: twigs and leaves).
Depth	Depth in cm measured.
Bottom Slope	Percent slope of the bottom.
Slope Category	Categorical classification of calculated bottom slope: 1 = 0-3.0%, 2 = 3.1-6.0%, 3 = 6.1-9.0%, 4 = 9.1-12.0%, and 5 = greater than 12%.
Woody debris	Binary code used to determine if coarse woody debris was present (1) or absent (0) during coarse woody debris transect measurements.
Total Coverage	Percent coverage of submersed aquatic vegetation (SAV) measured to the nearest 5%.
Coverage Category	Categorical classification of percent coverage of submersed aquatic vegetation: 1 = 0 – 33%, 2 = 33 – 66%, 3 = 67 – 100%.
# Species	Number of aquatic vegetative species measured at each location.

Appendix 2: Location data for implanted transmitters in lower Green Bay, 2009.

Waypoint	Date	Latitude	Longitude
004 Dt	28-May-09	44.6345	-88.0297
014 5-11	11-May-09	44.6173	-88.0134
014 Dt	29-May-09	44.6173	-88.0134
024 5-28	29-May-09	44.6675	-87.9906
024 5-29	29-May-09	44.6664	-87.9908
024 Dt	9-Jun-09	44.6670	-87.9905
034 5-21	21-May-09	44.5721	-88.0369
034 5-21 2	21-May-09	44.5716	-88.0378
034 5-7	7-May-09	44.5761	-88.0337
034 Dt	19-Jun-09	44.5718	-88.0382
044 5-18	18-May-09	44.5044	-88.0223
044 5-18 2	18-May-09	44.5048	-88.0233
044 5-4	4-May-09	44.4709	-88.0510
044 5-4 2	4-May-09	44.4735	-88.0499
044 5-5	5-May-09	44.4737	-88.0512
044 5-5 2	5-May-09	44.4736	-88.0514
044 Dt	24-May-09	44.5038	-88.0222
054 5-18	18-May-09	44.4563	-88.0607
054 5-22	22-May-09	44.4554	-88.0614
054 5-25	25-May-09	44.4551	-88.0622
054 5-27	27-May-09	44.4553	-88.0622
054 6-1	1-Jun-09	44.4557	-88.0618
054 6-1 2	1-Jun-09	44.4550	-88.0618
054 Dt	3-Jun-09	44.4550	-88.0618
074 5-29	29-May-09	44.6182	-88.0130
074 5-29 2	29-May-09	44.6182	-88.0129
074 5-7	7-May-09	44.6143	-88.0071
074 5-7 2	7-May-09	44.6130	-88.0083
074 5-7 3	7-May-09	44.6056	-88.0099
074 Dt	8-Jun-09	44.6179	-88.0135

Appendix 2 (continued): Location data for implanted transmitters in lower Green Bay, 2009.

Waypoint	**Date**	**Latitude**	**Longitude**
084 5-18	18-May-09	44.5253	-88.0099
084 5-18 2	18-May-09	44.5245	-88.0099
084 Dt	1-Jun-09	44.5242	-88.0099
095 6-10	10-Jun-09	44.5599	-87.9098
095 6-22	22-Jun-09	44.6190	-87.8594
114 5-14	14-May-09	44.5019	-88.0217
114 6-10	10-Jun-09	44.5402	-87.9982
114 6-10 2	10-Jun-09	44.5402	-87.9983
114 6-17	17-Jun-09	44.5402	-87.9982
114 Dt	21-Jun-09	44.5402	-87.9982
124 5-12	12-May-09	44.5713	-87.9008
124 Dt	15-May-09	44.5713	-87.9006
154 5-22	22-May-09	44.4821	-88.0335
154 5-25	25-May-09	44.4821	-88.0338
154 5-25 2	25-May-09	44.4822	-88.0331
154 5-27	27-May-09	44.4822	-88.0334
154 6-1	1-Jun-09	44.4824	-88.0334
154 Dt	3-Jun-09	44.4825	-88.0325
164 5-18	18-May-09	44.5014	-88.0217
164 5-4	4-May-09	44.5347	-88.0084
164 5-5	5-May-09	44.5377	-88.0068
164 Dt	25-May-09	44.5017	-88.0207
174 5-4	4-May-09	44.4695	-88.0526
174 5-4 2	4-May-09	44.4646	-88.0540
174 5-5	5-May-09	44.4646	-88.0540
174 5-5 2	5-May-09	44.4645	-88.0541
174 Dt	24-May-09	44.4641	-88.0541
184 5-5	5-May-09	44.5293	-88.0085
184 5-7	7-May-09	44.5534	-88.0138

Appendix 2 (continued): Location data for implanted transmitters in lower Green Bay, 2009.

Waypoint	Date	Latitude	Longitude
194 5-18	18-May-09	44.4804	-88.0351
194 5-22	22-May-09	44.4731	-88.0430
194 5-5	5-May-09	44.4731	-88.0442
194 6-1	1-Jun-09	44.5351	-88.0083

Appendix 3: Location data for implanted transmitters in the Menominee River, 2010.

Waypoint	Date	Latitude	Longitude
004 05-10-10	10-May-10	45.0981	-87.6093
004 5-24-10	24-May-10	45.1059	-87.6017
024 5-16-10	16-May-10	45.1023	-87.6230
024 5-21-10	21-May-10	45.1024	-87.6219
024 Dt	21-May-10	45.1024	-87.6218
033 05-10-10	10-May-10	45.1023	-87.6226
033 5-10-10	10-May-10	45.1014	-87.6221
033 5-12-10	12-May-10	45.1016	-87.6211
033 5-16-10	16-May-10	45.1022	-87.6215
033 5-21-10 1	21-May-10	45.1022	-87.6212
033 Dt	21-May-10	45.1022	-87.6204
044 05-10-10	10-May-10	45.0976	-87.6059
044 5-12-10	12-May-10	45.0973	-87.6031
064 05-10-10	10-May-10	45.0977	-87.6052
064 5-11-10	11-May-10	45.0970	-87.6103
064 5-12-10	12-May-10	45.0973	-87.6100
064 5-16-10	16-May-10	45.0975	-87.6103
064 5-17-10	17-May-10	45.0972	-87.6104
064 Dt	21-May-10	45.0974	-87.6107
094 05-10-10	10-May-10	45.1020	-87.6172
094 5-11-10	11-May-10	45.1016	-87.6170
094 5-12-10	12-May-10	45.1013	-87.6178
094 5-13-10	13-May-10	45.1014	-87.6181
094 5-16-10	16-May-10	45.1014	-87.6184
094 5-21-10	21-May-10	45.1009	-87.6170
094 Dt	21-May-10	45.1010	-87.6171
124 5-10-10	10-May-10	45.1043	-87.6295
124 5-12-10	12-May-10	45.1041	-87.6295
124 5-10-10	10-May-10	45.1037	-87.6312
124 5-16-10	16-May-10	45.1044	-87.6287
124 5-17-10	17-May-10	45.1053	-87.6306

Appendix 3 (continued): Location data for implanted transmitters in the Menominee River, 2010.

Waypoint	Date	Latitude	Longitude
124 Dt	21-May-10	45.1050	-87.6300
154 5-16-10	16-May-10	45.0997	-87.6145
336 5-10-10	10-May-10	45.1016	-87.6282
336 Dt	11-May-10	45.1016	-87.6282
344 5-10-10	10-May-10	45.1021	-87.6314
344 5-12-10	12-May-10	45.1022	-87.6314
344 Dt	13-May-10	45.1022	-87.6314
357 5-10-10	10-May-10	45.1018	-87.6206
357 5-10-10 2	10-May-10	45.1012	-87.6237
357 5-12-10	12-May-10	45.1013	-87.6216
357 5-12-10 1	12-May-10	45.1014	-87.6212
357 Dt	13-May-10	45.1014	87.6215
366 05-10-10	10-May-10	45.0976	-87.6104
366 5-11-10	11-May-10	45.0973	-87.6101
366 5-12-10	12-May-10	45.0970	-87.6099
366 5-16-10	16-May-10	45.0974	-87.6101
366 Dt	17-May-10	45.0972	-87.6105
378 5-24-10	24-May-10	45.0921	-87.5882
378 5-24-10 1	24-May-10	45.0920	-87.5884
378 6-9-10	9-Jun-10	45.0970	-87.5887
378 6-13-10	13-Jun-10	45.0898	-87.5872
378 6-21-10	21-Jun-10	45.0948	-87.5920
378 6-22-10	22-Jun-10	45.0937	-87.5902

Appendix 4: Location data for implanted transmitters in Little Sturgeon Bay, 2010.

Waypoint	**Date**	**Latitude**	**Longitude**
084 Dt	20-May-10	44.8257	-87.5530
104 5-13-10	14-May-10	44.8374	-87.5540
104 5-20-10	20-May-10	44.8382	-87.5534
104 5-23-10	23-May-10	44.8383	-87.5535
104 5-27-10	27-May-10	44.8377	-87.5556
104 Dt	17-Jun-10	44.8377	-87.5556
133 5-20-10	20-May-10	44.8332	-87.5474
133 5-23-10	23-May-10	44.8607	-87.5276
133 5-27-10	27-May-10	44.8320	-87.5610
133 Dt	27-May-10	44.8318	-87.5612
194 5-20-10	20-May-10	44.8326	-87.5612
194 5-23-10	23-May-10	44.8380	-87.5553
194 6-14-10	14-Jun-10	44.8296	-87.5541
194 Dt	17-Jun-10	44.8300	-87.5543

Appendix 5a: Fox River habitat data.

Waypoint	**Latitude**	**Longitude**	**Date**	**Spawn**	**Development**	**Immediate Shoreline**
044 Dt	44.5038	-88.0222	24-May-09	1	0	sand
054 Dt	44.4550	-88.0618	3-Jun-09	1	0	wetland
084 Dt	44.5242	-88.0099	1-Jun-09	1	1	riprap
154 Dt	44.4825	-88.0325	3-Jun-09	1	1	riprap
164 Dt	44.5017	-88.0207	25-May-09	1	0	wetland
174 Dt	44.4641	-88.0541	24-May-09	1	1	riprap
Spawning Habitat Averages (SHA)						
Background Habitat Averages (BHA)						
1	44.4639	-88.0543	2-Jun-10	0	1	riprap
2	44.4686	-88.0504	2-Jun-10	0	1	sand
3	44.4693	-88.0497	2-Jun-10	0	0	sand
4	44.4724	-88.0465	2-Jun-10	0	0	grass_shrub
5	44.4718	-88.0441	2-Jun-10	0	1	riprap
6	44.4737	-88.0408	2-Jun-10	0	1	riprap
7	44.4780	-88.0369	2-Jun-10	0	1	grass_shrub
8	44.4782	-88.0363	2-Jun-10	0	1	sand
9	44.4797	-88.0343	2-Jun-10	0	1	rock
10	44.4801	-88.0340	2-Jun-10	0	1	riprap
11	44.4859	-88.0310	2-Jun-10	0	1	sand
12	44.4886	-88.0276	2-Jun-10	0	1	riprap
13	44.4903	-88.0263	2-Jun-10	0	0	wetland
14	44.4906	-88.0262	2-Jun-10	0	0	wetland
15	44.4930	-88.0227	2-Jun-10	0	1	riprap
16	44.4970	-88.0226	2-Jun-10	0	1	riprap
17	44.4988	-88.0220	2-Jun-10	0	1	rock
18	44.4996	-88.0220	2-Jun-10	0	1	riprap
19	44.5010	-88.0207	2-Jun-10	0	1	riprap

Appendix 5a (continued): Fox River habitat data.

Waypoint	Latitude	Longitude	Date	Spawn	Development	Immediate Shoreline
20	44.5018	-88.0207	2-Jun-10	0	1	riprap
21	44.5026	-88.0212	2-Jun-10	0	0	grass_shrub
22	44.5062	-88.0208	2-Jun-10	0	1	riprap
23	44.5078	-88.0205	2-Jun-10	0	1	riprap
24	44.5087	-88.0202	2-Jun-10	0	1	riprap
25	44.5137	-88.0181	2-Jun-10	0	1	riprap
26	44.5203	-88.0089	2-Jun-10	0	1	riprap
27	44.5293	-88.0078	2-Jun-10	0	1	riprap
28	44.5298	-88.0080	2-Jun-10	0	1	riprap
29	44.5309	-88.0077	2-Jun-10	0	1	riprap
30	44.5358	-88.0048	2-Jun-10	0	0	wetland
31	44.5373	-88.0041	2-Jun-10	0	1	riprap
32	44.5377	-88.0038	2-Jun-10	0	1	riprap
33	44.5391	-88.0065	2-Jun-10	0	1	riprap
34	44.5318	-88.0097	2-Jun-10	0	1	rock
35	44.5315	-88.0098	2-Jun-10	0	1	rock
36	44.5313	-88.0099	2-Jun-10	0	1	sand
37	44.5298	-88.0100	2-Jun-10	0	1	riprap
38	44.5188	-88.0168	2-Jun-10	0	1	rock
39	44.5113	-88.0234	2-Jun-10	0	1	riprap
40	44.5045	-88.0243	2-Jun-10	0	1	riprap
41	44.5040	-88.0246	2-Jun-10	0	1	riprap
42	44.5037	-88.0248	2-Jun-10	0	1	riprap
43	44.5020	-88.0257	2-Jun-10	0	1	rock
44	44.5008	-88.0256	2-Jun-10	0	1	rock
45	44.4980	-88.0249	2-Jun-10	0	1	riprap
46	44.4966	-88.0264	2-Jun-10	0	1	rock
47	44.4928	-88.0287	2-Jun-10	0	1	rock
48	44.4917	-88.0300	2-Jun-10	0	1	riprap
49	44.4911	-88.0307	2-Jun-10	0	1	riprap

Appendix 5a (continued): Fox River habitat data.

Waypoint	Latitude	Longitude	Date	Spawn	Development	Immediate Shoreline
50	44.4891	-88.0331	2-Jun-10	0	1	rock
51	44.4585	-88.0592	8-Jun-10	0	1	sand
52	44.4562	-88.0615	8-Jun-10	0	1	sand
53	44.4508	-88.0638	8-Jun-10	0	1	riprap
54	44.4504	-88.063	8-Jun-10	0	1	rock
55	44.4507	-88.0715	8-Jun-10	0	1	riprap
56	44.4519	-88.0740	8-Jun-10	0	1	rock
57	44.4555	-88.0745	8-Jun-10	0	1	rock
58	44.4565	-88.0736	8-Jun-10	0	1	sand
59	44.4554	-88.0689	8-Jun-10	0	1	sand
60	44.4557	-88.068	8-Jun-10	0	1	riprap
61	44.4574	-88.0681	8-Jun-10	0	1	riprap
62	44.4600	-88.0634	8-Jun-10	0	1	riprap
63	44.4609	-88.0613	8-Jun-10	0	1	riprap
64	44.4655	-88.0576	8-Jun-10	0	0	wetland
65	44.4656	-88.0573	8-Jun-10	0	0	wetland
66	44.4660	-88.0567	8-Jun-10	0	0	wetland
67	44.4670	-88.0552	8-Jun-10	0	0	wetland
68	44.4694	-88.0560	8-Jun-10	0	0	sand
69	44.4692	-88.0536	8-Jun-10	0	1	wetland
70	44.4714	-88.0519	8-Jun-10	0	0	wetland
71	44.4749	-88.0502	8-Jun-10	0	0	rock
72	44.4751	-88.0497	8-Jun-10	0	0	sand
73	44.4757	-88.0488	8-Jun-10	0	0	sand
74	44.4773	-88.0488	8-Jun-10	0	1	riprap
75	44.4771	-88.0484	8-Jun-10	0	1	riprap
76	44.4786	-88.0486	8-Jun-10	0	1	riprap
77	44.4788	-88.0477	8-Jun-10	0	1	riprap
78	44.4789	-88.0460	8-Jun-10	0	0	wetland
79	44.4831	-88.0439	8-Jun-10	0	1	sand
80	44.4859	-88.0399	8-Jun-10	0	1	riprap

Appendix 5b: Fox River habitat data.

Waypoint	Environmental Shoreline	Bedrock	Boulder	Cobble	Gravel
044 Dt	lawn	0	3.462	3.077	22.31
054 Dt	shrub	0	0	0.667	20.67
084 Dt	shrub	0	27.5	57.5	15
154 Dt	shrub	0	0	0.667	44.667
164 Dt	shrub	0	0.667	7.333	14
174 Dt	shrub	0	0	11	12
SHA		0	5.3	13.4	21.4
BHA		0	12.2	8.4	21.8
1	concrete	0	0	75	25
2	rip rap	0	0	0	5
3	shrub	0	0	20	80
4	grasses	0	0	0	20
5	shrub	0	0	100	0
6	shrub	0	0	40	60
7	rip rap	0	0	0	10
8	shrub	0	0	0	20
9	rip rap	0	0	0	95
10	concrete	0	0	0	100
11	rip rap	0	0	0	5
12	shrub	0	0	0	55
13	shrub	0	0	0	0
14	shrub	0	0	0	0
15	shrub	0	0	0	0
16	shrub	0	0	0	20
17	shrub	0	0	0	10
18	concrete	0	0	0	0
19	shrub	0	0	80	20

Appendix 5b (continued): Fox River habitat data.

Waypoint	Environmental Shoreline	Bedrock	Boulder	Cobble	Gravel
20	shrub	0	0	40	25
21	shrub	0	0	0	60
22	shrub	0	70	30	0
23	shrub	0	100	0	0
24	grasses	0	100	0	0
25	concrete	0	75	25	0
26	lawn	0	50	0	50
27	lawn	0	0	0	100
28	lawn	0	100	0	0
29	lawn	0	0	50	50
30	phrag	0	0	0	0
31	concrete	0	0	0	0
32	concrete	0	0	0	100
33	shrub	0	0	0	50
34	shrub	0	0	0	0
35	shrub	0	0	0	0
36	shrub	0	0	0	0
37	concrete	0	0	0	0
38	boul	0	0	50	50
39	rip rap	0	0	0	10
40	rip rap	0	50	25	25
41	shrub	0	0	0	50
42	shrub	0	0	0	50
43	cobb	0	0	25	75
44	shrub	0	0	0	10
45	shrub	0	0	0	90
46	shrub	0	0	0	50
47	concrete	0	0	0	70
48	concrete	0	100	0	0
49	concrete	0	0	25	75

Appendix 5b (continued): Fox River habitat data.

Waypoint	Environmental Shoreline	Bedrock	Boulder	Cobble	Gravel
50	boul	0	0	50	50
51	phrag	0	0	0	0
52	phrag	0	0	0	0
53	concrete	0	0	40	60
54	lawn	0	100	0	0
55	shrub	0	0	0	0
56	shrub	0	0	0	40
57	san	0	0	0	5
58	rip rap	0	0	0	0
59	rip rap	0	0	0	0
60	trees	0	0	0	0
61	lawn	0	0	0	0
62	shrub	0	0	0	0
63	lawn	0	0	0	0
64	trees	0	0	0	0
65	trees	0	0	0	0
66	trees	0	0	0	0
67	lawn	0	0	0	0
68	phrag	0	0	0	0
69	rip rap	0	0	0	0
70	trees	0	0	0	0
71	trees	0	0	0	0
72	phrag	0	0	0	0
73	phrag	0	0	0	0
74	concrete	0	100	0	0
75	concrete	0	90	0	10
76	concrete	0	40	0	60
77	concrete	0	0	0	0
78	trees	0	0	0	0
79	rip rap	0	0	0	0
80	shrub	0	0	0	0

Appendix 5c: Fox River habitat data.

Waypoint	Sand	Silt	Clay	Concrete	Litter	Depth	Bottom Slope
044 Dt	47.31	15.38	0	0	1.154	85	16
054 Dt	26	52.67	0	0	0.333	93	1
084 Dt	0	0	0	0	0	116	0
154 Dt	39.667	15	0	0	0	112	5.1
164 Dt	37	41	0	0	3.667	86	1.5
174 Dt	26	51	0	0	0	75	1.4
SHA	29.3	29.2	0	0	0.9	94.5	4.2
BHA	28.9	22.3	5.2	1.3	0.4	77.5	4
1	0	0	0	0	0	115	11.6
2	90	5	0	0	0	117	2
3	0	0	0	0	0	53	12.9
4	70	10	0	0	0	135	1.5
5	0	0	0	0	0	63	10.7
6	0	0	0	0	0	37	12.3
7	35	5	50	0	0	66	13.2
8	10	0	70	0	0	74	4
9	5	0	0	0	0	68	5.8
10	0	0	0	0	0	57	5.3
11	90	5	0	0	0	123	0.8
12	40	5	0	0	0	86	5.2
13	95	5	0	0	0	81	1.8
14	95	5	0	0	0	84	1.2
15	80	20	0	0	0	82	2.2
16	75	5	0	0	0	99	5.8
17	85	5	0	0	0	60	1
18	0	100	0	0	0	97	4.8
19	0	0	0	0	0	79	4.8

Appendix 5c (continued): Fox River habitat data.

Waypoint	Sand	Silt	Clay	Concrete	Litter	Depth	Bottom Slope
20	30	5	0	0	0	98	0.2
21	40	0	0	0	0	38	2.8
22	0	0	0	0	0	56	0.6
23	0	0	0	0	0	99	0.6
24	0	0	0	0	0	55	0.4
25	0	0	0	0	0	70	0
26	0	0	0	0	0	36	0.2
27	0	0	0	0	0	54	0.6
28	0	0	0	0	0	26	4.6
29	0	0	0	0	0	58	0.4
30	0	100	0	0	0	100	0.8
31	0	0	0	100	0	123	1.8
32	0	0	0	0	0	94	0.2
33	0	0	50	0	0	102	1.2
34	100	0	0	0	0	100	1
35	75	25	0	0	0	34	0
36	80	20	0	0	0	35	0.2
37	20	80	0	0	0	51	2.2
38	0	0	0	0	0	88	0
39	0	0	90	0	0	115	9
40	0	0	0	0	0	85	0.8
41	40	10	0	0	0	95	1
42	50	0	0	0	0	103	7.6
43	0	0	0	0	0	129	1
44	85	5	0	0	0	60	0.4
45	10	0	0	0	0	85	3.4
46	40	10	0	0	0	130	0.4
47	15	15	0	0	0	38	2
48	0	0	0	0	0	47	2
49	0	0	0	0	0	29	2

Appendix 5c (continued): Fox River habitat data.

Waypoint	Sand	Silt	Clay	Concrete	Litter	Depth	Bottom Slope
50	0	0	0	0	0	30	0.2
51	90	10	0	0	0	54	4.8
52	50	50	0	0	0	51	0.2
53	0	0	0	0	0	95	0.4
54	0	0	0	0	0	54	2.8
55	0	100	0	0	5	75	1
56	60	0	0	0	0	55	1
57	0	15	80	0	0	74	1.6
58	80	10	10	0	0	77	1.4
59	50	50	0	0	0	88	4.2
60	90	10	0	0	0	73	3.6
61	0	100	0	0	0	55	4
62	85	15	0	0	5	37	1.4
63	90	10	0	0	0	77	5.2
64	30	70	0	0	0	69	3
65	20	80	0	0	0	52	2.8
66	30	70	0	0	5	53	2.2
67	40	60	0	0	0	57	1.2
68	10	30	60	0	5	117	0.6
69	30	70	0	0	5	98	0.2
70	10	90	0	0	0	92	1.2
71	40	60	0	0	0	125	4.8
72	25	75	0	0	5	78	5.2
73	0	95	5	0	0	86	2.6
74	0	0	0	0	0	50	0.8
75	0	0	0	0	0	72	0.4
76	0	0	0	0	0	150	0.2
77	20	80	0	0	0	83	1.5
78	25	75	0	0	0	67	16
79	80	20	0	0	0	94	37.6
80	0	100	0	0	0	152	50.7

Appendix 5d: Fox River habitat data.

Waypoint	Slope Cat	Woody Debris	Total Coverage	Coverage Cat	# Species
044 Dt	5	1	2	1	0
054 Dt	1	0	29	1	1
084 Dt	1	0	0	1	0
154 Dt	2	0	0	1	0
164 Dt	1	1	6	1	1
174 Dt	1	0	6	1	1
SHA	1.8	0.3	7.2	1	0.5
BHA	1.6	0	4.5	1	0.4
1	4	0	0	1	0
2	1	0	15	1	1
3	5	0	5	1	1
4	1	0	0	1	0
5	4	0	0	1	0
6	5	0	0	1	0
7	5	0	0	1	0
8	2	0	5	1	1
9	2	0	5	1	1
10	2	0	0	1	0
11	1	0	0	1	0
12	2	0	25	1	1
13	1	0	5	1	1
14	1	0	5	1	1
15	1	0	30	1	1
16	2	0	5	1	1
17	1	0	30	1	1
18	2	0	0	1	0
19	2	0	0	1	0

Appendix 5d (continued): Fox River habitat data.

Waypoint	Slope Cat	Woody Debris	Total Coverage	Coverage Cat	# Species
20	1	0	0	1	0
21	1	0	5	1	1
22	1	0	0	1	0
23	1	0	0	1	0
24	1	0	0	1	0
25	1	0	0	1	0
26	1	0	0	1	0
27	1	0	0	1	0
28	2	0	0	1	0
29	1	0	0	1	0
30	1	0	10	1	1
31	1	0	0	1	0
32	1	0	5	1	1
33	1	0	0	1	0
34	1	0	0	1	0
35	1	0	5	1	1
36	1	0	15	1	1
37	1	0	35	2	1
38	1	0	0	1	0
39	3	0	0	1	0
40	1	0	0	1	0
41	1	0	0	1	0
42	3	0	5	1	1
43	1	0	0	1	0
44	1	0	0	1	0
45	2	0	0	1	0
46	1	0	0	1	0
47	1	0	0	1	0
48	1	0	0	1	0
49	1	0	0	1	0

Appendix 5d (continued): Fox River habitat data.

Waypoint	Slope Cat	Woody Debris	Total Coverage	Coverage Cat	# Species
50	1	0	0	1	0
51	2	0	5	1	1
52	1	0	0	1	0
53	1	0	0	1	0
54	1	0	0	1	0
55	1	0	0	1	0
56	1	0	0	1	0
57	1	0	5	1	2
58	1	0	60	2	1
59	2	0	0	1	0
60	2	0	0	1	0
61	2	0	0	1	0
62	1	0	0	1	0
63	2	0	5	1	1
64	1	0	0	1	0
65	1	0	10	1	1
66	1	0	10	1	1
67	1	0	0	1	0
68	1	0	0	1	0
69	1	0	5	1	1
70	1	0	0	1	0
71	2	0	0	1	0
72	2	0	25	1	1
73	1	0	0	1	0
74	1	0	0	1	0
75	1	0	0	1	0
76	1	0	0	1	0
77	1	0	10	1	2
78	5	0	5	1	1
79	5	0	10	1	1
80	5	0	0	1	0

Appendix 6a: Lower bay habitat data.

Waypoint	Latitude	Longitude	Date	Spawn	Development	Immediate Shoreline
004 Dt	44.6345	-88.0297	28-May-09	1	1	riprap
014 Dt	44.6173	-88.0134	29-May-09	1	0	wetland
024 Dt	44.667	-87.9905	9-Jun-09	1	0	wetland
034 Dt	44.5718	-88.0382	19-Jun-09	1	0	wetland
074 Dt	44.6179	-88.0135	8-Jun-09	1	0	wetland
114 Dt	44.5402	-87.9982	21-Jun-09	1	1	riprap
124 Dt	44.5713	-87.9006	15-May-09	1	1	sand
Spawning Habitat Averages (SHA)						
Background Habitat Averages (BHA)						
1	44.5754	-87.9052	3-Jun-10	0	0	sand
2	44.5649	-87.9055	3-Jun-10	0	1	rock
3	44.5646	-87.9058	3-Jun-10	0	1	dock
4	44.5625	-87.9069	3-Jun-10	0	1	rock
5	44.5461	-87.9200	3-Jun-10	0	1	rock
6	44.5439	-87.9241	3-Jun-10	0	0	rock
7	44.5338	-87.9419	3-Jun-10	0	1	rock
8	44.5323	-87.9494	3-Jun-10	0	0	wetland
9	44.5320	-87.9723	3-Jun-10	0	1	sand
10	44.5327	-87.9757	3-Jun-10	0	1	sand
11	44.5343	-87.9808	3-Jun-10	0	1	wetland
12	44.5358	-87.9841	3-Jun-10	0	0	rock
13	44.5408	-88.0060	3-Jun-10	0	1	rock
14	44.5425	-88.0071	3-Jun-10	0	1	rock
15	44.5448	-88.0096	3-Jun-10	0	1	rock
16	44.5449	-88.0101	3-Jun-10	0	1	rock
17	44.5492	-88.0163	3-Jun-10	0	1	wetland
18	44.5517	-88.0205	3-Jun-10	0	0	wetland
19	44.5519	-88.0208	3-Jun-10	0	0	wetland
20	44.5534	-88.0219	3-Jun-10	0	0	wetland

Appendix 6a (continued): Lower bay habitat data.

Waypoint	**Latitude**	**Longitude**	**Date**	**Spawn**	**Development**	**Immediate Shoreline**
21	44.5599	-88.0272	3-Jun-10	0	0	wetland
22	44.5624	-88.0263	3-Jun-10	0	0	wetland
23	44.5673	-88.0255	3-Jun-10	0	0	wetland
24	44.5765	-88.0345	3-Jun-10	0	0	wetland
25	44.5750	-88.0196	3-Jun-10	0	0	wetland
26	44.5813	-88.0167	3-Jun-10	0	0	wetland
27	44.5822	-88.0149	3-Jun-10	0	0	wetland
28	44.5863	-88.0139	3-Jun-10	0	0	wetland
29	44.5891	-88.0135	3-Jun-10	0	0	wetland
30	44.5923	-88.0089	3-Jun-10	0	0	wetland
31	44.5952	-88.0084	3-Jun-10	0	0	wetland
32	44.6121	-88.0099	3-Jun-10	0	1	riprap
33	44.6153	-88.0109	3-Jun-10	0	0	wetland
34	44.6172	-88.0114	3-Jun-10	0	0	wetland
35	44.6230	-88.0112	3-Jun-10	0	0	wetland
36	44.6241	-88.0100	3-Jun-10	0	0	wetland
37	44.6222	-88.0111	3-Jun-10	0	0	wetland
38	44.6182	-88.0107	3-Jun-10	0	0	wetland
39	44.6093	-88.0049	3-Jun-10	0	0	wetland
40	44.6012	-87.9941	3-Jun-10	0	0	wetland
41	44.5934	-87.9862	3-Jun-10	0	0	wetland
42	44.5812	-87.9819	3-Jun-10	0	0	sand
43	44.6634	-87.9885	7-Jun-10	0	0	wetland
44	44.6645	-87.9885	7-Jun-10	0	0	wetland
45	44.6648	-87.9887	7-Jun-10	0	0	wetland
46	44.6658	-87.9896	7-Jun-10	0	0	wetland
47	44.6737	-87.9935	7-Jun-10	0	0	wetland
48	44.6747	-87.9931	7-Jun-10	0	0	wetland
49	44.6768	-87.9919	7-Jun-10	0	0	wetland
50	44.6767	-87.9925	7-Jun-10	0	0	wetland
51	44.6678	-87.9976	7-Jun-10	0	0	wetland
52	44.6638	-87.9999	7-Jun-10	0	0	wetland

Appendix 6a (continued): Lower bay habitat data.

Waypoint	Latitude	Longitude	Date	Spawn	Development	Immediate Shoreline
53	44.6615	-87.9959	7-Jun-10	0	0	wetland
54	44.6601	-88.0029	7-Jun-10	0	0	wetland
55	44.6542	-88.001	7-Jun-10	0	0	wetland
56	44.6528	-88.0021	7-Jun-10	0	0	wetland
57	44.6494	-88.0018	7-Jun-10	0	0	wetland
58	44.6450	-88.002	7-Jun-10	0	1	wetland
59	44.6289	-88.0075	7-Jun-10	0	0	wetland
60	44.6220	-88.0053	7-Jun-10	0	0	wetland
61	44.6196	-88.0050	7-Jun-10	0	0	wetland
62	44.6149	-88.0008	7-Jun-10	0	0	sand
63	44.6094	-87.9945	7-Jun-10	0	0	sand
64	44.6058	-87.9904	7-Jun-10	0	0	sand
65	44.5996	-87.9835	7-Jun-10	0	0	sand
66	44.5921	-87.9789	7-Jun-10	0	0	wetland
67	44.5870	-87.9799	7-Jun-10	0	0	rock
68	44.5776	-87.9241	7-Jun-10	0	0	sand
69	44.5683	-87.9487	7-Jun-10	0	0	sand
70	44.5691	-87.9533	7-Jun-10	0	0	sand
71	44.5671	-87.9711	7-Jun-10	0	1	sand
72	44.5569	-87.9899	7-Jun-10	0	1	rock
73	44.5586	-87.9927	7-Jun-10	0	1	rock
74	44.5585	-87.9941	7-Jun-10	0	1	rock
75	44.5594	-87.9989	7-Jun-10	0	0	rock
76	44.5585	-88.0006	7-Jun-10	0	0	rock
77	44.6312	-88.0166	7-Jun-10	0	1	riprap
78	44.6324	-88.0187	7-Jun-10	0	0	grass_shrub
79	44.6349	-88.0302	7-Jun-10	0	1	riprap
80	44.6346	-88.0321	7-Jun-10	0	1	riprap

Appendix 6b: Lower bay habitat data.

Waypoint	Environmental Shoreline	Bedrock	Boulder	Cobble	Gravel	Sand
004 Dt	lawn	0	0	0	0	0
014 Dt	phrag	0	0	0	0	53.33
024 Dt	wetland	0	0	0	0	78
034 Dt	wetland	0	0	0	0	0
074 Dt	grasses	0	0	0	0	75.67
114 Dt	shrub	0	13.33	0	0	85.667
124 Dt	lawn	0	5.33	26	16.667	45.33
SHA		0	2.7	3.7	2.4	48.3
BHA		0	1.3	3.5	4	73.4
1	phrag	0	0	0	0	100
2	shrub	0	0	50	50	0
3	cobb	0	0	0	100	0
4	gravel	0	0	0	0	100
5	gravel	0	0	0	50	50
6	grasses	0	0	0	50	50
7	boul	0	0	0	0	100
8	phrag	0	0	0	0	100
9	phrag	0	0	0	0	100
10	san	0	0	0	0	100
11	grasses	0	0	0	0	100
12	phrag	0	0	0	0	0
13	shrub	0	0	0	0	100
14	shrub	0	0	0	0	100
15	shrub	0	0	0	0	100
16	shrub	0	0	0	0	100
17	phrag	0	0	0	0	100
18	phrag	0	0	0	0	80
19	phrag	0	0	0	0	90
20	phrag	0	0	0	0	50

Appendix 6b (continued): Lower bay habitat data.

Waypoint	Environmental Shoreline	Bedrock	Boulder	Cobble	Gravel	Sand
21	phrag	0	0	0	0	20
22	phrag	0	0	0	0	80
23	phrag	0	0	0	0	85
24	phrag	0	0	0	0	10
25	phrag	0	0	0	0	90
26	phrag	0	0	0	0	90
27	phrag	0	0	0	0	90
28	phrag	0	0	0	0	95
29	phrag	0	0	0	0	100
30	phrag	0	0	0	0	100
31	phrag	0	0	0	0	100
32	lawn	0	0	0	0	60
33	phrag	0	0	0	0	40
34	phrag	0	0	0	0	30
35	phrag	0	0	0	0	30
36	phrag	0	0	0	0	0
37	phrag	0	0	0	0	40
38	phrag	0	0	0	0	5
39	phrag	0	0	0	0	95
40	phrag	0	0	0	0	100
41	phrag	0	0	0	0	100
42	phrag	0	0	0	0	100
43	phrag	0	0	0	0	40
44	phrag	0	0	0	0	100
45	phrag	0	0	0	0	100
46	phrag	0	0	0	0	40
47	phrag	0	0	0	0	70
48	phrag	0	0	0	0	70
49	phrag	0	0	0	0	0
50	phrag	0	0	0	0	10
51	phrag	0	0	0	0	70
52	phrag	0	0	0	0	90

Appendix 6b (continued): Lower bay habitat data.

Waypoint	Environmental Shoreline	Bedrock	Boulder	Cobble	Gravel	Sand
53	phrag	0	0	0	0	95
54	phrag	0	0	0	0	90
55	phrag	0	0	0	0	85
56	phrag	0	0	0	0	90
57	phrag	0	0	0	0	90
58	boul	0	0	0	0	90
59	phrag	0	0	0	0	100
60	phrag	0	0	0	0	95
61	phrag	0	0	0	0	100
62	shrub	0	0	0	0	100
63	grasses	0	0	0	0	100
64	grasses	0	0	0	0	100
65	phrag	0	0	0	0	100
66	phrag	0	0	0	0	100
67	grasses	0	0	80	0	20
68	shrub	0	0	0	0	100
69	shrub	0	0	0	0	100
70	shrub	0	0	0	0	100
71	shrub	0	0	0	0	100
72	trees	0	0	0	0	100
73	trees	0	0	0	0	100
74	shrub	0	100	0	0	0
75	sand	0	0	0	0	95
76	sand	0	0	0	0	95
77	rr	0	0	100	0	0
78	grasses	0	0	0	5	80
79	shrub	0	0	50	25	25
80	shrub	0	0	0	40	50

Appendix 6c: Lower bay habitat data.

Waypoint	**Silt**	**Clay**	**Concrete**	**Litter**	**Depth**	**Bottom Slope**	**Slope Category**
004 Dt	100	0	0	13	70	16	5
014 Dt	46.67	0	0	0	90	0.8	1
024 Dt	22	0	0	0	157	0.9	1
034 Dt	100	0	0	0	76	0.4	1
074 Dt	24.33	0	0	0	89	1	1
114 Dt	1	0	0	0	110	9.5	4
124 Dt	6.667	0	0	0	25	1.2	1
SHA	43	0	0	1.9	88.1	4.3	2
BHA	17.9	0	0	0	78.4	4.3	1.5
1	0	0	0	0	92	0.2	1
2	0	0	0	0	94	5.2	2
3	0	0	0	0	110	2.4	1
4	0	0	0	0	68	2	1
5	0	0	0	0	92	1.6	1
6	0	0	0	0	20	3.4	2
7	0	0	0	0	124	2.8	1
8	0	0	0	0	97	0.6	1
9	0	0	0	0	81	-1	1
10	0	0	0	0	80	1	1
11	0	0	0	0	94	2.2	1
12	100	0	0	0	135	0	1
13	0	0	0	0	89	1.2	1
14	0	0	0	0	87	1	1
15	0	0	0	0	87	3.2	2
16	0	0	0	0	60	0.4	1
17	0	0	0	0	60	1	1
18	20	0	0	0	97	4.8	2
19	10	0	0	0	79	4.8	2
20	50	0	0	0	98	0.2	1

Appendix 6c (continued): Lower bay habitat data.

Waypoint	Silt	Clay	Concrete	Litter	Depth	Bottom Slope	Slope Category
21	80	0	0	0	38	2.8	1
22	20	0	0	0	56	0.6	1
23	15	0	0	0	99	0.6	1
24	90	0	0	0	55	0.4	1
25	10	0	0	0	70	0	1
26	10	0	0	0	36	-0.2	1
27	10	0	0	0	54	0.6	1
28	5	0	0	0	26	4.6	2
29	0	0	0	0	58	0.4	1
30	0	0	0	0	100	0.8	1
31	0	0	0	0	123	1.8	2
32	40	0	0	0	94	-0.2	1
33	60	0	0	0	102	1.2	1
34	70	0	0	0	100	1	1
35	70	0	0	0	34	0	1
36	100	0	0	0	35	0.2	1
37	60	0	0	0	51	2.2	1
38	95	0	0	0	88	0	1
39	5	0	0	0	115	9	3
40	0	0	0	0	85	0.8	1
41	0	0	0	0	95	1	1
42	0	0	0	0	103	7.6	3
43	60	0	0	0	129	-1	1
44	0	0	0	0	60	-0.4	1
45	0	0	0	0	85	3.4	2
46	60	0	0	0	130	0.5	1
47	30	0	0	0	38	2	1
48	30	0	0	0	47	2	1
49	100	0	0	0	29	2	1
50	90	0	0	0	30	0.2	1
51	30	0	0	0	54	4.8	2
52	10	0	0	0	51	0.2	1

Appendix 6c (continued): Lower bay habitat data.

Waypoint	Silt	Clay	Concrete	Litter	Depth	Bottom Slope	Slope Category
53	5	0	0	0	95	0.4	1
54	10	0	0	0	54	2.8	1
55	15	0	0	0	75	1	1
56	10	0	0	0	55	1	1
57	10	0	0	0	74	1.6	1
58	10	0	0	0	77	1.4	1
59	0	0	0	0	88	4.2	2
60	5	0	0	0	73	3.6	2
61	0	0	0	0	55	4	2
62	0	0	0	0	37	1.4	1
63	0	0	0	0	77	5.2	2
64	0	0	0	0	69	3	1
65	0	0	0	0	52	2.8	1
66	0	0	0	0	53	2.2	1
67	0	0	0	0	57	-1.2	1
68	0	0	0	0	117	0.6	1
69	0	0	0	0	98	0.2	1
70	0	0	0	0	92	-1.2	1
71	0	0	0	0	125	4.8	2
72	0	0	0	0	78	-5.2	2
73	0	0	0	0	86	2.6	1
74	0	0	0	0	50	62.5	5
75	5	0	0	0	72	0.4	1
76	5	0	0	0	150	0.2	1
77	0	0	0	0	83	55.3	5
78	15	0	0	0	67	16	5
79	0	0	0	0	94	37.6	5
80	10	0	0	0	152	50.7	5

Appendix 6d: Lower bay habitat 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	0.1	36.7	1.9	1.9
BHA	0	16.6	1.3	0.5
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
20	0	0	1	0

Appendix 6d (continued): Lower bay habitat data.

Waypoint	Woody Debris	Total Coverage	Coverage Category	# Species
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
51	0	100	3	2
52	0	60	2	2

Appendix 6d (continued): Lower bay habitat data.

Waypoint	**Woody Debris**	**Total Coverage**	**Coverage Category**	**# Species**
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 7a: Menominee River habitat data.

Waypoint	Latitude	Longitude	Date	Spawn	Development	Immediate Shoreline
024 Dt	45.1024	-87.6218	21-May-10	1	0	sand
033 Dt	45.1022	-87.6204	21-May-10	1	0	sand
064 Dt	45.0974	-87.6107	21-May-10	1	1	riprap
094 Dt	45.1010	-87.6171	21-May-10	1	1	riprap
124 Dt	45.1050	-87.6300	21-May-10	1	0	grass_shrub
336 Dt	45.1016	-87.6282	11-May-10	1	1	riprap
344 Dt	45.1022	-87.6314	13-May-10	1	1	riprap
357 Dt	45.1014	-87.6215	13-May-10	1	0	sand
366 Dt	45.0972	-87.6105	17-May-10	1	0	sand
Spawning Habitat Averages (SHA)						
Background Habitat Averages (BHA)						
3	45.0920	-87.5945	19-May-10	0	1	riprap
4	45.0918	-87.5972	19-May-10	0	1	rock
5	45.0925	-87.5980	19-May-10	0	1	riprap
13	45.0972	-87.6056	19-May-10	0	1	rock
15	45.0954	-87.6055	19-May-10	0	0	grass_shrub
16	45.0925	-87.5997	19-May-10	0	0	wetland
17	45.0930	-87.6011	19-May-10	0	0	wetland
19	45.0953	-87.6081	19-May-10	0	0	grass_shrub
20	45.0961	-87.6087	19-May-10	0	0	grass_shrub
21	45.0961	-87.6093	19-May-10	0	0	grass_shrub
22	45.0964	-87.6096	19-May-10	0	0	sand
23	45.0968	-87.6098	19-May-10	0	0	sand
24	45.0973	-87.6093	19-May-10	0	0	grass_shrub
25	45.0969	-87.6085	19-May-10	0	0	wetland
26	45.0974	-87.6084	19-May-10	0	0	sand
27	45.0972	-87.6074	19-May-10	0	0	sand
28	45.0976	-87.6073	19-May-10	0	0	grass_shrub
29	45.0978	-87.6080	19-May-10	0	0	sand

Appendix 7a (continued): Menominee River habitat data.

Waypoint	Latitude	Longitude	Date	Spawn	Development	Immediate Shoreline
30	45.0974	-87.6080	19-May-10	0	0	sand
32	45.0973	-87.6117	26-May-10	0	1	riprap
33	45.0984	-87.6124	26-May-10	0	1	riprap
35	45.1011	-87.6169	26-May-10	0	1	riprap
36	45.1012	-87.6181	26-May-10	0	1	riprap
37	45.1014	-87.6219	26-May-10	0	0	sand
38	45.1014	-87.6221	26-May-10	0	0	sand
39	45.1020	-87.6237	26-May-10	0	0	dock
40	45.1020	-87.6237	26-May-10	0	0	dock
41	45.1023	-87.6238	26-May-10	0	0	grass_shrub
42	45.1026	-87.6227	26-May-10	0	0	rock
43	45.1025	-87.6222	26-May-10	0	0	riprap
44	45.1023	-87.6216	26-May-10	0	0	sand
45	45.1024	-87.6215	26-May-10	0	0	riprap
46	45.1021	-87.6208	26-May-10	0	0	sand
47	45.1020	-87.6203	26-May-10	0	0	riprap
48	45.1026	-87.6213	26-May-10	0	0	sand
49	45.1038	-87.6226	26-May-10	0	0	sand
50	45.1057	-87.6219	26-May-10	0	1	rock
51	45.1049	-87.6202	26-May-10	0	1	sand
52	45.1036	-87.6245	26-May-10	0	0	wetland
53	45.1037	-87.6241	26-May-10	0	0	sand
54	45.1039	-87.6246	26-May-10	0	0	sand
55	45.1037	-87.6249	26-May-10	0	0	rock
56	45.1021	-87.6226	26-May-10	0	0	sand
57	45.1020	-87.6222	26-May-10	0	0	sand
58	45.1016	-87.6211	26-May-10	0	0	sand
59	45.1053	-87.6286	1-Jun-10	0	0	grass_shrub
60	45.1064	-87.6312	1-Jun-10	0	0	rock
61	45.1063	-87.6321	1-Jun-10	0	0	rock
62	45.1061	-87.6330	1-Jun-10	0	0	rock
63	45.1063	-87.6341	1-Jun-10	0	1	rock

Appendix 7a (continued): Menominee River habitat data.

Waypoint	Latitude	Longitude	Date	Spawn	Development	Immediate Shoreline
64	45.1059	-87.6324	1-Jun-10	0	0	rock
65	45.1045	-87.6330	1-Jun-10	0	0	grass_shrub
66	45.1043	-87.6324	1-Jun-10	0	1	rock
67	45.1050	-87.6303	1-Jun-10	0	0	grass_shrub
68	45.1034	-87.6330	1-Jun-10	0	0	rock
69	45.1025	-87.6320	1-Jun-10	0	1	rock
70	45.1018	-87.6307	1-Jun-10	0	1	rock
71	45.1025	-87.6316	1-Jun-10	0	1	rock
72	45.1025	-87.6318	1-Jun-10	0	1	rock
73	45.1032	-87.6299	1-Jun-10	0	1	rock
74	45.1033	-87.6271	1-Jun-10	0	1	rock
75	45.1024	-87.6277	1-Jun-10	0	1	rock
76	45.1021	-87.6268	1-Jun-10	0	1	riprap
77	45.1012	-87.6281	1-Jun-10	0	1	rock
78	45.1009	-87.6243	1-Jun-10	0	1	riprap
79	45.1008	-87.6235	1-Jun-10	0	1	riprap
80	45.1029	-87.6186	1-Jun-10	0	1	riprap
81	45.1029	-87.6184	1-Jun-10	0	0	grass_shrub
82	45.1024	-87.6171	1-Jun-10	0	1	riprap
83	45.1023	-87.6168	1-Jun-10	0	1	riprap
84	45.1015	-87.6151	1-Jun-10	0	1	riprap
85	45.1013	-87.6149	1-Jun-10	0	1	riprap
86	45.1004	-87.6131	1-Jun-10	0	1	riprap
87	45.1001	-87.6126	1-Jun-10	0	1	riprap
88	45.0984	-87.5987	1-Jun-10	0	1	riprap
89	45.0960	-87.5924	1-Jun-10	0	1	riprap
90	45.0960	-87.5921	1-Jun-10	0	1	riprap

Appendix 7b: Menominee River habitat data.

Waypoint	Environmental Shoreline	Bedrock	Boulder	Cobble	Gravel	Sand
024 Dt	shrub	0	0	0	3	74.3
033 Dt	shrub	0	0	0	6.66	81
064 Dt	concrete	0	0	0	0	91.667
094 Dt	shrub	0	0	2.667	0.333	84.333
124 Dt	shrub	0	14	54.33	31.667	0
336 Dt	grasses	0	4.17	91.67	4.1667	0
344 Dt	lawn	0	0	0	67	30
357 Dt	grasses	0	0	70.36	13.929	15.714
366 Dt	grasses	0	0	0	0	66
SHA		0	2	24.3	14.1	49.2
BHA		0	12.5	15.2	18.9	33.1
3	shrub	0	0	0	25	75
4	grasses	0	0	100	0	0
5	grasses	0	0	50	50	0
13	shrub	0	0	0	75	25
15	grasses	0	0	0	0	0
16	phrag	0	0	0	0	0
17	grasses	0	0	0	0	0
19	shrub	0	0	0	0	0
20	shrub	0	0	0	0	40
21	shrub	0	0	0	0	90
22	shrub	0	0	0	0	0
23	shrub	0	0	0	0	0
24	shrub	0	0	0	0	70
25	phrag	0	0	0	0	0
26	shrub	0	0	0	0	40
27	shrub	0	0	0	0	0
28	shrub	0	0	0	0	100
29	shrub	0	0	0	0	100

Appendix 7b (continued): Menominee River habitat data.

Waypoint	Environmental Shoreline	Bedrock	Boulder	Cobble	Gravel	Sand
30	shrub	0	0	0	0	15
32	shrub	0	0	25	70	5
33	grasses	0	0	0	80	20
35	shrub	0	0	0	0	85
36	shrub	0	0	0	0	90
37	grasses	0	0	0	40	60
38	grasses	0	0	0	50	50
39	shrub	0	0	0	0	90
40	shrub	0	0	0	10	85
41	shrub	0	0	0	15	80
42	boul	0	0	0	0	85
43	shrub	0	0	0	0	65
44	shrub	0	0	0	0	65
45	shrub	0	0	0	0	90
46	shrub	0	0	0	0	90
47	shrub	0	0	0	0	85
48	shrub	0	0	0	0	20
49	grasses	0	0	0	0	35
50	gravel	0	0	0	100	0
51	grasses	0	0	0	0	90
52	shrub	0	0	50	0	50
53	grasses	0	0	0	0	90
54	grasses	0	0	0	0	70
55	shrub	0	0	0	100	0
56	shrub	0	0	0	0	90
57	shrub	0	0	0	35	60
58	grasses	0	0	0	0	95
59	grasses	0	0	20	75	5
60	grasses	0	75	0	25	0
61	grasses	0	80	20	0	0
62	grasses	0	0	90	10	0
63	grasses	0	100	0	0	0

Appendix 7b (continued): Menominee River habitat data.

Waypoint	**Environmental Shoreline**	**Bedrock**	**Boulder**	**Cobble**	**Gravel**	**Sand**
64	grasses	0	0	100	0	0
65	grasses	0	50	0	0	40
66	shrub	0	0	90	10	0
67	grasses	0	0	10	20	70
68	shrub	0	0	95	5	0
69	rr	0	50	25	25	0
70	grasses	0	0	40	35	20
71	grasses	0	10	0	80	10
72	grasses	0	0	0	100	0
73	grasses	0	0	0	0	80
74	shrub	0	0	50	50	0
75	concrete	0	100	0	0	0
76	grasses	0	100	0	0	0
77	shrub	0	0	100	0	0
78	grasses	0	0	20	80	0
79	concrete	0	0	0	0	0
80	shrub	0	0	30	10	60
81	shrub	0	0	50	50	0
82	shrub	0	100	0	0	0
83	shrub	0	100	0	0	0
84	cobb	0	0	100	0	0
85	cobb	0	0	100	0	0
86	cobb	0	0	5	60	30
87	gravel	0	0	0	90	10
88	shrub	0	0	0	80	20
89	shrub	0	100	0	0	0
90	shrub	0	100	0	0	0

Appendix 7c: Menominee River habitat data.

Waypoint	Silt	Clay	Concrete	Litter	Depth	Bottom Slope
024 Dt	22	0	0	6	68	5.5
033 Dt	12.667	0	0	36.7	58	1.8
064 Dt	8.333	0	0	0	83	1.8
094 Dt	12.667	0	0	0	76	1.6
124 Dt	0	0	0	0	68	0.9
336 Dt	0	0	0	0	69	16.2
344 Dt	3	0	0	0	65	-1.5
357 Dt	0	0	0	0	49	22.5
366 Dt	34	0	0	0	103	-1.9
SHA	10.3	0	0	4.7	71	5.2
BHA	19	0	0.3	6.9	82.5	15
3	0	0	0	0	80	20.5
4	0	0	0	0	80	72.7
5	0	0	0	0	118	118
13	0	0	0	0	88	24.4
15	100	0	0	0	92	4.6
16	100	0	0	0	75	4
17	100	0	0	0	91	4.6
19	100	0	0	0	60	6.6
20	60	0	0	0	17	6.1
21	10	0	0	0	90	-6.3
22	100	0	20	0	110	9.2
23	100	0	0	0	77	3.6
24	30	0	0	0	35	2.8
25	100	0	0	0	40	1.4
26	60	0	0	0	55	2
27	100	0	0	0	84	1
28	0	0	0	0	47	3
29	0	0	0	0	77	8.4

Appendix 7c (continued): Menominee River habitat data.

Waypoint	**Silt**	**Clay**	**Concrete**	**Litter**	**Depth**	**Bottom Slope**
30	85	0	0	0	69	0.6
32	0	0	0	0	44	16.9
33	0	0	0	0	93	27.4
35	15	0	0	0	74	1
36	10	0	0	0	154	9.8
37	0	0	0	0	84	11.2
38	0	0	0	0	124	19.6
39	10	0	0	60	81	18.4
40	5	0	0	80	86	21.5
41	5	0	0	0	79	13.8
42	15	0	0	0	96	5.2
43	35	0	0	0	73	4.2
44	35	0	0	50	117	8.2
45	10	0	0	30	60	3.8
46	10	0	0	10	74	5
47	15	0	0	0	78	2.4
48	80	0	0	0	107	12.4
49	65	0	0	0	76	8.8
50	0	0	0	0	72	37.9
51	10	0	0	0	87	21.8
52	0	0	0	0	58	7.4
53	10	0	0	0	54	0.6
54	30	0	0	0	76	7.2
55	0	0	0	0	130	9.2
56	10	0	0	0	87	18.1
57	5	0	0	40	108	22
58	5	0	0	80	88	9.6
59	0	0	0	0	104	2.4
60	0	0	0	0	97	5.8
61	0	0	0	0	69	13.8
62	0	0	0	0	103	5.6
63	0	0	0	0	79	15.2

Appendix 7c (continued): Menominee River habitat data.

Waypoint	Silt	Clay	Concrete	Litter	Depth	Bottom Slope
64	0	0	0	0	72	6.4
65	10	0	0	50	90	15.8
66	0	0	5	0	58	12.1
67	0	0	0	0	54	3
68	0	0	0	0	106	0.6
69	0	0	0	0	66	2.8
70	5	0	0	0	39	0.4
71	0	0	0	40	70	2
72	0	0	0	0	110	3.4
73	20	0	0	20	77	8.8
74	0	0	0	0	178	1
75	0	0	0	0	75	17.9
76	0	0	0	0	130	39.4
77	0	0	0	0	80	4.4
78	0	0	0	0	61	15.6
79	0	0	0	0	61	10
80	0	0	0	0	99	22
81	0	0	0	0	65	19.7
82	0	0	0	0	81	67.5
83	0	0	0	0	57	31.7
84	0	0	0	0	54	15.4
85	0	0	0	0	120	35.3
86	5	0	0	0	108	31.8
87	0	0	0	0	126	38.2
88	0	0	0	75	98	28
89	0	0	0	0	64	35.6
90	0	0	0	0	56	29.5

Appendix 7d: Menominee River habitat 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	0.8	50.3	2.1	1.6
BHA	3.4	0.2	29	1.5	0.7
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
29	3	1	0	1	1

Appendix 7d (continued): Menominee River habitat data.

Waypoint	Slope Category	Woody Debris	Total Coverage	Coverage Category	# Species
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
62	2	0	0	1	0
63	5	0	0	1	0

Appendix 7d (continued): Menominee River habitat data.

Waypoint	Slope Category	Woody Debris	Total Coverage	Coverage Category	# Species
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 8a: Little Sturgeon Bay habitat data.

Waypoint	Latitude	Longitude	Date	Spawn	Development	Immediate Shoreline
104 Dt	44.8377	-87.5556	17-Jun-10	1	0	Rock
133 Dt	44.8318	-87.5612	27-May-10	1	1	Rip Rap
194 Dt	44.8300	-87.5543	17-Jun-10	1	Too far from shore	Too far from shore
Spawning Habitat Averages (SHA)						
Background Habitat Averages (BHA)						
1	44.8500	-87.5499	10-Jun-10	0	1	Shrub
2	44.8482	-87.5504	10-Jun-10	0	1	Rock
3	44.8467	-87.5533	10-Jun-10	0	1	Rock
4	44.8460	-87.5550	10-Jun-10	0	0	Wetland
5	44.8451	-87.5537	10-Jun-10	0	0	Wetland
6	44.8419	-87.5604	10-Jun-10	0	1	Rock
7	44.8417	-87.5604	10-Jun-10	0	1	Rock
8	44.8413	-87.5605	10-Jun-10	0	1	Rock
9	44.8379	-87.5545	10-Jun-10	0	1	Rock
10	44.8365	-87.5554	10-Jun-10	0	0	Rock
11	44.8355	-87.5562	10-Jun-10	0	1	Rock
12	44.8343	-87.5577	10-Jun-10	0	1	Rock
13	44.8329	-87.5582	10-Jun-10	0	0	Rock
14	44.8309	-87.5593	10-Jun-10	0	1	Rock
15	44.8300	-87.5611	10-Jun-10	0	0	Rock
16	44.8317	-87.5641	10-Jun-10	0	0	Wetland
17	44.8322	-87.5636	10-Jun-10	0	1	Rock
18	44.8324	-87.5637	10-Jun-10	0	1	Rock
19	44.8334	-87.5635	10-Jun-10	0	1	Rip Rap
20	44.8341	-87.5631	10-Jun-10	0	1	Rock
21	44.8356	-87.5621	10-Jun-10	0	1	sand
22	44.8362	-87.5614	10-Jun-10	0	0	Rock
23	44.8365	-87.5611	10-Jun-10	0	0	Rock
24	44.8368	-87.5617	10-Jun-10	0	0	Rock

Appendix 8a (continued): Little Sturgeon Bay habitat data.

Waypoint	**Latitude**	**Longitude**	**Date**	**Spawn**	**Development**	**Immediate Shoreline**
25	44.8370	-87.5620	10-Jun-10	0	0	Rock
26	44.8361	-87.5542	14-Jun-10	0	0	Rock
27	44.8333	-87.5565	14-Jun-10	0	1	Rock
28	44.8328	-87.5568	14-Jun-10	0	1	Rock
29	44.8323	-87.5567	14-Jun-10	0	1	Rock
30	44.8307	-87.5578	14-Jun-10	0	1	Rock
31	44.8254	-87.5575	14-Jun-10	0	0	Wetland
32	44.8263	-87.5566	14-Jun-10	0	0	Rock
33	44.8261	-87.5565	14-Jun-10	0	0	Rock
34	44.8253	-87.5578	14-Jun-10	0	0	Wetland
35	44.8269	-87.5581	14-Jun-10	0	0	Wetland
36	44.8279	-87.5567	14-Jun-10	0	1	Rock
37	44.8244	-87.5527	14-Jun-10	0	1	Rock
38	44.8248	-87.5531	14-Jun-10	0	1	Rip Rap
39	44.8250	-87.5526	14-Jun-10	0	0	Rock
40	44.8254	-87.5535	14-Jun-10	0	1	Rock
41	44.8257	-87.5528	14-Jun-10	0	1	Rip Rap
42	44.8255	-87.5525	14-Jun-10	0	1	Rip Rap
43	44.8272	-87.5539	14-Jun-10	0	1	Rip Rap
44	44.8282	-87.5528	14-Jun-10	0	1	Sand
45	44.8280	-87.5521	14-Jun-10	0	1	Wetland
46	44.8285	-87.5501	14-Jun-10	0	1	Wetland
47	44.8310	-87.5494	14-Jun-10	0	0	Wetland
48	44.8318	-87.5475	14-Jun-10	0	0	Rock
49	44.8312	-87.5473	14-Jun-10	0	0	Wetland
50	44.8309	-87.5469	14-Jun-10	0	0	Wetland
51	44.8307	-87.5449	14-Jun-10	0	1	Wetland
52	44.8324	-87.5457	14-Jun-10	0	0	Wetland
53	44.8321	-87.5445	14-Jun-10	0	0	Wetland
54	44.8331	-87.5434	14-Jun-10	0	0	Wetland
55	44.8331	-87.5416	15-Jun-10	0	0	Wetland
56	44.8344	-87.5437	15-Jun-10	0	0	Wetland

Appendix 8a (continued): Little Sturgeon Bay habitat data.

Waypoint	Latitude	Longitude	Date	Spawn	Development	Immediate Shoreline
57	44.8363	-87.5417	15-Jun-10	0	1	Rock
58	44.8387	-87.5414	15-Jun-10	0	0	Wetland
59	44.8437	-87.5399	15-Jun-10	0	0	Wetland
60	44.8437	-87.5383	15-Jun-10	0	0	Wetland
61	44.8441	-87.5376	15-Jun-10	0	0	Wetland
62	44.8445	-87.5379	15-Jun-10	0	0	Wetland
63	44.8448	-87.5366	15-Jun-10	0	0	Rock
64	44.8460	-87.5366	15-Jun-10	0	0	Rock
65	44.8469	-87.5348	15-Jun-10	0	1	Rock
66	44.8505	-87.5337	15-Jun-10	0	1	Rock
67	44.8505	-87.5341	15-Jun-10	0	1	Rock
68	44.8526	-87.5345	15-Jun-10	0	0	Rock
69	44.8527	-87.5347	15-Jun-10	0	0	Rock
70	44.8549	-87.5349	15-Jun-10	0	1	Sand
71	44.8307	-87.5643	16-Jun-10	0	0	Wetland
72	44.8295	-87.5648	16-Jun-10	0	1	Rip Rap
73	44.8292	-87.5651	16-Jun-10	0	1	Rock
74	44.8289	-87.5665	16-Jun-10	0	0	Wetland
75	44.8292	-87.5681	16-Jun-10	0	1	Rock
76	44.8282	-87.5639	16-Jun-10	0	0	Wetland
77	44.8278	-87.5638	16-Jun-10	0	0	Wetland
78	44.8269	-87.5641	16-Jun-10	0	0	Grasses
79	44.8261	-87.5651	16-Jun-10	0	0	Grasses
80	44.8455	-87.5581	16-Jun-10	0	1	Wetland

Appendix 8b: Little Sturgeon Bay habitat data.

Waypoint	Environmental Shoreline	Bedrock	Boulder	Cobble	Gravel
104 Dt	Shrub	0	0	0	0
133 Dt	Lawn	0	0	0	0
194 Dt	Too far from shore	0	0	0	0
SHA		0	0	0	0
BHA		0	2.9	13.8	26.8
1	Shrub	0	50	50	0
2	Rock	0	0	75	15
3	Grasses	0	0	0	5
4	Shrub	0	0	0	40
5	Rock	0	0	0	80
6	Rock	0	0	0	70
7	Rock	0	0	10	80
8	Rock	0	0	20	45
9	Rock	0	0	0	95
10	Rock	0	0	0	0
11	Rock	0	0	50	0
12	Shrub	0	0	0	100
13	Shrub	0	0	0	0
14	Trees	0	0	0	0
15	Shrub	0	0	0	0
16	Grasses	0	0	0	0
17	Lawn	0	0	0	0
18	Lawn	0	0	0	0
19	Lawn	0	0	0	0
20	Lawn	0	0	0	0
21	Lawn	0	0	0	0
22	Grasses	0	0	10	80
23	Grasses	0	30	20	50
24	Trees	0	0	0	60

Appendix 8b (continued): Little Sturgeon Bay habitat data.

Waypoint	Environmental Shoreline	Bedrock	Boulder	Cobble	Gravel
25	Trees	0	0	0	30
26	Grasses	0	0	80	20
27	Rock	0	0	50	50
28	Shrub	0	0	25	25
29	Dock	0	0	85	15
30	Shrub	0	0	0	20
31	Shrub	0	0	0	0
32	Shrub	0	0	0	70
33	Shrub	0	0	0	90
34	Trees	0	0	0	0
35	Trees	0	0	0	0
36	Concrete	0	0	0	0
37	Lawn	0	0	0	0
38	Lawn	0	0	0	0
39	Grasses	0	0	0	85
40	Lawn	0	0	0	0
41	Grasses	0	50	0	0
42	Shrub	0	0	0	0
43	Lawn	0	0	0	0
44	Lawn	0	0	0	0
45	Lawn	0	0	0	0
46	Rock	0	0	0	0
47	Lawn	0	0	0	0
48	Shrub	0	0	0	0
49	Trees	0	0	0	0
50	Trees	0	0	60	25
51	Lawn	0	0	0	0
52	Shrub	0	0	20	70
53	Shrub	0	0	0	45
54	Grasses	0	0	30	0
55	Wetland	0	0	10	15
56	Wetland	0	0	0	20

Appendix 8b (continued): Little Sturgeon Bay habitat data.

Waypoint	Environmental Shoreline	Bedrock	Boulder	Cobble	Gravel
57	Dock	0	0	0	50
58	Wetland	0	0	0	75
59	Shrub	0	0	50	25
60	Shrub	0	0	0	75
61	Shrub	0	0	25	50
62	Shrub	0	0	0	75
63	Shrub	0	0	100	0
64	Shrub	0	0	80	0
65	Shrub	0	0	25	65
66	Grasses	0	0	15	60
67	Dock	0	25	30	30
68	Grasses	0	0	20	70
69	Rock	0	0	15	70
70	Grasses	0	0	50	45
71	Rip Rap	0	0	0	0
72	Concrete	0	75	0	0
73	Shrub	0	0	0	85
74	Grasses	0	0	95	0
75	Lawn	0	0	0	0
76	Grasses	0	0	0	0
77	Wetland	0	0	0	0
78	Grasses	0	0	0	0
79	Grasses	0	0	0	0
80	Wetland	0	0	0	70

Appendix 8c: Little Sturgeon Bay habitat data.

Waypoint	Sand	Silt	Clay	Concrete	Litter	Depth	Bottom Slope	Slope Category
104 Dt	40	60	0	0	0	241	2.2	1
133 Dt	0	100	0	0	0	96	0.1	1
194 Dt	10	90	0	0	0	301	0.2	1
SHA	16.7	83.3	0	0	0	212.7	0.8	1
BHA	21.5	33.8	0	0	0	79.8	6.9	2
1	0	0	0	0	0	90	1.6	1
2	10	0	0	0	0	77	3.2	2
3	0	95	0	0	0	67	19.1	5
4	0	60	0	0	0	56	2.2	1
5	20	0	0	0	0	97	8	3
6	30	0	0	0	0	68	18.9	5
7	10	0	0	0	0	58	11.8	4
8	35	0	0	0	0	65	13.8	5
9	0	5	0	0	0	85	1.8	1
10	15	85	0	0	0	154	1.8	1
11	0	50	0	0	0	74	49.3	5
12	0	0	0	0	0	87	6.6	3
13	0	100	0	0	0	100	1.3	1
14	60	40	0	0	0	53	9.4	4
15	0	100	0	0	0	66	1.8	1
16	0	100	0	0	0	67	1.4	1
17	20	80	0	0	0	81	0.8	1
18	20	80	0	0	0	75	0.2	1
19	20	80	0	0	0	82	1.4	1
20	10	90	0	0	0	91	-0.6	1
21	5	95	0	0	0	83	0.8	1
22	10	0	0	0	0	68	0.4	1
23	0	0	0	0	0	86	5.2	2
24	0	40	0	0	0	74	-10.3	4

Appendix 8c (continued): Little Sturgeon Bay habitat data.

Waypoint	Sand	Silt	Clay	Concrete	Litter	Depth	Bottom Slope	Slope Category
25	0	70	0	0	0	121	44.8	5
26	0	0	0	0	0	89	2.2	1
27	0	0	0	0	0	114	5	2
28	50	0	0	0	0	60	15.8	5
29	0	0	0	0	0	88	2.6	1
30	50	30	0	0	0	71	2.6	1
31	15	85	0	0	0	92	1.6	1
32	30	0	0	0	0	131	5.2	2
33	0	10	0	0	0	37	2.2	1
34	30	70	0	0	0	94	0.2	1
35	20	80	0	0	0	101	1.4	1
36	95	5	0	0	0	152	4.5	2
37	15	85	0	0	0	83	18.4	5
38	0	100	0	0	0	85	8.2	3
39	10	5	0	0	0	44	40	5
40	0	100	0	0	0	80	1.2	1
41	0	50	0	0	0	100	100	5
42	15	85	0	0	0	86	16.2	5
43	60	40	0	0	0	74	2.2	1
44	0	0	0	0	0	108	0.2	1
45	90	10	0	0	0	113	1	1
46	80	20	0	0	0	59	1.8	1
47	95	5	0	0	0	132	1.8	1
48	95	5	0	0	0	87	1.4	1
49	95	5	0	0	0	68	0.6	1
50	10	5	0	0	0	36	0.4	1
51	20	80	0	0	0	27	1.2	1
52	10	0	0	0	0	67	1	1
53	50	5	0	0	0	40	0.2	1
54	65	5	0	0	0	97	0.6	1
55	75	0	0	0	0	54	0.4	1
56	80	0	0	0	0	123	-3.4	2

Appendix 8c (continued): Little Sturgeon Bay habitat data.

Waypoint	Sand	Silt	Clay	Concrete	Litter	Depth	Bottom Slope	Slope Category
57	20	30	0	0	0	99	0.6	1
58	15	10	0	0	0	56	2.8	1
59	25	0	0	0	0	119	0.4	1
60	15	10	0	0	0	60	2.6	1
61	15	10	0	0	0	58	1.4	1
62	10	15	0	0	0	107	2.2	1
63	0	0	0	0	0	18	1.6	1
64	10	10	0	0	0	123	3.8	2
65	0	10	0	0	0	87	1	1
66	10	15	0	0	0	72	1.6	1
67	10	5	0	0	0	107	0.8	1
68	10	0	0	0	0	55	6	1
69	10	5	0	0	0	53	0.8	1
70	0	5	0	0	0	90	2.2	1
71	5	95	0	0	0	67	0.8	1
72	0	25	0	0	0	87	10.6	4
73	10	5	0	0	0	95	2.6	1
74	0	5	0	0	0	40	25	5
75	0	100	0	0	0	86	23.9	5
76	10	90	0	0	0	52	1.4	1
77	0	100	0	0	0	15	-3	1
78	40	60	0	0	0	52	10.6	4
79	85	15	0	0	0	54	2	1
80	0	30	0	0	0	114	15.6	5

Appendix 8d: Little Sturgeon Bay habitat data.

Waypoint	Woody Debris	Total Coverage	Coverage Category	# Species
104 Dt	0	95	3	3
133 Dt	1	86	3	3
194 Dt	0	49	2	1
SHA	0.3	76.7	2.7	2.3
BHA	0	31.9	1.6	1.4
1	0	0	1	0
2	0	0	1	0
3	0	5	1	2
4	0	5	1	1
5	0	45	2	1
6	0	5	1	1
7	0	5	1	1
8	0	5	1	2
9	0	5	1	1
10	0	75	3	3
11	0	5	1	1
12	0	5	1	1
13	0	40	2	4
14	0	30	1	4
15	0	10	1	2
16	0	70	3	3
17	0	40	2	1
18	0	100	3	3
19	0	80	3	2
20	0	80	3	2
21	0	100	3	2
22	0	0	1	0
23	0	0	1	0
24	0	60	2	1

Appendix 8d (continued): Little Sturgeon Bay habitat data.

Waypoint	Woody Debris	Total Coverage	Coverage Category	# Species
25	0	50	2	1
26	0	0	1	0
27	0	50	2	3
28	0	10	1	1
29	0	0	1	0
30	0	15	1	2
31	0	100	3	2
32	0	50	2	2
33	0	0	1	0
34	0	100	3	1
35	0	30	1	3
36	0	40	2	1
37	0	100	3	1
38	0	30	1	2
39	0	10	1	1
40	0	70	3	6
41	0	100	3	1
42	0	75	3	2
43	0	0	1	0
44	0	30	1	2
45	0	100	3	1
46	0	50	2	1
47	0	5	1	1
48	0	20	1	2
49	1	0	1	0
50	0	0	1	0
51	0	20	1	1
52	0	5	1	1
53	0	5	1	1
54	0	5	1	1
55	0	25	1	1
56	0	10	1	2

Appendix 8d (continued): Little Sturgeon Bay habitat data.

Waypoint	Woody Debris	Total Coverage	Coverage Category	# Species
57	0	20	1	1
58	0	20	1	1
59	0	0	1	0
60	0	0	1	0
61	0	5	1	1
62	0	40	2	1
63	0	0	1	0
64	0	20	1	1
65	0	50	2	1
66	0	80	3	1
67	0	20	1	1
68	0	0	1	0
69	0	0	1	0
70	0	5	1	1
71	0	30	1	2
72	0	5	1	1
73	0	15	1	2
74	0	5	1	2
75	0	40	2	1
76	0	100	3	3
77	0	100	3	2
78	0	10	1	2
79	0	10	1	2
80	1	100	3	4