A Remote Sensing Analysis Of The Effects Of Watershed Disturbance And Riparian Integrity On Stream Fish Communities In The Red River Of The North Basin

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A REMOTE SENSING ANALYSIS OF THE EFFECTS OF WATERSHED DISTURBANCE AND RIPARIAN INTEGRITY ON STREAM FISH COMMUNITIES IN THE RED RIVER OF THE NORTH BASIN

by

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This thesis, submitted by Nicholas Kludt, in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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This thesis is being submitted by the appointed advisory committee as having met all of the requirements of the School of Graduate Studies at the University of North Dakota and is hereby approved.

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ABSTRACT

The relationships between fish species guilds, riparian cover, and vegetation disturbances in the surrounding landscape were examined across the 11 western tributaries of the Red River of the North. Archival stream sampling data, collected from 1993-2011 by North Dakota state agencies, were analyzed relative to temporally-appropriate land-cover predictors generated from National Land Cover Database and National Agricultural Imagery Program products.

The 0-30 m riparian cover width was the most influential landscape predictor influencing fish structure. The 0-30 m riparian cover displayed interactive effects with 30-50 m riparian cover width and watershed land-cover disturbance. These riparian scales were identified by a PCA of intact riparian area, determined from digitized 1m remotely sensed images. Tolerant and omnivorous species guilds had higher percent compositions where riparian cover in the 0-30 m scale was degraded. Conversely, insectivorous and benthic insectivorous species guilds had higher percent compositions where the 0-30 m riparian cover was more intact. Although suspended sediment loading resulting from riparian disturbance is suspected as a potential mechanism for the riparian effect, the limits of the 0-30 m riparian scale are recognized. The 0-30 m riparian scale is presently a proxy variable, as the results identify a structural relationship with the landscape and assumes mechanisms.

The investigation of riparian scaling also has implications for the incorporation of riparian effects into fisheries landscape analysis. Relationships between fish communities and riparian integrity or riparian composition have been reported at a variety of arbitrarily selected scales. To test the effects of generalizing riparian scale, a 0-50 m riparian scale was used rather than the 0-30 m scale determined to be the most important. The more general scale displayed slightly different relationships than were shown to exist. Caution should therefore be exercised if arbitrarily selecting riparian scale widths for fisheries landscape analysis.

CHAPTER I

INTRODUCTION

Stream fish communities are shaped in part by the watershed because of terrestrial inputs of sediments and other substances into streams (Horne and Goldman 1994). Variation in community structure is a response to variation in the environment, with fish occupying local niches that are most suitable. Agricultural land-use and other activities that disturb vegetation have been identified as key contributors of sediment in streams (Schlosser and Karr 1981, USEPA 1990). Sediment, in turn, is an important factor that shapes fish community structure through physiological and behavioral mechanisms. It is then logical that agricultural land-use has been shown to have a significant influence on fish community structure (Park et al. 2006). Riparian buffers attenuate sediment input by stabilizing soils, slowing runoff velocity, and increasing sediment deposition, thereby limiting the impact of vegetation disturbance in the watershed on stream fish communities (Waters 1995). A stream fish community's integrity is therefore potentially shaped by the interactions between land-use disturbances that generate sediment and the riparian buffer that prevents sediment from reaching the stream.

Aquatic ecologists and fisheries managers began intensive monitoring of stream fish communities and aquatic ecosystem integrity in response to the passage of the 1972

Water Quality Act Amendments. A variety of entities maintain a resultant wealth of archival fish sampling data. More recently, many of these data began to include spatial position information due to the rise of geographic information systems (GIS) and geospatial analysis in aquatic ecology. The proliferation of publicly available remote sensing imagery has made temporally-appropriate landscape data available in many regions. In both cases, the data cumulatively cover a broad spatial and temporal scale. The data therefore lend themselves to novel spatial and temporal analyses transcending the limits of the original studies for which they were collected. The fusion of archival fish sampling data, remotely sensed imagery, and GIS problem-solving enables the investigation of multi-scale landscape impacts on stream fish communities.

Studies of limited scale have examined the effects of landscape factors on stream fish abundance in the Red River of the North's drainage basin in North Dakota (Kelsch and DeKrey 1998, Kelsch and Alm 2001). Large amounts of stream fish sampling data have been collected in the basin, and the species present have been well documented (North Dakota Game and Fish Department 1962, 1964, 1975, 1977, Peterka 1978, Enblom 1982, Hansen et al. 1984, Neel 1985, Renard et al. 1986, Peterka 1991, Kelsch and DeKrey 1998, Kelsch and Alm 2001). Two state agencies, the North Dakota Game and Fish Department and the North Dakota Department of Health, maintain stream fish databases incorporating geospatial information from 1990 to 2012. For the first time, this project unifies the aforementioned abundance datasets and analyzes them spatially relative to land-cover and riparian integrity in a broad-scale GIS study.

The fundamental hypothesis tested was that the Red River of the North (hereafter the Red River) drainage basin's fish communities are spatially dependent on variations in riparian integrity and land-cover disturbance. The following objectives were used to examine the effects of land-use disturbance and riparian cover integrity on stream fish communities and specifically: 1) Quantify the levels of disturbed land-cover and riparian integrity of sampled reaches using remote sensing, 2) Create an integrated database joining the calculated land-cover data to archival stream sampling data from the North Dakota Game and Fish Dept. and the North Dakota Dept. of Health, and 3) Elucidate and test a statistical rationale linking spatial and quantitative land-cover variables with downstream fish-community assemblages.

Study Region

The major western drainages emptying into the Red River, ordered by confluence south to north, are the Bois de Sioux, Wild Rice, Sheyenne, Maple, Elm, Goose, Wilson-Sandhill, Turtle, Forest, Park, and Pembina rivers. The study region comprises these watersheds confined by the state boundaries of North Dakota (Fig. 1). The tributaries are part of the greater Souris-Red-Rainy region (Region 09) (USGS 2013).

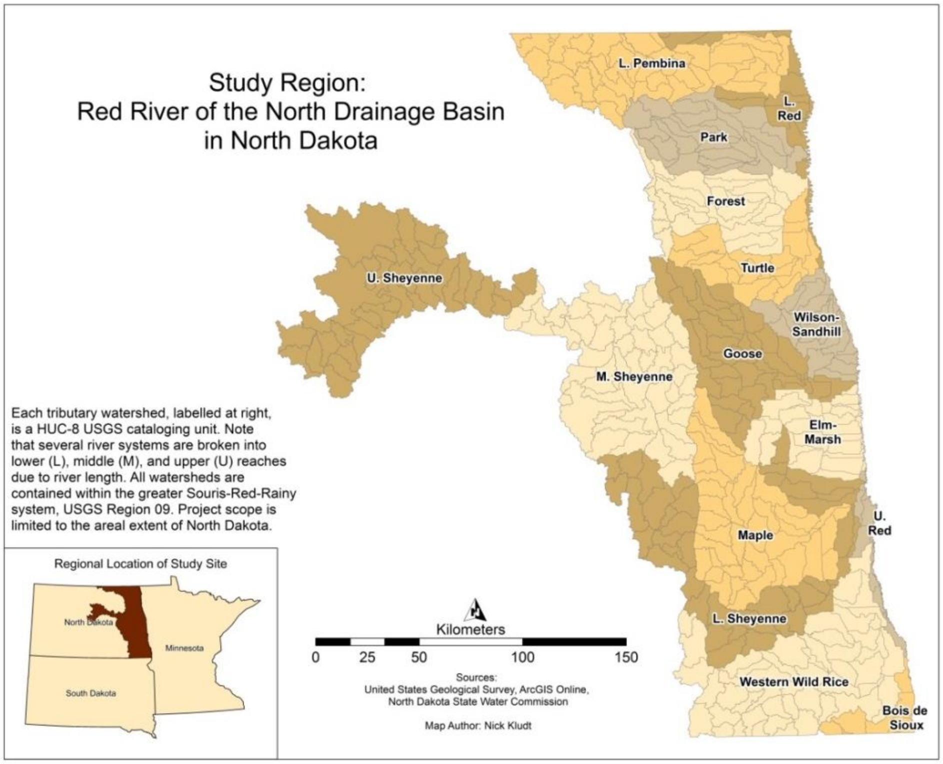

Figure 1: Map of Red River drainage basin.

The Red River system is primarily located in the Lake Agassiz ecoregion, with some headwaters in the Northern Glaciated Plains, as defined by Omernik (1987). The system is the major hydrologic unit of what once was a glacial lake. It drains nearly 34,000 km^2 in eastern North Dakota (Renard et al. 1986), roughly equivalent to 18.5% of the state's total area. Agricultural land-use accounts for 81% of the total land-cover in the basin (Strong 2010). Stream gradient varies from 0.04 to 0.25 m/km (Renard et al. 1986), with eight low-head dams on the mainstem. River flow increases greatly as the river widens in the lower segments. Mean annual flow at the river start in Wahpeton, ND, is 18.6 m^3/s, and increases to 127.9 m^3/s at Drayton, ND, just south of the Canadian border (Lyons 2008).

Sediment

Sediment is a potential mechanism of disturbance that can affect a stream fish community. Agriculture is by far the most significant contributor to sedimentation (Waters 1995), estimated at three times greater than any other source based on its national average (USEPA 1990). Several studies (Costa 1975, Lenat et al. 1979, Clark 1987) have shown, among all other sources, that the production of sediment and its subsequent transport to streams is greatest from row crops and other cultivated fields. Approximately 71.5% of the land surface is cultivated in the Red River Basin (Strong 2010). In conjunction with underlying geology prone to sedimentation (Lyons 2008), the high degree of cultivation in the Red River Basin is very likely a contributor to sediment in rivers and streams.

Livestock grazing is also a common disturbance in the region, with 9.5% of the land grazed or hayed (Strong 2010). Waters (1995) concluded overgrazing of a stream's riparian area results in immense damage to streams, mainly through bank destabilization and subsequent increased sedimentation. Where riparian areas are damaged by overgrazing or denuding of vegetative cover, natural processes, such as storm runoff, boost stream sediment load and decrease in-stream habitat quality. Sediment in the region can come from many sources, through both natural and anthropogenic disturbances. Because fish communities have evolved and formed in response to natural sedimentation, the anthropogenic disturbances are suspected to be responsible for changes in fish communities.

The Red River system is characterized by suspended sediments, primarily clays and silts that are relics of the Agassiz glacial lake plain (Stoner 1993, Goldstein 1995, Lyons 2008). Sediment is defined as particles transported by moving water ranging in size from <4μm to >256mm, with clay and silt particles <4μm and 4-62μm, respectively (Cummins 1962). Sediment transport in streams is conventionally divided into two types; suspended load and bed load (Richards 1982). Bed load consists of large particles that are transported along the bottom of a stream by sliding, rolling, or saltating. Conversely, suspended load is transported in the water column, and is generally composed of small particles. The mean total suspended load for the Red River Basin has been calculated at 42 mg/L (Stoner et al.1993).

Riparian Buffering

Riparian buffer areas play a key role in reducing the amount of sediment that makes its way into streams from agricultural lands (Yuan et al. 2009). Riparian buffering is the filtering function of vegetated strips abutting a stream or river. The reduced velocity of runoff as it moves through streamside vegetation decreases entrained sediment capacity. Sediment subsequently falls out of entrainment as a function of reduced velocity (Leopold et al. 1964).

Within the Red River study region, it is generally accepted that land-use disturbances, primarily through agriculture, have adversely affected fish communities (Niemela et al. 1998). The buffering effects of intact riparian cover have been demonstrated to improve fish communities by decreasing sediment load. Within the Red River Basin, Talmage et al. (2002) noted correlations between the riparian zone and stream conditions. At both local and larger scales, improvements in riparian zone quality were correlated with increased quality of the fish community. Community quality was assessed using the regional index of biotic integrity (IBI).

General restoration and enhancing the quality of riparian areas has been recommended as a means to improve stream conditions across the broadest range of environments (Schlosser and Karr 1981). An operational definition of an ideal riparian buffer is therefore necessary. In an extensive review of research across a wide array of grasses and forest buffers varying in composition, Yuan et al. (2009) found buffers over 6 m in width effective. Based again on review, Waters (1995) recommended 15-90 m as a general guideline for riparian buffer width. The proposed widths highlight the wide variation found in current riparian width recommendations. Both authors also examined the influence of riparian zone vegetative composition, but found effective widths to be indistinguishable between varieties of grasses, woody cover, and combinations thereof.

The importance of riparian width is also noted by major agencies. The USDA Natural Resources Conservation Service (NRCS) provides landowners with improvement protocols for riparian buffer strips. All protocols dealing with riparian buffers or filter strips use a uniform set of widths (USDA[a,b,c,d] 2012). According to NRCS protocols, buffers are to be 30-150 ft. wide, approximated at 10-50 m. The protocols have consistent widths regardless of vegetative land-cover type.

Sediment Effects on Fish

A large body of work exists documenting the effects of suspended sediment on the salmonids because of disturbances caused by forestry practices in the Pacific Northwest. Few reports list suspended sediment as a direct cause of mortality, except at extremely high levels (McLeay et al. 1987, Redding et al. 1987, Reynolds et al. 1989). The sublethal effects of suspended sediment are instead the focus. Sublethal respiratory impairment reduces fish health and limits normal activity. Berg and Northcote (1985) and

Servizi and Martens (1992) observed what were believed to be behavioral and physiological adaptations to tolerate acute increases in suspended sediment levels, such as a naturally occurring sediment pulse event. It was noted, however, that chronic exposure to elevated sediment levels, as generated by anthropogenic sources, could exceed the adapted tolerances.

The lethal or sublethal effects of suspended sediment on warm water fishes are less well-documented than those of salmonids. Although studies in this area are relatively few, great variation exists among species tolerance to suspended sediment (Waters 1995). Some fish may simply relocate when sediment loads increase (Barton 1977). The fishes remaining must cope with challenges presented by elevated suspended sediment levels.

Experiments show no significant effect of sediment on survival and hatch success of walleye (*Sander vitreus*) eggs at suspended sediment concentrations up to 500 mg/L (Suedel et al. 2012), although a fine silt covering of the substrate prevents adhesion of eggs, leading to egg entrainment and subsequent mortality (Crane and Farrell 2013). Species with parental care reproductive strategies are generally more successful in high silt environments, compared to broadcast spawners (Berkman and Rebeni 1987). Importantly, suspended sediment still inhibits reproductive success in species with parental care, as demonstrated by the centrarchids, notably largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), and redear sunfish (*Lepomis microlophus*) (Buck, 1956).

Suspended sediments have been shown to scour the gill tissues in larval walleye, leading to suffocation (Cordone and Kelley 1961). High suspended sediment levels have been noted as a lethal factor to larval walleye, mechanistically attributed to gill damage

(Mion 1998). Smallmouth bass (*Micropterus dolomieu*) appear to be highly affected by increased levels, with reduced feeding and growth of smallmouth bass larvae and fry due to loss of visual orientation in their environment. Development is impaired because of reduced predatory ability, especially in early fry stages (Cleary 1956, Larimore 1975).

In adult fishes, sublethal respiratory impairment is also a concern. Increased suspended sediment can reduce dissolved oxygen in the water column, and, at exceptionally high levels, may cause a thickening of the gill epithelium decreasing oxygen uptake (Horkel and Pearson 1976, Waters 1995). Other fishes, such as the common carp (*Cyprinus carpio*), can thrive in waters with high suspended sediment levels, expanding their range while conditions deteriorate for other species (Smith 1971).

Suspended sediment has behavioral implications, as well. The feeding success of fish species that rely on visual search strategies can be impaired (Henley et al. 2013). Bluegill feeding activity decreases at 60 nephelometric turbidity units (Gardener 1981). Suspended sediment is far less detrimental to adult walleye, with peak feeding occurring at medium turbidity levels, defined as 1-2m Secchi depths (McMahon et al. 1984). For prey fishes, it has been demonstrated that increased turbidity reduces predator recognition, potentially leading to increased mortality (Ferrari 2010). For both predator and prey species, relocation behavior has been observed if sediment loads exceed physiological tolerances (Barton 1977).

Generally, fish differ in behavioral and physiological responses to suspended sediment caused by landscape disturbance. Fishes that have similar responses to environmental challenges and occupy similar niches can be grouped into guilds, or groups of species that share a similar set of characteristics or niche occupancy.

Guilds and Hypothesized Landscape Interactions

The use of guilds to analyze fish community data is an accepted method. The index of biotic integrity (IBI) and its fish guilds were developed by Karr (1981) as an alternative to single-species abundance and chemical content monitoring of stream status, methods criticized as inappropriate for determining overall aquatic habitat health (Thurston 1979, Gosz 1980, Karr and Dudley 1981). To resolve these issues, Karr (1981) proposed the IBI, based on fish community structure. Guilds were developed as a convenient way of organizing fish community structure and analyzing it relative to the surrounding environment. During the adaptation of the IBI to the Red River Basin, all fish occurring historically or presently in the region were grouped into ecological guilds through the combined work of Niemela et al. (1998), Barbour et al. (1999), Pflieger (1997), and others. These guilds are employed here to examine how segments of the stream fish community respond to landscape disturbance and riparian integrity. For guild species lists, see Section 1 of the Appendix.

Fishes of the Red River can be divided into ecological guilds based on three categories: feeding preference, feeding mode, and environmental tolerance. A fish species belongs to a specific guild in each of the three categories. Abundances of fish at any location differ between guilds because each guild responds uniquely to acute and chronic toxicity and stress from environmental conditions (Karr 1981). Following Niemela et al. (1998), not all guilds within the three categories are used in this study. Instead, only a subset of specific guilds hypothesized to be useful for addressing questions related to sediment and landscape influences were chosen.

The first guilds are derived from feeding preference. Each of these guilds is defined by predator choice. The guilds are omnivorous, insectivorous, and piscivorous species. In locations where the surrounding landscape is highly disturbed and riparian integrity is low, the omnivorous guild percent compositions are expected to be higher. Inversely, if the surrounding landscape is not disturbed and riparian integrity is high, the insectivore percent compositions are expected to be higher. If the surrounding landscape is highly disturbed and the riparian integrity is low, then the piscivores should show very low percent compositions due to visual impairment.

The next guild is derived from feeding mode. Feeding mode refers to mouth position, feeding habitat, and, to a lesser extent, prey type. Benthic insectivores are a guild of sub-terminal mouth fishes that rely on prey that require adequate interstitial benthic cover. Benthic insectivores are adversely affected by siltation. In locations where the surrounding landscape is highly disturbed and riparian integrity is low, percent compositions of the benthic insectivores are expected to be very low.

The final guild is derived from environmental tolerance. Variation in tolerance for degraded conditions differs among fish species. Physiological factors shape community structures. The tolerant species guild is able to thrive in conditions detrimental to other species. In locations where the surrounding landscape is highly disturbed and riparian integrity is low, percent composition of the tolerant guild is expected to be higher.

Guilds are not only formulated based on the ecology and physiology of organisms. Special guilds addressing human goals and concerns are also developed to help inform management of populations. A management objective in fisheries biology often relates to effective use of monies to preserve or enhance populations. Members of managerial guilds are analyzed together, regardless of ecological guild membership, to build general principles regarding best-use practices. These principles transcend individual ecological guilds, informing strategies that create the best return on investment for conservation and management dollars.

The first management guild is “Game Fish Status.” Game fish guild membership is limited to fish whose capture is specifically regulated by the sport fishing laws of North Dakota. Understanding the relationship between terrestrial factors and the sport fish community is helpful for effectively leveraging conservation dollars for maximum public recreational and consumptive benefit. Members of the game fish guild are hypothesized to thrive in pristine environments, so more pristine streamside conditions should yield a better sport fishery. In locations where the landscape is less disturbed and riparian integrity is high, a higher percent composition of game fish is predicted.

The second management guild is “Species of Concern.” Members of this guild are defined by the Dakota Chapter of the American Fisheries Society (1994). To be included, a species must be native to the watershed. Furthermore, the species must have a) numbers declining from human activity, b) a unique and limited habitat, c) suspected problems with abundance or distribution, or d) limited historical citations. Again, more pristine streamside conditions are assumed to be beneficial for this guild. In locations where the landscape is less disturbed and riparian integrity is high, a higher percent composition of species of concern is predicted.

To summarize my hypotheses, if the landscape is more disturbed and riparian integrity is low, then tolerant and omnivorous guild percent composition are predicted to be high. Inversely, if the landscape is less disturbed and riparian integrity is high, then insectivorous, piscivorous, benthic insectivorous, game fish, and species of concern are predicted to be high.

CHAPTER II

METHODS

Sampling Database

Archival fish sampling data were obtained from the North Dakota Department of Health and the North Dakota Game and Fish Department. Electrofishing sampling events (n=181) occurred from 1993-2011 across the Red River basin. Data from other gears, although available in limited quantities, were not used because electrofishing has distinct selectivity and efficiency biases, potentially leading to confounding influences (Poesch 2014, Reynolds 1996, Wiley and Tsai 1983). Despite species detectability concerns (Reynolds 1996), electrofishing data presented the largest temporal and spatial coverage of the study area.

All data entries were split into three temporal bins and given an identification key based on land-cover data availability. Bins were named after the most temporally appropriate National Land Cover Database (NLCD) products available for the sampled periods. Data collection years 1993-1998 were grouped in the "1992" bin, years 2005-2007 were grouped in the "2006" bin, and years 2010-2011 were grouped in the "2011" bin (Figure 2). Replicate samples at a given location within each temporal bin were averaged to avoid spatial autocorrelation from uneven sampling concentrations. A unique replicate key was given to each averaged sample abundance and the associated collection datum.

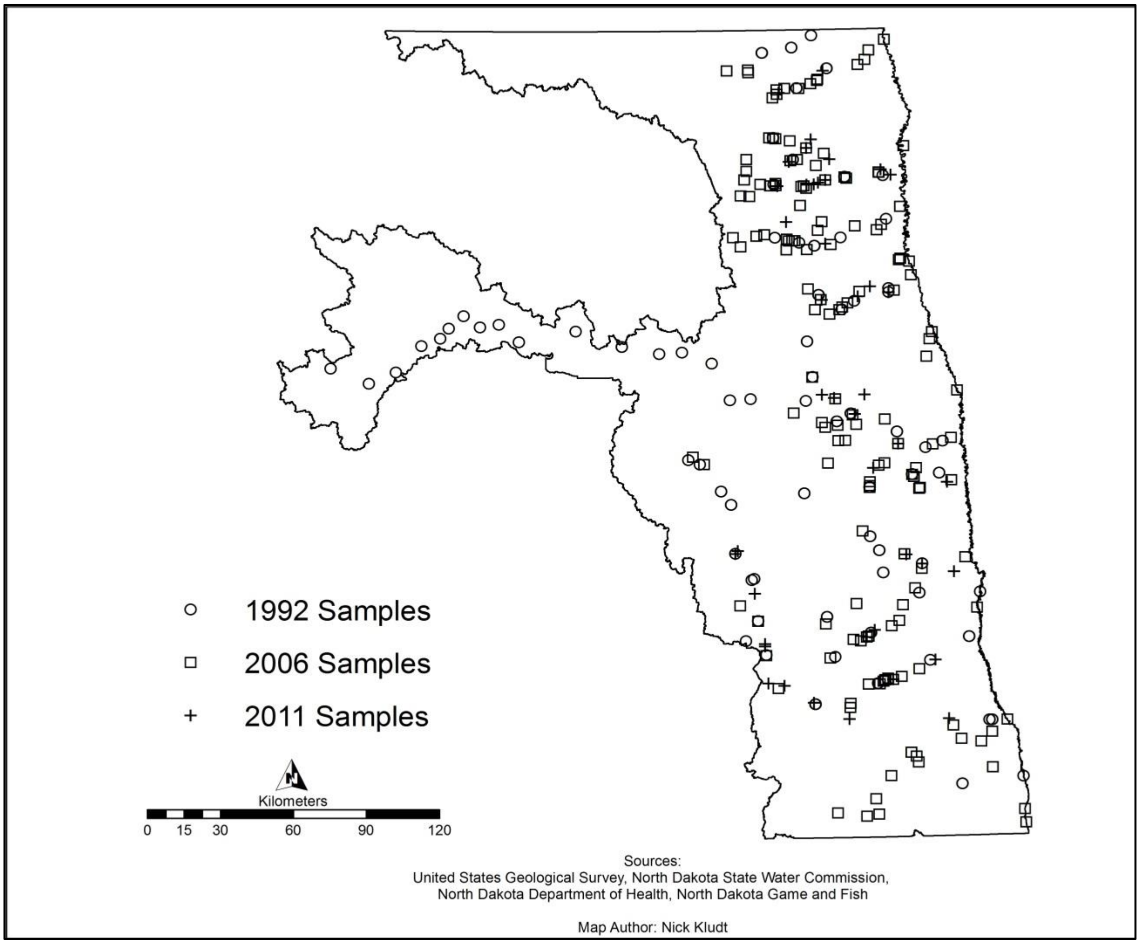

Figure 2: Archival sampling locations in the Red River basin organized by three temporal bins. Samples were collected from 1993-2011 and were placed into temporal bins for analytical purposes. Note the uneven spatial and temporal distribution of sampling locations. This variation prevented comparisons of temporal bins relative to each other, and necessitated data pooling for final analysis.

Abundances were then converted to percent species compositions to standardize for differences in catch per unit effort and varying sampling protocols. Percent compositions of species were pooled by guild. Percent compositions were calculated for the environmentally tolerant, omnivore, insectivore, benthic insectivore, and piscivore ecological guilds, as well as the game fish and species of concern management guilds.

The replicate keyed dataset, or the final product of initial archival fish sampling data processing, formed the basis for further analyses. Uneven temporal and spatial replication (Figure 2), including a sampling gap from 1998-2005, made comparison of the three temporal bins inadvisable. Geoprocessing, conducted in ArcMap 10.2 (Environmental Systems Research Institute, Redlands, California) unless otherwise noted, proceeded with the replicate keys linking sampling data to the appropriate land-cover data in each temporal bin.

Stream Digitizing and Percent Riparian Integrity Calculation

A highly accurate stream map of the Red River tributaries was the foundational layer necessary for establishing fish assemblage – land-cover relationships. The existing U.S. Geological Survey (USGS) and N.D. State Water Commission stream shapefile was unsuitable due to cartographic over-generalization, so a more accurate stream map was needed.

The 1997-1998 USGS digital orthophoto quarter-quadrangles (DOQQ) rasters, along with 2006 and 2010 National Agriculture Imagery Program (NAIP) rasters were the highest quality temporally appropriate aerial imagery available for the 1992, 2006, and 2011 temporal bins, respectively. Using a separate shapefile for each temporal bin, the USGS stream shapefile was edited to follow the centerline of the perennially flowing Red River tributaries. This eliminated generalization and ensured all distance measures based on the stream line were accurate to the greatest extent possible.

In each temporal bin, the replicate keyed sampling points were overlain on the appropriate stream line and aerial imagery. Sectioning the sampled stream reaches was a two part process. Using the “Split Line at Point” tool, each continuous stream line was cleaved into smaller sections divided by sampling points. The “Split” tool then was used to subset a 3-km reach of the stream line fragments upstream of each sampling site. The

3-km stream reach reflects the hypothesized scale where riparian processes influenced stream conditions (Barton et al. 1985).

Using the appropriate imagery, the 3-km stream reach footprints were digitized, yielding a polygon representative of the spatial extent of the area upstream from the sampling point. A 50-m buffer was applied to the stream footprint polygons. The ends of the buffer were squared using the “Trace” digitizing tool to follow the river course on both sides. The rounded buffer ends were removed by squaring buffers perpendicular to the direction stream channel. This created a template buffer.

Within the 50-m template buffer, all intact riparian cover was digitized. A ring buffer was then applied with five 10 m rings. The ring buffer was clipped to the extent of the intact riparian cover shapefile (Figure 3). The clipped ring buffer areas were tabulated using the “Calculate Geometry” tool. Each ring is referred to by its outer distance from the stream bank and spans only 10 m (e.g., the 10-m buffer covers 0-10 m and the 50-m buffer cover 40-50 m). This process yielded the area of intact riparian cover within 10-m bands out from the bank to a maximum of 50 m. Intact riparian area in each band was converted to a percentage to ease comparability of sites.

Intact riparian area was defined as any riparian cover adjacent to the stream possessing undisturbed vegetation that would stabilize the bank area against erosion and could potentially function as a sheet runoff filter. Rip-rapped areas or other artificially stabilized areas were also classified as intact. The opposite was non-intact riparian area, or any area adjacent to the stream with naturally bare ground, cultivated agricultural land, vegetation removal, or substantial disturbance. In essence, non-intact riparian cover included areas that were not intact riparian cover, regardless of land-cover type.

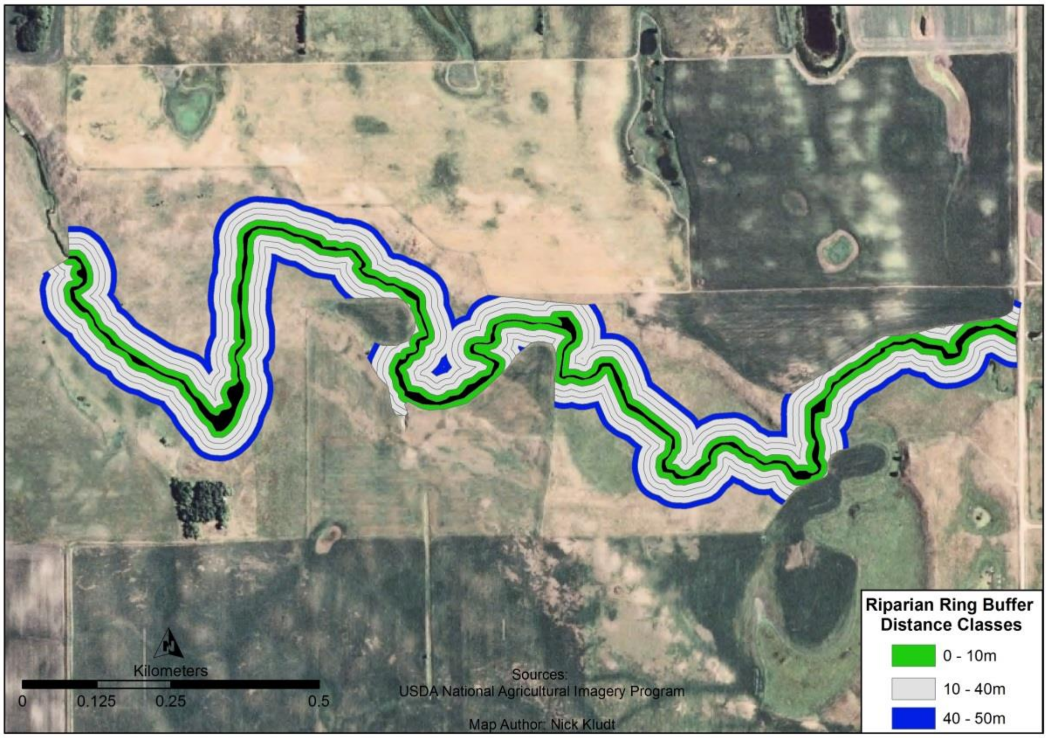

Figure 3: Processed ring buffers surrounding a stream reach (shown in black) at a sample location. Note the clipping of the ring buffers to cover only intact riparian cover and the emphasis on the 10 m and 50 m riparian rings. Based on a principle components analysis, the intact percentage of these rings was used for inferences about scaling of riparian effects.

HUC-12 Disturbed Land-cover Calculation

The 1992 (Vogelmann et al. 2001), 2006 (Fry et al. 2011), and 2011 (Jin et al. 2013) NLCD full classification scheme was deemed irrelevant to prevention of suspended sediment, and was reduced to avoid spurious correlations. The NLCD products were reclassified into 3 classes (Table 1). The 1992 NLCD uses a different classification scheme than the other two products, necessitating slight modifications to the reclassification scheme. After NLCD reclassification, the new Disturbed, Undisturbed, and Open Water categories were accuracy assessed to ensure local classifications were functioning reliably. Disturbances were defined as human-induced changes that destabilized the land-cover and natural hydraulic processes, enhancing runoff potential. NLCD land-cover classes based on disturbances were placed into the Disturbed category. The Open Water class was discarded following accuracy assessment as it had no relation to landscape inputs into aquatic systems.

Table 1: Reclassification categorizations of 1992, 2006, and 2011 National Land Cover Database (NLCD) to a simple 3-class system. Given the large number of land classes irrelevant to the impact of land-cover disturbance on stream fishes in the base NLCD classification, there was potential for correlations arising from Freedman's Paradox. Differences in 1992 and 2006/2011 NLCD land-cover classification schemes led to two reclassification approaches.

	1992 NLCD	
Disturbed	Undisturbed	Open Water
Bare rock/Sand/Clay	Perennial Snow/Ice	Open Water
Quarries/Strip Mines/Gravel Pits	Deciduous Forest	
Transitional	Evergreen Forest	
Orchard/Vineyards/Other	Mixed Forest	
Row Crops	Shrubland	
Small Grains	Grasslands/Herbaceous	
Fallow	Woody Wetlands	
Pasture/Hay	Emergent Herbaceous Wetlands	
Urban/Recreational Grasses		
Low Intensity Residential		
High Intensity Residential		
Commercial/Industrial/Transportation		
	2006 & 2011 NLCD	
Disturbed	Undisturbed	Open Water
Barren Land	Perennial Snow/Ice	Open Water
Cultivated Crops	Deciduous Forest	
Pasture/Hay	Evergreen Forest	
Developed Open Space	Mixed Forest	
Developed Low Intensity	Dwarf Shrub	
Developed Medium Intensity	Shrub/Scrub	
Developed High Intensity	Grasslands/Herbaceous	
	Sedge/Herbaceous	
	Lichens	
	Moss	
	Woody Wetlands	
	Emergent Herbaceous Wetlands	

Reclassified land-cover data were accuracy assessed in ERDAS Imagine 2013 (Hexagon Geospatial, Madison, Alabama) using the accuracy assessment module. A stratified random sample of 30 points per land-cover class was applied and assessed for each reclassified raster. The reference images were the same imagery from the riparian delineation (1997-98 USGS DOQQ, 2006 NAIP, 2010 NAIP). The individual land-cover class accuracy minimum was 80.56%, and all reclassification overall accuracies exceeded 90% (Table 2). A Kappa analysis, analogous to a Chi-square test of land-cover classification error, was conducted. All Kappa values exceeded the 0.80 level (Table 2), indicating high producer accuracy (Congalton and Green 2008). Results were satisfactory, and no remedial action was necessary.

Table 2: Accuracy assessment results for reclassified National Land Cover Database products. Reference images were corresponding 1997-98 USGS DOQQ, 2006 NAIP, and 2010 NAIP. All percent accuracies and Kappa values were satisfactory.

		1992	2006	2011
Percent Accuracy	Disturbed	94.29	90.91	80.56
	Undisturbed	87.50	93.75	91.31
	Water	100.00	100.00	100.00
	Overall	93.63	94.89	90.62
Kappa Statistic		0.83	0.92	0.87

Land-cover proportions were tabulated by HUC-12. The land-cover analysis was conducted at the HUC-12 USGS catalog unit scale, which is the fourth administrative subdivision level of the greater Souris-Rainy-Red USGS Region 09. The HUC-12 level was chosen to minimize pseudo-replication, as a larger catalog or catchment unit would contain multiple sample reaches.

Statistical Analysis

Because the archival stream sampling data include locational information, they are considered geospatial data. Geospatial data are unique because of Tobler's first law of geography, which states, "Everything is related to everything else, but near things are more related than distant things" (Tobler 1970). In geostatistics, Tobler's relationships between data points are referred to as spatial autocorrelation (Legendre 1993). This is a violation of the independent observations assumption. Because all aspects of the project involve locational relationships, this is an important consideration. If not dealt with, spatial autocorrelation could bias the fit of the landscape-fish community model.

In the study design, averaging replicate observations and using the HUC-12 catalog unit reduced clustering of data points, which helped prevent spatial autocorrelation problems. Formal testing of spatial autocorrelation was implemented using SAM: Spatial Analysis in Macroecology (Rangel et al. 2010). Spatial autocorrelation was tested using Moran's I and was implemented for each of the analysis guilds described in Chapter 1. Correlogram inflection points and Moran's I values were satisfactory (see Section 2, Appendix), with interpretation following Legendre and Legendre (2012). Spatial autocorrelation was assumed to be inconsequential.

All further statistical analyses were conducted in R (R Core Team 2013). Initial analyses focused on identifying correlational structure of predictor variables. Potential colinearity of the ring buffers at each sampling reach was explored using a principle component analysis (PCA), conducted using libraries "lattice," (Sarkar 2014) and "devtools" (Wickham 2014). The exploratory analysis was conducted to understand how the land-cover predictors related to each other. Multiple regression tests are fairly robust, but are more reliable when all assumptions are nearly, if not completely, met. Avoiding the inclusion of unnecessary variables was a priority, as spurious correlations that are not biologically relevant can arise via Freedman's Paradox.

Table 3: Pearson's product moment correlation tests examining colinearity structure between riparian ring buffers. Note the weakest correlation, denoted with (*).

Riparian Buffer Correlations	Pearson's r	t-value	df	p-value
10 m and 20 m	0.832	20.434	186	<0.0001
10 m and 30 m	0.631	11.095	186	<0.0001
10 m and 40 m	0.581	9.748	186	<0.0001
10 m and 50 m*	0.531	8.543	186	<0.0001
20 m and 30 m	0.919	31.756	186	<0.0001
20 m and 40 m	0.858	22.756	186	<0.0001
20 m and 50 m	0.808	18.673	186	<0.0001
30 m and 40 m	0.974	59.031	186	<0.0001
30 m and 50 m	0.939	37.338	186	<0.0001
40 m and 50 m	0.987	83.108	186	<0.0001

Table 4: Principle components analysis loadings examining groupings of the riparian buffers. Note loading directionality difference between riparian buffers in principle component 2 (PC 2).

Riparian Buffer Rings	PC 1	PC 2	PC 3
50m	0.589	0.496	-0.400
40m	0.570	0.167	0.609
30m	0.483	-0.302	-0.109
20m	0.301	-0.741	-0.321
10m		-0.293	0.596
Proportion of Variance	0.951	0.039	0.007

The PCA was used to determine potential groupings of the riparian ring buffers. Due to severe, yet expected, colinearity of predictors (Table 3), principle component (PC) 1 was a representative of the buffers correlating to themselves (Table 4). PC 2 had two distinct groupings of buffers, from 0-30 m and 30-50 m. The biplot shows how these components act in similar directions along PC 1, but have different directionality on PC 2 (Figure 4). The directionality difference, along with the loading difference, prompted the investigation of potential riparian scaling effects. The 10-m and 50-m buffers were retained as representative of the 0-30 m and 30-50 m groupings, respectively. The 10-m and 50-m buffers were also the least collinear (Table 3).

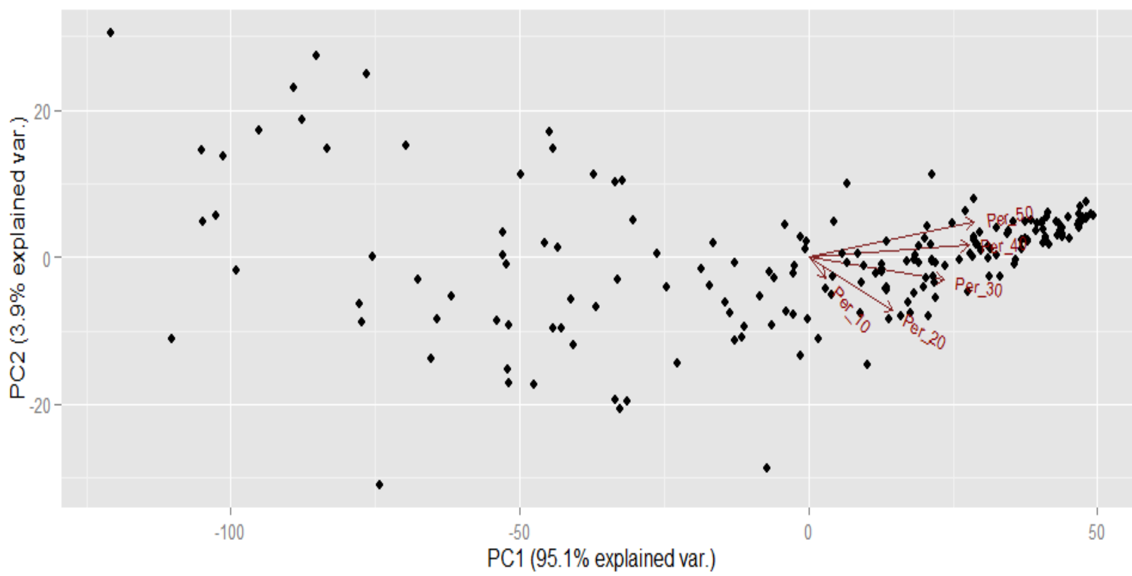

Figure 4: Principle components biplot examining groupings of the 10 m riparian buffers. PC = principle component. The in-chart notation "Per_x" is the percent integrity of a buffer ring distance class. Note the differences in directionality between riparian buffers in component 2. See Table 3 for PCA loadings.

The correlation test for the Disturbed and Undisturbed land-cover classes was also significant (p = <0.0001, Pearson's r = -0.997, t = -183.332, df = 186). The two variables are highly correlated because they are opposites. Under our classification scheme, if a parcel is not Disturbed, it is Undisturbed. We therefore only retained the disturbed land-cover class, along with the 10-m and 50-m riparian buffers, for the final analysis.

Multiple regressions using an information theoretic multi-model inference approach were used to determine if the 10-m riparian buffer, 50-m riparian buffer, and disturbed land-cover class influenced guild percent composition as hypothesized.

Normality and tolerance values were assessed and found to be satisfactory. Initial model assessment was conducted using AICc to rank models. Individual predictor support was assessed by summing AICc weights of all candidate models that included the predictor (MacKenzie et al. 2006). The ΣW scale is 0-1, with 0 offering no support and 1 offering substantial support (MacKenzie et al. 2006). Model-averaged estimates were generated to understand the landscape predictor effects. Multi-model inference and model averaging was conducted using library “AICcmodavg.” (Mazerolle 2014).

CHAPTER III

RESULTS

Following the methods described in the previous chapter, percent composition by guild was analyzed relative to proportional riparian integrity at 0-30 m and 30-50 m scale and disturbed HUC-12 land-cover. Multi-model inference was the primary tool for detecting effects. Full model sets are included for each guild (Table 5). Models are ranked by ΔAICc relative to the top-performing model. In a separate ranking, a strict ΔAICc $\geq$4 threshold was used to differentiate candidate model performances from the intercept (null) model performance (Burnham and Anderson 1998). Only models exceeding the threshold value were considered meaningful. Models for the tolerant, omnivorous, insectivorous, benthic insectivorous, and species of concern guilds displayed meaningful relationships with landscape predictors. Piscivorous and game fish models were inconclusive.

Meaningful tolerant, omnivorous, insectivorous, and benthic insectivorous guild models consistently included the 10-m riparian term. Most models that included the 10-m term performed better than the intercept model in these guilds. Given the superior performance of the models including the 10-m riparian term, evidence seems to suggest that the proportion of intact vegetation in the 0-30 m riparian scale is important across several guilds. The low differences in residual standard error indicate that the effect is not major, but model performances indicate it is consistently meaningful.

The 50-m riparian term, representative of the proportion of intact riparian vegetation in the 30-50 m scale, was independently meaningful for the insectivorous and species of concern guilds. The independent 50-m riparian term model did not perform as well as the 10-m riparian model. The proportion of disturbed watershed land-cover did not perform well independently, but was included in top-performing models for each guild.

Table 5: AICc model selection results by guild. Guilds with meaningful relationships denoted with (*). Superior model performances are strictly differentiated from the intercept model performance (ΔAICc ≥4) denoted with (**). Note the consistently good performance of the 10-m riparian term, representative of the 0-30 m riparian scale. W is AICc weight, LL is log-likelihood, SE is standard error. Note the low differences in LL score and residual SE across models in each guild.

Guild	Predictors	K	AICc	ΔAICc	W	Residual SE
Tolerant*	10m **	3	1802.00	0.00	0.48	28.87
	10m + Disturbed**	4	1803.76	1.77	0.20	28.92
	10m + 50m**	4	1803.82	1.82	0.20	28.92
	10m + 50m + Disturbed**	5	1805.31	3.32	0.09	28.95
	Intercept only	2	1809.75	7.75	0.01	29.55
	50m	3	1810.34	8.34	0.01	29.51
	Disturbed	3	1810.42	8.43	0.01	29.52
	50m + Disturbed	4	1811.82	9.83	0.00	29.55
Omnivorous*	10m**	3	1807.73	0.00	0.36	29.31
	10m + Disturbed**	4	1808.35	0.61	0.26	29.27
	10m + 50m**	4	1809.33	1.60	0.16	29.35
	10m + 50m + Disturbed	5	1810.36	2.62	0.10	29.34
	50m	3	1811.70	3.97	0.05	29.62
	50m + Disturbed	4	1812.71	4.98	0.03	29.62
	Disturbed	3	1813.10	5.37	0.02	29.73
	Intercept only	2	1814.13	6.40	0.01	29.90
Insectivorous*	10m**	3	1814.49	0.00	0.31	29.84
	10m + Disturbed**	4	1815.18	0.68	0.22	29.81
	10m + 50m**	4	1815.45	0.96	0.19	29.83
	10m + 50m + Disturbed**	5	1816.78	2.28	0.10	29.85
	50m**	3	1816.87	2.38	0.09	30.03
	50m + Disturbed	4	1818.18	3.69	0.05	30.05
	Disturbed	3	1819.65	5.16	0.02	30.25
	Intercept only	2	1821.54	6.05	0.02	30.41

Table 5 Cont.

Guild	Predictors	K	AICc	ΔAICc	W	Residual SE
Benthic Insectivorous*	10m**	3	1583.89	0.00	0.52	16.16
	10m + 50m**	4	1585.97	2.08	0.18	16.20
	10m + Disturbed**	4	1585.98	2.09	0.18	16.20
	10m + 50m + Disturbed	5	1588.08	4.20	0.06	16.25
	50m	3	1590.54	6.65	0.02	16.45
	Intercept only	2	1590.81	6.92	0.02	16.51
	Disturbed	3	1592.53	8.64	0.01	16.54
	50m + Disturbed	4	1592.63	8.74	0.01	16.49
Piscivorous	Intercept only	2	15559.76	0.00	0.32	15.20
	50m	3	1560.63	0.87	0.21	15.19
	Disturbed	3	1561.72	1.96	0.12	15.24
	10m	3	1561.80	2.04	0.12	15.24
	10m + 50m	4	1562.47	2.71	0.08	15.22
	50m + Disturbed	4	1562.71	2.95	0.07	15.23
	10m + Disturbed	4	1563.80	4.04	0.04	15.28
	10m + 50m + Disturbed	5	1564.57	4.81	0.03	15.26
Game Fish	Intercept only	2	1598.64	0.00	0.38	16.85
	50m	3	1600.48	1.85	0.15	16.89
	10m	3	1600.68	2.05	0.14	16.90
	Disturbed	3	1600.69	2.06	0.14	16.90
	10m + 50m	4	1602.36	3.72	0.06	16.93
	50m + Disturbed	4	1602.48	3.85	0.06	16.93
	10m + Disturbed	4	1602.77	4.13	0.05	16.94
	10m + 50m + Disturbed	5	1604.38	5.74	0.02	16.97
Species of Concern*	50m**	3	1245.74	0.00	0.40	6.58
	50m + Disturbed	4	1247.15	1.41	0.20	6.58
	10m + 50m	4	1247.67	1.93	0.15	6.59
	10m + 50m + Disturbed	5	1249.10	3.37	0.07	6.60
	Disturbed	3	1249.14	3.40	0.07	6.63
	Intercept only	2	1249.98	4.24	0.05	6.67
	10m + Disturbed	4	1250.79	5.05	0.03	6.65
	10m	3	1251.05	5.32	0.03	6.67

Summed model weights for each term give further evidence for the 10-m riparian term effect (Table 6). The tolerant, omnivorous, insectivorous, and benthic insectivorous guilds displayed meaningful relationships in the multi-model approach, and the summed weights help dissect the importance of each predictor. For the aforementioned guilds, the

10-m riparian weight is notably larger than the 50-m, disturbed, and intercept weights. The higher 10-m weight is evidence for a greater effect relative to the other predictors.

The 50-m model weights were larger with the insectivorous and species of concern guilds. The insectivore guild showed evidence for an 50-m effect, but at only half of the strength of the 10-m effect. The species of concern 50-m weight supports the lone meaningful model for the guild.

Table 6: Summed model AICc weights (ΣW) by guild by landscape predictors. Guilds with meaningful relationships determined from model selection denoted with (*). Note the consistently high ΣW of the 10-m riparian term, representative of the 0-30 m riparian scale, with Species of Concern as the one exception.

Guild	10m	50m	Disturbed	Intercept
Tolerant*	0.97	0.30	0.30	0.01
Omnivorous*	0.88	0.34	0.41	0.01
Insectivorous*	0.82	0.43	0.39	0.02
Benthic Insectivourous*	0.94	0.27	0.26	0.01
Piscivorous	0.27	0.39	0.26	0.32
Game Fish	0.27	0.29	0.27	0.38
Species of Concern*	0.28	0.82	0.37	0.05

Model Averaged Estimates

Model averaged estimates offer further insight into the influence of the landscape predictors on the guilds. The effect of the 10-m riparian term, representing the proportion of intact vegetation in the 0-30 m riparian scale, was supported by the MMI for the tolerant, omnivorous, insectivorous, and benthic insectivorous guilds. The 50-m riparian term, representative of the intact 30-50-m riparian scale, showed an effect on the species of concern. All of these effects are explored more explicitly through averaging of the previously explored candidate model estimates. If the confidence interval for a result included zero, the estimate was considered to have no support. Without exception, this corroborated good and poor predictor performance in the multi-model analysis above.

Table 7: Model averaged estimates of guild responses to riparian cover and disturbed land-cover predictors. Meaningful results are denoted by asterisks (*).

		Model Averaged Estimate	Unconditional SE	95% CI
10 m Riparian	Tolerant*	-1.59	0.53	-2.62, -0.55
	Omnivorous*	-1.36	0.54	-2.41, -0.30
	Insectivorous*	1.30	0.56	0.20, 2.41
	Benthic insectivorous*	0.83	0.29	0.26, 1.40
	Species of Concern	-0.02	0.14	-0.30, 0.26
50 m Riparian	Tolerant	0.05	0.01	-0.15, 0.26
	Omnivorous	-0.08	0.11	-0.30, 0.14
	Insectivorous	0.13	0.11	-0.09, 0.35
	Benthic insectivorous	0.00	0.06	-0.11, 0.12
	Species of Concern*	0.05	0.02	0.01, 0.09
Disturbed Land-cover	Tolerant	0.08	0.12	-0.16, 0.31
	Omnivorous	0.14	0.12	-0.10, 0.38
	Insectivorous	-0.13	0.12	-0.38, 0.11
	Benthic insectivorous	0.00	0.07	-0.13, 0.13
	Species of Concern	-0.03	0.03	-0.09, 0.03

The tolerant and omnivorous guilds displayed a similar response to the 10-m riparian term. Both guilds displayed clear negative relationships with the 0-30 m riparian cover scale (Table 7). As the proportion of intact riparian cover within that band increased, the proportion of tolerant and omnivorous individuals in the sampled reach decreased proportionally. These results agree with the hypothesized interactions.

The insectivorous and benthic insectivorous guilds also displayed similar responses to the 10-m riparian term. Both guilds displayed clear positive relationships with the 0-30 m riparian cover scale (Table 7). As the proportion of riparian cover within that band increased, the proportion of insectivorous and benthic insectivorous individuals in the sampled reach increased proportionally. These results again agree with the hypothesized interactions.

The species of concern guild showed the only response to the 30-50-m riparian scale, represented by the 50-m term. The response to increased larger scale riparian cover is a shallow increase in proportion of species of concern. The effect is subtle, but nonetheless existent.

Table 8: Model averaged estimates of guild responses to pooled 50-m riparian cover and disturbed land-cover predictors. Meaningful results are denoted by asterisks (*).

		Model Averaged Estimate	Unconditional SE	95% CI
Pooled Riparian	Tolerant*	-0.25	0.13	-0.49, 0.00
	Omnivorous*	-0.45	0.12	-0.69, -0.20
	Insectivorous*	0.48	0.13	0.23, 0.73
	Benthic insectivorous*	0.18	0.07	0.04, 0.32
	Species of Concern*	0.06	0.03	0.00, 0.11
Disturbed Land-cover	Tolerant	0.08	0.13	-0.18, 0.34
	Omnivorous	0.02	0.13	-0.23, 0.27
	Insectivorous	0.00	0.13	-0.26, 0.25
	Benthic insectivorous	0.04	0.07	-0.11, 0.18
	Species of Concern	-0.03	0.03	-0.09, 0.02

When the riparian scales were pooled to investigate consequences of coarser scaling, all guilds displayed effects similar to those observed when the scales were separated (Table 8). The strengths of the estimated relationships were less dramatic for the tolerant, omnivorous, insectivorous, and benthic insectivorous species. The species of concern response remained very similar. It seems that the generalization induced by the pooling diluted strong relationships. The single weak relationship remained constant.

CHAPTER IV

DISCUSSION

A substantial body of evidence suggests that landscapes have an effect on fish throughout the United States (Meador et al. 2008, Heitke et al. 2006, Bramblett 2005, Sawyer et al. 2004, Van Sickle et al. 2004, Volstad et al. 2003, Lyons et al. 2001, Lammert and Allen 1999, Niemela et al. 1998, Lyons et al. 1996, Leonard and Orth 1986, Smith 1971). Furthermore, although the landscape is increasingly acknowledged as an important force structuring fish communities, in-stream habitat variables (substrate, depth, current velocity, channel unit) continue to explain large portions of variance when analyzed in conjunction with out-stream characteristics (Talmage et al. 2002, Brewer and Rabeni 2011, Brewer 2013). This study sought to understand the influence of landscape disturbance and riparian scaling on specific portions of the fish community assemblage judged to be useful for broad ecological inference. In-stream variables, although known to be important, were deliberately excluded, because the primary focus was to understand land-cover effects in an agriculturally-dominated, low-gradient warm water system.

Guild Responses

In most cases, guilds responded as hypothesized to the land-cover variables. Although model strengths were not exceptional, guild responses to the land-cover predictors were consistent, lending credibility to the patterns observed. All guild responses supported the hypothesized dynamics or were inconclusive. No patterns contradictory to the hypotheses were observed. Sediment was identified as a potential driver of community response, but it not the only possible explanation of the patterns observed. Levels of watershed disturbance and proportions of riparian integrity are proxy variables generalized to a single proportional category, each representative of a host of mechanisms by which a stream can be influenced. Although exact causation cannot be determined by this study, the relationships do suggest the relative importance of each land-cover predictor to the aquatic system.

The tolerant and omnivorous guilds responded similarly to proportions of intact vegetation in the 0-30 m riparian scale, exhibiting negative relationships between reduced percent composition and increased riparian intactness. Stated differently, if riparian integrity was low, percent composition of the tolerant and omnivorous guilds was higher. The similar response is unsurprising, considering the high proportion of species shared by the two guilds. If areas with low riparian integrity are considered more disturbed, as considered here, the guilds' responses are consistent with those reported elsewhere.

Tolerant and omnivorous species have been shown to increase in abundance in degraded stream reaches (Bramblett 2005, Niemela et al. 1998, Lyons et al. 1996, Leonard and Orth 1986, Smith 1971). This response has been documented across 11 states and the major ecoregions of the American West, with agricultural and urban land-cover disturbances implicated in environmental degradation (Meador et al. 2008). Given the literature agreement, it is reasonable to assume that low levels of riparian integrity reflect high levels of local vegetation disturbance. By extension, the meaningful 0-30 m riparian scale reflects the local scale at which disturbance is affecting the tolerant and omnivorous guilds.

The insectivorous and benthic insectivorous guilds, which responded similarly to the 0-30 m intact riparian cover, also share many species. The guilds both increased in percent composition when riparian integrity, or levels of intact vegetation, was high. If we again assume that riparian integrity is analogous to local disturbance levels, guild responses are comparable with other studies. Increased insectivore percent composition is linked to lower levels of disturbance and more desirable stream conditions (Lyons et al. 2001). Both guilds are sensitive to disturbance due to prey reliance on interstitial benthic cover. If disturbed, larval insect diversity decreases, leading to a decrease in insectivore abundance (Niemela et al. 1998). Percent compositions of insectivorous and benthic insectivorous species (as well as tolerant and omnivorous species) respond to increased levels of percent fine streambed particles (< 16 mm) (Bramblett et al. 2005). Disturbance of the local 0-30 m riparian scale is therefore reflective of these observations.

The species of concern (SOC) guild was an interesting case, apparently responding to the 30-50-m riparian scale. The strength of the relationship was very subtle, and although the results for the guild were meaningful, they may have arisen from data paucity issues. SOC accounted for a mere 2.11% of the total fish sampled. Of the 11 SOC detected, nine were included in either the insectivore or benthic insectivore guild. It is therefore assumed that SOC responses would be comparable to those guilds. The hornyhead chub (*Nocomis biguttatus*, 21 sites) and troutperch (*Percopsis omiscomaycus*, 18 sites) were the most commonly detected SOC, with all other species detected at ≤ six sites. Independent analyses conducted on hornyhead chub and troutperch were inconclusive, leading to very low confidence in the SOC results. It’s tempting to draw conclusions linking increased levels of riparian integrity to SOC percent compositions.

Given the weak evidence for an effect and the data paucity issues, the connection between the SOC guild and larger riparian extents is tenuous at best. While there may weak statistical evidence for an effect, it is judged to be spurious correlation at this time.

Dissecting Effects of Riparian Scale

Ecological processes operate across multiple scales, which should dictate the data used to investigate them. In examination of landscape effects on riverine systems, the central question is whether local or catchment scale factors have greater impact (Hunsaker and Levine 1995). The difference in scale necessitates application of remote sensing data differing in spatial resolution. The use of products with coarser resolutions, such as the 30 m pixel of Landsat TM, in riparian areas is discouraged if local accuracy is a concern. Riparian areas are border areas, and the large pixels do not contain a homogenous land-cover type, but are instead a mixed pixel. These mixed pixels are unreliable for local analysis (Campbell 2007). Local-scale phenomena are best examined with higher spatial resolution data (Baker et al. 2006), while landscape variables can be successfully examined with more coarse resolutions (Lammert and Allan 1999). Local riparian cover was investigated using 1 m resolution NAIP images, and land-cover status was determined using NLCD 30 m resolution reclassifications. This approach worked well, and is a good option for future investigations.

The latitudinal riparian scale for seems to function along conventional wisdom: the closer the riparian cover is to the stream, the more functionally important it becomes. Riparian cover in the 0-30 m range has been shown to act as a filter of suspended sediment (Leopold et al. 1964, Waters 1995, Yuan et al. 2009) and temperature moderator (Barton et al. 1985, Bartholow 1989). Both suspended sediment loads and temperature force community composition. The consistent performance of the 0-30 m predictor indicates a higher importance of this scale relative to the outer 30-50 m riparian cover. It is notable that these important effects were determined from 1 m resolution imagery.

Meaningful effects of intact riparian width on fish communities are difficult to determine from preexisting literature. Sometimes the riparian variation is not considered in favor of larger scale variation (Brewer 2013, Brewer and Rabeni 2011). In other studies, riparian widths are determined arbitrarily, including 90 m (2015 National Fish Habitat Partnership, in press), 30 m and 100 m (Wang 2002). Finally, the riparian area, a remote sensing border area, is occasionally examined with coarse resolution data, which can mask important variation. This has led to considerable confusion regarding riparian effect scaling (Goetz 2006), most often demonstrated by riparian studies using Landsat-derived land-cover maps. Significant riparian widths derived from these sources include 30 m (Sawyer et al. 2004), 50 m (Lammert and Allen 1999), 60 m (Heitke et al. 2006), 100 m (Volstad et al. 2003), and 120 m (Van Sickle et al. 2004). Given the wide range of models and widths that supported effects, important variation clearly exists in the local riparian scale.

Despite no widely employed quantitative threshold defining the effective riparian zone, all of the aforementioned studies nonetheless succeeded in establishing a relationship between the stream community and adjacent riparian cover. Given my results, it is entirely possible that important near-stream riparian landscape effects were driving the relationships, despite being masked by the coarser spatial resolutions. As demonstrated here, even when treating the entire 50 m riparian buffer as one scale, relationships similar to the 0-30 m scale were observed. All of this occurred despite the generalization deliberately induced when pooling the meaningful scale (0-30 m) with the not meaningful scale (30-50 m). Even though meaningful results can be obtained from coarse resolution (>30 m) riparian data, the best available spatial resolution data ought to be employed when making management decisions. As demonstrated, it gives a clearer picture of which riparian scales are important relative to project goals and objectives.

The 3-km stream reach used as the local scale for this project was based on recommendations by Barton et al. (1985), one of the foundational studies for the Environmental Protection Agency's Rapid Bioassessment Protocol for Wadeable Stream and Rivers. Three kilometers upstream from a site was suggested as a scale that would influence populations. The performance of our local riparian predictors support, but do not expand, that idea. The longitudinal scale along the stream may differ based on regional environment, but seems to be applicable in this situation.

Are Landscape Disturbances Meaningful?

Considered in isolation, the disturbed land-cover was not meaningful in any of the guild analyses. Were disturbances of natural land-cover completely benign, as far as fish communities in the region were concerned? A large body of literature and our results agree this is likely not the case. While the disturbed land-cover might be unimportant when considered alone, it does not function in isolation in the ecological world. Disturbed land-cover interacts with the riparian zone, thus becoming meaningful when considered along with appropriate riparian scaling.

The model representing disturbed land-cover and the appropriate riparian scale always performed well among the model families. Although predictors can function independently within scales, the most landscape variation is usually explained by interactions of multiple scales (Gido et al. 2006). Interactive effects of multiple scales of landscape predictors are known in prairie (Gido et al. 2006) and agricultural stream systems (Heitke et al. 2006). The disturbed land-cover and riparian scales examined here follow similar patterns.

The disturbed land-cover class was composed of reclassified urban and agricultural NLCD land-cover classes. Streams and the fish in them are affected by agricultural (Waters 1995, USEPA 1990, Costa 1975, Lenat et al. 1979, Clark 1987) and urban land-use (Brewer 2013, Utz et al. 2010, Brown et al. 2005, Paul and Meyer 2001). Disentangling the effects of some land-cover types can be difficult, however, as land-use (i.e. agriculture) is often colinear with natural environmental features (soil type and slope). In this case, the stream was simply more affected by the proportion of intact riparian vegetation, which could act as a mitigating factor for disturbed land-use influences on the stream.

Applications and Implications

The Environmental Protection Agency's Rapid Bioassessment Protocol for Wadeable Stream and Rivers (RBP) is widely employed for stream fish habitat assessment. It includes both in-stream and riparian quality metrics. These metrics were developed from salmonid research on cold water streams (Naiman et al. 1993, Bauer and Burton 1993, Barbour and Stribling 1991, Gregory et al. 1991, Bartholow 1989, Barton et al. 1985, Platts et al. 1983). Current practices generalize the salmonid-derived metrics to warm-water systems (Larsen 2013).

Our findings indicate the implementation of the RBP riparian metrics in warm-water systems is likely a sound practice. Currently, sites with > 18 m of riparian cover receive top RBP scores (Platts et al. 1983). The RBP therefore investigates local riparian cover within the local scale found to be meaningful. If drastically different scales were observed, there would be cause for concern. Given the good performance of the 0-30 m riparian scale in our analysis across large spatial and temporal scales, the RBP generalizations are appropriate.

This study sought to understand the influence of land-cover disturbance and riparian scaling within the tributaries on the Red River of the North. Our results indicated multiple scales of land-cover effects of stream fishes, with particular emphasis on importance of intact riparian cover. Within the region, the 0-30 m riparian scale is an important indicator of the fish community. Further, more attention ought to be given to riparian scaling in landscape studies both in and outside of the region. Our results demonstrate that important fine-scale effects can be distorted by use of inappropriate scales in remote sensing analyses.

APPENDIX

Guilds

Table A1: Guild species compositions from Niemela et al. (1998) used to investigate influences of disturbance and riparian integrity. OM: Omnivore, IN: Insectivore, PI: Piscivore, BI: Benthic insectivore, TO: Tolerant, GF: Game fish, SC: Species of concern.

Common Name	Scientific Name	OM	IN	PI	BI	TO	GF	SC
Banded Killifish	*Fundulus diaphanus*							x
Bigmouth Buffalo	*Ictiobus cyprinellus*	x			x	x		
Bigmouth Shiner	*Notropis dorsalis*		x		x			
Black Bullhead	*Ameiurus melas*	x				x		
Black Crappie	*Pomoxis nigromaculatus*			x			x	
Blackchin Shiner	*Notropis heterodon*		x					
Blacknose Dace	*Rhinichthys atratulus*		x			x		
Blacknose Shiner	*Notropis heterolepis*		x					
Blackside Darter	*Percina maculata*		x					
Bluegill	*Lepomis macrochirus*		x				x	
Bluntnose Minnow	*Pimephales notatus*	x			x			
Brook Stickleback	*Culaea inconstans*		x			x		
Brown Bullhead	*Ameiurus nebulosus*	x						
Burbot	*Lota lota*			x			x	
Central Mudminnow	*Umbra limi*		x			x		x
Central Stoneroller	*Campostoma anomalum*				x			x
Channel Catfish	*Ictalurus punctatus*			x		x	x	
Chestnut Lamprey	*Ichthyomyzon castaneus*			x				x
Common Carp	*Cyprinus carpio*	x				x		
Common Shiner	*Luxilus cornutus*		x					
Creek Chub	*Semotilus atromaculatus*		x			x		
Emerald Shiner	*Notropis atherinoides*		x					
Fathead Minnow	*Pimephales promelas*	x				x		
Finescale Dace	*Phoxinus neogaeus*		x					
Flathead Chub	*Platygobio gracilis*		x					x
Freshwater Drum	*Aplodinotus grunniens*		x			x		
Golden Redhorse	*Moxostoma erythrurum*		x		x			
Golden Shiner	*Notemigonus crysoleucas*		x			x		
Goldeye	*Hiodon alosiodes*		x					
Greater Redhorse	*Moxostoma valenciennesi*		x		x			x
Green Sunfish	*Lepomis cyanellus*		x					
Hornyhead Chub	*Nocomis biguttatus*		x					x
Iowa Darter	*Etheostoma exile*		x					

Table A1.1 cont.

Common Name	Scientific Name	OM	IN	PI	BI	TO	GF	SC
Johnny Darter	*Etheostoma nigrum*		x					
Largemouth Bass	*Micropterus salmoides*			x			x	
Largescale Stoneroller	*Campostoma oligolepis*				x			x
Logperch	*Percina caprodes*		x					x
Longnose Dace	*Rhinichthys cataractae*		x		x			
Mooneye	*Hiodon tergisus*		x					
Muskellunge	*Esox masquinongy*			x			x	
Northern Pike	*Esox lucius*			x			x	
Northern Redbelly Dace	*Phoxinus eos*		x					x
Orangespotted Sunfish	*Lepomis humilis*		x					
Pearl Dace	*Margariscus margarita*		x					x
Pugnose Shiner	*Notropis anogenus*	x						
Pumpkinseed	*Lepomis gibbosus*		x					
Quillback	*Carpiodes cyprinus*	x			x	x		
River Darter	*Percina shumardi*							x
River Shiner	*Notropis blennius*		x		x			
Rock Bass	*Ambloplites rupestris*			x				
Sand Shiner	*Notropis stramineus*		x		x			
Sauger	*Sander canadensis*			x			x	
Saugeye	*S. canadensis x S. vitreus*			x			x	
Shorthead Redhorse	*Moxostoma macrolepidotum*				x			
Silver Chub	*Macrhybopsis storeriana*		x		x			x
Silver Lamprey	*Ichthyomyzon unicuspis*			x				x
Silver Redhorse	*Moxostoma anisurum*		x		x			x
Smallmouth Bass	*Micropterus dolomieu*			x			x	
Spotfin Shiner	*Cyprinella spiloptera*		x					
Spottail Shiner	*Notropis hudsonius*							
Stonecat	*Noturus flavus*							
Tadpole Madtom	*Noturus gyrinus*		x					
Trout-Perch	*Percopsis omiscomaycus*							x
Walleye	*Sander vitreus*			x			x	
White Bass	*Morone chrysops*			x			x	
White Crappie	*Pomoxis annularis*			x			x	
White Sucker	*Catostomus commersoni*	x			x	x		
Yellow Bullhead	*Ameiurus natalis*	x						x
Yellow Perch	*Perca flavescens*		x				x	

Spatial Autocorrelation Testing Results

Preventative measures, such as averaging replicate samples at within temporal bins, were used to avoid influences of spatial autocorrelation. Each guild across sampling locations was tested for spatial autocorrelation using Moran's I testing in SAM: Spatial Analysis in Macroecology. All default settings were used. Moran's I is measured on a -1 to 1 scale, with 0 indicating no influence. No spatial filters were employed because Moran's I values and correlogram inflections in the low distance classes were not deemed substantial enough to warrant further action. The weak Moran's I values observed in all guilds indicate a very low influence of spatial autocorrelation on the landscape analyses.

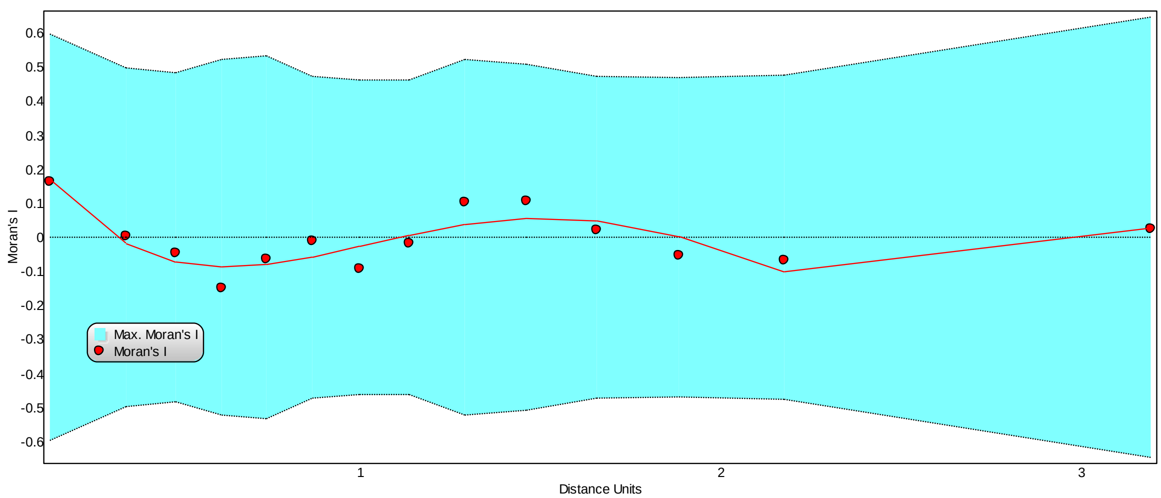

Figure A1: Tolerant guild Moran's I correlogram. Note the weak values throughout, with no values exceeding 0.2.

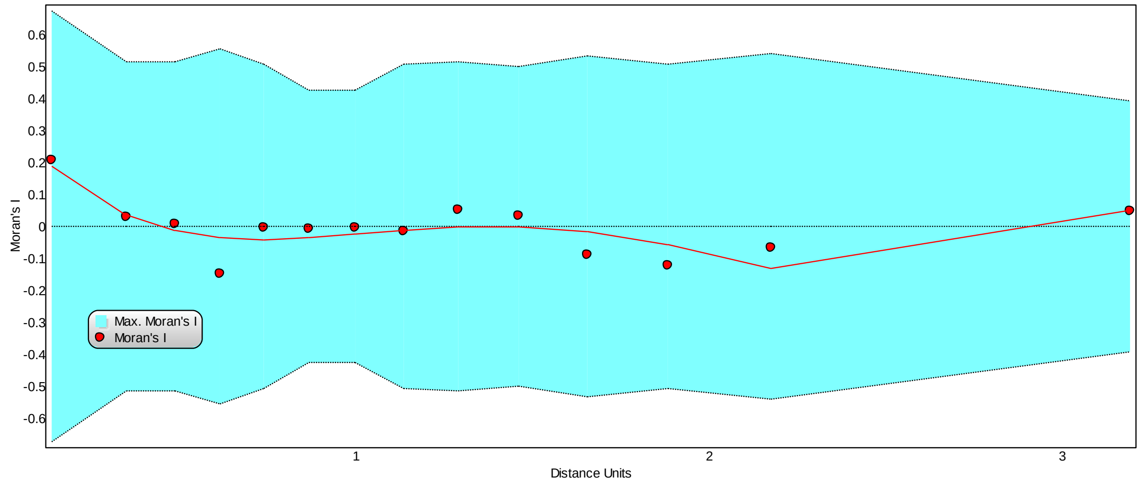

Figure A2: Omnivorous guild Moran's I correlogram. Note the weak values throughout, with no values exceeding 0.2.

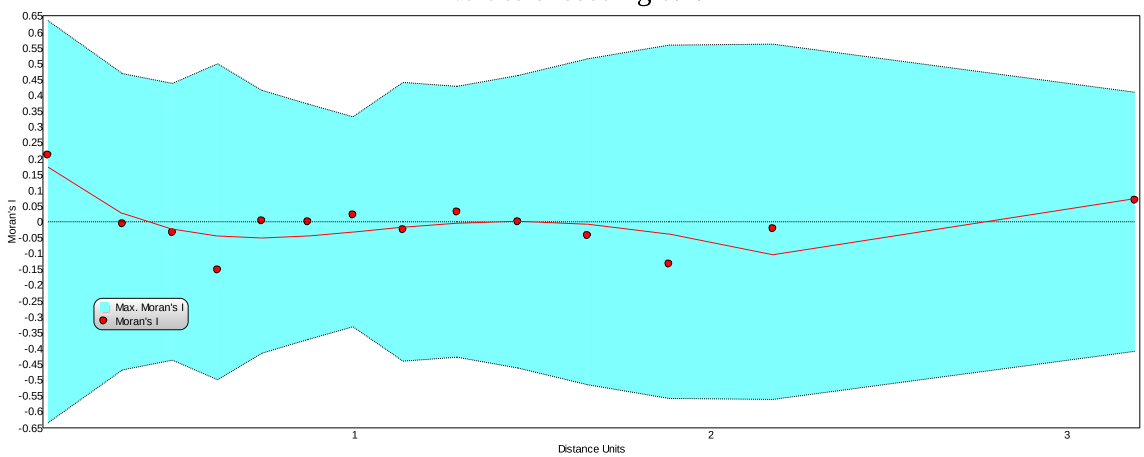

Figure A3: Insectivore guild Moran's I correlogram. Note the weak values throughout, with no values exceeding 0.2.

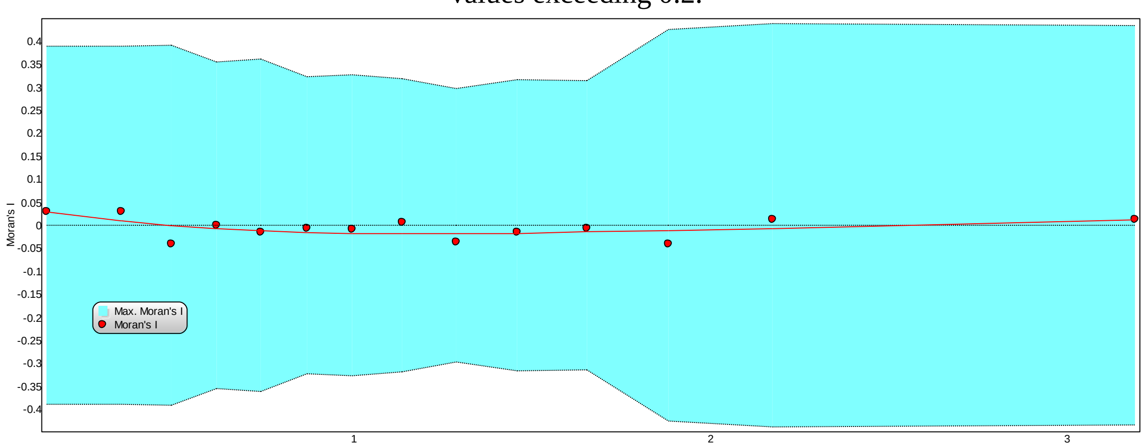

Figure A4: Piscivore guild Moran's I correlogram. Note the weak values throughout, with no values exceeding 0.2.

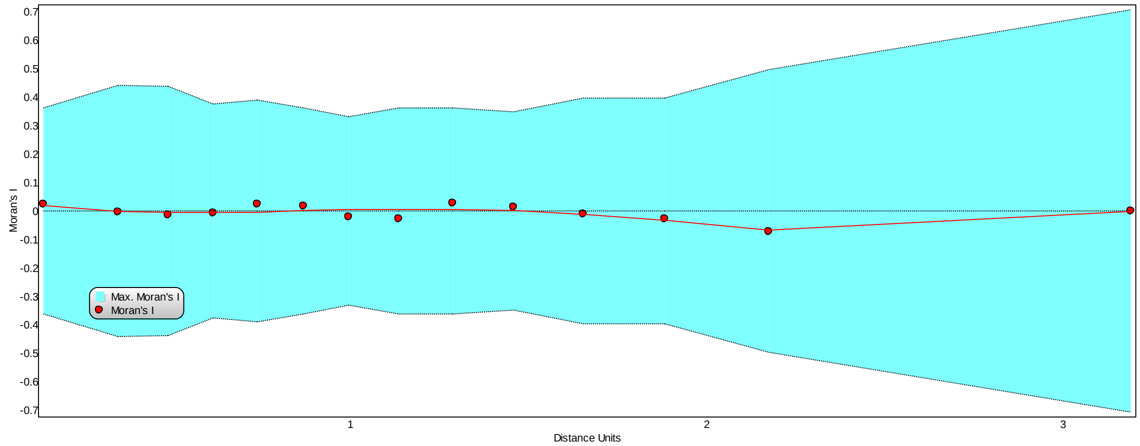

Figure A5: Benthic insectivore guild Moran's I correlogram. Note the weak values throughout, with no values exceeding 0.2.

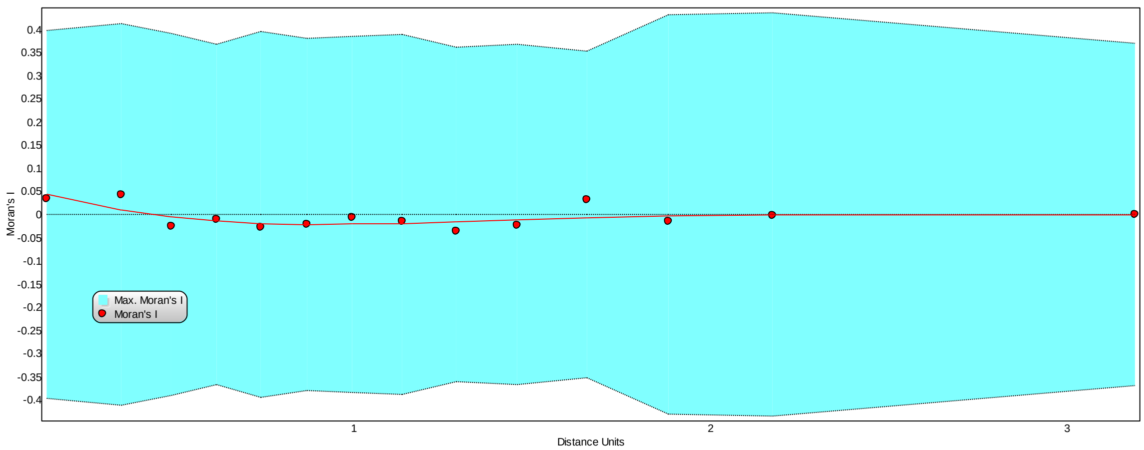

Figure A6: Game fish guild Moran's I correlogram. Note the weak values throughout, with no values exceeding 0.2.

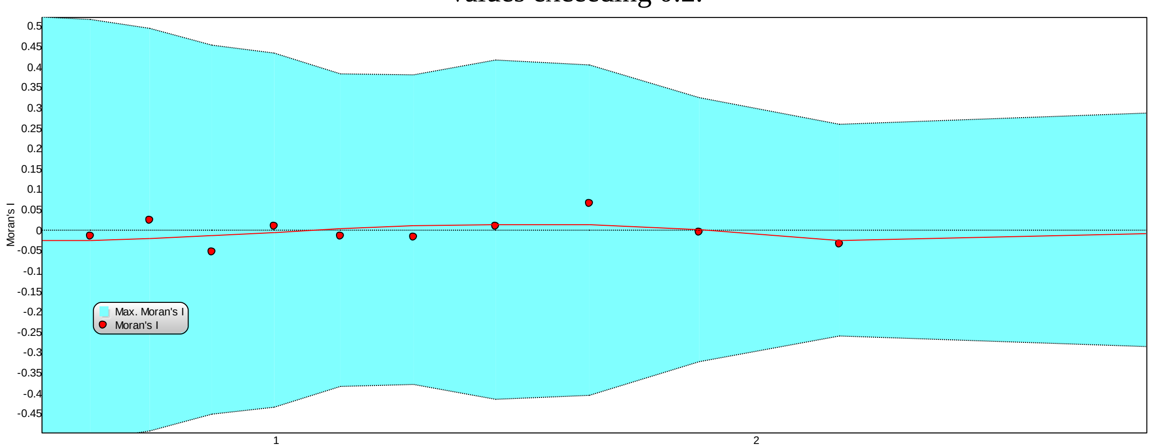

Figure A7: Species of concern guild Moran's I correlogram. Note the weak values throughout, with no values exceeding 0.2.

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