INFLUENCES OF VEGETATED BUFFERS ON FISH HABITAT IN AGRICULTURAL STREAMS IN MICHIGAN: IMPLICATIONS FOR CONSERVATION

By

Linda I. Ortiz-Gonzalez

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ABSTRACT

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Agriculture provides food for humans and animals around the globe, however, it is also a stressor to ecosystems, including streams and the organisms they support. To reduce negative effects of agriculture on streams and ensure that it is practiced sustainably, conservation practices can help to address environmental concerns from agriculture. The goal of this research is to evaluate the utility of one conservation practice, vegetated stream buffers, in reducing effects of agriculture on stream fish habitats. In Chapter 1, we test for influences of forested buffers on fish habitat 30 streams draining heavily agricultural land in the Grand and Saginaw River basins, Michigan. Forested buffers have historically been promoted to reduce nutrient and sediment loading to streams, but they also contribute woody debris, maintain geomorphic units, and improve channel stability by preventing bank erosion, and our results showed that more forest in buffers was associated with decreased sedimentation and less channel erosion. Additionally, we also found that wetlands in buffers were associated with reduced streambed sediment. For Chapter 2, we extrapolated results from Chapter 1 to streams in the Grand, Saginaw, Kalamazoo, and St. Joseph River basins in Michigan to identify where implementation of vegetated buffers may improve fish habitat. This resulted in a series of maps showing locations of streams with limited fish habitat based on a lack of vegetation in their buffers along with maps showing locations of currently protected lands to identify areas that could benefit from additional conservation practices. Results from both studies will aid stakeholders by proving information to help them protect or implement vegetated buffers in heavily agricultural watersheds to improve fish habitat.

To my family, friends, and all of those who believed in me.

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ABSTRACT

Agriculture plays a critical role in our society; it is an essential activity for providing food, supporting food security, and enhancing economies for people around the world. At the same time, agriculture can be a stressor that can affect multiple physical and biological characteristics of freshwater habitats. Managing sustainable and healthy water resources while maintaining profitable agriculture is a challenging yet essential goal. In this study, we describe the value of forested stream buffers in heavily agricultural watersheds in central Michigan, U.S.A. by analyzing how fish habitat is affected by the amount of forested buffer present. In addition, we evaluate relationships between fish habitat variables and multiple landscape factors to better understand effects of forested buffers compared to other influences on fish habitat. Our study documents benefits of forested buffers on multiple features of fish habitat in streams draining heavily agricultural landscapes, such as decreasing sedimentation and protecting channel morphology. Additionally, we show that wetlands in buffers, another form of natural vegetation, also benefits measures of fish habitat including less fines and less sedimentation. This study is important because compared to studies documenting effects of agricultural land on stream nutrients levels, far fewer studies have been conducted that describe effects of forested buffers on physical fish habitat on heavily agricultural land. The results obtained from this study will benefit stakeholders by identifying amounts of forested and wetland buffers associated with desirable fish habitat factors, and this will also aid in prioritizing actions to protect or establish buffers in tributaries of heavily agricultural watersheds of central Michigan.

INTRODUCTION

Agriculture is an essential activity for providing food, supporting food security, and enhancing economies for people around the world. Currently, 99% of the world's food supply comes from terrestrial vs. aquatic systems, including marine and freshwater habitats (FAO, 1998). For this reason, agriculture plays a critical role in the food security and economies of nearly every country globally (Tanentzap et al., 2015). Demands for agricultural products are expected to increase across the world due to growing populations, and greater pressure will continue to be placed on agriculture to meet these demands. In spite of its global importance, agriculture can have multiple negative effects on physical and biological characteristics of terrestrial ecosystems including affecting air quality, degrading soils, and altering plant and animal communities (e.g., Pimentel et. al., 1994, Altieri, 1999). Additionally, agriculture can also have multiple negative effects on aquatic ecosystems, including changing hydrologic and thermal regimes, inputs of sediments, and water chemistry (e.g., Poff et al., 1997, Piggott et al., 2012, Crane and Farrell, 2013). To minimize agriculture's negative effects and ensure that agriculture can be practiced more sustainably, it is critical to understand the varied influences of agriculture on ecosystems across the globe.

Michigan is one of the most agriculturally diverse states in the Nation, and Michigan farmers produce more than 300 different agricultural products (Michigan Farm Bureau, 2020). In 2016, Michigan was ranked first by the United States Department of Agriculture - National Agricultural Statistics Service (USDA-NASS) for production of cucumbers for pickles, blueberries, and tart cherries. In addition, Michigan is the Nation's second largest grower of Christmas trees, with farms concentrated in a few locations throughout the state. The Michigan Department of Agriculture and Rural Development reported in 2017 that the food and agriculture industry contributed $101.2 billion annually to the state's economy, with field crops like corn, soybeans, and other grains contributing the most followed by livestock production. According to the available data, 26% of the land area in Michigan is classified as agriculture (NLCD, 2011), and unique characteristics of Michigan's landscape that contribute to the state's agricultural economy include its climate, topography, soils, and geology. These landscape factors also contribute to an abundance and diversity of freshwater ecosystems across Michigan. Michigan borders four of the five Laurentian Great Lakes, the state includes thousands of inland lakes, and Michigan has at least 36,000 miles of streams and rivers (NHDPlusV1; USEPA and USGS, 2005). Because of these diverse habitats, Michigan supports many different fish species with recreational, spiritual, and ecological value. This underscores the importance of promoting sustainable agriculture in Michigan to minimize environmental concerns for freshwaters and to promote conservation of important fish species.

Many studies have occurred that describe agriculture's effects on water quality, and streams in agricultural landscapes commonly have excessive nutrient levels due to increased inputs of nitrogen and phosphorus because of fertilizer applications (Omernick et al., 1981, Heathwaite and Johnes, 1996, Johnson et al., 1997 and McDowell, 2019). Comparatively, fewer studies have occurred that describe agriculture's effects on physical stream fish habitat, but examples do occur in the literature. For example, agriculture contributes to higher water temperatures by generating extra runoff from crop fields due to the fact that soils in agricultural landscapes are often compacted (Piggott et al., 2012) and because of the removal of streamside vegetation to increase cropland acres which reduces stream shading (Sweeny and Newbold, 2014). Most fish species have optimal thermal ranges, and water temperatures outside of those ranges can negatively affect fish metabolism and growth (Morgan et al., 2001). Additionally, water temperatures strongly influence egg viability and serve as spawning cues for many fish species (Hokanson et al., 1973; Diana et al., 1995). Removal of streamside vegetation can also lead to reductions in woody debris found in the channel and therefore reduce cover available for fishes (Westveer et al., 2017). Another consequence is that large amounts of sediment are generated from agricultural landscapes due to the continuous working of the ground during planting or harvesting; this disturbs soils making them more susceptible to erosion. This can also increase amounts of fine sediments in stream channels (e.g., Jones et al., 1999), and it can change channel morphology which can alter water velocity in the channel (Gordon et al., 2008). According to a review by Cooper (1993), suspended sediment represents the greatest aquatic contaminant resulting from agriculture, even greater than nutrients. Because of the many negative effects that agriculture has had on aquatic habitats, abundances and distributions of many different groups of aquatic organisms have been affected by agriculture, including fishes (Walser and Bart, 2006).

Understanding and minimizing negative effects of agriculture on aquatic ecosystems is a critical research need. To decrease the impacts from agricultural land on streams, it is important to acknowledge that agriculture (and other landscape-scale stressors) operates over different spatial scales (including catchments and riparian zones) to affect the habitat conditions in streams (Allan and Johnson, 1997 and Zorn and Wiley, 2006). This approach has been explained by many researchers as a landscape approach (Hynes, 1975, Vannote et al., 1980, Frissel et al.,1986 and Allan, 2004), which establishes that physical and biological characteristics of streams are affected by the surrounding landscapes that they drain. Because of this, we can use ideas supported by the landscape approach to understand the mechanisms by which agricultural land may be impacting streams and draw insights from our findings to establish management strategies.

One strategy that has been widely implemented across the US as a mechanism to protect stream ecosystems from anthropogenic activities, including agriculture, is the establishment of forested buffers (Lowrance, 1998). Forested buffers include strips of trees or shrubs that have been either naturally established or planted along stream banks. They can hold soils in place, reduce sedimentation and nutrient loading, protect the shape of stream channels, moderate stream water temperature, and contribute organic matter to streams (Mander et al., 2005). Historically, establishing forested buffers along streams has commonly been recommended as a Best Management Practice (BMP) to mitigate effects of agricultural land use due to their capacity to reduce pollution and improve water quality (e.g., Karr and Scholosser 1977, Omernick et al., 1987, Richard et al., 1996 and Stauffer et al., 2011), however, less research has been done to document effects of buffers on physical stream fish habitat, especially in heavily agricultural watersheds, in part due to the many pathways by which agriculture may affect habitat (Maloney and Weller, 2011).

To help meet this need, the goal of this study is to evaluate the degree to which forested buffers influence effects of agriculture on physical fish habitat in streams in central Michigan. Streams chosen for this study include small tributaries draining landscapes with intensive agricultural land use in their catchments and with varying amounts of forest in buffers to best evaluate forested buffer influences. In support of this goal, our first objective is to identify a meaningful set of habitat variables and landscape factors to use in analysis. Habitat variables will be selected from different categories including measures of channel morphology, substrate, fish cover, large wood, and riparian vegetation to characterize multiple aspects of stream physical habitat, and landscape factors will include catchment agriculture and forest in buffers as well as other factors known to affect stream habitat. Our second objective is to test for differences in habitat variables across groups of sites with different amounts of forested buffers; this will allow us to evaluate whether or not the amount of forested buffers present is strongly associated with differences in fish habitat. Finally, our third objective is to predict each habitat variable from a set of landscape variables to better understand which landscape factors may be associated with fish habitat variables. Collectively, our results can help natural resources managers regarding management of streams in highly agricultural watersheds.

METHODS

Study region

The study region includes the Grand and Saginaw River basins located in Michigan's Lower Peninsula (Figure B.1.1). The Grand River basin drains an area of 14,432 km^2, and the Saginaw River basin drains an area of 19,606 km^2. Land use in both basins is dominated by agriculture. Major crops grown in the region include corn, soybeans, beets and grains, and livestock production is also common. Average precipitation in the Lower Peninsula of Michigan varies from less than 28 inches per year in the northeastern Lower Peninsula to up to 38 inches annually in the southwestern Lower Peninsula (Sommers, 1984), and precipitation received in both basins is relatively similar. The sites selected for this study are from the upper, contiguous portions of both basins to ensure broad similarity in surficial lithology and soils. Surficial lithology refers to materials such as silt, clay, sand, gravel, cobble, boulders, and/or bedrock near the earth's surface that were deposited through glacial or lacustrine processes (Farrand and Bell, 1982). The term soils refers to unconsolidated mineral or organic material on the immediate surface of the Earth that serves as a natural medium for the growth of land plants which are classified by their textures (e.g. clay loam, silty clay, loamy sand, etc., Soil Science Society of America, 2020). Multiple fish species are found in streams of these basins. Some of the most common include: White Sucker (*Catostomus commersonii*), Johnny Darter (*Etheostoma nigrum*), Creek Chub (*Semotilus atromaculatus*), Green Sunfish (*Lepomis cyanellus*), Eastern Blacknose Dace (*Rhinichthys atratulus*), Rock Bass (*Ambloplites rupestris*), Common Shiner (*Luxilus cornutus*), Central Mudminnow (*Umbra limi*) and Bluntnose Minnow (*Pimephales notatus*) (Crawford et al. 2016).

Spatial framework

We used the 1:100,000 scale National Hydrography Dataset Plus Version 1 (NHDPlusV1; USEPA and USGS, 2005) to characterize rivers in the study region. The finest spatial unit used for our analyses is the stream reach, which is defined as a section of stream from headwaters to confluences, confluences to confluences, and confluences to river mouths (Figure B.1.2, Wang et al. 2011). Individual reaches are drained by their associated local catchments which include the landscape that drains directly to stream reaches. Information from within local catchments can be aggregated for network catchments (Tsang et al. 2014), which represent the total upstream land area draining to stream reaches. We also developed local buffers that encompass the land area (90 m) on either side of a given stream reach to characterize riparian influences. Similar to local and network catchments, information from within all local buffers upstream of a given stream reach can be aggregated throughout the entire upstream river network to create a network buffer summary (Figure B.1.2).

Landscape data

We obtained land use/land cover information from the National Land Cover Database (2011). Categories included the amount of forest, urban, wetland, and agriculture, and these were summarized as percentages of local catchments and buffers; we then aggregated information to network catchments and buffers (Tsang et al. 2014). Catchment area was calculated by aggregating the area of local catchments provided in the NHDPlusV1. In addition, we also obtained data from the 1992 SPAtially Referenced Regressions On Watershed attributes (SPARROW) to characterize non-point source pollution from farms which included farm nitrogen yields and farm phosphorus yields at the network catchment scale. The percentage of ground water contribution to stream base flow was obtained from the US Geological Survey (USGS; Wolock 2003) and summarized at the network catchment scale. Mean annual precipitation (mm) and mean annual air temperature (ºC) data (1990-2010) were obtained from Parameter-elevation Relationships On Independent Slopes Model (PRISM) and summarized to local and network catchments. Also, we used the mean slope in the reach (m/m) from the NHDPlusV1 (Table A.1.1).

Site selection

GIS criteria

The Saginaw River and Grand River basins contain a total of 3,515 stream reaches as characterized from the NHDPlusV1. We used a geographic information system (GIS) to identify small stream reaches draining catchments less than 500 km^2 in area located in the upper portions of both basins to ensure similarity between sites from the two basins based on surficial lithology and climate (Figure B.1.2). Next, we excluded reaches that had less than 50% agriculture in their network catchments because we wanted to test for the effects of forested buffers on streams draining catchments with intensive agriculture. This process resulted in a total of 3,141 potential reaches that met our criteria. Potential reaches were then classified into 3 different categories which included low amounts of forested land use in network buffers (0 to 15% forested buffer), medium amounts of forested land in network buffers (15% to 30% forested buffer), and high amounts of forested land in network buffers (30% to 100% forested buffer). To maximize sampling efficiency, we selected stream sites within approximately a one-hour drive of Lansing, Michigan.

Field criteria

From the pool of potential stream reaches identified using the GIS criteria above, we first stratified them by forested buffer categories to ensure that we had at least 10 stream reaches in each category and then randomly selected 38 sites to visit in the field in spring 2017 to verify that they were suitable for sampling later in the summer. This resulted in visiting 14 in the low forested buffer category, 14 in the medium forested buffer category, and 10 in the high forested buffer category. We selected sites for sampling based on multiple factors. Stream sites had to have perennial flow, and they needed to be accessible (i.e., located near road crossings, parks or public land). This resulted in selecting a total of 30 stream reaches to collect data from, 16 reaches located in the Grand River basin and 14 in the Saginaw River basin (Figure B.1.1). At the end, 10 were in the low forested buffer category, 11 in the medium forested buffer category, and 9 in the high forested buffer category (Table A.1.2).

Field data collection

Within selected stream reaches, data were collected from a single sample reach 130 m in length using visual estimation methods as well as quantitative measures from June to September of 2017. The beginning of each study reach occurred at least 30 m away from any bridge crossing or access road to reduce potential habitat disturbances associated with physical structures. Data were collected in each of 7 categories of habitat variables (Table A.1.3). Measures of channel morphology, substrate, and fish cover were collected from 5 points equally spaced across 13 transects throughout a reach (10 m from each other), and riparian vegetation data were collected on each stream bank of the transect (left and right) following protocols described in Simonson et al. (1994), Wills et al. (2008), and Tingley (2010).Woody debris, additional substrate measurements, and visual habitat assessment metrics (MDEQ 2002) were collected from throughout the entire stream reach (Figure B.1.2).

Channel morphology

Bankfull and wetted widths were measured at each of 13 transects within each sample reach (Simmons et al. 1994; Figure B.1.2). Stream depth measurements were also taken at five points across each transect. We calculated the average, maximum, and minimum values for these factors and used them as variables for further analysis. We also evaluated the bank stability visually on each bank at all 13 transects following Simonson et al. (1994) and the Michigan Department of Environmental Quality Procedure 51 (MDEQ 2002). Bank stability classes used in this procedure include: 1- good (i.e., < 25% of stream bank is bare soil), 2-fair (i.e., 25-50% of streambank is bare soil), 3-poor (i.e., 50-75% of streambank is bare soil) and 4-very poor (i.e., > 75% of the streambank is bare soil). All measurements were averaged to calculate a single estimate of bank stability at each site.

Substrate

We quantified substrate in two different ways for this study. First, we conducted pebble counts throughout the length of the entire sample reach. This involved collecting a minimum of 100 pebbles from the thalweg throughout the sample reach and measuring the diameter (mm) of each pebble using a gravelometer. The different size categories measured in mm included: <2, 2 to 2.8, 2.8 to 4, 4 to 5.6, 5.6 to 8, 8 to 11, 11 to 16, 16 to 22.6, 22.6 to 32, 32 to 45, 45 to 64, 64 to 90, 90 to 128 and 128 to 180. These measurements were then summarized into one of four major categories: sand and fines (<2 mm), fine gravel (>2 to 5.6 mm), gravel (>5.6 to 16mm), and coarse gravel/cobble (>16 to 180 mm). The second way in which we measured substrate was to identify the dominant substrate visually at 5 points in each transect as either clay, detritus, silt, sand, fine gravel, coarse gravel, cobble, or boulder. We combined these substrate types into three major groups according to their size, and groups included fines (clay, detritus, sand and silt), gravel (coarse gravel and fine gravel), and cobble/boulder, which allowed us to calculate the total percentage of substrate types across all the of transects within a sample reach.

Fish cover

Fish cover types were visually determined at five points at each transect. Fish cover types include: undercut bank, log jam, stump, single log, brush pile, small brush pile/leaves, detritus, boulder, emergent macrophytes, submerged macrophytes, submerged macrophytes/roots, brush piles/roots, roots, filamentous algae, artificial structure, beaver dam, live tree, bedrock or no cover. A subset of these fish cover types were combined into three major categories: all wood (single log, brush pile, small brush pile/leaves, brush pile/root, roots and live tree), plants and algae (emergent vegetation, submerged vegetation and algae), and no cover. The percentages of each cover type were calculated and retained for further analysis.

Riparian vegetation

We visually evaluated the dominant riparian vegetation in an approximately 10 m long by 20 m wide area on both banks at every transect. Riparian vegetation categories included: cropland, pasture, grassland, shrubs, conifers, deciduous trees, swamp/wetland, yard/lawn, residential land, farmstead, recreational land, road, commercial land, exposed rock and barren land. A subset of the previously mentioned riparian vegetation categories were combined into agriculture (cropland, farmstead and pastureland), natural vegetation (grassland, shrubs, conifers, deciduous trees and swamp/wetland), urban (yard, residential land, recreational land, road, commercial land) and exposed rock. The results were combined from both riparian zones for each transect and summarized as the percentage of each riparian category across the entire sample site.

Large wood

Two types of woody debris were assessed in this study, single logs and collections of wood. For single logs, we counted the total number of 6 ft lengths in 6 in diameter classes (e.g. 6”, 12”, 18” and 24”; Simonson et al. 1994, Wills et al. 2008, and Tingley, 2010). The areas of individual collections of wood were measured (ft^2) and classified as either natural log jam, beaver dam, or brush deposit. We used the total area of all woody structures (ft^2) and the total count of all the 6’ lengths wood as variables in further analysis.

Michigan Department of Environmental Quality (MDEQ) Procedure 51

The Michigan Department of Environmental Quality (MDEQ) Procedure 51 (MDEQ 2002) protocol determines stream condition and habitat quality is based on visual scores for a variety of physical characteristics. We used to visually estimate the following characteristics: epifaunal substrate/available cover, pool substrate characterization, pool variability, sediment deposition, channel flow status- maintained flow and flashiness, channel alteration, channel sinuosity, bank stability, vegetative protection and riparian vegetative zone width (Table A.1.18). Each of the metrics had an assigned score that was combined into a total score for the reach describing habitat quality in four categories: excellent >154, good 105-154, marginal 56-104 and poor <56.

Data preparation

We first investigated the distributional properties of all landscape and habitat variables including the mean, maximum, and minimum values to identify variables that did not range substantially across our study sites, and we removed them from further analyses. All landscape variables were transformed to achieve linearity for further analyses, except for visual habitat assessment metrics. We then used SPSS Version 24 to evaluate the distributions of the habitat variables by investigating P-P plots. If a variable did not follow a linear distribution, it was transformed to achieve linearity for further analysis. Visual habitat assessment metrics did not require transformation, but other variables used in analysis did. Percentage variables were transformed using arcsine square root, count variables were transformed using square root, and continuous variables were transformed using natural log (following Ross, 2013).

Variable selection

Habitat variables

To reduce redundancy in variables selected for analysis, we ran a Pearson's correlation on variables within each of the 7 variable groupings (Table A.1.4). When a pair of variables was highly correlated within categories (absolute value of correlation coefficient > 0.6), only one variable was kept based on ecological interpretability.

Landscape variables

We ran a Pearson's correlation analysis on variables summarized within the same spatial scale. These included local buffer, local catchment, network buffer, and network catchment, but we included slope (a reach scale variable) in the network catchment correlation analysis because we had the most variables summarized at this spatial extent. Similar to the approach taken for the habitat variables, if a pair of landscape variables was highly correlated (absolute value of correlation coefficient > 0.5), only one variable was kept based on its ecological interpretability and relevance to our study.

Testing for differences in groups

Analysis of variance (ANOVA) and post hoc tests

Selected habitat variables were next evaluated by ANOVA to test for differences in means across groups of sites within each of the low, medium, and high forested buffer categories. We also tested for homogeneity of variance to determine the most appropriate post-hoc test to use to identify individual differences in groups. The Bonferroni post hoc test was used for variables identified as having equal variances, while the Games-Howell post hoc test was used for those with unequal variances.

Predicting fish habitat variables from landscape variables

We used stepwise multiple linear regression to evaluate which of our selected landscape variables were related to each of the fish habitat variables. One of the objectives for this step was to evaluate the association between forested buffers and fish habitat, with our assumption being that when forested buffers were influential to a fish habitat variable, forested buffers would be identified as a significant predictor (Table A.1.17). We used SPSS Version 24 to run the forward stepwise multiple linear regression; F statistic ($P = 0.1$) was used as the model entry criterion and F statistic ($P = 0.15$) as a removal criterion. The models for each of the habitat variables were evaluated by first considering overall model significance ($p<0.01$), next by considering the amount of variance explained in each habitat factor (based on the adjusted R^2 value), and finally by considering the contributions of individual landscape variables on habitat using the standard Beta and its significance ($p<0.10$). If two landscape variables were present for any of the habitat categories, the standard beta allowed us to recognize the direction and strength of each variable within a particular model.

RESULTS

Habitat variable selection

Habitat variables ranged substantially across sample reaches (Table A.1.2). For channel morphology, wetted average width ranged from 4.78 ft to 41.92 ft, and average depth ranged from 0.13 ft to 1.50 ft. Fines were typically the dominant substrate type with an average of 56.98% and 69.54% characterized throughout the reach and within transects, respectively. All wood (e.g., single log, brush pile, small brush pile/leaves, brush pile/roots, roots, live tree), plants and algae (e.g., emergent macrophytes, submerged macrophytes, filamentous algae) and no cover were the most common types of fish cover in our study sites. The area of woody structures in our study sites ranged from 0 to 1172 ft^2 and averaged 166.58 ft^2. The riparian vegetation was primarily natural vegetation (grassland, shrubs, deciduous forest), and it ranged from 92.31% to 100%. Based on the visual assessment metrics, sediment deposition had an average of 7.00 out of 20, channel alteration an average of 12.97 out of 20 and bank stability an average of 4.12 out of 10. Many of the visual habitat metrics indicated that streams were generally in good quality, ranging from 36 points to 142 points in the total score.

From our initial list of 83 habitat variables, we chose 16 based on their interrelationships and their ecological interpretability and that fell into each of our 7 categories. Table A.1.5 shows correlations among channel morphology variables. We chose two variables in this category, average depth and wetted average width. We selected these variables over maximum and minimum values and over bankfull values because they represent conditions more typically experienced in the stream channels of our study sites. For fish cover (Table A.1.6), we chose plants and algae and all wood because they better represented fish habitat than the variable no cover. Table A.1.7 shows correlations for large wood, and we selected area of woody structures and total count of all 6 ft lengths. Correlations for riparian vegetation are presented in Table A.1.8, and we chose grassland and shrubs because they were the two most common types of riparian vegetation that we encountered on study sites. For the visual assessment metrics (Table A.1.9), we chose epifaunal substrate/available cover, sediment deposition, channel alteration and bank stability because these factors that are likely to be positively affected by forested buffers (Sweeney, 2014). We chose fines and gravel substrate in the transect (Table A.1.10), because fines were highly correlated to cobble/boulder and because natural vegetation on the riparian zone may have a positive effect on the amounts of coarse vs. fine substrate (Lyons et. al. 2000). For this same reason, we also chose fines and fine gravels in the reach (Table A.1.11).

Landscape variable selection

Across our study sites, some of the landscape factors varied substantially while others varied less (Table A.1.3). Network catchment area ranged from 10.30 km² to 234.46 km² across the entire region. Agriculture in the network catchment ranged from 50.84% to 89.20% and averaged 66.14%, indicating intensive agriculture across our study sites. The forest present in the network buffer varied from 2.18% to 70.38 % and averaged 21.79%, while wetlands in the network buffer also varied widely across the study sites, averaging 17.23% and ranging from 1.80% to 50%. Stream reach slope ranged from 0.00015 m/m to 0.00946 m/m and averaged 0.00196 m/m, indicating that slope did not vary substantially across our study sites. Climate across study sites also ranged very little (average annual air temperature in local catchments ranged from 8.33 to 8.82 ºC, while average annual precipitation ranged from 798.67 mm to 924.75 mm, which supports the similarity in climate between study sites from each basin.

We investigated relationships between natural and anthropogenic landscape variables summarized within spatial units based on Pearson's correlations. Table A.1.12 shows correlations among variables summarized within local buffers, Table A.1.13 shows correlations among variables summarized within network buffers, Table A.1.14 shows correlations among variables summarized within local catchments, and Table A.1.15 shows correlations among variables summarized within network catchments. While the investigation of correlations among landscape factors helped us understand patterns in our data, our selection of 8 landscape factors was driven by ecological reasoning (Table A.1.16). Catchment area, slope and groundwater at the network catchment spatial unit were selected because they are known to be important to fish habitat in Michigan streams (Infante et. al., 2006 and Baker et al., 2003). Network catchment agriculture, farm N yield, and farm P yield at the network catchment spatial unit are key to our study goal because we were evaluating study sites with intensive agricultural land use in their catchments, and network buffer forest was chosen because we wish to test effects of this landscape feature on streams fish habitat in heavily agricultural catchments. In addition, we selected wetlands in the buffer as an important natural ecosystem with the ability to reduce nitrogen and phosphorus coming from agricultural land (Woltemade, 2000). Both landscape variables, forested buffers and wetlands in the buffers, can help us to identify their value and benefits for fish habitat when present on heavily agricultural watersheds.

Testing for differences in groups

We tested for differences in each of our habitat variables across groups of sites with low, medium, and high amounts of forest in their buffers using ANOVA. We used the Bonferroni post hoc test to look for differences in site groups based on average depth, area of woody structures, total count of all 6' lengths, gravel in the transect, fine gravel in the reach, and fines through the reach. We used the Games- Howell post hoc test to test for differences in groups based on wetted average width, fish cover (all wood and plants and algae), riparian vegetation (grassland and shrubs), average bank stability, epifaunal substrate/available cover, sediment deposition, and channel alteration and fines through the transect.

Five variables were significantly different across groups of sites with different amounts of forest in their buffers. First, average depth was significantly lower in sites with high amounts of forest in their buffers than in sites with low amounts of forest in buffers (Figure B.1.3). Second, the amount of gravel in the transect was greater at sites with medium amounts of forest in their buffer than sites with low amounts of forest in buffers; gravel at sites with high amounts of forest in their buffers did not differ from low or medium categories (Figure B.1.4). Also, we observed more fines in the transect at sites with low amounts of forest in buffers (Figure B.1.5), and the same trend was observed for fines and fine gravel in the reach (Figure B.1.6 and Figure B.1.7), which was expected. Additionally, large wood (total count of 6' lengths) was significantly different in sites with different amounts of forested buffers, however, it increased with less forest, which was the opposite trend of what we were expecting (Figure B.1.8).

Three variables were not significantly different across groups, yet trends in the data suggested outcomes that matched our expectations. Wetted average width was not significantly different between groups of sites with differing levels of forested buffers. However, it did appear to be lowest on average in sites with the highest amount of forest in their buffers, and the lack of significance may have been due to the presence of two outliers (Figure B.1.9). Similarly, the fish cover variable characterizing plants and algae was lowest for sites with the highest amount of forest in their buffers (Figure B.1.10), and grassland in the immediate riparian zone decreased slightly with more forested buffers (Figure B.1.11).

Seven variables were not significantly different across groups of sites with differences in forested buffers, and trends could not be detected. These included all wood (fish cover) (Figure B.1.12), area of wood structures (Figure B.1.13), shrubs (riparian vegetation) (Figure B.1.14), bank stability (Figure B.1.15), epifaunal substrate/available cover (Figure B.1.16), sediment deposition (Figure B.1.17) and channel alteration (Figure B.1.18).

Predicting fish habitat from landscape

Stepwise multilinear regression was performed to predict habitat variables from landscape factors. Ten out of 16 habitat variables were significantly predicted: wetted average width, average depth, all wood, area of woody structures, total count of 6 ft lengths, grassland in the riparian zone, bank stability, sediment deposition, fines in the transect and fines in the reach (Table A.1.17), and the remaining six habitat variables were not significantly predicted. Network catchment area was a significant predictor of wetted average width and average depth; with larger catchment areas, widths were greater, and depths were deeper at our study sites. Network catchment area was better explained by the average depth with an adjusted R^2 value of 0.23 versus 0.16 from the wetted average width.

Another important predictor was groundwater, increasing levels of groundwater were associated with an increase in 6 ft logs in the stream, a decrease of grassland in the riparian zone, and less bank stability, but the reasons for the associations between groundwater and these habitat variables are unclear. One outcome that did match our expectations was the influence of catchment agriculture on fines in the transect and fines in the reach; with more catchment agriculture, fines increased (and fines in the reach were the best predicted habitat variable with an adjusted R2 of 0.33). Forest in the network buffer was also negatively associated with the presence of fines in the reach. Finally, wetlands in the network buffer was the most common predictor of the habitat variables. It was associated with a higher presence of grassland in the riparian zone, less wood for fish cover, fewer logs in the stream, and less amount of sediments.

DISCUSSION

Overview

Our study documented effects of forested buffers on multiple features of fish habitat in streams draining heavily agricultural landscapes in central Michigan, U.S.A. This study is important because compared to studies documenting effects of agricultural land on stream nutrient levels, far fewer studies have been conducted that describe effects of forested buffers on physical fish habitat in streams draining heavily agricultural land. Based on results of our ANOVA, we saw that stream depth decreased with more forest in buffers, and that the amount of fine sediments comprising stream beds was greater with less forest in buffers. The relationship between fine sediments and forested buffers in our study region was also supported by regression analysis; with more forest in buffers, we saw a significant decrease in the amount of fine sediment comprising stream beds. Besides the influences of forest in buffers and because of our analytical approach, we also detected the influence of wetlands in buffers on multiple measures of fish habitat in our study region. Wetlands in buffers were associated with increased levels of riparian vegetation and decreases in fish cover and large wood in the stream channel. Wetlands were also associated with decreased sediment deposition within stream channels (characterized by a visual habitat assessment metric), reflecting the ability of riparian wetlands to reduce sediment input in heavily agricultural landscapes. Collectively, our results show the importance of two types of natural landcovers, both forest and wetlands in buffers, on aspects of physical fish habitat in streams draining heavily agricultural landscapes. These findings have important implications to balance sustainable agriculture with conservation efforts of stream ecosystems in central Michigan.

Forested buffer effects on stream fish habitat

Our study showed that forest in buffers was associated with two channel morphology variables. First, the average depth of streams decreased with more forest in buffers. The reason we may have detected this trend is because during high stream flow events, forested buffers may minimize erosion of stream channels because of the presence of undisturbed native plant cover and roots (Zaimes et al., 2004). Another reason for this result may be because forested buffers are known to be effective for reducing and capturing surface runoff (Osborne and Kovacic, 1993), ultimately reducing the magnitude of high flows that would enter stream channels. Second, we saw that wetted width of stream channels decreased with increasing amounts of forested buffers. This may also be explained by the effectiveness of native plant cover and roots for preventing erosion (Zaimes et al., 2004). In support of the importance of forested buffers for preventing changes in channel morphology, Krzeminska et al. (2019) documented the stability of stream banks covered with trees in Norway, emphasizing that they are more stable than banks covered with grass and shrubs and that they provide streams with greater ability to resist erosion.

Through our regression analysis, we also found that both measures of channel morphology were affected by network catchment area. Both average wetted width and depth increased as catchment area increased. Larger catchment areas drain more water from the landscape; because of this, channel dimensions are larger to carry higher flows (Brooks et al. 2003).

Our study also showed that fine sediments increased with less forest in buffers, and we detected this outcome through results of ANOVA and regression analyses. Forested buffers have the capacity for trapping sediments and reducing their input to stream channels by slowing runoff and allowing sediment to settle out before it would reach the stream channel (Allan and Castillo 2007). These results are similar to other studies that documented the important role of forested buffer on preventing sedimentation in stream channels (Omernick et al., 1981 and Horwitz et al., 2008).

Through our study, we expected to see an increase of woody debris and wood structures in stream channels with higher amounts of forested buffers because of the potential for more trees, yet that was not the case based on our results. One reason could be due to the fact that trees may have been removed from riparian zones. This might have occurred to prevent trees from falling into stream channels and impeding stream flows. A second reason may be due to breakdown rates in heavily agricultural streams. In a study of Appalachian streams, McTammany et al. (2006) showed that elevated nutrients and temperatures occur in agricultural streams, which promotes higher microbial activity on wood resulting in faster breakdown rates, potentially explaining less wood in the channel with higher amounts of agriculture. Additionally, Ross et al. (2019) emphasized that recruitment of woody debris into stream channels is more common as riparian trees age. We did not have the capacity to evaluate the age of the forest cover occurring within our riparian zones, and it follows that trees in the riparian zones of some of our study streams may be relatively young. This is because historically, in many areas of Michigan, forested buffers were not common or present on agricultural lands or were cut for timber. Currently, however, farmers may be more aware of the benefits of forested buffers and more willing to implement them by taking advantage of the financial assistance provided by local, state, or federal agencies to help with implementation costs. For example, Natural Resources Conservation Service (NRCS) manage various Farm Bill Programs that provide financial and technical assistance to help landowners with the implementation of forested buffers and many other conservation practices.

Agriculture effects on stream fish habitat

Agriculture can affect the composition or type of substrate in streams by increasing sediments entering streams from adjacent fields. As part of our study, we observed two trends that we expected to detect. Results showed that fine sediments increased with increasing amounts of agricultural land in network catchments, while gravel increased with increasing amounts of forested buffers. In a study of Wisconsin streams, Wang et al. (1997) found that when more than 50% of stream catchments were devoted to agriculture, an increase in fine substrate was observed along with a decrease in other measures of habitat quality including measures of channel morphology, fish cover, bank conditions and riparian vegetation. However, Wang et al. (1997) did not evaluate how the presence of forested buffers in the riparian zone may have potentially affected their findings. Building on Wang et al. (1997), we studied streams draining catchments with more than 50% agricultural land and accounted for the presence of forested buffers to evaluate their effects on stream fish habitat variables. As part of our study we observed positive effects of having a buffer on those streams draining agricultural land.

Wetland buffer effects on stream fish habitat

As part of our analytical approach, we tested influences of multiple landscape factors on measures of stream habitat, and we found that wetlands in the network buffer had a significant negative effect on sediment deposition (as measured by a visual habitat assessment metric). According to a review by Johnston (1991), wetlands have the ability to trap sediments and nutrients. These abilities will benefit waters draining landscapes with wetlands by reducing turbidity and suspended solids and by retaining phosphorus and other contaminants. This review also recognized that the location of wetlands within catchments is key to their effectiveness for trapping sediments, and it stands to reason that wetlands in close proximity to stream channels may prevent sediments from entering stream channels more effectively than wetlands located far from streams. Gleason and Euliss (1998) provided an overview that describes that wetlands in the buffer near agricultural landscapes can actually be filled with sediments at a higher rate than wetlands in grassland landscapes; this highlights the role of wetlands in filtering sediments.

In addition, we observed significant associations between wetlands in buffers and other habitat variables with our regression analyses. First, wetlands were positively associated with grassland; and we interpreted this outcome as indicating that this type of vegetation is common in the wetlands in our study region. Second, wetlands in buffers are negatively associated with large wood, which can be the result of the absence of trees. Finally, fish cover was also negatively associated with wetlands, and it could be due to the fact that this habitat variable depends in part on trees. These results should not be interpreted as suggesting that wetlands do not have positive effects on fish habitat. Type of wetland and their locations will affect the benefits they provide (Blackwell and Pilgrim, 2011).

Advantages of conducting a study with the landscape approach

The landscape approach describes the understanding of broad scale influences on stream systems, establishing that physical and biological characteristics of streams are affected by the surrounding landscapes that they drain (Allan 2004). Our study helps to better describe interactions between landscapes and stream habitats to better address negative impacts of human land uses, in this case agriculture, on streams (Frissell et al., 1986; Allan, 2004). Recognizing the interactions between agricultural land and streams and the role that forested buffers play throughout catchments will allow us to identify streams that have sufficient amounts of forested buffers to promote good fish habitat and streams that have limited amount of forested buffers that could be targeted for conservation actions. Mapping these results will provide managers with insights for valuable locations or priority areas to work (Ortiz, this volume). The identified areas can help to minimize the impacts to fish habitat when taking in consideration features and location of forested buffers. For example, streams draining heavily agricultural landscapes across the state of Michigan could be identified, and the amount of forested buffers present on those heavy agricultural streams can be evaluated for protection or restoration opportunities at the network catchment scale.

Study limitations

We acknowledge possible limitations to this study. The first is the lack of information related to how forested buffers were established. For example, we do not know when forested buffers were established naturally or through the implementation of a conservation practice. This could affect the degree to which different types of forested buffers may be influencing fish habitat by providing cover all year long (e.g. conifers vs hardwoods). Second, we do not know the age of the forested buffers evaluated; older forests may have a strong capability to slow runoff or keep soils in place due to the mature roots. A third limitation may be due to the fact that we combined pastureland and crop land from the National Landscape Database (NLCD, 2011) and designated both cover types as agriculture land use. These two cover types might have different effects on fish habitat. Pastureland offers cover year around, which can help with the reduction of runoff and sedimentation, versus cropland where soil is disturbed once or multiple times a year, exposing the soil and removing the cover. A fourth limitation is that we only had the capacity to collect data from two basins in Michigan (Grand and Saginaw). We would suggest that future studies include samples from other heavily agricultural basins in

Michigan such as Kalamazoo and St. Joseph to capture additional information from other areas and include the majority of the agricultural land in the state. Depending on findings, this could lend additional support to the role of forested buffers in protecting fish habitat.

Value of conservation practices and management

There is a need to implement activities that can minimize agriculture's negative effects on aquatic ecosystems (Tilman, 1999). Best management practices (BMPs), also known as conservation practices, are defined as actions that could be implemented to protect water quality, promote soil health, and address other environmental concerns that result from human activities on the landscape, including agricultural land use (Yates et al., 2007). BMPs have been recommended for decades to control and mitigate pollution from diverse sources (Lam et al., 2011), and multiple BMPs have been developed to protect both terrestrial and aquatic ecosystems from degradation or pollution resulting from agricultural land use. Maintaining fish habitat should represent a priority for conserving and promoting healthy fish populations for many stakeholders because freshwater fish are recognized as one of the most threatened groups of vertebrates globally (Pryor et al. 2014, Paukert et al. 2017). Based on our study, the implementation or preservation of forested buffers on heavily agricultural basins is a powerful conservation method to improve or maintain several fish habitat variables. In order to encourage adoption of conservation practices, it is important to focus on increasing awareness of the financial and environmental benefits coming from any conservation practice. Also, scientists need to recognize that additional studies are needed to clearly understand the right tools and information that will help to motivate changes in behavior and management to influence the implementation of conservation practices (Reimer et al., 2012). In addition, other studies have documented that streams with wooded riparian zones had higher index of biological integrity

(IBI) scores, species richness, diversity, and percentages of benthic insectivores and herbivores than streams with open riparian zones (Stauffer et al., 2000). Plus, Roth et al. (1996) demonstrated that the vegetated riparian zones through the entire watershed (equivalent to our network buffers) were more important for fish communities than just vegetated local segments of riparian zones. This can support the need of preserving or implementing forested buffers to promote a diverse and healthy fish community (Omerick et al., 1981). Future studies can use the information obtained from our study to identify opportunities to apply conservation efforts to promote fish habitat with the implementation of forested buffers in heavy agricultural catchments, especially in areas were channel erosion or deposition of fine sediments are a key concerns.

APPENDICES

APPENDIX A: TABLES

Table A.1.1. Natural and anthropogenic landscape variables summarized in local and network catchments and buffers at the Grand and Saginaw River watershed, Michigan. Variables selected for analysis are noted by (*).

Spatial unit	Code	Variable	Mean	Max	Min
Local buffer					
	lburban	Urban (%)	8.70	75.79	2.33
	lbforest	Forest (%)	25.16	70.38	0.26
	lbwetland	Wetland (%)	21.25	72.62	0.00
	lbpasture	Pasture (%)	15.07	31.82	0.00
	lbcrop	Crop (%)	27.77	91.27	0.00
	lbag	Agriculture (pasture and crop combined, %)	41.41	92.38	0.00
Network buffer					
	nburban	Urban (%)	6.63	22.83	2.34
	nbforest	Forest (%)*	21.79	70.38	2.18
	nbwetland	Wetland (%)*	17.23	50.96	1.80
	nbpasture	Pasture (%)	15.85	32.71	2.20
	nbcrop	Crop (%)	37.02	81.84	7.17
	nbag	Agriculture (pasture and crop combined, %)	52.87	90.62	16.77
Local catchment					
	lcurban	Urban (%)	8.14	41.80	2.96
	lcforest	Forest (%)	20.53	55.47	1.78
	lcwetland	Wetland (%)	11.21	42.79	0.00
	lcpasture	Pasture (%)	18.99	39.29	0.81
	lccrop	Crop (%)	39.39	88.92	0.00
	lcag	Agriculture (pasture and crop combined, %)	58.39	91.15	4.10
	lctemp	Annual average temperature (ºC)	8.64	8.82	8.33
	lcprecip	Annual average precipitation (mm)	839.55	924.75	798.67
	lcelevmax	Max elevation (m)	237.24	277.26	178.49

Table A.1.1. (Cont'd)

Spatial unit	Code	Variable	Mean	Max	Min
Network catchment					
	ncurban	Urban (%)	7.77	25.17	4.90
	ncforest	Forest (%)	14.68	26.33	2.48
	ncwetland	Wetland (%)	9.96	20.34	1.20
	ncpasture	Pasture (%)	19.67	32.79	4.73
	nccrop	Crop (%)	46.47	72.80	24.70
	Ncag	Agriculture (pasture and crop combined, %)*	66.14	89.20	50.84
	nctemp	Annual average temperature (°C)	8.65	8.80	8.44
	ncprecip	Annual average precipitation (mm)	839.71	924.75	800.33
	farmnyield	Nitrogen yield (commercial, manure and biosolids. kg/km^2/yr)*	3494.18	6649.22	1993.80
	farmpyield	Phosphorus yield (commercial, manure & biosolids. kg/km^2/yr)*	535.37	1018.78	305.48
	uNyield	Nitrogen yield (commercial, kg/km^2/yr)	5943.33	9995.90	2367.01
	uPyield	Phosphorus yield (commercial, kg/km^2/yr)	859.97	1456.21	341.69
	gwindex	Ground water contribution to baseflow (%)*	51.57	64.00	38.90
	Areasqkmc	Catchment area (km^2)*	41.55	234.46	10.30
Reach					
	slope	Stream reach slope (m/m)*	0.00196	0.00946	0.00015

Table A.1.2. List of the selected study sites including relative amount of forested land in network buffers, site code, reach code (COMID), and location (Grand=G, Saginaw=S).

Amount of forest in network buffer	Site code	COMID	County/road/other
Low			
	1G	12143940	Eaton/Canfield Road
	2G	12241570	Shiawassee/Shaftsburg Road
	3G	12242024	Ingham/Brown Road/east of field
	4G	12242064	Ingham/Kipp Road/ west of college
	5G	12242542	Ingham/Denis Road/Williamston
	1S	13016037	Shiawassee/Cronk Road
	2S	13017403	Shiawassee/Geeck Road
	3S	13027059	Midland/Smith Crossing
	4S	13032297	Livingston/Gannon Road
	5S	13028375	Saginaw/Hemlock Road
Medium			
	6S	13038956	Midland/Stewart Road/Cross street Primg Dr.
	7S	13030921	Shiawassee/Prior Road
	8S	13028587	Saginaw/Steel Road
	9S	13015357	Saginaw/Chesaning Road
	10S	13028045	Saginaw/Thomas Road/near golf course
	6G	12242060	Ingham/Frost Road/east of M-52
	7G	12242002	Ingham/Howell Road/Mud Creek
	8G	12241988	Ingham/Harper Road/west of Aurelius
	9G	12241926	Ingham/Holt Road/ west of Williamston Road
	10G	12144072	Eaton/Johnson Road
	11G	12143906	Eaton/Kinsel Highway
High			
	11S	13031007	Shiawassee/Pierce Road
	12S	13028121	Saginaw/Fordney Road
	13S	13027937	Saginaw/Steel Road
	14S	13016625	Saginaw/East Road
	12G	12241992	Eaton/Ransom Highway/under the highway
	13G	12241924	Eaton/Canal Road/by Diamondale
	14G	9007603	Ionia/Sayles Road
	15G	9007597	Ionia/Riverside Drive
	16G	9004271	Ionia /4 Mile Road

Table A.1.3. Habitat variables by group collected from the study sites including mean, maximum (max), and minimum (min) values from the Grand and Saginaw River watersheds, Michigan. Variables selected for analysis are noted by (*).

Category	Variable	Mean	Max	Min
Channel morphology				
	Bankfull average width (ft)	17.17	52.39	6.92
	Bankfull max width (ft)	22.51	65.70	11.20
	Bankfull min width (ft)	12.96	44.60	4.30
	Average depth (ft)*	0.65	1.50	0.13
	Depth max (ft)	1.56	2.94	0.30
	Depth min (ft)	0.14	0.56	0.02
	Wetted average width (ft)*	12.70	41.92	4.78
	Wetted max width (ft)	17.56	52.10	6.30
	Wetted min width (ft)	9.26	38.00	2.70
	Average bank stability[1]	2.89	4.00	1.08
	Max bank stability[1]	3.80	4.00	2.00
	Min bank stability[1]	1.77	4.00	1.00
Substrate (% of substrate in categories from pebble counts through the reach)				
	Fines (<2 mm in diameter)*	56.98	100.00	4.27
	Fine gravel (2 to 5.6 mm in diameter)*	9.25	49.08	0.00
	Gravel (5.6 to 16 mm in diameter)	14.83	41.00	0.00
	Coarse gravel and cobble (16 to 180 mm in diameter)	12.04	59.44	0.00
Substrate (% of transect locations with substrate types)				
	Fines*	69.54	100.00	15.38
	Gravel*	13.92	38.81	0.00
	Cobble/boulder	16.50	78.46	0.00
	Hard pan	0.05	1.47	0.00
	Bedrock	0.00	0.00	0.00

Table A.1.3. (Cont'd)

Category	Variable	Mean	Max	Min
Fish cover (% of locations in transects with cover types)				
	No cover	77.37	100.00	13.85
	All wood (includes single log, brush pile, small brush pile/leaves, brush pile/roots, roots, live tree)*	8.84	64.62	0.00
	Single log	0.67	15.38	0.00
	Brush pile	0.41	6.15	0.00
	Small brush pile/leaves	5.27	49.23	0.00
	Brush pile/roots	0.05	1.49	0.00
	Roots	1.84	13.85	0.00
	Live tree	0.61	10.61	0.00
	Plants and algae (includes emergent macrophytes, submerged macrophytes, filamentous algae)*	13.33	86.15	0.00
	Emergent macrophytes	1.08	13.85	0.00
	Submerged macrophytes	10.20	86.15	0.00
	Submerged macrophytes/roots	0.05	1.54	0.00
	Filamentous algae	2.05	52.31	0.00
	Undercut banks	0.00	0.00	0.00
	Log jam	0.00	0.00	0.00
	Stump	0.05	1.54	0.00
	Detritus	0.41	6.15	0.00
	Boulders	0.00	0.00	0.00
	Artificial structure	0.00	0.00	0.00

Table A.1.3. (Cont'd)

Category	Variable	Mean	Max	Min
	Beaver dam	0.00	0.00	0.00
	Bedrock	0.00	0.00	0.00
Large wood				
	Area of woody structures (ft^2)*	166.58	1172.00	0.00
	Total count of all 6' lengths*	5.63	36.00	0.00
	Total count of 6' lengths >6" in diameter	3.37	15.00	0.00
	Total count of 6' lengths >12" in diameter	1.57	19.00	0.00
	Total count of 6' lengths >18" in diameter	0.53	10.00	0.00
	Total count of 6' lengths >24" in diameter	0.17	5.00	0.00
Riparian vegetation (% across both banks in each transect)				
	Barren	0.32	6.25	0.00
	Deciduous forest	22.63	100.00	0.00
	Grassland*	46.74	100.00	0.00
	Shrubs*	30.06	88.46	0.00
	Natural Vegetation (grassland, shrubs, deciduous forest)	99.43	100.01	92.31
	Agriculture (cropland, farmstead and pasture)	0.00	0.00	0.00
	Cropland	0.00	0.00	0.00
	Farmstead	0.00	0.00	0.00
	Pasture	0.00	0.00	0.00
	Urban (recreational, road, residential, yard, commercial, expose rock)	0.26	7.69	0.00
	Recreational	0.00	0.00	0.00
	Road	0.00	0.00	0.00
	Residential	0.00	0.00	0.00
	Yard	0.26	7.69	0.00
	Commercial	0.00	0.00	0.00
	Exposed Rock	0.00	0.00	0.00

Table A.1.3. (Cont'd)

Category	Variable	Mean	Max	Min
Visual habitat assessment metrics				
	Epifaunal substrate/available cover[2]*	8.80	19.00	1.00
	Pool substrate characterization[2]	9.03	19.00	0.00
	Pool variability[2]	1.03	9.00	0.00
	Sediment deposition[2]*	7.00	19.00	0.00
	Maintained flow volume[3]	6.10	10.00	0.00
	Flashiness[3]	5.13	10.00	1.00
	Channel alteration[2]*	12.97	19.00	7.00
	Channel sinuosity[2]	6.30	17.00	1.00
	Bank stability (average for left and right bank)[3]*	4.12	10.00	1.00
	Bank stability (left)[3]	4.20	10.00	1.00
	Bank stability (right)[3]	4.03	10.00	1.00
	Vegetative protection (average for left and right bank)[3]	4.50	9.00	1.50
	Vegetative protection (left)	4.53	9.00	1.00
	Vegetative protection (right)	4.57	9.00	2.00
	Riparian vegetative zone width (average for left and right bank)[3]	6.30	9.00	2.00
	Riparian vegetative zone width (left)[3]	6.20	9.00	1.00
	Riparian vegetative zone width (right)[3]	6.40	9.00	3.00
	Total score	86.33	142.00	36.00

[1] For bank stability, 1 is low stability and 4 is high stability.
[2] 1 is poor quality and 20 is excellent quality.
[3] 1 is poor quality and 10 is excellent quality.

Table A.1.4. Summary of one-way analysis of variance (ANOVA) results comparing habitat variables across different forested buffer groupings. Significant differences across groups are noted by p. < 0.05.

Habitat category	Variable	Sum of Squares	df	Mean Square	F	Sig.
Channel morphology						
	Wetted average width	1.10	2.00	0.55	2.28	0.12
	Average depth	2.98	2.00	1.49	7.15	< 0.01
Fish cover						
	All wood	0.03	2.00	0.02	4.22	0.03
	Plants and algae	0.01	2.00	0.00	0.28	0.76
Large wood						
	Area of woody structures	500.70	2.00	250.35	3.52	0.04
	Total count of all 6' lengths	16.35	2.00	8.18	3.58	0.04
Riparian vegetation						
	Grassland	0.06	2.00	0.03	0.89	0.42
	Shrubs	0.03	2.00	0.01	0.60	0.56
Visual habitat assessment metrics						
	Epifaunal substrate/available cover	67.86	2.00	33.93	1.18	0.32
	Sediment deposition	61.74	2.00	30.87	0.98	0.39
	Channel alteration	9.75	2.00	4.88	0.47	0.63
	Bank stability (average for left and right bank)	0.80	2.00	0.40	1.34	0.28
Substrate (% of transect locations with substrate types)						
	Fines	25.96	2.00	12.98	4.73	0.02
	Gravel	34.77	2.00	17.38	6.51	0.01
Substrate (% of substrate in categories from pebble counts through the reach)						
	Fines	53.08	2.00	26.54	7.72	0.00
	Fine gravel	23.24	2.00	11.62	3.87	0.03

Table A.1.5. Pearson's correlations for all channel morphology variables. Bold correlation coefficient indicates significance at a 0.05 level or less. Variable codes are as follows: wetted average width (WAW), wetted maximum width (WMXW), wetted minimum width (WMNW), average bankfull width (ABW), bankfull maximum width (BMXW), bankfull minimum width (BMNW), average depth (AD), depth maximum (DMX) and depth minimum (DMN).

	WAW	WMXW	WMNW	ABW	BMXW	BMNW	AD	DMX	DMN
WAW	1.00								
WMXW	0.87	1.00							
WMNW	0.97	0.78	1.00						
ABW	0.86	0.94	0.79	1.00					
BMXW	0.78	0.92	0.70	0.96	1.00				
BMNW	0.89	0.82	0.87	0.91	0.81	1.00			
AD	0.68	0.33	0.74	0.32	0.24	0.48	1.00		
DMX	0.54	0.32	0.55	0.27	0.21	**0.44**	0.81	1.00	
DMN	**0.46**	0.11	0.54	0.17	0.06	0.29	0.72	**0.38**	1.00

Table A.1.6. Pearson's correlations between fish cover variables. Bold correlation coefficient indicates significance at a 0.05 level or less.

	Plants and algae	No cover	All wood
Plants and algae	1.00		
No cover	**-0.83**	1.00	
All wood	-0.15	**-0.42**	1.00

Table A.1.7. Pearson's correlations between large wood variables.

	Area of woody structures	Total count of all 6' lengths
Area of woody structures	1.00	
Total count of all 6' lengths	0.49	1.00

Table A.1.8. Pearson's correlations between riparian vegetation variables.

	Barren	Deciduous forest	Grassland	Shrubs
Barren	1.00			
Deciduous forest	0.04	1.00		
Grassland	-0.00	-0.62	1.00	
Shrubs	-0.01	-0.28	-0.58	1.00

Table A.1.9. Pearson's correlations between visual habitat assessment metrics (MDEQ Procedure 51). Bold correlation coefficient indicates significance at a 0.05 level or less. Variable codes are as follows: epifauna/substrate available cover (ESAC), pool substrate characterization (PSC), sediment deposition (SD), maintained flow volume (MFV), flashiness (F), channel alteration (CA), channel sinuosity (CS), average bank stability (ABS), average vegetative protection (AVP) and average riparian vegetative zone width (ARVZW).

	ESAC	PSC	SD	MFV	F	CA	CS	ABS	AVP	ARVZW
ESAC	1.00									
PSC	**0.43**	1.00								
SD	**0.41**	0.29	1.00							
MFV	0.19	0.14	0.20	1.00						
F	**0.45**	**0.39**	0.27	0.48	1.00					
CA	0.65	-0.02	0.32	0.07	0.27	1.00				
CS	0.61	0.03	0.14	0.02	0.09	0.64	1.00			
ABS	0.31	**0.39**	0.07	0.52	0.77	0.21	-0.03	1.00		
AVP	0.11	0.34	0.20	0.22	0.47	0.08	-0.12	0.63	1.00	
ARVZW	0.14	0.31	0.24	0.11	0.47	0.14	-0.12	0.50	0.96	1.00

Table A.1.10. Pearson's correlations between substrate types in the transect.

	Cobble/boulder	Gravel	Fines
Cobble/boulder	1.00		
Gravel	0.36	1.00	
Fines	-0.91	-0.52	1.00

Table A.1.11. Pearson's correlations between substrate types at the reach scale.

	Fines	Fine gravel	Gravel	Coarse gravel/cobble
Fines	1.00			
Fine gravel	-0.36	1.00		
Gravel	-0.78	0.35	1.00	
Coarse gravel/cobble	-0.75	0.03	0.50	1.00

Table A.1.12. Pearson's correlations between natural and anthropogenic variables at the local buffer spatial unit. Bold correlation coefficient indicates significance at a 0.05 level or less.

	Urban	Forest	Wetland	Agriculture
Urban	1.00			
Forest	0.00	1.00		
Wetland	-0.16	0.03	1.00	
Agriculture	-0.30	-0.58	**-0.45**	1.00

Table A.1.13. Pearson's correlation between natural and anthropogenic variables at the network buffer spatial unit.

	Urban	Forest	Wetland	Agriculture
Urban	1.00			
Forest	-0.16	1.00		
Wetland	-0.09	0.08	1.00	
Agriculture	-0.03	-0.80	-0.63	1.00

Table A.1.14. Pearson's correlation between natural and anthropogenic variables at the local catchment spatial unit. Bold correlation coefficient indicates significance at a 0.05 level or less. The abbreviation ‘Max. elev.” refers to maximum elevation.

	Urban	Forest	Wetland	Agriculture	Temp.	Precipitation	Max. elev.
Urban	1.00						
Forest	0.10	1.00					
Wetland	-0.14	0.23	1.00				
Agriculture	-0.35	-0.89	-0.52	1.00			
Temp.	0.33	-0.33	**-0.44**	0.32	1.00		
Precipitation	-0.08	0.10	-0.20	0.04	0.10	1.00	
Max. elev.	-0.14	**-0.38**	-0.24	**0.43**	0.63	0.47	1.00

Table A.1.15. Pearson's correlation between natural and anthropogenic variables at the network catchment spatial unit. Bold correlation coefficient indicates significance at a 0.05 level or less. The code GW stands for groundwater delivery to channels.

	Urban	Forest	Wetland	Agriculture	Farm N yield	Farm P yield	uN yield	uP yield	Temp.	Precip.	GW	Slope	Catchment area
Urban	1.00												
Forest	-0.05	1.00											
Wetland	-0.11	0.32	1.00										
Agriculture	-0.35	-0.78	-.067	1.00									
Farm N yield	-0.11	**-0.44**	-0.53	0.59	1.00								
Farm P yield	-0.11	**-0.44**	-0.53	0.59	1.00	1.00							
uN yield	-0.17	-0.52	**-0.41**	0.62	0.81	0.81	1.00						
uP yield	-0.14	-0.52	**-0.41**	0.60	0.82	0.82	0.98	1.00					
Temp.	0.11	-0.18	0.18	-0.01	0.50	0.50	0.22	0.21	1.00				
Precip.	-0.07	**0.38**	-0.09	-0.14	0.16	0.16	0.12	0.11	0.18	1.00			
GW	-0.07	0.31	0.19	-0.25	**0.45**	**0.45**	**0.37**	**0.38**	0.34	0.78	1.00		
Slope	-0.08	**0.41**	-0.19	-0.12	0.12	0.12	0.00	0.02	**-0.45**	0.49	0.36	1.00	
Catchment area	-0.14	**-0.46**	0.16	0.26	0.18	0.18	0.31	0.25	-0.07	-0.52	**0.42**	0.52	1.00

Table A.1.16. Pearson's correlation between natural and anthropogenic variables selected for future analyses. Bold correlation coefficient indicates significance at a 0.05 level or less. The code GW stands for groundwater delivery to channels.

	Network buffer forest	Network buffer wetland	Network catchment agriculture	Farm N yield	Farm P yield	GW	Slope	Catchment area
Network buffer forest	1.00							
Network buffer wetlands	0.08	1.00						
Network catchment agriculture	**-0.45**	**-0.41**	1.00					
Farm N yield	-0.05	**-0.45**	0.59	1.00				
Farm P yield	-0.05	**-0.45**	0.59	1.00	1.00			
GW	0.48	0.30	-0.25	**-0.45**	**-0.45**	1.00		
Slope	0.72	0.01	-0.12	0.12	0.12	0.36	1.00	
Catchment area	-0.51	-0.18	0.26	0.18	0.18	**-0.42**	-0.52	1.00

Table A.1.17. Stepwise forward multiple linear regressions predicting habitat variables from landscape variables. Model significance of *P* value to (0.15). Variable codes are as follows: wetted average width (WAW), average depth (AD), all wood (AW), plants and algae (PA), area of woody structures (AWS), total count of all 6'lenghts (6'), grassland (G), shrubs (S), bank stability (BS), epifaunal substrate/available cover (ESAC), sediment deposition (SD), channel alteration (CA), gravel transect (GT), fines transect (FT), fines in the reach (FR), and fine gravel in the reach (FGR).

Habitat variable	Landscape variable	R^2	Adj r^2	AIC	Standard beta	F	Variable sig	Model sig
WAW	areasqkm	0.18	0.16	-43.29	0.43	6.33	0.02	0.02
AD	areasqkm	0.25	0.23	-42.27	0.50	9.50	0.01	0.01
AW	nbwetlands	0.14	0.11	-162.75	-0.37	4.39	0.05	0.05
PA								n/a
AWS	ncag	0.20	0.17	129.00	0.45	7.07	0.01	0.01
6'	gwindex	0.31	0.26	23.44	0.49	6.12	0.01	0.01
	nbwetland				-0.46		0.01	
G	nbwetland	0.19	0.13	-104.37	0.41	3.18	0.03	0.06
	gwindex				-0.32		0.09	
S								n/a
BS	gwindex	0.11	0.08	-35.94	-0.33	3.42	0.08	0.08
ESAC								n/a
SD	nbwetland	0.16	0.13	101.09	-0.40	5.46	0.03	0.03
CA								n/a
GT								n/a
FT	ncag	0.25	0.19	33.65	0.61	4.41	0.01	0.02
	farmnyield				-0.44		0.04	
FR	ncag	0.37	0.33	39.53	0.40	7.97	0.03	0.00
	nbforest				-0.32		0.08	
FGR								n/a

Table A.1.18. Visual stream condition and habitat quality score sheet from the Michigan Department of Environmental Quality (MDEQ) Procedure 51 (MDEQ 2002).

HABITAT ASSESSMENT FIELD DATA SHEET - GLIDE/POOL STREAMS

Habitat Parameter	Condition Category			
	Excellent	Good	Marginal	Poor
1. Epifaunal Substrate/ Available Cover	Greater than 50% of substrate favorable for epifaunal colonization and fish cover; mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonization potential (i.e., logs/snags that are not new fall and not transient).	30-50% mix of stable habitat; well-suited for full colonization potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of new fall, but not yet prepared for colonization (may rate at high end of scale).	10-30% mix of stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed.	Less than 10% stable habitat; lack of habitat is obvious; substrate unstable or lacking.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
2. Pool Substrate Characterization	Mixture of substrate materials, with gravel and firm sand prevalent; root mats and submerged vegetation common.	Mixture of soft sand, mud, or clay; mud may be dominant; some root mats and submerged vegetation present.	All mud or clay or sand bottom; little or no root mat; no submerged vegetation.	Hard-pan clay or bedrock; no root mat or vegetation.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
3. Pool Variability	Even mix of large-shallow, large-deep, small-shallow, small-deep pools present.	Majority of pools large-deep; very few shallow.	Shallow pools much more prevalent than deep pools.	Majority of pools small-shallow or pools absent.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
4. Sediment Deposition	Little or no enlargement of island or point bars and less than <20% of the bottom affected by sediment deposition.	Some new increase in bar formation, mostly from gravel, sand, or fine sediment; 20-50% of the bottom affected; slight deposition in pools.	Moderate deposition of new gravel, sand, or fine sediment on old and new bars; 50-80% of the bottom affected; sediment deposits at obstructions, constrictions, and bends; moderate deposition of pools prevalent.	Heavy deposits of fine material, increased bar development; more than 80% of the bottom changing frequently; pools almost absent due to substantial sediment deposition.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
5a. Channel Flow Status - Maintained Flow Volume	Water reaches base of both lower banks, and minimal amount of channel substrate is exposed.	Water fills >75% of the available channel; or <25% of channel substrate is exposed.	Water fills 25-75% of the available channel, and/or riffle substrates are mostly exposed.	Very little water in channel and mostly present as standing pools.
SCORE	10 9	8 7 6	5 4 3	2 1 0
5b. Channel Flow Status – Flashiness	Vegetation along the stream bank is complete nearly to the waters edge. Little or no evidence of frequent changes in discharge and/or frequent high water events that scours stream bank vegetation. Large woody debris (if present) stable and extending laterally across the stream channel.	Some evidence of bank scour approximately 4-8 inches above the waters surface. Large woody debris (if present) mostly stable and extending partially into the active stream channel.	Bank scour evidence 9-18 inches above the waters surface. Large woody debris (if present) tend to lay more against the stream bank rather than extending into the active channel.	Bank scour (>20 inches) along the stream channel. . Large woody debris are generally absent from the active channel and/or may exist as woody debris jams along the stream bank above the active channel.
SCORE	10 9	8 7 6	5 4 3	2 1 0
6. Channel Alteration	Channelization or dredging absent or minimal; stream with normal pattern.	Some channelization present, usually in areas of bridge abutments; evidence of past channelization, i.e., dredging (greater than past 20 yr) may be present, but recent channelization is not present.	Channelization is continuous but not recent (>5 years). Embankments without mature trees and dominated by grasses and shrubs.	Stream reach has been recently channelized (<5 years) . OR Banks shored with gabion, rock, cement or bare earth. Instream habitat greatly altered or removed entirely. Bank vegetation moderately dense to absent.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Table A.1.18. (Cont'd)

Habitat Parameter	Condition Category			
	Excellent	Good	Marginal	Poor
7. Channel Sinuosity	The bends in the stream increase the stream length 3 to 4 times longer than if it was in a straight line. (Note – channel braiding is considered normal in coastal plains and other low-lying areas. This parameter is not easily rated in these areas).	The bends in the stream increase the stream length 2 to 3 times longer than if it was in a straight line.	The bends in the stream increase the stream length 1 to 2 times longer than if it was in a straight line. (Note: lack of sinuosity may be due to channelization)	Channel straight; waterway has been channelized for a long distance.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
8. Bank Stability (score each bank)	Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected.	Moderately stable; infrequent, small areas of erosion mostly healed over. 5-30% of bank in reach has areas of erosion.	Moderately unstable; 30-60% of bank in reach has areas of erosion; high erosion potential during floods.	Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; obvious bank sloughing; 60-100% of bank has erosional scars.
SCORE (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0
9. Vegetative Protection (score each bank) Note: determine left or right side by facing downstream	More than 90% of the streambank surfaces and immediate riparian zone covered by native vegetation, including trees, understory shrubs, or nonwoody macrophytes; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally.	70-90% of the streambank surfaces covered by native vegetation, but 1 class of plants is not well-represented; disruption evident but not affecting full plant growth potential to any great extent; more than one-half of the potential plant stubble height remaining.	50-70% of the streambank surfaces covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining.	Less than 50% of the streambank surfaces covered by vegetation; disruption of streambank vegetation has been removed to 2 inches or less in average stubble height.
SCORE (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0
10. Riparian Vegetative Zone Width (score each bank riparian zone)	Width of riparian zone >150 feet and dominated by native vegetation including trees, shrubs, or non-woody macrophytes or wetlands; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally. Human activities (i.e., parking lots, roadbeds, clear-cuts, lawns, or crops) have not impacted zone.	Width of riparian zone 75-150 feet; human activities have impacted zone only minimally.	Width of riparian zone 10-75 feet; human activities have impacted zone a great deal.	Width of riparian zone <10 feet; little or no riparian vegetation due to human activities.
SCORE (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0

Total Score_____________

APPENDIX B: FIGURES

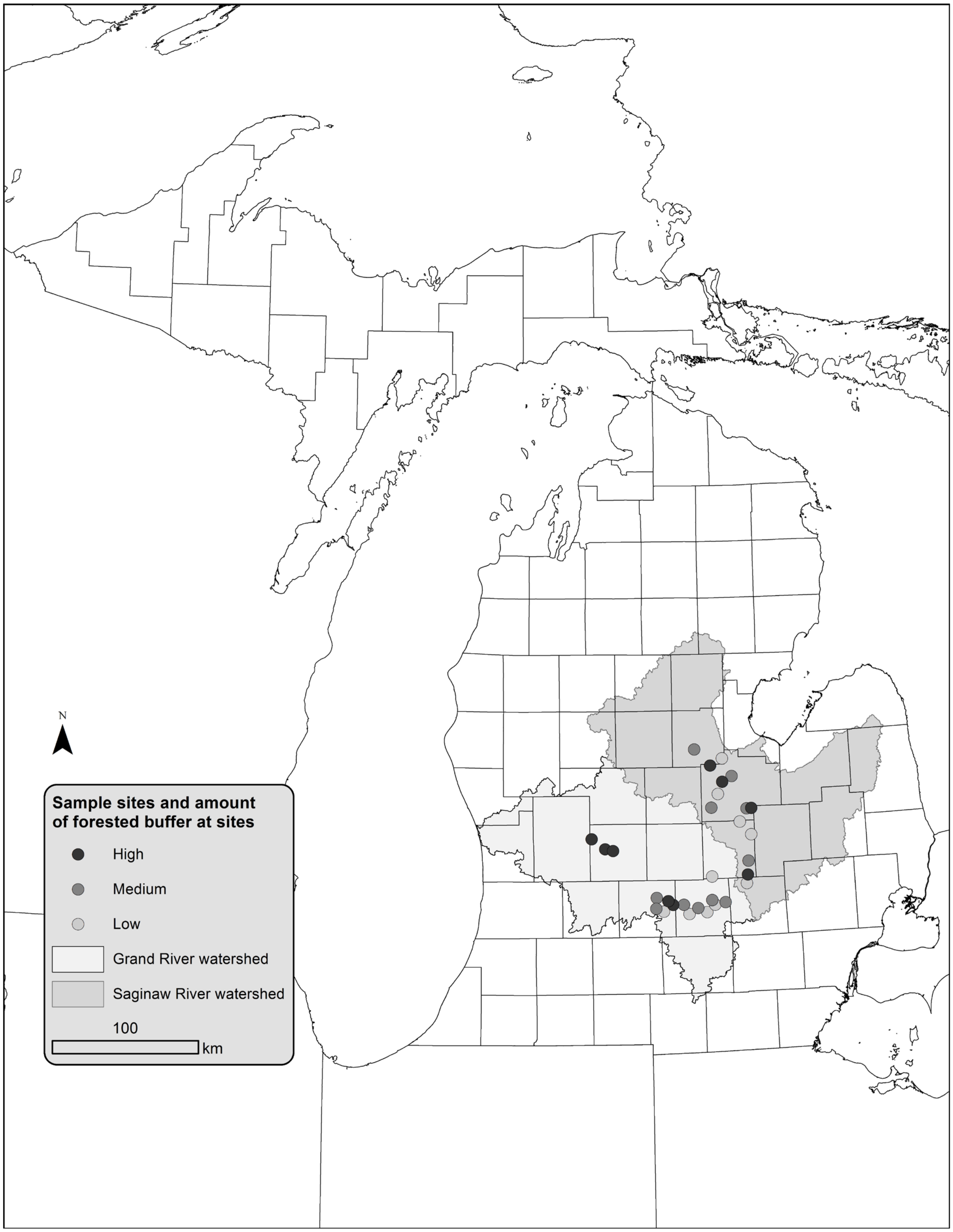


Figure B.1.1. Location of the selected sites by forested buffer category on each basin.

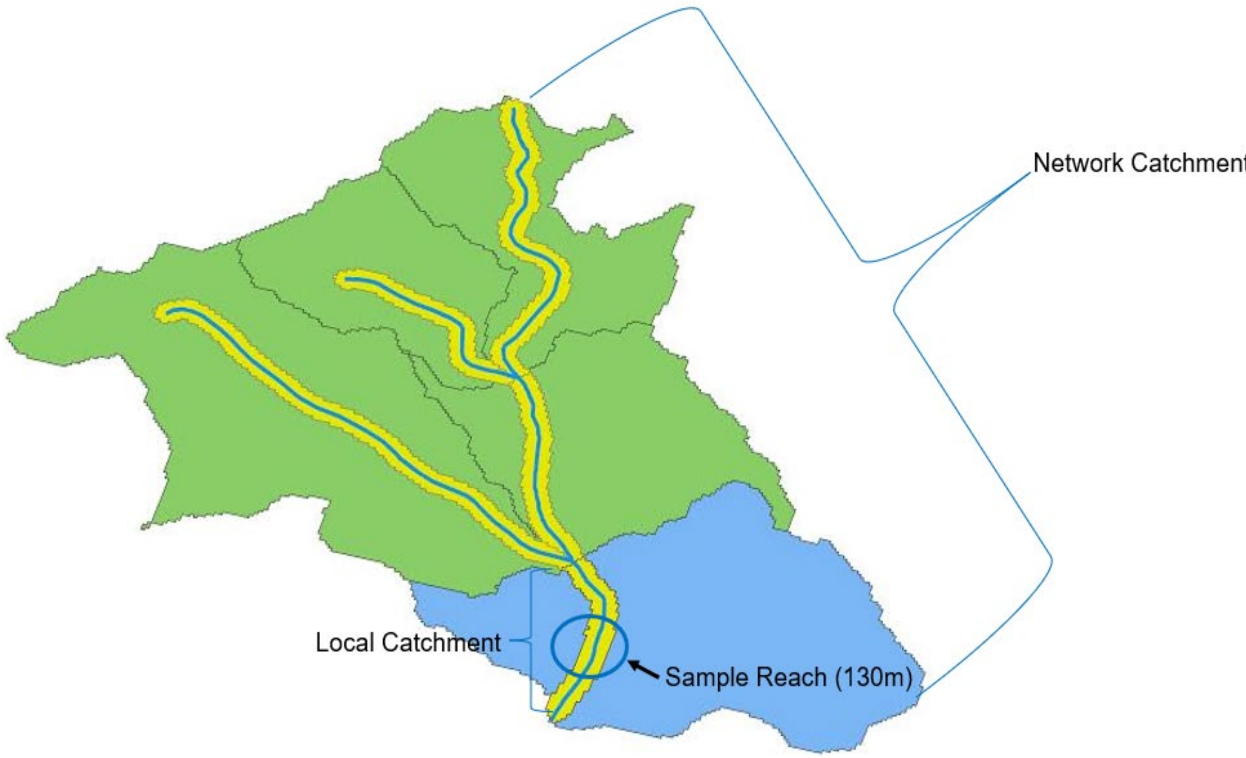


Figure B.1.2. Spatial units used for site selection and data analysis. Sample reaches (blue oval, 130m) were chosen in each stream reach that met study criteria. Study reaches are influenced both by their local catchment (blue) and the entire network catchment (blue and green). Riparian zone was analyzed within a 90m buffer (yellow) of each sample reach. See Crawford et al. (2016).

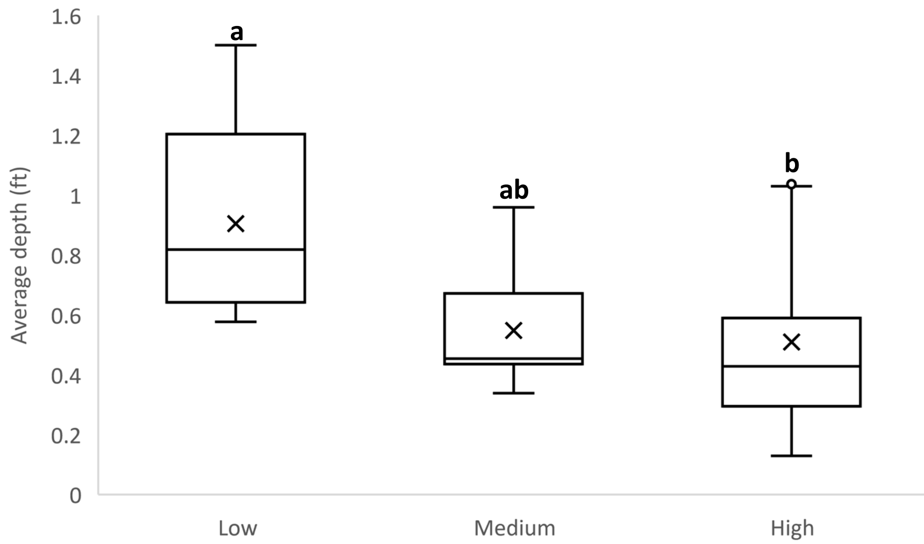


Figure B.1.3. Box plots showing average depth by forested buffers groups.

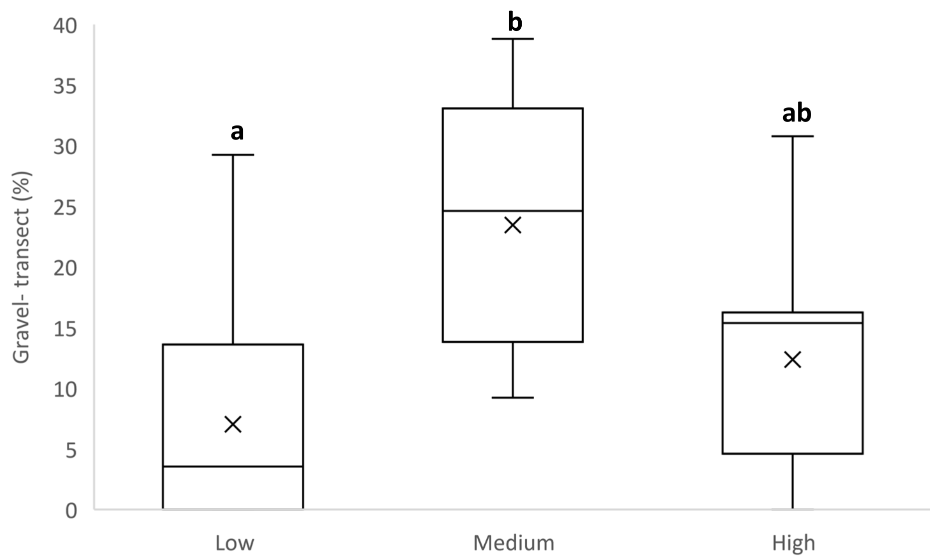


Figure B.1.4. Box plots showing the percentage of gravel in the transect by forested buffers groups.

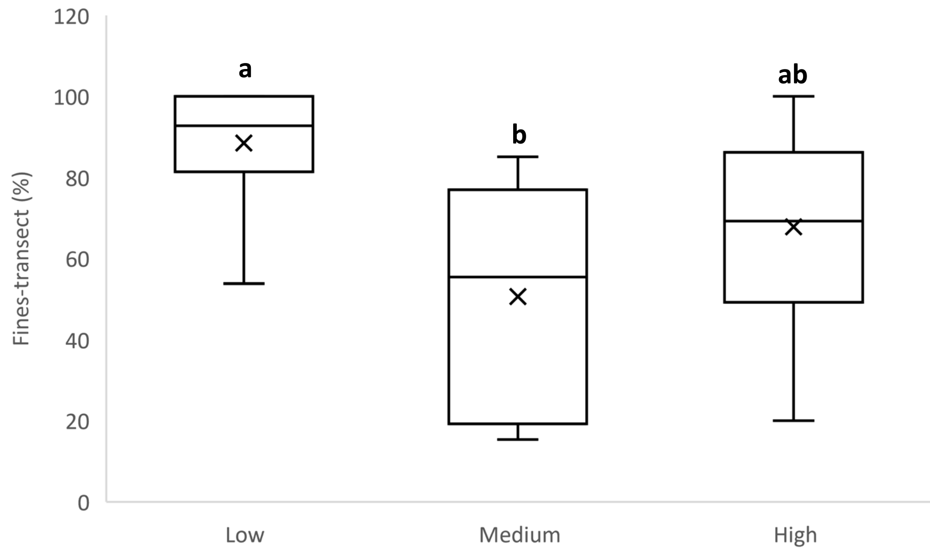


Figure B.1.5. Box plots showing the percentage of fines in the transect by forested buffers groups.

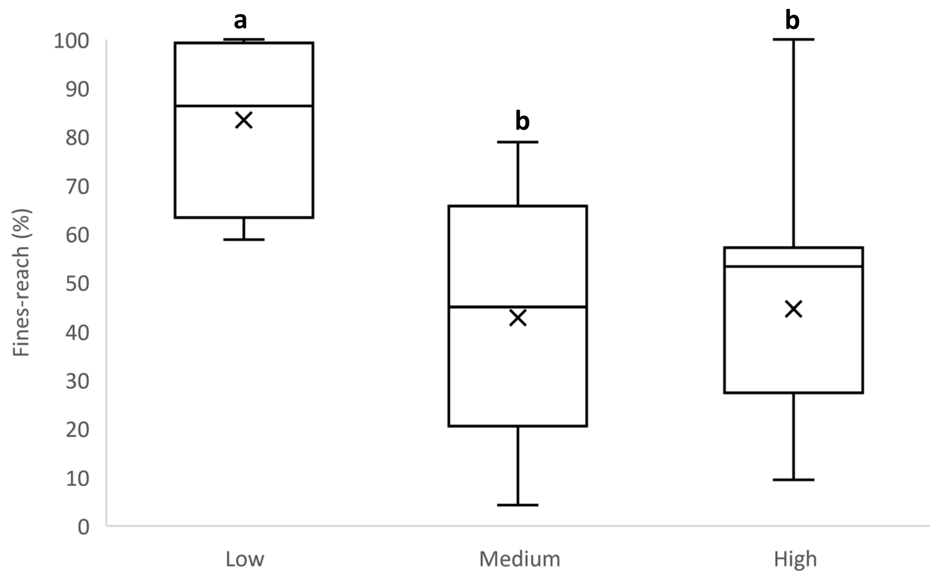


Figure B.1.6. Box plots showing the percentage of fines in the reach by forested buffers groups.

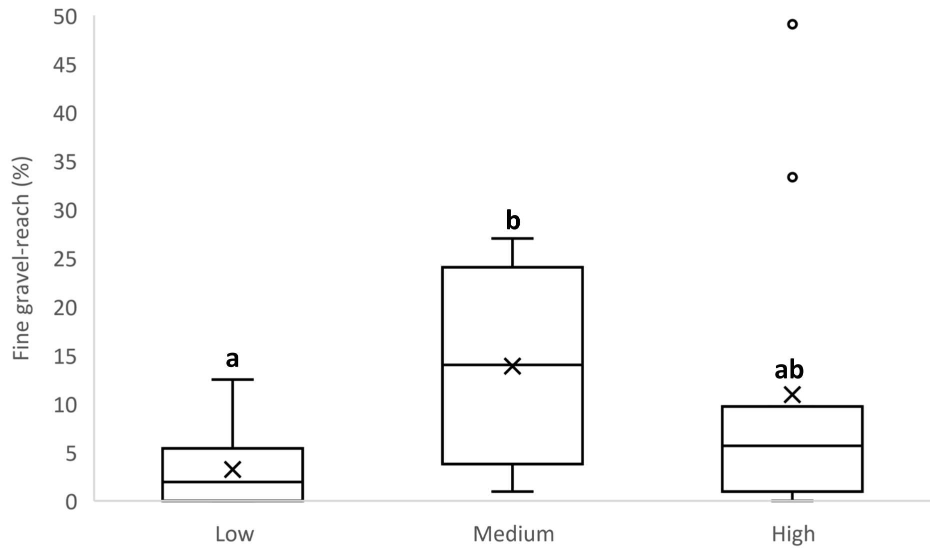


Figure B.1.7. Box plots showing the percentage of fine gravel in the reach by forested buffers groups.

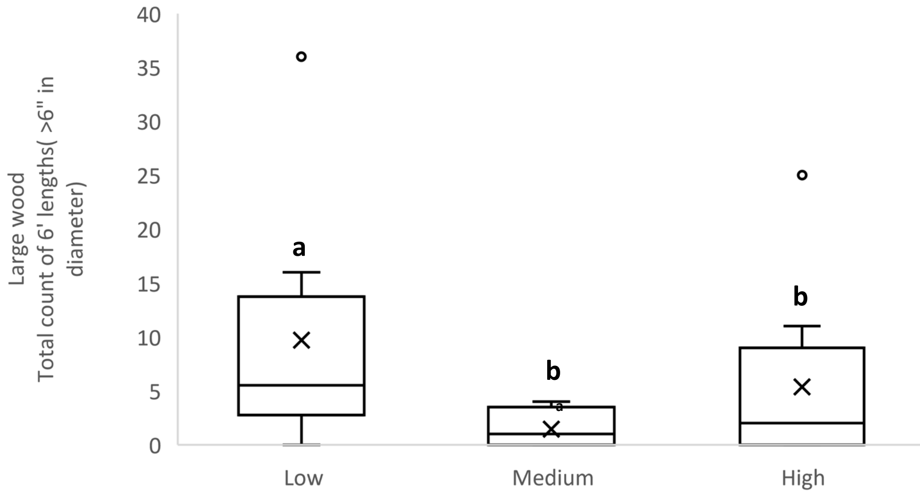


Figure B.1.8. Box plots showing the amount of large wood by forested buffers groups.

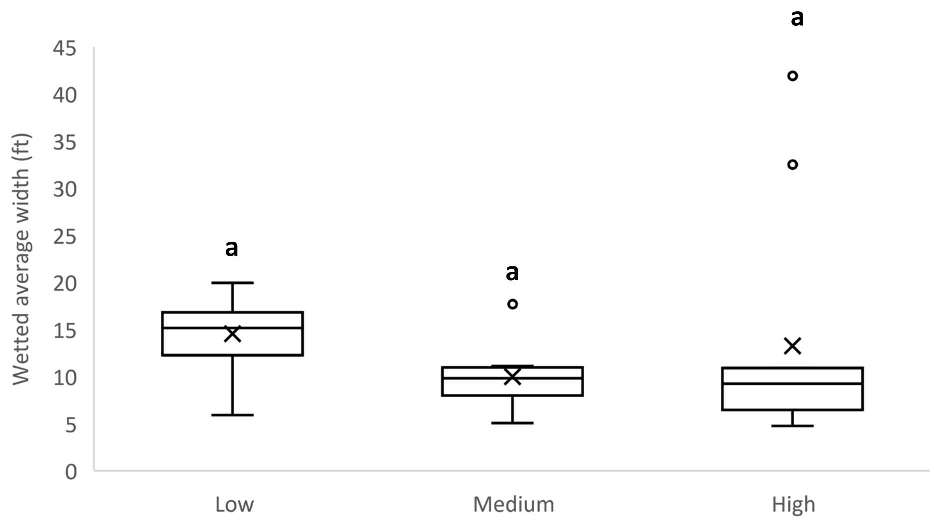


Figure B.1.9. Box plots showing wetted average width by forested buffers groups.

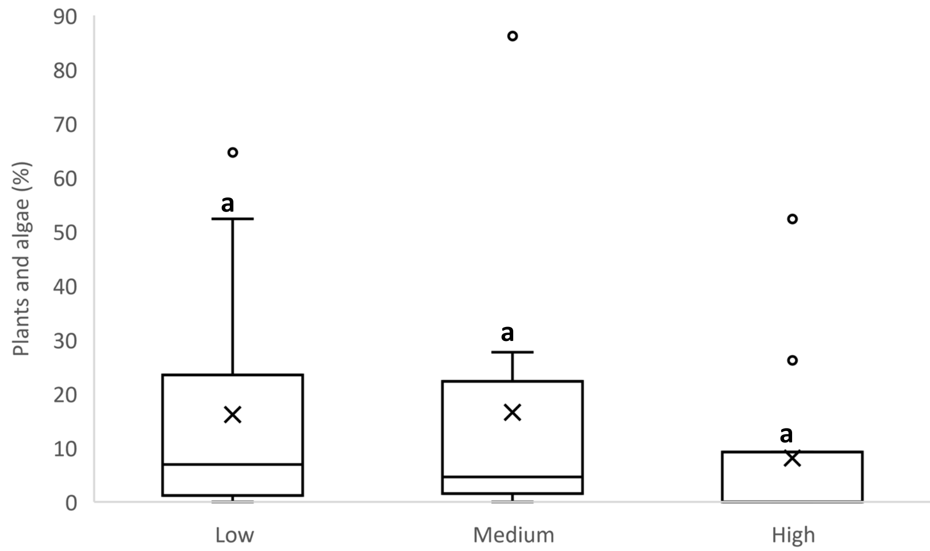


Figure B.1.10. Box plots showing the percentage of plants and algae as a fish cover by forested buffers.

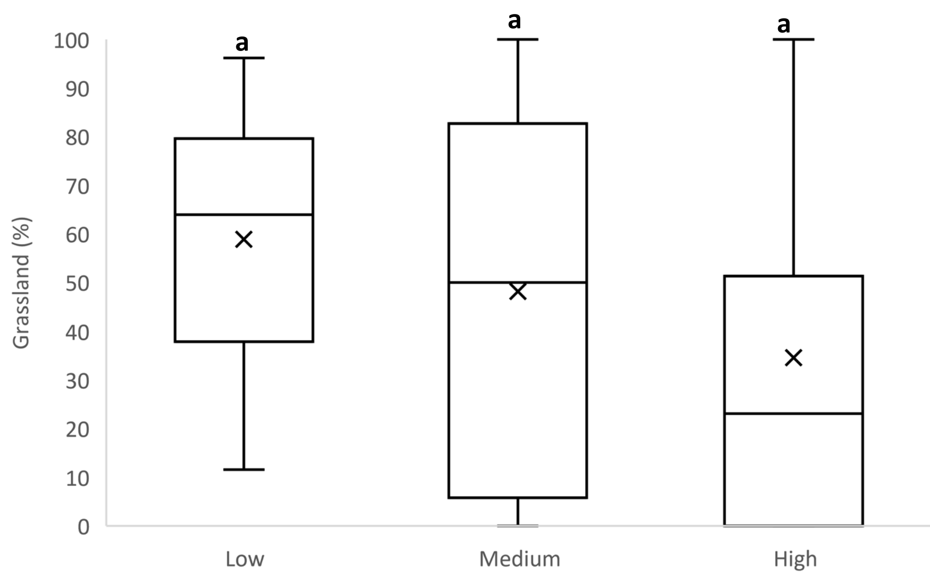


Figure B.1.11. Box plots showing the percentage of grassland as a riparian vegetation by forested buffers groups.

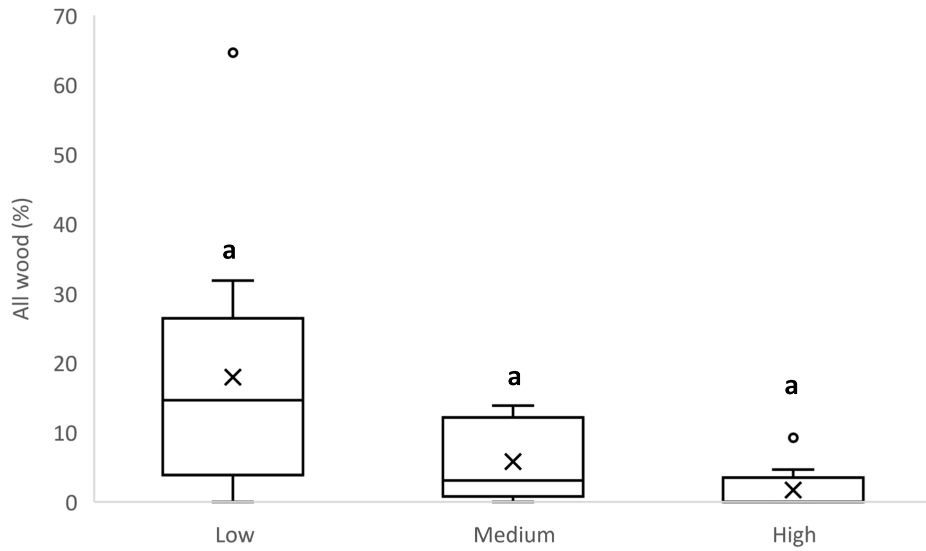


Figure B.1.12. Box plots showing the percentage of wood as a fish cover by forested buffers groups.

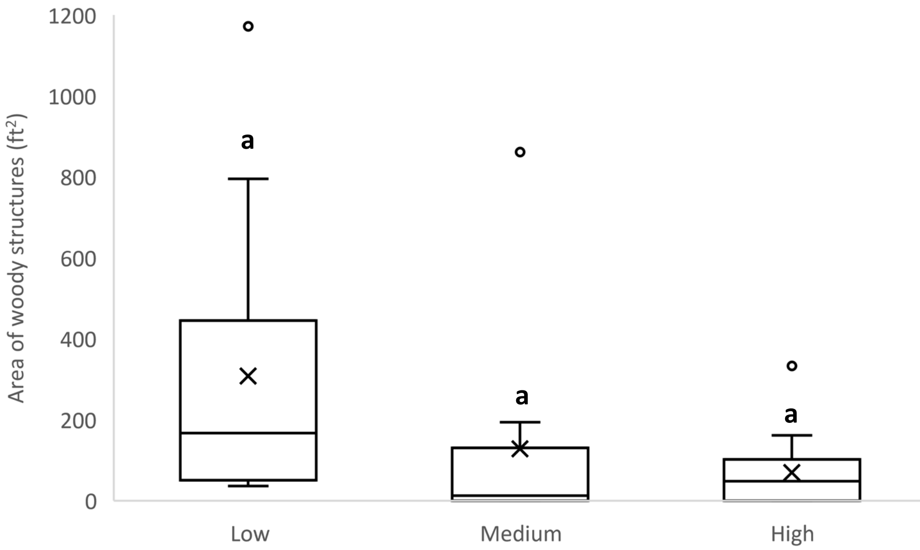


Figure B.1.13. Box plots showing the amount of the area of woody structures by forested buffers.

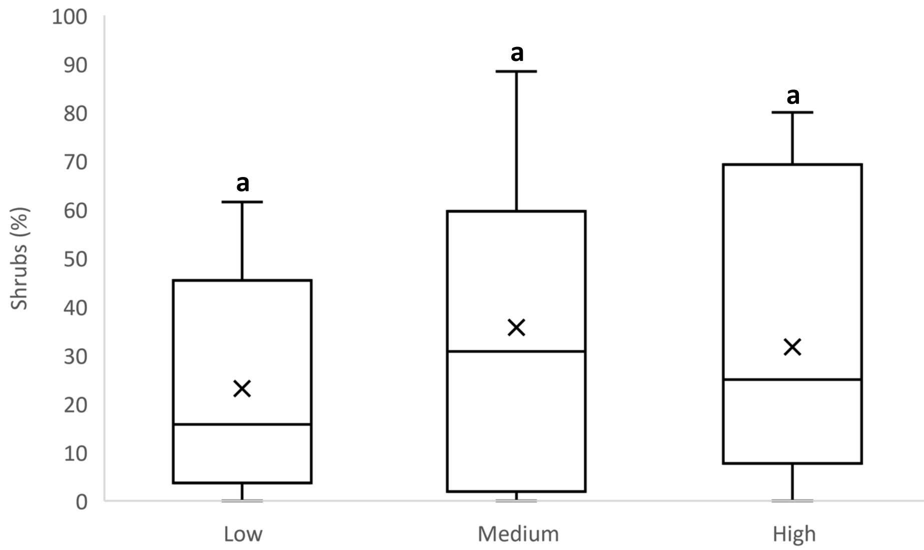
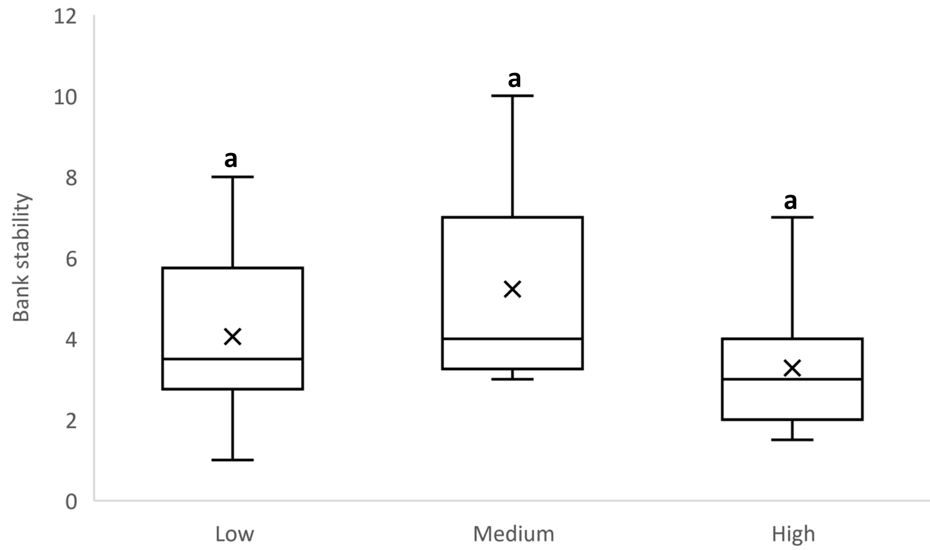
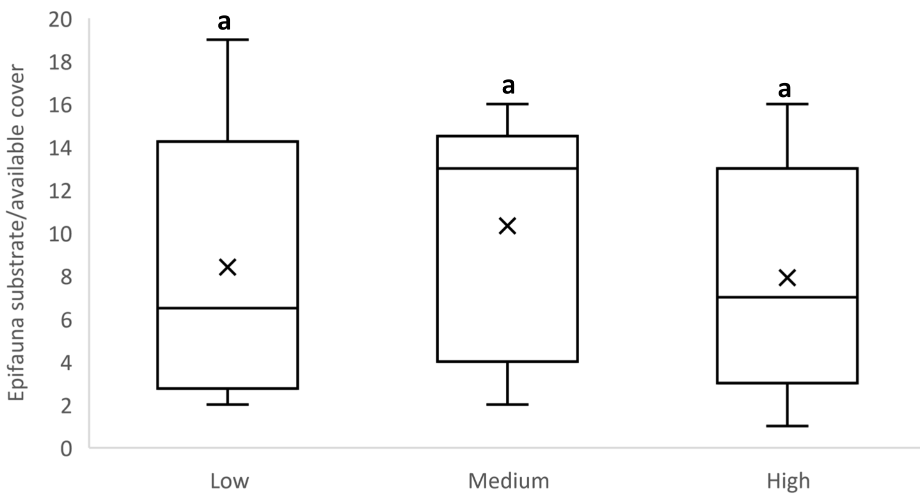


Figure B.1.14. Box plots showing the percentage of shrubs as a riparian vegetation by forested buffers.



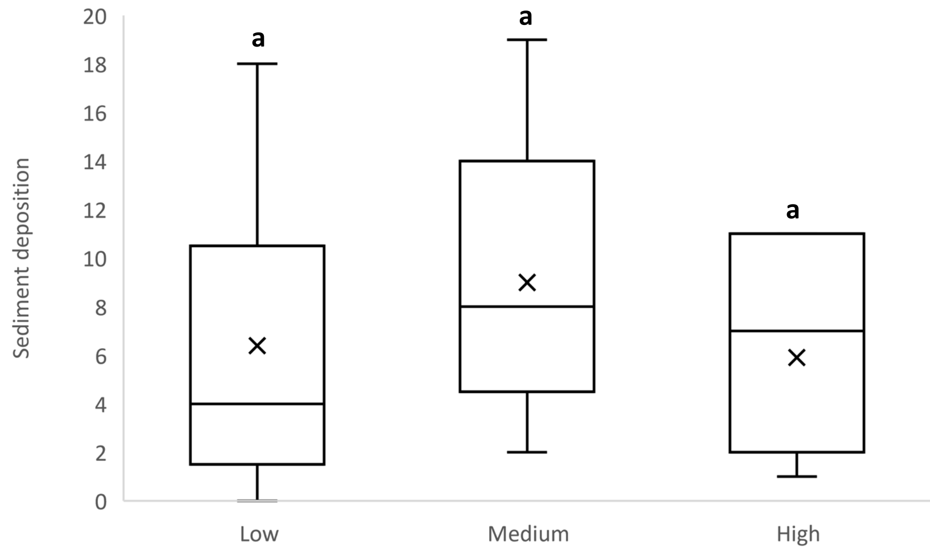
1 is poor quality and 10 is excellent quality

Figure B.1.15. Box plots showing the bank stability by forested buffers groups.



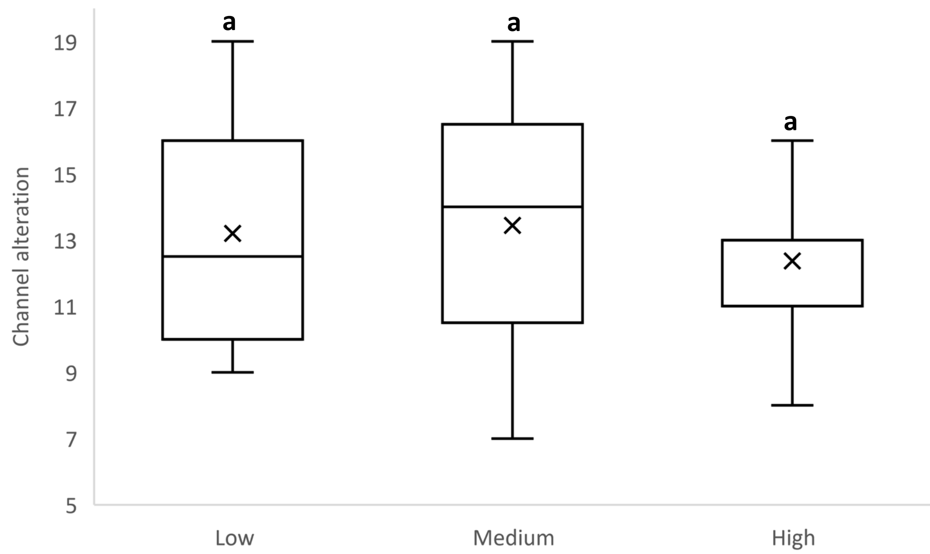
1 is poor quality and 20 is excellent quality

Figure B.1.16. Box plots showing the epifauna substrate/available cover by forested buffers groups.



1 is poor quality and 20 is excellent quality

Figure B.1.17. Box plots showing the sediment deposition by forested buffers groups.



1 is poor quality and 20 is excellent quality

Figure B.1.18. Box plots showing the channel alteration by forested buffers groups.

LITERAURE CITED

LITERATURE CITED

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CHAPTER 2: EVALUATING STREAM BUFFERS THROUGHOUT MICHIGAN'S LOWER PENINSULA: DEVELOPING SPATIALLY-EXPLICIT RECOMMENDATIONS FOR CONSERVING STREAM FISH HABITATS.

ABSTRACT

Naturally-vegetated stream buffers, including buffers containing forests and wetlands, are widely recognized as landscape features that can protect and preserve streams from negative effects of agricultural land use. Benefits of buffers include helping to slow surface runoff, preventing erosion of stream channels, and reducing stream bed sedimentation and nutrient delivery to streams. In this study, we created a series of maps to identify stream reaches with varying amounts of forest and wetland in their stream buffers in heavily agricultural catchments in four major river basins in Michigan: the Grand, Saginaw, Kalamazoo and St. Joseph. Through these maps, we identify reaches with levels of forest and wetland in their buffers that should promote good fish habitat as well as reaches lacking forest and wetlands in their buffers as a strategy for thinking about where to implement conservation practices that could minimize effects of agriculture. We also map reaches along with locations of currently protected lands to better understand how commonly this particular conservation action may have already been applied. This study is important because it provides baseline information for many stream reaches throughout a large portion of the state of Michigan as well as recommendations over a large spatial extent. This study can serve as the first piece of information that stakeholders can use to evaluate or decide where in these river basins they would like to focus their conservation efforts.

INTRODUCTION

Naturally-vegetated stream buffers are areas of vegetation in the riparian zones of streams connecting stream and terrestrial habitats. They have long been recognized as a landscape feature that can protect and preserve streams from negative effects of anthropogenic activities occurring on terrestrial landscapes, including agriculture (Lovell and Sullivan, 2006), and common negative effects of agriculture that can affect streams include erosion of soils from the landscape, generation of surface runoff, and delivery of excess nutrients and sediments to stream channels (Piggott et al. 2012, Jones et al. 1999). Naturally-vegetated stream buffers may be comprised of different types of vegetation. For example, forested buffers include strips of vegetation dominated by trees, either naturally established or planted along stream banks, and forested buffers can help to hold soils in place, slow surface runoff, prevent erosion of stream channels, reduce stream bed sedimentation, moderate stream water temperature, and contribute organic matter to streams (e.g., Ortiz, this volume, Osborne and Kovacic, 1993, Mander et al., 2005). In addition, wetland buffers include naturally hydrophytic vegetation adjacent to streams, and studies have also documented benefits of wetland buffers including their ability to capture surface runoff, reduce high flows in stream channels, and filter sediments and nutrients from runoff, reducing inputs to streams (e.g., Ortiz this volume, Johnston, 1991, Phillips, 2017).

Historically, the removal of natural streamside vegetation in agricultural landscapes to increase croplands was a common practice leading to many negative effects on stream habitats (Sweeny and Newbold, 2014). Early efforts to protect or restore naturally vegetated streamside buffers in agricultural landscapes were historically driven by their capacity to reduce nutrients and sediments and to improve water quality (Mc Conigley et al., 2017), and currently, these benefits of buffers are well known. However, besides improving water quality, restoring riparian buffers along streams can also improve other aspects of stream fish habitat. In Chapter 1 (Ortiz, this volume), we described some benefits of forested and wetland buffers to fish habitat in streams draining heavily agricultural landscapes in central Michigan. Besides showing that forested buffers were associated with less sedimentation and more gravel in small streams, we also showed the importance of forested buffers for maintaining the integrity of channel morphology. We also found that wetlands in buffers were associated with decreased sediment deposition within stream channels. These results were detected through data collected from 30 streams located in two watersheds of Michigan, the Grand and the Saginaw River basins, and through our analytical approach, we documented amounts of forest in stream buffers that would benefit fish habitat, as well as the fact that more wetlands in buffers are also beneficial. By extending findings from Chapter 1 through a larger area and considering other conservation actions already being applied, including protection of landscapes from human land uses including agriculture, we could aid in efforts to prioritize conservation actions including strategically identifying locations for establishment of buffers or for protection of landscapes.

The goal of this chapter is to help meet that need. We will extend findings from Chapter 1 throughout a larger area by developing a series of maps showing the amounts of forest and wetland in buffers of streams found in multiple basins in Michigan including the Saginaw, Grand, Kalamazoo, and St. Joseph Rivers. These basins include hundreds of miles of small streams draining heavily agricultural areas that could be targeted for conservation actions. First, using Geographic Information System (GIS) we identify the amount of forest and wetland in network buffers of small streams (<500 km^2 in drainage area) located in heavily agricultural catchments ($>50\%$ agriculture) in each of the four basins. This objective will help us to identify potential areas where stakeholders can focus their conservation efforts by highlighting streams that may have limited fish habitat due to minimal amounts of forest and wetlands in their buffers. It will also allow us to make spatially-explicit recommendations to identify locations to implement conservation practices including vegetated buffers or other strategies to improve stream fish habitat. Next, we also consider locations that currently have protected landscapes and integrate those results into maps to account for the potential effect of this conservation practice. This study builds on results from our previous investigation to provide stakeholders with meaningful information to aid them in decision-making.

METHODS

Study region

The study region includes the Saginaw, Grand, Kalamazoo and St. Joseph River basins located in Michigan's Lower Peninsula (Figure B.2.1). The Saginaw River basin, the largest in Michigan, drains an area of 16,120 km^2, the Grand River basin drains an area of 14,432 km^2, the Kalamazoo River basin drains an area of 5,258 km^2 and the St. Joseph River basin drains an area of 12,201 km^2 (Table A.2.1) (NHDPlusV1; USEPA and USGS, 2005). Agriculture is a major land use in all of the four basins. It is the dominant land use in the St. Joseph, occurring in 57.72% of the basin, and it is lowest in the Saginaw, occurring in 49.99% of the basin (Table A.2.1). Livestock production is common in all basins, but type of crops grown varies. In the Grand and Saginaw, the major crops grown are corn, soybeans, beets, and grains, while in the Kalamazoo and St. Joseph, specialty crops are more common such as blueberries, apple, and cherries. These differences in crops in each of the basins is partially due to differences in the average annual temperature and precipitation in the basins as well as differences in other landscape features such as coarse geology (Table A.2.1). Besides agriculture, other land uses also vary by basin (Table A.2.1). The Grand has the most urban land (14.04 %), while the

Saginaw has the least urban (11.71%). The percentage of wetlands is highest in the Saginaw (19.57%) and lowest in the St. Joseph (15.67%). The Kalamazoo leads in forest (21.72%), while the St. Joseph has the least forest (10.80%).

Spatial framework

We used the 1:100,000 scale National Hydrography Dataset Plus Version 1 (NHDPlusV1; USEPA and USGS, 2005) to characterize rivers in the study region. The finest spatial unit used for our analyses is the stream reach, defined as sections of streams extending from headwaters to confluences, confluences to confluences, and confluences to river mouths (Figure B.2.2, Wang et al. 2011). Individual reaches are drained by their associated local catchments which represent the landscapes that drains directly to stream reaches. Information from within local catchments can be aggregated for network catchments (Tsang et al. 2014), which represent the total upstream land area draining to stream reaches. For the purposes of this study, we considered the land area (90 m) on either side of a given stream reach to characterize riparian influences. Similar to local and network catchments, information from within all local buffers upstream of a given stream reach can be aggregated throughout the entire upstream river network to create a network buffer summary (Figure B.2.1).

Landscape data

We obtained land use/land cover information from the National Land Cover Database (NLCD, 2011) for the four study river basins. Categories of land use/land cover data that we used for analysis included the amount of forest, wetland, agriculture, and urban land in network catchments and network buffers. We summarized each of these land covers from subcategories included in the NLCD. Agriculture was a combination of pasture/hay and cultivated crops;

forest was a combination of deciduous forest, evergreen forest and mixed forest; and wetland was a combination of woody wetlands and emergent herbaceous wetlands. Additionally, urban land was a combination of urbanized open space and high, medium, and low intensity urban land uses. We also obtained locations of protected lands in Michigan from the Protected Areas Database of the United States (PAD-US v1.4; USGS, 2016). This database has the most complete information of protected areas including easements in the USA. The PAD-US database categorizes protected lands into four status categories based on management: Status 1 and 2 include areas with the most stringent protection for biodiversity, having highly restricted use and permanent protection from conversion of natural land cover (e.g., national parks and reserves), and only with natural disturbances allowed (e.g., fire). Status 3 includes lands with permanent protection from conversion of natural land cover for the majority of the designated area, but multiple uses are allowed including resource extraction (e.g., logging, mining) and recreational vehicle use (e.g., state game areas, federal off-highway vehicle trails). Status 4 lands are those that do not have documented protection (Cooper et al., 2019). For our analysis, we used Status 1, 2, and 3 lands to identify locations of protected lands on the selected basins.

Site selection

The Saginaw, Grand, Kalamazoo and St. Joseph River basins contain a total of 15,167 stream reaches as characterized from the NHDPlusV1 (Table A.2.2). We used a geographic information system (GIS) to identify those that drain areas less than 500 km^2 in size (these small streams include many headwaters in the region) and with 50% or more of agriculture in their network catchments, the same size criteria used to select the steams studied in Chapter 1. Previous research has shown that streams draining catchments with more than 50% of agricultural land use may experience multiple negative effects to stream fish habitat including increases in fine substrate, altered channel morphology, reduced fish cover, altered bank conditions, and altered riparian conditions (Wang et al., 1997). Also, because small stream comprise such a large portion of the stream network, understanding agricultural impacts in headwaters will help us to understand effects in the lower portion of the watershed. The selection process resulted in a total of 4,579 stream reaches in the Grand, 5,354 in the Saginaw, 1,492 in the Kalamazoo and 3,742 in the St. Joseph that met our criteria (Table A.2.2). The reaches were then classified into 3 different categories which included low amounts of forested land use in network buffers (0 to 15% forested buffer), medium amounts of forested land in network buffers (15% to 30% forested buffer), and high amounts of forested land in network buffers (30% to 100% forested buffer); these classes were defined based on differences in habitat tested for in Chapter 1 (Ortiz, this volume). In addition, we also created 3 different categories based on the percentage of wetlands in the network buffer; low (0-10%), medium (10%-50%) and high (50%-100%). While these ranges were based on the distribution of our data, results of Chapter 1 showed us broadly that streams with higher amounts of wetlands in their buffer have less sedimentation (Ortiz, this volume).

After categories were defined, we created a map that showed the streams that met our stream size and agricultural land use criteria, and we created additional maps that summarized these streams based on the amounts of forest and wetland in their buffers (low, medium and high) to describe patterns. Next, we also mapped reaches summarized into categories based on forest and wetland in their buffers along with locations of protected lands across the study basins. We use these maps to summarize patterns and then propose management recommendations based on results.

RESULTS

Stream reaches that met the criteria of draining catchments less than 500 km^2 in area and with 50% or more agriculture in their catchments were very common in our study region, comprising 58.21 % of all land area (Table A.2.2, Figure B.2.1). From a total of 15,167 reaches in the four basins, 8,607 reaches met the criteria (Table A.2.2). These reaches were common in all four basins. We found that 69.40% of all reaches in the St. Joseph met the criteria, followed by 58.90% of all reaches in the Grand, 53.15% of all reaches in the Kalamazoo, and 47.07% (the fewest) of all reaches in the Saginaw. These reaches also drain large portions of the basins: 71.58% of the St. Joseph, 62.99% of the Grand, 52.61% of the Kalamazoo and 45.67% of the Saginaw. Because these small streams reaches are typically headwaters, conditions in most of these reaches will have direct effects on all downstream waters throughout the study basins. Figure 2 shows the spatial arrangement of the stream reaches that met these criteria, and we detected some variability in their locations across basins. For example, in the Kalamazoo, reaches that met the criteria are concentrated in two zones of the basin (upper portion and northwest portion). The reaches in the St. Joseph are distributed throughout the basin, and for the Grand and Saginaw, reaches are concentrated mostly in the middle portion of both basins but are absent from larger cities or highly urbanized areas such as Grand Rapids and Lansing (Figure B.2.3).

Figure B.2.4 shows study streams categorized by the amount of forest in their buffers. While study streams with high amounts of forest occur in all basins, streams in the Kalamazoo have the most, with an average across all sites of 12.74% (Table A.2.3). Additionally, streams with low amounts of forest in their buffers occur in every basin, and streams in the Saginaw have the lowest with an average of 10.79% (Table A.2.3). Figure B.2.5 shows study streams categorized by the amount of wetlands in their buffer. Wetlands in the buffer were present in all basins, and we observed the highest average amount in the St. Joseph (25.87%) and the lowest in the Saginaw (10.22%) (Table A.2.3).

In addition, we combined our study reaches by forested buffer categories with protected areas within the state (Figure B.2.6). As indicated in Figure B.2.6, most of the protected areas are located in stream catchments with low amounts of forest in stream buffers. Table A.2.4 shows that the percentages of reaches with low amount of forest in their buffers and protected areas in their catchments are higher in comparison to reaches with high and medium amounts of forest in their buffers. This includes 9.61% of reaches with low amounts of forest in buffers in the Grand, 10.58% in the St. Joseph, 11.48% in the Saginaw and 11.97% in the Kalamazoo. We also evaluated wetlands by buffer categories with protected areas (Figure B.2.7). Table A.2.5 summarizes results for each basin, and the higher percentages are in the category of medium amount of wetlands in the buffer and protected areas with 10.17% in the Grand, 8.85% in the Saginaw, 8.78% in the St. Joseph and 8.55% in the Kalamazoo.

DISCUSSION

Overview

In Chapter 1, we documented benefits of forested and wetland buffers to stream fish habitat in 30 sites in the Saginaw and Grand River Basins. In this study, however, we extend those results through thousands of locations in four river basins in Michigan. This study is important because by extrapolating results from Chapter 1, we identify all stream reaches in the study region likely to have limits to fish habitat resulting from heavily agricultural catchments and the lack of forest and wetlands in their buffers. Additionally, we identify those reaches that should be in generally good condition, with effects of catchment agriculture lessened due to forest and wetlands in their stream buffers. Collectively, these results can be used to inventory all streams in the study region and develop an understanding of baseline conditions that may exist currently. Also, by combining these results with locations of protected lands, we can develop insights into specifically where places are already protected and where more protection or other actions may be needed.

Prominence of headwater streams draining agricultural landscapes

While definitions of headwater streams can vary, they are generally defined as first or second order tributaries comprising a stream network (Vannote et al., 1980). Flow in headwaters often originates from groundwater. Additionally, it is acknowledged that they contribute to the movement of materials from river network origins to river mouths (Richardson, 2019), and that they are the connection between upland areas and the river network (Freeman et al. 2007). While headwater streams are small in size, many typically comprised the river network. In 2019, Colvin and others highlighted that 79% of stream network in the USA is comprised of headwater streams, emphasizing that headwater streams are dominant fluvial features in any watershed. For that reason, it is critical to conserve headwater streams, which will contribute to the conservation of all flowing waters in the United States. Besides selecting headwater streams for our study reaches, all of them had more than 50% agriculture in their catchments, and 56% of all the reaches in four study basins met these criteria. This indicates how pervasive effects of agriculture may be to headwaters in the study region as well as to downstream waters. Therefore, conserving or implementing forest and wetlands in stream buffers represents an important strategy to protect not only reaches from agriculture but entire river networks.

Conservation practices

Conservation practices (also known as Best Management Practices (BMPs) have been identified as effective methods or techniques to prevent or minimize environmental issues that result from human activities on the landscape, including water quality impairments resulting from agricultural land use (Yates et al., 2007). As mentioned in Chapter 1, conservation practices have been recommended for decades, and many agencies and organizations at the local, state, and federal level are increasing their efforts to support conservation. This is being done by the allocation of more funding into the state budget or Farm Bill programs to help with implementation of practices by providing technical and/or financial assistance to apply BMPs. In Michigan, local agencies can include watershed councils; state agencies include Soil and Water Conservation Districts (SWCD) and the Michigan Department of Natural Resources (MDNR); and federal agencies include the US Fish and Wildlife Service (USFWS), Natural Resources Conservation Service (NRCS) and non-profit organizations like The Nature Conservancy (TNC) and Trout Unlimited (TU).

Conservation practices can minimize environmental issues to streams by slowing surface runoff; trapping sediments, fertilizers, pesticides and pathogens; and stabilizing stream banks by keeping soil in place. Additionally, they can provide other benefits to fish habitat and aquatic organisms including moderating stream temperatures, providing organic matter to streams, and providing various forms of fish cover (Einheuser et al., 2012). Some examples of conservation practices include cover crops, crop rotation, reduce till and no-till, grassed waterway, filter strips and riparian buffers (forest or wetland) (Field Office Technical Guide (FOTG), NRCS 2020). Cover crops are grasses, legumes, forbs, or other herbaceous plants for seasonal cover; they improve soil structure and reduce wind and water erosion. Crop rotation helps by disrupting the cycle of growing the same type of crop every year on the same piece of land or field, this can be as simple as incorporating hay or small grains after corn to reduce tillage and provide better erosion control. Reduce no-till and no-till prevent soil erosion by providing cover to the soil surface year-round before and after harvest. Grassed waterway is a shaped or graded channel within a field that helps to slow down water movement and reduce the amount of sediments carried by surface runoff. Filter strips are similar to grassed waterways, but they are usually located at the edge of the crop field, and they slow water flow, filter runoff, and remove contaminants before they reach water bodies. Riparian buffers, a focus of this research, are strips of vegetation, either naturally established or planted along stream banks, and they can filter out sediments, organic matter, and other pollutants; shade streams to lower water temperature; and prevent erosion of stream channels to improve habitat for aquatic organisms (Mander et al., 2005).

The implementation of conservation practices is highly dependent on the goal or objective of the individual or agency and the benefits that a specific practice is intended to provide. However, once a conservation practice has been implemented, its actual effectiveness can be hard to determine due to the complexity of the system and other factors that can be difficult to account for (Game et al., 2014) like project scale, past and current conditions of the site, and outside stressors (e.g. urbanization, land degradation, and climate change). By combining multiple conservation practices, the likelihood of benefits can be increased. For example, by mapping our study reaches along with protected lands, we have preliminary information on how lands may already be managed. Reaches draining lands with protected areas in their catchments may be areas where additional protections could be applied more easily than if the land was not protected. Such information can help in decision making when selecting conservation practices suitable for protected lands in addition to stream buffers.

Study limitations

Some limitations should be noted as part of this study. First, we conducted our field work within a small region of the state (30 stream reaches in the Grand and Saginaw River basins) and extrapolated our results to all reaches in the Grand, Saginaw, Kalamazoo and St. Joseph basins. While we found meaningful relationships between forest and wetlands in stream buffers and some fish habitat variables, additional data collection should be performed to validate those results. Second, we assumed that conditions were very similar in all reaches meeting our selection criteria, but each location may have other stressors that we did not characterize as part of our study (e.g. urban areas, dams, water withdrawals, etc.). Third, we strongly recommend the implementation of conservation practices due to all the benefits that they provide, but that is not always an easy task. The initial establishment of conservation practices can be costly due to expenses associated with materials and labor, loss of revenue from taking land out of production, or changes in revenue because changes in the management of the land are needed. Fourth, we need to recognize that the designation of protected land can change due to ownership or management, and if this occurs, other methods may be necessary to maintain good fish habitat.

Conclusions

Agriculture plays a critical role in our society, and it is an important land use that will remain in our landscape for many years to come to provide food and support the economy. We need to learn how to alleviate its effects by implementing mitigation strategies such as conservation practices to protect stream habitats. Our intent is to raise awareness by categorizing stream reaches where conservation efforts can be effective to address the lack of buffers or lack of protected land, representing a threat to fish habitat in the future. This study will help stakeholders to have a visual representation of stream reaches than can be targeted for conservation efforts or at least will allow them to gain insights of possible project areas to study in more detail to conduct other research in the future.

APPENDICES

APPENDIX A: TABLES

Table A.2.1. Summary of landscape factors in each study basin.

Basin	Drainage area (km^2)	Urban (%)	Agricultural (%)	Forest (%)	Wetland (%)	Avg. annual air temp (ºC)	Avg. annual precip. (mm)	Coarse geology (%)
Grand	14435	14.04	51.4	15.77	16.59	9.22	933.83	33.51
Saginaw	16134	11.71	44.99	20.51	19.57	8.68	868.16	46.91
Kalamazoo	5274	12.98	45.99	21.72	15.97	9.66	1017.92	53.98
St. Joseph	12187	12.96	57.72	10.8	15.67	10.01	1014.64	77.68

Table A.2.2. Summary of reaches that meet study criteria in each basin (catchment areas less than 500 km^2 and with more than 50% agriculture).

Basin	Total reaches (#)	Reaches meeting criteria (#)	Reaches meeting criteria (%)	Area meeting criteria (km^2)	Area meeting criteria (%)
Grand	4579	2697	58.90	9092	62.99
Kalamazoo	1492	793	53.15	2774	52.61
Saginaw	5354	2520	47.07	7368	45.67
St. Joseph	3742	2597	69.40	8724	71.58
All basins	15167	8607	56.75	27958	58.21

Table A.2.3. Average values of landscape variables for study sites by basin.

Scale	Variable / Basin	St. Joseph	Grand	Kalamazoo	Saginaw
Network catchment					
	Network catchment area (km^2)	64.57	39.21	42.02	32.06
	Urban (%)	7.74	7.26	6.94	7.34
	Agriculture (%)	67.43	71.09	67.52	73.80
	Forest (%)	10.42	10.53	13.56	10.16
	Wetland (%)	11.20	9.59	9.58	6.89
Network buffer					
	Urban (%)	6.39	6.03	5.99	6.73
	Agriculture (%)	44.67	56.41	46.38	68.29
	Forest (%)	11.45	12.13	12.74	10.79
	Wetland (%)	25.87	20.58	25.66	10.22

Table A.2.4. Forested buffers categories and protected land

Basin	Area meeting criteria (km^2)	High forested buffer, protected land (km^2)	High forested buffer, protected land (%)	Medium forested buffer, protected land (km^2)	Medium forested buffer, protected land (%)	Low forested buffer, protected land (km^2)	Low forested buffer, protected land (%)
Grand	9092	65	0.71	454	4.99	874	9.61
Kalamazoo	2774	31	1.11	59	2.11	332	11.97
Saginaw	7368	39	0.52	263	3.57	846	11.48
St. Joseph	8724	154	1.76	278	3.19	923	10.58
All basins	27958	288	1.03	1054	3.77	2975	10.64

Table A.2.5. Wetland buffers categories and protected land.

Basin	Area meeting criteria (km^2)	High wetland buffer, protected land (km^2)	High wetland buffer, protected land (%)	Medium wetland buffer, protected land (km^2)	Medium wetland buffer, protected land (%)	Low wetland buffer, protected land (km^2)	Low wetland buffer, protected land (%)
Grand	9092	189	2.08	924	10.17	279	3.07
Kalamazoo	2774	95	3.41	237	8.55	90	3.23
Saginaw	7368	35	0.48	652	8.85	460	6.24
St. Joseph	8724	259	2.97	766	8.78	330	3.78
All basins	27958	578	2.07	2580	9.23	1158	4.14

APPENDIX B: FIGURES

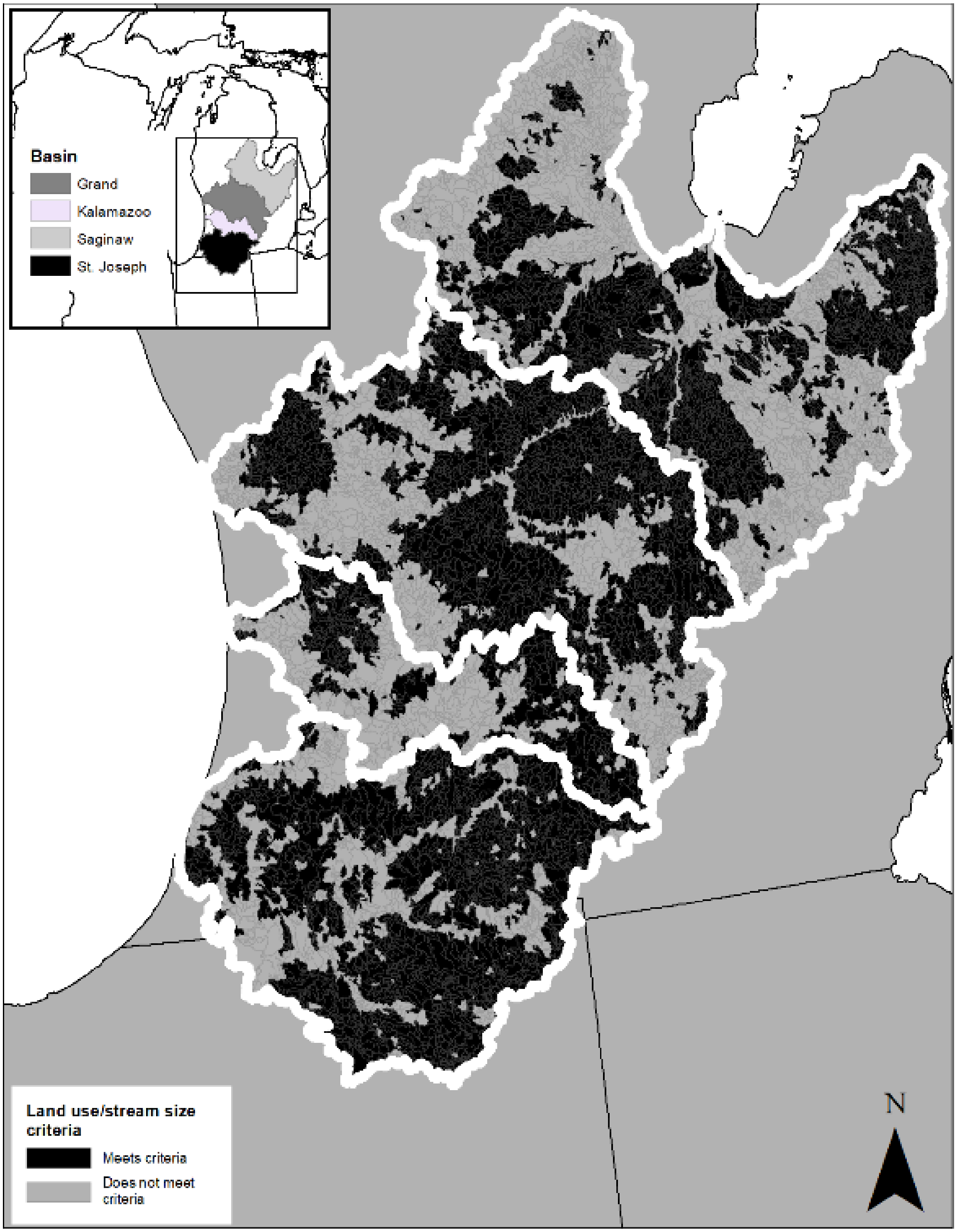

Figure B.2.1. Study basins with stream reaches draining areas less than 500 km^2 and with 50% or more of agricultural land in their catchments; these are described as streams that “meet” criteria.

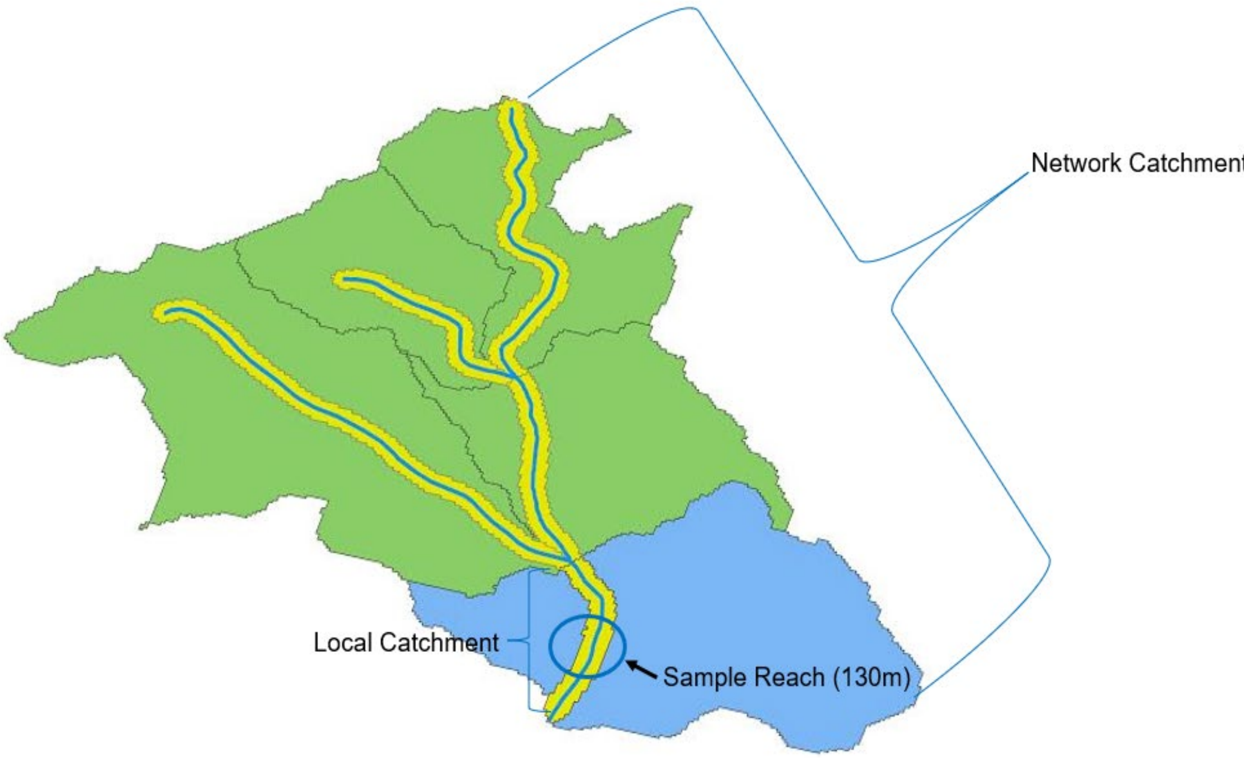

Figure B.2.2. Spatial units used for site selection and data analysis. Sample reaches (blue oval, 130m) were chosen in each stream reach that met study criteria. Study reaches are influenced both by their local catchment (blue) and the entire network catchment (blue and green). Riparian zone was analyzed within a 90m buffer (yellow) of each sample reach. See Crawford et al. (2016).

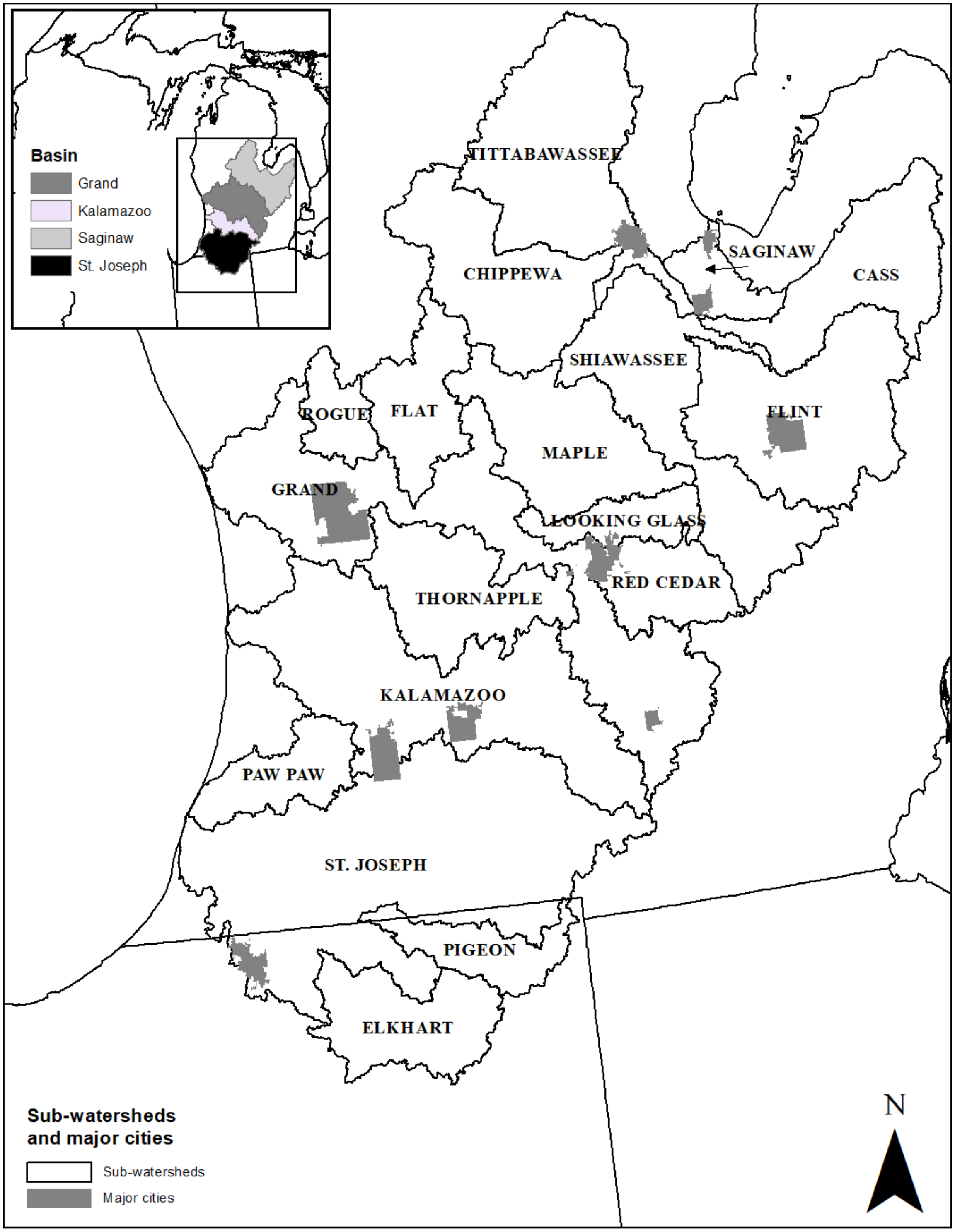

Figure B.2.3. Study basins with sub-watersheds (based off the MI DNR Major Watersheds layer) and major cities (based off Michigan's cities GIS layer queried to anything > 7000 acres in size).

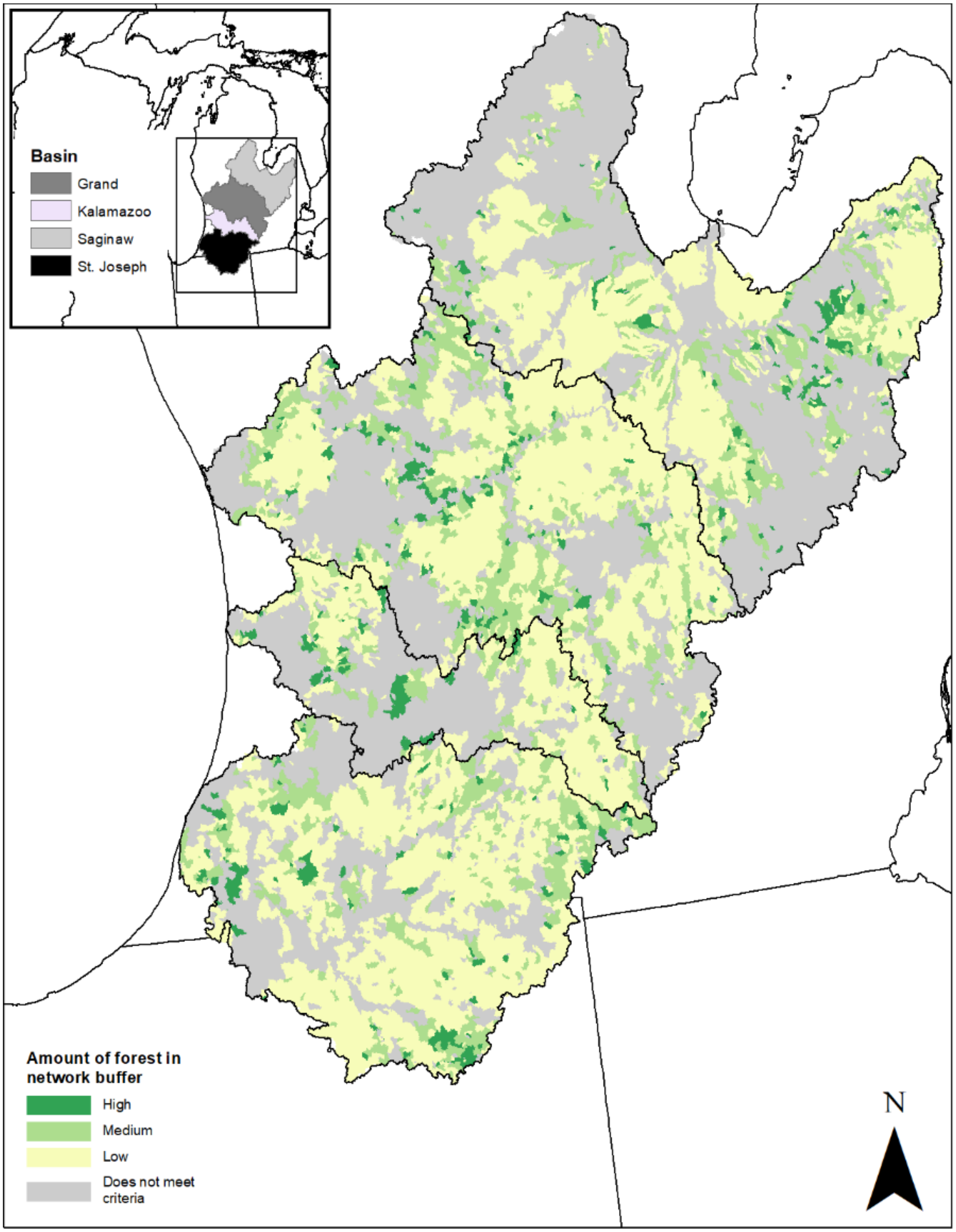

Figure B.2.4. Study basins with stream reaches categorized by the amount of forest in network buffers.

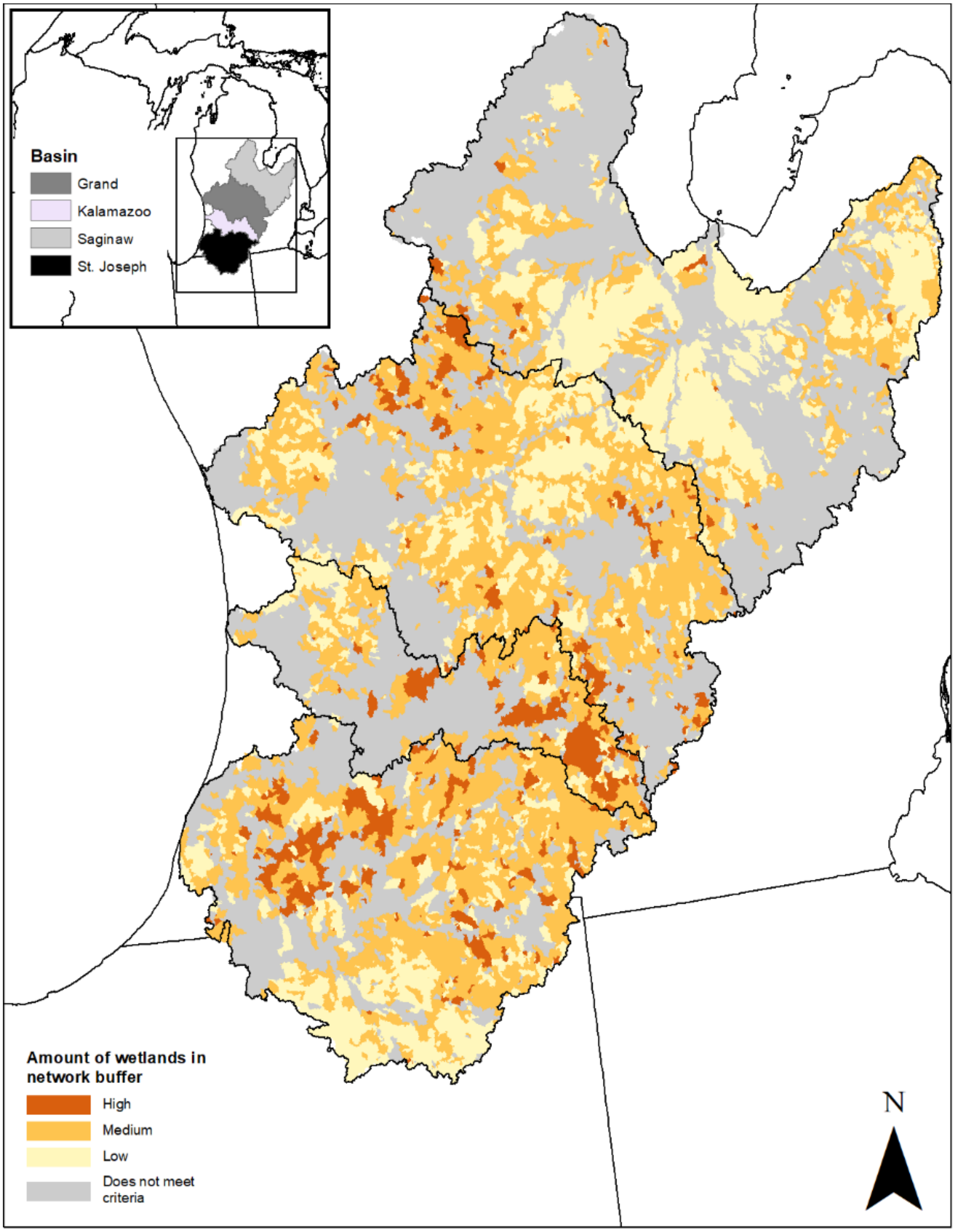

Figure B.2.5. Study basins with stream reaches categorized by the amount of wetland in network buffers.

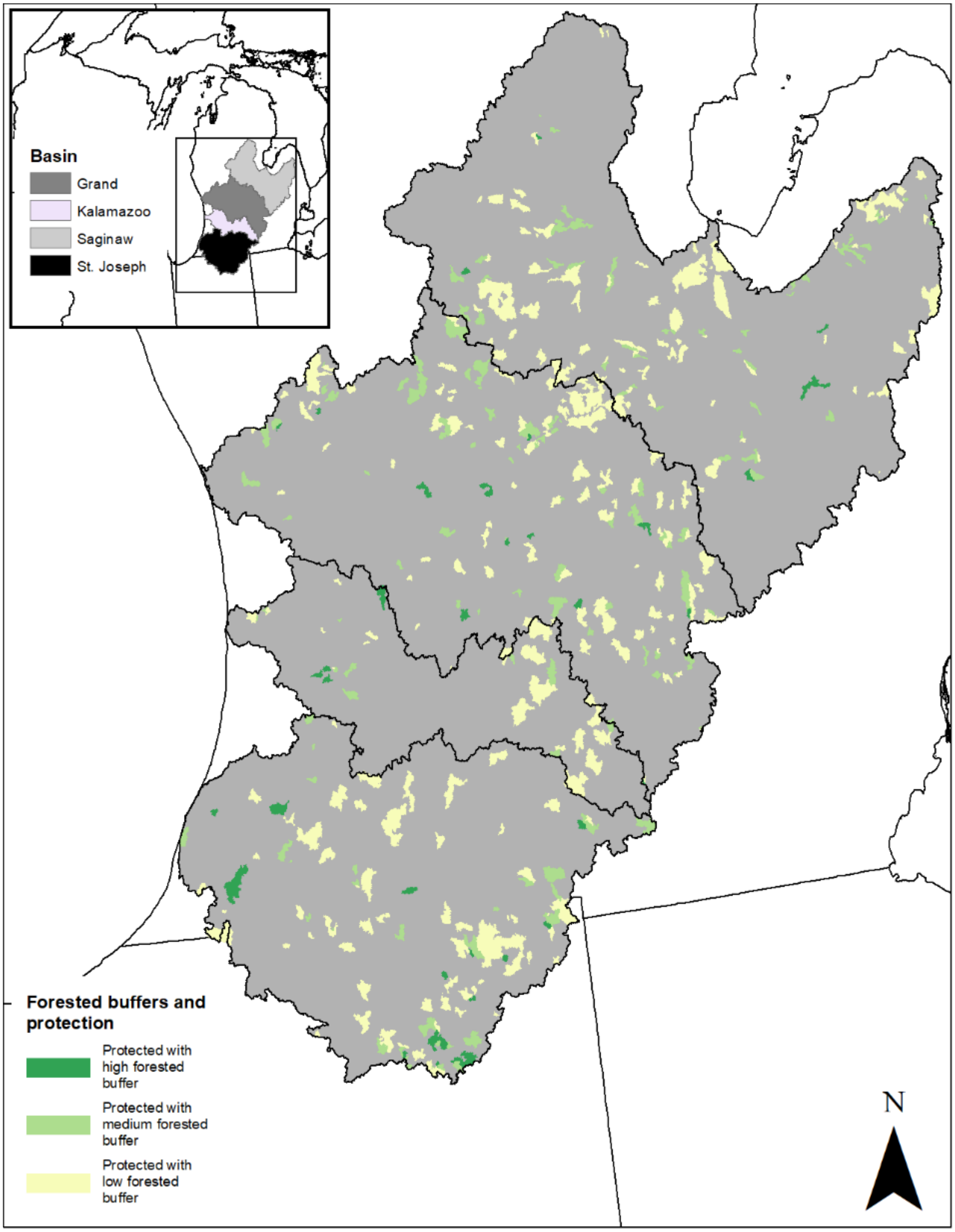

Figure B.2.6. Local catchments of stream reaches categorized by forest in buffers and with protected areas in catchments.

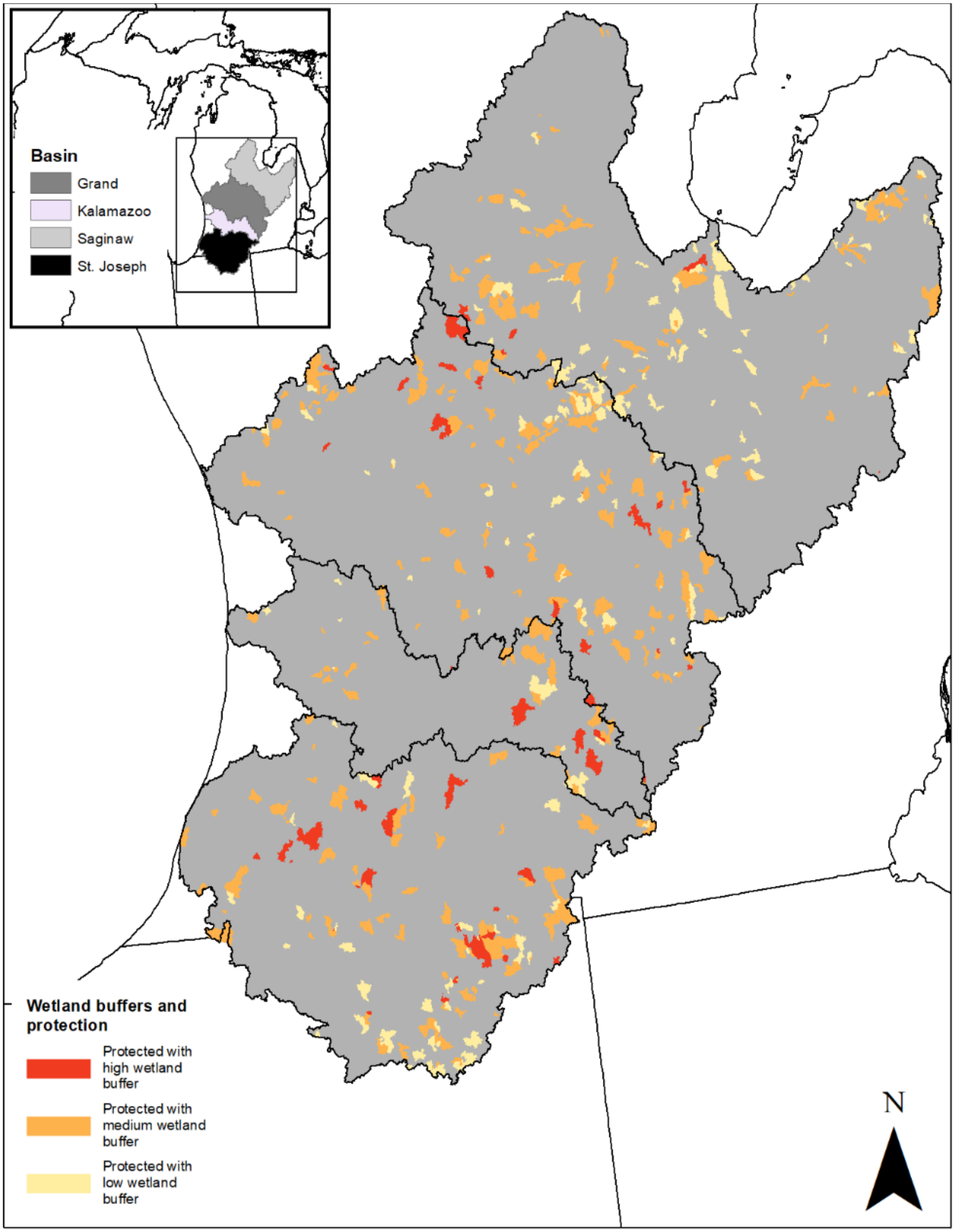

Figure B.2.7. Local catchments of stream reaches categorized by wetlands in buffers and with protected areas in catchments.

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MANAGEMENT RECOMMENDATIONS

Freshwater fish habitat continues to decline globally due to many stressors including agriculture, the focus of this study. However, effects of agriculture on fish habitat may be minimized through implementation of conservation practices such as forested buffers and wetland buffers. Our analyses of relationships between forest and wetland buffers on habitat in streams draining heavily agricultural watersheds helped us to identify locations and opportunities for managing agricultural land with buffers more effectively in Michigan. Building on our findings, we present a set of management recommendations to stakeholders along with a set of future studies that could build from our work.

CHAPTER 1: EFFECTS OF FORESTED BUFFERS ON FISH HABITAT IN STREAMS OF CENTRAL MICHIGAN: BALANCING SUSTAINABLE AGRICULTURE AND STREAM FISH CONSERVATION

In Chapter 1, we collected data from 30 sites in two major river basins in central Michigan, and our results demonstrated that forested buffers and wetland buffers positively affect stream fish habitat in heavily agricultural watersheds, including reducing streambed sedimentation and promoting channel morphology structure. Results obtained from this study will benefit stakeholders through our identification of the amounts of forested buffers and wetland buffers associated with desirable fish habitat factors This knowledge will aid in efforts to prioritize conservation actions to protect or establish buffers in tributaries of heavily agricultural watersheds of central Michigan.

Management actions

First, managers should identify streams with more than 30% of forested buffers in their networks as a benchmark for promoting fish habitat. If streams are draining heavily agricultural landscapes and have less than 30% vegetation in their buffers, additional steps should be taken to increase the amount of forested buffers in that watershed, including replanting buffers. Second, managers should facilitate the mechanisms to implement forested buffers for streams draining 50% or more of agricultural land and limited vegetation in their buffers (less than 30%), including providing funding, equipment, and labor, because these are the streams most in need of management actions. By targeting these types of streams, we anticipate seeing a reduction in sedimentation and in the erosion of channel morphology. In addition, we recommend to the managers to identify streams with sufficient amount of wetlands to promote a healthy fish habitat (we assume it is more than 50%). That will help them to identify benchmark conditions of a watershed, county or any area in particular for prioritization of management actions.

Future studies

Additional studies will enhance the results obtained from this study and increase our chances for successful management and conservation in the future. First, we recommend an evaluation to assess the conditions or quality of stream fish habitat based on the type of tree species composing the forested buffer. Another study that would be useful would be to compare effects of vegetated buffers on stream fish habitat across different spatial scales. Such a study could evaluate influences of local vs. network buffers. A third study can be developed by focusing on the financial benefits provided by forested buffers and wetland buffers; that will help us to clarify what monetary value can be attributed to the presence of these conservation practices. Such a study could take into consideration the costs involved that could be mitigated by implementation of forested buffers along with the costs of sediment management and fish stocking. A fourth study could include a behavioral analysis to understand motivations, actions and desires from private landowners or farmers to implement conservation practices on their properties.

CHAPTER 2: EVALUATING STREAM BUFFERS THROUGHOUT MICHIGAN'S LOWER PENINSULA: DEVELOPING SPATIALLY-EXPLICIT RECOMMENDATIONS FOR CONSERVING STREAM FISH HABITATS

Chapter 2 builds on Chapter 1 by extending results determined from 30 sites to all similar streams in four basins in central Michigan, the Grand, Saginaw, Kalamazoo, and St. Joseph. In Chapter 2, we create maps showing the amounts of forest and wetlands in network buffers of all small streams (<500 km^2 in area) in all four basins and assume that areas with limited vegetation in buffers may have limited fish habitat, while buffer areas with more than 30% forest or 50% wetlands may have adequate fish habitat. The information provided in Chapter 2 can also help stakeholders to identify areas where conservation efforts are needed.

Management actions

Managers need to identify and investigate streams with limited forests and wetlands in their buffers not only in private lands but also in protected areas in the state. This could potentially lead into other findings while comparing lands with different management activities throughout the year. Along with that, managers should re-evaluate the amount of acres designated as protected within the state and track the existing conservation practices that have been applied recently to better account for actions taking place in protected land. Another recommendation is to create a community program or engagement program to strength the participation and support of the community or watershed associations in the target areas; this may lead into more people implementing new buffers or protecting existing buffers. The information provided in Chapter 1, can also help managers to draft a strategy to extrapolate the results from Chapter 1 to other areas with heavy agriculture within the state of Michigan or even other states.

Future studies

One study that would be beneficial would be to test the effectiveness of a set of conservation practices in protected lands vs agricultural lands. This could lead to important findings because while we recognize that farmland may have more activity related to conservation than protected lands, it would be useful to describe benefits of conservation practices on stream habitat in both types of lands. A second future study should take in consideration the local climate and the most-commonly planted crops by watershed; those factors may affect streambed sedimentation. A third study to consider would be to evaluate any potential effects coming from nearby urban areas and determine if they served as a second stressor besides agriculture on some measures of habitat.