DEVELOPMENT OF AN INDEX OF LANDSCAPE DEVELOPMENT INTENSITY FOR PREDICTING THE ECOLOGICAL CONDITION OF AQUATIC AND SMALL ISOLATED PALUSTRINE WETLAND SYSTEMS IN FLORIDA

By

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To Sarita and Sofía Manuela.

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LIST OF ACRONYMS

ANOVA	Analysis of variance
BASINS	Better Assessment Science Integrating Point and Nonpoint Sources
CWA	Clean Water Act
DD	Decimal degrees
DEM	Digital elevation model
DO	Dissolved oxygen (units: mg/L)
DOQQ	Digital Orthographic Quarter Quad
DTM	Digital terrain model
ED	Edge density (units: meters/hectare)
FDEP	Florida Department of Environmental Protection
FDOT	Florida Department of Transportation
FLUCCS	Florida Land Use and Cover and Forms Classification System
FWCI	Florida Wetland Condition Index (unit less)
GIS	Geographic Information System
HUC	Hydrologic Unit Code
IBI	Index of Biological Integrity
IJI	Interspersion and Juxtaposition Index (units: %)
LCI	Lake Condition Index (unit less)
LDI	Landscape Development Intensity Index (unit less)
LDI-ILD	LDI-inverse linear distance (unit less)
LDI-ISD	LDI-inverse square distance (unit less)
LDI-PLU	LDI-proportion of land use (unit less)
LU/LC	Land use/land cover
NAPP	National Aerial Photography Program
NED	National Elevation Dataset
NO_2/NO_3	nitrate/nitrite-nitrogen (units: mg/L)
NTU	Nephelometric turbidity units
PCA	Principal Components Analysis
PD	Patch density (units: # of patches /100 hectares)
PR	Patch richness (unit less)
PRD	Patch richness density (units: # /100 hectares)
SC	Specific conductance (units: µmhos/cm)
SCI	Stream Condition Index (unit less)
SHDI	Shannon Diversity Index (unit less)
SHEI	Shannon Evenness Index (unit less)
TKN	Total Kjeldahl nitrogen (units: mg/L)
TN	Total nitrogen (units: mg/L)
TP	Total phosphorus (units: mg/L)
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
USEPA	U.S. Environmental Protection Agency
VIF	Variance Inflation Factor
WCI	Wetland Condition Index (unit less)
WMD	Water Management District
WQI	Water Quality Index (unit less)

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Freshwater ecosystems, while vital components of landscapes and essential for human well-being, are increasingly threatened by the ever-escalating intensity of human development. In this study, the main objective was to analyze the influence of human development intensity on the ecological condition and water quality of isolated forested wetlands, streams, and lakes in Florida. An index of Landscape Development Intensity (LDI), derived from the non-renewable areal empower density of land use, was used as a measure of the human disturbance gradient against which the ecological condition and water quality of 118 isolated palustrine forested wetlands, 69 streams, and 54 lakes were analyzed at different landscape scales. Landscape pattern metrics were also calculated for study ecosystems and tested for relationships with indicators of ecosystem condition and water quality.

Overall, the LDI had the greatest predictive ability for bioindicators of ecological condition in wetlands and streams, explaining up to 30% and 27% of variability, respectively. The LDI was a significant factor in explaining the variability of water quality variables only for streams.

Changes in landscape scale (grain and extent) had small effects on the LDI. Differences in LDI scores were noticeable when developed lands were added with increasing area. The use of

distance-weighting functions provided little enhancement of the predictive power of the LDI; distance-weighted LDIs did increase by 7% the predictive power for bioindicators for streams.

Landscape pattern metrics explained up to 44% of variability in bioindicators of wetland condition, and 22% and 42% for stream and lakes. They also accounted for up to 60% and 39% in the variance of water quality variables for streams and lakes, respectively. When included with the LDI in multiple regressions they increased by 25% the amount of variance explained in bioindicators of wetland condition and 52% for lakes.

In general, the LDI had higher predictive power for bioindicators of ecosystem condition than for chemical constituents of the ecosystems studied, which are more variable with season, time of day, and hydrologic conditions. The LDI may have greater correlation with bioindicators because they may be more integrative of anthropogenic impacts and have higher correlation with ecological condition.

CHAPTER 1
INTRODUCTION

Freshwater ecosystems are essential components of many landscapes. They are also home to myriad species and are vital to humans for the countless products and services that they provide. Despite their value, freshwater systems are increasingly modified by people's use of resources, causing changes in their ecological condition and threatening societal well-being. Thus, investigating how human behavior in the landscape affects freshwater ecosystems is a matter of critical importance (Naiman et al. 1995; Baron et al. 2003; Allan 2004). To this end, this research was designed to develop a quantitative understanding of the influence of human development intensity on the ecological condition of streams, lakes, and small isolated palustrine forested wetlands in Florida.

Statement of the Problem

The effect of land use/land cover changes on freshwater ecosystems has been recognized for some time (Likens et al. 1970; Haynes 1975; Omernik, 1977; Karr and Schlosser 1978; Peterjohn and Correl 1984; Allan and Flecker 1993). Human-related activities such as deforestation, silviculture, agricultural intensification, urbanization, and drainage of flooded areas may all negatively affect freshwater systems (Carpenter et al. 1996; Carpenter et al. 1998; Giller and Malmqvist 1998). The problem may be exacerbated as human population increases, the remaining natural lands are converted to other uses, and human activities in already transformed lands are further intensified to respond to development needs.

Population growth and land development are the main forces driving changes in Florida's landscapes (Reynolds 1999). Currently, Florida is the fourth most-populated state in the United States, with more than 17 million people; it is projected that by 2030 the state's population will total 28.7 million (U.S. Census Bureau 2005). By 1997 the rate of rural land loss in the state was about 60,000 hectares per year, and it is projected that from 2000 to 2020 an additional 53,000 hectares per year will be converted from rural to urban uses (Reynolds 1999). These trends suggest that Florida's freshwater systems will be facing increased human pressures and the need to better understand how the state's streams, lakes and isolated forested wetlands may be affected by land development.

Wetlands, streams, and lakes integrate all energy flows occurring in their drainage basins, with water acting as the main element for materials transport and defining the cumulative impacts of human activities in the lands surrounding them (Naiman et al. 1995; Wear et al. 1998). Energy inputs into freshwater systems from the surrounding landscape that are different from their more natural flows may result in gradual differences in internal structure, processes, and eventually system organization. Thus, freshwater systems may experience water quality modifications and changes in aquatic ecological communities as energy inputs are altered due to land development.

The assessment of how human landscape-level activities affect aquatic systems requires the use of indicators that describe landscape attributes (O'Neil et al. 1997; Gergel et al. 2002). Land use intensity is an attribute of landscapes that might be related to the condition of freshwater systems, since as the intensity of human development of landscapes increases, the greater the potential for ecological degradation (Brown 2003b; Brown and Vivas 2005). Land use intensity can be quantified based on the amount of energy used by humans in their development activities. Emergy, the energy that was used to make a product or service and expressed in units of one type of energy (Odum 1996), allows quantifying natural and economic flows in meaningful common units and developing metrics that describe land use intensity which can then be related to water quality and biotic variables. This in turn may allow for new insights in to the assessment of the condition of Florida's aquatic systems.

Different indices or metrics of landscape pattern, which describe landscape heterogeneity in terms of its composition (presence, relative abundance and diversity of patches) and configuration (spatial distribution of patches) have also been proposed (O'Neil et al. 1997; Cifaldi et al. 2004) and to some extent tested (Johnson et al. 1997; Griffith et al. 2002) to analyze the relationship between human uses of landscapes and the condition of freshwater systems. Despite the lack of conclusive evidence that would suggest a set of metrics that can best be used to describe this relationship, pattern metrics are valuable landscape indicators that can help in understanding how humans impact freshwater systems (Turner et al. 2001).

Human influences on freshwater systems occur at multiple spatial scales ranging from the local scale, where for example the removal of riparian forests may result in increased local sediment inputs to water bodies, altered water heat flows due to shade removal, changes in woody-debris inputs, and shifts in the composition of aquatic biological communities (Jones et al. 1999; Naiman and Décamps 1997; Poole and Berman 2001); to the watershed scale, where land use regulates hydrological budgets and differences in the amount of sediments and nutrients transported by surface runoff (Soranno et al. 1996; Allan 2004). Levin (1992) has argued that the description of the variability and predictability of the environment is only meaningful when the multiple scales that may be of importance to an organism or process are considered. Landscape scale is described in terms of its grain (i.e., spatial resolution) and extent (i.e., size of the study area) (Wiens 1989; Turner et al. 2001). Multiple studies (Richards et al. 1996; Allan et al. 1997; Gergel et al. 1999) have documented the importance of scale in determining the influence of landscape attributes on the ecological condition of freshwater systems. However, there are mixed conclusions about the scales at which land use most affects freshwater systems, suggesting that this matter still requires further investigation (Turner et al 2001).

The influence of human activities on freshwater ecosystems may also depend on the distance between landscape features. For example, material transport originating from agricultural lands can be attenuated with increasing distance from freshwater systems (Soranno et al. 1996) and may be significantly reduced by the presence of riparian forests in drainage basins where developed lands are common (Correll et al. 1992; Naiman and Décamps 1997). Since land use proximity is believed to be important in how human activities affect freshwater systems, emphasizing the value of nearby lands over that of more distant lands in land-water interaction studies may prove to be valuable (O'Neil et al. 1997). Several studies of land-water interface (Comeleo et al. 1996; King et al. 2005) have considered distance-weighting of land use; however, the benefits of this approach as well as the best way of weighting land use remains unclear (King et al. 2005).

This dissertation explores how landscape development intensity might affect the condition of isolated forested wetlands, streams, and lakes in Florida. It investigates properties of indicators of landscape development intensity with changes in landscape scale. It statistically relates landscape development intensity and landscape pattern with indicators of ecosystem conditions and water quality at different spatial scales, and considering distance-weighting of land use. The question of how landscape pattern indicators may complement landscape development intensity indicators in their ability to predict ecological condition is also considered.

Plan of Study

How human activities affect aquatic ecosystems is a central aspect of land-water interface studies. The assessment of this relationship requires measurable indicators that describe human behavior in the landscape and that will allow an understanding of how it contributes to the ecological impoverishment of freshwater ecosystems. This investigation approaches this need through a landscape analysis that uses concepts and tools of environmental accounting using emergy. Accordingly, the three main objective of this work are the following:

- Describe spatial properties of indicators of landscape development intensity with changes in landscape scale (i.e., grain and extent) and distance.
- Determine statistically the ability of landscape development intensity indicators to predict the ecological condition of streams, lakes, and small isolated forested wetlands at different landscape scales and considering land use distance.
- Develop statistical models to predict the ecological condition and water quality of streams, lakes, and small isolated forested wetlands from landscape pattern and determine the spatial scale at which relationships are most relevant.
- Assess how landscape pattern can complement the ability of landscape development intensity to predict the ecological condition of streams, lakes, and small isolated forested wetlands.

To accomplish the first objective emergy analysis enabled the evaluation of the spatial non-renewable energy characteristics (non-renewable areal empower density) of different land uses in Florida. These in turn allowed quantifying the non-renewable areal empower density of the drainage basins or hydrological contribution areas of the systems under investigation, which were determined using Geographic Information Systems (GIS) methods. Finally, an index of Landscape Development Intensity (LDI) was calculated for each drainage basin. The LDI was calculated at various landscape grains and extents to assess landscape-scale effects on the index. The landscape grain was varied systematically considering the spatial characteristics of the original land use data used for each system studied. The landscape extent over which the LDI was calculated was varied from artificially defined hydrological contributing areas of different sizes to entire drainage basins. Two distance-weighting algorithms were used to test the effect of distance on the LDI.

The second and third objectives were achieved by statistically relating the landscape indicators to indicators of ecological condition and water quality variables for isolated forested wetlands, lakes, and streams. The LDI was used as a measure of the human disturbance gradient against which the ecological condition and water quality of freshwater systems was analyzed using simple linear regression. The spatial distribution and patterns of human development in drainage basins were determined following concepts and guidelines from the field of landscape ecology and within the GIS environment. Multiple regression analysis allowed developing statistical models to investigate how much of the variation in indicators of ecosystem condition and water quality variables was explained by the landscape pattern metrics. Relationships were explored considering various grain sizes and spatial extents to assess scale effects on the predictive power of both types of landscape indices.

For the fourth objective pattern metrics were used as additional independent variables in multiple regression analysis to explore how much of the remaining variance initially accounted for by the LDI could be explained when the two types of landscape indicators were used together. A discussion of the value of landscape indicators for predicting ecological condition of freshwater systems fallowed. The results from this dissertation are intended to be a contribution to the development and testing of methods for the assessment and monitoring of freshwater systems in Florida.

Concepts and Approaches to Understanding Human Impacts on Freshwater Systems

Emergy and Empower Density

Emergy is a measure of the available energy that was used to make a product or process and that has been corrected for different qualities. The solar emergy of a product is the emergy of the product expressed in equivalent solar energy that is required to generate it (Odum 1996). The units of emergy are emjoules (for emergy joules) and the units of solar emergy are solar emjoules (abbreviated sej).

A flow of emergy is empower (measured in solar emjoule per time); when it is applied in a unit area it is referred to as empower density (areal empower density) and can be interpreted as a measure of work per area per time (units: sej/ha-yr) (Odum 1996). An area with high energy use, such as a city, will have a higher areal empower density than areas using less energy, such as rural areas.

Emergy flows are organized hierarchically into spatial patterns with emergy flows per area more concentrated in hierarchical centers such as cities (Brown 1980; Odum 1996). Based on this observation, Brown and Vivas (2005) suggested that the impacts of human activities might be related spatially to the intensity of energy use and that the areal empower density might serve as a measure of the level of human-induced impacts on ecological systems. Consider, for example, a land-use practice such as agriculture (Figure 1-1); it is highly probable that as agriculture is intensified by the increased use of fertilizers, pesticides, heavy machinery, and fossil fuels, among other non-renewable inputs as shown in the right side of Figure 1-1, the chances of degrading nearby freshwater systems (on the left in Figure 1-1) with higher loads of nutrients and sediments in runoff water will be higher over time. As the use of the land intensifies, there is greater potential for environmental impacts. These impacts can be assessed spatially using the empower densities of land use as a measure of the degree of the impacts of human activities. When multiple land uses or landscapes with different levels of development intensity are considered, described, and organized based on their empower densities, the areal empower density can be use as a metric that describes the human disturbance gradient.

Human Disturbance Gradient

Environmental variation is ordered in space and spatial environmental patterns determine the structure and function of ecological systems. Like natural environmental gradients, land development gradients provide a means to explain spatially or predict human impacts on ecological systems (McDonnell and Pickett 1990). Since humans have influenced, altered, or transformed almost every ecosystem around the globe, with most landscapes today falling between a gradient of completely natural to highly developed areas (Brown and Vivas 2005), the human-induced impacts on the landscape can be organized along a disturbance gradient depending on the intensity of the human activities within it (McDonnell and Pickett 1990; McMahon and Cuffney 2000; Brown and Vivas 2005). The human disturbance gradient, which can be described and quantified using landscape emergy-based indices, was used to assess the impact on freshwater ecosystems that result from human activities within their watersheds.

Landscape Pattern

Landscape pattern refers to the spatial composition and configuration of the elements present in a landscape. Landscape pattern results from the interaction of multiple abiotic and biotic factors and the way in which humans use the land (Turner et al. 2001). The quantification of landscape pattern is a necessary step in order to describe the interactions between spatial pattern and ecological processes (Gustafson 1998; Turner et al. 2001; Turner 2005). The relationship between spatial pattern and ecological processes is the fundamental idea that defines the science of landscape ecology (Turner et al. 2001).

Many landscape measures or metrics have been developed that describe how landscapes are structured (O'Neill et al. 1988; McGarigal and Marks 1995; O'Neill et al. 1999) and constitute a direct way for establishing the relationship between pattern and process (Gustafson 1998; Turner et al. 2001). Landscape metrics provide information about the composition and configuration of landscapes (McGarigal and Marks 1995). Composition metrics provide descriptions of the presence, relative abundance, and diversity of patches in the landscape, while configuration metrics represent the spatial distribution of patches in the landscape.

The concepts and analytical tools used in landscape ecology are also applicable to the study of freshwater systems (Wiens 2002). Thus, metrics of landscape pattern allow quantifying anthropogenic disturbance and provide a means to establishing links between human actions in watersheds and their impact on wetlands, streams, and lakes.

Importance of Scale

The review of the recent literature on land-water interactions reveals that human impacts on freshwater systems occur at multiple spatial scales. It is also clear from this review that determining the scale(s) that are appropriate for establishing predictive relationships between human actions at the landscape level and their effects on freshwater systems is an ongoing challenge. In this dissertation the relationship between the intensity and pattern of development and the ecological condition of freshwater systems was assessed at several scales in order to determine the scales at which such relationships are best observed.

Scale has been defined as the spatial or temporal dimensions of an object and is described by the grain and extent (Turner et al. 2001). Grain refers to the finest spatial resolution of observation of a phenomenon, while extent is the total area of study (Wiens 1989; Turner et al. 2001). Wiens (1989) clarifies that, defined this way, the grain of an investigation is different from the way MacArthur and Levins (1964) considered grain as being "a function of how animals exploit resource patchiness in environments" (page 387). Throughout this study grain and extent will be used following the definitions by Wiens (1989) and Turner et al. (2001).

Watershed as the Unit of Analysis

A watershed can be defined as the area of land draining to a specific point or area on a stream, lake, or wetland[1]. Watersheds are usually considered to be defined landscape units since their boundaries can be relatively easily defined based on topographic and hydrologic factors (Hunsaker and Levine 1995; NRC 1999). This characteristic, and their integrative properties of environmental process including human impacts, makes watersheds functional systems for research in many different scientific fields including geomorphology, hydrology, stream ecology, landscape ecology, and ecosystem management (USEPA 1996; Allan et al. 1997; NRC 1999; Turner et al. 2001).

Florida's surface waters have been divided into 52 major basins or hydrologic units based on the country's nationwide surface hydrologic features system, which was developed by the United States Geological Survey. The system is hierarchical and allows the definition of more detailed hydrologic units. As a result, Florida's surface waters have been further subdivided into about 3,830 sub-basins or watersheds. This watershed subdivision has allowed the state to manage its water resources on the basis of hydrologic units despite the complexity of the states surface and subsurface water flows. Through the development of surface and groundwater monitoring programs and the assessment of the impacts of point and non-point source discharges on surface waters within Florida's watersheds, the state fulfills the requirements that were established under Sections 305(b) and 303(d) of the Federal Clean Water Act, and accomplishes the goals of the 1999 Florida Watershed Restoration Act (FDEP 2004).

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[1] Allan (1995) mentions that in American usage the terms drainage basin, catchment, and watershed are synonymous, even though catchments may be used to refer to small basins. Accordingly, these three terms were used interchangeably throughout this dissertation.

Emergy has often been used to evaluate the work of nature and the work of humans in generating products and services in watershed systems, to describe and assess their patterns of development, and to propose management alternatives (Odum 1996). Turner et al. (2001) has pointed out that the study of watersheds overlaps with that of landscape ecology, either when different watersheds are compared or when the internal characteristics of a watershed are explored. Accordingly, concepts and tools that are commonly used in environmental accounting using emergy and landscape ecology were used in this study in the assessment of the relationship of patterns of watershed development and their effect on isolated forested wetlands, streams, and lakes in Florida.

Previous Studies

Although concerns over the effect of land use/land cover on freshwater systems has existed for some time only recently, with the development of GIS technology, remotely sensed imagery, and advances in landscape ecology, has there been a greater attempt to quantify these relationships. In this section, a review of the literature related to the main research objectives of this dissertation is presented. Emergy studies of watersheds, landscapes, and land use are summarized herein. Some of the concepts and results from these studies are the basis for the calculation of and index of Landscape Development Intensity (LDI) whose development and applications are also considered. Finally, studies that relate landscape pattern metrics to ecosystems condition at different scales and for different freshwater systems are reviewed.

Emergy Studies

Emergy accounting has enabled relating economic development with environmental change for a great variety of products and processes around the world. Most of this work is summarized in Odum (1996), and more recently was published in a series of folios by the H. T. Odum Center for Environmental Policy of the University of Florida (Odum 2000; Odum et al.

2000a; Brown and Bardi 2001; Brandt-Williams 2001; Kangas 2002), and in the proceedings of the biennial Emergy Synthesis Research Conferences initiated in 1999 (Brown 2000; Brown 2003a; Brown 2005). The scientific basis of the emergy methodology is described in great detail in Odum (1994). Within this work, studies on watersheds, landscapes, and land use are of particular interest for this research.

Watersheds studies using emergy

The study of watersheds using emergy began more than 20 years ago. These studies have described properties of watersheds, their patterns of development, and have been used as the basis for management purposes. Diamond (1984) and Odum et al. (1987) evaluated the properties of stream orders in the Mississippi River Basin based on their environmental and economic empower. These studies revealed that the geopotential energy fluxes were greatest at intermediate to high order levels while the delta and floodplains presented the greatest emergy since different energies (i.e., watershed, coast, and trade) converged in these areas. Romitelli (1997) evaluated the work done by water energies in six watersheds in southeastern Brazil and in the Coweeta basin in North Carolina, United States. The chemical potential and geopotential energies of water were found to be coupled; the geopotential energy, maximized at middle elevations, allowed the dispersal of nutrients and sediments in the floodplains. Transformities[2] of chemical potential energy were found to increase downstream.

Research aimed at analyzing the patterns of development in watersheds include the study by Odum et al. (1986) in the Amazon Basin, where economic development and ecological organization were found to be hierarchical and organized to maximize available energies from within and without the system. Howington (1999) looked at the spatial organization of the

[2] Transformity is defined as “the emergy of one type required to make a unit of energy of another type” (Odum 1996, page 289).

Catatumbo River basin from an emergy perspective. Spatial emergy patterns were used to describe how resources were used and the patterns of development in this basin which is shared between two countries, Colombia and Venezuela. Total renewable empower density increases downstream while nonrenewable empower density increased upstream. Since the middle to upper basin was more developed, the author suggested that growth in this area should be done in such a way that its impact on water quality is minimized, thus improving the ability of downstream wetlands to buffer development impacts. Studying the Cache River watershed in northeastern Arkansas, United States, Odum et al. (1998b) found that environmental contributions within the system accounted for about half of the watersheds' wealth (measured in emergy units) while the other half was from inputs purchased outside the system. The Cache River watershed, mostly an agricultural area based on indigenous soils and waters, proved to be a net emergy exporter. In Florida, Brandt-Williams (1999) used measures of materials, energy and emergy, to study the links between two lakes and their respective watersheds. Lakes were found to be areas of high emergy concentration due to the flow of energy and materials from their watersheds. Simulation models determined that the influence of the watersheds on the lakes increased with higher use of nonrenewable inputs within the basin. Also in Florida, Parker (1998) found that the empower density increased downstream in the St. Marks watershed and was highest in the central region of the basin, where nonrenewable inputs such as electricity and fuel dominated. Intermediate empower densities characterized the lower end of the basin where the landscape changes from urban- to rural-dominated land uses.

Tilley (1999) estimated the benefits provided by three forested watersheds in the Southern Appalachians, United States, based on the emergy required to develop and maintain services and products. The benefits of several combinations of economic investment in recreation and timbering were evaluated using empower. Maximum empower (optimum intensity of forest development) was found at intermediate levels of economic investment.

Landscapes and land use

Studies aimed at evaluating landscapes using emergy are originally found in Brown (1980), which studied the relationship between energy flows and the hierarchical organization of urban and regional systems in Florida to test the hypothesis of energy control of landscapes. The results suggested that landscapes are organized hierarchically based on their quality measurements obtained using embodied energy (emergy). In this study, the power density and volume of structure associated with 11 urban land uses in Florida were also calculated. Power density, as well as volume of structure, showed a strong correlation with increasing complexity of land uses.

Whitfield (1994) used emergy to analyze the organization of urban systems based on land use patterns in Jacksonville, Florida. There was a high ratio of purchased resources to renewable resources indicating the high dependency of the city on outside resources. The land use pattern of Jacksonville largely determined the type and amount of resources used. Alternative land use patterns suggested by the author were found to reduce resource use and to reduce the impact on the contribution of natural systems. In this study emergy evaluations for 13 different urban land uses and three agricultural land uses were developed.

Lambert (1999) created a spatial model of the distribution of energy flows and storages in Alachua County, Florida, and used it to analyze spatial patterns of energy transformation hierarchy in relation to spatial patterns of urban landscapes. Maps of transformities showed that areas with low transformities are more dispersed and organized surrounding centrally-located areas with higher transformities. The results suggested that urban landscapes tend to develop spatial patterns that can be described in terms of an energy transformation hierarchy.

Brandt-Williams (1999) developed emergy evaluations for different land uses within lake watersheds in Florida. Key emergy-based ratios relevant to agriculture (transformity, emergy per mass, and empower density) were calculated. Boggess (1994) related the spatial distribution of empower to phosphorus runoff from different land uses in an agricultural watershed of the north Okeechobee basin in Florida. Maximum phosphorus loads occurred at intermediate empower densities (agricultural lands uses) while empower increased downstream. Other production processes of interest that were evaluated using emergy include natural systems (Orell 1998; Bardi and Brown 2001), forestry (Christianson 1984; Doherty 1995; Odum et al. 2000b), mining (Kangas 1983; Odum 1996; Kangas 2002), aquaculture (Odum and Arding 1991; Brown et al. 1992; Ortega et al. 2000) and transportation (Odum and Odum 1987; McGrane 1994).

Measures of the intensity of landscape development

Brown and Vivas (2005) calculated an index of landscape development intensity (LDI) using land use data and measures of the intensity of development derived from energy use per unit area. The LDI was developed to estimate the potential impacts from human-dominated activities on ecological systems within watersheds of different sizes in Florida. The LDI was proposed as a measure of the human disturbance gradient.

Previously, Parker (1998) used preliminary versions of the LDI based on physical and emergy measurements to correlate them to model results from a spatial pollutant model for total phosphorus (TP) for subbasins of the St. Marks Watershed in Northern Florida. The LDIs showed a good association with the TP loads above background levels, particularly an imperviousness LDI and the empower density LDIs. This study showed that despite the fact that predicting TP loads at low development intensities is difficult; at higher levels of human development the LDI in its various forms may be a good predictor of nutrients accumulation that can result from more intense human activities. Based on these research findings, Parker (1998) suggested that development intensity indices could be useful for policy purposes.

Cohen et al. (2004) used a preliminary version of the LDI calculated by Brown and Vivas (2005) as a measure against which a floristic quality assessment index (FQAI) could be compared and to provide evidence of its importance in the assessment of the ecological condition of small isolated herbaceous wetland systems. The FQAI is a numerically-based expert opinion index used to associate plant species to a particular habitat or to determine their tolerance to varying disturbance intensity. Strong associations between the LDI and the FQAI provided evidence of the relevance of the floristic index for biological assessment studies and of the LDI as a measure of the human disturbance gradient.

Using the LDI, Lane (2003) developed three indices as quantitative measures of biological integrity using metrics for diatoms, macrophytes, and macroinvertebrates for isolated herbaceous depressional wetlands in Florida. Similarly, Reiss (2004) developed a Wetland Condition Index (WCI) for the same groups of organisms for isolated forested wetlands in Florida; and Reiss and Brown (2005) developed a preliminary Florida Wetland Condition Index (FWCI) for forested strand and floodplain wetlands. In all three cases these indices allowed the comparison of changes in the composition of biological communities of wetlands along gradients of landscape development intensity. Fore (2004, 2005) used modified versions of the LDI to assess the biological conditions of streams and lakes in Florida, respectively.

Surdick (2005) analyzed how human land uses of varying intensities surrounding isolated forested wetlands in Florida affected the species composition of birds and amphibians. Amphibians that were obligatory ephemeral pond breeders decreased with increasing land use intensity. For birds, insectivores, bark gleaners, canopy gleaners, territorial species, ground nesters, and cavity nesters also decreased with increasing land use intensity, while omnivores, herbivores, ground gleaners, canopy nesters, and exotic species increased with increasing land use intensity. The differences between species composition in less developed landscapes and highly developed landscapes were significant, following a gradient of increasing dissimilarity from undeveloped lands to silviculture, agriculture, and urban land uses, respectively. Surdick (2005) pointed out the relevance of the LDI for ecological studies involving changes along a disturbance gradient. Since the LDI is GIS-based, it is more time- and cost-efficient than indices that rely heavily on field data. Additionally, the LDI provides a quantitative measure of the human disturbance gradient compared to most indices used in studies involving measures of land use intensity which tend to be qualitative in nature.

Mack (2006) tested the robustness of the LDI as a wetland condition assessment procedure using a large reference wetland data set in Ohio. The LDI was significantly correlated with the Ohio Rapid Assessment Method for Wetlands (ORAM), an independent measure of the human disturbance gradient. The LDI was also correlated with Ohio's Vegetation Index of Biotic Integrity (VIBI), a multi-metric index of wetland integrity. The most significant relationships were found between the LDI and metrics from emergent wetlands, followed by forested wetlands, and shrub wetlands. Mack (2006) emphasized the robustness of the LDI as a measure of the human disturbance gradient given its theoretical foundations and quantitative nature.

Landscape Pattern: Quantification and Application

Metrics of landscape pattern allow the quantification of composition and spatial configuration of human–dominated land uses in watersheds and provide quantitative measurements of human-induced impacts. They are useful in watershed management because they can be used to assess changes in water quality (USEPA 1994; O'Neill et al. 1997; Gergel et al. 2002; Griffith 2002; Turner 2005). Such recognition has led to the development of research directed towards understanding the behavior and relevance of metrics in watershed studies, to explore relationships between land use/land cover and water chemistry and between land use/land cover and the condition of freshwater biological communities, and to determine the spatial scale that best describes such relationships.

Selection of pattern metrics

The quantification of landscape pattern has received considerable attention due to the widely accepted relationship between spatial pattern and ecological processes. The question of what the minimum number and types of measurements are that appropriately describe overall landscape status is of special interest. Since one metric alone cannot capture all the relevant aspects of pattern, multi-metric measurements are required. To help in the identification of landscape indicators or metrics for monitoring landscapes in terms of land cover and land use patterns, Riitters et al. (1995) have suggested the use of measurements that provide information on six dimensions or orthogonal factors that can be represented by six independent metrics: average perimeter-area ratio, contagion, standardized patch size, patch- perimeter-area scaling, number of attribute classes, and large-patch density-area scaling. Turner et al. (2001) have recommended the use of a minimum of five metrics that are independent from each other when used to describe a landscape. In the assessment of watershed integrity, USEPA (1994) and O'Neill et al. (1997) have recommended the use of landscape indicators of patterns that provide information on at least three dimensions: spatial composition, shape complexity, and spatial configuration. Several authors (Cain et al. 1997; Cifaldi et al. 2004; Kearns et al. 2005) have made efforts to identify a set of core metrics that can be generally used as pattern measurements in watershed and ecological condition of aquatic ecosystem studies Factor analysis and principal component analyses; which account for most of the variance among the original variables (Johnson and Gage 1997; Dytham 1999), have been frequently used for such a purpose. Even though similar sets of metrics have been proposed, their behavior across different landscape remains uncertain and requires further investigation (Cifaldi et al. 2004).

Landscape influences on ecosystem condition

Studies of the influence of land use on surface waters for different ecosystems using landscape pattern metrics can be divided into two related groups; those that study changes in water chemistry, and those that focus on the changes in the characteristics of aquatic biological communities.

Water chemistry. Water chemistry studies have emphasized the study of the relationship between land use and excess nutrients, particularly nitrogen and phosphorus. Hunsaker and Levine (1995) used the proportion of seven land use types, dominance, and contagion as landscape metrics in an effort to develop methods to characterize landscape attributes that influence water quality at different scales in the Wabash River in Illinois. Their results showed that landscape metrics were effective predictors of phosphorus and nitrogen loads. Landscape metrics (eight variables combined) accounted for 71 to 85% of the variance in phosphorus loads, and 42 to 53% of the variance for nitrogen loads across a range of watershed sizes. In a study of multiple watersheds in the Mid-Atlantic region, Jones et al. (2001) used metrics of land use composition (fraction occupied by different land uses) to explain the high amounts of variation in nutrient and sediment loads to streams. Landscape metrics consistently explained the variability of nitrogen (65 to 85%) and dissolved phosphorus (73%) inputs to streams. Crosbie and Chow-Fraser (1999) showed that the water chemistry of 22 marshes in the Great Lakes basin was significantly affected by land use in their respective watersheds. Using principal components analysis they were able to show that the content of inorganic solids and phosphorus in the sediments and the ionic strength of the water positively correlated with percent agricultural land. However, soluble reactive phosphorus and nitrate nitrogen concentration in the water did not correlate with land use. Soranno et al. (1996) developed a simple model to account for spatial pattern in topography and land use using GIS. Land use scenarios were used to explain annual phosphorus loads in Lake Mendota, Wisconsin, which is a nutrient-rich lake in a watershed dominated by agricultural and urban lands. Modeling results showed that phosphorus loading was greatest when natural vegetation was converted to agricultural or urban land uses. Studies that have found evidence of the relationship between landscape metrics and water chemistry for nitrogen and phosphorus include Osborne and Willey (1988), Johnes et al. (1996), Johnson et al. (1997), Jones et al. (2001), Griffith et al. (2002), Brett et al. (2005), and Uuemaa et al. (2005); for suspended sediments Johnson et al. (1997), Crosbie and Chow- Fraser (1999), Jones et al. (2001), Sponseller et al. (2001), and Houlahan and Findlay (2004); for conductivity Hunsaker and Levine (1995), Crosbie and Chow- Fraser (1999), Sponseller et al. (2001), and Griffith et al. (2002); for alkalinity Johnson et al. (1997) and Sponseller et al. (2001); for dissolved organic carbon (Gergel et al. 1999); and Uuemaa et al. (2005) for biological and chemical oxygen demand.

Biological integrity. The use of landscape metrics to assess changes in the characteristics of aquatic biological communities has also been investigated. Roth et al. (1996) studied the effect of land use/land cover on the biological integrity of stream ecosystems in River Raisin in Michigan. They evaluated the condition of streams using an Index of Biological Integrity (IBI) and a habitat index (HI). The IBI was developed based on 10 metrics of fish collected from the streams. The HI was calculated based on nine metrics that measure in-stream and bank variables. The results showed that the stream biotic integrity and habitat quality correlated negatively with the percent of agricultural land and positively with the extent of wetlands and forests. For the same watershed, Lammert and Allan (1999) examined fish and macroinvertebrate assemblages to relate the overall biotic condition of streams to patterns of land use. They found that land use immediate to the streams was a good predictor of biotic condition. They used proportions of agricultural and forested land as the metrics of landscape pattern. Sponseller et al. (2001) have suggested that differences in the structure of the macroinvertebrate assemblages in nine headwater basins in the southern Appalachian region could be explained by land cover patterns. Two land use classes, forested and non-forested land, and their proportions, were used in the analysis. Wang et al. (2001) analyzed the relationship of the amount and spatial pattern of land cover with stream fish communities in 47 small watersheds in Wisconsin. Their results suggested that the increase in urbanization had negatively affected stream habitat and fish communities. Again, land use proportion was the preferred landscape metric. In a study of 20 watersheds in West Virginia, Snyder et al. (2003) found that urban land use negatively affected the biological integrity of streams. Biological integrity was quantified using a fish-based IBI. No meaningful relationships were found between the proportion of agricultural lands and the IBI. Similar studies that included fish and macroinvertebrates are those by Richards et al. (1996), Allan et al. (1997), Mensing et al. (1998), Galatowitsch et al. (1999), Griffith et al. (2002), Pess et al. (2002), Townsend et al. (2003), and Wang et al (2003). Other studies have considered amphibians (Galatowitsch et al. 1999; Knutson et al. 1999; Guerry and Hunter 2002), birds (Miller et al. 1997; Galatowitsch et al. 1999; Austin et al. 2001), and plants (Miller et al. 1997; Galatowitsch et al. 2000).

Landscape scale influences on freshwater ecosystem condition

Since landscapes and watersheds are complex systems, their study requires a multi-scale approach to fully understand and manage them (USEPA 1994; Allan and Johnson 1997; Hay et al. 2001). The importance of landscape scale in determining land use-water relationships has led to questions regarding how responses vary when relationships are analyzed using different spatial resolutions, and how the spatial extent at which land use pattern can best explain changes in the condition of freshwater ecosystems. These studies have at times shown contrasting results and at other times complementary observations.

Grain size. Hunsaker and Levine (1995) developed methods to characterize landscape attributes that influence water quality at various scales. They compared land use data from the Wabash River basin in Illinois and the Lake Ray Roberts watershed in Texas with very different spatial resolutions; the Illinois data were courser. Specifically they looked at different areas of influence, the entire watershed, hydrological active areas, and equidistant corridors of 200 meters and 400 meters around streams to model the influence of the landscape on water quality. They were able to show that for the Illinois basin water quality could be accurately predicted from land use information for the entire watershed, while land use near streams was not a critical factor in modeling water quality. These results contradicted to some extent those of the Texas site, whose results showed that all land use areas were important to modeling. In Michigan, several studies have looked at the landscape influence on stream biotic integrity at different scales in the River Raisin watershed. Based on Frissell et al. (1986), the hierarchical framework for stream habitat classification (habitat-reach-segment-subcatchment-basin), Allan et al. (1997) and Roth et al. (1996) have suggested that the influence of land use on stream integrity is scale-dependent. These studies showed that the sub-catchment scale was the best predictor of stream biotic condition when analyzing land use at a regional scale. A similar study conducted by Lammert and Allan (1999) used a finer scale measurement for the same watershed, which presented different results. In this case, habitat and immediate land use were better predictors of stream biotic integrity than land use for the entire catchment. However, this was only true for macroinvertebrates. The authors argued that measurements at the habitat level may not be appropriate in explaining the variability in fish assemblages at that scale.

Spatial extent. Studies that considered different spatial extents have also shown varying results. Wang et al. (2001) found in a study of 47 small watersheds in southeastern Wisconsin that land use within 50-meter buffers had more influence on fish assemblages than land use within buffers of 100-meters and greater; and more influence for land use data within a 1.6-km radius upstream from sampling sites than for land use data within greater radiuses upstream. Snyder et al. (2003) found that land use patterns for the whole watershed were more strongly associated with fish assemblages than riparian land use patterns in a West Virginia study; Mensing et al. (1998) obtained similar results in a study of riparian wetlands in Minnesota. Wang et al. (2003) concluded from a study of 79 watersheds in Great Lakes region that the relative influence of land use among other variables at the reach scale on fish assemblages may be more important in non-developed areas, while land use at the watershed scale may be a more important variable with increasing modification of the landscape by humans. The findings by Sponseller et al. (2001) for macroinvertebrates in streams of the Appalachian region seem to support the hypothesis that local or near-stream land use has a strong influence on the structure of the assemblage. They quantify land cover at five spatial scales: the entire catchment, the riparian corridor, and three buffers extending 200, 1000, and 2000 meters upstream of sampling reaches. Landscape pattern within the 200-meter buffer presented the best relationship with macroinvertebrate metrics. Mensing et al. (1998) results for macroinvertebrates also provided evidence in this direction. In New Zealand, Townsend et al. (2003) found that the proportion of pasture land within the riparian zone of the Taieri River accounted for most of the variation in macroinvertebrate assemblages than for the entire watershed.

In the analysis of the influence of land use on changes in the water chemistry, results by Johnson et al. (1997) showed that total phosphorus and total suspended solids were much better explained by the land use within a 100-meter buffer for streams of the Saginaw Bay Catchment in central Michigan than for the entire subcatchment. Total nitrogen, nitrate, orthophosphate, and alkalinity were equally explained by land use at the two scales. For a watershed in southeastern Michigan, Allan et al. (1997) found that nutrient and sediment inputs were influenced more by the land use measured at broader scales than at more local scales. In a study that included a total of 73 wetlands in Ontario, Canada, Houlahan and Findlay (2004) found that the effect that the land use surrounding wetlands has on water and sediments nutrients could extend for relatively large distances after considering a series of land buffers at different intervals that range up to 5000 meters from the wetlands' edges. They found that water phosphorus and nitrogen levels correlated strongly with forest cover at 2,250 meters from the wetland edge. Gergel et al. (1999) reported that the proportion of wetlands in the watershed was a better predictor of dissolved organic carbon (DOC) than in 200-meter riparian buffers for rivers in Wisconsin. For lakes, the proportion of wetlands within 50-meter buffers seemed to explain more of the DOC than the proportion of wetlands for entire watersheds.

Study Area: Florida, an Overview

Physical and Ecological Aspects

Florida is an ecologically and climatically diverse region located in the southeastern tip of the United States. The state has approximately 14 million hectares in land area, two-thirds of which occur as a long peninsula running in a north-south direction and with a humid subtropical climate. The remaining third of Florida's land surface, know as the Panhandle, is located in the northwest portion of the state and has a more temperate climate. Florida has a relatively flat terrain with a mean elevation of approximately 30 meters above sea level. Florida's climate is generally warm and humid, with rains that vary seasonally averaging between 1.2 to 1.5 meters per year (Chen and Gerber 1990).

Northern Florida is within the southern temperate zone and is home to both deciduous and evergreen hardwood forests, including pine trees in the uplands and bottom hardwoods in the alluvial plains (Odum et al. 1998a). The Okefenokee Swamp, a headwater wetland, is an important feature of the landscape to the northeast. Pine flatwoods are also common in Central Florida where individual stands may comprise very large areas intermixed with other less extended forest systems and wetlands including isolated cypress heads, bayheads, wet prairies, and marshes (Abrahamson and Hartnett 1990). The southern tip of the peninsula, although highly modified by development, still contains tropically-influenced hammock forests. However, the most outstanding natural feature of Florida's southern landscape is the presence of a complex system of wetlands that include the Everglades, wet prairies, sawgrass and tree islands, and the Big Cypress headwater wetland (Odum et al. 1998a).

Wetlands (marshes and swamps) are a common feature of Florida's landscapes. The largest freshwater mash area is the Everglades in South Florida, while other freshwater mashes are unevenly distributed throughout the state. Unlike marshes, swamps are widely distributed throughout the state and constitute a diverse set of systems that can be found in river floodplains, in the margins of lakes, or as isolated systems in the form of strands or ponds (cypress domes). A cypress dome is illustrated in Figure 1-3 in the form of a systems diagram which shows the main components and processes of a forested wetland in Florida. The main inflows into the cypress dome are sunlight, wind, and water (rain, runoff, and groundwater) as shown to the left of the diagram. Rainwater is the main water inflow and source of nutrients. Oxygen and carbon dioxide are brought into the wetland from the air. Runoff from the surroundings is limited since the drainage area of cypress domes is usually small. Wetland trees, herbaceous vegetation, and algae are the main producers in the system. Organic matter, mostly produced within the system, may accumulate in large quantities as part of the wetland's soil. Consumers include bottom-dwelling macroinvertebrate and amphibians, as well as birds and mammals which are usually occasional visitors.

Florida is home to more than 1,700 streams and rivers, which comprise approximately 80,000 kilometers (km) in length (Nordlie 1990; Fernald and Purdum 1998). There is great variation among Florida's rivers and streams in terms of their physical characteristic and their chemical and biological features. The state also has over 300 springs, most of which are artesian (Nordlie 1990). Figure 1-4 is a system diagram of the main components and processes of a section of a Florida stream. Main inflows in the system are light, wind, and water in the form or rain, runoff, and stream-inflow as shown to the left in the diagram. Light drives photosynthetic production as it is used by phytoplankton, submerged plants, and emergent plants when present. Carbon dioxide required for photosynthesis is brought into the system from the air. Runoff from the surrounding lands bring into the system organic matter, nutrients, and sediments. Nutrients are absorbed by producers and microbes. Organic matter accumulates as detritus, a portion of which is decomposed by microbes. Some organic matter and the sediments flow downstream. Filter feeders, bottom feeders, and fish are among the stream/river consumers.

The state is also home to around 7,800 lakes that are over one-half of a hectare in size and which cover at least 9,720 square kilometers (km^2), or 6 percent, of Florida's surface area (Brenner et al. 1990; Fernald and Purdum 1998). The lakes are distributed unevenly in the state with more than half located in the central sandy ridge system (Brenner et al. 1990). However, the largest lake in the state, Lake Okeechobee, is located in the South. Florida's lakes are very diverse in terms of their physical, chemical, and biological features. Figure 1-5 depicts a typical lake in Florida. Main inflows in the system are light, wind, and rain. Other waters inputs are in the form of runoff and groundwater. Photosynthetic production is driven by light and may be limited depending on the lakes depth. Phytoplankton, submerged plants and algae, and emergent plants are among the main producers. Carbon dioxide and oxygen are brought into the lake's water by the wind. Runoff from the surrounding lands brings organic matter and nutrients into the system. Nutrients are absorbed by producers and microbes while organic matter accumulates as detritus, a portion of which is decomposed my microbes. Organic matter and sediments tend to accumulate in the lakes bottom. In the absence of a surface water outflow, which is a common aspect of most Florida lakes, the hydrologic connections with the outer systems are limited to groundwater exchange and evaporation. Zooplankton, bottom feeders, fish, and birds are among the lakes' consumers.

Estuarine systems are also common in Florida. In the northern part of the state they dominated by salt marsh communities, while in the southern half mangroves and sea grasses are the predominant ecosystems. The southern-most portion of the state contains the Florida Keys, which are separated from the peninsula by the grass flats of Florida Bay. Coral reefs are present along the Keys.

Land Use

Humans have lived in Florida for more than 10,000 years. The earliest Floridians were hunter-gathers and had little impact on the state's landscapes (Ewel 1990a). With the adoption of agriculture by native Floridians some 800 years ago, the features of the state's landscapes began to change first by the use of fire, and more recently by deforestation, intensification of agriculture, dewatering and canalization of aquatic systems, and urbanization (Ewel 1990a; Reynolds 1999).

Currently, about 31% percent of Florida's land area is in upland forests (Wear 2002). It is expected that this figure will decrease in the future due to development pressures in the state. It is estimated that approximately 2.5 million hectares of forest lands have been lost in Florida since the 1930s; and land development greatly contributed to this change (FDACS 2005). Wetlands (marshes and swamps), which used to occupy more than half of the state's land area, today account for 30% percent of Florida's land area with 2.2 million hectares covered by forested wetlands or swamps (Ainslie 2002). Although the rate of loss of wetlands to other land uses has decreased compared to the period between the 1950s to the 1970s when it reached its peak, wetlands will continue to be lost in Florida due to agriculture, urban development, and silviculture. Forested wetlands will be affected particularly by urbanization and conversion to other wetland types (Ainslie 2002). Agricultural lands cover 30% of Florida's land area (USDA 2005). Although between 1945 and 1974 the area in agriculture increased steadily, since then it has remained about the same. Florida's urban land uses account for approximately 12 percent of the land area (Wear 2002).

Freshwater Ecosystem Degradation

Overall, the main sources for the impairment of the state's surface waters are urban and agricultural runoff, domestic and industrial wastewaters, and hydrologic alterations (Paulic et al. 1996). The presence of high levels of nutrients, high loads of organic matter that may result in low concentrations of dissolved oxygen, siltation, habitat degradation, and bacterial contamination are the main problems leading to stream degradation (Paulic et al. 1996). Problems for lakes have resulted mostly from nutrient enrichment, the presence of toxins and metals, acidification, and habitat degradation (Brenner et al. 1990, Paulic et al. 1996). Most of the problems that are facing lakes and streams are also common in the forested wetlands of the state. Physical disturbance or modification has been of special concern because of the characteristics of these systems. Since forested wetlands are abundant with trees, almost every wetland in the state has experienced some type of logging since the late 1800s (Ewel 1990b). Although these forests may regenerate after logging has occurred, this regeneration may not happen without some degree of shift in their community composition.

Scale of Investigation

Florida's hydrologic units' subdivision of watersheds defined the area of investigation for streams and lakes in the assessment of human impacts on the quality of surface waters. Selected watersheds were distributed throughout the state excluding the Everglades and Florida Keys. In addition, a sample of 118 isolated forested wetlands, also distributed throughout the state, was used to complement the analysis of human landscape scale impacts on freshwater systems.

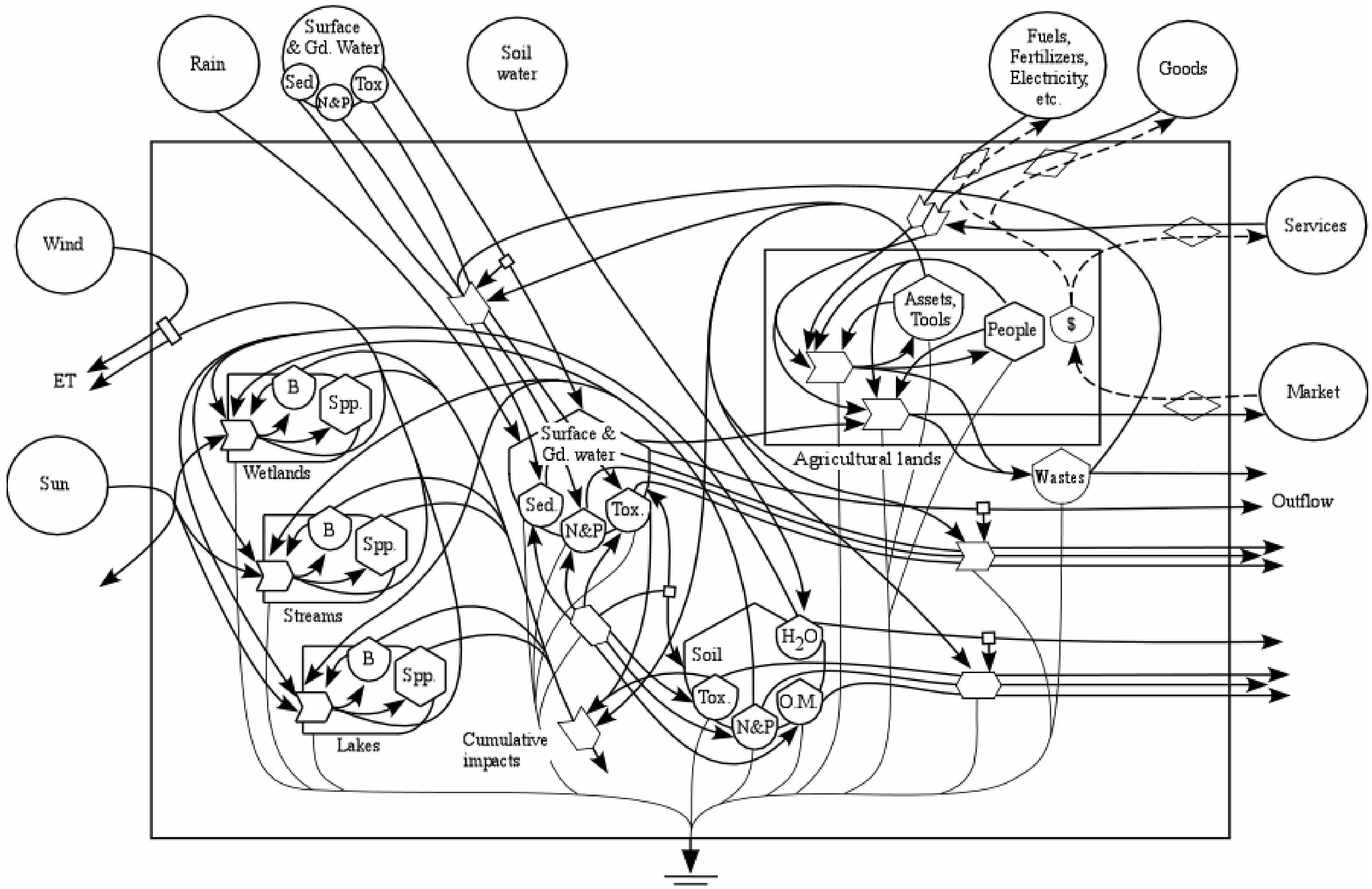


Figure 1-1. Systems diagram of the impacts of agricultural lands on freshwater ecosystems. B = biomass, Spp. = species, Sed. = sediments, N & P = nitrogen and phosphorus, Tox. = toxins, and O. M. = organic matter (modified from Brown and Vivas 2005). The symbols used are explained in Appendix A-1. Agricultural lands are represented with a box symbol provided that the elements included (and their interactions) are not limited to the fields or crops but to a variety of components.

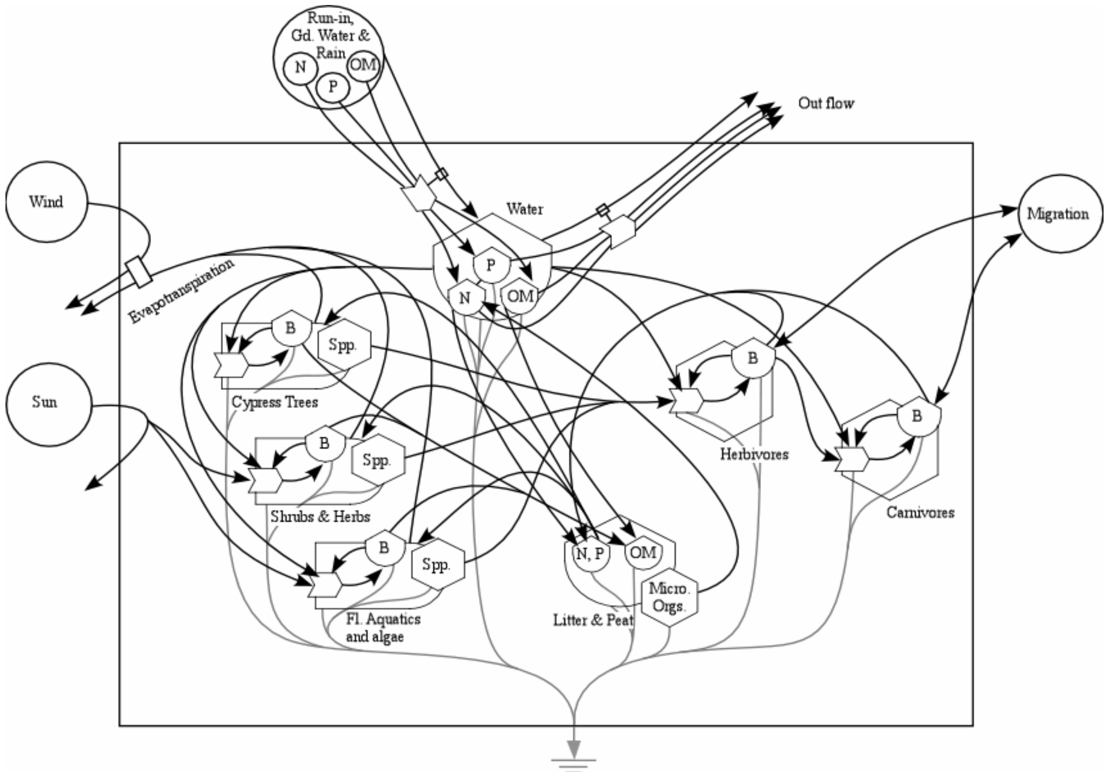


Figure 1-2. Systems diagram of a Florida cypress dome.

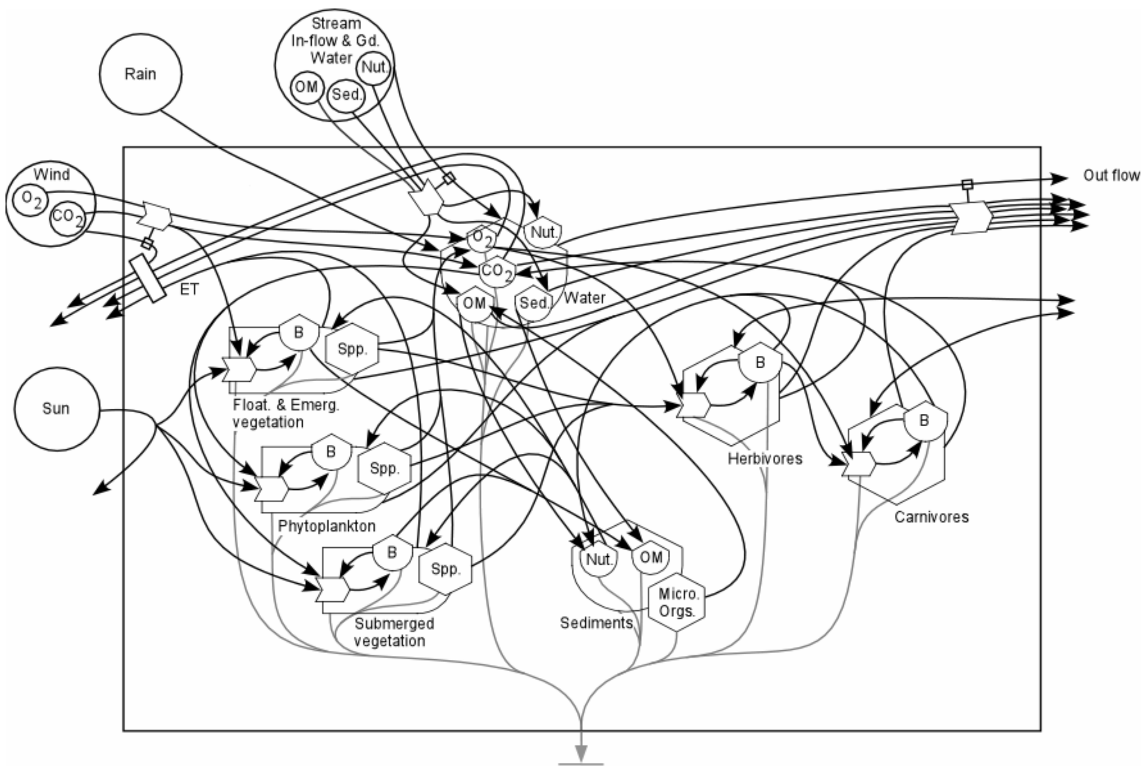


Figure 1-3. Systems diagram of a stream section in Florida.

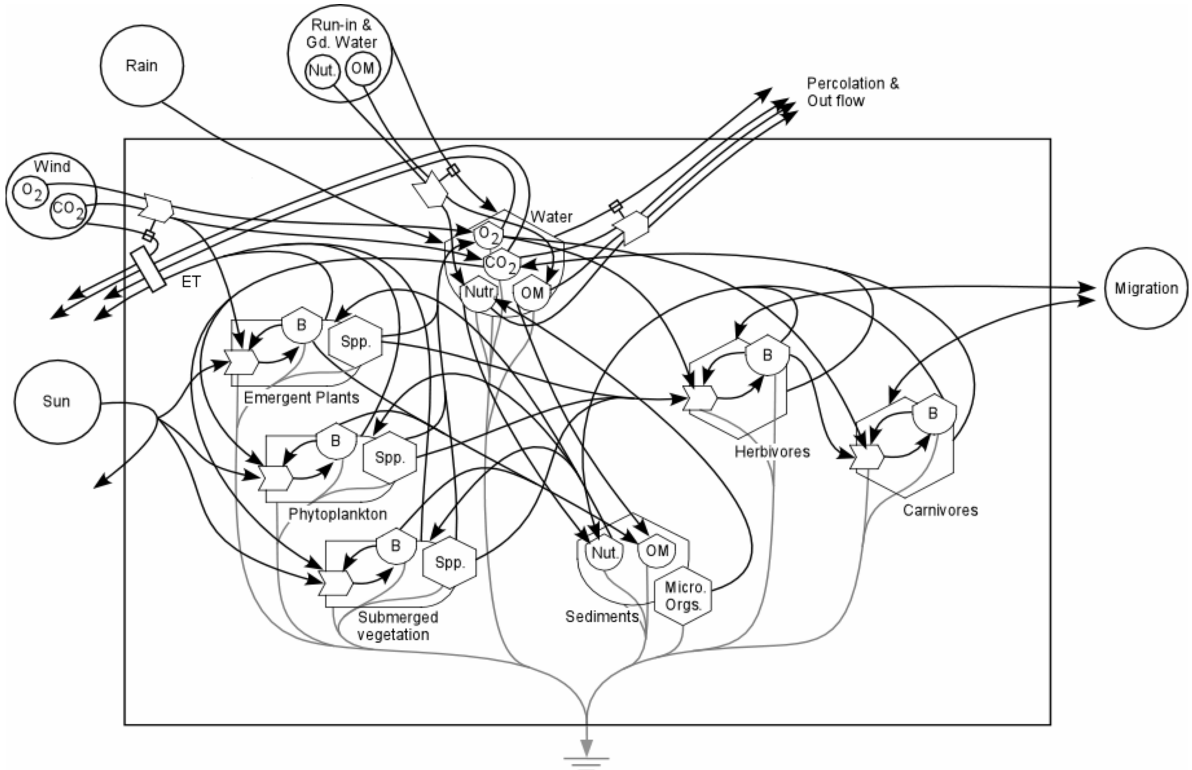


Figure 1-4. Systems diagram of a Florida lake.

CHAPTER 2
METHODS

The Landscape Development Intensity Index (LDI) and landscape pattern indices were calculated for watersheds and areas of influence of different sizes surrounding 118 isolated forested wetlands, 69 streams, and 54 lakes in Florida. The indices were used to assess the influence of human development on these aquatic ecosystems. This chapter describes site selection, data sources, scales of analysis, and selection and calculation of landscape indices. The statistical analyses that were used are also described.

Site Selection

Isolated Forested Wetlands

The isolated forested wetlands included in this study were selected following the criteria set by Reiss (2004) for the development of sets of biological indicators to assess the ecological integrity of isolated forested wetlands in Florida. With a nearly equal spatial distribution of wetlands within each of the four Florida wetland ecoregions (Panhandle, North, Central, and South) defined by Lane (2000), a total of 118 isolated forested wetlands were identified through field surveys and with the aid of aerial photography. The isolated forested wetlands varied in size from 0.07 to 2.1 hectares (mean = 0.68; SD = 0.44). Their locations are presented in Figure 2-1.

Isolated forested wetlands were selected *a priori* as belonging to one of three different landscapes: isolated forested wetlands surrounded mainly by undeveloped lands (n = 37), which are hereafter referred to as reference isolated forested wetlands; isolated forested wetlands within an agricultural landscape (n = 40), which are hereafter referred to as agricultural isolated forested wetlands; and isolated forested wetlands within an urban landscape (n = 41), which are hereafter referred to as urban isolated forested wetlands. The reference isolated forested wetlands were generally located on conservation lands including state and national parks and forests, county and city lands, and private conservation tracts. Agricultural isolated forested wetlands were usually surrounded by cattle pasture, row crops, tree crops, and silvicultural land uses. Urban isolated forested wetlands were surrounded by a variety of residential, commercial, industrial, recreational, and public land uses; many of the urban isolated forested wetlands were believed to have previously belonged to an agricultural landscape (Reiss 2004). Table 2-1 provides general information about each wetland, including the sampling date and surrounding land use.

Streams

Site selection was made from the stream sample used in the development of the stream condition index (SCI) for Florida and initially reported by Barbour et al. (1996b). The SCI was developed using seven descriptors, or metrics, of stream benthic macroinvertebrates that are altered with increased human disturbance (Barbour et al. 1996a; Barbour et al. 1996b). The SCI was recalibrated by Fore (2004) and new streams were included in the analysis with a final total sample of 223 streams. The streams that were selected in the development of the original SCI were distributed homogenously in Florida into three bioregions (Panhandle, Peninsula, and Northeast) in order to control for the biological variance that would otherwise occur (Barbour et al. 1996b). Bioregions resulted from the aggregation of Florida's stream ecoregions that were developed by Griffith et al. (1994), and did not consider the Everglades since the streams in this area have been subject to significant hydrologic alterations (Barbour et al. 1996b).

Site selection was made considering only those streams for which the macroinvertebrate data were collected between 1993 and 1995. The stream sample size was further narrowed based on the availability of water quality data for each stream and for the same period of time using EPA's Water Quality Storage and Retrieval (STORET) database (available at www.epa.gov/storpubl/legacy/gateway.htm) and the data used in the surface water quality assessment that was developed for Florida in 1996 by Paulic et al. (1996) (also known as the

305[b] Report). Since not every site had water quality data associated with it, and to increase sample size, the selection of water quality data was made increasing the sampling time range for each station (or site) ± 1year. Finally, sampling stations used as tests sites in the development of the SCI that were associated with point sources of pollution were removed from the stream sample. As a result, a total of 69 streams were selected in Florida. Their locations are shown in Figure 2-2 as STORET sampling stations. Table 2-2 provides information on each stream, including the STORET sampling station number, the drainage basin name, and the United States Geological Survey (USGS) Hydrologic Unit Code (HUC) that identifies the hydrologic unit to which each stream belongs, and the corresponding stream bioregion.

Lakes

Lakes were selected using a subset of the lakes currently used by FDEP in the development of a biological index for Florida lakes which was initially reported by Gerritsen et al. (2000). The development of this index originally included six metrics in three alternative lake condition indexes (LCI) that were based on biological data collected between 1993 and 1997 for 206 lakes within 36 of the 47 Florida lake regions that are identified by Griffith et al. (1997). In addition, the lakes were classified into five categories based on three independent factors: water color, pH, and ecoregions. This classification allowed the identification of Florida's lakes by types: acid-clear lakes of ecoregion 65 (Southeast Plains), acid-clear lakes of ecoregion 75 (Atlantic Coastal Plain), acid-colored lakes, alkaline-clear lakes, and alkaline-colored lakes. The lakes were also associated to Level 3 ecoregions as defined by Omernik (1987). The development of the LCI is an ongoing process led by FDEP; thus far 500 potential lakes have been identified to examine the relationships between macroinvertebrate communities, water quality variables, and land use within lake basins (FDEP 2005).

Lake selection for this dissertation was made from a subset of 102 lake sampling stations provided by FDEP (R. Frydenborg 2005, Environmental Assessment Section, Bureau of Laboratories, personal communication). Only those lakes for which the macroinvertebrate data were collected by the same agency between the years 1993 and 1995 were considered. The availability of water quality data for each lake and for the same period of time was determined using the data provided by FDEP and using the STORET database. Since not every site had water quality data associated with it, the final selection of sites was made increasing the sampling time range ± 1year in order to increase sample size. As a result, 54 lakes were selected and their location is shown in Figure 2-3 as STORET sampling stations. Table 2-3 provides general information about each lake, including the lake's name, STORET sampling station number, and ecoregion.

Data Sources

Land Use / Land Cover Data and Land Use Classification Systems

The required land-use data of the surrounding landscapes of the isolated forested wetlands were delineated using color-infrared orthorectified images (Digital Orthographic Quarter Quad [DOQQ]) for the year 1999, with a 1-meter resolution and 3.75 x 3.75-minutes in extent. The on-screen digitizing was displayed on a computer screen at a scale of approximately 1:5,000. The spatial data were updated and verified in the field during May-September of 2001 and May-October of 2002. Figure 2-4 illustrates the land-use data delineated for a wetland within an urban landscape. The data were comparable to biological and water chemistry data collected during the same dates and were used by Reiss (2004) in developing the Wetland Condition Index (WCI), a quantitative measure of the biological integrity of isolated forested wetlands in Florida.

The land-use data for the drainage areas for streams and lakes were obtained from FDEP's geodata directory, which is available at www.dep.state.fl.us/gis. The data were originally developed by the five Water Management Districts (WMDs) in the State of Florida for the years 1995, 1999, and 2000. The 1995 datasets were developed by each WMD via photo interpretation to capture land use/cover information from DOQQs. The National Aerial Photography Program (NAPP), a multiple-agency program coordinated by the USGS that provides panchromatic and color infrared aerial photos of the United States at 1:40,000 (USGS 2006), recorded the images from 1993 through 1995. The 1999 and 2000 datasets were developed from the 1995 datasets and were updated using DOQQs that were obtained by NAPP during 1999 and 2000. Table 2-4 summarizes the information related to the land use datasets that were developed by each of Florida's five WMDs that are used in this study.

The land use/cover features developed by the WMDs are categorized according to the Florida Land Use and Cover and Forms Classification System (FLUCCS). The FLUCCS was developed by the Florida Department of Transportation (FDOT), following guidelines set by the USGS, and is a hierarchical system of categories with four levels ranging from general to specific. Level I consists of nine classes (Urban and Built-up, Agriculture, Rangeland, Upland Forest, Water, Wetlands, Barren Land, Transportation/Communication/Utilities, and Special Classifications) (FDOT 1999) which are further subdivided into finer detail (Levels II through IV) and increase in resolution with each level.

Land Use Intensity Classification

Using the general structure of the FLUCCS and the definitions set for each of the land uses included in this classification system, and based on the energy flow characteristics of each land use type, a classification scheme of land use was developed according to the intensity of human development. The land use categories for the intensity of human development are defined in Table 2-5. This classification system of land use intensity consists of 25 categories and is limited to one level that was matched with the classes of Levels II and III of the FLUCCS. The matched classes are presented in Appendix B. The choice of land use intensity categories adheres to the specific research needs for this dissertation, and complements the research done by Brown (1980), Harper (1994), Parker (1998), and Brandt-Williams (1999).

Non-renewable and purchased energies were the primary source for quantifying the intensity of human activity, which in emergy calculations is expressed as emergy use per unit area per time or "areal empower density" (Odum 1996). The non-renewable and purchased areal empower density was calculated as average values for land use categories from previous studies by Brown (1980), Whitfield (1994), Doherty (1995), Parker (1998), and Brandt-Williams (1999; 2001). In these previous studies, the energy consumption data were collected from actual billing records and from the literature, and the data were averaged on a per unit area basis for different land use types. A summary of the emergy evaluations used is presented in Appendix C. The resulting areal empower densities for the 25 land use categories or the intensity of human development are presented in Table 2-6. Most of Florida landscapes will fall somewhere within the provided scale of values when they are described in terms of the use of non-renewable and purchased energies.

The land use data for the surrounding landscapes (buffer areas) of the sample isolated forested wetlands, as well as the drainage basins of the sample streams and lakes, were reclassified using the land use intensity classes and values from Table 2-6. Figures 2-5 and 2-6 shows results of this reclassification process.

Water Chemistry Data

Isolated forested wetlands

The water chemistry data for the isolated forested wetlands were collected between 2001 and 2002 by a research team from the Center for Wetlands at the University of Florida. Water samples were collected for a total of 75 isolated forested wetlands and were taken from the deepest pool of each wetland when a minimum of 10 centimeters of standing water was present throughout at least half of the wetland. Water samples were collected only once.

Water samples were analyzed by the FDEP Central Chemistry Laboratory in Tallahassee, Florida. The water chemistry measures measured by FDEP were color, turbidity, pH, specific conductance (SC), ammonia-nitrogen, nitrate/nitrite-nitrogen (NO_2/NO_3), total Kjeldahl nitrogen (TKN), and total phosphorus (TP). Dissolved oxygen (DO) and water temperature measurements were taken onsite using a YSI-55 Dissolved Oxygen hand meter. Among the variables measured, only turbidity (n = 75), SC (n = 33), TP (n = 75), and DO (n = 71) were used in this study to explore the relationship between the changes in land use and the potential impact on the ecological condition of these systems. Total nitrogen (TN, n = 62) was also included as a water chemistry variable and was calculated as the sum of NO_2/NO_3 and TKN. DO, TN, and TP were as given concentrations (mg/L), turbidity as nephelometrics turbidity units (NTU) and SC was measured as micromhos per centimeter (µmhos/cm). All of these water chemistry variables have been reported to be relevant for watershed-land use water quality studies and used to assess the ecosystem condition of freshwater systems (Osborne and Wiley 1988; Johnson et al. 1997; Tufford et al. 1998; Tufford et al. 2003; Houlahan and Findlay 2004; Brett et al. 2005). Information on the availability of water chemistry data for the sample isolated forested wetlands is provided in Appendix D (Table D-1).

Streams

The water chemistry data for streams used in this study were obtained primarily from the data used in developing the Water Quality Index (WQI) to assess the condition of Florida's streams in 1996, and included as part of the 1996 305(b) Report. This is a biennial water quality report submitted by the State of Florida to the EPA in which the status of the water quality in the state is detailed, as required by Section 305(b) of the Clean Water Act (CWA) (Paulic et al.

1996). The WQI is the arithmetic mean of six water quality categories (clarity, DO, oxygen-demanding substances, bacteria, nutrients, and biological diversity) and uses data obtained from EPA's STORET database. The WQI is reported with values ranging from 0 to 99. High index scores are indicative of water quality impairment.

Paulic and collaborators (1996) used 26 water quality measurements from STORET water chemical data for two different periods of time, 1980 to 1989 and 1990 to 1995 to define the six water quality categories that compose the WQI. In some cases, more than one measurement was reported for water quality variables for each STORET station. Thus, the annual average was calculated for the data in these cases and then used. The criteria that were followed in calculating an annual mean dictated that a station had to be sampled at least once during the colder months and once during the warmer months for a given year. For the study performed for this dissertation, only five water quality measurements were considered (i.e. turbidity, DO, NO_3/NO_2-N, TN, and TP) in addition to the WQI to explore the relationship between human development, quantified through the landscape indices, and their potential impact on the water quality of Florida streams. Only data reported for the period between 1992 and 1996 were used, with the exception of three sites for which data reported for 1990-1994 were also included. This exception was made to increase the sample size, since the water chemistry data were not available for all the streams that were initially considered. The water quality data used from the 305(b) Report were complemented with data obtained directly from the STORET database (available at www.epa.gov/storpubl/legacy/gateway.htm) for sampling stations not considered in the development of the WQI. These stations included mainly those sampled during 1996. Data selection and usage was made following the same criteria set by Paulic et al. (1996), as well as that which was reported as collected by FDEP. TN was calculated from STORET data as the sum of nitrate/nitrite nitrogen and TKN. Water chemistry data were available for a total of 47 streams, and the water chemistry measurements were reported as concentrations. Appendix D (Table D-2) presents a summary of the information on the water chemistry variables considered for streams in this study.

Lakes

The water quality data for lakes used in this study were collected by FDEP between 1993 and 2000. Unlike the data for streams, many lakes were sampled only once; therefore, the data were not discarded and were considered for further analysis. For cases in which there was more than one measurement for a given year, the annual average was calculated for each variable. The water quality data, which corresponded to the years 1996-2000 were provided by FDEP (R. Frydenborg 2005, Environmental Assessment Section, Bureau of Laboratories personal communication), and are available by accessing EPA's STORET database. Five water chemistry variables were considered: ammonia nitrogen, NO_3/NO_2-N, TKN, TN, and TP. TN was calculated as the sum of NO_3/NO_2-N and TKN, and all water chemistry measurements were reported as concentrations. Appendix D (Table D-3) presents a summary of the water quality variables used for the lakes in this study.

Biological Data

Isolated forested wetlands

The individual index for each of the three biological assemblages used in the development of the Florida WCI by Reiss (2004) was used in the assessment of the effect of land use on the condition of wetlands. The WCI is a multimetric index that quantifies the biological integrity of pond-cypress wetlands. The index resulted from the combination of 19 metrics (7 diatom metrics, 6 macrophyte metrics, and 6 macroinvertebrate metrics) that measure changes in the biological community composition of wetlands along a gradient of human disturbance. The metric composition of each WCI is presented in Appendix E.

Potential scores for the diatoms WCI ranged from 0-70, while the WCIs for the macrophytes and the macroinvertebrates ranged from 0-60. In all three cases, higher values represent the isolated forested wetlands that are surrounded by low-intensity land uses (Reiss 2004). The WCI scores for each wetland are also presented in Appendix E. It should be noted that Reiss (2004) used the LDI that was reported by Brown and Vivas (2005) as the measure of the human disturbance gradient in the development of the WCI. This LDI was an earlier version of the area-based LDI that is used in this dissertation (a description of this LDI is presented later). However, the WCI was still considered useful for testing the predictive power of the new form of the LDI.

Streams

The biological data used for streams are summarized in the SCI that was first developed by Barbour et al. (1996b) for Florida. The SCI is an index that quantifies the biological integrity of streams and is used as a biomonitoring tool to assess the effectiveness of non-point source pollution control in the state. The original SCI aggregated seven metrics representing characteristics of bottom-dwelling macroinvertebrates that are expected to change along a human disturbance gradient. Least-impaired streams were defined as sites that were wadeable (first to third order), showed minimum signs of disturbance, and were completely within subecoregions. These sites were defined as reference sites and serve to differentiate between least-impaired and impaired streams (Barbour et al. 1996b). SCI scores ranged between 7, which refer to a very poor biological condition, and 33, which relate to a very good biological condition. The SCI was calibrated for summer and winter biological index periods.

The original version of the SCI was recently refined by Fore (2004). This newest version of the SCI aggregates 10 metrics that also represent characteristics of bottom-dwelling macroinvertebrates that are expected to change along a human disturbance gradient. The human disturbance gradient was developed by combining and scoring measures of hydrologic condition, habitat condition, and water quality measured as the concentration of ammonia nitrogen. It also includes an earlier form of the LDI (area-weighted). The values are reported on a scale from 0 to 100 with low values associated with most disturbed streams, and high values corresponding to the least disturbed sites. Additionally, the SCI is independent of watershed size and geographic region, and shows a small variability between seasonal and annual changes (Fore 2004).

Both versions of the SCI were used in this dissertation and in those cases in which more than one SCI score was reported for a given site (one score for each of multiple sampling seasons), the average was used (arithmetic mean). The metric composition of both versions of the SCI and the SCI values for each sampling station used are presented in Appendix F. The SCI data used in this dissertation were provided by FDEP (R. Frydenborg 2005, Environmental Assessment Section, Bureau of Laboratories, personal communication) and were developed using field data for benthic macroinvertebrates collected by FDEP between 1992 and 1995.

Lakes

The Lake Condition Index (LCI) for Florida was used to assess changes in the biotic community composition of lakes due to the influence of land use surrounding these bodies of water. The LCI was developed by Gerritsen et al. (2000) and quantifies the biological integrity of lakes. The index aggregates six metrics that represent characteristics of bottom-dwelling macroinvertebrates that are expected to change along the human disturbance gradient. Index values range from 0 to 100, with low values associated with most-disturbed lakes and high values corresponding to least-impaired lakes.

The LCI scores for lakes used in this dissertation were also provided by FDEP (R. Frydenborg 2005, Environmental Assessment Section, Bureau of Laboratories, personal communication). The lake data were collected by FDEP staff between 1996 and 2000. The LCI's metric composition and the LCI score for each lake is presented in Appendix G.

Scales of Analysis

The boundaries of hydrological active areas were overlain on land use maps to quantify the total area of each land use class within each boundary contributing or affecting each surface water system. For the isolated forested wetlands, equidistant areas or buffers were used rather than a strict drainage area to determine the contributing effect of different land uses on the wetlands. For streams and lakes, two drainage basins were used: 1) basins delineated using elevation data and a geographic information system (GIS) and 2) equidistant buffers.

Isolated Forested Wetlands

The land uses associated with the isolated forested wetlands were considered based on the landscape surrounding each site at 20, 100, and 200 meters from its borders. The use of buffer areas instead of strict drainage areas was considered appropriate due to the lack of detailed topographic data that would allow modeling the hydrological contributing areas to these small systems, most of which are located in the relatively flat terrain of many Florida landscapes. Land use buffer areas for each wetland were obtained using GIS (ArcView 3.2, ESRI ®1992-1999) by first delineating buffer contours that were drawn using a specified distance (20, 100, and 200 meters) from the study isolated forested wetlands, and then by using the buffers to extract the land use data from the previously delineated land use within the surrounding landscape of each wetland. The original wetland boundary was delineated from DOQQs for 1999. To ensure the accuracy of the delineation, boundaries for the isolated forested wetlands were verified on the ground and corrected when required. In all cases, the geographic location of each sample wetland was obtained using a Global Positioning System (Garmin III – GPS) unit. The extracted land use was reclassified based on the land use intensity classification system. Figure 2-7 depicts the three spatial scales used.

Streams

The land uses associated with streams were considered at three different spatial scales or hydrological active areas: the total drainage area or total watershed for each stream, a riparian zone or equidistant areas of influence of 400 meters around streams, and a riparian zone or equidistant area of influence of 100 meters around stream. Figure 2-8 illustrates the three spatial scales used. The drainage areas for streams, as well as the stream networks, were determined using the Better Assessment Science Integrating Point and Nonpoint Sources 3.0 (BASINS 3.0) environmental analysis system. The BASINS computer program was developed by the Office of Water of the EPA to support environmental and ecological studies, and decision-making at the watershed level (EPA 2001). The BASINS assessment tools are integrated into ArcView 3.2. The boundaries of the 400- and 100-meter buffers were calculated using equidistant widths of 400 meters and 100 meters on both sides of the streams networks that were obtained from the drainage basins modeling.

The delineation of drainage basins and the stream networks using BASINS required the use of a digital terrain model (DTM), a grid map that masks the DTM, and a pre-digitized stream network, as summarized in Figure 2-9. The DTM provides the topographic information required in many watershed models (Sole and Valanzano 1996). The National Elevation Dataset (NED) was used as the preferred DTM. The NED is a 30-meter raster-based dataset produced by the USGS, and assembled from quadrangle-based (7.5-minute) 10- and 30-meter digital elevation models (DEM). The NED significantly reduces the pre-processing steps for spatial analysis that is usually required when using DEMs. In addition, the NED is available for large areas in only one file, thereby avoiding the need to use multiple files of digital elevation data when used in large-scale watershed analysis (Gesch et al. 2002). The DTM for each drainage basin was masked using a state-wide watershed boundaries coverage developed by FDEP between 1994 and 1997. FDEP subdivided the state into approximately 4,400 watersheds using EPA's River Rich File 3 (RF3) and the USGS Hydrological Units (HUCs) (Paulic et al. 1996). The pre-digitized state-wide streams networks used were obtained from FDEP's geodata database, which is available at http://www.dep.state.fl.us/gis/. The final calculation of the drainage basin boundary was made using a stream outlet that corresponded to the location of a STORET water quality sampling station that was previously identified and with known biological and water chemistry data. The output for a modeled drainage basin is presented in Figure 2-10.

Even though the NED was the best publicly elevation data available at the time that this study was undertaken, the accuracy of the NED for watershed delineation stream network definition was not quantitatively tested. It has been noted (Kost et al. 2002) that the NED may limit the quality of certain hydrologic procedures. To reduce potential errors, the delineation of watersheds and stream channels was done using the automatic delineation method available in BASINS. The number of sub-watersheds and stream channels to be delineated was determined in all cases using the threshold area, or critical source area, suggested by BASINS. By using an automatic delineation method over a manual delineation method, both available in BASINS, the chances for mistakes in the delineation are reduced as long as the DTM used is accurate (Oksanen and Sarjakoski 2005). Additionally, BASINS removes non-draining zones (sinks), thereby improving the accuracy in watershed delineation stream network definition.

Once the drainage basins and stream network were delineated, the land use within the drainage basins was selected from Florida's five WMDs' land use datasets using GIS. The land use within a 100-meter and 400-meter distance of the modeled streams was captured using buffers in a similar way as described for the isolated forested wetlands. In all cases, the area of the different land uses was recalculated once the land use data were obtained.

Lakes

For lakes, three spatial scales of analysis were also considered: the total drainage area or total watershed for each lake, an area of influence or equidistant buffer of 400 meters, and an area of influence or equidistant buffer of 100 meters. Figure 2-11 illustrates the three scales of work. The drainage areas for each lake were determined using a hydrological extension for ArcView 3.2 and the steps followed were similar to those described previously for streams. The DTM used was the NED. For each lake, the DTM was cut (clipped) using a corresponding watershed boundary from FDEP's state-wide watershed boundaries coverage. After clipping the DTM, sinks were removed and each resulting unit was smoothed and flow directions were calculated. Finally, using the resulting drainage direction map and grid coverage for each lake studied, the drainage area or catchment was derived draining the uphill area to the lake. After the drainage basins for each lake were delineated, the land use within each catchment was selected from Florida's five WMD land use datasets using GIS and following the same procedure as described above for the streams.

Landscape Indices

To assess the impact of human activities on the condition of aquatic systems, two different sets of landscape indices were used: the LDI and landscape pattern metrics. The following paragraphs provide a description of how the indices were selected and calculated, and how they were tested to assess their behavior when computed at different grain sizes.

Landscape Development Intensity Index

Method of calculation

Three measurements of the landscape development intensity (LDI) or level of human activity in the landscape based on energy flow and expressed as emergy (sej), were used. The LDI was calculated based on the developed or nonrenewable empower density of the landscape which is the emergy per area per time and its units are sej/ha/yr, and can be interpreted as a measure of the areal work per time. This quantitative measure of the intensity of human use of landscapes permits the scaling of the intensity of activity based on non-renewable energy used, which is common to all human-dominated landscapes (Brown and Vivas 2005).

The LDI for each watershed or area of influence was calculated using land use data and existing emergy evaluations for different land uses in Florida. The quantification of the metrics was done using the GIS software MFworks Version 3.0 (Keigan Systems, Inc. ® 2002) and a spreadsheet (Microsoft® Office Excel 2003). The total metric value for the landscape (drainage basin, area of influence, or other land use proportion) to the receiving surface water system was calculated based on the log scale of the ratio of nonrenewable empower density to the average state renewable empower density, which is the baseline (Brown and Vivas 2006). The equation used for calculation of the LDI is the following:

$$LDI = 10 * \log (empPD_{Total}/emPD_{Ref}) \qquad \text{Equation 2-1}$$

where LDI is the landscape development intensity index; $empPD_{Total}$ is the areal empower density for a landscape unit (wetland, stream, lake) including the background environment; and $emPD_{ref}$ is the areal empower density of background environment which is equal to 1.81E 15 sej/ha/yr or the empower density of rain in Florida calculated after Odum et al. (1998a).

The areal empower density for each landscape unit is calculated based on the non-renewable and purchased empower densities of the various land use types present within the landscape unit. The non-renewable energies may include electricity, fuels, fertilizers, pesticides, water (both public water supply and irrigation), and human labor. Human services were not included in the calculation of the indices for agricultural land uses. Refer to Table 2-6 for the non-renewable and purchased areal empower densities of the various land use types considered.

The LDI was calculated in three different ways for each area of influence and for entire watersheds. First, the index was calculated based on the proportion of each land use type and their development intensity (non renewable and purchased areal empower density), regardless of the distance of each land use type from the target aquatic system. Second, it was calculated assuming that the effect of development intensity on the landscape unit decreases linearly with distance from the target aquatic system. Third, the metric was calculated assuming that the effect of development intensity on the landscape unit decreases in inverse-square with distance from the target aquatic system. For simplicity, during the rest of this document these metrics will be referred to as to as the LDI-proportion of land use (LDI-PLU), the LDI-inverse linear distance (LDI-ILD), and the LDI-inverse square distance (LDI-ISD), respectively. The specific steps (scripts) followed for each calculation of the non renewable and purchased areal empower density for each landscape using the GIS are presented in Appendix H.

Scale dependency

To investigate the scale dependency of the LDI, it was calculated for each landscape using different grain sizes and keeping the extent constant. For isolated forested wetlands, grain (pixel) size was systematically changed from 5 meters to 70 meters for a total of eight different pixel sizes (5, 10, 20, 30, 40, 50, 60, and 70 meters). Each time the rescaling of the grain size began with the 5 x 5-meter cell size, which corresponds to the approximate minimum mapping area of the original land use data, following the same procedure used by Wu et al. (2002). The higher end of the range corresponds to the maximum grain size after which less than 30 pixels will result for a 200-meter buffer. The 200-meter buffer was the preferred extent, due to the process of pixel aggregation that results from the increase in grain size. For streams, grain (pixel) size was systematically changed from 20 meters to 170 meters using the same rescaling rule applied for the isolated forested wetlands, with distance intervals of 30 meters for a total of six different grain sizes (20, 50, 80, 110, 140, and 170 meters). The lower end of this range represents the approximate minimum mapping area of the original land use data. The higher end corresponds to the maximum grain size after which less than 30 pixels will result for the smallest watershed included in the stream sample studied. The preferred extent used was the drainage basin or total watershed range. All rescaling was done in MFworks Version 3.0 using the most frequent occurring value method, a widely used procedure in ecological and spatial data analysis to aggregate categorical data (Wu 2004). In this rescaling method the value of a pixel in the new map is determined based on the patch type with the most pixels within a moving window in the original map; to break a tie the highest value is used by default in MFworks Version 3.0.

Landscape Pattern Metrics

Landscape pattern metrics have been suggested as appropriate landscape indices to assess the impact of land use on surface waters (EPA 1994; O'Neill et al. 1997; Liu and Cameron 2001; Gergel et al. 2002; Cifaldi et al. 2004) for watersheds of different sizes (Cifaldi et al. 2004; Kearns et al. 2005). It is recommended that metrics selection for quantifying landscape pattern should at least consider metrics that will effectively respond to research needs, that the behavior of the metrics be known, and that redundancy among metrics should be avoided whenever possible (Gustafson 1998; Turner et al. 2001).

Metric selection

Preliminary metric selection was done through literature review of studies that have previously linked landscape pattern with ecosystem condition and water quality variables. A total of 17 metrics were identified and are described in Table 2-7. Metric identification was done regardless of the type of freshwater system investigated.

Most studies seem to be directed to studying land-water interactions in rivers and streams, with apparently less work having been done for lakes and wetlands. To analyze the relationship of landscape pattern and indicators of ecosystem condition and water quality variables, the same set of 17 metrics was initially used for lakes, streams, and isolated forested wetlands. For isolated forested wetlands, pattern metrics were calculated only for the 200-meter buffer areas since these systems and their surrounding landscapes are small and bias in calculating pattern metrics may result when calculated for the 100- and 20-meter buffer areas. Following O'Neill et al. (1996) and Turner et al. (2001)'s recommendation that the extent for the study landscape should be at least two times larger than the landscape patches in order to avoid a bias in metric measurements, a total of 56 of 118 wetland landscapes (or 200-m buffer areas) were selected for metrics calculations. For streams, 68 out of 69 sites were included in watershed analyses, and 64 sites out of 69 sites were included for metrics calculation in buffer areas of 400 and 100 meters. For lakes 48 of 54 sites were included for metrics calculation for all three spatial extents.

The effects on landscape pattern metrics when changing spatial scale is well documented and many pattern metrics are sensitive to changes in both grain and extent (Turner et al. 1989, Griffith et al. 2000; Wu et al. 2000; Wu et al. 2002; Shen et al. 2004; Wu 2004; Uuemaa et al. 2005). As a result, investigating changes in the behavior of landscape pattern metrics as a result of variations in spatial scale was of secondary interest in this dissertation. However, landscape pattern metrics were calculated at four grain sizes for each freshwater system: for isolated forested wetlands at 5 x 5, 10 x 10, 20 x 20, and 30 x 30 meters; for streams at 20 x 20, 50 x 50, 80 x 80, and 110 x 110 meters; and for lakes at 20 x 20, 40 x 40, 60 x 60, and 80 x 80 meters.

Only four scales were considered to minimize the number of one-cell patches formed due to cell aggregation when rescaling since multiple once-cell patches may result in bias metric calculation (McGarigal and Marks 1995). Additionally, working with a reduced number of grain sizes helped to preserve to some extent the accuracy of representation of the original data

To evaluate the spatial extent at which pattern metrics best explain variations in ecosystem condition and water quality variables for streams and lakes, the grain size has held constant and metrics were calculated for the whole watershed and for 400- and 100-meter buffers. The grain size used in the spatial extent analysis was the approximate minimum mapping area.

Landscape metric calculation

Landscape metrics were calculated for each watershed and buffer area using the spatial analysis program Fragstats version 3.3 (McGarigal et al. 2002). Fragstats quantifies landscape structure and has been used widely in landscape ecology research, including research performed for watersheds and aquatic ecosystems. Fragstats computes three groups of metrics: patch, type or class, and landscape metrics. To calculate the metrics, ArcGrids were exported into Fragstats after converting vector coverages of watersheds and buffer areas into raster (5 x 5-meter cell size) coverages for isolated forested wetlands, and raster (20 x 20-meter cell size) coverages for stream and lakes. The chosen cell sizes corresponded to the approximate minimum mapping units of the land use data for the three systems under investigation. To obtain data at different grain sizes, the grids were rescaled using a nearest neighbor method always starting from the smallest cell size considered. Although this method is used for resampling spatial data it can also be used for rescaling since it effectively increases the grain size of a map (Li and Wu 2004). Since the rescaling of raster data may result in disjoint patches due to the aggregation or division of patches, the rescaled data were visually examined to ensure accurate representation of the original data as suggested by McGarigal et al. (2002). All metrics were calculated in batch file format using an 8-cell rule in a standard window mode with two output files: class metrics and landscape metrics.

Data Analysis

In this section, the methods used to describe and investigate the behavior of the LDI calculated in three different ways at different spatial scales are described. The process followed to identify a set of uncorrelated landscape pattern metrics that could be used to assess land use-ecological condition interactions is also considered. To investigate the relationship between land use and ecosystem condition using the LDI and landscape pattern indices, regression analysis was used. The different tests used are explained.

Study Sites, Water Chemistry Variables, and Biological Variables

Descriptive statistics were used to typify the systems under investigation. Watershed characteristics for each set of systems assessed (isolated forested wetlands, streams, and lakes) were described based on their sizes and land use composition. Since isolated forested wetlands were not analyzed based on strict drainage areas, the 200-meter buffer was used to describe the surrounding landscape of each wetland.

Watersheds were also described based on their intensity of development measured as the sum of the areal nonrenewable and purchased empower density (sej/ha/yr). Comparative statistics were used to describe differences in the intensity of human activity between reference, agricultural, and urban isolated forested wetlands.

Landscape Development Intensity Index

Description and behavior

LDI values were compared for different grain sizes at which they were calculated for a subset of isolated forested wetlands buffers (n = 15) and streams watersheds (n = 15) with LDI scores that were considered representative of the whole range of LDI values for each group of systems. The degree of dispersion of the LDI values for each site was analyzed visually and calculating the standard deviation from the mean LDI values. Scalograms were then used to emphasize differences among low, intermediate, and high LDI scores for the landscapes investigated. Scalograms have frequently been used to investigate the behavior of landscape indices due to changes in both grain size and extent (Turner et al. 1989, Wu et al. 2000; Wu et al. 2002; Shen et al. 2004; Wu 2004; Uuemaa et al. 2005).

To test the behavior of the LDI with changes in spatial extent, the Kruskal-Wallis test was used. This test is the non-parametric form of the one-way analysis of variance (Dytham 1999). The Wilcoxon's signed ranks test, the non-parametric equivalent of the paired t-test (Dytham 1999), was used to discern differences among medians of the LDI calculated in its three forms: LDI-PLU, LDI-ILD, and LDI-ISD. Both non-parametric tests were run using Minitab (Version 14.1, Minitab® Release 14 Statistical Software).

Spearman's rank order correlation, the non-parametric measure of correlation (Dytham 1999), was used to assess the degree of association between the LDI calculated in the three different ways. This analysis determined the degree to which each form of the LDI contains redundant information. Correlations were run using Minitab.

Relationship between the LDI and ecosystem condition

Simple linear regression analysis was used to explore the relationship between the LDI and indicators of ecosystem condition. Simple linear regression also allowed the determination of the grain size at which the LDI was more strongly related to measures of ecosystem condition. Regression analysis has often been used in landscape ecology studies to quantify the explanatory power of landscape variables at different spatial scales (Pearson 1993; Pearson and Turner 1995;

Tufford et al. 1998; Gergel et al. 1999, Houlahan et al. 2006). Regression results were graphically represented using scalograms by plotting the coefficients of determination (r^2) against the LDI measured at increasing scales. Residual plots allowed to visually determining for inequality of variances (Dytham 1999; Minitab 2003). Water chemistry variables were $\log_{10}$ transformed when required. All regressions were run using Minitab.

Landscape Pattern Metrics

Description and selection

The process followed to reduce the 17 landscape pattern metrics to a smaller set of uncorrelated variables that can be used as independent measures to assess the relationship between land use and ecosystem condition was similar to that used by Cifaldi et al. (2004) and Kearns et al. (2005). Using Kearns et al. (2005) rationales, first, descriptive statistics (mean, standard deviation, minimum and maximum values) were used to characterize metrics and to determine if any metrics presented values that would suggest error in metric calculation. Metrics with high standard deviation (i.e., greater than the mean) were considered indicative of possible errors in metric calculation, and metrics with very low standard deviation were considered as unable to discriminate among landscapes. Minimum and maximum values of metrics helped to determine whether calculated values were outside the range of values in accordance with definitions of the metrics. Any of these conditions would result in the removal of metrics. Second, the remaining metrics were tested for redundancy using Pearson’s product-moment correlation. In deciding which metrics should be removed from further analysis, the criteria for data reduction set by Riitters et al. (1995) for Pearson’s correlations greater than 0.90 were used. Before correlation analysis could be performed, metrics were tested for normality using the Anderson-Darling normality test. Metrics with a p-value of less than 0.05 were considered to be unlikely normally distributed (Dytham 1999). After testing for normality, metrics that were not normally distributed were transformed (square root, logarithmic, and arcsine square-root transformations).

Principal Components Analysis (PCA) was used to further reduce the number of metrics to a set that explained most of the variation in the data. PCA is an ordination (multivariate) technique that graphically summarizes complex relationships among variables, and reduces the number of variables to a set of compound axes that represent most of the information contained in the original set of variables (ter Braak 1995; McCune and Grace 2002). The resulting axes can then be used as independent variables in ANOVA or regression analysis (Johnson and Gage 1997). PCA has frequently been used to reduce the number of landscape pattern variables to a set of uncorrelated metrics based on a set of orthogonal (uncorrelated) axes (Riitters et al. 1995; Cain et al. 1997; Johnson et al. 1997; Griffith et al. 2000; Cifaldi et al. 2004; Kearns et al. 2005). Variables considered for further analysis were determined using the general rule that an axis with eigenvalues of less than one is considered not significant (Riitters et al. 1995; Kearns et al. 2005). PCA was run using PC-ORD version 4.41 for Windows (McCune and Mefford 1999).

Influence of landscape pattern on ecosystem condition

Multiple regression analysis was performed using the water chemistry and biological indicators of ecosystem condition as dependent variables and the PCA's resulting axes as independent variables. Multiple regressions determined the best prediction of a dependent variable by using more than one independent variable simultaneously. The prediction is defined as a linear equation (Sokal and Rohlf 1981; Dytham 1999). To assess the adequacy of the regression models, residuals were examined. Residual analysis allows testing for the normal distribution of the residuals, an assumption of regression analysis, and establishes that the relationship between the variables is linear (Dytham 1999; Minitab 2003). Variance Inflation Factors (VIF) were calculated to confirm the linear independence of the predictor variables. The

VIF is the factor by which the standardized unexplained variance is inflated due to multicollinearity among the predictor variables (Sokal and Rohlf 1981; Minitab 2003). The greater the correlation among the predictor variables, the larger the VIF. As a general rule, a VIF > 5 is signal of poor regression coefficients estimation (Montgomery and Peck 1982; Berk 2004). Multiple regression models and significance tests were estimated using Minitab.

The LDI, Landscape Pattern, and Ecosystem Condition

To test the effect of landscape pattern on the relationship between the LDI and indicators of ecosystem condition, multiple regression analysis was used. Multiple regression analysis is an extension of simple regression and allows using more than one predictor variable to estimate values of response variables (Sokal and Rohlf 1981; Dytham 1999). This technique was considered useful because it helped to investigate how the LDI and the landscape pattern metrics performed together as predictor variables. To assess the adequacy of the regression models, residuals and VIFs were examined. All tests were run using Minitab.

Table 2-1. Surrounding land use and date of sampling for 118 isolated forested wetlands in Florida (source: Reiss 2004).

Site Code*	Sample Date	Surrounding Land Use**	Latitude (DD)	Longitude (DD)
SA1	6/5/01	Cattle & Crops	26.45639	-81.62487
SA2	6/6/01	Citrus	26.65347	-81.49650
SA3	6/27/01	Cattle	26.87612	-80.21323
SA4	7/30/01	Row Crops	26.26321	-81.41238
SA5	7/31/01	Cattle & Crops	26.28800	-81.22514
SA6	9/5/01	Cattle	26.75042	-81.35194
SA7	7/31/02	Woodland	26.69303	-81.64284
SA8	7/31/02	County Park	26.72535	-81.65383
SA9	8/1/02	Cattle	26.69032	-81.58596
SR1	6/28/01	County Park	26.95371	-80.18218
SR2	7/3/01	State Park	27.00919	-80.14564
SR3	7/24/01	State Reserve	26.86817	-80.41380
SR4	8/1/01	National Park	25.98619	-81.24261
SR5	8/21/01	State Preserve	26.10439	-81.34650
SR6	9/18/01	NWR	26.39318	-80.24319
SR7	7/15/02	County Park	26.73059	-80.25719
SR8	7/17/02	County Airport	26.86345	-80.23689
SR9	7/24/02	County park	26.72182	-80.25839
SU1	6/6/01	Residential & Golf	26.58418	-81.82126
SU2	6/29/01	School Campus	26.70849	-80.20811
SU3	7/4/01	Residential	26.82646	-80.15216
SU4	8/22/01	Residential	26.32488	-81.77125
SU5	8/23/01	Industrial	26.38015	-81.79557
SU6	9/30/01	Industrial	26.31050	-81.78732
SU7	7/16/02	Comercial	26.65032	-80.21265
SU8	7/16/02	Com. & Residential	26.73417	-80.11917
SU9	7/23/02	Residential	26.62327	-80.20051
SU10	7/30/02	Roads & Canals	26.77605	-81.35576
CA1	5/23/01	Row Crops	29.48414	-81.44358
CA2	5/30/01	Cattle	28.04368	-81.03569
CA3	6/7/01	Pullet Farm	28.24835	-82.09155
CA4	6/21/01	Cattle	27.81016	-80.53548
CA5	7/10/01	Cattle	28.06925	-81.42633
CA6	7/23/01	Citrus	27.53684	-80.64084
CA7	7/3/02	Silviculture & Cattle	28.47059	-82.11763
CA8	7/19/02	Dairy farm	28.14343	-82.22698
CA9	7/24/02	Citrus	27.43523	-80.64827
CR1	5/30/01	Conservation Tract	28.03325	-81.01988
CR2	6/14/01	Conservation Tract	28.08000	-81.40000
CR3	6/20/01	State Park	27.84150	-80.56868
CR4	8/10/01	WMD	28.39459	-81.97103

Table 2-1. Continued.

Site Code*	Sample Date	Surrounding Land Use**	Latitude (DD)	Longitude (DD)
CR5	8/13/01	State Park	28.77954	-81.39938
CR6	8/15/01	State Forest	27.78911	-81.46244
CR7	5/30/02	City Owned	28.11667	-82.34595
CR8	7/2/02	State Forest	28.48059	-82.00019
CR9	7/11/02	State Preserve	28.50238	-80.98923
CR10	10/9/02	State Park	27.22257	-82.29842
CR11	10/9/02	State Park	27.23897	-82.34602
CU1	5/31/01	University Campus	28.60519	-81.19494
CU2	6/15/01	Residential	28.45969	-81.26527
CU3	7/16/01	Commercial	28.07078	-82.50734
CU4	8/14/01	Roadside	28.46612	-81.27323
CU5	9/11/01	Roadside	28.32963	-81.53056
CU6	9/12/01	Golf Course	28.31473	-81.54881
CU7	5/30/02	City Owned	28.10109	-82.38816
CU8	7/1/02	Industrial	29.47656	-81.26731
CU9	7/8/02	Commercial	28.42875	-81.47282
CU10	8/7/02	Park	27.88246	-82.27471
CU11	8/8/02	Park	29.56134	-81.21028
NA1	5/21/01	Cattle	29.74165	-82.26923
NA2	6/4/01	Cattle	29.94500	-81.72512
NA3	6/19/01	Silviculture	30.30300	-82.41403
NA4	7/20/01	Row Crops	29.79279	-81.50204
NA5	7/27/01	Cattle	29.59070	-82.72842
NA6	7/31/01	Silv., Cat., Row Crops	30.02212	-83.09392
NA7	5/22/02	Row Crops	29.79495	-82.41924
NA8	5/21/02	Silviculture	29.67920	-81.73589
NA9	6/10/02	Silviculture	29.47003	-83.09615
NA10	7/12/02	Silviculture	29.81470	-81.83806
NA11	7/24/02	Cattle	29.01557	-82.38937
NA12	7/26/02	Cattle & Crops	29.80023	-82.41417
NR1	5/26/01	University Land	29.76662	-82.20515
NR2	6/18/01	City Park	29.66101	-82.27516
NR3	7/10/01	State Forest	29.13109	-82.62290
NR4	7/11/01	WMD	30.47229	-81.49923
NR5	8/6/01	Military	30.01672	-82.01836
NR6	8/21/01	State Park	28.63427	-82.57047
NR7	5/28/02	State Park	30.16982	-81.93639
NR8	8/5/02	State Park	30.17871	-81.93942
NR9	8/29/02	State Forest	29.28337	-82.61729
NU1	5/22/01	Road Side	29.73240	-82.38854
NU2	6/11/01	Residential & Golf	28.73751	-82.54058

Table 2-1. Continued.

Site Code*	Sample Date	Surrounding Land Use**	Latitude (DD)	Longitude (DD)
NU3	6/26/01	Residential	29.72551	-82.35376
NU4	6/27/01	Residential	30.17120	-82.66393
NU5	6/28/01	Residential	30.23957	-81.52941
NU6	8/1/01	Residential & Instit.	30.20305	-81.76350
NU7	5/15/02	Residential & Comm.	29.67127	-82.32561
NU8	6/3/02	Residential & Golf	30.11208	-81.62379
NU9	6/12/02	Industrial	30.20991	-82.64868
NU10	7/29/02	Residential & Instit.	30.40546	-81.72289
PA1	5/24/01	Cattle	30.46537	-82.70119
PA2	5/29/01	Cattle	30.50303	-83.12786
PA3	7/3/01	Crops & Turf Grass	30.77000	-87.14000
PA4	7/2/01	Row Crops	30.97707	-87.49655
PA5	8/8/01	Cattle	30.61916	-85.74185
PA6	8/9/01	Cattle	30.78991	-85.88736
PA7	6/5/02	Cattle	30.58314	-83.72990
PA8	8/8/02	Silviculture	29.95437	-84.59852
PA9	8/13/02	Row Crops	30.78313	-84.95956
PA10	8/14/02	Silviculture	30.83094	-86.96921
PR1	6/15/01	National Forest	29.95488	-84.99321
PR2	7/3/01	WMD	30.47204	-87.07998
PR3	7/4/01	Military	30.42565	-86.75117
PR4	8/9/01	State Forest	30.40339	-85.88346
PR5	8/10/01	State Forest	30.35190	-86.17112
PR6	8/18/01	National Forest	30.26229	-84.82198
PR7	6/4/02	Conservation Tract	30.67379	-84.22337
PR8	8/7/02	NWR	30.04041	-84.44025
PU1	6/14/01	Residential	30.44130	-84.32875
PU2	7/5/01	Residential	30.41486	-86.79694
PU3	8/17/01	Residential & Comm.	30.21191	-85.64720
PU4	8/17/01	Residential Park	30.78597	-85.68024
PU5	9/28/01	Commercial& Silv.	30.76760	-85.68549
PU6	9/29/01	Commercial	30.19020	-85.77982
PU7	6/18/02	Resid. & Orchard	30.45497	-87.32888
PU8	6/19/02	Industrial & Silv.	30.19108	-85.68608
PU9	6/20/02	Residential	29.93822	-85.39423
PU10	7/25/02	Institutional	30.48783	-84.27853

*Site Codes correspond to the ecoregion (Lane 2000), land use category, and sample order: S = south, C =central, N = north and P = panhandle; R = reference, A = agriculture and U = urban.
**Surrounding Land Use abbreviations: NWR = National Wildlife Refuge; WMD = Water Management District; Resid. = Residential; Cat. = Cattle; Comm. = Commercial; Instit. = Institutional; Silv. = Silviculture.

Table 2-2. STORET sampling station numbers, drainage basins, Hydrologic Unit Codes (HUC), and bioregions for 69 study streams in Florida.

STORET station #	Drainage Basin	HUC	Bioregion
19010042	Calkins Creek	03070204	Northeast
19010099	Pigeon Creek	03070204	Northeast
19020027	Alligator Creek	03070205	Northeast
20010454	Juniper Creek	03080101	Peninsula
20010455	Blackwater Creek	03080101	Peninsula
20020004	Little Orange Creek	03080102	Peninsula
20020012	Oklawaha River	03080102	Peninsula
20020317	Silver River	03080102	Peninsula
20020404	Orange Creek	03080102	Peninsula
20020424	Oklawaha River	03080102	Peninsula
20030263	Rowell Creek	03080103	Northeast
20030264	Sal Taylor Creek	03080103	Northeast
20030265	Sal Taylor Creek	03080103	Northeast
20030340	Rowell Creek	03080103	Northeast
20030341	Yellow Water Creek	03080103	Northeast
20030342	Yellow Water Creek	03080103	Northeast
20030419	Black Creek	03080103	Northeast
20030437	North Fork Black Creek	03080103	Northeast
20030549	Yellow Water Creek	03080103	Northeast
20030550	Rowell Creek	03080103	Northeast
21010018	South Falling Creek	03110201	Northeast
21010032	Hamilton Rocky Creek	03110201	Northeast
22020010	Quincy Creek	03120003	Panhandle West
22020049	Mule Creek	03120003	Panhandle West
22020062	Oklawaha Creek	03120003	Panhandle West
22020077	Unnamed Branch	03120001	Panhandle West
22020093	Quincy Creek	03120003	Panhandle West
22030062	McBride Slough	03120001	Panhandle East
22030064	Central Drainage Ditch	03120001	Panhandle East
23010464	Withlacooche River	03100208	Peninsula
24010002	Manatee River Ab Dam	03100202	Peninsula
24020134	Fishhawk Creek	03100204	Peninsula
24030013	Hillsborough River	03100205	Peninsula
24030044	Hillsborough River	03100205	Peninsula
24030142	Hillsborough River	03100205	Peninsula

Table 2-2. Continued.

STORET station #	Drainage Basin	HUC	Bioregion
25020014	Oak Creek	03100101	Peninsula
25020111	Horse Creek	03100101	Peninsula
26010029	Arbuckle Creek	03090101	Peninsula
26010430	Parker Bay Drain	03080101	Peninsula
26010593	Fisheating Creek	03090103	Peninsula
26010972	Reedy Creek	03090101	Peninsula
26011019	Livingston Creek	03090101	Peninsula
26011020	Lake Weohyakapka	03090101	Peninsula
28010223	Jonathan Dickinson	3090202	Peninsula
28010224	South Indian River	03090202	Peninsula
28010232	North St. Lucie	03090202	Peninsula
28010239	Tidal St. Lucie	03090202	Peninsula
28010608	Tidal St. Lucie	03090202	Peninsula
28020147	West Caloosahatchee	03090205	Peninsula
28020148	Tidal Caloosahatchee	03090205	Peninsula
28020221	Telegraph Swamp	03090205	Peninsula
28020232	Tidal Caloosahatchee	03090205	Peninsula
28020233	Tidal Caloosahatchee	03090205	Peninsula
28020234	Estero Bay	03090204	Everglades
31010050	Crooked Creek	03130011	Panhandle West
31010051	Sweetwater Creek	03130011	Panhandle West
31020037	Bridge Creek	03130012	Panhandle West
31020038	Waddells Mill Creek	03130012	Panhandle West
31020040	Ten Mile Creek	03130012	Panhandle West
32010021	Alaqua Creek	03140102	Panhandle West
32020030	Camp Branch	03140203	Panhandle West
32020063	Little Crooked Creek	03140203	Panhandle West
32030023	Ecofina Creek	03140101	Panhandle West
32030024	So Fk Little Bear Creek	03140101	Panhandle West
33010054	McDavid Creek	03140106	Panhandle West
33010065	Rest Area Run	03140106	Panhandle West
33010068	Eleven Mile Creek	03140106	Panhandle West
33040014	Big Horse Creek	03140103	Panhandle West
33040015	Pine Log Creek	03140103	Panhandle West

Table 2-3. STORET station numbers, lake name, Hydrologic Unit Codes (HUC), and ecoregions for 54 study lakes in Florida.

STORET station #	Lake name	HUC	Ecoregion
20010048	Lake Orienta	3080101	Central Florida Ridges and Uplands
20010110	Sawgrass Lake	3080101	Eastern Florida Flatwoods
20010222	Lake Kathryn	3080101	Central Florida Ridges and Uplands
20010299	Lake Kilarney	3080101	Central Florida Ridges and Uplands
20010311	Lake Underhill	3090101	Central Florida Ridges and Uplands
20010334	Lake Fairview	3080101	Central Florida Ridges and Uplands
20010336	Lake Ivanhoe	3080101	Central Florida Ridges and Uplands
20010337	Lake Minnehaha	3080101	Central Florida Ridges and Uplands
20020014	Hammond Lake	3080102	Central Florida Ridges and Uplands
20020015	Dixie Lake	3080102	Central Florida Ridges and Uplands
20020062	Lake Jumper	3080102	Central Florida Ridges and Uplands
20020064	South Twin Lake	3080102	Central Florida Ridges and Uplands
20020065	Lake Gibson	3080102	Central Florida Ridges and Uplands
20020066	Lake Umatilla	3080102	Central Florida Ridges and Uplands
20030417	Georges Lake	3080103	Eastern Florida Flatwoods
20030438	Lake Johnson	3080103	Central Florida Ridges and Uplands
23010434	Lake Rousseau West	3100208	Gulf Coast Flatwoods
23010435	Lake Rousseau East	3100208	Gulf Coast Flatwoods
25010079	Lake Webb	3100103	Southwestern Florida Flatwoods
25020552	Sunshine Lake	3100101	Southwestern Florida Flatwoods
25020554	Lake Zappa	3100101	Southwestern Florida Flatwoods
26010032	Alligator Lake	3090101	Eastern Florida Flatwoods
26010037	Lake Lizzie	3090101	Eastern Florida Flatwoods
26010039	Trout Lake	3090101	Eastern Florida Flatwoods
26010040	Brick Lake	3090101	Eastern Florida Flatwoods
26010105	Lake Porter	3090101	Central Florida Ridges and Uplands
26010116	Fish lake	3090101	Eastern Florida Flatwoods
26010303	Lake Persimmon	3090101	Central Florida Ridges and Uplands
26010304	Lake Clay	3090101	Central Florida Ridges and Uplands
26010325	Lake Adelaide	3090101	Central Florida Ridges and Uplands
26010326	Lake Little Bonnet	3090101	Central Florida Ridges and Uplands
26010327	Lake Trout	3090101	Central Florida Ridges and Uplands
26010331	Lake Huntley	3090101	Central Florida Ridges and Uplands
26010526	Lake Jackson	3090101	Central Florida Ridges and Uplands
26010528	Lake Jackson	3090101	Central Florida Ridges and Uplands

Table 2-3. Continued.

STORET station #	Lake name	HUC	Ecoregion
26010531	Lake Jackson	3090101	Central Florida Ridges and Uplands
26010556	Lake Sebring	3090101	Central Florida Ridges and Uplands
26010585	Lake Carrie	3090101	Central Florida Ridges and Uplands
26010591	Dinner Lake	3090101	Central Florida Ridges and Uplands
26010605	Lake Viola	3090101	Central Florida Ridges and Uplands
26010644	Lake Josephine East	3090101	Central Florida Ridges and Uplands
26010645	Lake Josephine- Mid	3090101	Central Florida Ridges and Uplands
26010646	Lake Josephine- West	3090101	Central Florida Ridges and Uplands
26010647	Lake Rachard	3090101	Central Florida Ridges and Uplands
26010648	Lake Denton	3090101	Central Florida Ridges and Uplands
28020242	Crystal Lake	3100103	Southwestern Florida Flatwoods
28030068	Lake Avalon	3090204	Big Cypress
32010038	Sand Hammock Pond	3140203	Dougherty/Marianna Plains
32020113	Juniper Lake	3140203	Dougherty/Marianna Plains
32030081	Martin Lake	3140101	Gulf Coast Flatwoods
33010064	Crescent Lake	3140107	Gulf Coast Flatwoods
33020097	Lake Stone	3140305	Southern Pine Plains and Hills
33020098	Cotton Lake	3140305	Southern Pine Plains and Hills
33030057	Bear Lake	3140104	Southern Pine Plains and Hills

Table 2-4. Summary information of the land use data used (source: Florida Department of Environmental Protection, www.dep.state.fl.us/gis).

Northwest Florida Water Management District	
Date of Data	1995
Data Layer Name	Land Use – North West Florida
Description	Northwest Florida Water Management District Land Use, Cover, and Forms Classification System
Type	Polygon
Scale	1:24,000
Source Material	National Aerial Photography Program color-infrared imaging
Scale of Source Material	1:40,000
Date of Source Material	1994/1995
Suwannee River Water Management District	
Date of Data	1995
Data Layer Name	sr_landuse95
Description	Florida Land Use, Cover, and Forms Classification System
Type	Polygon
Scale	1:40,000
Source Material	National Aerial Photography Program color-infrared imaging
Scale of Source Material	1:40,000
Date of Source Material	1994/1995
St. Johns River Water Management District	
Date of Data	1995
Data Layer Name	landcover95
Description	FLUCC Land Use / Land Cover
Type	Polygon
Scale	1:40,000
Source Material	National Aerial Photography Program color-infrared imaging
Scale of Source Material	1:40,000
Date of Source Material	1993/1994/1995
Date of Data	2000
Description	Land cover and land use in the St. Johns River Water Management District
Type	Polygon
Scale	1:12,000
Source Material	National Aerial Photography Program color-infrared imaging
Scale of Source Material	1:12,000 and 1:24,000
Date of Source Material	1999/2000
Southwest Florida Water Management District	
Date of Data	1995
Data Layer Name	Southwest Florida Water Management District Land Use / Land Cover 1994-1995
Description	FLUCC Land Use / Land Cover
Type	Polygon
Scale	1:24,000
Date of Source Material	1994/1995

Table 2-4. Continued.

Southwest Florida Water Management District	
Date of Data	1999
Data Layer Name	SWFWMD 1999 Land Use
Description	SWFWMD 1999 land use/cover features categorized according to the Florida Land Use, Cover, and Forms Classification System
Type	Polygon
Scale	1:12,000
Source Material	1995 land use updated via 1999 DOQQs
Scale of Source Material	1:12,000
Date of Source Material	1999/2000
Date of Data	1995
Data Layer Name	sf_landuse95
Description	South Florida Water Management District Land use/cover 1994-1995
Type	Polygon
Scale	1:24,000
Source Material	National Aerial Photography Program color-infrared imaging
Scale of Source Material	1:40,000
Date of Source Material	1994/1995/1996

Table 2-5. Land uses and definitions.

Land Use	Definition
Natural Land / Open Water	Open water, upland, or wetland with low manipulations.
Pine Plantation	Land devoted to the growth of mostly pine trees with different stocking densities.
Rangeland	Native rangeland and woodland pasture with presence of livestock.
Pasture	Areas where the natural vegetation has been altered by drainage, irrigation, etc., for the grazing of domestic animals. Does not include livestock.
Low Intensity Pasture	Areas where the natural vegetation has been altered by drainage, irrigation, etc., for the grazing of domestic animals with a density of less than 1.0 animal/ha.
High Intensity Pasture	Areas where the natural vegetation has been altered by drainage, irrigation, etc., for the grazing of domestic animals with a density of more than 1.0 animals/ha.
Tree Crops	Areas devoted to the production of tree crops such as citrus groves, fruit orchards, vineyards, and other groves.
Row crops	Areas devoted to the production of all types of vegetables usually grown in rows, whether producing or not.
High Intensity Agriculture	Dairy farms and large-scale cattle feed lots, chicken farms, and hog farms.
Low Intensity Open Space / Recreational	Areas of natural vegetation in cities maintained as nature parks, and undeveloped land that may be occupied by low impacted natural vegetation in an agricultural or urban landscape.
Medium Intensity Open Space/Recreational	Areas with grassy lawns in urban landscapes including recreational land such as playgrounds, ball fields, and swimming beaches. Also applies to land that has been cleared and prepared for construction and/or development, dirt roads, barren land, and open areas surrounding paved roads and power lines. Includes human-created water bodies (retention ponds, canals, reservoirs, etc).
High-intensity Open Space / Recreational	Applies to stadiums not associated with institutions such as schools and universities, golf courses, and racetracks (horse, dog, car).
Low-density Single Family Residential	Areas that are predominantly residential units with a density less than 5 units/ha.
Medium Intensity Single Family Residential	Areas that are predominantly residential units with a density between 5 and 12 units/ha.
High Intensity Single Family Residential	Areas that are predominantly residential units with a density of more than 12 units/ha.
Low-intensity Multi-family Residential	Areas that are predominantly multi-family residential units such as condominiums and apartment buildings up to 2 stories.
High-intensity Multi-family Residential	Areas that are predominantly multi-family residential units such as condominiums and apartment buildings with 3 or more stories.

Table 2-5. Continued.

Land Use	Definition
Low Intensity Commercial	Commercial strip.
High-intensity Commercial	Commercial mall with associated storage buildings and parking lots, hotels, convention centers, and theme parks.
Institutional	Schools, universities, religious, military, medical and professional facilities, and government buildings.
Industrial	Land uses include manufacturing, assembly or processing of materials/products and associated buildings and grounds. Also includes extractive areas and mining operations, water supply plants, and solid waste disposal.
Low Intensity Transportation	Paved road with no more than 2 lanes, and railroads.
High-intensity Transportation	Paved road with more than 2 lanes, airports, railroad terminals, bus and truck terminals, port facilities, and auto parking facilities when not directly related to other land uses.
Low-intensity Central Business District	Central business districts with an average of 2 stories.
High-intensity Central Business District	Central business districts with an average of more than 2 stories.

Table 2-6. Intensity of human development classification and non-renewable and purchased areal empower density for selected land uses.

Notes	Land Use Intensity Category (LI=Low Intensity; MI=Middle Intensity; HI=High Intensity)	Non-Renewable & Purchased Areal Empower Density (E14 sej/ha/yr)
1	Natural Land / Open Water	0.00
2	LI-Open Space / Recreational	2.77
3	Rangeland	3.20
4	Pine Plantation	5.10
5	Pasture (improved)	19.53
6	LI-Pasture	36.90
7	HI-Pasture	51.52
8	Tree Crops	65.39
9	MI-Open Space / Recreational	67.35
10	Row crops	117.11
11	HI-Agriculture	195.00
12	LI-Single Family Residential	1077.00
13	HI-Open Space / Recreational	1230.00
14	MI-Single Family Residential	2461.50
15	LI-Transportation	3080.00
16	HI-Single Family Residential	3729.50
17	LI-Commercial	3758.00
18	Institutional	4042.20
19	HI-Transportation	5020.00
20	Industrial	5210.60
21	LI-Multifamily Residential	7391.50
22	HI-Commercial	12661.00
23	HI-Multifamily Residential	12825.00
24	LI-Central Business District	16150.30
25	HI-Central Business District	29401.30

Notes

1	Non-renewable and purchased empower density for natural systems.	0.00		
2	Average of empower densities of 1, 3 and 4			Assumed
3	Based on 18 acres/animal	0.14	cow/ha/yr	After Tanner & Bradley (1992)
	Empower density to support one steer:	22.85	E14 sej/J	Brandt-Williams (2002)
	= Natural Land (1) + 3.2 E14 sej/ha/yr	3.20	E14 sej/J	
4	After Doherty (1995)			
5	After Brandt-Williams (2002)			
6	Based 3.25 acres/animal	0.76	cow/ha/yr	After Pate (1999)
	Empower density to support one steer:	22.85	E14 sej/J	Brandt-Williams (2002)
	= Improved Pasture (5) + 17.37 E14 sej/ha/yr	36.90	E14 sej/J	
7	Based on 1.4 brood cow/ha/yr (1.75 acres/animal)			After Pate (1999)
	Empower density to support one steer:	22.85	E14 sej/J	Brandt-Williams (2002)
	= Improved Pasture (5) + 31.99 E14 sej/ha/yr	51.52	E14 sej/J	
8	Brandt-Williams (2002)			
9	Average of empower densities of 5, 8, and 10.			Assumed after Odum (1994)

Table 2-6. Continued.

Notes				
10	Average of empower densities for 12 row crops.			After Brandt-Williams (2002)
11	Based on 0.79 dairy cows /acre/yr	1.95	cow/ha/yr	After USDA (2002)
	Empower density to support one cow:	100.00	E14 sej/J	Brandt-Williams (2002)
		195.00	E14 sej/J	
12	Based on Parker (1998) and Brown (1980)			
13	Based on the emergy evaluation for a golf course			After Behrend (2000)
14	Based on Parker (1998) and Brown (1980). Includes mobile home medium density.			
15	Based on Parker (1998)			
16	Based on Brown (1980). Includes mobile home high density.			
17	Based on Parker (1998) and Brown (1980)			
18	After Brown (1980)			
19	Based on Parker (1998)			
20	Based on Parker (1998) and Brown (1980)			
21	Based on Parker (1998) and Brown (1980)			
22	Based on Parker (1998) and Brown (1980)			
23	After Brown (1980)			
24	After Brown (1980)			
25	After Brown (1980)			

Table 2-7. Description of landscape pattern metrics selected for this study. Acronyms, descriptions, and units according to McGarigal et al. (2002).

Landscape Pattern Metric	Acronym	Description	Units	References
Class level metrics				
Percent agriculture	PLAND_Ag	PLAND equals the percentage of the landscape comprised of agricultural land.	%	Allan et al. 1997; Jones et al. 2001; Cifaldi et al. 2004; Kearns et al. 2005
Percent urban	PLAND_Urb	PLAND equals the percentage of the landscape comprised of urban land.	%	Allan et al. 1997; Jones et al. 2001; Cifaldi et al. 2004; Kearns et al. 2005
Percent forests	PLAND_For	PLAND equals the percentage of the landscape comprised of forested land.	%	Allan et al. 1997; Jones et al. 2001; Cifaldi et al. 2004; Kearns et al. 2005
Percent wetlands	PLAND_Wet	PLAND equals the percentage of the landscape comprised of wetland land.	%	Allan et al. 1997; Jones et al. 2001; Cifaldi et al. 2004; Kearns et al. 2005
Landscape level metrics				
Patch richness	PR	PR equals the number of different patch types present within the landscape boundary.	None ($PR \geq 1$, without limit)	Griffith et al. 2002
Patch richness density	PRD	PRD equals the number of different patch types present within the landscape boundary divided by total landscape area (m2), multiplied by 10,000 and 100 (to convert to 100 hectares).	#/100 ha ($PRD > 0$, without limit)	Uuemaa et al. 2005
Patch density	PD	Number of patches of the landscape divided by total landscape area (m2), multiplied by 10,000 and 100 (to convert to 100 hectares).	#patches/100ha ($PD > 0$, constrained by cell size)	Johnson et al. 1997; Griffith et al. 2002; Cifaldi et al. 2004; Kearns et al. 2005; Uuemaa et al. 2005
Mean patch size	AREA_MN	MN equals the sum, across all patches in the landscape, of the corresponding patch metric values[1], divided by the total number of patches.	Ha ($AREA > 0$, without limit)	Miller et al. 1997
Patch size coefficient of variation	AREA_CV	CV equals the standard deviation divided by the mean, multiplied by 100 to convert to a percentage, for the corresponding patch metric[1].	%	Cifaldi et al. 2004
Edge density	ED	ED equals the sum of the lengths (m) of all edge segments in the landscape, divided by the total landscape area (m2), multiplied by 10,000 (to convert to hectares).	m/ha ($ED \geq 0$, without limit)	Cifaldi et al. 2004; Uuemaa et al. 2005

Table 2-7. Continued.

Landscape Pattern Metric	Acronym	Description	Units	References
Interspersion and juxtaposition index	IJI	IJI measures the extent to which patch types are interspersed (not necessarily dispersed); higher values result from landscapes in which the patch types are well interspersed (i.e., equally adjacent to each other), whereas lower values characterize landscapes in which the patch types are poorly interspersed.	%	Griffith et al. 2002, Cifaldi et al. 2004; Kearns et al. 2005
Mean shape index	SHAPE_MN	MN equals the sum, across all patches in the landscape, of the corresponding patch metric values[2], divided by the total number of patches.	None (SHAPE ≥ 1, without limit)	Kearns et al. 2005; Uuemaa et al. 2005
Shannon's diversity index	SHDI	SHDI equals minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion.	None (SHDI ≥ 0, without limit)	Miller et al. 1997; Uuemaa et al. 2005
Dominance (calculated as its complement – evenness, where evenness = 1-dominance)	SHEI	Shannon's evenness index is expressed such that an even distribution of area among patch types results in maximum evenness.	None (0 ≤ SHEI ≤ 1)	USEPA 1994; Hunsaker and Levine 1995
Contangion	CONTAG	Contagion measures both patch type interspersion (i.e., the intermixing of units of different patch types) as well as patch dispersion (i.e., the spatial distribution of a patch type).	%	USEPA 1994; Hunsaker and Levine 1995; Miller et al. 1997; Griffith et al. 2002; Kearns et al. 2005; Uuemaa et al. 2005
Fractal dimension (calculated as the mean patch fractal dimension)	FRAC_MN	FRAC_MN equals the sum of 2 times the logarithm of patch perimeter (m) divided by the logarithm of patch area of patch (m^2) for each patch in the landscape, divided by the number of patches. An indicator of shape complexity.	None (1 ≤ FRAC_MN ≤ 2)	USEPA 1994; Liu and Cameron 2001
Mean Euclidian nearest neighbor distance	ENN_MN	MN equals the sum, across all patches in the landscape, of the corresponding patch metric values[3], divided by the total number of patches.	Meters (ENN > 0, without limit.)	Uuemaa et al. 2005

[1] AREA equals the area (m^2) of the patch, divided by 10,000 (to convert to hectares).

[2] SHAPE equals patch perimeter (given in number of cell surfaces) divided by the minimum perimeter (given in number of cell surfaces) possible for a maximally compact patch (in a square raster format) of the corresponding patch area.

[3] ENN equals the distance (m) to the nearest neighboring patch of the same type, based on shortest edge-to-edge distance.

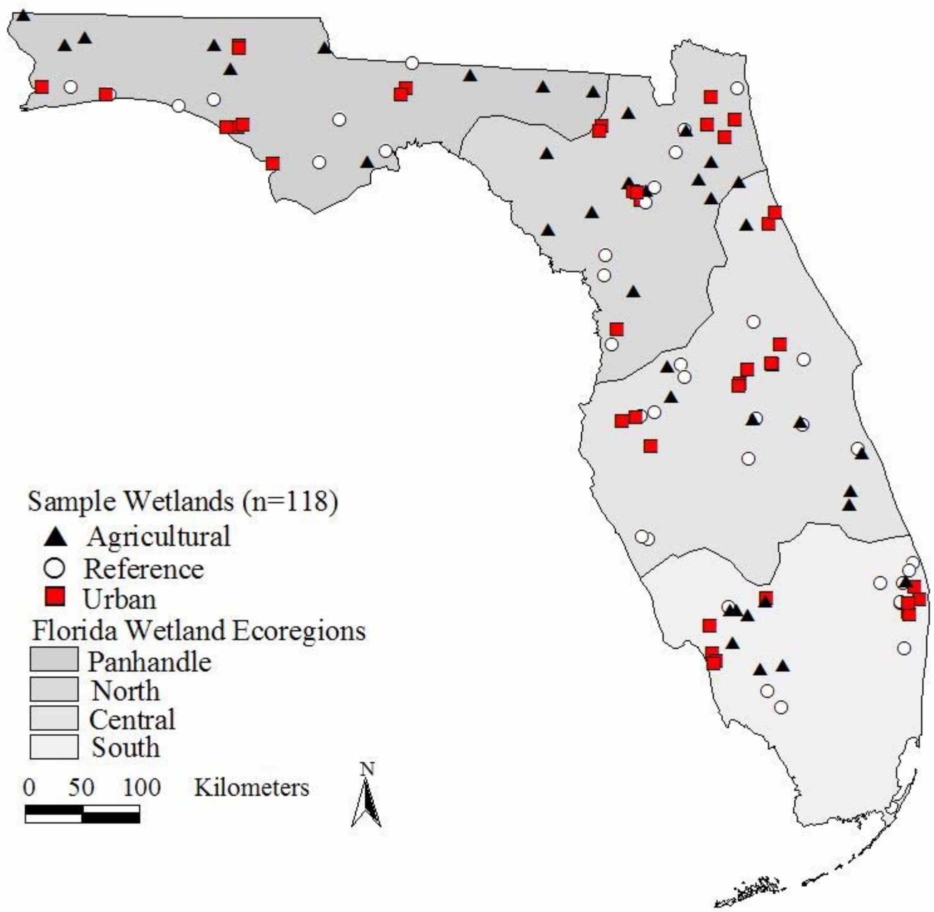


Figure 2-1. Study site location by ecoregions of 118 isolated forested wetlands in Florida.

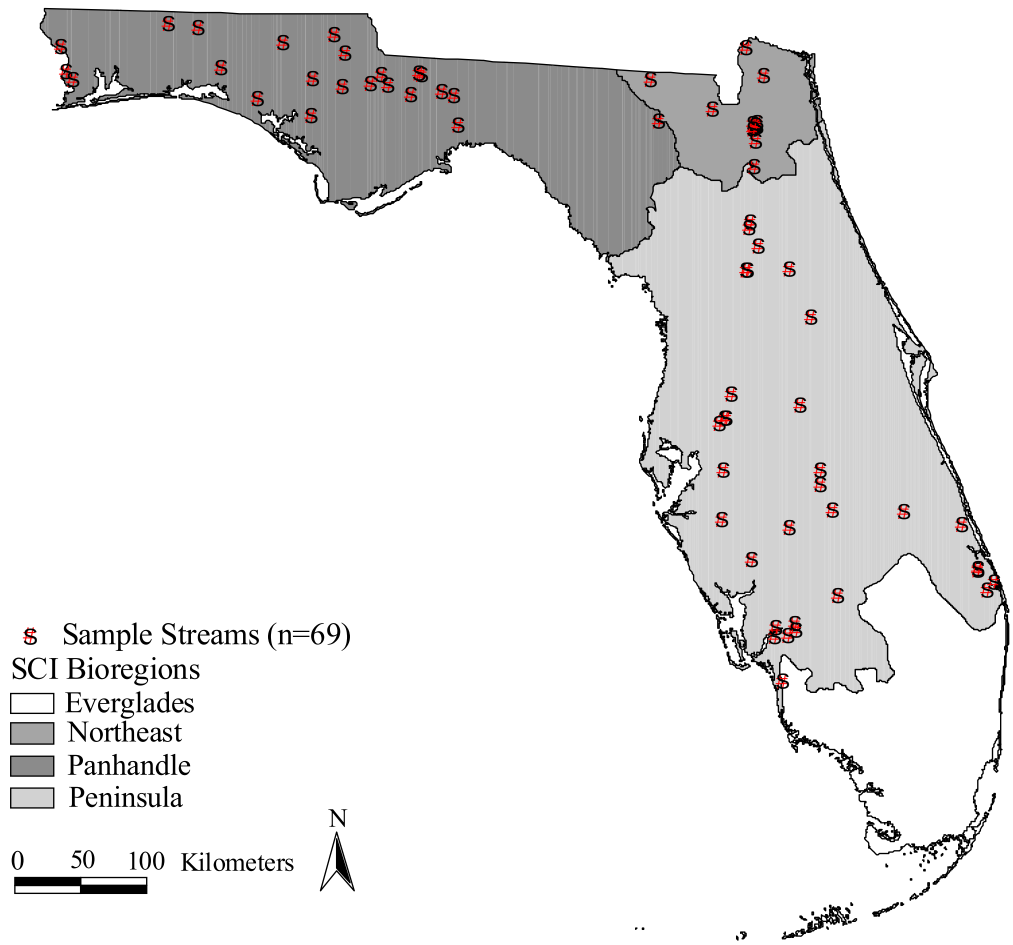


Figure 2-2. Study site location by ecoregions of 69 streams in Florida. Streams locations indicated as STORET sampling stations.

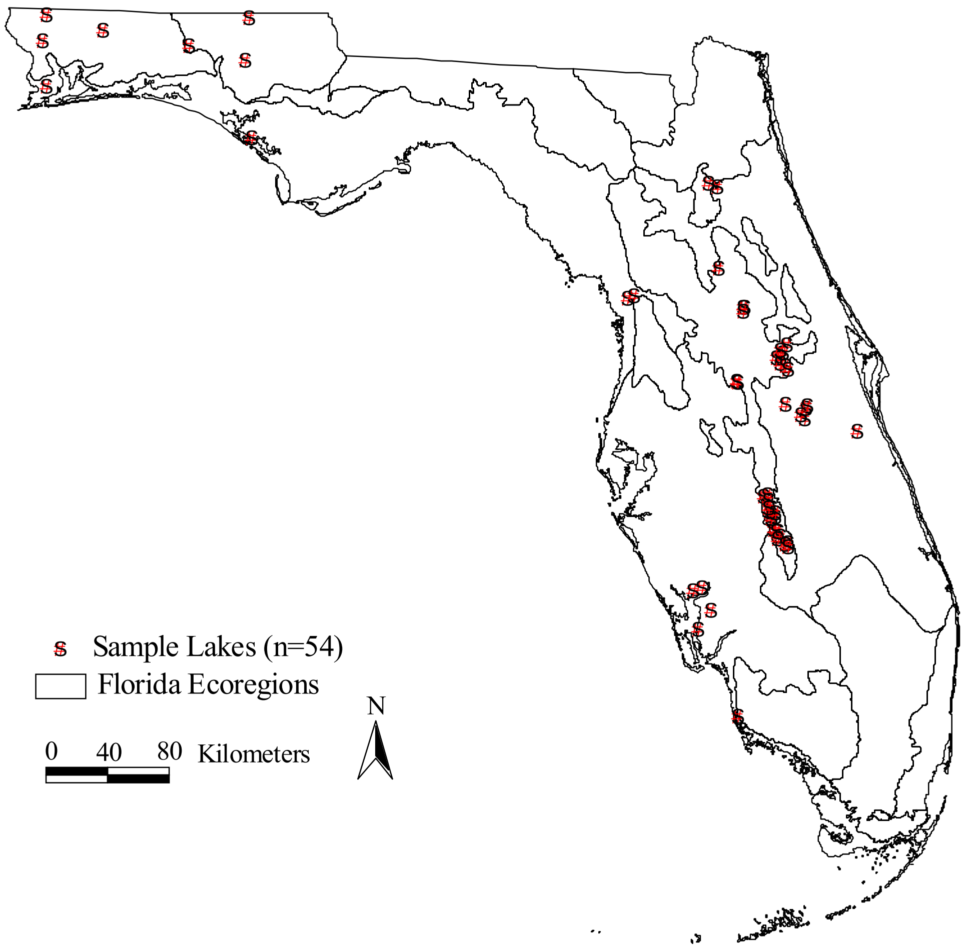


Figure 2-3. Study site location of 54 lakes in Florida.

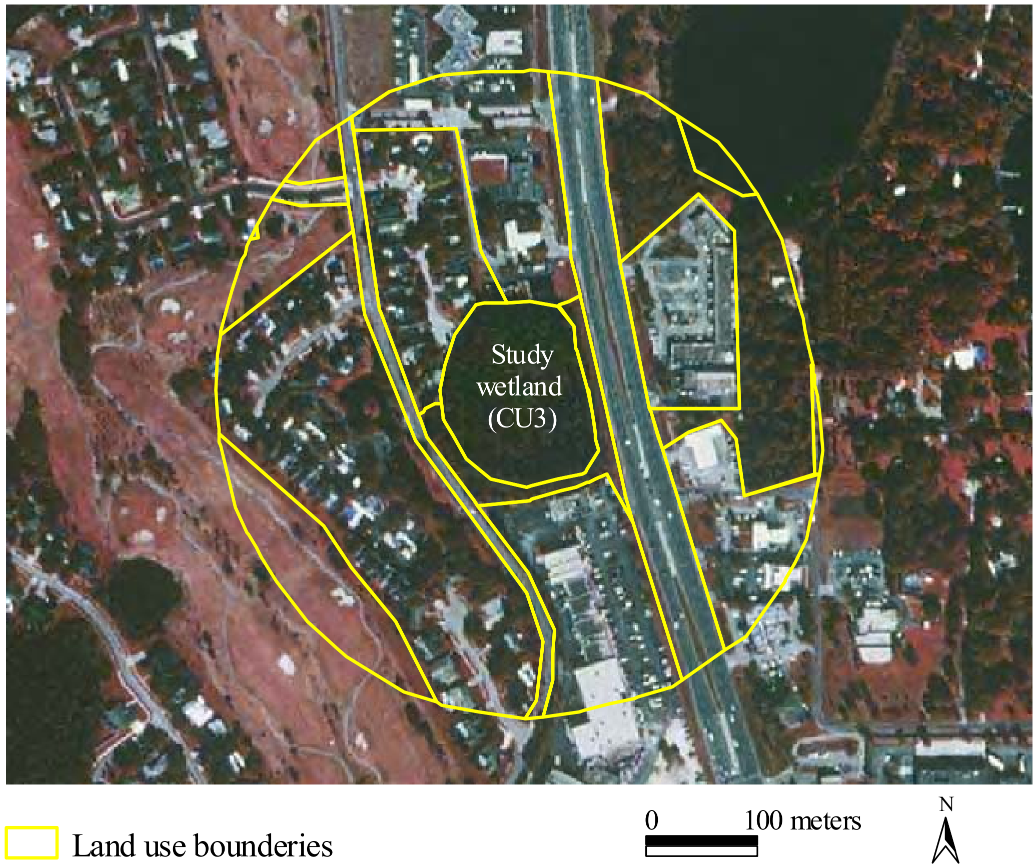


Figure 2-4. Major land use patches delineated from an aerial photo within a 200 meter buffer area surrounding a study wetland (CU3) within an urban landscape.

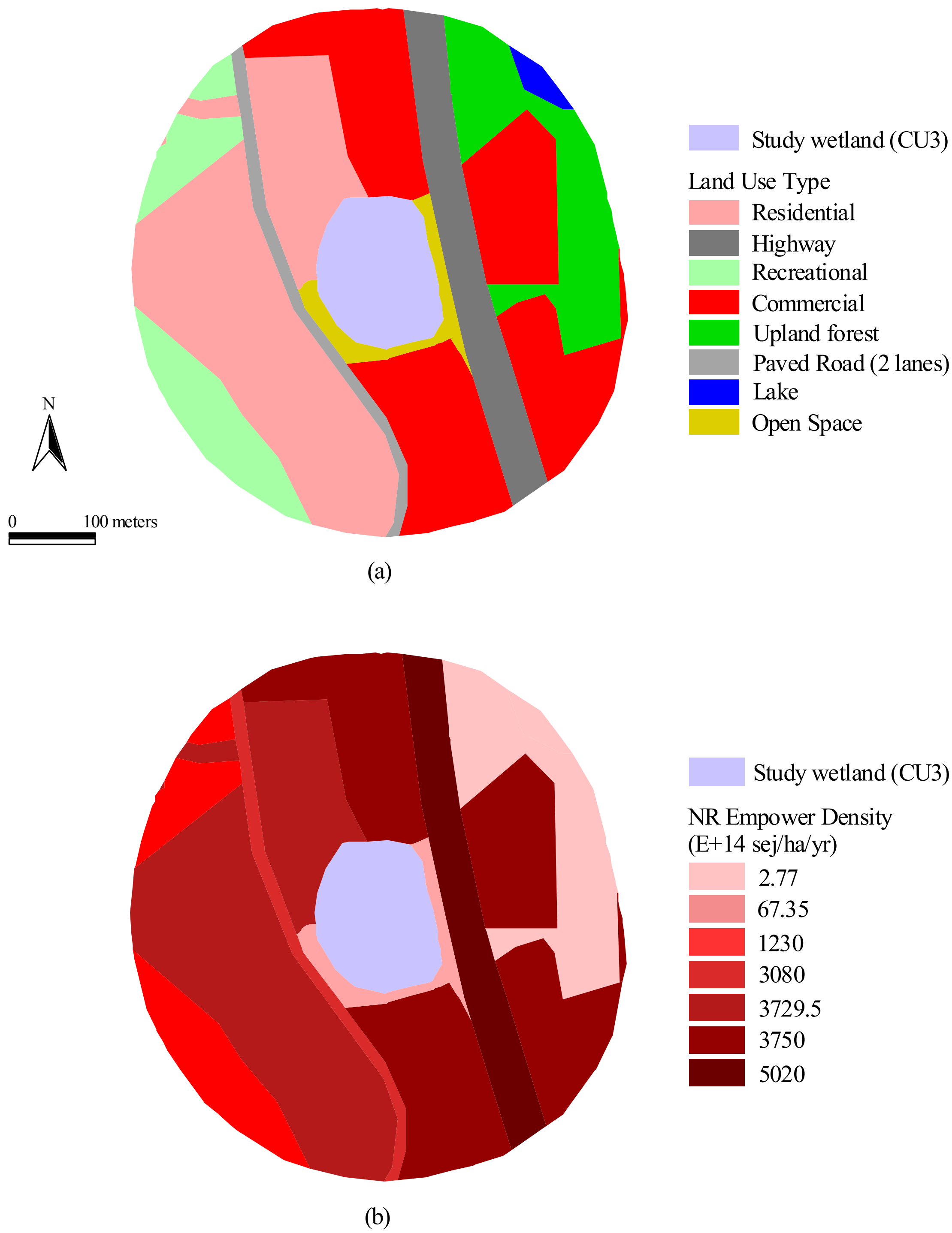
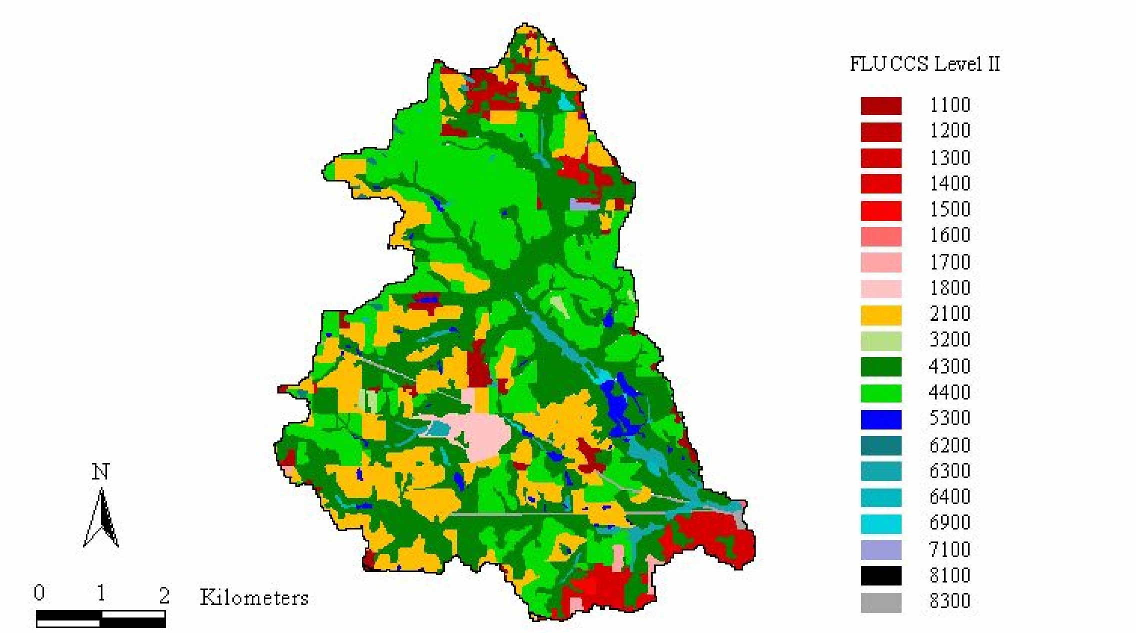
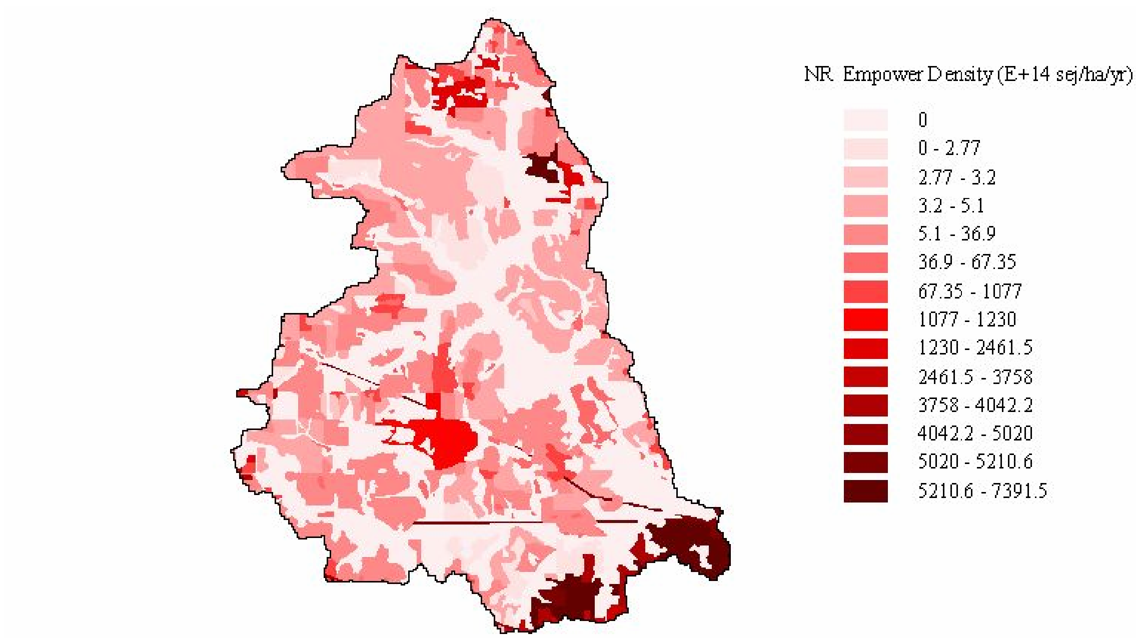


Figure 2-5. Landscape surrounding an isolated forested wetland in Florida showing (a) general land use categories and (b) land use based on the intensity of human activities measured as non-renewable empower density.



(a)



(b)

Figure 2-6. Land use types for a Florida stream watershed based on (a) the FLUCCS (refer to Appendix B for codes' descriptions) and (b) the intensity of human activities measured as non-renewable empower density.

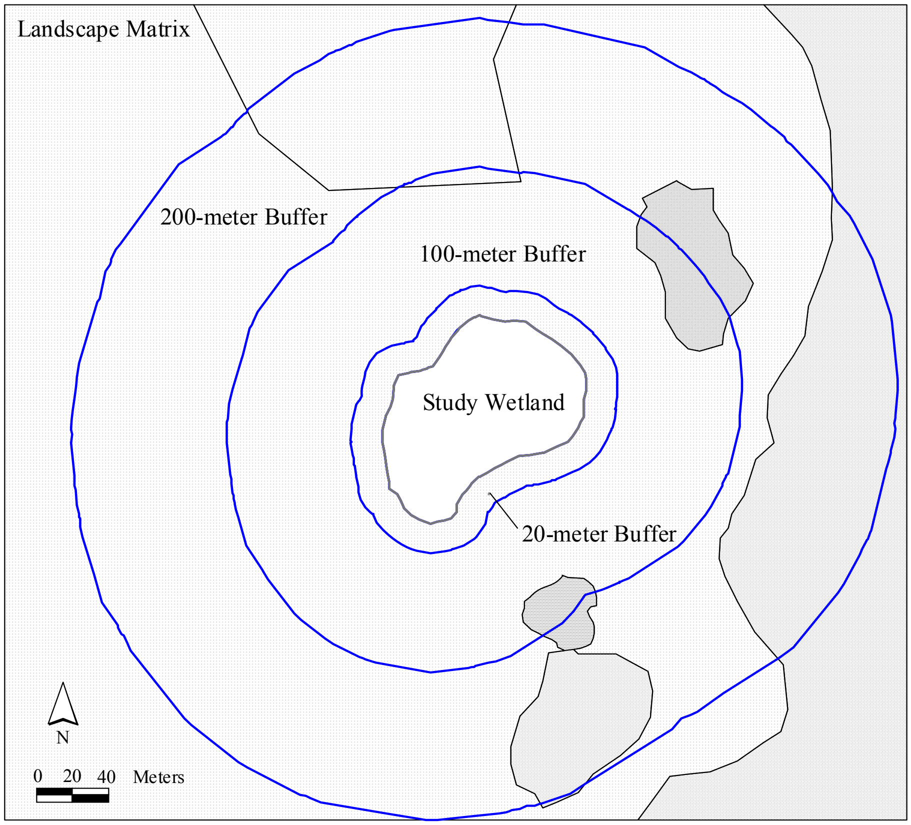


Figure 2-7. Spatial scales of analysis for the isolated forested wetlands. Equidistant areas of 20, 100, and 200 meters were used to determine the contributing effect of land use on isolated forested wetlands.

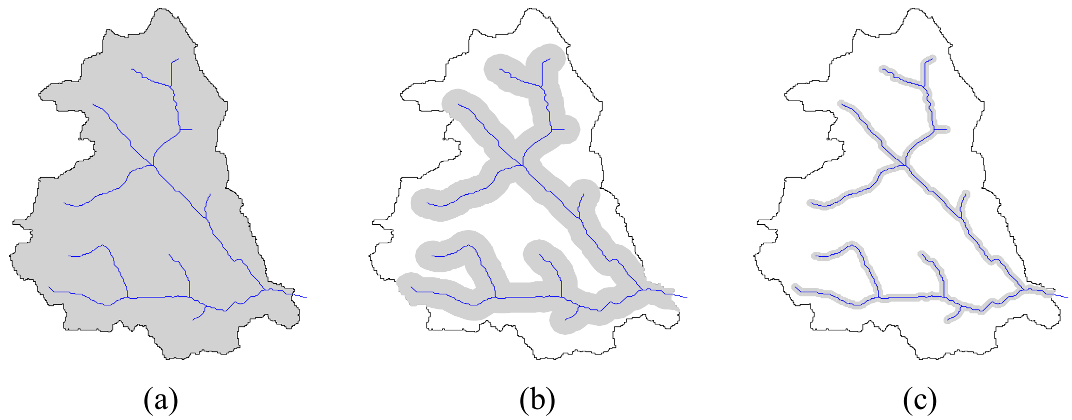


Figure 2-8. Spatial scales of analysis for streams: (a) total drainage area or total watershed, (b) equidistant area of influence of 400 meters around the stream, and (c) equidistant area of influence of 100 meters around the stream.

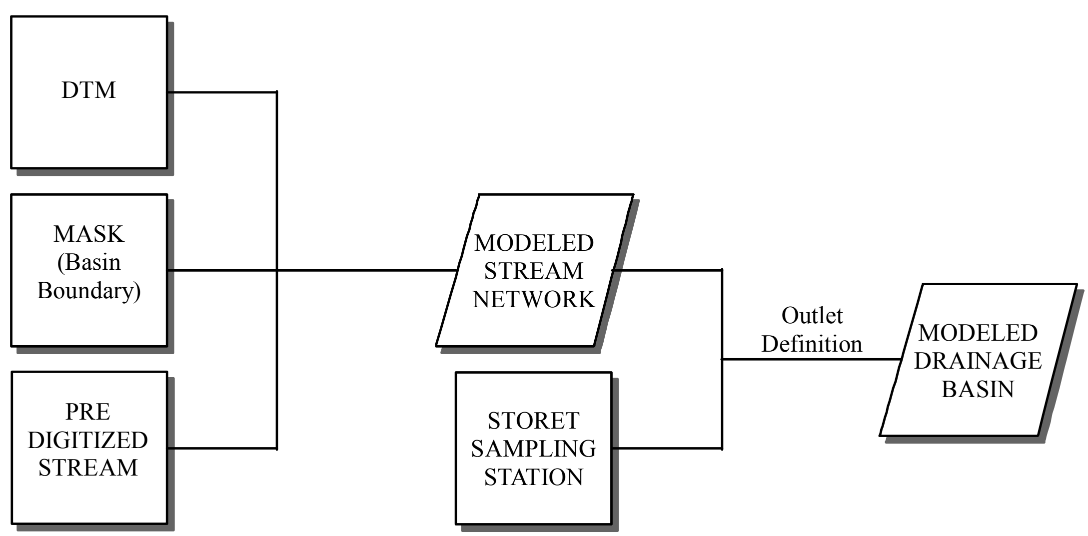


Figure 2-9. Flow chart showing the main steps followed for the delineation of drainage basins using US EPA's BASINS 3.0 software.

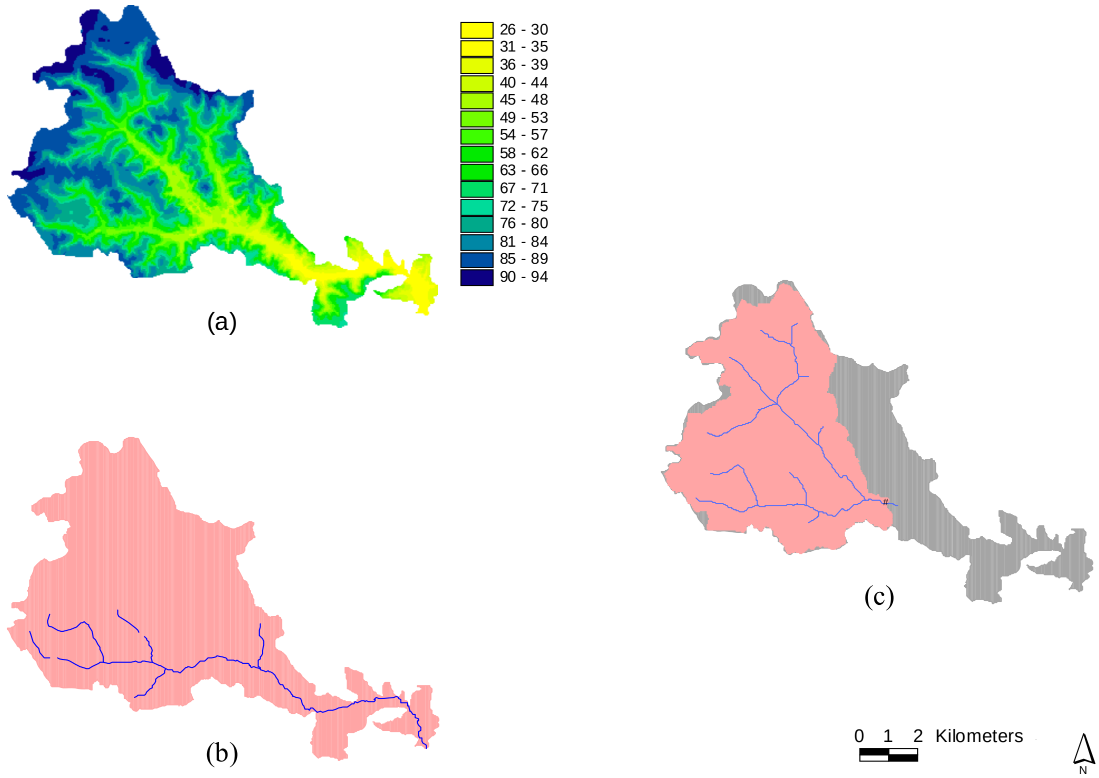
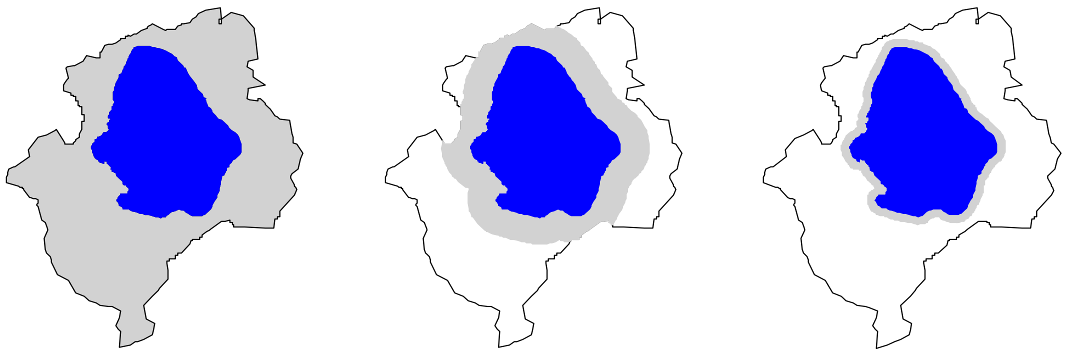


Figure 2-10. Graphic representation of the steps followed in the delineation of the area draining to a water quality sampling site (STORET 22020093). (a) DTM of the main drainage basin (units = meters); (b) basin's mask with a pre-digitized stream network; and (c) modeled drainage boundary with modeled stream network and outlet (water quality sampling station).



(a) (b) (c)

Figure 2-11. Spatial scales of analysis for lakes: (a) total drainage area or total watershed, (b) equidistant area of influence of 400 meters around the lake, and (c) equidistant area of influence of 100 meters around the lake.

CHAPTER 3
RESULTS

This chapter presents the results of the landscape analysis performed on isolated forested wetlands, streams, and lakes in Florida to study the relationship between human land use intensity (LDI), landscape pattern metrics, and indicators of ecosystem condition water quality variables for these freshwater systems. The LDI was correlated to water quality variables and biological indicators for each freshwater system at multiple landscape scales. The effects of spatial scale on the LDI and its predictive power are detailed herein. For landscape pattern metrics, the selection process of a set of metrics that best describes the surrounding landscape of the systems studied is shown. The metrics selected were also correlated to water quality variables and biological indicators at multiple landscape scales. Finally, the effect of landscape pattern on the relationship between the LDI and indicators of ecosystem condition and water quality variables that resulted after using the LDI together with the pattern metrics in multiple regression analysis is presented.

Land Use/Land Cover Composition of the Freshwater Systems

Isolated Forested Wetlands

Each isolated forested wetland buffer area was *a priori* classified as reference, agricultural, or urban through inspection of aerial photography (DOQQs). The result of the *a priori* classification was that 37 isolated forested wetlands had buffer areas classified as reference, 40 had agricultural buffer areas, and 41 had urban buffer areas. Table 3-1 summarizes the land use characteristics of the *a priori* buffer area classes. The land use/land cover composition for buffer areas for each of the 118 isolated forested wetlands is presented in Appendix I. Reference isolated forested wetlands were primarily surrounded by forests, which accounted for almost 73% of the land use/land cover within a 200-meter buffer distance from the study sites.

Approximately 25% of the 200-meter buffer areas were covered with wetlands other than the site under investigation. Other land use/land covers accounted for less than 3% of the surrounding landscapes. Agricultural isolated forested wetlands were imbedded within landscapes surrounded mostly by agricultural crops, pasture lands, and rangelands. These land uses accounted for approximately 66% of the land surrounding the isolated forested wetlands within this category. Forests represented 21% of the land use/land cover; and wetlands were present in 28 sites, covering about 8% of the landscapes. Sixty-four percent (64%) of the landscapes surrounding the urban sites were occupied by urban land uses. Forested areas and wetlands were less prevalent in urban sites than in agricultural sites, occupying only 18% and 4% of the surrounding landscapes, respectively. Lands devoted to transportation uses were more representative of urban lands, accounting for about 10% of the buffer areas in urban landscapes.

The non-renewable and purchased areal empower density was calculated within the 200-meter buffer surrounding each wetland. Table 3-2 presents summary statistics for the areal empower density for the *a priori* defined buffer areas. Although the surrounding landscapes of the reference sites consisted mostly of natural lands, a high variability in the areal empower density for this wetland category was observed. A maximum value of 227.7 E+14 sej/ha/yr suggests that there were sites among the reference isolated forested wetlands that included high-intensity land uses in their surrounding landscapes. Summary statistics for the agricultural isolated forested wetlands show that on average these sites were within the range of what may be a characteristic value for a landscape that consists mostly of agricultural lands. The minimum non-renewable and purchased areal empower density value corresponds to lands planted with pine trees that have an areal empower density similar to that of natural lands. The maximum non-renewable and purchased areal empower density value reflects the development intensity characteristics of land uses with high energy demands such as dairy farms or chicken farms. On average, urban isolated forested wetlands had non-renewable and purchased areal empower densities that were two orders of magnitude higher than the reference and agricultural isolated forested wetlands. The range of non-renewable and purchased areal empower values at the lower end describes sites with transitional lands that are less developed, while the higher range of areal empower values describes sites with intense use of energy such as commercial malls and high-rise residential areas.

Streams and Lakes

Table 3-3 presents summary statistics for the drainage area size and land use composition for 69 streams and 54 lakes. Information on the total area and the land use/land cover composition for each drainage area is included in Appendices I and J for streams and lakes, respectively. The drainage areas for streams varied considerably in size with the largest drainage basin three orders of magnitude larger than the smallest one. The land use/land cover composition of the drainage basins was very diverse and represented a wide range of land use types with landscapes varying from almost completely forested (site S56; see Appendix J) to completely urbanized (site S29).

For lakes, drainage basins also varied considerably in size, however, on average these were much smaller than the streams' watersheds. The smallest lake drainage basin was just over 8 hectares and the largest was more than 3,500 hectares. Although the land use/land cover composition of the drainage basins was diverse, urban lands were most common in the landscapes surrounding the sample lakes. The land use composition of the drainage basins varied from completely covered with natural lands (site L53; see Appendix K) to entirely urban (site L20).

Mean values ± the standard deviation of the non-renewable and purchased areal empower density for the drainage areas of the sample streams and lakes calculated in three different ways are shown in Table 3-4. There was a large variability among the streams in terms of their development intensity. Results showed that none of the watersheds were completely occupied by natural lands or waters, and that at least some of the resources used were either non-renewable or purchased. At the other end of the development gradient, the resource use within the watershed with the highest non-renewable and the purchased areal empower density value was characteristic of a highly urbanized landscape.

There was also a large variability among the lakes based on their development intensity. Note that the average areal density was higher for the lakes than for the streams. Lakes' watersheds were more urbanized than those of the streams. The average resource use among all lake watersheds was equivalent to a landscape with a resource use comparable to low-intensity family residential lands.

Description of the Landscape Development Intensity Index

The LDI was calculated for varying grain sizes and spatial extents of the sample isolated forested wetlands, streams, and lakes, to test the effect of spatial grain size and spatial extent on which the LDI is calculated.

Scale Dependence: Grain Size

Isolated forested wetlands

The LDI was calculated for eight different grain sizes (5 x 5, 10 x 10, 20 x 20, 30 x 30, 40 x 40, 50 x 50, 60 x 60, and 70 x 70 meters) and using the 200-meter buffer area surrounding the sample of isolated forested wetlands as the spatial extent for analysis. LDI scores for 15 representative isolated forested wetlands selected from the total set of 118 wetlands are shown in Figure 3-1. The LDI scores for the total wetland sample are presented in Appendix L. In general, changing the grain size had a modest effect on the LDI scores. The highest variability was among intermediate LDI scores that corresponded to the most heterogeneous landscapes or landscapes composed of a combination of natural, agricultural, and/or urban land uses. The site that presented the highest variability among the total sample of isolated forested wetlands (n = 118) was SU10 (mean = 7.39, SD = 3.49 for the LDI-ILD). The surrounding landscape for this site was in transition between natural lands and urban (i.e., housing) that were developed with streets already constructed but without housing units. LDI scores varied from high values to lower values as the LDI was calculated with increasing grain size (refer to Appendix L). It was also observed that the LDI scores based on area only were consistently higher than the LDI scores based on a decrease in distance from the study isolated forested wetlands.

Individual landscape scalograms presented in Figure 3-2 provide detailed information on the effect of changing grain size on the LDI for six representative isolated forested wetland buffers with low, medium, and high LDI values. Trends in the variation of the LDI scores for small wetland buffers suggest that the effect of grain size on the LDI may be important for landscapes with intermediate LDI scores. For these landscapes, the effect of cell aggregation may remove small patches with high development intensity that when present at fine grain sizes may have a strong influence on the landscape LDI score. This situation can be appreciated in Figure 3-3, where the effect of changing grain size for the six wetland buffers is shown. Of particular interest is Figure 3-3(c) - wetland PA1, where the disappearance of the low-intensity transportation patch beyond a grain size of 40 x 40 meters had a strong effect on the LDI score of the wetland buffer when the LDI was calculated based on area only (LDI-PLU).

Streams

For streams, the LDI was calculated for six different grain sizes (20 x 20, 50 x 50, 80 x 80, 110 x 110, 140 x 140, and 170 x 170 meters) and using the total drainage area as the spatial extent for analysis. Figure 3-4 shows LDI scores for 15 representative streams' watersheds selected from the total set of 69 streams. The LDI scores for the total sample of drainage basins for streams are presented in Appendix M. Changing the grain size had a small effect on the LDI scores. This can be attributed to the fact that for stream watersheds urban patches were not rare. The disappearance of some urban patches with cell aggregation had less effect on the LDI score for streams than the effect observed for the isolated forested wetlands, since for the former some urban lands tended to remain with changes in scale allowing for less variability in LDI scores.

The highest variability was among intermediate LDI scores that correspond to the most heterogeneous landscapes or landscapes composed of a combination of natural, agricultural, and/or urban land uses. The site that presented the highest variability among the total sample of streams was site S42 (mean = 9.30, SD = 2.59, for the LDI-PLU; see Appendix M). Site S26 in Figure 3-4 was unique among the sample streams since it had a high LDI score and a relatively high standard deviation. A bigger spread in the LDI values was reported for sites with intermediate LDI scores that were calculated based on the proportion occupied by each land use type. Of interest in Figure 3-4 is that there appears to be a difference in the trend among the scores for the three LDI forms. While the LDI-PLU and the LDI-ILD scores tend to increase linearly with no large departures for the different sites, the LDI-ISD presents more variability suggesting the effect of the flood plain (natural buffers) on some of the sites.

Individual drainage basin scalograms presented in Figure 3-5 provide detailed information on the effect of changing grain size on the LDI for six of the streams' watersheds that were considered. Trends in the variation of the LDI scores for each LDI form suggest that, despite some small variations, the emergy-based index varies very little with changes in grain size between 20 x 20- and 170 x 170-meters for stream watersheds.

Scale Dependence: Spatial Extent

Isolated forested wetlands

To test how the LDI varies with changes in spatial extent, the grain size was held constant at 5 x 5 meters and the LDI in its three forms was calculated for buffer areas of 20, 100, and 200 meters around the study isolated forested wetlands. The Kruskal-Wallis test initially implied that there were no significant differences among the LDI scores for the three extents ($n = 118$; LDI-PLU, $H = 4.80$, $p = 0.091$; LDI-ILD, $H = 5.35$, $p = 0.069$; LDI-ISD, $H = 5.02$, $p = 0.081$). However, a comparison of LDI values with changes in extent based on *a priori* classes, as shown in Figure 3-6, suggested that there were differences among LDI values with increasing extent, especially among reference sites and urban sites. These differences can be attributed to the fact that there was an increase in the number of land-use classes included in the wetland buffers with increasing scale. LDI values tended to be higher with changes in extent as more developed lands were included in the buffers. The Kruskal-Wallis test confirmed the significance of the differences in LDI scores with increasing extent among reference isolated forested wetlands ($n = 38$; LDI-PLU, $H = 13.79$, $p = 0.001$; LDI-ILD, $H = 13.42$, $p = 0.001$; LDI-ISD, $H = 12.33$, $p = 0.002$) and among urban isolated forested wetlands ($n = 41$; LDI-PLU, $H = 8.88$, $p = 0.012$; LDI-ILD, $H = 12.32$, $p = 0.002$; LDI-ISD, $H = 12.87$, $p = 0.002$).

Table 3-5 and Figure 3-7 show the extent of the association between each form of the LDI calculated for the three different extents. In all cases there was a very strong positive correlation among the three forms of the LDI; the weakest association was found between the LDI-PLU calculated for the 200-meter buffer area and the LDI-ISD calculated for the 20-meter buffer area ($r = 0.86$, $p < 0.001$). The matrix plot of the relationship between pairs of LDI scores for different extents confirmed that LDI scores tended to be higher for the largest extent that, as was suggested previously, presented more developed lands than the smallest extent considered (20-

meter buffer). Note that differences among the 100-meter buffer and the 200-meter buffer were minimal, suggesting that it might not be necessary to consider the land beyond 100 meters in order to account for most of the lands that might influence small isolated forested wetland systems.

Streams

The grain size for streams was held constant at 20 x 20 meters and the LDI in its three forms was calculated for buffer areas of 100 and 400 meters from the sample streams and for the entire drainage basin. The Kruskal-Wallis test initially implied that there were no significant differences among the LDI-PLU scores for the three extents ($n = 69$; $H = 5.14$, $p = 0.077$). However, differences among the LDI-ILD scores with changes in scale were significantly different ($n = 69$; $H = 6.65$, $p = 0.036$), as were the differences among the LDI-ISD scores ($n = 69$; $H = 6.97$, $p = 0.031$), suggesting that the LDI is scale-dependent. When LDI values were disaggregated into low ($n = 17$), intermediate ($n = 35$), and high ($n = 17$) development intensity classes as shown in Figure 3-8, differences among LDI values with increasing extent were suggested for the LDI-PLU at the low and intermediate ranges of values. These results also suggest that LDI values tend to increase as more developed lands are included in larger landscape areas. The Kruskal-Wallis test confirmed the significance of the differences among streams within the low LDI range of values ($n =69$; LDI-PLU, $H = 11.97$, $p = 0.003$; LDI-ILD, $H = 13.48$, $p = 0.001$; LDI-ISD, $H = 12.45$, $p = 0.002$) and among streams within the intermediate LDI range of values (LDI-PLU, $H = 13.90$, $p = 0.001$; LDI-ILD, $H = 17.72$, $p < 0.001$; LDI-ISD, $H = 18.72$, $p < 0.001$). The fact that there were no significant differences among sites with high LDI values could be attributed to the large extent overlap among these sites, most of which tended to have small watersheds.

Correlations between each form of the LDI calculated for the three different extents are shown in Table 3-6 and Figure 3-9. In all cases there was a very strong positive correlation among all forms of the emergy-based index; the weakest association was found between the LDI-PLU calculated for the watershed scale and the LDI-ISD calculated for the 100-meter buffer area scale ($r = 0.84$, $p < 0.001$). The small variability among pairs of LDI scores for landscapes surrounding streams observed in Figure 3-9 suggests that patterns of development remained relatively similar with changes in extent.

Lakes

The grain size for the lakes was also held constant at 20 x 20 meters and the LDI in its three forms was calculated for buffer areas of 100 and 400 meters from the sample lakes and for the entire drainage basin. The Kruskal-Wallis test suggested that there were no significant differences among the LDI-PLU scores for the three extents ($n = 54$; $H = 1.36$, $p = 0.507$), and that there were no significant differences among the LDI-ILD scores ($n = 54$; $H = 2.87$, $p = 0.238$) or the LDI-ISD scores ($n = 54$; $H = 5.23$, $p = 0.073$). When LDI values were compared by disaggregating them into low ($n = 13$), intermediate ($n = 28$), and high ($n = 13$) development intensity classes as shown in Figure 3-10, statistically significant differences (Kruskal-Wallis test) among LDI values with increasing extent were only observed for the LDI-ILD at the low ($H = 7.04$, $p = 0.03$) and intermediate ranges of values ($H =8.42$, $p = 0.015$), and for the LDI-ISD at the low ($H = 8.82$, $p = 0.012$), intermediate ($H =14.02$, $p = 0.001$), and high ranges of values ($H = 7.62$, $p = 0.02$). Small differences among LDI groups for lake basins were due to the fact that the lands within the basins were more developed and no new land use types that will result in significant changes in LDI scores were added with increasing extent.

Table 3-7 provides information on the correlations between the three forms of the LDI calculated at three different spatial extents for the sample lakes. A strong positive relationship for all pairs of LDI forms was reported. The weakest association was found between the LDI-PLU calculated for the watershed scale and the LDI-ISD calculated for the 100-meter buffer area scale ($r = 0.78$, $p < 0.001$). Figure 3-11 shows the relationship between pairs of LDI scores for the different extents for the sample lakes. Note that in Figure 3-11 it can be observed that patterns of development of the lakes' watersheds tended to be different with changes in extent with developed lands, becoming more common with increasing scale.

Relationship between Land Use Intensity and Ecosystem Condition

Isolated forested wetland condition

Water quality: spatial extent. Simple linear regression was used to estimate the level of association between the LDI and five water chemistry variables at different spatial extents while holding the grain size constant at 5 x 5-meters. All dependent variables were $\log_{10}$ transformed to satisfy requirements of regression analysis. Results for the regressions are presented in Table 3-8. The highest variability in the DO was explained by the LDI-PLU at the 200-meter scale. The regression had a very poor fit ($r^2 = 0.07$), but the overall relationship was significant ($F_{1,69} = 5.01$, $p = 0.028$). Figure 3-12 shows the relationship between the LDI-PLU and the isolated forested wetlands' DO ($\log_{10}$ transformed) at the 200-meter spatial extent. Regression results among the three LDI forms were very small at all scales.

The LDI-PLU explained slightly more of the variability in the water's specific conductance (SC) at the 200-meter scale ($r^2 = 0.21$, $F_{1,31} = 7.98$, $p = 0.008$) with an increase in the strength of the association between the two variables with increasing scale. Regression results for the LDI-PLU were also slightly higher than for the other two forms of the LDI at all three scales. The relationship between the LDI-PLU and isolated forested wetlands' water SC ($\log_{10}$ transformed) at the 200-meter scale is shown in Figure 3-13. Significant results for TP resulted only when TP was regressed against the LDI-PLU, with the strongest association established at the 20-meter scale. The regression had a very poor fit ($r^2 = 0.065$), but the overall relationship was significant ($F_{1,73} = 5.07$, $p = 0.027$). The relationship between the LDI-PLU and isolated forested wetlands' water TP ($\log_{10}$ transformed) at the 20-meter scale is shown in Figure 3-14. None of the regressions between the LDI and TN or between the LDI and the water turbidity were significant. The analysis of residuals suggested that the model for SC satisfied the requirements of regression. The regression model for DO showed some level of heteroscedasticity. For TP, the residuals were not normally distributed and unequal variances were observed.

Water quality: grain size. The proportion of the variance in water chemistry variables explained by the LDI measured at different grain sizes was tested by calculating regression coefficients (r^2) for each scale independently and holding the spatial extent constant at the 200-meter scale (see Figure 3-15). The significance of the regression results is shown in Table 3-9. More of the variability in the water DO was explained by the LDI-PLU almost equally at all grain sizes. The relationship between DO and the LDI-PLU was shown previously in Figure 3-12.

For the water SC, more of the variability was explained by the LDI-PLU at the 20 x 20-meter grain size ($r^2 = 0.208$, $F_{1,31} = 8.14$, $p = 0.008$). Minimal differences were observed among all of the scales considered for the LDI-PLU. The relationship between the specific conductance and the LDI-PLU was shown previously in Figure 3-13. The LDI was not significantly associated to the concentration of TN, TP, or the isolated forested wetlands' water turbidity at any scale.

Biological indicators: spatial extent. Simple linear regression allowed estimating the degree of association between the LDI and the WCI for macrophytes, macroinvertebrates, and diatoms at different spatial extents and holding the grain size constant at 5 x 5 meters.

Regression results are presented in Table 3-10. The LDI-PLU explained more of the variability of the macrophyte WCI at the 20-meter buffer scale ($r^2 = 0.30$, $F_{1,116} = 48.78$, $p < 0.001$), with the strength of the relationship decreasing with increasing scale for the LDI-PLU and the LDI-ILD. Figure 3-16 shows the relationship between the LDI-PLU and the macrophyte WCI at the 20-meter scale. The plot between the LDI-PLU and the macrophyte WCI shows a decrease in WCI scores with increasing development intensity. However, two distinct sets of data points grouped at approximate LDI values of 5 to10 and 15 to 23 for isolated forested wetlands with low scores in the macrophyte WCI are apparent.

For the macroinvertebrate WCI more of the variance was explained by the LDI-PLU at the 20-meter scale ($r^2 = 0.24$, $F_{1,77} = 24.17$, $p < 0.001$), and a decrease in the strength of the association with increasing scale was also reported for the LDI-PLU and the LDI-ILD. The relationship between the LDI-PLU and macroinvertebrate WCI at the 20-meter scale is shown in Figure 3-17. The plot shows differences between the WCI scores for isolated forested wetlands with surrounding landscapes with low LDI-PLU values and wetland landscapes with intermediate and high LDI-PLU values.

For the diatom WCI the strongest relationship was found with LDI-PLU at the 100-meter scale ($r^2 = 0.24$, $F_{1,48} = 15.32$, $p < 0.001$). For diatoms, the proportion of the variance explained by the LDI was higher at broader scales for all forms of the LDI. Figure 3-18 shows the relationships between the LDI-PLU and diatom WCI at the 100-meter scale. The plot between the LDI-PLU and the diatom WCI showed higher WCI scores for sites with low LDI-PLU than for sites with middle and high LDI-PLU. However, among the isolated forested wetlands with middle and high LDI-PLU two distinct sets of data points grouped at approximate LDI values of 5 to10 and at 15 to 25 were observed.

The analysis of residuals (normal probability plots, residuals versus variables plots, and plots of residuals versus the fitted values) suggested that the relationship between the LDI and the macrophyte WCI was non-linear and that the data were not normally distributed. For the macroinvertebrate WCI and the diatom WCI residual plots suggested a linear relationship between the variables and a normal distribution of the data. However, the regression model for the diatom WCI showed some level of heteroscedasticity.

Biological indicators: grain size. The variability of the WCI for macrophytes, macroinvertebrates, and diatoms explained by the LDI measured at different grain sizes while holding the spatial extent constant at the 200-meter scale, was tested by calculating regression coefficients (r^2) for each scale independently (see Figure 3-19 and Table 3-11). The proportion of the variance in the macrophytes WCI explained by the LDI decreased as the grain size was increased, with more of the variability explained by the LDI at the 5 x 5-meter grain size. The LDI-PLU accounted for more of the variability in the WCI than the other two forms of the index.

Figure 3-20 shows the relationship between the macrophyte WCI and the LDI at the most significant scale ($r^2 = 0.243$, $F_{1,116} = 37.15$, $p < 0.001$). The macrophyte WCI decreased with increasing development intensity. More of the variability that was explained by the LDI for the macroinvertebrate WCI occurred at the 50 x 50-meter cell resolution. At this grain size the LDI-ILD explained most of the proportion of the variance. However, the difference with the other two forms of the LDI was very small. The relationship between the macroinvertebrate WCI and the LDI at the most significant scale is shown in Figure 3-21 ($r^2 = 0.198$, $F_{1,77} = 18.95$, $p < 0.001$). The macroinvertebrate WCI decreased with increasing development intensity. For the diatom WCI, more of the variability was explained by the LDI-PLU at the 30 x 30-meter cell resolution, although differences in the 5 x 5-meter to 30 x 30-meter cell size range were minimal. Beyond the 30 x 30-meter cell size, the proportion of the total variance explained by the LDI tended to decrease with increasing grain size. The relationship between the diatom WCI and the LDI at the most significant scale is shown in Figure 3-22 ($r^2 = 0.231$, $F_{1,48} = 14.44$, $p < 0.001$).

Stream condition

Water quality: spatial extent. Simple linear regression was used to asses the relationship between the LDI and five water chemistry variables and the WQI at different spatial extents, holding the grain size constant at 20 x 20 meters. When needed, the dependent variables were log-transformed to satisfy regression analysis requirements. Regression results are presented in Table 3-12. More of the variability in the concentration of DO was explained equally by the LDI-ILD and the LDI-ISD at the watershed scale. Regressions had a fair fit ($r^2 = 0.41$) and were highly significant (LDI-ILD: $F_{1,35} = 24.03$, $p < 0.001$; LDI-ISD: $F_{1,35} = 24.22$, $p < 0.001$, respectively). Figure 3-23 shows the relationships between the LDI-ISD and the DO at the watershed scale. The concentration of DO decreased with increasing development intensity.

The LDI-PLU explained more of the variability in the concentration of NO_3-N and TN at the watershed scale (NO_3-N: $r^2 = 0.14$, $F_{1,44} = 7.13$, $p = 0.011$; TN: $r^2 = 0.17$, $F_{1,45} = 9.21$, $p = 0.004$). For NO_3-N, the strength of the association with the LDI decreased with decreasing scale and was lowest with the LDI-ISD. The relationships between the LDI-PLU and the NO_3-N at the watershed scale are shown in Figure 3-24. An increase in NO_3-N with increasing development intensity is suggested, despite the weak association between the variables. For TN, regression results showed that for the LDI-PLU were only slightly higher than for the other two forms of the LDI at all three scales. Figure 3-25 presents the relationships between the LDI-PLU and TN at the watershed scale. An increase in TN with increasing development intensity can be observed despite the scatter in the data.

None of the regressions between the LDI and TP were statistically significant except for the LDI-ISD at the 100-meter scale, where a poor fit was reported ($r^2 = 0.08$, $F_{1,45} = 4.09$, $p = 0.049$). Significant results for the relationship between the WQI and the three forms of the LDI were observed at all scales. The strongest association was found when the WQI was regressed against the LDI-ISD at the watershed scale ($r^2 = 0.33$; $F_{1,35} = 17.38$, $p < 0.001$). The strength of the association between the two variables tended to slightly decrease with increasing scale. The relationship between the LDI-ISD and the WQI for streams is shown in Figure 3-26. The plot shows what appears to be a linear relationship between the two variables with the WQI increasing with increasing development intensity. However, a relatively high scatter at low development intensity values was apparent. None of the regressions between the LDI and the streams' water turbidity were significant. The analysis of residuals for each significant regression model showed that all models seemed adequate. Some level of heteroscedasticity was observed for the TP and the WQI models.

Water quality: grain size. The proportion of the variance in five water chemistry variables and the WQI explained by the LDI measured at different grain size was tested by calculating regression coefficients (r^2) for each scale independently and holding the spatial extent constant at the watershed scale (Figure 3-27). The significance of the regression results are shown in Table 3-13. More of the variability in the water DO was explained by the LDI-ISD at the 170 x 170-meter grain size with the LDI-ILD explaining almost the same amount of the variation in the concentration of DO. Figure 3-28 shows the relationship between DO and the LDI-ISD at the most statistically significant scale ($r^2 = 0.452$, $F_{1,35} = 28.86$, $p < 0.001$). The plot shows that the concentration of DO decreased with increasing development intensity.

More of the variance in the concentration of NO_3-N was explained by the LDI-PLU at the 170 x 170-meter grain size. The differences between the regressions for the LDI-PLU and the regressions for the LDI-ISD were relatively large, with the LDI-ISD explaining almost 50% less of the total variance explained by the LDI-PLU at all scales measured. Figure 3-29 shows the relationship between the concentration of NO_3-N and the LDI-PLU at the most statistically significant scale ($r^2 = 0.147$, $F_{1,44} = 7.61$, $p = 0.008$). The concentration of NO_3-N tended to increase with increasing development intensity. For TN, most of the variation in its concentration was also explained by the LDI-PLU at the 170 x 170-meter grain size. The three forms of the explained almost the same amount of variability in the concentration of TN at finer grain sizes. Some variation in the predictive power of the LDI was seen at the broader grain sizes where the LDI-ILD and the LDI-ISD explained less of the total variance in the concentration of TN than the LDI-PLU. Figure 3-30 shows the relationship between the concentration of TN and the LDI-PLU at the most statistically significant scale ($r^2 = 0.232$, $F_{1,45} = 13.163$, $p = 0.001$). The concentration of TN increased with increasing development intensity.

The LDI-ISD at the 170 x 170-meter grain size was the best predictor of the variability in the WQI scores. The LDI calculated at coarser grain sizes explained slightly more of the variance than when it was calculated at finer grain sizes. At all scales, the LDI-ISD explained approximately 10% and 5% more of the total variance in the WQI than the LDI-ILD and the LDI-PLU, respectively. Figure 3-31 shows the relationship between the WQI and the LDI-ISD at the most statistically significant scale ($r^2 = 0.364$, $F_{1,35} = 20.04$, $p < 0.001$). Higher scores for the WCI were reported at higher values of development intensity. The relationship between the LDI and TP and between the LDI and the streams' water turbidity were not statistically significant at any grain size.

Stream condition index: spatial extent. The degree of association between the LDI and the SCI at different spatial extents was estimated using simple linear regression and holding the grain size constant at 20 x 20 meters. The regression results are presented in Table 3-14. Among the three forms of the LDI, the LDI-ISD explained more of the variability for the SCI_1 scores at the 100-meter buffer scale ($r^2 = 0.27$, $F_{1,66} = 24.11$, $p < 0.001$;) as well as the variability for the SCI_2 scores at the same spatial extent ($r^2 = 0.26$, $F_{1,67} = 23.71$, $p < 0.001$). However, differences with the proportion of the variance in the SCI explained at other scales were small, particularly at the watershed scale. At all scales, the LDI-ISD explained more of the variability for the SCI than the other forms of the LDI.

Figure 3-32 shows the relationships between the LDI-ISD and the SCI_1 at the 100-meter scale. The plot between the LDI-ISD and the SCI_1 shows a decrease in the SCI scores with increasing development intensity, especially beyond an LDI score of 10. The plot of residuals versus the fitted values showed that the relationship between the SCI_1 and the LDI-ISD was not linear. Additionally, the residuals were not normally distributed. The relationships between the LDI-ISD and the SCI_2 at the 100-meter scale are shown in Figure 3-33. The plot of residuals versus the fitted values also suggested a non-linear relationship between the SCI_2 and the LDI-ISD. However, the residuals were normally distributed.

Stream condition index: grain size. The proportion of the variance in the SCI explained by the LDI measured at different grain sizes was tested by calculating regression coefficients (r^2) for each scale independently and holding the spatial extent constant at the watershed scale (see Figure 3-34 and Table 3-15). Changes in the grain size had minimal effect on the amount of the variability in the SCI_1 explained by the LDI. Among all forms of the LDI, the LDI-ISD calculated at the 20 x 20-meter grain size explained more of the variance in the SC_1 ($r^2 = 0.228$,

$F_{1,66} = 19.54$, $p < 0.001$). The relationship between these two variables is presented in Figure 3-35. Similarly, changes in the grain size had minimal effect on the amount of the variability in the SCI_2 explained by the LDI. Once more, the LDI-ISD calculated at the 20 x 20-meter grain size explained more of the variance in the SCI_2 ($r^2 = 0.252$, $F_{1,67} = 22.53$, $p < 0.001$). Figure 3-36 shows the relationship between the SCI_2 and the LDI-ISD.

Lake condition

Simple linear regression models indicated that the LDI was not significantly related at any of the lake condition variables tested when relationships were analyzed for different landscape extents (Tables 3-16). The LDI only explained close to 4% of the variance in the concentration of ammonia-N ($F_{1,52} = 1.99$, $p = 0.164$, for the LDI-ILD at the watershed scale). For the concentration of NO_3/NO_2-N, only 2% of the variance was accounted for by the LDI ($F_{1.52} = 1.14$, $p = 0.29$, for the LDI-ISD at the 100-meter scale). The concentrations of TKN and TN were also poorly correlated with the LDI. Only less than 2% of the variation in the concentrations of both variables were explained, with the highest regression reported for the LDI-ISD at the 400-meter scale in both cases ($F_{1.51} = 0.60$, $p = 0.441$; and $F_{1,51} = 0.81$, $p = 0.374$; respectively). Similarly, TP was poorly associated with the LDI ($r^2 = 0.053$, $F_{1.51} = 2.85$, $p = 0.097$, for the LDI-ILD at the watershed scale). The LCI was also poorly associated, with the LDI-PLU explaining only 1% of the variance in the index scores at the watershed scale ($F_{1,51} = 0.67$, $p = 0.417$).

Similarly, the LDI was not significantly related at any of the lake condition variables tested when different landscape grains were considered (Table 3-17). For the concentration of ammonia-N and among the different forms of the LDI, the LDI-ILD only explained slightly more than 4% of the variance ($F_{1,52} = 2.33$, $p = 0.133$, for the LDI-ILD for the 40 x 40-m scale). For the concentration of NO_3/NO_2-N, less than 1% of the variance was explained by the LDI

($F_{1.52}$ = 0.38, p = 0.538, for the LDI-ILD at the 20 x 20-meter scale). Approximately 2% of the variation in the concentration of TKN was accounted for by the LDI ($F_{1.51}$ = 0.76, p = 0.338, for the 40 x 40-m scale). A similar result was reported for the association between the concentration of TN and the LDI (r^2 = 0.022, $F_{1.51}$ = 1.17, p = 0.285). For TP, the LDI-PLU accounted for more of the variation in the concentration of TP, explaining 5% at the 80 x 80-meter scale ($F_{1.51}$ = 3.14, p = 0.082). Finally, only 2% of the variation in the LCI was explained by the LDI-PLU at the 40 x 40-meter scale ($F_{1,51}$ = 1.08, p = 0.305).

Landscape Pattern Metrics

Isolated Forested Wetlands

Metric selection: grain size

Pattern metrics were calculated for landscapes surrounding isolated forested wetlands by exporting ArcGrids into Fragstats with 5 x 5-, 10 x 10-, 20 x 20-, and 30 x 30-meter cell resolutions. None of the metrics showed unusual values that would suggest that any of these could not be considered for further analysis. Descriptive statistics on each metric calculated for the scales considered is provided in Appendix N, Table N-1, as well as information on the transformations used to obtain a normal distribution in the metrics scores. The land use composition metrics (PLAND_Urb, PLAND_Ag, PLAND_For, and PLAND_Wet) showed high variability; however, this behavior was considered normal given the fact that zero scores were common among the metrics due to the *a priori* selection of the sample isolated forested wetlands. All metrics showed some level of variability (SD > 0) making them useful to discriminate between landscapes. However, the metric IJI was reported as undefined for one site (NA7) where the landscape measured had less than three patch types. IJI is based on patch adjacencies and does not report a score for landscapes with less than three patches (McGarigal et al. 2002). In addition, transformation normality was not achieved in any case and a very significant statistic for the Anderson-Darling test was reported ($p < 0.005$). As a result, IJI was removed from further analysis.

Correlation analysis to test for redundancy among the remaining landscape pattern metrics and to reduce the number of metrics used in multivariate statistics tests are shown in Table 3-18. The metrics PD and AREA_MN were highly correlated at the 5 x 5-meter ($r = –1.00$, $p < 0.001$), 10 x 10-meter ($r = –1.00$, $p < 0.001$), 20 x 20-meter ($p = –0.97$, $p < 0.001$), and 30 x 30-meter ($p = –0.97$, $p < 0.001$) cell sizes. At the landscape level these metrics are both dependent on the number of patches and the total landscape area, making them highly redundant (McGarigal et al. 2002). The metrics SHAPE_MN and FRAC_MN were also highly correlated at all the four scales considered ($r = 0.92$, $p < 0.001$; $r = 0.94$, $p < 0.001$; $r = 0.95$, $p < 0.001$; $r = 0.94$, $p < 0.001$, with increasing grain size, respectively). Both SHAPE_MN and FRAC_MN are measurements of patch shape complexity and are based on perimeter-to-area ratio relationships (McGarigal et al. 2002). As a result, they may convey the same information about the complexity of patch forms in the landscape. Similarly, PR and PRD were highly correlated regardless of the grain size at which the metrics were calculated ($r = 0.91$, $p < 0.001$; $r = 0.93$, $p < 0.001$; $r = 0.93$, $p < 0.001$; $r = 0.93$, $p <0.005$, with increasing grain size, respectively). PR and PRD are highly redundant when calculated for landscapes that are similar in area and when the maximum number of patch classes is a constant (McGarigal and Marks 1995). Pearson’s correlations between the metrics CONTAG and SHEI were also very significant when calculated at the 5 x 5-meter ($r = –0.95$, < 0.001) and 10 x 10-meter ($r = –0.9003$, $p < 0.001$) cell sizes. The strength of the relationship decreased slightly with increases in grain size ($r = –0.84$, $p < 0.001$; and $r = –0.86$, $p < 0.001$ at the 20 x 20-meter and 30 x 30-meter grain sizes, respectively).

Following Riitters et al. (1995)'s measure of Pearson correlations of |r| > 0.9 for the reduction of metrics, AREA_MN, FRAC_MN, and PR were eliminated from further analysis for all of the scales considered. Based on the same criterion SHEI was eliminated from the 5 x 5-meter and the 10 x 10-meter grain size set of variables. AREA_MN was chosen for elimination over PD since first-order statistics provide information of limited value about the size of patches. More meaningful information about the variability of landscapes based on patch sizes can be obtained from the metric AREA_CV (a metric not among the candidates for elimination), whose scores can be better explained when considered along with the results for PD (McGarigal and Marks 1995). FRAC_MN was eliminated because it may present problems of interpretation (McGarigal and Marks 1995). PR measures the number of patch types present in the landscape while PRD measures richness on a per area basis, allowing for comparisons among landscapes (McGarigal and Marks 1995). As a result, the latter was preferred. SHEI was not considered for further analysis at the 5 x 5-meter and 10 x 10-meter grain sizes since two other measures of patch diversity were already included (PRD and SHDI). Additionally, CONTAG was the only metric left that would aid in describing the isolated forested wetlands' landscapes based on patch adjacencies; thus, it was preferred over SHEI.

Principal components analysis of the landscape pattern metrics showed varying results for each scale considered. Eigenvalues and the proportion of the variance explained by each component are presented in Table 3-19. For the 5 x 5-meter grain size the first five components explained close to 81% of the variation in the 12 landscape variables. The total percent of the variance explained by the same number of components for the rest of the grain sizes was similar to the 5 x 5-meter dataset, with the 10 x 10-meter and 20 x 20-meter scales being almost equal and the 30 x 30-meter scale slightly higher (82.4%). However, the number of significant components (eigenvalue > 1) was of six for the 10 x 10-, 20 x 20-, and 30 x 30-meter scales. These components explained 89.21%, 89.22%, and 90.93 % of the variance in the landscape variables, respectively.

The factor loadings for the first six eigenvectors for each grain size are presented in Tables 3-20 through 3-23. Components were labeled to represent the metric that loaded highest with each axis for each grain size. For example, component 1 for the 5 x 5-meter grain size was labeled URB since the metric PLAND_Urb loaded highest with this component. Component 2 was labeled HETER since the metric PD loaded highest with this component and describes aspects of patch type heterogeneity in the landscape. The metric SHAPE_MN loaded highest with component 3, so it was labeled SHAPE. Components 4 and 5 were labeled to describe that the percent of agricultural land (AG) and the percent of forest land (FOR) were most important in these axes, respectively. Finally, in component 6 the metric that quantifies the nearest neighbor distance among patches of the same type (ENN_MN) loaded highest and was labeled DIST. Other metrics not represented in PC matrix for the 5 x 5-meter grain size include those that describe the diversity of path types; when these metrics correlated highest with any of the components, they were labeled DIVERS (e.g., component 1 at the 20 x 20-meter grain size).

The proportion of urban land had the highest loading (negative) with the first component for both the 5 x 5-meter and 10 x 10-meter scales, while the proportion of isolated forested wetlands had a positive but slightly smaller loading for both datasets as well. In addition, at both scales there was a negative correlation between the metrics that describe the diversity of patches in the landscape (PRD and SHDI) and this component. This distribution can be attributed to changes along a gradient of land uses ranging from highly urbanized wetland landscapes to landscapes with no urban lands present. For the 20 x 20-meter and 30 x 30-meter scales, the proportion of urban lands and wetlands were not as important in the first component. Instead, the diversity metrics SHDI and SHEI presented the highest loading (negative) with this axis. The third diversity metric, PRD, also was negatively correlated with this component. Additionally, the metric AREA_CV which measures the variability of patch size relative to the mean patch size in the landscape presented a positive correlation with this component for the 20 x 20-meter grain size.

The second component was dominated by the patch density (PD) and edge density (ED) variables. These metrics were approximately equally important for all scales and had a positive correlation with this component, except for the 30 x 30-meter grain size. The metric SHAPE_MN had the highest negative correlation with the third component at the 5 x 5-meter grain size. However, this metric showed a low loading with this axis for the rest of the grain sizes as a consequence of the aggregation of pixels with increasing scale, which resulted in the simplification of patch forms. The metric CONTAG also showed a negative correlation with this component at the 5 x 5-meter grain size as well as for the 10 x 10-meter and 20 x 20-meter grain sizes where the loading was even higher. At the 30 x 30-meter grain size CONTAG also had a negative correlation with this axis although the strength of the relationship was lower than for the other scales. Additionally, with increasing scale the class metrics PLAND_Urb and PLAND_Wet increased their correlation with this axis. The former had a negative correlation with this component while the latter had a positive correlation with this component. In summary, this component can be described as a patch interspersion/dispersion gradient with landscapes with a few large, contiguous patches at one end of the axis and landscapes with more dispersed patches at the other end of the axis with a separation of urban sites form the agricultural and reference sites.

Metrics with the highest loading with the fourth component for the 5 x 5-meter grain size included PLAND_Ag and CONTAG, with both metrics presenting a negative correlation with this axis. For the 10 x 10-meter grain size, SHAPE_MN had the highest (positive) loading with this component. For the 20 x 20-meter and 30 x 30-meter grain sizes, PLAND_Ag again had the highest loading with this component; however, the trend of the relationship with this axis was negative. When PLAND_Ag was dominant, PLAND_For correlated inversely but moderately with this axis. The fifth component summarizes the spatial patterns in forest cover (PLAND_For) at the 5 x 5-meter and 10 x 10-meter grain sizes; at the 20 x 20-meter and 30 x 30-meter grain sizes ENN-MN and SHAPE_MN were dominant, with PLAND_For decreasing in importance with increasing scale. Finally, the sixth component was highly correlated to PLAND_For at the 20 x 20- and 30 x 30-meter grain sizes, while for the 10 x 10-meter grain size ENN-MN had a high positive correlation with this axis.

Regression analysis

Significant components that resulted from the PCA of landscape pattern metrics were used as independent variables in multiple regression analysis to test for relationships with the WCI for macrophytes, macroinvertebrates, and diatoms, and with water chemistry variables. These regression results are presented in Table 3-24. Significant relationships were found only for TP among the water chemistry variables considered. The strongest relationship was reported at the 30 x 30-meter grain size ($R^2 = 0.45$, $F_{6,25} = 5.18$, $p < 0.001$) with very similar results for the 10 x10-meter ($R^2 = 0.44$, $F_{6,25} = 4.99$, $p = 0.002$) and 20 x 20-meter ($R^2 = 0.43$, $F_{6,25} = 4.82$, $p = 0.002$) scales. For the 30 x 30-meter grain size, components 4 and 5 were the only independent variables significantly related to TP ($p = 0.005$ and $p = 0.001$, respectively). For the 20 x 20-meter grain size, the same components were the only predictors significantly associated to TP ($p = 0.002$ and $p = 0.003$, respectively). For the 10 x 10-meter scale the p-values for the estimated coefficients of components 5 and 6 ($p = 0.01$ and $p = 0.001$, respectively) indicated that these were the only independent variables significantly related to TP. At the 5 x 5-meter scale the relationship between significant components resulting from the PCA of landscape pattern metrics and TP was not significant. The analysis of residuals (normal plots of residuals, residuals versus variables plots, and plots of residuals versus the fitted values) for the regression model at the 30 x 30-meter scale suggested that the relationship between the LDI and TP was fairly linear and that the residuals were normally distributed. However, the residuals presented some level of heteroscedasticity. Variance Inflation Factors (VIF) were reported as being < 5 for all components, which indicated a good regression coefficient estimation.

Among the WCIs, significant relationships were found for the macrophytes, with the highest variance explained at the 10 x 10-meter grain size ($R^2 = 0.44$, $F_{6,44} = 7.49$, $p < 0.001$). Differences between the four grain sizes were small: 5 x 5-meter ($R^2 = 0.42$, $F_{5,45} = 7.45$, $p < 0.001$), 20 x 20-meter ($R^2 = 0.39$, $F_{6,44} = 6.41$, $p < 0.001$), and 30 x 30-meter ($R^2 = 0.42$, $F_{6,44} = 6.97$, $p < 0.001$). Components that were significantly related ($p < 0.05$) to the macrophyte WCI varied between scales. At the 5 x 5-meter scale components 1 and 4 were the only independent variables significantly related to the macrophyte WCI, with estimated coefficients with p-values of 0.023 and < 0.001, respectively. For the 10 x 10-meter scale components 4 and 5 were significantly associated with the macrophyte WCI, with $p < 0.001$ in both cases. Components 3 and 4 were also the only axes significantly related to the macrophyte WCI at the 20 x 20-meter scale, with p-values for the estimated coefficients of 0.015 and < 0.001, respectively. At the 30 x 30-meter level three components (2, 3, and 4) explained most of the variation in the macrophyte WCI ($p = 0.034$, $p = 0.009$, and $p < 0.001$, respectively). For the macroinvertebrate WCI, regressions were significant only at the 20 x 20-meter grain size ($R^2 = 0.26$, $F_{6,24} = 2.71$, p =

0.038). Component 1 was the only predictor significantly associated with the response variable ($p = 0.003$). No significant relationships were found between the components from the PCA of landscape pattern metrics and the diatom WCI. The analysis of residuals for the macrophyte WCI regression model at the most statistically significant scale suggested that the relationship between the PCA components and the macrophyte WCI was linear and that the residuals were normally distributed. Additionally, variances were fairly homogeneous. The residual plots also suggested a linear relationship between the variables and a normal distribution of the data for the macroinvertebrate WCI. The regression model for the macroinvertebrate WCI also showed fairly homogeneous variances. For all cases the VIFs were reported as being < 5.

Streams

Metric selection: grain size

Pattern metrics were calculated for drainage basins by exporting ArcGrids into Fragstats with 20 x 20-, 50 x 50-, 80 x 80-, and 110 x 110 -meter cell resolutions. Descriptive statistics on each metric calculated for each scale considered, as well as information on the transformations used to obtain a normal distribution in the metrics scores are provided in Appendix N, Table N-2. The metric FRAC_MN was removed from further analysis since it was not able to differentiate between different landscapes. At all scales the standard deviation for this metric was 0.01.

Redundancy was tested for among the remaining landscape pattern metrics using Pearson's correlation analysis. Table 3-25 shows the correlation results of all pairs of metrics considered. The metrics PD and AREA_MN were highly correlated at all the scales considered ($r = -0.96$, $p < 0.001$, for all four grain sizes). The metrics CONTAG and SHEI were also highly correlated at all the four scales considered ($r = -0.98$, $p < 0.001$; $r = -0.93$, $p < 0.001$; $r = -0.91$, $p < 0.001$; $r = -0.92$, $p < 0.001$, with increasing grain size, respectively). Following Riitters et al. (1996)'s measure of Pearson correlations of $|r| > 0.9$ for the reduction of metrics, AREA_MN and

CONTAG were eliminated from further analysis for all the scales considered. AREA_MN was chosen over PD for elimination since first-order statistics provide information of limited value about the size of patches. More meaningful information about the variability of landscapes based on patch sizes can be obtained from the metric AREA_CV (a metric not among the candidates for elimination), whose scores can be better explained when considered together with the results for PD (McGarigal and Marks 1995). The exclusion of CONTAG was quite arbitrary. Since SHEI measures the evenness component of landscape diversity, an aspect that is not captured by the PR or SHDI (the other two metrics that quantify diversity of the landscape level), it was preferred over CONTAG.

Principal components analysis of the landscape pattern metrics calculated for different scales showed similar results. Eigenvalues and the proportion of the variance explained by each component are presented in Table 3-26. The total percent of the variance explained by the six components was very similar among all grain sizes and explained between 90% and 92% of the variation in the 14 landscape variables.

The results for the first four components with an eigenvalue of greater than one and worthy of interpretation were also very similar. These four components together explained approximately 80% of the variation in the landscape variables. The factor loadings for these four eigenvectors for each grain size are presented in Tables 3-27 through 3-30.

Components were labeled to represent the metric that loaded highest with each axis for each grain size. For example, for the 20 x 20-meter grain size component 1 was labeled DIVERS1 since the metric SHEI (Shannon Evenness Index) loaded highest with this component. Component 2 was labeled DIVERS2 since the metric PR (patch richness) loaded highest with this component. The metric PLAND_Wet loaded highest with component 3, so it was labeled

WET. In component 4 the metric that quantifies the nearest neighbor distance among patches of the same type (ENN_MN) loaded highest and was labeled DIST. The same reasoning was used to label the components at other grain sizes.

At all scales, the first component tended to be dominated by the metrics that describe the diversity of patches in the landscape, particularly by SHEI which emphasizes the evenness component of diversity. The metric that quantifies patch interspersion and juxtaposition (IJI) correlated fairly with axis 1, especially at the 20 x 20- and 50 x 50 meter grain sizes. At the 80 x 80- and 110 x 110-meter scales AREA_CV and ED were more important that IJI.

The second component was also influenced by metrics that measure aspects relatively to the diversity of patches in the landscape. In this component the richness of patches was emphasized rather that their even distribution in space. The metrics PR and SHEI correlated highest with this component, particularly at the 80 x 80- and 110 x 110-meter scales. The metric ENN_MN, which measures the distance of a patch type to its nearest neighboring patch of the same type, was also fairly correlated with this axis at all grain sizes with its influence tending to decrease with increasing scale. The proportion of land use under forests (PLAND_For) was also an important variable in this axis particularly at the 80 x 80- and 110 x 110-meter scales.

Component 3 was clearly summarized by a gradient of urban to wetland types. The metrics PLAND_Urb and PLAND_Wet correlated negatively with each other at all grain sizes and fairly with this component. Also, the importance of spatial patterns in agricultural and forested land covers tended to increase with the increasing scale. However, a shift in the direction of the association between the metrics and axis 3 was noticed between the finer scales (20 x 20 and 50 x 50 meters) and the broader scales (80 x 80 and 110 x 110 meters). The metric with the highest loading with the forth component for the 20 x 20-meter grain size was ENN_MN which correlated negatively with this axis at this scale. This metric became less important with increasing scale while the metric SHAPE_MN tended to load higher with increasing scale. This axis was also influenced by the metrics AREA_CV and PLAND_Ag.

Metric selection: spatial extent

In addition to the watershed scale, landscape pattern metrics were calculated for stream buffers of 100 and 400 meters, keeping the grain size constant at 20 x 20 meters. Descriptive statistics on each metric calculated for 63 sample streams for the three scales considered, as well as information on the transformations used to obtain a normal distribution in the metrics scores is provided in Appendix N, Table N-3. The metric FRAC_MN had a standard deviation of 0.01 at all scales. As a result, this metric was removed from further analysis since FRAC_MN was not able to differentiate between different landscapes.

Pearson's correlations were used to test for the redundancy among the remaining metrics. The results of all pairs of metrics are shown in Table 3-31. The metrics PD and AREA_MN were highly correlated at all scales considered ($r = -0.98$, $p < 0.001$; $r = -0.99$, $p < 0.001$; $r = -0.96$, $p < 0.001$, with increasing extent, respectively). The metrics CONTAG and SHEI were also highly correlated at all the three scales ($r = -0.93$, $p < 0.001$; $r = -0.96$, $p < 0.001$; $r = -0.98$, $p < 0.001$, with increasing extent, respectively). Following Riitters et al. (1996)'s measure of Pearson correlations of $|r| > 0.9$ for the reduction of metrics, AREA_MN and CONTAG were eliminated from further analysis for all the scales considered.

The results of the principal components analysis of the landscape pattern metrics showed varying results with changes in spatial extent. Table 3-32 shows the eigenvalues and the proportion of the variance explained by each component for each scale considered. The total percent of the variance explained by the six components was similar among all spatial extents and explained approximately 88% to 91% of the variation in the remaining landscape variables.

The results for the first four components (eigenvalue > 1) were also fairly similar, explaining 79% of the variance in the landscape metrics at the 400-meter and watershed scales, and 75% at the 100-meter scale. The factor loadings for the first four eigenvectors for each extent are presented in Tables 3-33 through 3-35. Components were labeled to represent the metric that loaded highest with each axis for each spatial extent.

The first component was influenced by the metrics that describe the diversity of patches in the landscape, particularly by SHDI which loaded fairly and negatively at all scales and with SHEI increasing its influence with increasing scale. The metric that quantifies patch interspersion and juxtaposition (IJI) also loaded fairly and negatively with this component at all scales. The metric PLAND_For also had some influence and correlated positively with this axis, tending to decrease with increasing scale.

The second component was dominated by the metrics PRD and AREA_CV at the 100-meter scale. Both metrics loaded equally on this component and were inversely correlated with each other. The PD metric also had some influence on this component at this scale. The metrics PRD, AREA_CV, and PD also were important at the 400-meter scale; however, ED appeared as the metric that loaded highest and had a positive association with axis 2 at this scale. ED also loaded highest and positively with axis 2 at the watershed scale; a change in the magnitude of the loadings was observed. Also at the watershed scale, diversity metrics related to the richness of patches (PR and PRD) also loaded fairly (negatively) with this component. The metrics PLAND_For and PLAND_Ag also had some influence on this axis and correlated inversely with each other.

Component 3 was influenced by the proportion of wetlands (PLAND_Wet), particularly at the 100- and 400-meter scale, although there was a change in the magnitude of the loadings with changes in scale. At the finer scale there was also some influence of the ED and PD variables, which had a negative correlation with this component. The influence of these metrics on this axis decreased with increasing scale. The patch area coefficient of variation (AREA_CV) also correlated fairly especially at the 400-m and watershed scales. At the watershed scale the metric ENN_MN correlated highest with this axis. This component can be summarized as a gradient of wetland spatial patterns ranging from landscapes with high presence of wetlands to landscapes where land types other than wetlands were more common, with the presence of isolated patches of the same type at the watershed scale.

The fourth component showed differences among the metrics that loaded highest with changes in scale. At the 100-meter extent the metrics ED, SHAPE_MN, and IJI correlated highest with axis 4; although IJI had a positive association with the axis while the other two metrics presented a negative association with the axis. For the 400-meter and watershed scales the proportion of agricultural lands (PLAND_Ag) and the proportion of wetlands (PLAND_Wet) had the strongest influence on the axis, with the metrics correlating inversely with each other. A gradient of landscape ranging from agricultural- to wetlands-dominated landscapes seemed apparent at broader scales.

Regression analysis: grain size

Multiple regression analysis was used to explore the relationships between significant components that resulted from the PCA of landscape pattern metrics and water chemistry variables for streams and the SCI. These results are presented in Table 3-36. A significant relationship was found at all scales when the landscape pattern variables were related to DO, with the strongest association at the 110 x110-meter grain size (R^2 = 0.22, $F_{4,31}$ = 3.42, p = 0.020). Component 2 explained more of the variability in the dependent variable (estimated coefficient with p-value of 0.032). For NO_3-N, significant but weak relationships were found only for the 50 x 50- and 110 x 110-meter grain sizes. At these scales the amount of the variability that the landscape pattern variables were able to account for was the same ($R^2 = 0.13$, $F_{4,40} = 2.62$, $p = 0.049$). There was a good association at all scales between the landscape pattern variables and TN. The strongest relationship was found at the 20 x 20-meter grain size ($R^2 = 0.60$, $F_{4,41} = 18.14$, $p < 0.001$), with components 1, 2, and 4 significantly related to TN (estimated coefficients with p-values of < 0.001, 0.002, and 0.007, respectively). A decrease in the strength of the association between variables was observed with increasing scale. A significant relationship between the landscape pattern variables and TP was also found for every grain size considered, with the strongest association at the 20 x 20-meter scale ($R^2 = 0.42$, $F_{4,41} = 8.96$, $p < 0.001$). The p-value for the estimated coefficient of component 4 was 0.001, indicating that it was the only component significantly related to TP. The strength of the association between variables decreased with increasing grain size. There were no significant relationships between the independent variables and the water turbidity and the WQI. Residual analysis (normal probability plots, residuals versus variables pots, and plots of residuals versus the fitted values) suggested that all of the relationships between the independent and dependent variables were fairly linear and that variables satisfied the requirements of normality. Some level of heteroscedasticity was observed in the regression models for DO, TN, and TP.

There were no significant relationships found between the landscape pattern variables and the SCI_1 at any of the grain sizes, or between the landscape pattern variables and the SCI_2.

Regression analysis: spatial extent

The relationships between significant components that resulted from the PCA of landscape pattern metrics and the water chemistry variables for streams and the SCI are summarized in Table 3-37. A significant relationship was reported between water turbidity and the landscape pattern variables for the 100-meter scale only ($R^2 = 0.24$, $F_{4,29} = 3.66$, $p = 0.016$). However, the analysis of residual plots showed that the level of association between variables was highly influenced by one observation (outlier), which may help to explain the differences reported in the regression results between scales. Estimated coefficients for components 1 and 2 were significantly associated to the dependent variable ($p = 0.004$ and $p = 0.02$, respectively). For DO, a significant relationship with the landscape pattern variables was found at all scales, with the strongest association found at the 100-meter scale ($R^2 = 0.34$, $F_{4,30} = 5.40$, $p = 0.002$). Components 1 and 3 were significantly related to DO (estimated coefficients with p-value of 0.006 for both cases). The amount of the variance in the concentration for DO explained by the independent variables showed a tendency to decrease with increasing scale. For NO_3-N, a significant relationship with the landscape pattern variables was found for the watershed scale only ($R^2 = 0.24$, $F_{4,37} = 4.20$, $p = 0.007$). Component 1 was significantly related to NO_3-N (estimated coefficient with p-values of 0.016). The strongest relationship with the landscape pattern variables for TN was also found at the watershed scale ($R^2 = 0.59$, $F_{4,38} = 16.35$, $p < 0.001$), with components 1, 2, and 3 significantly related (estimated coefficients with p-values of < 0.001, <0.001, and 0.033, respectively). The strength of the association between variables tended to decrease with decreasing scale. Regressions at all scales were statistically significant. TP was also significantly related to the landscape pattern variables at all scales. The strongest relationship was also reported for the watershed scale ($R^2 = 0.44$, $F_{4,41} = 9.32$, $p < 0.001$). Components 2, 3, and 4 were significantly related to TP (estimated coefficients with p-values of 0.008, 0.002, and 0.043, respectively) at this scale. The results showed that the amount of variability in the concentration of TP explained by the independent variables tended to decrease with decreasing scale. A significant relationship between the independent variables and the WQI was found at the 400-meter and watershed scales. Among these, the strongest association was found at the 400-meter scale ($R^2 = 0.29$, $F_{4,30} = 4.46$, $p = 0.006$). Component 4 was the only axis significantly related to the WQI with an estimated coefficient with a p-value of 0.004. The analysis of residuals for the most significant findings suggested a linear relationship between the response and predictor variables. All regression models satisfied the requirements of normality. Some level of heteroscedasticity was observed for the DO, NO_3-N, TP, TN, and WQI models. Unequal variances among residuals were more evident for the TN and the WQI models.

A significant relationship between the landscape pattern variables and the SCI_1 was found only for the 100-meter scale ($R^2 = 0.17$, $F_{4,57} = 4.18$, $p = 0.005$). The analysis of residual plots seemed to suggest that the regression model was not adequate to explain the relationship between variables; the normal plot of residuals showed that the residuals were not normal distributed and the residuals against the fits plot showed that the residuals did not have a constant variance. For the SCI_2, a significant relationship with the landscape variables was found at the 100-meter and 400-meter scales. The most significant model was the one for the 100-meter scale ($R^2 = 0.22$, $F_{4,63} = 5.41$, $p = 0.001$). According to the analysis of residual plots, this regression model seemed more adequate to explain the relationship between variables. Plots showed a normal distribution of the residuals and a fairly constant variance. A linear relationship between the variables was suggested in the plot of the standardized residuals and the standardized predicted values. For the SCI_1, component 4 was the only axis significantly related to this variable with an estimated coefficient with a p-value of 0.001; components 1 and 3 were significantly associated with the SCI_2 (estimated coefficients with p-values of 0.002 and 0.003, respectively).

Lakes

Metric selection: grain size

Pattern metrics were calculated for lake drainage basins (n = 48) exporting ArcGrids into Fragstats with 20 x 20-, 40 x 40-, 60 x 60-, and 80 x 80-meter cell grain sizes. Descriptive statistics and information on the transformations in scores for each metric calculated for each scale considered are provided in Appendix N, Table N-4. None of the metrics showed unusual values that would suggest that any of these could not be considered for further analysis. However, the metric FRAC_MN was not able to differentiate between different landscapes, and showed a standard deviation of 0.01 for all grain sizes. As a result, this metric was not considered for further analysis.

Correlation analysis was used to test for redundancy among the remaining landscape pattern metrics. Table 3-38 shows the correlation results of all pairs of metrics considered. The metrics PD and AREA_MN were highly correlated at all scales considered ($r = -1.00$, $p < 0.001$; $r = -0.96$, $p < 0.001$; $r = -0.96$, $p < 0.001$; $r = -1.00$, $p < 0.001$, with increasing scale, respectively). The metrics CONTAG and SHEI were also highly correlated at all of the scales considered ($r = -0.98$, $p < 0.001$; $r = -0.96$, $p < 0.001$; $r = -0.951$, $p < 0.001$; $r = -0.93$, $p < 0.001$, with increasing grain size, respectively). Thus, the metrics AREA_MN and CONTAG were eliminated from further analysis.

The results of the principal components analysis, including the eigenvalues and the proportion of the variance explained by the first six components for each grain size considered, are presented in Table 3-39. The first five components (eigenvalue > 1) explained between 81.4% (40 x 40-meter scale) and 83.7% (20 x 20-meter scale) of the variance in the landscape pattern metrics. The factor loadings for the fist five components are shown in Tables 3-40 through 3-43. Components were labeled to represent the metric that loaded highest with each axis for each grain size. For example, for the 20 x 20-meter grain size component 1 was labeled DIVERS1 since the metric SHEI (Shannon Evenness Index) loaded highest with this component. Component 2 was labeled DIVERS2 since the metric PRD (path richness density) loaded highest with this component. The metrics PLAND_Urb and AREA_CV correlated highest and equally with component 3, so it was labeled URB/SIZE. In components 4 and 5 the metrics PLAND_Wet and PLAND_Ag loaded highest in each component and were labeled WET and AG, respectively. A similar reasoning was used to label the components at other grain sizes.

The first component was influenced by the metrics that describe the diversity of patches in the landscape, particularly by the metrics SHDI and SHEI, which presented a negative load at all scales. The metric ED also loaded fairly and negatively with this component at all scales. At the 20 x 20- and 60 x 60-meter scales the metric PD also had a fair correlation with component 1. The metric IJI also had some influence on axis 1 although it loaded poorly at the 80 x80-meter scale. This component can be summarized as a patch diversity gradient ranging from landscapes with diverse land uses evenly distributed in space to landscapes dominated by a few land uses.

For the second component PRD correlated highest with this axis at the finer to medium scales, with less influence at 80 x 80-meter grain size. The metric PLAND_Wet was also fairly correlated with this axis, particularly at the 20 x 20- and 60 x 60-meter scales. The metric PD also loaded fairly with this component, with its importance tending to increase with increasing scale. In summary, this component is characterized as a diversity/heterogeneity gradient ranging from landscapes dominated by a small number of patch types, among which wetlands were dominant, to more diverse, patchy landscapes.

The metrics that correlated highest with the third component included PLAND_Urb and PLAND_For, which were negatively correlated with each other. However, the direction of the relationship of these metrics with component 3 shifted with changes in scale. The metric ENN_MN also had a fair load with this axis at the 40 x 40-, 60 x 60-, and 80 x 80-meter scales, increasing its influence with increasing scale. At the 20 x 20-meters grain size the metrics AREA_CV and PR correlated fairly and negatively with axis 3. This component can be summarized as a development gradient ranging from landscapes with a few large forested patches to landscapes with a high diversity of patches and with urban lands well represented.

The fourth component summarizes spatial patterns in agricultural land cover. The metric PLAND_Ag correlated highly with this component, particularly at broader grain sizes. At the finest scale considered, the metric PLAND_Wet had a fair loading with this axis and correlated negatively with PLAND_Ag. For the fifth component, the metrics PLAND_Ag and PLAND_For had a fair correlation with this axis, especially at the finer scales considered. At the broader scales AREA_CV correlated highest with this component.

Metric selection: spatial extent

In addition to the watershed scale, landscape pattern metrics were calculated for landscape buffers of 100 and 400 meters surrounding lakes ($n = 44$) and keeping the grain size constant at 20 x 20 meters. Descriptive statistics and information on the transformations used to obtain a normal distribution in scores for each metric calculated for each scale considered are provided in Appendix N, Table N-5. Among the 17 metrics, only FRAC_MN was excluded from further analysis since it was not able to differentiate between the different landscapes showing ($SD = 0.02$ for the 100-m buffer and 400-m buffer scales and $SD = 0.01$ for the watershed scale).

The analysis for establishing redundancy among metrics showed very similar results to those presented for the selection of metrics based on changes in grain size. Pearson's correlation results of all pairs of metrics are presented in Table 3-44. The metrics PD and AREA_MN showed a very high correlation ($r = -0.92$, $p < 0.001$; $r = -0.99$, $p < 0.001$; $r = -0.97$, $p < 0.001$, with increasing scale, respectively). The metrics CONTAG and SHEI were also highly correlated at all of the spatial extents considered ($r = -0.95$, $p < 0.001$; $r = -0.98$, $p < 0.001$; $r = -0.98$, $p < 0.001$; with increasing scale, respectively). As a result, the metrics AREA_MN and CONTAG were eliminated from further analysis.

Results of the principal components analysis, including the eigenvalues and the proportion of the variance explained by the first six components for each spatial extent considered, are presented in Table 3-45. The first five components (eigenvalue > 1) explained between 80.0% (100-meter scale) and 81.5% (watershed scale) of the variance in the landscape pattern metrics. The factor loadings for the first five components are shown in Tables 3-46 through 3-48. Components were labeled to represent the metric that loaded highest with each axis for each spatial extent using a similar reasoning to the one used to label the components in the landscape grain analysis.

The first component correlated highest with the metrics SHDI and SHEI, which loaded negatively at all of the scales with this axis. The metric PRD had a fair negative loading with this component. Its influence decreased with increasing scale and PR became more important. The metrics PD and ED also correlated to some extent with component 1, with their influence tending to decrease with increasing scale. The metric IJI also loaded fairly and negatively with this component, especially at coarser scales. This component was a diversity gradient ranging from landscapes with numerous patches relatively evenly distributed in space and with a variety of land use types represented, to landscapes dominated by a small number of patches usually belonging to one or few land use types.

The second component also correlated highest with metrics that provide information on patch diversity. The metric PR loaded positively with component 2 with its influence tending to decrease with increasing scale. PRD loaded negatively with component 2 and its influence tended to increase with increasing scale. AREA_CV was positively correlated with component 2 at all scales. Similarly, ENN_MN had a positive correlation with component 2, especially at the broader scales. This component summarizes a diversity gradient contrasting patch diversity quantified based on the total number of patches and quantified relative to the total landscape area. Landscapes ranged from sites with numerous patches of various sizes and with a variety of land use types represented to landscapes dominated by a small number of rather homogenous patches sizes belonging to a few land use types.

Component 3 summarized a development gradient where metrics that described the proportion of land use types in the landscape correlated highest with this component. The metric PLAND_Urb correlated fairly with component 3 at all scales although it showed a shift in the direction of the correlation (positive) at the 400-meter buffer scale. The metric PLAND_Wet also loaded fairly with component 3 at all scales and was inversely correlated with PLAND_Urb. The metric PLAND _For loaded fairly and negatively with component 3 at the watershed scale. The metrics ENN_MN and IJI also had a fairly positive level of association to this axis at the finest scale. Their influence on component 3 decreased with increasing scale.

The metric SHAPE_NM correlated highest and negatively with component 4 at the 100-meter buffer scale. The influence of this metric on axis 4 tended to decrease with increasing scale. The metric PD also loaded fairly with this component with the highest correlation (positive) reported at the 400-meter scale. At the watershed scale AREA_CV loaded fairly with component 4. The fifth component also seemed to summarize a development gradient in which PLAND_For had a high negative correlation with component 5 at the 100-meter scale. At the 400-meter and watershed scales PLAND_Ag had a fairly high correlation with this axis, although a shift in the direction of the relationship was observed. At the 400-meter scale, PLAND_For loaded fairly and positively with component 5 but loaded poorly with this axis at the watershed scale. At this same scale PLAND_Urb had some effect on axis 5 and correlated inversely with PLAND_Ag.

Regression analysis: grain size

The relationships between significant components that resulted from the PCA of landscape pattern metrics and water chemistry variables for lakes and the LCI were explored using multiple regression analysis. For each grain considered the spatial extent was held constant at the watershed scale. Regression results are presented in Table 3-49. A significant relationship was found at all scales when the landscape pattern variables were related to TN, with the strongest association established at the 20 x 20-meters grain size ($R^2 = 0.29$, $F_{5,41} = 4.80$, $p = 0.002$). Components 1 and 5 were significantly related to TN (estimated coefficients with p-values of 0.014 and < 0.001, respectively). A significant but weak relationship between the landscape pattern metrics and TP was also found but only for the 20 x 20-meter grain size ($R^2 = 0.17$, $F_{5,41} = 2.93$, $p = 0.024$). The p-values for the estimated coefficients of components 2 and 4 were 0.016 and 0.012, indicating that they were significantly related to TP. For the LCI, significant relationships with the landscape variables were found at all grain sizes with the strongest association reported at the 40 x 40-meter scale ($R^2 = 0.39$, $F_{5,41} = 6.86$, $p < 0.001$). Components 1 (estimated coefficient with $p < 0.001$) and 5 (estimated coefficient with $p = 0.013$) were significantly associated to the LCI. Residual analysis showed that residuals for all models were normally distributed and that the most significant relationships between the above variables were fairly linear. However, for the TP model the variance among residuals did not appear constant.

Regression analysis: spatial extent

Table 3-50 summarizes the regression results of multiple regression analysis used to test for relationships between significant components that resulted from the PCA of landscape pattern metrics measured at three different spatial extents and the water chemistry variables for lakes and the LCI. For this analysis the grain size was held constant at the 20 x 20-meter grain size. When the landscape pattern metrics were related to TKN, a significant relationship was reported for the 400-meter buffer scale ($R^2 = 0.25$, $F_{5,37} = 3.83$, $p = 0.007$). Among all components only component 5 was significantly related to TKN (estimated coefficient with p value of 0.037). The analysis of residuals showed that the residuals did not follow a normal distribution. In addition, the variance among residuals was not constant and a non-linear pattern was observed from the plot of residuals versus fits. There was a significant relationship between the landscape pattern metrics and TN at the 400-meter buffer and watershed scales. The strongest association was reported for the 400-meter buffer scale ($R^2 = 0.39$, $F_{5,37} = 6.38$, $p < 0.001$) with components 1, 3, and 5 explaining most of the variation in the concentration of TN (estimated coefficients with p values of 0.004, 0.012, and 0.001, respectively). The analysis of residuals revealed that the residuals did follow a normal distribution. However, the variance among residuals was not constant.

When TP was regressed against the landscape variables, a significant relationship was found only for the 400-meter buffer scale ($R^2 = 0.21$, $F_{5,37} = 3.25$, $p = 0.015$). Component 3 explained most of the variation in the concentration of TP (estimated coefficients with p value of 0.001). The analysis of residuals confirmed that the residuals followed a normal distribution. The plot of residuals versus fits showed that the random variation of the residuals increased as the fitted values increased, an indicative of non-constant variance. The strongest association between the LCI and the landscape variables was found for the 400-meter buffer scale. The model had a fair fit ($R^2 = 0.42$) and was statistically significant ($F_{5,41} = 7.01$, $p < 0.001$). The estimated coefficients for component 1 ($p = 0.001$) and component 2 ($p < 0.001$) showed that these components explained more of the variability in the LCI scores. According to the residuals analysis the residuals had a normal distribution and the variance among residuals did not appear constant. Regression models for the LCI at the 100-meter buffer and watershed scales were also statistically significant.

Land Use Intensity, Landscape Pattern, and Ecosystem Condition

Multiple factor models that included both the LDI and pattern metrics as independent factors were use to analyze the predictive power the landscape variables had when used together to explain the variability in water quality variables and biological indicators. Changes in the proportion of the total variability of the response variables explained by the landscape variables were interpreted as the added predictive power to the LDI that resulted after using the LDI together with significant components that resulted from the PCA of landscape pattern metrics. Results are presented for all three freshwater systems studied.

Isolated Forested Wetlands

For isolated forested wetlands, relationships were assessed using only the data for the 200-meter buffer, and at four grain sizes which corresponded to the spatial scales at which the pattern metrics were calculated. Regression results for significant associations for a sample of isolated forested wetlands are shown in Table 3-51. Among the water chemistry variables considered, an increase in the amount of the variability explained was reported only for TP, with more of the variance of the concentration of TP explained at the 30 x 30-m grain size when the LDI-PLU was used with the landscape pattern metrics ($R^2 = 0.43$, $F_{7,24} = 4.31$, $p = 0.03$; $\Delta R^2 = 0.39$).

Among the biological indicators of wetland condition, when the LDI-ISD and the landscape metric pattern variables were used together, up to an additional 25% of the total variance in the macrophytes WCI scores was explained at the 10 x 10-meter grain size (R^2 = 0.44, $F_{7,43}$ = 6.53, p < 0.001). For the macroinvertebrate WCI, up to an additional 17% of the total variance in the macroinvertebrate WCI scores was explained at the 30 x 30-meter grain size when the LDI-ISD and the landscape metric pattern variables were used together as independent variables (R^2 = 0.34, $F_{7,23}$ = 3.18, p = 0.017). There were no significant relationships between the diatom WCI and the landscape indices. Adding the landscape pattern metrics to the LDI resulted in a decrease in the amount of the variance explained by these variables (see Table O-1 in Appendix O).

Streams

Significant results for multiple regressions are shown in Tables 3-52 and 3-53 for landscape variables measured with changes in grain size and with changes in spatial extent, respectively (all other regression results are presented in Appendix O). For TN, and additional 46% of the total variance in the concentration of TN was explained when the pattern metrics were used together with the LDI-PLU at the 5 x 5-m grain size (R^2 = 0.63, $F_{5,40}$ = 16.61, p < 0.001). For TP, and additional 37% of the total variance in the concentration of TP was explained when the pattern metrics were used together with the LDI-ISD also at the 5 x 5-m grain size (R^2 = 0.40, $F_{5,40}$ = 7.05, p < 0.001). In both cases, the differences among the amount of the variance accounted for by the landscape variables was minimal when the different forms of the LDI were used. When the landscape pattern metrics were used together with the LDI to explain the variability in the WQI, an additional 11% to 13 % of the total variance was explained with changes in grain size. The most significant relationship was reported at the 110 x 110-m scale when the LDI-ISD was used in combination with the landscape variables (R^2 = 0.46, $F_{5,30}$ = 6.99, p < 0.001; ΔR^2 = 0.12).

For changes in spatial extent, regression results showed that when the LDI and the landscape pattern variables were used together in multiple regression analysis these variables allowed a significant prediction of the variation in the streams' water SC but only at the 100-meter buffer scale. More of the SC was explained by the factor model that included the LDI-ISD ($R^2 = 0.29$, $F_{5,28} = 3.67$, $p = 0.011$; $\Delta R^2 = 0.28$). For DO, more of the variance was explained by landscape variables at the watershed scale level when the LDI-PLU was used ($R^2 = 0.44$, $F_{5,29} = 6.25$, $p = 0.004$; $\Delta R^2 = 0.04$). Models with the LDI and the landscape pattern metrics were better predictors of TN concentrations at all scales. More of the remaining variance was explained at the watershed scale when the LDI-PLU was used ($R^2 = 0.62$, $F_{5,37} = 14.54$, $p < 0.001$; $\Delta R^2 = 0.45$) with minimal differences among models with different LDI forms. The variability in the concentration of TP was equally explained by the landscape variables at the 400-meter buffer scale and at the watershed scale ($R^2 = 0.42$) with minimal differences among models with different forms of the LDI. The LDI and the landscape pattern variables explained an additional 35% to 41% of the total variance in TP depending on the form of the LDI considered. The landscape pattern metrics were also important additional factors in explaining together with the LDI the remaining variance for the WQI. The largest change was reported for the 400-meter buffer scale for the LDI-PLU ($\Delta R^2 = 0.24$). Nevertheless, the strongest association between variables was established for the LDI-ISD at the same spatial extent ($R^2 = 0.49$, $F_{5,29} = 7.65$, $p < 0.001$; $\Delta R^2 = 0.20$).

When the LDI and the landscape pattern metrics were included as independent variables in multiple regression models, at all grain sizes there was a decrease in the amount of the variability in the SCI explained by these variables compared to the amount of the variance explained by the LDI alone. The most significant relationship between the SCI_1 and the landscape variables was found for the 80 x 80-meter grain size for the regression model that included the LDI-ISD (R^2 = 0.10, $F_{5,60}$ = 2.45, p = 0.044; ΔR^2 = -0.12). For the SCI_2, the most significant relationship was found at the 20 x 20-meter grain size for the model that included the LDI-ISD (R^2 = 0.15, $F_{5,61}$ = 3.37, p = 0.009; ΔR^2 = -0.10).

For changes in spatial extent, there was also a decrease in the amount of the variability in the SCI explained by these variables compared to the amount of the variance explained by the LDI alone. More of the variance in the SCI_1 scores was accounted for by the landscape variables at the 100-meter buffer scale where when the LDI-ISD was used (R^2 = 0.19, $F_{5,56}$ = 3.81, p = 0.005; ΔR^2 = -0.03). For the SCI_2, the strongest association between variables was reported at the 100-meter buffer scale for the model that included the LDI-ISD (R^2 = 0.31, $F_{5,57}$ = 5.05, p = 0.001, ΔR^2 = -0.01). For both the SCI_1 and the SCI_2, differences in the amount of the variance of the SCI explained by the independent variables were very small when the different forms of the LDI were used.

Lakes

The significant results for multiple regressions that included the LDI and the landscape pattern metric variables to explore how much of the variation in water quality variables and indicators of ecosystem condition was explained by these variables at different grain sizes and different spatial extents are shown in Tables 3-54 and 3-55, respectively (non-significant regression results are presented in Appendix O). A significant increase in the amount of the variability explained in the concentration of TN was observed at all scales considered. The largest change occurred at the 20 x 20-meter scale (ΔR^2 = 0.34) for the model that included the LDI-PLU (R^2 = 0.34, $F_{6,40}$ = 4.97, p = 0.001). For TP, the relationship with the landscape variables was only significant at the 20 x 20 meter scale with more of the variance explained by the model that included the LDI-PLU (R^2 = 0.17. $F_{6,40}$ = 2.61, p < 0.031; ΔR^2 = 0.15). For the

LCI, the largest change in the unexplained variance of LCI scores occurred at the 40 x 40-meter scale with a ΔR^2 of 0.48 when the LDI-PLU was used as an independent variable. The landscape indicators explained 50% of the total variance in the LCI scores ($F_{6,40} = 8.76$, $p < 0.001$).

For changes in spatial extent, regression results showed that multiple factor models that included the LDI jointly with the landscape pattern metrics allowed explaining 24% of the variance in TKN at the 400-meter buffer scale when the LDI-PLU was used as one of the independent variables ($F_{6,36} = 3.20$, $p = 0.013$; $\Delta R^2 = 0.24$). Very similar results were reported when the other forms of the LDI were used. For NO_3/NO_2-N, the multiple regression model that included the LDI-PLU for the watershed scale was the only model that reported a significant relationship between the landscape variables and TKN; however, the relationship was weak ($R^2 = 0.17$, $F_{6,37} = 2.51$, $p = 0.038$; $\Delta R^2 = 0.17$). The models that included the LDI-PLU and the LDI-ILD at the 400-meter scale showed the strongest associations between the landscape variables and TN ($R^2 = 0.40$, $p < 0.001$, $\Delta R^2 = 0.40$, in both cases). For TP, the relationship with the landscape variables was only significant at the 400-meter scale. Among the different LDI forms, the model that included the LDI-ILD explained more of the variance in TP ($R^2 = 0.23$, $F_{6,36} = 3.09$, $p < 0.015$; $R^2 = 0.23$). Significant relationships between the LCI and the landscape variables were observed at all spatial extents considered. Among these, more of the variance in the LCI was explained by the multiple factor model that included the LDI-PLU at the watershed scale ($R^2 = 0.52$ $F_{6,36} = 8.72$, $p < 0.001$; $\Delta R^2 = 0.52$).

Table 3-1. Percent values for the land use/land cover (LU/LC) for *a priori* defined 200-meter buffer areas for the sample of isolated forested wetlands (n = 118). The number of sites for each *a priori* category that included each LU/LC class in their surrounding landscape is shown. LU/LC classes were defined according to Level 1 of the FLUCCS.

A priori Classes	Urban	Agriculture	Rangeland	Forest	Water	Wetland	Transportation[a]
Reference							
% of total buffer	0.5	0.0	0.0	72.8	0.1	24.5	2.2
# of sites	2	0.0	0.0	36	3	31	26
Agricultural							
% of total buffer	0.5	61.9	4.5	21.2	2.0	8.2	1.7
# of sites	5	32	5	21	25	28	19
Urban							
% of total buffer	63.9	1.5	0.0	17.5	2.7	4.1	10.5
# of sites	41	5	0.0	32	23	16	39

[a] Includes access, dirt, and paved roads.

Table 3-2. Summary statistics of the non-renewable and purchased areal empower density (E+14 sej/ha/yr) for *a priori* defined buffer area classes of the isolated forested wetlands. The non-renewable areal empower density was calculated based on the proportion occupied by each land use type within a 200-meter buffer of the sample wetlands.

	n	Mean	SD (±)	Minimum	Maximum
Reference	37	24.1	54.5	0.0	227.7
Agricultural	40	61.3	57.6	3.3	260.9
Urban	41	2239.2	1563.9	288.8	8164.4

Table 3-3. Summary statistics on the size and the land use/land cover (LU/LC) composition for the drainage areas for the sample streams (n = 69) and lakes (n = 54).

	Streams		Lakes	
	Mean	SD (±)	Mean	SD (±)
Size (ha)	11,371.5	14,740.0	468.2	643.7
LU/LC [a] (%)				
Urban	12.97	18.20	49.21	31.60
Agriculture	19.55	20.28	27.23	19.59
Rangeland	5.09	6.71	11.47	14.44
Forest	44.79	25.68	18.29	19.45
Water	1.65	2.83	3.06	4.46
Wetland	16.73	10.34	13.82	14.46
Barren land[b]	0.35	1.01	0.17	0.22
Transportation	1.63	2.86	5.88	11.83

[a] LU/LC categories defined according to Level 1 of the FLUCCS classification scheme.

[b] Areas of bare soil or rock (FDOT 1999).

Table 3-4. Summary statistics of the non-renewable and purchased areal empower density (E+14 sej/ha/yr) for the sample streams and lakes[a].

	Streams	Lakes
EmpDen-PLU	432.67 ± 765.01	1662.98 ± 1668.6
EmpDen-ILD	218.89 ± 347.46	1072.56 ± 1163.35
EmpDen-ISD	135.25 ± 207.07	813.99 ± 888.53

[a] The areal empower density was calculated based on the proportion occupied by each land use type (EmpDen-PLU), and assuming that the effect of development intensity on the landscape decreased linearly with distance (EmpDen-ILD), and in inverse square with distance (EmpDen-ISD). All calculations were made for the total drainage basin.

Table 3-5. Spearman correlation between the three forms of the LDI calculated for the sample isolated forested wetlands at three different spatial extents (buffer areas of 20, 100, and 200 meters surrounding wetlands).

		20-meter			100-meter			200-meter	
	LDI	PLU	ILD	ISD	PLU	ILD	ISD	PLU	ILD
20-m	ILD	0.99							
	ISD	0.99	0.99						
100-m	PLU	0.94	0.93	0.91					
	ILD	0.95	0.94	0.93	0.99				
	ISD	0.96	0.95	0.94	0.98	1.00			
200-m	PLU	0.89	0.88	0.86	0.96	0.95	0.94		
	ILD	0.90	0.89	0.88	0.97	0.96	0.96	1.00	
	ISD	0.92	0.92	0.90	0.99	0.98	0.97	0.99	0.99

Table 3-6. Spearman correlations between the three forms of the LDI calculated for the sample streams at three different spatial extents (100 meters, 400 meters, and the total watershed).

		100-meter			400-meter			Watershed	
	LDI	PLU	ILD	ISD	PLU	ILD	ISD	PLU	ILD
100-m	ILD	0.97							
	ISD	0.93	0.98						
400-m	PLU	0.98	0.96	0.91					
	ILD	0.96	0.97	0.95	0.98				
	ISD	0.93	0.96	0.96	0.95	0.99			
Watershed	PLU	0.94	0.90	0.84	0.96	0.93	0.90		
	ILD	0.93	0.92	0.88	0.95	0.95	0.93	0.99	
	ISD	0.91	0.92	0.90	0.93	0.95	0.96	0.95	0.99

Table 3-7. Spearman correlations between the three forms of the LDI calculated for the sample lakes at three different spatial extents (100 meters, 400 meters, and the total watershed).

		100-meter			400-meter			Watershed	
	LDI	PLU	ILD	ISD	PLU	ILD	ISD	PLU	ILD
100-m	ILD	0.90							
	ISD	0.82	0.92						
400-m	PLU	0.99	0.87	0.79					
	ILD	0.93	0.99	0.91	0.91				
	ISD	0.90	0.97	0.94	0.87	0.96			
Watershed	PLU	0.98	0.86	0.78	1.00	0.90	0.86		
	ILD	0.92	0.94	0.85	0.91	0.96	0.92	0.90	
	ISD	0.91	0.97	0.92	0.88	0.97	0.99	0.87	0.93

Table 3-8. Simple linear regression values (r^2) for regressions between the LDI and the water chemistry variables measured at three landscape extents for the sample isolated forested wetlands (α-level of 0.05).

	20-meter buffer		100-meter buffer		200-meter buffer	
LDI-PLU	r^2	p	r^2	p	r^2	p
$Log_{10}(DO^a)$	0.05	0.051	0.06	0.040	0.07	0.028
$Log_{10}(SC^b)$	0.12	0.053	0.15	0.024	0.21	0.008
$Log_{10}(TN^c)$	0.04	0.096	0.03	0.165	0.02	0.215
$Log_{10}(TP^d)$	0.07	0.027	0.06	0.043	0.04	0.071
$Log_{10}(Turb^e)$	0.03	0.164	0.04	0.078	0.03	0.111
LDI-ILD						
$Log_{10}(DO)$	0.04	0.100	0.05	0.063	0.06	0.046
$Log_{10}(SC)$	0.12	0.052	0.13	0.043	0.18	0.014
$Log_{10}(TN)$	0.04	0.080	0.03	0.139	0.03	0.155
$Log_{10}(TP)$	0.05	0.060	0.05	0.059	0.04	0.094
$Log_{10}(Turb)$	0.02	0.250	0.04	0.106	0.03	0.141
LDI-ISD						
$Log_{10}(DO)$	0.03	0.130	0.04	0.079	0.05	0.062
$Log_{10}(SC)$	0.12	0.051	0.11	0.056	0.16	0.023
$Log_{10}(TN)$	0.04	0.075	0.04	0.110	0.03	0.129
$Log_{10}(TP)$	0.04	0.092	0.04	0.079	0.04	0.104
$Log_{10}(Turb)$	0.01	0.362	0.03	0.138	0.03	0.156

[a] Dissolved oxygen; [b] Specific conductance; [c] Total nitrogen; [d] Total phosphorus; [e] Turbidity

Table 3-9. Simple linear regression results (r^2) showing the proportion of total variance in each of five water chemistry variables explained by the LDI calculated at eight different grain sizes (meters on a side) for the sample isolated forested wetlands (* = $p < 0.05$, ** = $p < 0.01$).

	5-m	10-m	20-m	30-m	40-m	50-m	60-m	70-m
LDI-PLU								
Log_{10}(DO)	0.069*	0.067*	0.066*	0.064*	0.067*	0.065*	0.060*	0.068*
Log_{10}(SC)	0.205**	0.207**	0.208**	0.204**	0.205**	0.206**	0.200**	0.193*
Log_{10}(TN)	0.019	0.020	0.019	0.018	0.019	0.019	0.018	0.025
Log_{10}(TP)	0.044	0.042	0.042	0.043	0.044	0.042	0.042	0.038
Log_{10}(Turb[a])	0.034	0.034	0.035	0.035	0.033	0.032	0.033	0.027
LDI-ILD								
Log_{10}(DO)	0.057*	0.057*	0.056*	0.053	0.067*	0.064*	0.059*	0.058*
Log_{10}(SC)	0.179*	0.182*	0.181*	0.173*	0.177*	0.173*	0.142*	0.154*
Log_{10}(TN)	0.026	0.027	0.028	0.024	0.029	0.030	0.027	0.032
Log_{10}(TP)	0.038	0.037	0.036	0.039	0.040	0.039	0.043	0.042
Log_{10}(Turb[a])	0.030	0.029	0.030	0.031	0.025	0.020	0.030	0.031
LDI-ISD								
Log_{10}(DO)	0.050	0.050	0.048	0.047	0.061*	0.059*	0.047	0.052
Log_{10}(SC)	0.155*	0.159*	0.157*	0.151*	0.153*	0.158*	0.125*	0.136*
Log_{10}(TN)	0.031	0.032	0.033	0.030	0.034	0.035	0.030	0.035
Log_{10}(TP)	0.036	0.035	0.034	0.036	0.037	0.037	0.039	0.039
Log_{10}(Turb[a])	0.027	0.027	0.028	0.028	0.02	0.016	0.029	0.025

[a] Turbidity.

Table 3-10. Simple linear regression values (r^2) for regressions between the LDI and the WCI measured at three spatial extents for the sample isolated forested wetlands.

	20-meter buffer		100-meter buffer		200-meter buffer	
LDI-PLU	r^2	p	r^2	p	r^2	p
Macrophyte WCI	0.30	<0.001	0.27	<0.001	0.24	<0.001
Macroinvertebrate WCI	0.24	<0.001	0.23	<0.001	0.18	<0.001
Diatom WCI	0.19	0.002	0.24	<0.001	0.23	<0.001
LDI-ILD						
Macrophyte WCI	0.23	<0.001	0.24	<0.001	0.21	<0.001
Macroinvertebrate WCI	0.20	<0.001	0.20	<0.001	0.18	<0.001
Diatom WCI	0.15	0.006	0.20	0.001	0.20	0.001
LDI-ISD						
Macrophyte WCI	0.19	<0.001	0.21	<0.001	0.19	<0.001
Macroinvertebrate WCI	0.18	<0.001	0.19	<0.001	0.17	<0.001
Diatom WCI	0.12	0.016	0.17	0.003	0.19	0.002

Table 3-11. Simple linear regression results (r^2) showing the proportion of total variance in each of the three WCIs explained by the LDI in its three forms calculated at different grain sizes (meters on a side) for the sample isolated forested wetlands. All results were significant ($p < 0.01$).

	5-m	10-m	20-m	30-m	40-m	50-m	60-m	70-m
LDI-PLU								
Macrophyte WCI	0.243	0.239	0.237	0.236	0.229	0.229	0.214	0.215
Macroinvertebrate WCI	0.183	0.180	0.174	0.179	0.179	0.188	0.164	0.179
Diatom WCI	0.228	0.229	0.228	0.231	0.225	0.225	0.219	0.213
LDI-ILD								
Macrophyte WCI	0.209	0.207	0.207	0.205	0.203	0.202	0.193	0.183
Macroinvertebrate WCI	0.179	0.177	0.172	0.171	0.183	0.198	0.163	0.172
Diatom WCI	0.203	0.205	0.206	0.208	0.208	0.196	0.187	0.205
LDI-ISD								
Macrophyte WCI	0.190	0.189	0.190	0.191	0.188	0.184	0.174	0.174
Macroinvertebrate WCI	0.172	0.172	0.170	0.168	0.182	0.191	0.156	0.177
Diatom WCI	0.186	0.189	0.192	0.195	0.193	0.186	0.164	0.189

Table 3-12. Coefficients of determination (r^2) for simple linear regressions between the three forms of the LDI and the water chemistry variables and the Water Condition Index (WQI) measured at three spatial extents for the sample streams (α-level of 0.05).

	100-meter buffer		400-meter buffer		Watershed	
LDI-PLU	r^2	p	r^2	p	r^2	p
Log_{10}(Turb[a])	0.04	0.299	0.02	0.405	0.03	0.334
DO[b]	0.40	<0.001	0.34	<0.001	0.40	<0.001
Log_{10}(NO_3-N[c])	0.07	0.080	0.09	0.040	0.14	0.011
Log_{10}(TN[d])	0.13	0.011	0.10	0.030	0.17	0.004
Log_{10}(TP[e])	0.02	0.350	0.01	0.490	0.01	0.491
WQI[f]	0.21	0.004	0.21	0.004	0.22	0.003
LDI-ILD						
Log_{10}(Turb)	0.001	0.886	0.002	0.829	0.01	0.564
DO	0.33	<0.001	0.31	<0.001	0.41	<0.001
Log_{10}(NO_3-N)	0.04	0.188	0.07	0.084	0.10	0.031
Log_{10}(TN)	0.11	0.021	0.09	0.043	0.16	0.005
Log_{10}(TP)	0.05	0.139	0.02	0.353	0.02	0.335
WQI	0.26	0.001	0.25	0.002	0.28	<0.001
LDI-ISD						
Log_{10}(Turb)	0.007	0.654	0.003	0.765	0.001	0.845
DO	0.31	<0.001	0.31	<0.001	0.41	<0.001
Log_{10}(NO_3-N)	0.01	0.446	0.04	0.168	0.08	0.061
Log_{10}(TN)	0.11	0.025	0.09	0.039	0.16	0.005
Log_{10}(TP)	0.08	0.049	0.03	0.241	0.03	0.247
WQI	0.32	<0.001	0.29	0.001	0.33	<0.001

[a] Turbidity, [b] Dissolved oxygen, [c] Nitrate nitrogen, [d] Total nitrogen, [e] Total phosphorus, [f] Water Quality Index.

Table 3-13. Simple linear regressions (r^2) showing the proportion of total variance in each of five water chemistry variables and the WQI explained by the LDI calculated at six different grain sizes (meters on a side) for streams (* = $p < 0.05$, ** = $p < 0.01$).

	20-m	50-m	80-m	110-m	140-m	170-m
LDI-PLU						
Log_{10}(Turb)	0.030	0.029	0.030	0.033	0.035	0.045
DO	0.403**	0.395**	0.398**	0.427**	0.439**	0.444**
Log_{10}(NO_3-N)	0.139*	0.140*	0.142*	0.138*	0.141*	0.147**
Log_{10}(TN)	0.170**	0.167**	0.168**	0.196**	0.210**	0.232**
Log_{10}(TP)	0.011	0.010	0.011	0.015	0.017	0.027
WQI	0.222**	0.220**	0.223**	0.225**	0.238**	0.255**
LDI-ILD						
Log_{10}(Turb)	0.011	0.010	0.011	0.013	0.014	0.019
DO	0.407**	0.402**	0.407**	0.438**	0.448**	0.451**
Log_{10}(NO_3-N)	0.101*	0.100*	0.101*	0.099*	0.100*	0.106*
Log_{10}(TN)	0.164**	0.160**	0.163**	0.189**	0.194**	0.209**
Log_{10}(TP)	0.021	0.019	0.020	0.024	0.027	0.036
WQI	0.279**	0.277**	0.275**	0.285**	0.301**	0.313**
LDI-ISD						
Log_{10}(Turb)	0.001	0.001	0.002	0.002	0.003	0.004
DO	0.409**	0.405**	0.409**	0.442**	0.449**	0.452**
Log_{10}(NO_3-N)	0.078	0.077	0.078	0.076	0.077	0.081
Log_{10}(TN)	0.159**	0.156**	0.157**	0.186**	0.184**	0.197**
Log_{10}(TP)	0.030	0.027	0.029	0.033	0.036	0.045
WQI	0.332**	0.330**	0.328**	0.340**	0.354**	0.364**

Table 3-14. Simple linear regression values (r^2) for regressions between the three forms of the LDI and the SCI measured at three spatial extents for the sample streams.

	100-meter buffer		400-meter buffer		Watershed	
LDI-PLU	r^2	p	r^2	p	r^2	p
SCI_1[a]	0.20	<0.001	0.17	0.001	0.17	0.001
SCI_2[b]	0.24	<0.001	0.19	<0.001	0.19	<0.001
LDI-ILD						
SCI_1	0.24	<0.001	0.20	<0.001	0.21	<0.001
SCI_2	0.26	<0.001	0.22	<0.001	0.23	<0.001
LDI-ISD						
SCI_1	0.27	<0.001	0.22	<0.001	0.23	<0.001
SCI_2	0.26	<0.001	0.22	<0.001	0.25	<0.001

[a]SCI defined by Barbour et al. (1996b); [b]SCI defined by Fore (2004).

Table 3-15. Simple linear regression results (r^2) showing the proportion of total variance in the SCI explained by the LDI in its three forms calculated at six different grain sizes (meters on a side) for the sample streams. All regressions were significant at $p < 0.01$.

	20-m	50-m	80-m	110-m	140-m	170-m
LDI-PLU						
SCI_1[a]	0.167	0.162	0.162	0.163	0.167	0.167
SCI_2[b]	0.185	0.178	0.177	0.179	0.181	0.178
LDI-ILD						
SCI_1	0.205	0.198	0.200	0.200	0.203	0.203
SCI_2	0.228	0.219	0.222	0.221	0.222	0.221
LDI-ISD						
SCI_1	0.228	0.221	0.223	0.224	0.227	0.227
SCI_2	0.252	0.242	0.245	0.244	0.246	0.247

[a]SCI defined by Barbour et al. (1996b); [b]SCI defined by Fore (2004).

Table 3-16. Coefficients of determination (r^2) for simple linear regressions between the three forms of the LDI and the water chemistry variables and the Lake Condition Index (LCI) measured at three spatial extents for the sample lakes (α-level of 0.05).

	100-meter buffer		400-meter buffer		Watershed	
LDI-PLU	r^2	p	r^2	p	r^2	p
Log_{10}(Ammonia-N)	0.007	0.547	0.024	0.267	0.014	0.387
Log_{10}(NO_3/NO_2-N)	0.007	0.535	0.003	0.703	0.003	0.712
Log_{10}(TKN)	0.011	0.445	0.008	0.532	<0.001	0.996
Log_{10}(TN)	0.005	0.603	0.016	0.366	0.002	0.714
Log_{10}(TP)	0.007	0.553	0.025	0.255	0.028	0.229
LCI	<0.001	0.968	<0.001	0.957	0.013	0.417
LDI-ILD	r^2	p	r^2	p	r^2	p
Log_{10}(Ammonia-N)	0.005	0.615	0.020	0.303	0.037	0.164
Log_{10}(NO_3/NO_2-N)	0.016	0.366	<0.001	0.938	0.007	0.538
Log_{10}(TKN)	0.010	0.469	0.010	0.471	0.005	0.608
Log_{10}(TN)	0.003	0.714	0.015	0.383	0.013	0.421
Log_{10}(TP)	0.002	0.723	0.017	0.355	0.053	0.097
LCI	0.001	0.873	<0.001	0.948	0.002	0.746
LDI-ISD	r^2	p	r^2	p	r^2	p
Log_{10}(Ammonia-N)	0.004	0.650	0.020	0.312	0.037	0.163
Log_{10}(NO_3/NO_2-N)	0.022	0.290	<0.001	0.899	0.004	0.644
Log_{10}(TKN)	0.008	0.516	0.012	0.441	0.007	0.544
Log_{10}(TN)	0.001	0.820	0.016	0.374	0.014	0.403
Log_{10}(TP)	0.001	0.820	0.013	0.414	0.043	0.136
LCI	0.002	0.751	0.004	0.666	<0.001	0.888

Table 3-17. Simple linear regression results (r^2) showing the proportion of total variance in each of five water chemistry variables and the LCI explained by the LDI in its three forms calculated at six different grain sizes (meters on a side) for the sample lakes (α-level of 0.05).

	20-m	40-m	60-m	80-m	100-m	120-m
LDI-PLU						
Log_{10}(Ammonia-N)	0.014	0.017	0.017	0.034	0.012	0.010
Log_{10}(NO_3/NO_2-N)	0.003	0.001	0.002	0.003	0.002	0.002
Log_{10}(TKN)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Log_{10}(TN)	0.002	0.001	0.002	0.004	0.002	0.003
Log_{10}(TP)	0.028	0.024	0.027	0.058	0.023	0.022
LCI	0.013	0.021	0.013	0.009	0.011	0.011
LDI-ILD						
Log_{10}(Ammonia-N)	0.037	0.043	0.036	0.032	0.033	0.029
Log_{10}(NO_3/NO_2-N)	0.007	0.001	0.006	0.006	0.005	0.005
Log_{10}(TKN)	0.005	0.015	0.005	0.006	0.006	0.005
Log_{10}(TN)	0.013	0.022	0.013	0.013	0.013	0.013
Log_{10}(TP)	0.053	0.021	0.051	0.049	0.044	0.042
LCI	0.002	0.001	0.002	0.002	0.001	0.001
LDI-ISD						
Log_{10}(Ammonia-N)	0.037	0.035	0.035	0.033	0.032	0.028
Log_{10}(NO_3/NO_2-N)	0.004	0.003	0.003	0.003	0.002	0.002
Log_{10}(TKN)	0.007	0.008	0.007	0.008	0.008	0.008
Log_{10}(TN)	0.014	0.013	0.013	0.013	0.014	0.014
Log_{10}(TP)	0.043	0.044	0.041	0.040	0.033	0.032
LCI	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 3-18. Pearson's correlations between landscape pattern metrics calculated at four different grain sizes (meters on a side) for the isolated forested wetlands. Some of the metrics descriptors (acronyms) of the columns have been renamed for convenience.

Metric	% Urb[a]	% Ag[b]	% For[c]	% Wet[d]	PD	ED	A_MN[e]	A_CV[f]	SHAP[g]	FRAC[h]	ENN[i]	CONT[j]	PR	PRD	SHDI
5-m															
PLAND_Ag	-0.65														
PLAND_For	-0.24	-0.28													
PLAND_Wet	-0.73	0.21	0.08												
PD	-0.06	-0.15	0.21	0.18											
ED	-0.01	-0.23	0.10	0.16	0.78										
AREA_MN	0.06	0.15	-0.21	-0.18	-1.00	-0.78									
AREA_CV	-0.46	0.29	0.07	0.40	0.49	0.35	-0.49								
SHAPE_MN	0.09	-0.10	-0.04	-0.11	-0.02	0.46	0.02	0.15							
FRAC_MN	-0.02	-0.02	0.01	-0.04	0.13	0.46	-0.13	0.33	0.92						
ENN_MN	-0.17	0.08	0.11	0.07	0.22	0.21	-0.22	0.05	0.02	0.05					
CONTAG	0.03	0.10	0.06	-0.22	-0.05	-0.11	0.05	0.34	0.22	0.28	-0.15				
PR	0.38	-0.11	-0.01	-0.42	0.39	0.15	-0.39	-0.05	-0.20	-0.15	0.16	0.10			
PRD	0.33	-0.10	0.02	-0.32	0.46	0.20	-0.46	-0.06	-0.20	-0.14	0.16	0.00	0.91		
SHDI	0.35	-0.16	-0.03	-0.31	0.26	0.07	-0.26	-0.31	-0.33	-0.34	0.19	-0.45	0.83	0.79	
SHEI	0.07	-0.07	-0.10	0.08	-0.11	-0.13	0.11	-0.46	-0.36	-0.42	0.11	-0.95	0.05	0.12	0.59
10-m															
PLAND_Ag	-0.65														
PLAND_For	-0.24	-0.28													
PLAND_Wet	-0.73	0.21	0.08												
PD	-0.06	-0.16	0.21	0.13											
ED	0.01	-0.23	0.07	0.15	0.75										
AREA_MN	0.06	0.16	-0.21	-0.13	-1.00	-0.75									
AREA_CV	-0.27	0.11	0.09	0.22	0.61	0.39	-0.61								
SHAPE_MN	0.26	-0.12	-0.19	-0.19	-0.27	0.31	0.27	-0.18							
FRAC_MN	0.21	-0.06	-0.18	-0.17	-0.17	0.32	0.17	-0.04	0.94						
ENN_MN	-0.18	0.12	0.12	0.06	-0.05	0.08	0.05	-0.10	0.11	0.08					
CONTAG	0.07	0.09	0.05	-0.28	-0.11	-0.27	0.11	0.37	-0.05	-0.02	-0.11				
PR	0.38	-0.11	-0.02	-0.42	0.27	0.19	-0.27	-0.16	-0.06	-0.13	0.12	0.10			
PRD	0.32	-0.10	0.01	-0.32	0.37	0.23	-0.37	-0.14	-0.13	-0.15	0.01	0.04	0.93		
SHDI	0.35	-0.16	-0.03	-0.31	0.16	0.14	-0.16	-0.44	-0.07	-0.16	0.11	-0.37	0.85	0.80	
SHEI	0.06	-0.06	-0.10	0.09	-0.12	-0.06	0.12	-0.60	-0.06	-0.12	0.09	-0.91	0.11	0.14	0.59

Table 3-18. Continued.

Metric	% Urb[a]	% Ag[b]	% For[c]	% Wet[d]	PD	ED	A_MN[e]	A_CV[f]	SHAP[g]	FRAC[h]	ENN[i]	CONT[j]	PR	PRD	SHDI
20-m															
PLAND_Ag	-0.65														
PLAND_For	-0.23	-0.29													
PLAND_Wet	-0.73	0.21	0.07												
PD	-0.05	-0.12	0.03	0.19											
ED	0.00	-0.22	0.06	0.16	0.82										
AREA_MN	-0.01	0.15	-0.07	-0.07	-0.97	-0.81									
AREA_CV	-0.17	0.10	-0.02	0.09	0.66	0.48	-0.67								
SHAPE_MN	0.05	-0.08	0.01	-0.10	-0.41	0.08	0.40	-0.29							
FRAC_MN	0.15	-0.18	0.08	-0.17	-0.33	0.13	0.29	-0.27	0.95						
ENN_MN	-0.14	0.13	0.03	0.02	0.20	0.21	-0.26	0.24	0.08	0.12					
CONTAG	0.11	0.11	0.00	-0.32	-0.22	-0.38	0.17	0.30	-0.12	-0.10	-0.06				
PR	0.38	-0.09	-0.06	-0.42	0.18	0.21	-0.28	-0.14	-0.04	0.09	0.14	0.11			
PRD	0.34	-0.09	-0.03	-0.33	0.24	0.23	-0.32	-0.16	-0.13	0.00	0.08	0.04	0.93		
SHDI	0.36	-0.16	-0.04	-0.32	0.07	0.17	-0.15	-0.45	0.02	0.12	0.03	-0.30	0.87	0.84	
SHEI	0.08	-0.08	-0.09	0.09	-0.13	-0.01	0.16	-0.67	0.10	0.09	-0.06	-0.84	0.15	0.20	0.59
30-m															
PLAND_Ag	-0.65														
PLAND_For	-0.24	-0.28													
PLAND_Wet	-0.71	0.20	0.07												
PD	-0.05	-0.17	0.00	0.24											
ED	-0.03	-0.21	0.08	0.16	0.86										
AREA_MN	0.01	0.17	-0.06	-0.12	-0.97	-0.85									
AREA_CV	-0.19	0.11	-0.05	0.13	0.46	0.25	-0.49								
SHAPE_MN	0.07	-0.06	0.00	-0.12	-0.37	0.06	0.38	-0.36							
FRAC_MN	0.18	-0.14	0.02	-0.21	-0.29	0.13	0.29	-0.45	0.94						
ENN_MN	-0.14	0.17	0.08	-0.05	0.11	0.13	-0.14	0.28	0.03	0.07					
CONTAG	0.13	0.08	0.02	-0.31	-0.32	-0.52	0.24	0.44	-0.26	-0.35	0.02				
PR	0.30	-0.06	0.00	-0.38	0.35	0.31	-0.43	-0.09	-0.17	-0.03	0.12	0.04			
PRD	0.28	-0.06	0.01	-0.31	0.42	0.31	-0.48	-0.10	-0.31	-0.16	0.01	0.02	0.93		
SHDI	0.30	-0.13	-0.02	-0.30	0.31	0.37	-0.35	-0.43	-0.02	0.15	-0.04	-0.36	0.86	0.82	
SHEI	0.05	-0.06	-0.09	0.09	0.06	0.23	0.00	-0.73	0.25	0.36	-0.15	-0.86	0.20	0.20	0.62

[a] % Urb = PLAND_Urb; [b] % Ag = PLAND_Ag; [c] % For = PLAND_For; [d] % Wet = PLAND_WET; [e] A_MN = Area_MN; [f] A_CV = AREA_CV; [g] SHAP = SHAPE_MN; [h] FRAC = FRAC_MN; [i] ENN = ENN_MN; [j] CONT = CONTAG.

Table 3-19. Eigenvalues and variance explained by the first seven axes for the principal components analysis at four different grain sizes (meters on a side) for isolated forested wetlands.

Component	1	2	3	4	5	6	7
5-m							
Eigenvalue	2.93	2.53	1.83	1.30	1.12	0.95	0.56
% of variance explained	24.43	21.11	15.26	10.80	9.36	7.89	4.68
Cumulative % of variance	24.43	45.54	60.80	71.59	80.96	88.85	93.53
10-m							
Eigenvalue	2.84	2.42	1.71	1.47	1.21	1.06	0.59
% of variance explained	23.68	20.17	14.23	12.24	10.08	8.81	4.94
Cumulative % of variance	23.68	43.85	58.08	70.32	80.40	89.21	94.15
20-m							
Eigenvalue	3.11	2.59	2.25	1.41	1.15	1.08	0.71
% of variance explained	23.90	19.93	17.32	10.88	8.88	8.33	5.47
Cumulative % of variance	23.90	43.82	61.14	72.02	80.89	89.22	94.69
30-m							
Eigenvalue	3.31	2.55	2.31	1.41	1.14	1.11	0.61
% of Variance explained	25.49	19.60	17.75	10.85	8.75	8.50	4.67
Cumulative % of variance	25.49	45.09	62.83	73.68	82.43	90.93	95.59

Table 3-20. The 5 x 5-meter grain size for isolated forested wetland buffers: principal component matrices showing pattern metric factor loadings.

Metrics	URB	HETER	SHAPE	AG	FOR	DIST
PLAND_Urb	-0.49	-0.10	-0.32	-0.01	-0.08	-0.11
PLAND_Ag	0.31	-0.08	0.32	-0.49	-0.20	0.15
PLAND_For	0.05	0.18	-0.03	0.38	0.71	0.28
PLAND_Wet	0.41	0.16	0.26	0.28	-0.06	-0.26
PD	-0.02	0.58	-0.04	-0.07	0.07	-0.21
ED	0.02	0.52	-0.27	0.13	-0.27	-0.08
AREA_CV	0.36	0.31	-0.12	-0.31	0.10	-0.17
SHAPE_MN	0.10	0.06	-0.55	0.06	-0.39	0.27
ENN_MN	0.00	0.26	0.19	0.05	-0.16	0.80
CONTAG	0.14	-0.09	-0.41	-0.50	0.40	0.14
PRD	-0.37	0.31	0.14	-0.39	0.13	0.00
SHDI	-0.44	0.21	0.33	-0.11	-0.04	-0.01

Table 3-21. The 10 x 10-meter grain size for isolated forested wetland buffers: principal component matrices showing pattern metric factor loadings.

Metrics	URB	HETER	CONTAG	SHAPE	FOR	ENN
PLAND_Urb	-0.50	-0.09	-0.31	0.12	0.02	-0.09
PLAND_Ag	0.32	-0.13	0.24	-0.26	-0.54	0.16
PLAND_For	0.07	0.20	0.00	-0.13	0.73	0.29
PLAND_Wet	0.41	0.16	0.31	0.12	0.08	-0.25
PD	-0.01	0.62	-0.09	-0.06	-0.08	-0.06
ED	-0.07	0.53	0.00	0.40	-0.17	0.07
AREA_CV	0.29	0.37	-0.40	-0.05	-0.18	0.08
SHAPE_MN	-0.13	-0.13	-0.07	0.65	-0.21	0.27
ENN_MN	0.03	0.02	0.35	0.11	0.06	0.75
CONTAG	0.09	-0.12	-0.55	-0.31	-0.10	0.39
PRD	-0.40	0.25	0.12	-0.38	-0.20	0.13
SHDI	-0.45	0.14	0.36	-0.23	-0.09	0.00

Table 3-22. The 20 x 20-meter grain size for isolated forested wetland buffers: principal component matrices showing pattern metric factor loadings

Metrics	DIVERS	HETER	CONTAG	AG	SHAPE	FOR
PLAND_Urb	-0.34	0.04	-0.44	-0.19	0.03	-0.30
PLAND_Ag	0.22	-0.15	0.22	0.62	-0.17	-0.01
PLAND_For	0.05	0.04	0.04	-0.41	0.08	0.81
PLAND_Wet	0.25	0.07	0.48	-0.03	0.18	0.04
PD	0.15	0.58	-0.03	0.02	0.15	-0.07
ED	0.05	0.56	0.05	-0.18	-0.16	-0.12
AREA_CV	0.42	0.31	-0.22	0.01	-0.05	-0.13
SHAPE_MN	-0.13	-0.16	0.10	-0.33	-0.67	-0.09
ENN_MN	0.09	0.20	0.04	0.14	-0.65	0.17
CONTAG	0.22	-0.23	-0.50	0.17	-0.03	0.21
PRD	-0.32	0.27	-0.19	0.38	-0.02	0.30
SHDI	-0.47	0.21	0.00	0.27	-0.03	0.20
SHEI	-0.41	0.05	0.42	0.02	0.09	-0.10

Table 3-23. The 30 x 30-meter grain size for isolated forested wetland buffers the wetland buffer: principal component matrices showing pattern metric factor loadings

Metrics	DIVERS	HETER	URB/WET	AG	SHAPE	FOR
PLAND_Urb	-0.19	0.32	-0.43	-0.21	-0.11	0.26
PLAND_Ag	0.18	-0.11	0.25	0.64	-0.20	-0.06
PLAND_For	0.01	-0.07	0.02	-0.37	0.35	-0.75
PLAND_Wet	0.08	-0.34	0.43	-0.04	0.29	0.12
PD	-0.24	-0.52	-0.16	-0.09	0.01	0.16
ED	-0.32	-0.42	-0.03	-0.25	-0.19	0.07
AREA_CV	0.28	-0.42	-0.26	-0.09	-0.16	0.15
SHAPE_MN	-0.07	0.27	0.26	-0.30	-0.48	-0.07
ENN_MN	0.07	-0.19	-0.04	0.03	-0.65	-0.44
CONTAG	0.39	0.10	-0.40	0.13	0.09	-0.11
PRD	-0.33	-0.09	-0.35	0.37	0.11	-0.22
SHDI	-0.47	0.03	-0.14	0.28	0.02	-0.18
SHEI	-0.44	0.12	0.32	0.10	0.01	0.03

Table 3-24. Coefficients of determination, probabilities, and regression equations for multiple regressions between indicators of ecosystem condition and significant components resulting from the PCA of landscape pattern metrics at four grain sizes for the sample isolated forested wetlands (α – level of 0.05). Components that were significantly related to the dependent variable ($p < 0.05$) are indicated with an asterisk in the regression equation

Variable (Y)	n	R^2 (adj)	p	Regression equation
5-meter				
Water chemistry				
Log_{10}(DO)	29	0.01	0.399	Y = 0.171 - 0.003(URB) + 0.045(HETER) + 0.043(SHAPE) + 0.064(AG) + 0.043(FOR)
Log_{10}(SC)	17	0.15	0.247	Y = 2.18 - 0.043(URB) + 0.021(HETER) + 0.121(SHAPE) + 0.024(AG) - 0.106(FOR)
Log_{10}(TN)	32	0.01	0.389	Y = 0.226 + 0.02(URB) - 0.043(HETER) + 0.037(SHAPE) - 0.015(AG) - 0.075(FOR)
Log_{10}(TP)	32	0.16	0.091	Y = - 0.773 + 0.003(URB) - 0.06(HETER) + 0.081(SHAPE) - 0.243(AG) - 0.097(FOR)
Log_{10}(Turb)	32	0.00	0.637	Y = 0.581 - 0.107(URB) - 0.047(HETER) + 0.006(SHAPE) + 0.011(AG) - 0.008(FOR)
WCI				
Macrophyte	51	0.42	<0.001	Y = 24.9 + 2.10(URB)* + 1.70(HETER) - 2.01(SHAPE) + 7.29(AG)* - 0.14(FOR)
Macroinvertebrate	31	0.17	0.086	Y = 24.8 + 3.17(URB) + 0.77(HETER) - 2.65(SHAPE) + 0.85(AG) - 0.04(FOR)
Diatom	21	0.12	0.229	Y = 35.9 + 1.88(URB) + 1.15(HETER) + 2.34(SHAPE) + 6.48(AG) + 1.83(FOR)

Table 3-24. Continued.

Variable (Y)	n	R^2 (adj)	p	Regression equation
10-meter				
Water chemistry				
Log_{10}(DO)	29	0.00	0.591	Y = 0.157 + 0.081(CONTAG) + 0.018(SHAPE) + 0.067(FOR) - 0.017(DIST) - 0.013(URB) + 0.015(HETER)
Log_{10}(SC)	17	0.05	0.402	Y = 2.20 - 0.042(URB) + 0.013(HETER) + 0.123(CONTAG) - 0.019(SHAPE) - 0.062(FOR) - 0.009(DIST)
Log_{10}(TN)	32	0.07	0.262	Y = 0.221 + 0.018(URB) - 0.045(HETER) + 0.047(CONTAG) + 0.035(SHAPE) - 0.055(FOR) + 0.044(DIST)
Log_{10}(TP)	32	0.44	0.002	Y = - 0.755 + 0.036(URB) - 0.054(HETER) + 0.025(CONTAG) - 0.089(SHAPE) - 0.192(FOR)* + 0.318(DIST)*
Log_{10}(Turb)	32	0.00	0.79	Y = 0.584 - 0.098(URB) - 0.046(HETER) - 0.012(CONTAG) + 0.007(SHAPE) + 0.023(FOR) + 0.019(DIST)
WCI				
Macrophyte	51	0.44	<0.001	Y = 24.9 + 1.61(URB) + 1.51(HETER) + 0.96(CONTAG) + 5.94(SHAPE)* + 5.38(FOR)* + 0.42(DIST)
Macroinvertebrate	31	0.16	0.119	Y = 24.8 + 2.88(URB) + 1.17(HETER) - 2.05(CONTAG) + 2.35(SHAPE) + 0.24(FOR) + 0.78(DIST)
Diatom	21	0.06	0.363	Y = 36.0 + 1.82(URB) + 0.84(HETER) + 3.91(CONTAG) + 0.63(SHAPE) + 4.77(FOR) - 4.37(DIST)
20-meter				
Water chemistry				
Log_{10}(DO)	29	0.01	0.531	Y = 0.171 - 0.02(DIVERS) + 0.026(HETER) + 0.056(CONTAG) - 0.054(AG) - 0.033(SHAPE) + 0.051(FOR)
Log_{10}(SC)	17	0.07	0.379	Y = 2.18 - 0.065(DIVERS) + 0.024(HETER) + 0.088(CONTAG) + 0.061(AG) - 0.005(SHAPE) - 0.078(FOR)
Log_{10}(TN)	32	0.02	0.379	Y = 0.225 - 0.007(DIVERS) - 0.029(HETER) + 0.05(CONTAG) + 0.041(AG) - 0.072(SHAPE) - 0.049(FOR)
Log_{10}(TP)	32	0.43	0.002	Y = - 0.725 + 0.042(DIVERS) - 0.051(HETER) - 0.041(CONTAG) + 0.245(AG)* - 0.231(SHAPE)* + 0.075(FOR)
Log_{10}(Turb)	32	0.00	0.741	Y = 0.618 - 0.012(DIVERS) + 0.019(HETER) - 0.111(CONTAG) + 0.038(AG) - 0.027(SHAPE) + 0.055(FOR)
WCI				
Macrophyte	51	0.39	<0.001	Y = 24.9 + 1.26(DIVERS) + 1.27(HETER) + 2.62(CONTAG)* - 6.91(AG)* - 1.01(SHAPE) + 0.65(FOR)
Macroinvertebrate	31	0.26	0.038	Y = 24.9 + 4.25(DIVERS)* + 1.48(HETER) - 0.79(CONTAG) - 0.62(AG) - 0.07(SHAPE) + 0.38(FOR)
Diatom	21	0.09	0.312	Y = 35.7 + 1.44(DIVERS) + 1.26(HETER) + 3.91(CONTAG) - 3.90(AG) + 1.99(SHAPE) + 4.03(FOR)

Table 3-24. Continued.

Variable (Y)	n	R^2 (adj)	p	Regression equation
30-meter				
Water chemistry				
Log_{10}(DO)	29	0.01	0.591	Y = 0.157 - 0.013(DIVERS) + 0.015(HETER) + 0.081(URB/WET) + 0.018(AG) + 0.067(SHAPE) - 0.017(FOR)
Log_{10}(SC)	17	0.08	0.369	Y = 2.19 - 0.0552(DIVERS) - 0.0146(HETER) + 0.0416(URB/WET) + 0.103(AG) - 0.003(SHAPE) + 0.065(FOR)
Log_{10}(TN)	32	0.17	0.094	Y = 0.225 - 0.021(DIVERS) + 0.038(HETER) + 0.079(URB/WET) + 0.046(AG) - 0.097(SHAPE) + 0.016(FOR)
Log_{10}(TP)	32	0.45	0.001	Y = - 0.745 + 0.026(DIVERS) + 0.039(HETER) + 0.009(URB/WET) + 0.206(AG)* - 0.261(SHAPE)* - 0.132(FOR)
Log_{10}(Turb)	32	0.01	0.592	Y = 0.607 - 0.035(DIVERS) + 0.086(HETER) - 0.047(URB/WET) - 0.010(AG) - 0.079(SHAPE) - 0.061(FOR)
WCI				
Macrophyte	51	0.42	<0.001	Y = 24.9 - 0.493(DIVERS) - 2.10(HETER)* + 2.76(URB/WET)* - 6.82(AG)* + 1.53(SHAPE) - 0.02(FOR)
Macroinvertebrate	31	0.16	0.119	Y = 24.4 + 1.65(DIVERS) - 1.70(HETER) + 1.07(URB/WET) - 2.10(AG) - 1.73(SHAPE) + 0.53(FOR)
Diatom	21	0.13	0.251	Y = 35.5 - 0.12(DIVERS) - 2.77(HETER) + 3.68(URB/WET) - 2.83(AG) + 4.95(SHAPE) - 3.02(FOR)

Table 3-25. Pearson's correlations between landscape pattern metrics calculated at four different grain sizes (meters on a side) for the sample streams. Some of the metrics descriptors (acronyms) of the columns have been renamed for convenience.

Metric	% Urb[a]	%Ag[b]	%For[c]	% Wet[d]	PD	ED	A_MN[e]	A_CV[f]	SHAP[g]	ENN[h]	CONT[i]	IJI	PR	PRD	SHDI
20-m															
PLAND_Ag	-0.15														
PLAND_For	-0.41	-0.66													
PLAND_Wet	-0.33	-0.09	-0.15												
PD	0.04	-0.03	-0.22	0.21											
ED	0.05	-0.26	0.06	0.10	0.83										
AREA_MN	-0.02	0.03	0.25	-0.29	-0.96	-0.83									
AREA_CV	-0.35	0.33	-0.13	0.26	-0.06	-0.46	0.10								
SHAPE_MN	-0.31	-0.15	0.54	-0.28	-0.64	-0.31	0.71	-0.16							
ENN_MN	-0.36	0.29	-0.11	0.11	-0.38	-0.46	0.35	0.15	0.22						
CONTAG	-0.18	0.04	0.37	-0.18	-0.60	-0.62	0.62	0.46	0.36	0.04					
IJI	0.41	0.19	-0.59	-0.05	0.30	0.07	-0.29	-0.13	-0.47	0.05	-0.67				
PR	-0.10	0.28	-0.38	0.26	-0.09	-0.35	0.03	0.40	-0.19	0.69	-0.07	0.23			
PRD	0.44	-0.25	-0.03	-0.15	0.34	0.53	-0.36	-0.72	-0.28	-0.23	-0.36	-0.03	-0.40		
SHDI	0.01	0.18	-0.51	0.35	0.25	0.05	-0.31	0.03	-0.33	0.52	-0.67	0.60	0.77	-0.10	
SHEI	0.26	0.02	-0.48	0.18	0.48	0.45	-0.50	-0.42	-0.38	0.07	-0.98	0.76	0.20	0.33	0.76
50-m															
PLAND_Ag	-0.15														
PLAND_For	-0.41	-0.66													
PLAND_Wet	-0.33	-0.09	-0.15												
PD	0.03	-0.05	-0.18	0.19											
ED	0.07	-0.33	0.13	0.07	0.82										
AREA_MN	-0.01	0.06	0.20	-0.27	-0.96	-0.81									
AREA_CV	-0.39	0.37	-0.08	0.19	-0.20	-0.54	0.19								
SHAPE_MN	-0.19	-0.21	0.51	-0.30	-0.65	-0.26	0.73	-0.18							
ENN_MN	-0.41	0.31	-0.14	0.18	-0.29	-0.47	0.28	0.28	0.13						
CONTAG	-0.12	0.13	0.24	-0.17	-0.67	-0.70	0.66	0.57	0.27	0.11					
IJI	0.40	0.21	-0.64	-0.02	0.36	0.15	-0.35	-0.30	-0.40	0.11	-0.70				
PR	-0.11	0.29	-0.38	0.25	-0.10	-0.44	0.05	0.46	-0.25	0.69	0.07	0.26			
PRD	0.45	-0.25	-0.03	-0.16	0.34	0.56	-0.34	-0.76	-0.13	-0.24	-0.37	0.24	-0.43		
SHDI	-0.01	0.17	-0.49	0.35	0.25	-0.03	-0.29	0.02	-0.35	0.54	-0.54	0.66	0.77	-0.13	
SHEI	0.26	-0.02	-0.44	0.17	0.50	0.45	-0.50	-0.52	-0.31	0.05	-0.93	0.84	0.15	0.34	0.72

Table 3-25. Continued.

Metric	% Urb[a]	% Ag[b]	% For[c]	% Wet[d]	PD	ED	A_MN[e]	A_CV[f]	SHAP[g]	ENN[h]	CONT[i]	IJI	PR	PRD	SHDI
80-m															
PLAND_Ag	-0.15														
PLAND_For	-0.40	-0.66													
PLAND_Wet	-0.33	-0.09	-0.15												
PD	0.03	-0.10	-0.13	0.15											
ED	0.11	-0.35	0.13	0.07	0.84										
AREA_MN	0.00	0.11	0.15	-0.23	-0.96	-0.83									
AREA_CV	-0.42	0.34	-0.03	0.20	-0.31	-0.61	0.31								
SHAPE_MN	-0.27	-0.22	0.53	-0.18	-0.55	-0.22	0.62	-0.07							
ENN_MN	-0.47	0.34	-0.16	0.24	-0.21	-0.47	0.18	0.37	0.04						
CONTAG	-0.16	0.19	0.17	-0.14	-0.70	-0.75	0.70	0.66	0.23	0.21					
IJI	0.56	0.17	-0.63	-0.06	0.34	0.19	-0.33	-0.41	-0.47	-0.08	-0.62				
PR	-0.13	0.29	-0.38	0.25	-0.10	-0.44	0.06	0.47	-0.24	0.72	0.18	0.16			
PRD	0.44	-0.25	-0.03	-0.15	0.39	0.59	-0.38	-0.78	-0.17	-0.27	-0.43	0.31	-0.42		
SHDI	-0.02	0.17	-0.49	0.35	0.27	-0.02	-0.30	0.01	-0.32	0.56	-0.43	0.54	0.78	-0.12	
SHEI	0.33	-0.05	-0.42	0.15	0.53	0.51	-0.54	-0.61	-0.29	-0.07	-0.91	0.82	0.07	0.40	0.64
110-m															
PLAND_Ag	-0.15														
PLAND_For	-0.40	-0.66													
PLAND_Wet	-0.30	-0.05	-0.18												
PD	0.10	-0.12	-0.14	0.14											
ED	0.18	-0.36	0.12	0.04	0.85										
AREA_MN	-0.07	0.12	0.17	-0.23	-0.96	-0.83									
AREA_CV	-0.42	0.31	0.01	0.17	-0.46	-0.67	0.42								
SHAPE_MN	-0.28	-0.24	0.56	-0.16	-0.58	-0.25	0.66	0.01							
ENN_MN	-0.48	0.37	-0.19	0.33	-0.21	-0.48	0.17	0.44	-0.04						
CONTAG	-0.18	0.19	0.17	-0.18	-0.76	-0.76	0.75	0.70	0.27	0.27					
IJI	0.41	0.20	-0.62	0.14	0.42	0.19	-0.41	-0.39	-0.51	0.04	-0.65				
PR	-0.13	0.29	-0.38	0.35	-0.15	-0.49	0.09	0.48	-0.28	0.69	0.22	0.22			
PRD	0.45	-0.23	-0.04	-0.13	0.48	0.64	-0.45	-0.76	-0.22	-0.28	-0.43	0.27	-0.44		
SHDI	-0.02	0.17	-0.50	0.48	0.25	-0.07	-0.31	-0.01	-0.40	0.53	-0.40	0.64	0.77	-0.14	
SHEI	0.35	-0.06	-0.41	0.23	0.60	0.54	-0.60	-0.67	-0.35	-0.14	-0.92	0.83	0.02	0.42	0.60

[a] % Urb = PLAND_Urb; [b] % Ag = PLAND_Ag; [c] % For = PLAND_For; [d] % Wet = PLAND_WET; [e] A_MN = Area_MN; [f] A_CV = AREA_CV; [g] SHAP = SHAPE_MN; [h] ENN = ENN_MN; [i] CONT = CONTAG.

Table 3-26. Eigenvalues and variance explained by the first six axes for the principal components analysis at four different grain sizes (meters on a side) for stream watersheds.

Component	1	2	3	4	5	6
20-m						
Eigenvalue	4.08	3.61	1.81	1.57	0.93	0.68
% of variance explained	29.13	25.78	12.95	11.20	6.64	4.84
Cumulative % of variance	29.13	54.91	67.85	79.06	85.69	90.54
50-m						
Eigenvalue	4.10	3.83	1.79	1.52	0.89	0.67
% of variance explained	29.25	27.35	12.80	10.86	6.34	4.78
Cumulative % of variance	29.25	56.60	79.39	80.25	86.61	91.39
80-m						
Eigenvalue	4.34	3.73	1.83	1.28	0.88	0.69
% of variance explained	31.11	26.61	13.05	9.11	6.31	4.95
Cumulative % of variance	31.11	57.71	70.76	79.87	86.18	91.12
110-m						
Eigenvalue	4.58	3.92	1.69	1.09	0.83	0.65
% of Variance explained	32.69	28.00	12.05	7.80	5.92	4.65
Cumulative % of variance	32.69	60.68	72.74	80.53	86.45	91.10

Table 3-27. The 20 x 20-m grain size for stream watersheds: principal component matrices showing pattern metric factor loadings.

Metrics	DIVERS1	DIVERS2	WET	DIST
PLAND_Urb	-0.20	0.18	0.46	-0.21
PLAND_Ag	-0.09	-0.28	0.14	-0.37
PLAND_For	0.35	0.21	-0.19	0.33
PLAND_Wet	-0.11	-0.15	-0.50	0.11
PD	-0.33	0.18	-0.40	-0.13
ED	-0.23	0.35	-0.33	0.10
AREA_CV	0.11	-0.34	-0.28	-0.40
SHAPE_MN	0.36	0.00	0.19	0.35
ENN_MN	0.01	-0.38	0.12	0.41
IJI	-0.39	-0.07	0.24	-0.02
PR	-0.14	-0.43	-0.02	0.17
PRD	-0.19	0.36	0.15	0.13
SHDI	-0.35	-0.29	-0.03	0.32
SHEI	-0.43	0.02	0.04	0.28

Table 3-28. The 50 x 50-m grain size for stream watersheds: principal component matrices showing pattern metric factor loadings.

Metrics	DIVERS1	DIVERS2	WET	SHAPE
PLAND_Urb	-0.21	-0.15	0.48	-0.15
PLAND_Ag	-0.03	0.29	0.20	-0.38
PLAND_For	0.30	-0.26	-0.26	0.31
PLAND_Wet	-0.08	0.16	-0.49	0.07
PD	-0.35	-0.11	-0.39	-0.22
ED	-0.27	-0.32	-0.34	-0.01
AREA_CV	0.23	0.33	-0.18	-0.36
SHAPE_MN	0.30	-0.11	0.22	0.45
ENN_MN	0.04	0.37	0.01	0.39
IJI	-0.41	0.12	0.22	0.08
PR	-0.07	0.44	-0.02	0.15
PRD	-0.24	-0.32	0.13	0.10
SHDI	-0.31	0.33	-0.07	0.30
SHEI	-0.44	0.02	0.01	0.27

Table 3-29. The 80 x 80-m grain size for stream watersheds: principal component matrices showing pattern metric factor loadings.

Metrics	DIVERS1	DIVERS2	URB	SHAPE
PLAND_Urb	-0.28	-0.01	-0.48	0.08
PLAND_Ag	0.10	0.29	-0.29	-0.33
PLAND_For	0.14	-0.39	0.31	0.19
PLAND_Wet	0.03	0.18	0.46	-0.09
PD	-0.33	0.06	0.36	-0.35
ED	-0.36	-0.15	0.34	-0.17
AREA_CV	0.37	0.17	0.02	-0.35
SHAPE_MN	0.21	-0.26	0.00	0.52
ENN_MN	0.22	0.32	0.18	0.29
IJI	-0.34	0.26	-0.22	0.13
PR	0.14	0.43	0.07	0.18
PRD	-0.35	-0.15	-0.03	0.11
SHDI	-0.10	0.44	0.20	0.30
SHEI	-0.38	0.20	0.10	0.26

Table 3-30. The 110 x 110-m grain size for stream watersheds: principal component matrices showing pattern metric factor loadings.

Metrics	DIVERS1	DIVERS2	URB	SHAPE
PLAND_Urb	-0.26	-0.03	-0.48	-0.29
PLAND_Ag	0.09	0.28	-0.37	0.41
PLAND_For	0.14	-0.37	0.38	-0.12
PLAND_Wet	0.00	0.24	0.47	-0.02
PD	-0.36	0.04	0.27	0.41
ED	-0.37	-0.17	0.27	0.26
AREA_CV	0.38	0.16	-0.01	0.27
SHAPE_MN	0.22	-0.26	0.09	-0.47
ENN_MN	0.20	0.33	0.20	-0.02
IJI	-0.31	0.29	-0.13	-0.20
PR	0.14	0.42	0.07	-0.16
PRD	-0.35	-0.15	-0.03	0.03
SHDI	-0.11	0.44	0.21	-0.27
SHEI	-0.39	0.17	0.10	-0.26

Table 3-31. Pearson's correlations between landscape pattern metrics calculated at three spatial extents for the sample streams. Some of the metrics descriptors (acronyms) of the columns have been renamed for convenience.

Metric	% Urb[a]	% Ag[b]	% For[c]	% Wet[d]	PD	ED	A_MN[e]	A_CV[f]	SHAP[g]	ENN[h]	CONT[i]	IJI	PR	PRD	SHDI
100-m buffer															
PLAND_Ag	0.12														
PLAND_For	-0.31	-0.62													
PLAND_Wet	-0.36	-0.16	-0.32												
PD	0.08	-0.18	0.17	0.15											
ED	-0.12	-0.33	0.29	0.19	0.68										
AREA_MN	-0.02	0.24	-0.22	-0.19	-0.98	-0.66									
AREA_CV	-0.32	0.01	-0.14	0.42	-0.04	0.04	0.04								
SHAPE_MN	-0.20	-0.08	0.00	0.04	-0.53	0.23	0.56	0.19							
ENN_MN	0.33	0.42	-0.58	0.21	-0.30	-0.40	0.32	0.18	0.04						
CONTAG	-0.20	0.16	0.03	0.07	-0.40	-0.36	0.42	0.43	0.22	0.32					
IJI	0.29	0.20	-0.46	0.08	0.20	-0.27	-0.20	-0.09	-0.55	0.27	-0.51				
PR	0.37	0.36	-0.52	0.24	-0.12	-0.24	0.15	0.24	0.01	0.84	0.30	0.23			
PRD	0.56	0.06	-0.03	-0.28	0.33	0.09	-0.29	-0.66	-0.34	-0.01	-0.29	0.17	0.01		
SHDI	0.56	0.31	-0.53	0.13	0.15	-0.11	-0.14	-0.21	-0.30	0.61	-0.35	0.58	0.72	0.36	
SHEI	0.37	0.02	-0.24	-0.10	0.24	0.06	-0.26	-0.48	-0.33	-0.06	-0.93	0.67	-0.06	0.38	0.59
400-m buffer															
PLAND_Ag	0.02														
PLAND_For	-0.38	-0.74													
PLAND_Wet	-0.23	-0.13	-0.25												
PD	0.18	0.03	-0.18	0.25											
ED	-0.04	-0.21	0.21	0.14	0.81										
AREA_MN	-0.14	-0.01	0.16	-0.28	-0.99	-0.81									
AREA_CV	-0.19	0.26	-0.35	0.40	0.06	-0.20	-0.06								
SHAPE_MN	-0.31	-0.19	0.38	-0.13	-0.63	-0.14	0.65	-0.22							
ENN_MN	0.44	0.27	-0.48	0.13	-0.21	-0.40	0.20	0.19	-0.09						
CONTAG	-0.32	0.10	0.18	-0.21	-0.51	-0.48	0.51	0.42	0.31	0.01					
IJI	0.48	0.25	-0.59	0.24	0.38	0.07	-0.37	-0.06	-0.51	0.37	-0.72				
PR	0.39	0.32	-0.57	0.29	0.07	-0.21	-0.07	0.45	-0.23	0.80	0.04	0.38			
PRD	0.50	-0.04	-0.04	-0.22	0.36	0.23	-0.37	-0.51	-0.38	0.08	-0.35	0.31	-0.05		
SHDI	0.55	0.19	-0.58	0.36	0.34	0.11	-0.35	0.01	-0.36	0.63	-0.64	0.77	0.72	0.24	
SHEI	0.45	0.01	-0.34	0.23	0.40	0.31	-0.40	-0.39	-0.31	0.21	-0.96	0.81	0.16	0.40	0.79

Table 3-31. Continued.

Metric	% Urb[a]	% Ag[b]	% For[c]	% Wet[d]	PD	ED	A_MN[e]	A_CV[f]	SHAP[g]	ENN[h]	CONT[i]	IJI	PR	PRD	SHDI
Watershed															
PLAND_Ag	-0.04														
PLAND_For	-0.41	-0.72													
PLAND_Wet	-0.22	-0.20	-0.17												
PD	0.09	-0.01	-0.28	0.31											
ED	-0.03	-0.25	0.06	0.19	0.83										
AREA_MN	-0.04	0.01	0.30	-0.38	-0.96	-0.82									
AREA_CV	-0.15	0.31	-0.24	0.21	-0.02	-0.43	0.06								
SHAPE_MN	-0.22	-0.20	0.55	-0.41	-0.66	-0.27	0.73	-0.30							
ENN_MN	0.28	0.24	-0.28	-0.15	-0.45	-0.48	0.40	-0.10	0.07						
CONTAG	-0.35	0.05	0.40	-0.21	-0.60	-0.61	0.61	0.46	0.36	0.02					
IJI	0.47	0.23	-0.58	-0.01	0.30	0.03	-0.28	-0.04	-0.44	0.24	-0.68				
PR	0.30	0.24	-0.50	0.18	-0.06	-0.31	-0.01	0.31	-0.31	0.67	-0.11	0.34			
PRD	0.21	-0.21	-0.09	-0.04	0.36	0.54	-0.38	-0.66	-0.19	0.02	-0.37	0.08	-0.29		
SHDI	0.45	0.13	-0.62	0.28	0.29	0.10	-0.35	-0.07	-0.44	0.46	-0.72	0.70	0.76	0.02	
SHEI	0.43	0.02	-0.50	0.20	0.48	0.44	-0.50	-0.41	-0.38	0.15	-0.98	0.76	0.26	0.32	0.82

[a] % Urb = PLAND_Urb; [b] % Ag = PLAND_Ag; [c] % For = PLAND_For; [d] % Wet = PLAND_WET; [e] A_MN = Area_MN; [f] A_CV = AREA_CV; [g] SHAP = SHAPE_MN; [h] ENN = ENN_MN; [i] CONT = CONTAG.

Table 3-32. Eigenvalues and variance explained by the first six axes for the principal components analysis at three different spatial extents for streams.

Component	1	2	3	4	5	6
100-meter buffer						
Eigenvalue	4.21	3.06	1.91	1.32	0.94	0.86
% of variance explained	30.05	21.87	13.62	9.39	6.71	6.17
Cumulative % of variance	30.05	51.92	65.54	74.93	81.64	87.82
400-meter buffer						
Eigenvalue	4.84	2.91	1.97	1.35	0.96	0.69
% of variance explained	34.56	20.75	14.05	9.62	6.83	4.94
Cumulative % of variance	34.56	55.31	69.36	78.98	85.81	90.75
Watershed						
Eigenvalue	4.42	3.22	2.14	1.25	0.94	0.81
% of Variance explained	31.59	23.00	15.30	8.89	6.71	5.76
Cumulative % of variance	31.59	54.60	69.90	78.79	85.49	91.25

Table 3-33. The 100-meter spatial extent for streams: principal component matrices showing pattern metric factor loadings.

Metric	DIVERS	SIZE	WET	HETER
PLAND_Urb	-0.32	0.17	0.18	-0.34
PLAND_Ag	-0.25	-0.18	0.18	0.10
PLAND_For	0.35	0.23	0.08	-0.06
PLAND_Wet	-0.01	-0.22	-0.55	0.03
PD	-0.01	0.35	-0.49	-0.11
ED	0.18	0.21	-0.41	-0.45
AREA_CV	0.10	-0.38	-0.34	0.08
SHAPE_MN	0.19	-0.28	0.16	-0.43
ENN_MN	-0.34	-0.32	0.01	-0.18
IJI	-0.34	0.12	-0.18	0.44
PR	-0.33	-0.28	-0.11	-0.30
PRD	-0.20	0.38	0.14	-0.29
SHDI	-0.44	0.04	-0.14	-0.16
SHEI	-0.26	0.33	-0.07	0.18

Table 3-34. The 400-meter spatial extent for streams: principal component matrices showing pattern metric factor loadings.

Metric	DIVERS	HETER	WET	AG
PLAND_Urb	-0.29	0.09	-0.36	-0.05
PLAND_Ag	-0.17	-0.25	0.01	-0.56
PLAND_For	0.34	0.23	-0.06	0.27
PLAND_Wet	-0.14	-0.08	0.47	0.45
PD	-0.21	0.35	0.40	-0.19
ED	-0.03	0.43	0.33	0.03
AREA_CV	-0.05	-0.38	0.44	-0.11
SHAPE_MN	0.27	-0.13	-0.20	0.36
ENN_MN	-0.28	-0.30	-0.23	0.20
IJI	-0.39	0.10	-0.03	0.04
PR	-0.31	-0.31	0.02	0.15
PRD	-0.17	0.35	-0.28	-0.19
SHDI	-0.42	0.00	-0.03	0.27
SHEI	-0.33	0.27	-0.08	0.24

Table 3-35. The watershed spatial extent for streams: principal component matrices showing pattern metric factor loadings.

Metric	DIVERS	HETER	WET	AG
PLAND_Urb	-0.24	0.12	-0.29	0.05
PLAND_Ag	-0.06	0.34	0.03	0.57
PLAND_For	0.30	-0.36	-0.07	-0.23
PLAND_Wet	-0.12	-0.01	0.40	-0.49
PD	-0.33	-0.18	0.37	0.13
ED	-0.25	-0.39	0.20	0.04
AREA_CV	0.09	0.33	0.38	0.15
SHAPE_MN	0.32	-0.09	-0.32	-0.12
ENN_MN	-0.05	0.27	-0.46	-0.14
IJI	-0.35	0.22	-0.10	-0.05
PR	-0.26	-0.35	-0.21	0.26
PRD	-0.23	-0.37	-0.23	0.20
SHDI	-0.36	0.23	-0.09	-0.36
SHEI	-0.42	0.02	-0.10	-0.24

Table 3-36. Coefficients of determination, probabilities, and regression equations for multiple regressions between indicators of ecosystem condition and significant components resulting from the PCA of landscape pattern metrics at four grain sizes for the sample streams (α – level of 0.05). Components that were significantly related to the dependent variable ($p < 0.05$) are indicated with an asterisk in the regression equation.

Variable (Y)	n	R^2 (adj)	p	Regression equation
20-meter				
Water chemistry				
Log_{10}(Turbidity)	32	0.00	0.664	Y = 0.339 + 0.0228(DIVERS1) - 0.0468(DIVERS2) - 0.0662(WET) + 0.0367(DIST)
DO	36	0.18	0.033	Y = 6.33 + 0.265(DIVERS1) + 0.183(DIVERS2) - 0.397(WET) + 0.309(DIST)
$Log_{10}(NO_3\text{-}N)$	45	0.12	0.055	Y = - 0.952 - 0.124(DIVERS1)* + 0.0303(DIVERS2) + 0.106(WET) - 0.0998(DIST)
Log_{10}(TN)	46	0.60	<0.001	Y = - 0.0806 - 0.0621(DIVERS1)* - 0.0608(DIVERS2)* - 0.036(WET) - 0.0614(DIST)*
Log_{10}(TP)	46	0.42	<0.001	Y = - 1.28 - 0.0553(DIVERS1) - 0.0776(DIVERS2) - 0.0992(WET) - 0.193(DIST)*
WQI	36	0.11	0.105	Y = 35.0 - 0.343(DIVERS1) - 0.74(DIVERS2) + 0.93(WET) - 3.09(DIST)*
SCI				
SCI_1	66	0.01	0.354	Y = 28.5 + 0.372(DIVERS1) + 0.157(DIVERS2) - 0.120(WET) + 0.235(DIST)
SCI_2	67	0.03	0.205	Y = 61.8 + 1.89(DIVERS1) + 1.03(DIVERS2) – 3.03(WET) + 0.71(DIST)
50-meter				
Water chemistry				
Log_{10}(Turbidity)	32	0.00	0.769	Y = 0.36 + 0.0278(DIVERS1) + 0.0405(DIVERS2) - 0.0572(WET) + 0.0156(SHAPE)
DO	36	0.20	0.028	Y = 6.37 + 0.196(DIVERS1) - 0.248(DIVERS2) - 0.466(WET) + 0.224(SHAPE)
$Log_{10}(NO_3\text{-}N)$	45	0.13	0.049	Y = - 0.958 - 0.123(DIVERS1)* - 0.009(DIVERS2) + 0.118(WET) - 0.101(SHAPE)
Log_{10}(TN)	46	0.57	<0.001	Y= - 0.0874 - 0.0502(DIVERS1)* + 0.074(DIVERS2)* - 0.137(WET) - 0.0578(SHAPE)*
Log_{10}(TP)	46	0.41	<0.001	Y = - 1.29 - 0.0359(DIVERS1) + 0.0913(DIVERS2)* - 0.0421(WET) - 0.212(SHAPE)*
WQI	36	0.14	0.068	Y = 34.5 + 0.188(DIVERS1) _ 1.06(DIVERS2) + 1.95(WET) - 2.87(SHAPE)
SCI				
SCI_1	66	0.01	0.342	Y = 28.5 + 0.356(DIVERS1) - 0.188(DIVERS2) - 0.081(WET) + 0.27(SHAPE)
SCI_2	67	0.02	0.272	Y = 61.8 + 1.68(DIVERS1) – 1.23(DIVERS2) – 2.7(WET)* + 0.42(SHAPE)

Table 3-36. Continued.

Variable (Y)	n	R^2 (adj)	p	Regression equation
80-meter				
Water chemistry				
Log_{10}(Turbidity)	32	0.00	0.735	Y = 0.343 + 0.0447(DIVERS1) + 0.0186(DIVERS2) + 0.0652(URB) - 0.0109(SHAPE)
DO	36	0.19	0.032	Y = 6.38 + 0.076(DIVERS1) - 0.339(DIVERS2)* + 0.483(URB) - 0.024(SHAPE)
$Log_{10}(NO_3$-N)	45	0.12	0.057	Y = - 0.962 - 0.106(DIVERS1) + 0.0557(DIVERS2) - 0.124(URB) - 0.0764(SHAPE)
Log_{10}(TN)	46	0.54	<0.001	Y = - 0.0898 - 0.0037(DIVERS1)* + 0.0934(DIVERS2)* + 0.001(URB) - 0.0573(SHAPE)*
Log_{10}(TP)	46	0.36	<0.001	Y = - 1.29 - 0.0249(DIVERS1) + 0.108(DIVERS2)* - 0.0136(URB) - 0.208(SHAPE)*
WQI	36	0.11	0.106	Y = 34.6 + 0.64(DIVERS1) + 0.904(DIVERS2) - 2.51(URB) - 2.91(SHAPE)
SCI				
SCI_1	66	0.01	0.337	Y = 28.5 + 0.205(DIVERS1) - 0.361(DIVERS2) + 0.086(URB) + 0.265(SHAPE)
SCI_2	67	0.02	0.288	Y = 61.8 + 1.13(DIVERS1) – 2.02(DIVERS2) + 2.39(URB) - 0.42(SHAPE)
110-meter				
Water chemistry				
Log_{10}(Turbidity)	32	0.00	0.701	Y = 0.343 + 0.0382(DIVERS1) + 0.0224(DIVERS2) + 0.0575(URB) + 0.0403(SHAPE)
DO	36	0.22	0.020	Y = 6.42 + 0.039(DIVERS1) - 0.326(DIVERS2)* + 0.505(URB) + 0.210(SHAPE)
$Log_{10}(NO_3$-N)	45	0.13	0.049	Y = - 0.962 - 0.0983(DIVERS1) + 0.0441(DIVERS2) - 0.152(URB) + 0.0666(SHAPE)
Log_{10}(TN)	46	0.52	<0.001	Y = - 0.0947 - 0.0044(DIVERS1) + 0.0953(DIVERS2)* - 0.0122(URB) + 0.043(SHAPE)
Log_{10}(TP)	46	0.32	<0.001	Y = - 1.30 + 0.0318(DIVERS1) + 0.118(DIVERS2)* - 0.044(URB) + 0.176(SHAPE)*
WQI	36	0.14	0.066	Y = 34.6 + 0.68(DIVERS1) + 0.883(DIVERS2) - 3.18(URB) - 1.28(SHAPE)
SCI				
SCI_1	66	0.01	0.376	Y = 28.5 + 0.177(DIVERS1) - 0.330(DIVERS2) + 0.190(URB) - 0.266(SHAPE)
SCI_2	67	0.02	0.298	Y = 61.8 + 1.06(DIVERS1) - 1.78(DIVERS2) + 2.76(URB) + 0.76(SHAPE)

Table 3-37. Coefficients of determination, probabilities, and regression equations for multiple regressions between indicators of ecosystem condition and significant components resulting from the PCA of landscape pattern metrics at three spatial extents for the sample streams (α – level of 0.05). Components that were significantly related to the dependent variable ($p < 0.05$) are indicated with an asterisk in the regression equation.

Variable (Y)	n	R^2 (adj)	p	Regression equation
100-meter				
Water chemistry				
Log_{10}(Turbidity)	34	0.24	0.016	Y = 0.354 + 0.0954(DIVERS)* - 0.0909(SIZE)* - 0.0416(WET) - 0.0577(HETER)
DO	35	0.34	0.002	Y = 6.16 + 0.44(DIVERS)* - 0.051(SIZE) - 0.512(WET)* + 0.14(HETER)
$Log_{10}(NO_3$-N)	41	0.00	0.549	Y = - 0.998 - 0.0399(DIVERS) - 0.0475(SIZE) - 0.0378(WET) - 0.0891(HETER)
Log_{10}(TN)	43	0.35	<0.001	Y = - 0.0744 - 0.076(DIVERS)* - 0.0328(SIZE) + 0.0136(WET) - 0.0259(HETER)
Log_{10}(TP)	43	0.18	0.021	Y = - 1.32 - 0.0652(DIVERS) - 0.112(SIZE) - 0.0715(WET) + 0.0583(HETER)
WQI	35	0.13	0.086	Y = 35.3 - 0.37(DIVERS) – 1.33(SIZE) + 0.25(WET)* + 0.06(HETER)
SCI				
SCI_1	62	0.17	0.005	Y = 28.4 + 0.658(DIVERS)* - 0.32(SIZE) - 0.561(WET) + 0.175(HETER)
SCI_2	63	0.22	0.001	Y = 61.7 + 3.5(DIVERS)* - 1.43(SIZE) - 4.87(WET)* + 1.20(HETER)
400-meter				
Water chemistry				
Log_{10}(Turbidity)	34	0.00	0.713	Y = 0.405 + 0.0421(DIVERS) - 0.0105(HETER) + 0.0311(WET) + 0.0011(AG)
DO	35	0.22	0.020	Y = 6.30 + 0.294(DIVERS)* + 0.252(HETER) + 0.236(WET) + 0.342(AG)
$Log_{10}(NO_3$-N)	42	0.08	0.139	Y = - 0.931 - 0.101(DIVERS)* + 0.0312(HETER) - 0.0225(WET) - 0.122(AG)
Log_{10}(TN)	43	0.53	<0.001	Y= - 0.0730 - 0.0710(DIVERS)* - 0.0409(HETER)* + 0.0361(WET) - 0.0447(AG)
Log_{10}(TP)	43	0.41	<0.001	Y = - 1.29 - 0.0565(DIVERS) - 0.0874(HETER)* + 0.148(WET)* - 0.150(AG)*
WQI	35	0.29	0.006	Y = 35.6 - 0.496(DIVERS) - 1.60(HETER) - 0.84(WET) - 4.38(AG)*
SCI				
SCI_1	62	0.08	0.077	Y = 28.4 + 0.484(DIVERS)* + 0.002(HETER) + 0.405(WET) + 0.405(AG)
SCI_2	63	0.11	0.027	Y = 61.7 + 2.32(DIVERS)* + 0.2.32(HETER) + 3.71(WET)* + 2.91(AG)

Table 3-37. Continued.

Variable (Y)	n	R^2 (adj)	p	Regression equation
Watershed				
Water chemistry				
Log_{10}(Turbidity)	34	0.00	0.893	Y = 0.430 + 0.0158(DIVERS) - 0.0274(HETER) + 0.0036(WET) + 0.0017(AG)
DO	35	0.18	0.043	Y = 6.40 + 0.267(DIVERS) - 0.336(HETER)* + 0.146(WET) - 0.259(AG)
$Log_{10}(NO_3\text{-}N)$	42	0.24	0.007	Y = - 0.968 - 0.133(DIVERS)* - 0.0202(HETER) - 0.0698(WET) - 0.251(AG)
Log_{10}(TN)	43	0.59	<0.001	Y = -0.0738 - 0.0687(DIVERS)* - 0.0618(HETER)* + 0.0451(WET)* + 0.0346(AG)
Log_{10}(TP)	43	0.44	<0.001	Y = - 1.29 - 0.0398(DIVERS) + 0.104(HETER)* + 0.165(WET)* + 0.1294(AG)*
WQI	35	0.17	0.046	Y = 35.2 - 0.712(DIVERS) +1.26(HETER) - 0.11(WET) + 3.96(AG)*
SCI				
SCI_1	62	0.06	0.123	Y = 28.4 + 0.429(DIVERS)* - 0.202(HETER) + 0.145(WET) - 0.513(AG)
SCI_2	63	0.07	0.083	Y = 61.7 + 2.17(DIVERS) – 1.50(HETER) + 2.56(WET) – 2.58(AG)

Table 3-38. Pearson's correlations between landscape pattern metrics calculated at four different grain sizes (meters on a side) for the sample lakes. Some of the metrics descriptors (acronyms) of the columns have been renamed for convenience.

Metric	% Urb[a]	% Ag[b]	% For[c]	% Wet[d]	PD	ED	A_MN[e]	A_CV[f]	SHAP[g]	ENN[h]	CONT[i]	IJI	PR	PRD	SHDI
20-m															
PLAND_Ag	-0.31														
PLAND_For	-0.57	-0.08													
PLAND_Wet	-0.69	-0.02	0.35												
PD	0.10	0.00	0.02	-0.03											
ED	-0.09	-0.05	0.21	0.16	0.56										
AREA_MN	-0.10	0.00	-0.02	0.03	-1.00	-0.56									
AREA_CV	-0.04	-0.12	-0.23	0.39	-0.04	-0.11	0.04								
SHAPE_MN	-0.33	0.04	0.38	0.07	-0.31	0.29	0.31	-0.26							
ENN_MN	0.17	0.21	-0.08	-0.16	-0.45	-0.29	0.45	-0.03	-0.01						
CONTAG	0.32	-0.30	-0.21	-0.23	-0.43	-0.68	0.43	0.28	-0.12	0.09					
IJI	-0.09	0.32	0.06	-0.06	0.27	0.29	-0.27	-0.13	0.01	0.23	-0.56				
PR	0.21	-0.03	0.06	0.11	0.02	0.32	-0.02	0.38	-0.01	0.47	-0.15	0.28			
PRD	0.19	0.07	0.01	-0.45	0.53	0.11	-0.53	-0.68	-0.11	-0.25	-0.12	0.10	-0.46		
SHDI	-0.04	0.19	0.15	0.21	0.23	0.56	-0.23	0.08	0.01	0.33	-0.72	0.54	0.78	-0.25	
SHEI	-0.30	0.33	0.18	0.22	0.36	0.55	-0.36	-0.25	0.05	0.04	-0.98	0.58	0.23	0.07	0.78
40-m															
PLAND_Ag	-0.31														
PLAND_For	-0.57	-0.07													
PLAND_Wet	-0.67	-0.05	0.35												
PD	0.10	0.06	0.02	-0.14											
ED	-0.11	-0.04	0.24	0.19	0.53										
AREA_MN	-0.14	0.00	-0.06	0.15	-0.96	-0.52									
AREA_CV	0.06	-0.20	-0.24	0.28	-0.18	-0.08	0.15								
SHAPE_MN	-0.46	0.05	0.38	0.32	-0.52	0.14	0.55	-0.03							
ENN_MN	0.19	0.03	-0.08	-0.02	-0.37	-0.18	0.36	0.18	0.01						
CONTAG	0.31	-0.27	-0.24	-0.21	-0.49	-0.71	0.45	0.35	-0.02	0.08					
IJI	-0.04	0.25	0.05	-0.06	0.31	0.31	-0.37	-0.09	-0.12	0.22	-0.52				
PR	0.21	-0.05	0.05	0.12	-0.03	0.36	-0.01	0.44	0.07	0.60	-0.11	0.26			
PRD	0.16	0.12	0.02	-0.44	0.61	0.05	-0.63	-0.65	-0.45	-0.39	-0.14	0.14	-0.46		
SHDI	-0.03	0.16	0.15	0.21	0.22	0.61	-0.22	0.07	0.03	0.46	-0.68	0.50	0.78	-0.25	
SHEI	-0.27	0.31	0.19	0.20	0.39	0.56	-0.35	-0.33	-0.03	0.10	-0.96	0.54	0.20	0.08	0.76

Table 3-38. Continued.

Metric	% Urb[a]	% Ag[b]	% For[c]	% Wet[d]	PD	ED	A_MN[e]	A_CV[f]	SHAP[g]	ENN[h]	CONT[i]	IJI	PR	PRD	SHDI
60-m															
PLAND_Ag	-0.30														
PLAND_For	-0.58	-0.08													
PLAND_Wet	-0.69	-0.02	0.36												
PD	0.06	0.14	0.03	-0.19											
ED	-0.17	-0.04	0.27	0.26	0.45										
AREA_MN	-0.09	-0.11	-0.05	0.20	-0.96	-0.46									
AREA_CV	0.04	-0.13	-0.26	0.21	-0.28	-0.06	0.21								
SHAPE_MN	-0.50	-0.05	0.40	0.50	-0.64	0.05	0.67	-0.04							
ENN_MN	0.30	-0.02	-0.09	-0.10	-0.24	-0.03	0.25	0.19	-0.10						
CONTAG	0.27	-0.21	-0.24	-0.20	-0.54	-0.70	0.49	0.42	0.03	0.01					
IJI	0.09	0.16	-0.05	-0.17	0.50	0.30	-0.55	-0.10	-0.46	0.21	-0.51				
PR	0.15	0.04	0.05	0.13	-0.03	0.40	-0.04	0.48	-0.09	0.61	-0.08	0.23			
PRD	0.15	0.13	0.02	-0.44	0.64	-0.02	-0.64	-0.64	-0.49	-0.37	-0.18	0.27	-0.45		
SHDI	-0.04	0.18	0.16	0.22	0.23	0.63	-0.26	0.08	-0.07	0.51	-0.63	0.45	0.79	-0.23	
SHEI	-0.21	0.26	0.19	0.19	0.43	0.54	-0.39	-0.40	-0.05	0.17	-0.95	0.51	0.17	0.13	0.72
80-m															
PLAND_Ag	-0.31														
PLAND_For	-0.57	-0.07													
PLAND_Wet	-0.66	-0.05	0.32												
PD	0.06	0.10	0.16	-0.19											
ED	-0.24	-0.02	0.34	0.28	0.42										
AREA_MN	-0.06	-0.10	-0.16	0.19	-1.00	-0.42									
AREA_CV	0.02	-0.11	-0.20	0.26	-0.25	-0.06	0.25								
SHAPE_MN	-0.53	-0.12	0.32	0.52	-0.49	0.32	0.49	0.00							
ENN_MN	0.19	0.12	-0.12	-0.03	-0.35	-0.08	0.35	0.21	-0.03						
CONTAG	0.27	-0.30	-0.21	-0.17	-0.38	-0.62	0.38	0.36	-0.14	0.00					
IJI	0.10	0.22	-0.12	-0.10	0.47	0.34	-0.47	-0.02	-0.30	0.23	-0.44				
PR	0.14	0.03	0.08	0.13	-0.02	0.36	0.02	0.47	0.02	0.60	-0.06	0.27			
PRD	0.15	0.10	0.04	-0.42	0.69	-0.03	-0.69	-0.64	-0.48	-0.42	-0.09	0.18	-0.42		
SHDI	-0.07	0.19	0.18	0.21	0.19	0.62	-0.19	0.10	0.16	0.48	-0.60	0.45	0.79	-0.23	
SHEI	-0.24	0.28	0.20	0.18	0.34	0.57	-0.34	-0.36	0.18	0.12	-0.93	0.43	0.18	0.09	0.73

[a] % Urb = PLAND_Urb; [b] % Ag = PLAND_Ag; [c] % For = PLAND_For; [d] % Wet = PLAND_WET; [e] A_MN = Area_MN; [f] A_CV = AREA_CV; [g] SHAP = SHAPE_MN; [h] ENN = ENN_MN; [i] CONT = CONTAG.

Table 3-39. Eigenvalues and variance explained by the first six axes for the principal components analysis at four different grain sizes (meters on a side) for lakes watersheds.

Component	1	2	3	4	5	6
20-m						
Eigenvalue	3.722	2.898	2.193	1.601	1.309	0.69
% of variance explained	26.587	20.702	15.666	11.434	9.351	4.927
Cumulative % of variance	26.587	47.289	62.954	74.388	83.739	88.666
40-m						
Eigenvalue	3.451	3.014	2.478	1.412	1.044	0.757
% of variance explained	24.649	21.53	17.699	10.084	7.456	5.409
Cumulative % of variance	24.649	46.179	63.878	73.962	81.419	86.828
60-m						
Eigenvalue	3.458	3.249	2.65	1.147	1.077	0.677
% of variance explained	24.703	23.207	18.928	8.193	7.694	4.838
Cumulative % of variance	24.703	47.909	66.837	75.031	82.725	87.563
80 x 80-m						
Eigenvalue	3.564	3.045	2.586	1.25	1.035	0.799
% of variance explained	25.456	21.748	18.47	8.925	7.391	5.708
Cumulative % of variance	25.456	47.204	65.674	74.6	81.99	87.698

Table 3-40. The 20 x 20-m grain size for lake watersheds: principal component matrices showing pattern metric factor loadings.

Metric	DIVERS1	DIVERS2	URB/SIZE	WET	AG
PLAND_Urb	0.10	-0.33	-0.43	0.23	0.29
PLAND_Ag	-0.13	0.04	0.15	0.34	-0.59
PLAND_For	-0.14	0.20	0.40	-0.17	0.27
PLAND_Wet	-0.10	0.40	0.10	-0.44	-0.18
PD	-0.36	-0.32	-0.07	-0.34	-0.04
ED	-0.41	0.01	0.02	-0.11	0.35
AREA_CV	0.07	0.27	-0.43	-0.34	-0.18
SHAPE_MN	-0.01	0.21	0.38	0.19	0.42
ENN_MN	0.36	0.32	0.07	0.34	0.04
IJI	-0.34	0.01	-0.02	0.33	-0.19
PR	-0.21	0.26	-0.41	0.17	0.25
PRD	-0.10	-0.50	0.26	0.01	0.00
SHDI	-0.41	0.22	-0.21	0.22	0.07
SHEI	-0.43	0.09	0.09	0.17	-0.15

Table 3-41. The 40 x 40-m grain size for lake watersheds: principal component matrices showing pattern metric factor loadings.

Metric	DIVERS1	DIVERS2	URB	AG	SIZE
PLAND_Urb	0.17	0.10	0.53	0.09	0.26
PLAND_Ag	-0.11	0.13	-0.11	-0.57	-0.45
PLAND_For	-0.19	-0.03	-0.40	0.09	0.42
PLAND_Wet	-0.23	-0.25	-0.32	0.22	-0.32
PD	-0.11	0.47	0.04	0.34	-0.19
ED	-0.36	0.19	-0.06	0.39	0.13
AREA_CV	-0.05	-0.35	0.23	0.33	-0.46
SHAPE_MN	-0.12	-0.30	-0.33	-0.12	0.33
ENN_MN	-0.19	-0.22	0.34	-0.37	0.20
IJI	-0.30	0.22	0.11	-0.22	-0.09
PR	-0.36	-0.18	0.34	0.09	0.13
PRD	0.16	0.50	-0.07	-0.04	0.12
SHDI	-0.50	0.04	0.18	-0.02	0.06
SHEI	-0.41	0.25	-0.07	-0.14	-0.06

Table 3-42. The 60 x 60-m grain size for lake watersheds: principal component matrices showing pattern metric factor loadings.

Metric	DIVERS1	DIVERS2	URB	AG	SIZE
PLAND_Urb	0.01	-0.27	0.45	-0.19	0.24
PLAND_Ag	-0.13	-0.03	-0.12	0.79	-0.26
PLAND_For	-0.08	0.20	-0.37	-0.21	0.29
PLAND_Wet	-0.03	0.40	-0.25	-0.07	-0.26
PD	-0.33	-0.32	-0.14	-0.21	-0.30
ED	-0.38	0.12	-0.14	-0.39	-0.10
AREA_CV	0.08	0.26	0.36	-0.11	-0.56
SHAPE_MN	0.19	0.39	-0.24	0.06	0.28
ENN_MN	-0.18	0.16	0.39	0.21	0.43
IJI	-0.38	-0.16	0.06	0.08	-0.07
PR	-0.30	0.27	0.33	-0.06	-0.03
PRD	-0.08	-0.47	-0.22	-0.03	0.06
SHDI	-0.47	0.21	0.10	0.04	0.09
SHEI	-0.43	0.03	-0.19	0.15	0.18

Table 3-43. The 80 x 80-m grain size for lake watersheds: principal component matrices showing pattern metric factor loadings.

Metric	DIVERS	HETER	URB	AG	SIZE
PLAND_Urb	0.24	-0.09	-0.45	0.24	-0.31
PLAND_Ag	-0.09	-0.15	-0.01	-0.73	0.34
PLAND_For	-0.21	-0.03	0.36	0.18	-0.05
PLAND_Wet	-0.30	0.22	0.26	0.05	0.29
PD	0.00	-0.50	0.06	0.27	0.29
ED	-0.37	-0.22	0.12	0.32	-0.04
AREA_CV	-0.11	0.31	-0.27	0.23	0.57
SHAPE_MN	-0.26	0.28	0.31	-0.02	-0.32
ENN_MN	-0.21	0.11	-0.41	-0.27	-0.26
IJI	-0.17	-0.35	-0.22	-0.05	0.21
PR	-0.36	0.03	-0.37	0.17	0.03
PRD	0.25	-0.44	0.15	0.01	-0.02
SHDI	-0.46	-0.17	-0.19	0.01	-0.13
SHEI	-0.34	-0.31	0.08	-0.19	-0.25

Table 3-44. Pearson's correlations between landscape pattern metrics calculated at three spatial extents for the sample lakes. Some of the metrics descriptors (acronyms) of the columns have been renamed for convenience.

Metric	% Urb[a]	% Ag[b]	% For[c]	% Wet[d]	PD	ED	A_MN[e]	A_CV[f]	SHAP[g]	ENN[h]	CONT[i]	IJI	PR	PRD	SHDI
100-m buffer															
PLAND_Ag	-0.27														
PLAND_For	-0.44	0.11													
PLAND_Wet	-0.53	-0.03	-0.09												
PD	-0.29	0.17	0.17	0.25											
ED	-0.40	0.28	0.14	0.18	0.59										
AREA_MN	0.19	-0.18	-0.21	-0.08	-0.92	-0.58									
AREA_CV	-0.06	-0.45	-0.08	0.29	0.09	-0.25	-0.06								
SHAPE_MN	-0.13	0.13	-0.15	0.09	-0.51	0.32	0.51	-0.37							
ENN_MN	0.35	-0.13	-0.15	0.00	-0.34	-0.40	0.26	0.15	-0.06						
CONTAG	0.36	-0.51	-0.06	-0.15	-0.51	-0.77	0.49	0.55	-0.25	0.32					
IJI	0.27	0.18	0.09	-0.21	0.23	0.23	-0.23	-0.27	-0.13	0.15	-0.28				
PR	0.15	-0.18	0.04	0.19	0.18	0.07	-0.27	0.47	-0.18	0.46	0.17	0.19			
PRD	0.07	0.31	0.23	-0.39	0.36	0.45	-0.40	-0.72	0.02	-0.34	-0.51	0.37	-0.21		
SHDI	-0.03	0.22	0.11	0.14	0.45	0.45	-0.52	-0.13	-0.06	0.29	-0.56	0.39	0.65	0.26	
SHEI	-0.23	0.51	0.03	0.09	0.44	0.58	-0.43	-0.58	0.16	-0.13	-0.95	0.31	-0.07	0.49	0.69
400-m buffer															
PLAND_Ag	-0.31														
PLAND_For	-0.56	-0.08													
PLAND_Wet	-0.57	-0.02	0.16												
PD	-0.15	0.13	0.11	0.13											
ED	-0.17	0.04	0.22	0.11	0.60										
AREA_MN	0.16	-0.14	-0.13	-0.14	-0.99	-0.62									
AREA_CV	0.08	-0.23	-0.31	0.37	0.04	-0.13	-0.05								
SHAPE_MN	-0.14	0.00	0.14	0.05	-0.37	0.29	0.34	-0.07							
ENN_MN	0.28	0.03	-0.16	0.03	-0.37	-0.10	0.36	0.09	0.24						
CONTAG	0.42	-0.43	-0.24	-0.13	-0.48	-0.65	0.50	0.38	-0.15	-0.03					
IJI	-0.15	0.40	0.16	-0.02	0.22	0.32	-0.26	-0.17	0.20	0.30	-0.58				
PR	0.22	-0.10	0.05	0.20	0.06	0.35	-0.09	0.32	0.07	0.53	-0.11	0.34			
PRD	0.06	0.13	0.11	-0.43	0.39	0.17	-0.39	-0.66	-0.22	-0.35	-0.26	0.12	-0.43		
SHDI	-0.11	0.23	0.17	0.19	0.32	0.57	-0.34	-0.07	0.07	0.41	-0.74	0.59	0.73	-0.10	
SHEI	-0.38	0.46	0.20	0.12	0.40	0.51	-0.41	-0.38	0.09	0.12	-0.98	0.59	0.15	0.22	0.78

Table 3-44. Continued.

Metric	% Urb[a]	% Ag[b]	% For[c]	% Wet[d]	PD	ED	A_MN[e]	A_CV[f]	SHAP[g]	ENN[h]	CONT[i]	IJI	PR	PRD	SHDI
Watershed															
PLAND_Ag	-0.28														
PLAND_For	-0.62	-0.09													
PLAND_Wet	-0.66	-0.05	0.36												
PD	0.01	0.11	0.02	0.06											
ED	-0.14	0.00	0.23	0.19	0.54										
AREA_MN	0.01	-0.09	-0.07	-0.08	-0.97	-0.54									
AREA_CV	0.02	-0.08	-0.27	0.33	-0.07	-0.17	0.10								
SHAPE_MN	-0.29	-0.05	0.39	0.07	-0.31	0.33	0.29	-0.25							
ENN_MN	0.18	0.13	-0.07	-0.15	-0.41	-0.25	0.41	0.05	-0.07						
CONTAG	0.36	-0.36	-0.21	-0.23	-0.42	-0.67	0.43	0.31	-0.15	0.06					
IJI	-0.19	0.35	0.12	0.05	0.26	0.33	-0.31	-0.13	-0.01	0.22	-0.59				
PR	0.17	-0.03	0.08	0.14	-0.01	0.29	0.03	0.35	0.01	0.56	-0.15	0.32			
PRD	0.11	0.07	0.08	-0.34	0.50	0.12	-0.56	-0.70	-0.13	-0.29	-0.14	0.11	-0.48		
SHDI	-0.10	0.22	0.16	0.23	0.22	0.54	-0.20	0.04	0.04	0.41	-0.72	0.58	0.78	-0.25	
SHEI	-0.33	0.39	0.17	0.22	0.34	0.55	-0.34	-0.28	0.07	0.08	-0.98	0.61	0.22	0.08	0.78

[a] % Urb = PLAND_Urb; [b] % Ag = PLAND_Ag; [c] % For = PLAND_For; [d] % Wet = PLAND_WET; [e] A_MN = Area_MN; [f] A_CV = AREA_CV; [g] SHAP = SHAPE_MN; [h] ENN = ENN_MN; [i] CONT = CONTAG.

Table 3-45. Eigenvalues and variance explained by the first six axes for the principal components analysis at three different spatial extents for lakes.

Component	1	2	3	4	5	6
100-meter buffer						
Eigenvalue	3.83	2.487	2.215	1.586	1.069	0.877
% of variance explained	27.359	17.764	15.822	11.331	7.632	6.264
Cumulative % of variance	27.359	45.123	60.945	72.276	79.908	86.172
400-meter buffer						
Eigenvalue	3.676	2.736	1.953	1.626	1.249	0.878
% of variance explained	26.256	19.544	13.952	11.613	8.92	6.268
Cumulative % of variance	26.256	45.8	59.751	71.365	80.284	86.552
Watershed						
Eigenvalue	3.604	2.683	2.202	1.576	1.346	0.841
% of variance explained	25.742	19.162	15.729	11.258	9.616	6.004
Cumulative % of variance	25.742	44.904	60.633	71.89	81.507	87.511

Table 3-46. The 100-m spatial extent for lakes: principal component matrices showing pattern metric factor loadings.

Metric	DIVERS1	DIVERS2	URB	SHAPE	FOR
PLAND_Urb	0.17	-0.07	0.55	0.06	0.31
PLAND_Ag	-0.30	-0.11	-0.02	-0.14	-0.21
PLAND_For	-0.14	0.04	-0.14	0.32	-0.76
PLAND_Wet	0.00	0.30	-0.41	-0.30	0.12
PD	-0.30	0.32	-0.14	0.36	0.30
ED	-0.40	0.10	-0.17	-0.10	0.21
AREA_CV	0.32	0.39	-0.19	0.14	0.09
SHAPE_MN	-0.06	-0.27	-0.09	-0.61	-0.04
ENN_MN	0.18	0.24	0.36	-0.31	-0.29
IJI	-0.22	0.10	0.39	0.10	-0.03
PR	0.04	0.53	0.19	-0.12	-0.12
PRD	-0.38	-0.20	0.19	0.23	0.04
SHDI	-0.30	0.40	0.22	-0.19	-0.07
SHEI	-0.44	0.04	0.06	-0.21	0.09

Table 3-47. The 400-m spatial extent for lakes: principal component matrices showing pattern metric factor loadings.

Metric	DIVERS1	DIVERS2	WET	HETER	AG
PLAND_Urb	0.21	0.14	-0.54	0.27	0.15
PLAND_Ag	-0.22	-0.13	-0.08	-0.21	-0.63
PLAND_For	-0.19	-0.14	0.30	-0.23	0.41
PLAND_Wet	-0.12	0.21	0.55	0.02	-0.16
PD	-0.26	-0.22	0.11	0.56	-0.02
ED	-0.37	-0.04	0.04	0.22	0.38
AREA_CV	0.13	0.39	0.26	0.32	-0.16
SHAPE_MN	-0.10	0.15	0.01	-0.50	0.36
ENN_MN	-0.10	0.41	-0.31	-0.21	-0.07
IJI	-0.38	0.04	-0.20	-0.12	-0.14
PR	-0.23	0.44	-0.11	0.20	0.17
PRD	-0.07	-0.50	-0.25	0.09	0.10
SHDI	-0.45	0.20	-0.12	0.10	0.01
SHEI	-0.46	-0.10	-0.06	-0.06	-0.16

Table 3-48. The watershed spatial extent for lakes: principal component matrices showing pattern metric factor loadings.

Metric	DIVERS1	DIVERS2	URB	HETER	AG
PLAND_Urb	0.23	0.13	0.49	-0.02	-0.35
PLAND_Ag	-0.18	-0.06	0.14	0.12	0.63
PLAND_For	-0.21	-0.15	-0.40	0.21	-0.13
PLAND_Wet	-0.21	0.08	-0.45	-0.32	0.13
PD	-0.19	-0.32	0.22	-0.49	-0.08
ED	-0.36	-0.18	0.02	-0.17	-0.42
AREA_CV	0.05	0.42	-0.12	-0.48	0.09
SHAPE_MN	-0.11	-0.07	-0.33	0.41	-0.33
ENN_MN	-0.09	0.39	0.20	0.40	0.09
IJI	-0.37	-0.02	0.21	0.09	0.19
PR	-0.28	0.41	0.13	-0.01	-0.27
PRD	0.04	-0.51	0.25	0.08	-0.01
SHDI	-0.47	0.19	0.16	0.01	-0.10
SHEI	-0.45	-0.11	0.12	0.03	0.14

Table 3-49. Coefficients of determination, probabilities, and regression equations for multiple regressions between indicators of ecosystem condition and significant components resulting from the PCA of landscape pattern metrics at four grain sizes for the sample lakes (α – level of 0.05). Components that were significantly related to the dependent variable ($p < 0.05$) are indicated with an asterisk in the regression equation.

Variable (Y)	n	R^2 (adj)	p	Regression equation
20-meter				
Water chemistry				
Log_{10}(Ammonia-N)	48	0.00	0.507	Y = - 1.66 + 0.0183(DIVERS1) + 0.0139(DIVERS2) + 0.0408(URB/SIZE) - 0.0240(WET) - 0.0312(AG)
Log_{10}(NO_3/NO_2-N)	48	0.01	0.400	Y = - 1.73 - 0.0154(DIVERS1) + 0.0352(DIVERS2) - 0.0513(URB/SIZE) + 0.0454(WET) - 0.166(AG)
Log_{10}(TKN)	47	0.10	0.093	Y = - 0.188 + 0.0244(DIVERS1) + 0.0079(DIVERS2) - 0.0017(URB/SIZE) - 0.0414(WET) - 0.0552(AG)
Log_{10}(TN)	47	0.29	0.002	Y = - 0.109 + 0.0323(DIVERS1)* + 0.0022(DIVERS2) + 0.0098(URB/SIZE) - 0.0161(WET) - 0.0875(AG)*
Log_{10}(TP)	47	0.17	0.024	Y = - 1.51 + 0.0241(DIVERS1) + 0.0619(DIVERS2)* - 0.0051(URB/SIZE) - 0.0871(WET)* - 0.0095(AG)
LCI	47	0.38	<0.001	Y = 44.1 - 3.08(DIVERS1)* + 4.09(DIVERS2)* - 1.77(URB/SIZE) + 5.13(WET)* + 3.42(AG)
40-meter				
Water chemistry				
Log_{10}(Ammonia-N)	48	0.00	0.565	Y = - 1.66 + 0.0157(DIVERS1) - 0.0116(DIVERS2) - 0.0478(URB) - 0.0044(AG) - 0.0040(SIZE)
Log_{10}(NO_3/NO_2-N)	48	0.00	0.518	Y = - 1.73 - 0.0290(DIVERS1) - 0.0286(DIVERS2) + 0.0340(URB) - 0.0921 AG_1 - 0.142(SIZE)
Log_{10}(TKN)	47	0.06	0.199	Y = - 0.188 + 0.0204(DIVERS1) - 0.0180(DIVERS2) - 0.0168(URB) + 0.0010(AG) - 0.0635(SIZE)
Log_{10}(TN)	47	0.24	0.006	Y = - 0.110 + 0.0307(DIVERS1)* - 0.0155(DIVERS2) - 0.0240(URB) - 0.0348(AG) - 0.0732(SIZE)*
Log_{10}(TP)	47	0.11	0.081	Y = - 1.51 - 0.0035(DIVERS1) - 0.0649(DIVERS2)* - 0.0371(URB) + 0.0502(AG) - 0.0193(SIZE)
LCI	47	0.39	<0.001	Y = 44.2 - 5.02(DIVERS1)* - 1.78(DIVERS2) + 2.22(URB) - 2.34 AG_1 + 5.14(SIZE)*
60-meter				
Water chemistry				
Log_{10}(Ammonia-N)	48	0.00	0.417	Y = - 1.66 + 0.028(DIVERS1) + 0.0137(DIVERS2) - 0.0431(URB) + 0.0135(AG) + 0.0186(SIZE)
Log_{10}(NO_3/NO_2-N)	48	0.06	0.184	Y = - 1.73 - 0.0128(DIVERS1) + 0.0129(DIVERS2) + 0.0397(URB) + 0.16(AG) - 0.183(SIZE)
Log_{10}(TKN)	47	0.01	0.404	Y = - 0.189 + 0.0304(DIVERS1) + 0.0162(DIVERS2) - 0.0124(URB) + 0.0235(AG) - 0.0042(SIZE)
Log_{10}(TN)	47	0.24	0.005	Y = - 0.110 + 0.0406(DIVERS1)* + 0.0053(DIVERS2) - 0.0192(URB) + 0.0675(AG)* - 0.0246(SIZE)
Log_{10}(TP)	47	0.12	0.070	Y = - 1.51 + 0.0342(DIVERS1) + 0.0673(DIVERS2) - 0.0204(URB) - 0.0281(AG)* - 0.0024(SIZE)
LCI	47	0.34	<0.001	Y = 44.5 - 3.76(DIVERS1)* + 3.37(DIVERS2)* + 2.27(URB) + 0.77(AG) + 4.97(SIZE)*

Table 3-49. Continued.

Variable (Y)	n	R^2 (adj)	p	Regression equation
80-meter				
Water chemistry				
Log_{10}(Ammonia-N)	48	0.01	0.386	Y = - 1.66 + 0.0058(DIVERS) + 0.0227(HETER) + 0.0461(URB) - 0.0327(AG) - 0.0270(SIZE)
Log_{10}(NO_3/NO_2-N)	48	0.13	0.052	Y = - 1.73 - 0.0196(DIVERS) + 0.0027(HETER) - 0.0850(URB) - 0.133(AG) + 0.235(SIZE)*
Log_{10}(TKN)	47	0.06	0.173	Y = - 0.190 + 0.011(DIVERS) + 0.0343(HETER) + 0.0227(URB) - 0.0395(AG) - 0.0125(SIZE)
Log_{10}(TN)	47	0.28	0.002	Y = - 0.111 + 0.0219(DIVERS) + 0.0290(HETER)* + 0.0162(URB) - 0.0824(AG)* + 0.0211(SIZE)
Log_{10}(TP)	47	0.13	0.059	Y = - 1.51 - 0.0237(DIVERS) + 0.0758(HETER)* + 0.0286(URB) + 0.0084(AG) - 0.0118(SIZE)
LCI	47	0.28	0.002	Y = 44.4 - 4.64(DIVERS)* - 0.32(HETER) - 2.42(URB) + 1.02(AG) - 4.21(SIZE)

Table 3-50. Coefficients of determination, probabilities, and regression equations for multiple regressions between indicators of ecosystem condition and significant components resulting from the PCA of landscape pattern metrics at three spatial extents for the sample lakes (α – level of 0.05). Components that were significantly related to the dependent variable ($p < 0.05$) are indicated with an asterisk in the regression equation.

Variable (Y)	n	R^2 (adj)	p	Regression equation
100-meter				
Water chemistry				
Log_{10}(Ammonia-N)	44	0.00	0.498	Y = - 1.67 - 0.009(DIVERS1) + 0.0148(DIVERS2) - 0.0475(URB) + 0.0388(SHAPE) - 0.0251(FOR)
Log_{10}(NO_3/NO_2-N)	44	0.06	0.212	Y = - 1.80 - 0.0051(DIVERS1) + 0.149(DIVERS2) + 0.0301(URB) + 0.0486(SHAPE) + 0.0012(FOR)
Log_{10}(TKN)	43	0.00	0.575	Y = - 0.182 + 0.006(DIVERS1) - 0.0232(DIVERS2) - 0.028(URB) - 0.0025(SHAPE) + 0.0276(FOR)
Log_{10}(TN)	43	0.00	0.533	Y = - 0.126 + 0.0066(DIVERS1) - 0.0101(DIVERS2) - 0.0247(URB) + 0.0141(SHAPE) + 0.0349(FOR)
Log_{10}(TP)	43	0.08	0.152	Y = - 1.50 + 0.0373(DIVERS1) + 0.0405(DIVERS2) - 0.0664(URB)* + 0.0003(SHAPE) + 0.0139(FOR)
LCI	43	0.26	0.005	Y = 45.6 + 0.33(DIVERS1) + 4.42(DIVERS2) + 1.24(URB) - 5.45(SHAPE) - 3.25(FOR)
400-meter				
Water chemistry				
Log_{10}(Ammonia-N)	44	0.06	0.210	Y = - 1.67 + 0.012(DIVERS1) - 0.0281(DIVERS2) + 0.0632(WET)* - 0.0155(HETER) - 0.0511(AG)
Log_{10}(NO_3/NO_2-N)	44	0.02	0.347	Y = - 1.80 - 0.053(DIVERS1) + 0.0777(DIVERS2) + 0.0144(WET) + 0.0592(HETER) - 0.113(AG)
Log_{10}(TKN)	43	0.25	0.007	Y = - 0.178 + 0.0372(DIVERS1)* - 0.0224(DIVERS2) + 0.0423(WET)* + 0.0097(HETER) - 0.0622(AG)*
Log_{10}(TN)	43	0.39	<0.001	Y= - 0.122 + 0.0352(DIVERS1)* - 0.0165(DIVERS2) + 0.0417(WET)* + 0.018(HETER) - 0.0732 AG)*
Log_{10}(TP)	43	0.21	0.016	Y = - 1.50 + 0.0234(DIVERS1) + 0.0187(DIVERS2) + 0.115(WET)* + 0.0342(HETER) - 0.0132(AG)
LCI	43	0.42	<0.001	Y = 45.3 - 4.28(DIVERS1)* + 5.35(DIVERS2)* - 1.27(WET) - 3.07(HETER) + 0.38(AG)
Watershed				
Water chemistry				
Log_{10}(Ammonia-N)	44	0.08	0.149	Y = - 1.67 + 0.0127(DIVERS1) - 0.0008(DIVERS2) - 0.0716(WET)* - 0.0017(HETER) + 0.0545(AG)
Log_{10}(NO_3/NO_2-N)	44	0.06	0.222	Y = - 1.80 - 0.0456(DIVERS1) + 0.084(DIVERS2) + 0.0202(WET) - 0.0894(HETER) + 0.121(AG)
Log_{10}(TKN)	43	0.12	0.077	Y = - 0.179 + 0.0302(DIVERS1) + 0.0019(DIVERS2) - 0.0224(WET) - 0.0273(HETER) + 0.0578(AG)*
Log_{10}(TN)	43	0.29	0.003	Y = - 0.122 + 0.0289(DIVERS1)* + 0.0064(DIVERS2) - 0.0176(WET) - 0.0433(HETER)* + 0.0676 (AG)*
Log_{10}(TP)	43	0.14	0.063	Y = - 1.50 + 0.004(DIVERS1) + 0.0322(DIVERS2) - 0.0859(WET)* - 0.0532(HETER) + 0.0193(AG)
LCI	43	0.41	<0.001	Y = 45.3 - 4.69(DIVERS1)* + 4.2(DIVERS2)* + 0.39(WET) + 4.47(HETER)* - 1.12(AG)

Table 3-51. Multiple regression models at four grain sizes for the sample isolated forested wetlands: coefficients of determination, probabilities, and change in the amount of variability (ΔR^2) in indicators of ecosystem condition (α – level of 0.05). ΔR^2 is the added predictive power to the LDI that resulted after using the LDI together with significant components that resulted from the PCA of landscape pattern metrics.

Dependent Variable	Independent Variables	R^2 (adj)	p	ΔR^2
5 x 5-meter				
WCI				
Macrophytes	LDI-PLU; URB; HETER; SHAPE; AG; FOR	0.41	<0.001	0.17
	LDI-ILD; URB; HETER; SHAPE; AG; FOR	0.41	<0.001	0.20
	LDI-ISD; URB; HETER; SHAPE; AG; FOR	0.41	<0.001	0.22
Macroinvertebrates	LDI-ILD; URB; HETER; SHAPE; AG; FOR	0.25	0.040	0.07
	LDI-ISD; URB; HETER; SHAPE; AG; FOR	0.26	0.035	0.09
10 x 10-meter				
Water chemistry				
Log_{10}(TP)	LDI-PLU; URB; HETER; CONTAG; AG; FOR; ENN	0.41	0.004	0.37
	LDI-ILD; URB; HETER; CONTAG; AG; FOR; ENN	0.41	0.004	0.37
	LDI-ISD; URB; HETER; CONTAG; AG; FOR; ENN	0.41	0.004	0.38
WCI				
Macrophytes	LDI-PLU; URB; HETER; CONTAG; AG; FOR; ENN	0.43	<0.001	0.19
	LDI-ILD; URB; HETER; CONTAG; AG; FOR; ENN	0.43	<0.001	0.23
	LDI-ISD; URB; HETER; CONTAG; AG; FOR; ENN	0.44	<0.001	0.25
Macroinvertebrates	LDI-ISD; URB; HETER; CONTAG; AG; FOR; ENN	0.26	0.048	0.08
20 x 20-meter				
Water chemistry				
Log_{10}(TP)	LDI-PLU; DIVERS; HETER; CONTAG; AG; SHAPE; FOR	0.40	0.005	0.36
	LDI-ILD; DIVERS; HETER; CONTAG; AG; SHAPE; FOR	0.40	0.005	0.37
	LDI-ISD; DIVERS; HETER; CONTAG; AG; SHAPE; FOR	0.40	0.005	0.37
WCI				
Macrophytes	LDI-PLU; DIVERS; HETER; CONTAG; AG; SHAPE; FOR	0.38	<0.001	0.15
	LDI-ILD; DIVERS; HETER; CONTAG; AG; SHAPE; FOR	0.39	<0.001	0.18
	LDI-ISD; DIVERS; HETER; CONTAG; AG; SHAPE; FOR	0.40	<0.001	0.17
Macroinvertebrates	LDI-PLU; DIVERS; HETER; CONTAG; AG; SHAPE; FOR	0.28	0.036	0.11
	LDI-ILD; DIVERS; HETER; CONTAG; AG; SHAPE; FOR	0.31	0.026	0.13
	LDI-ISD; DIVERS; HETER; CONTAG; AG; SHAPE; FOR	0.33	0.019	0.16
30 x 30-meter				
Water chemistry				
Log_{10}(TP)	LDI-PLU; DIVERS; HETER; URB/WET; AG; SHAPE; FOR	0.43	0.003	0.39
	LDI-ILD; DIVERS; HETER; URB/WET; AG; SHAPE; FOR	0.43	0.003	0.39
	LDI-ISD; DIVERS; HETER; URB/WET; AG; SHAPE; FOR	0.43	0.003	0.39

Table 3-51. Continued.

Dependent Variable	Independent Variables	R^2 (adj)	p	ΔR^2
WCI				
Macrophytes	LDI-PLU; DIVERS; HETER; URB/WET; AG; SHAPE; FOR	0.41	<0.001	0.17
	LDI-ILD; DIVERS; HETER; URB/WET; AG; SHAPE; FOR	0.41	<0.001	0.21
	LDI-ISD; DIVERS; HETER; URB/WET; AG; SHAPE; FOR	0.42	<0.001	0.23
Macroinvertebrates	LDI-PLU; DIVERS; HETER; URB/WET; AG; SHAPE; FOR	0.28	0.035	0.10
	LDI-ILD; DIVERS; HETER; URB/WET; AG; SHAPE; FOR	0.32	0.021	0.15
	LDI-ISD; DIVERS; HETER; URB/WET; AG; SHAPE; FOR;	0.34	0.017	0.17

Table 3-52. Multiple regression models at four grain sizes for the sample streams: coefficients of determination, probabilities, and change in the amount of variability (ΔR^2) in indicators of ecosystem condition (α – level of 0.05). ΔR^2 is the added predictive power to the LDI that resulted after using the LDI together with significant components that resulted from the PCA of landscape pattern metrics.

Dependent Variable	Independent Variables	R^2 (adj)	p	ΔR^2
20 x 20-meter				
Water chemistry				
DO	LDI-PLU; DIVERS1; DIVERS2; WET; DIST	0.43	<0.001	0.02
	LDI-ILD; DIVERS1; DIVERS2; WET; DIST	0.40	0.001	0.00
	LDI-ISD; DIVERS1; DIVERS2; WET; DIST	0.38	0.001	-0.03
Log_{10}(TN)	LDI-PLU; DIVERS1; DIVERS2; WET; DIST	0.63	<0.001	0.46
	LDI-ILD; DIVERS1; DIVERS2; WET; DIST	0.63	<0.001	0.47
	LDI-ISD; DIVERS1; DIVERS2; WET; DIST	0.63	<0.001	0.47
Log_{10}(TP)	LDI-PLU; DIVERS1; DIVERS2; WET; DIST	0.40	<0.001	0.39
	LDI-ILD; DIVERS1; DIVERS2; WET; DIST	0.40	<0.001	0.38
	LDI-ISD; DIVERS1; DIVERS2; WET; DIST	0.40	<0.001	0.37
WQI	LDI-PLU; DIVERS1; DIVERS2; WET; DIST	0.34	0.003	0.12
	LDI-ILD; DIVERS1; DIVERS2; WET; DIST	0.40	0.001	0.12
	LDI-ISD; DIVERS1; DIVERS2; WET; DIST	0.44	<0.001	0.11
SCI				
SC_2	LDI-ILD; DIVERS1; DIVERS2; WET; DIST	0.13	0.018	-0.10
	LDI-ISD; DIVERS1; DIVERS2; WET; DIST	0.15	0.009	-0.10
50 x 50-meter				
Water chemistry				
DO	LDI-PLU; DIVERS1; DIVERS2; WET; SHAPE	0.42	0.001	0.02
	LDI-ILD; DIVERS1; DIVERS2; WET; SHAPE	0.40	0.001	0.00
	LDI-ISD; DIVERS1; DIVERS2; WET; SHAPE	0.38	0.001	-0.02
Log_{10}(TN)	LDI-PLU; DIVERS1; DIVERS2; WET; SHAPE	0.59	<0.001	0.43
	LDI-ILD; DIVERS1; DIVERS2; WET; SHAPE	0.60	<0.001	0.44
	LDI-ISD; DIVERS1; DIVERS2; WET; SHAPE	0.59	<0.001	0.44
Log_{10}(TP)	LDI-PLU; DIVERS1; DIVERS2; WET; SHAPE	0.39	<0.001	0.38
	LDI-ILD; DIVERS1; DIVERS2; WET; SHAPE	0.39	<0.001	0.37
	LDI-ISD; DIVERS1; DIVERS2; WET; SHAPE	0.38	0.001	0.36
WQI	LDI-PLU; DIVERS1; DIVERS2; WET; SHAPE	0.35	0.002	0.13
	LDI-ILD; DIVERS1; DIVERS2; WET; SHAPE	0.41	0.001	0.13
	LDI-ISD; DIVERS1; DIVERS2; WET; SHAPE	0.44	<0.001	0.11
SCI				
SC_2	LDI-ILD; DIVERS1; DIVERS2; WET; SHAPE	0.12	0.026	-0.10
	LDI-ISD; DIVERS1; DIVERS2; WET; SHAPE	0.14	0.015	-0.10

Table 3-52. Continued.

Dependent Variable	Independent Variables	R^2 (adj)	p	ΔR^2
80 x 80-meter				
Water chemistry				
DO	LDI-PLU; DIVERS1; DIVERS2; URB; SHAPE	0.41	0.001	0.01
	LDI-ILD; DIVERS1; DIVERS2; URB; SHAPE	0.40	0.001	-0.01
	LDI-ISD; DIVERS1; DIVERS2; URB; SHAPE	0.39	0.001	-0.02
Log_{10}(TN)	LDI-PLU; DIVERS1; DIVERS2; URB; SHAPE	0.57	<0.001	0.40
	LDI-ILD; DIVERS1; DIVERS2; URB; SHAPE	0.57	<0.001	0.40
	LDI-ISD; DIVERS1; DIVERS2; URB; SHAPE	0.56	<0.001	0.41
Log_{10}(TP)	LDI-PLU; DIVERS1; DIVERS2; URB; SHAPE	0.34	<0.001	0.33
	LDI-ILD; DIVERS1; DIVERS2; URB; SHAPE	0.34	<0.001	0.32
	LDI-ISD; DIVERS1; DIVERS2; URB; SHAPE	0.34	<0.001	0.31
WQI	LDI-PLU; DIVERS1; DIVERS2; URB; SHAPE	0.35	0.003	0.13
	LDI-ILD; DIVERS1; DIVERS2; URB; SHAPE	0.41	0.001	0.13
	LDI-ISD; DIVERS1; DIVERS2; URB; SHAPE	0.45	<0.001	0.12
SCI				
SC_1	LDI-ISD; DIVERS1; DIVERS2; URB; SHAPE	0.10	0.044	-0.12
SC_2	LDI-ILD; DIVERS1; DIVERS2; URB; SHAPE	0.12	0.024	-0.10
	LDI-ISD; DIVERS1; DIVERS2; URB; SHAPE	0.14	0.013	-0.10
110 x 110-meters				
Water chemistry				
DO	LDI-PLU; DIVERS1; DIVERS2; URB; SHAPE	0.44	<0.001	0.01
	LDI-ILD; DIVERS1; DIVERS2; URB; SHAPE	0.42	0.001	-0.02
	LDI-ISD; DIVERS1; DIVERS2; URB; SHAPE	0.41	0.001	-0.04
Log_{10}(TN)	LDI-PLU; DIVERS1; DIVERS2; URB; SHAPE	0.55	<0.001	0.35
	LDI-ILD; DIVERS1; DIVERS2; URB; SHAPE	0.55	<0.001	0.36
	LDI-ISD; DIVERS1; DIVERS2; URB; SHAPE	0.55	<0.001	0.36
Log_{10}(TP)	LDI-PLU; DIVERS1; DIVERS2; URB; SHAPE	0.30	0.001	0.29
	LDI-ILD; DIVERS1; DIVERS2; URB; SHAPE	0.30	0.001	0.28
	LDI-ISD; DIVERS1; DIVERS2; URB; SHAPE	0.31	0.001	0.27
WQI	LDI-PLU; DIVERS1; DIVERS2; URB; SHAPE	0.35	0.002	0.13
	LDI-ILD; DIVERS1; DIVERS2; URB; SHAPE	0.41	0.001	0.13
	LDI-ISD; DIVERS1; DIVERS2; URB; SHAPE	0.46	<0.001	0.12
SCI				
SC_1	LDI-ISD; DIVERS1; DIVERS2; URB; SHAPE	0.10	0.046	-0.13
SC_2	LDI-ILD; DIVERS1; DIVERS2; URB; SHAPE	0.12	0.024	-0.10
	LDI-ISD; DIVERS1; DIVERS2; URB; SHAPE	0.14	0.013	-0.10

Table 3-53. Multiple regression models at three spatial extents for the sample streams: coefficients of determination, probabilities, and change in the amount of variability (ΔR^2) in indicators of ecosystem condition (α – level of 0.05). ΔR^2 is the added predictive power to the LDI that resulted after using the LDI together with significant components that resulted from the PCA of landscape pattern metrics.

Dependent Variable	Independent Variables	R^2 (adj)	p	ΔR^2
100-meter buffer				
Water chemistry				
Log_{10}(Turbidity)	LDI-PLU; DIVERS; SIZE; WET; HETER	0.22	0.034	0.18
	LDI-ILD; DIVERS; SIZE; WET; HETER	0.25	0.020	0.25
	LDI-ISD; DIVERS; SIZE; WET; HETER	0.29	0.011	0.28
DO	LDI-PLU; DIVERS; SIZE; WET; HETER	0.41	0.001	0.01
	LDI-ILD; DIVERS; SIZE; WET; HETER	0.39	0.010	0.06
	LDI-ISD; DIVERS; SIZE; WET; HETER	0.40	0.001	0.09
Log_{10}(TN)	LDI-PLU; DIVERS; SIZE; WET; HETER	0.33	0.001	0.20
	LDI-ILD; DIVERS; SIZE; WET; HETER	0.33	0.001	0.22
	LDI-ISD; DIVERS; SIZE; WET; HETER	0.33	0.001	0.22
Log_{10}(TP)	LDI-PLU; DIVERS; SIZE; WET; HETER	0.18	0.027	0.16
	LDI-ILD; DIVERS; SIZE; WET; HETER	0.21	0.018	0.16
	LDI-ISD; DIVERS; SIZE; WET; HETER	0.22	0.012	0.14
WQI	LDI-PLU; DIVERS; SIZE; WET; HETER	0.35	0.003	0.14
	LDI-ILD; DIVERS; SIZE; WET; HETER	0.41	0.001	0.15
	LDI-ISD; DIVERS; SIZE; WET; HETER	0.48	<0.001	0.16
SCI				
SCI_1	LDI-PLU; DIVERS; SIZE; WET; HETER	0.17	0.009	-0.04
	LDI-ILD; DIVERS; SIZE; WET; HETER	0.18	0.006	-0.06
	LDI-ISD; DIVERS; SIZE; WET; HETER	0.19	0.005	-0.03
SCI_2	LDI-PLU; DIVERS; SIZE; WET; HETER	0.23	0.001	-0.01
	LDI-ILD; DIVERS; SIZE; WET; HETER	0.24	0.001	-0.02
	LDI-ISD; DIVERS; SIZE; WET; HETER	0.25	0.001	-0.01
400-meter buffer				
Water chemistry				
DO	LDI-PLU; DIVERS; HETER; WET; AG	0.32	0.006	-0.02
	LDI-ILD; DIVERS; HETER; WET; AG	0.27	0.012	-0.04
	LDI-ISD; DIVERS; HETER; WET; AG	0.27	0.014	-0.04
Log_{10}(TN)	LDI-PLU; DIVERS; HETER; WET; AG	0.53	<0.001	0.43
	LDI-ILD; DIVERS; HETER; WET; AG	0.52	<0.001	0.43
	LDI-ISD; DIVERS; HETER; WET; AG	0.52	<0.001	0.43
Log_{10}(TP)	LDI-PLU; DIVERS; HETER; WET; AG	0.40	<0.001	0.39
	LDI-ILD; DIVERS; HETER; WET; AG	0.41	<0.001	0.39
	LDI-ISD; DIVERS; HETER; WET; AG	0.42	<0.001	0.39

Table 3-53. Continued.

Dependent Variable	Independent Variables	R^2 (adj)	p	ΔR^2
WQI	LDI-PLU; DIVERS; HETER; WET; AG	0.45	<0.001	0.24
	LDI-ILD; DIVERS; HETER; WET; AG	0.47	<0.001	0.22
	LDI-ISD; DIVERS; HETER; WET; AG	0.49	<0.001	0.20
SCI				
SCI_1	LDI-ISD; DIVERS; HETER; WET; AG	0.11	0.040	-0.11
SCI_2	LDI-PLU; DIVERS; HETER; WET; AG	0.13	0.026	-0.07
	LDI-ILD; DIVERS; HETER; WET; AG	0.14	0.017	-0.08
	LDI-ISD; DIVERS; HETER; WET; AG	0.15	0.014	-0.07
Watershed				
Water chemistry				
DO	LDI-PLU; DIVERS; HETER; WET; AG	0.44	0.004	0.04
	LDI-ILD; DIVERS; HETER; WET; AG	0.42	0.005	0.01
	LDI-ISD; DIVERS; HETER; WET; AG	0.39	0.006	-0.02
Log_{10}(TN)	LDI-PLU; DIVERS; HETER; WET; AG	0.62	<0.001	0.45
	LDI-ILD; DIVERS; HETER; WET; AG	0.62	<0.001	0.46
	LDI-ISD; DIVERS; HETER; WET; AG	0.61	<0.001	0.45
Log_{10}(TP)	LDI-PLU; DIVERS; HETER; WET; AG	0.42	<0.001	0.41
	LDI-ILD; DIVERS; HETER; WET; AG	0.42	<0.001	0.35
	LDI-ISD; DIVERS; HETER; WET; AG	0.42	<0.001	0.39
WQI	LDI-PLU; DIVERS; HETER; WET; AG	0.32	0.006	0.10
	LDI-ILD; DIVERS; HETER; WET; AG	0.37	0.002	0.09
	LDI-ISD; DIVERS; HETER; WET; AG	0.42	0.001	0.09
SCI				
SC_1	LDI-ISD; DIVERS; HETER; WET; AG	0.10	0.045	-0.13
SC_2	LDI-ILD; DIVERS; HETER; WET; AG	0.13	0.020	-0.10
	LDI-ISD; DIVERS; HETER; WET; AG	0.15	0.012	-0.10

Table 3-54. Multiple regression models at four grain sizes for the sample lakes: coefficients of determination, probabilities, and change in the amount of variability (ΔR^2) in indicators of ecosystem condition (α – level of 0.05). ΔR^2 is the added predictive power to the LDI that resulted after using the LDI together with significant components that resulted from the PCA of landscape pattern metrics.

Dependent Variable	Independent Variables	R^2 (adj)	p	ΔR^2
20 x 20-meter				
Water chemistry				
Log_{10}(TN)	LDI-PLU; DIVERS1; DIVERS2; URB/SIZE; WET; AG	0.34	0.001	0.34
	LDI-ILD; DIVERS1; DIVERS2; URB/SIZE; WET; AG	0.29	0.003	0.27
	LDI-ISD; DIVERS1; DIVERS2; URB/SIZE; WET; AG	0.28	0.003	0.27
Log_{10}(TP)	LDI-PLU; DIVERS1; DIVERS2; URB/SIZE; WET; AG	0.17	0.031	0.15
	LDI-ILD; DIVERS1; DIVERS2; URB/SIZE; WET; AG	0.15	0.046	0.10
	LDI-ISD; DIVERS1; DIVERS2; URB/SIZE; WET; AG	0.15	0.045	0.11
LCI	LDI-PLU; DIVERS1; DIVERS2; URB/SIZE; WET; AG	0.44	<0.001	0.43
	LDI-ILD; DIVERS1; DIVERS2; URB/SIZE; WET; AG	0.41	<0.001	0.40
	LDI-ISD; DIVERS1; DIVERS2; URB/SIZE; WET; AG	0.39	<0.001	0.39
40 x 40-meter				
Water chemistry				
Log_{10}(TN)	LDI-PLU; DIVERS1; DIVERS2; URB; AG; SIZE	0.32	0.001	0.32
	LDI-ILD; DIVERS1; DIVERS2; URB; AG; SIZE	0.22	0.012	0.20
	LDI-ISD; DIVERS1; DIVERS2; URB; AG; SIZE	0.24	0.009	0.22
LCI	LDI-PLU; DIVERS1; DIVERS2; URB; AG; SIZE	0.50	<0.001	0.48
	LDI-ILD; DIVERS1; DIVERS2; URB; AG; SIZE	0.41	<0.001	0.41
	LDI-ISD; DIVERS1; DIVERS2; URB; AG; SIZE	0.42	<0.001	0.42
60 x 60-meter				
Water chemistry				
Log_{10}(TN)	LDI-PLU; DIVERS1; DIVERS2; URB; AG; SIZE	0.30	0.002	0.30
	LDI-ILD; DIVERS1; DIVERS2; URB; AG; SIZE	0.27	0.005	0.27
	LDI-ISD; DIVERS1; DIVERS2; URB; AG; SIZE	0.27	0.004	0.27
LCI	LDI-PLU; DIVERS1; DIVERS2; URB; AG; SIZE	0.39	<0.001	0.39
	LDI-ILD; DIVERS1; DIVERS2; URB; AG; SIZE	0.37	<0.001	0.37
	LDI-ISD; DIVERS1; DIVERS2; URB; AG; SIZE	0.29	<0.001	0.29
80 x 80-meter				
Water chemistry				
Log_{10}(TN)	LDI-PLU; DIVERS1; HETER; URB; AG; SIZE	0.30	0.002	0.30
	LDI-ILD; DIVERS1; HETER; URB; AG; SIZE	0.27	0.004	0.27
	LDI-ISD; DIVERS1; HETER; URB; AG; SIZE	0.27	0.004	0.27
LCI	LDI-PLU; DIVERS1; HETER; URB; AG; SIZE	0.32	0.001	0.32
	LDI-ILD; DIVERS1; HETER; URB; AG; SIZE	0.30	0.002	0.30
	LDI-ISD; DIVERS1; HETER; URB; AG; SIZE	0.29	0.003	0.29

Table 3-55. Multiple regression models at three spatial extents for the sample lakes: coefficients of determination, probabilities, and change in the amount of variability (ΔR^2) in indicators of ecosystem condition (α – level of 0.05). ΔR^2 is the added predictive power to the LDI that resulted after using the LDI together with significant components that resulted from the PCA of landscape pattern metrics.

Dependent Variable	Independent Variables	R^2 (adj)	p	ΔR^2
100-meter buffer				
LCI	LDI-PLU; DIVERS1; DIVERS2; URB; SHAPE; FOR	0.27	0.007	0.27
	LDI-ILD; DIVERS1; DIVERS2; URB; SHAPE; FOR	0.28	0.005	0.28
	LDI-ISD; DIVERS1; DIVERS2; URB; SHAPE; FOR	0.30	0.004	0.30
400-meter buffer				
Water chemistry				
Log_{10}(TKN)	LDI-PLU; DIVERS1; DIVERS2; WET; HETER; AG	0.24	0.013	0.24
	LDI-ILD; DIVERS1; DIVERS2; WET; HETER; AG	0.24	0.014	0.24
	LDI-ISD; DIVERS1; DIVERS2; WET; HETER; AG	0.23	0.015	0.23
Log_{10}(TN)	LDI-PLU; DIVERS1; DIVERS2; WET; HETER; AG	0.40	<0.001	0.40
	LDI-ILD; DIVERS1; DIVERS2; WET; HETER; AG	0.40	<0.001	0.40
	LDI-ISD; DIVERS1; DIVERS2; WET; HETER; AG	0.38	0.001	0.38
Log_{10}(TP)	LDI-PLU; DIVERS1; DIVERS2; WET; HETER; AG	0.20	0.026	0.20
	LDI-ILD; DIVERS1; DIVERS2; WET; HETER; AG	0.23	0.015	0.23
	LDI-ISD; DIVERS1; DIVERS2; WET; HETER; AG	0.22	0.017	0.22
LCI	LDI-PLU; DIVERS1; DIVERS2; WET; HETER; AG	0.43	<0.001	0.43
	LDI-ILD; DIVERS1; DIVERS2; WET; HETER; AG	0.44	<0.001	0.44
	LDI-ISD; DIVERS1; DIVERS2; WET; HETER; AG	0.41	<0.001	0.41
Watershed				
Water chemistry				
$Log_{10}(NO_3/NO_2\text{-}N)$	LDI-PLU; DIVERS1; DIVERS2; URB; HETER; AG	0.17	0.038	0.17
Log_{10}(TN)	LDI-PLU; DIVERS1; DIVERS2; URB; HETER; AG	0.37	0.001	0.37
	LDI-ILD; DIVERS1; DIVERS2; URB; HETER; AG	0.28	0.005	0.28
	LDI-ISD; DIVERS1; DIVERS2; URB; HETER; AG	0.23	0.006	0.23
LCI	LDI-PLU; DIVERS1; DIVERS2; URB; HETER; AG	0.52	<0.001	0.52
	LDI-ILD; DIVERS1; DIVERS2; URB; HETER; AG	0.46	<0.001	0.46
	LDI-ISD; DIVERS1; DIVERS2; URB; HETER; AG	0.44	<0.001	0.44

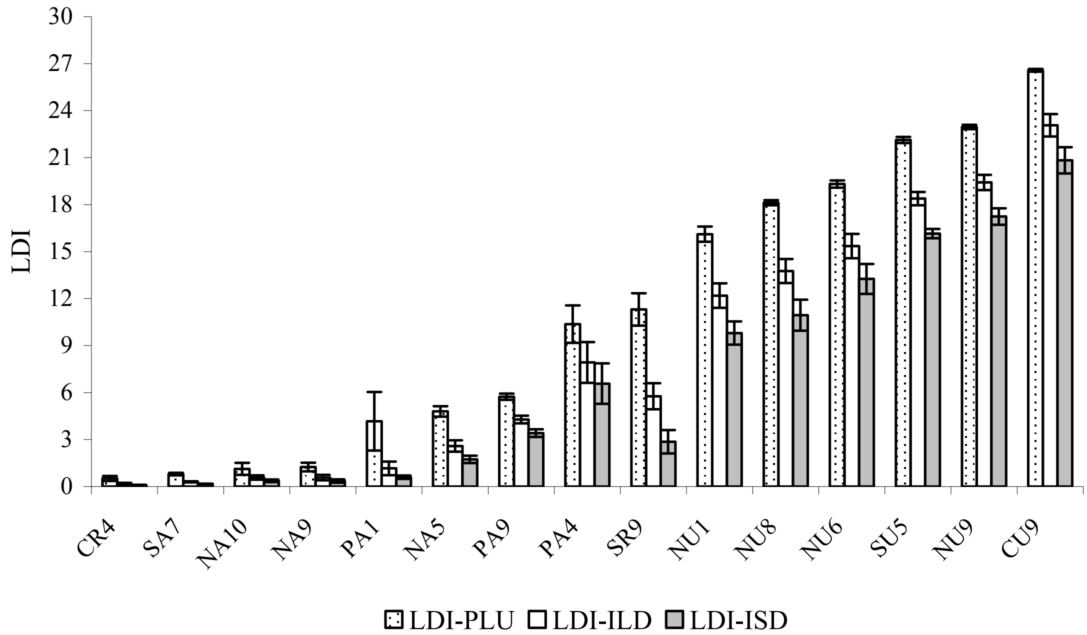


Figure 3-1. Mean LDI scores for a subsample of isolated forested wetlands (n = 15). For each site LDI scores are shown calculated in three different ways: based on land use proportions only (LDI-PLU), and considering a linear decrease with distance (PLU-ILD) and an inverse square decrease with distance (LDI-ISD). Error bars indicate the variance of LDI scores across grain sizes. Wetlands are identified by site codes.

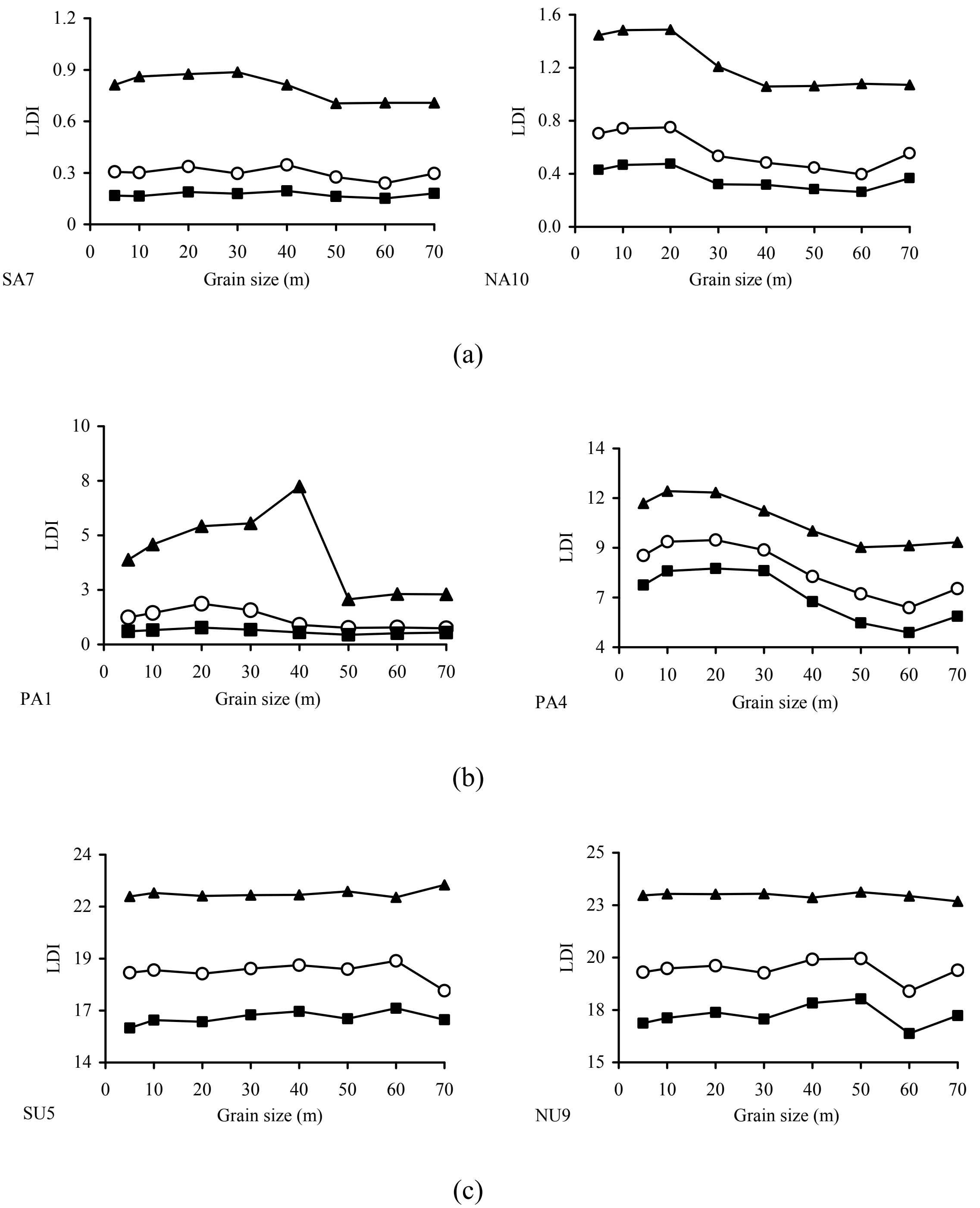


Figure 3-2. Scalograms showing the effect of changing the grain size on the LDI for a subsample of six isolated forested wetlands representing wetland buffers with (a) low LDI scores, (b) intermediate LDI scores, and (c) high LDI scores. (–▲– LDI-PLU; –○– LDI-ILD; –■–LDI-ISD). The site code for each wetland is shown.

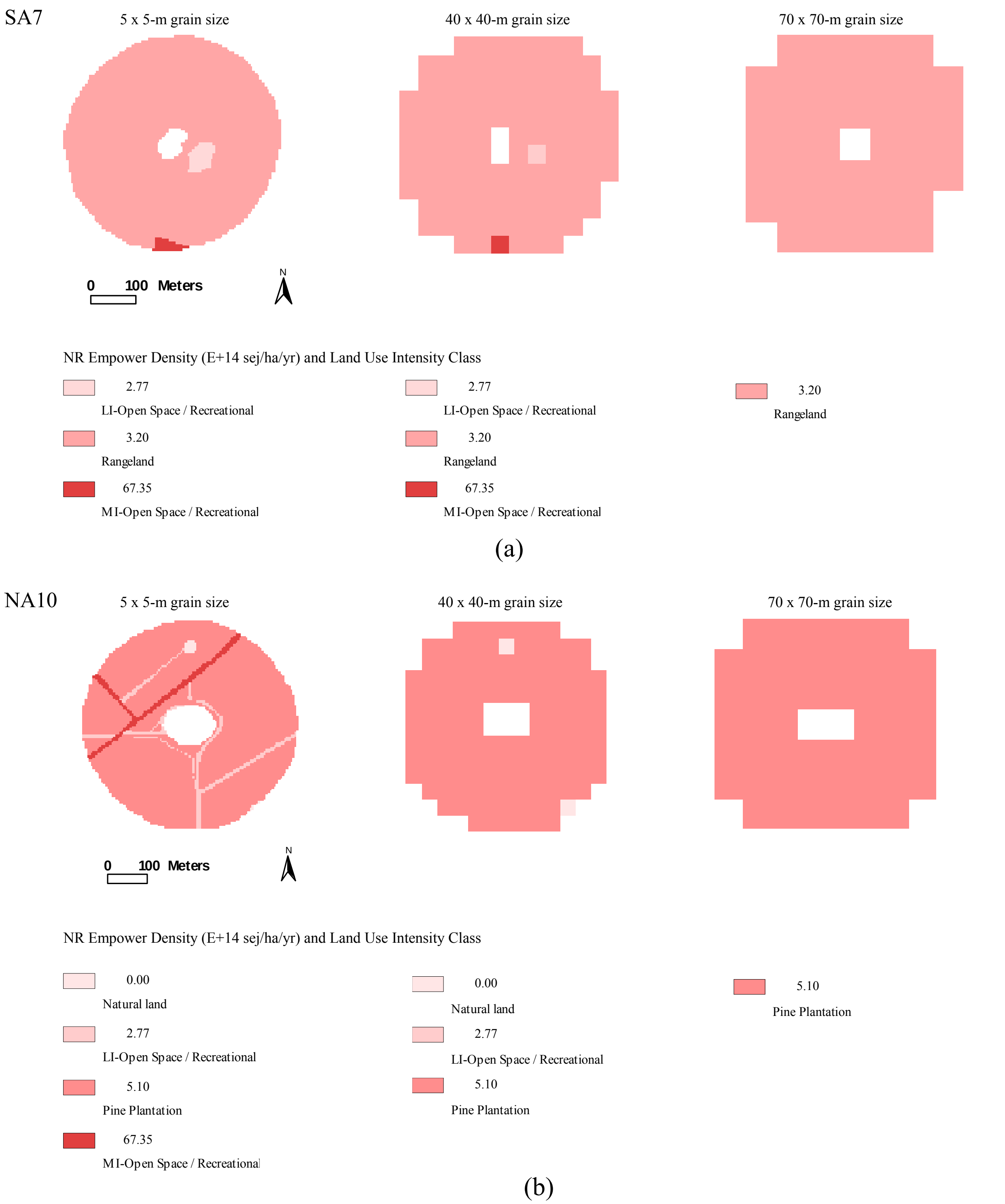
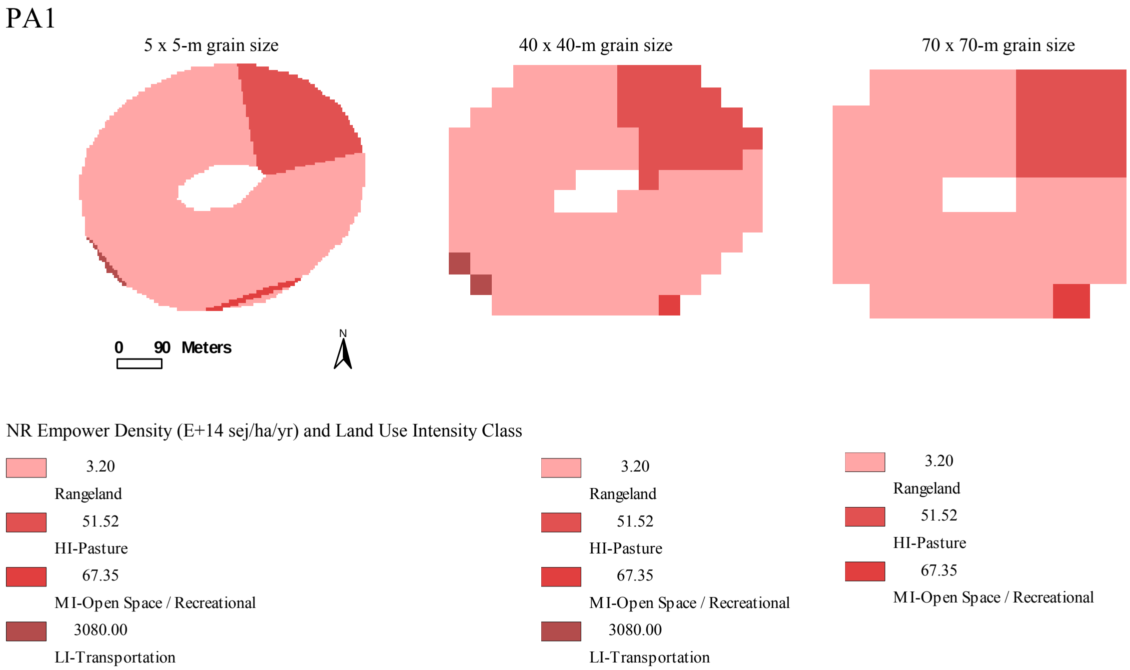
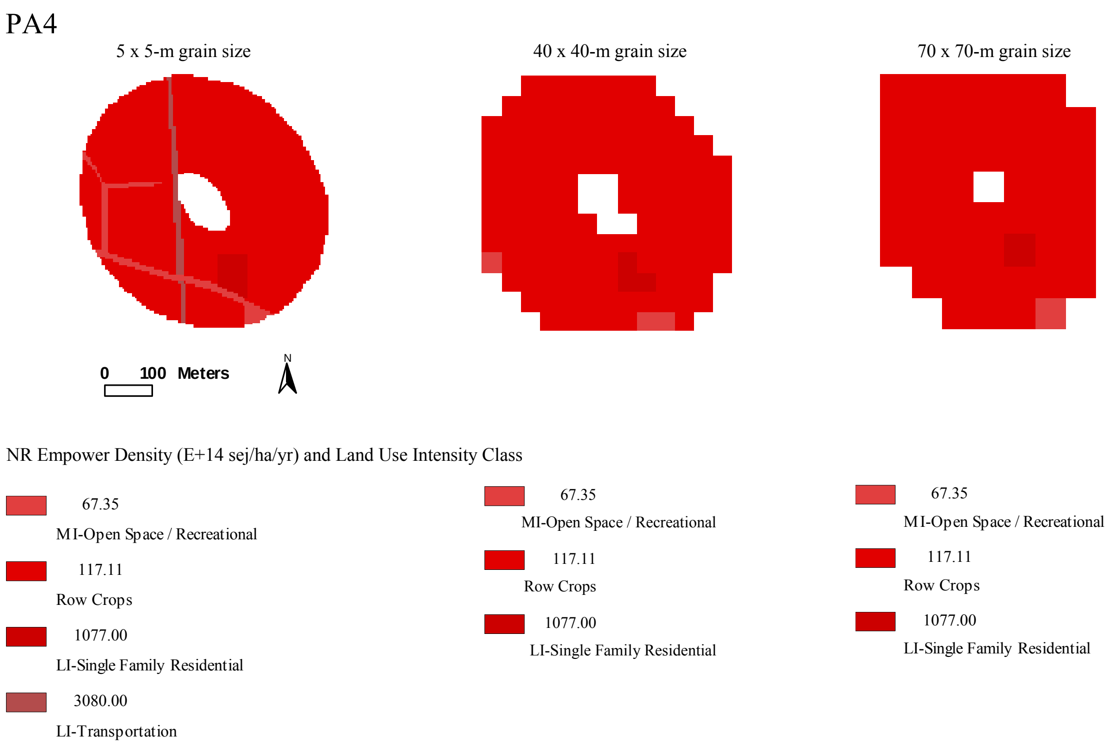


Figure 3-3. Landscapes surrounding a subsample of study isolated forested wetlands shown at three different grain sizes: 5 x 5 (original landscape), 40 x 40, and 70 x 70 meters. Landscapes were aggregated using the most frequently occurring value method. Sites: (a) SA7; (b) NA10; (c) PA1; (d) PA4; SU5; and (NU9). Table 2-1 explains site codification. Light to dark red denotes increasing non-renewable empower density.

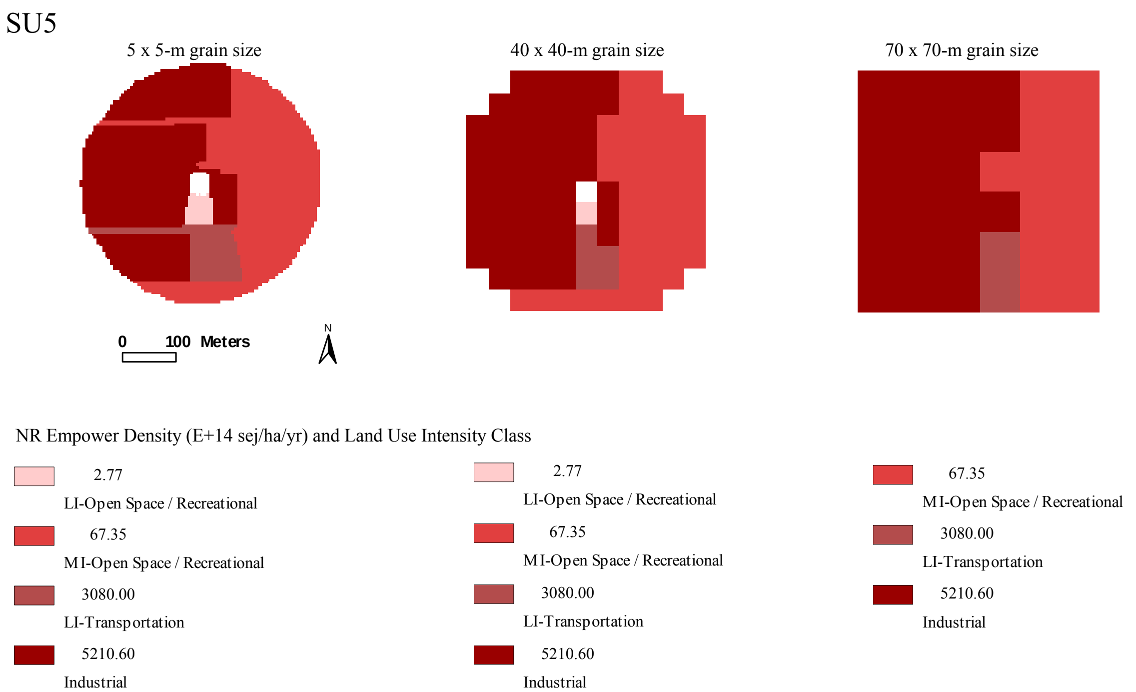


(c)

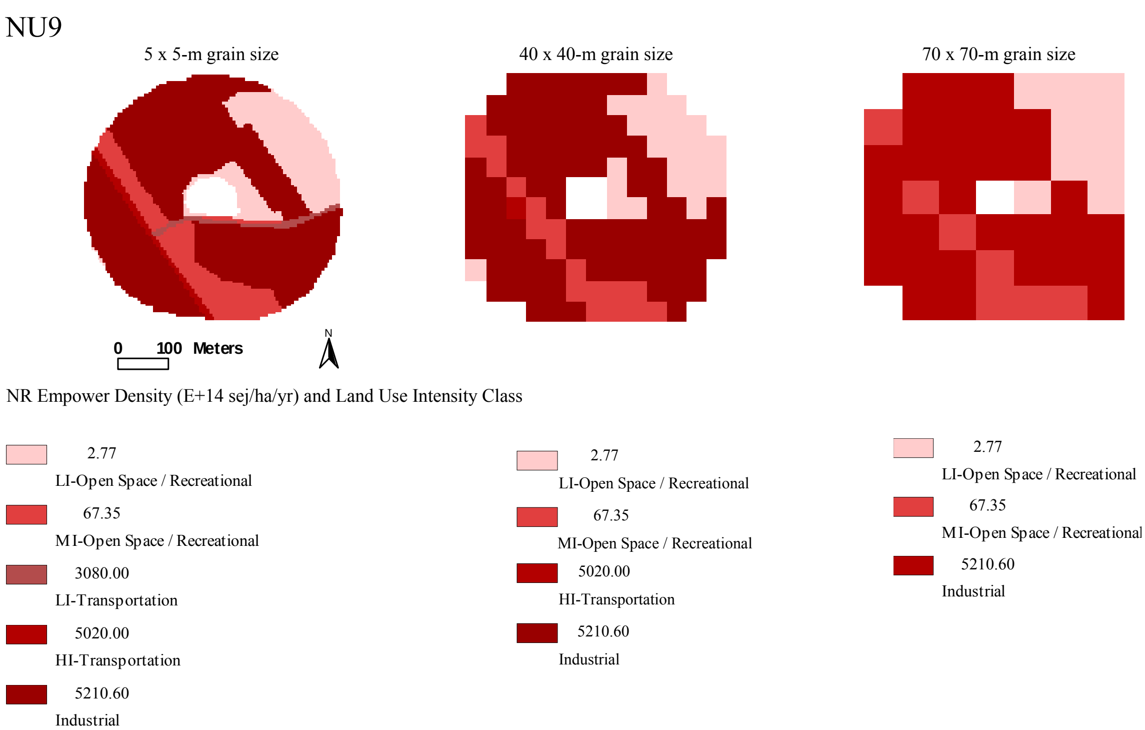


(d)

Figure 3-3. Continued.



(e)



(f)

Figure 3-3. Continued.

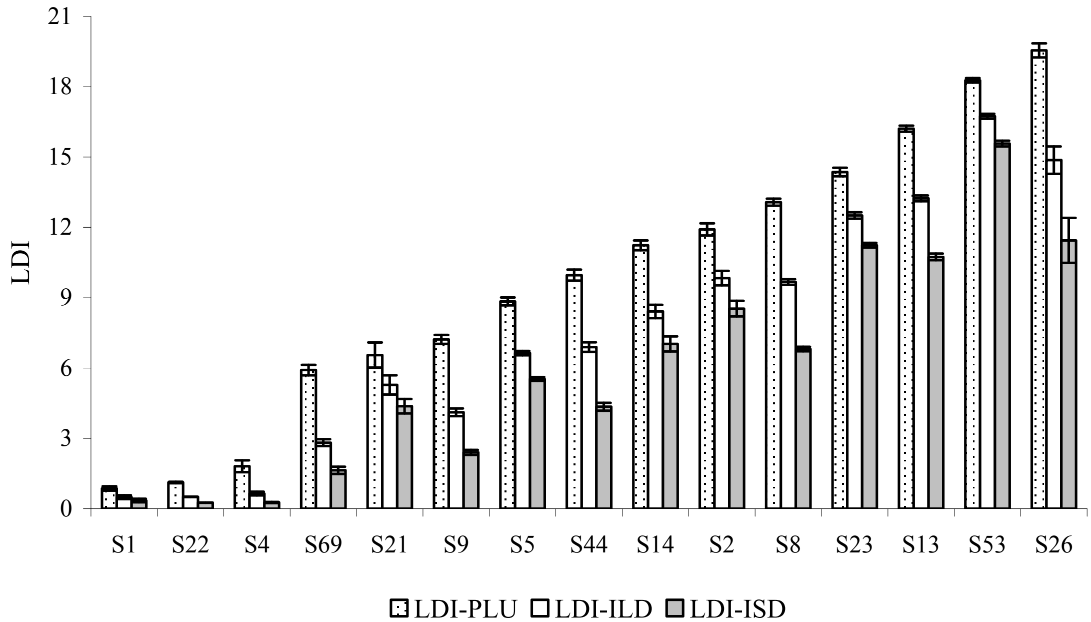
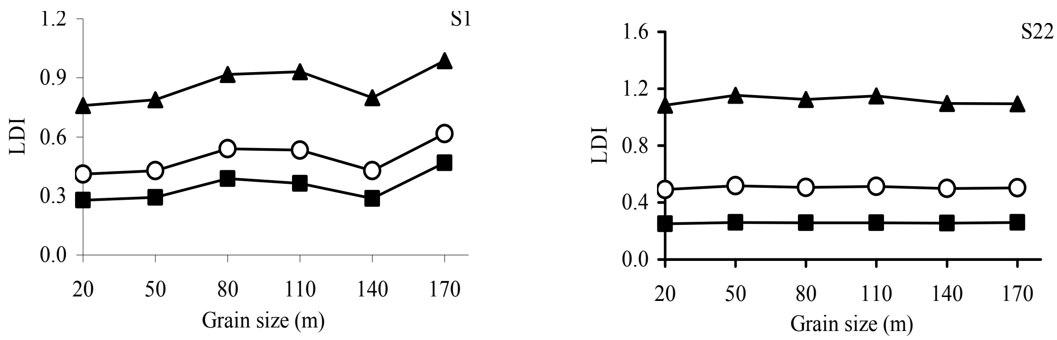
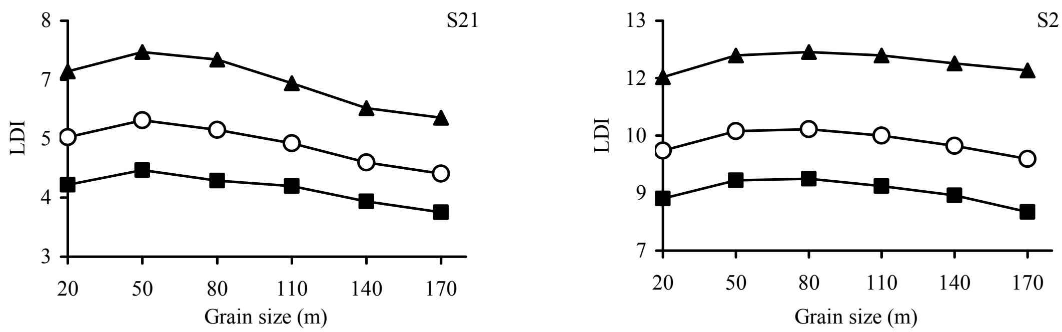


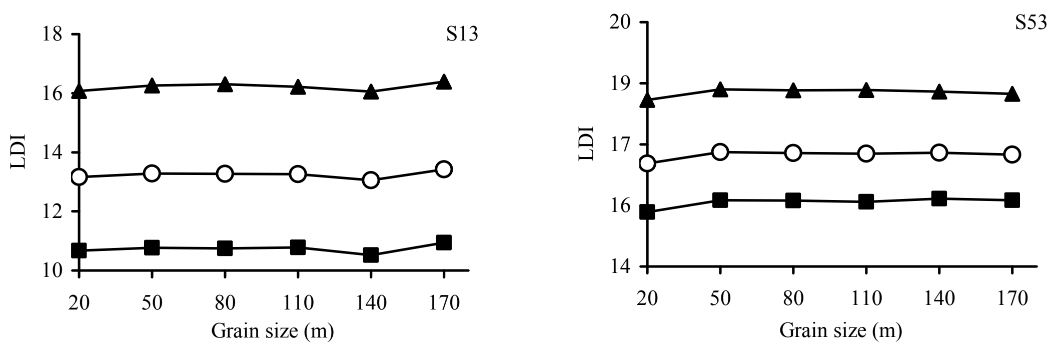
Figure 3-4. Mean LDI scores for a subsample of 15 stream drainage basins. For each site, LDI scores are shown calculated in three different ways: based on land use proportions only (LDI-PLU), and considering a linear decrease with distance (PLU-ILD) and an inverse square decrease with distance (LDI-ISD). Error bars indicate the variance of LDI scores across grain sizes. Stream drainage basins are identified by site codes.



(a)

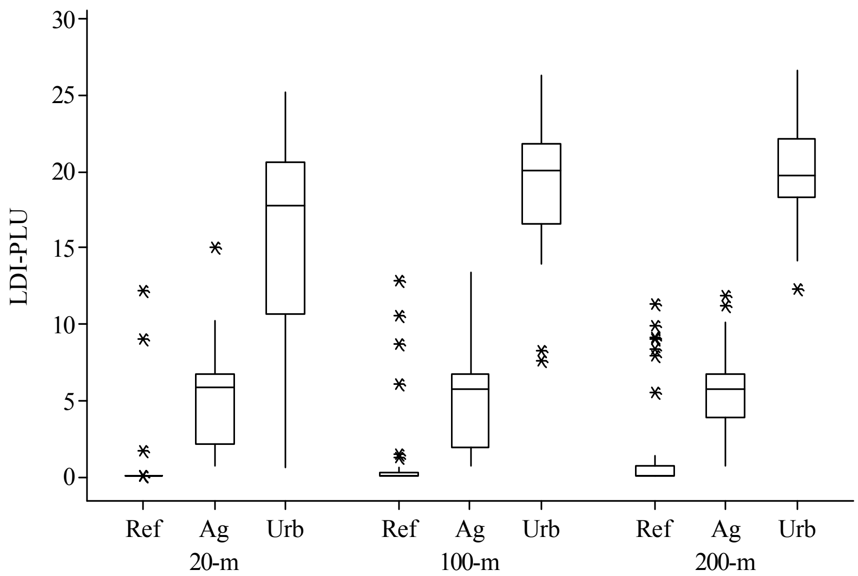


(b)

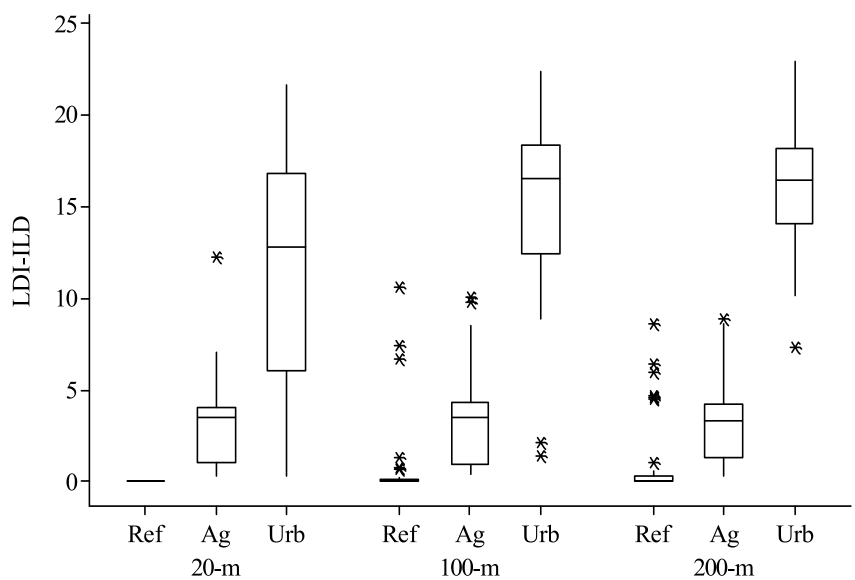


(c)

Figure 3-5. Scalograms showing the effect of changing the grain size on the LDI for a subsample of six streams representing stream watersheds with (a) low LDI scores, (b) intermediate LDI scores, and (c) high LDI scores. (–▲– LDI-PLU; –○–LDI-ILD; –■– LDI-ISD). The site code for each stream is shown.

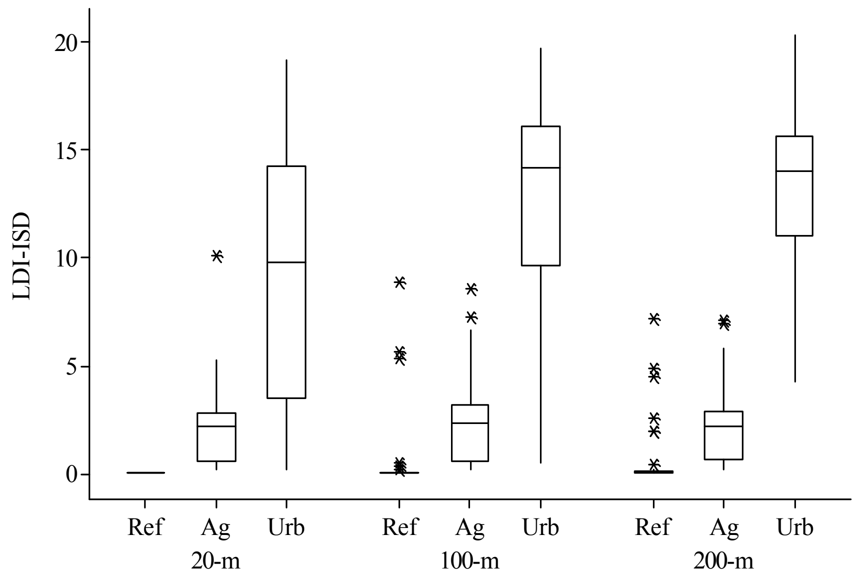


(a)



(b)

Figure 3-6. Comparison among LDI values calculated for isolated forested wetlands for three extents (20, 100, and 200 meters from wetlands' edge). LDIs were calculated based on (a) the proportion occupied by each land use type in the landscape unit – LDI-PLU; and assuming that the effect of development intensity decreased (b) linearly with distance – LDI-ILD, and (c) in inverse-square with distance – LDI-ISD. Groups within extent categories show wetlands' distribution based on *a priori* land use categories: Ref = reference, Ag = agricultural, and Urb = urban. Differences among extent categories were not significant (Kruskal-Wallis test, $p < 0.05$). Boxes delimit the 25th and 75th percentiles and solid lines indicate the median. Whiskers extend to the lowest and highest data values and asterisks show unusual observations.



(c)

Figure 3-6. Continued.

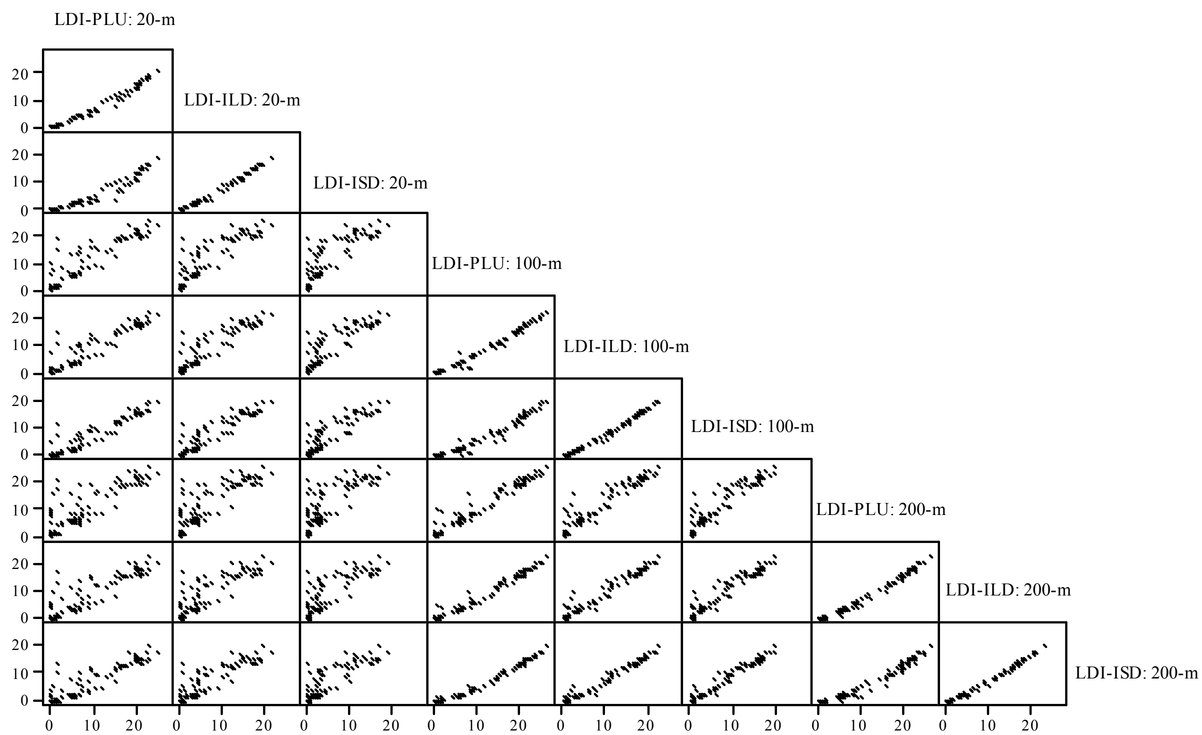
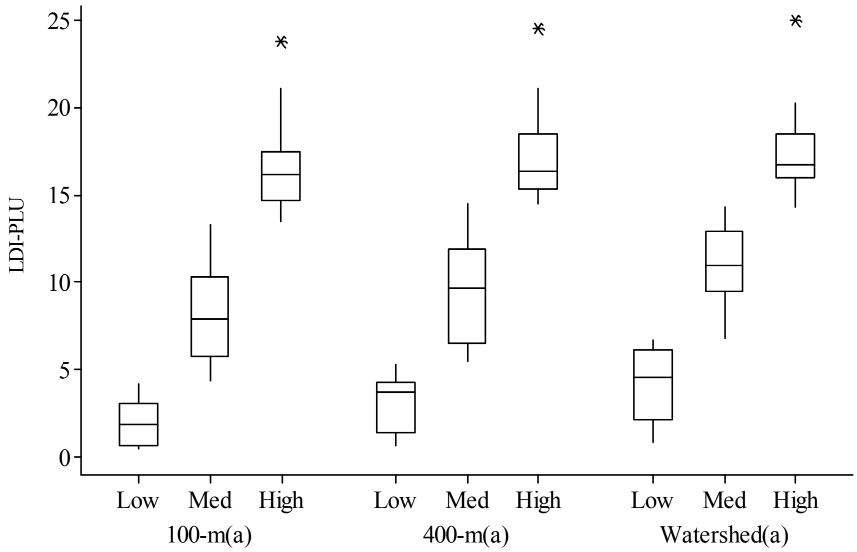
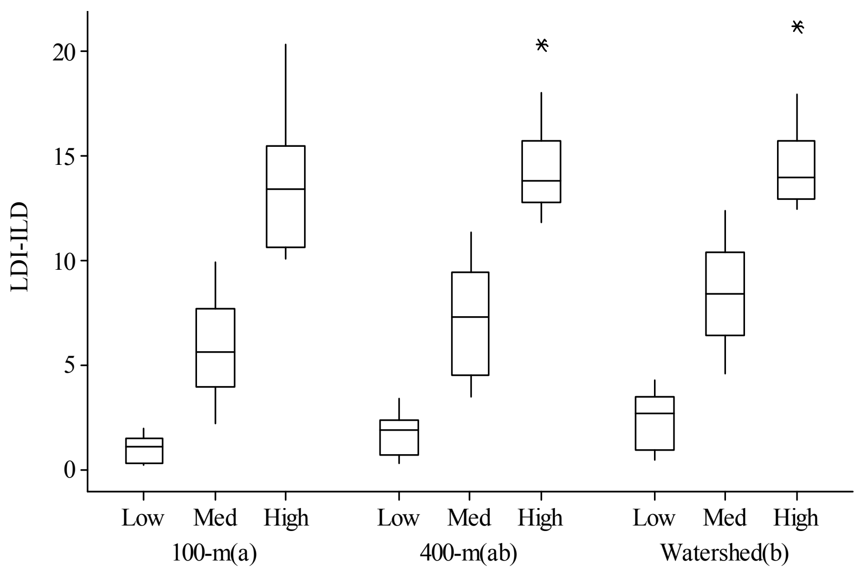


Figure 3-7. Matrix plot of the relationship between pairs of LDI scores calculated for three landscape extents (20-, 100-, and 200-meter) for the sample of isolated forested wetlands. LDIs were calculated based on land- use type proportions in the landscape unit (LDI-PLU); and based on a linear (LDI-ILD) and inverse square (LDI-ISD) decrease with distance of development intensity.

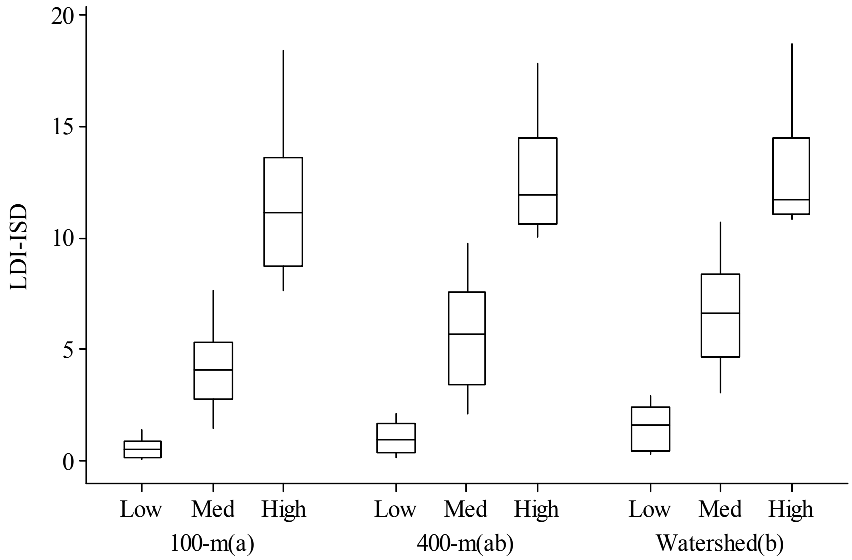


(a)



(b)

Figure 3-8. Comparison between LDI scores calculated for buffer areas of 100 and 400 meters from the sample streams and for the entire drainage basin. LDIs were calculated based on (a) the proportion occupied by each land use type in the landscape unit – LDI-PLU, and assuming that the effect of development intensity on the landscape decreased (b) linearly with distance – LDI-ILD, and (c) in inverse-square with distance – LDI-ISD. Groups within extent category show streams distribution for the first 25% (Low), the intermediate 50% (Med), and the higher 25% (High) of the data. Extent categories with similar letters were not significantly different (Kruskal-Wallis test, $p < 0.05$). Boxes delimit the 25th and 75th percentiles and solid lines indicate the median. Whiskers extend to the lowest and highest data values and asterisks show unusual observations.



(c)

Figure 3-8. Continued.

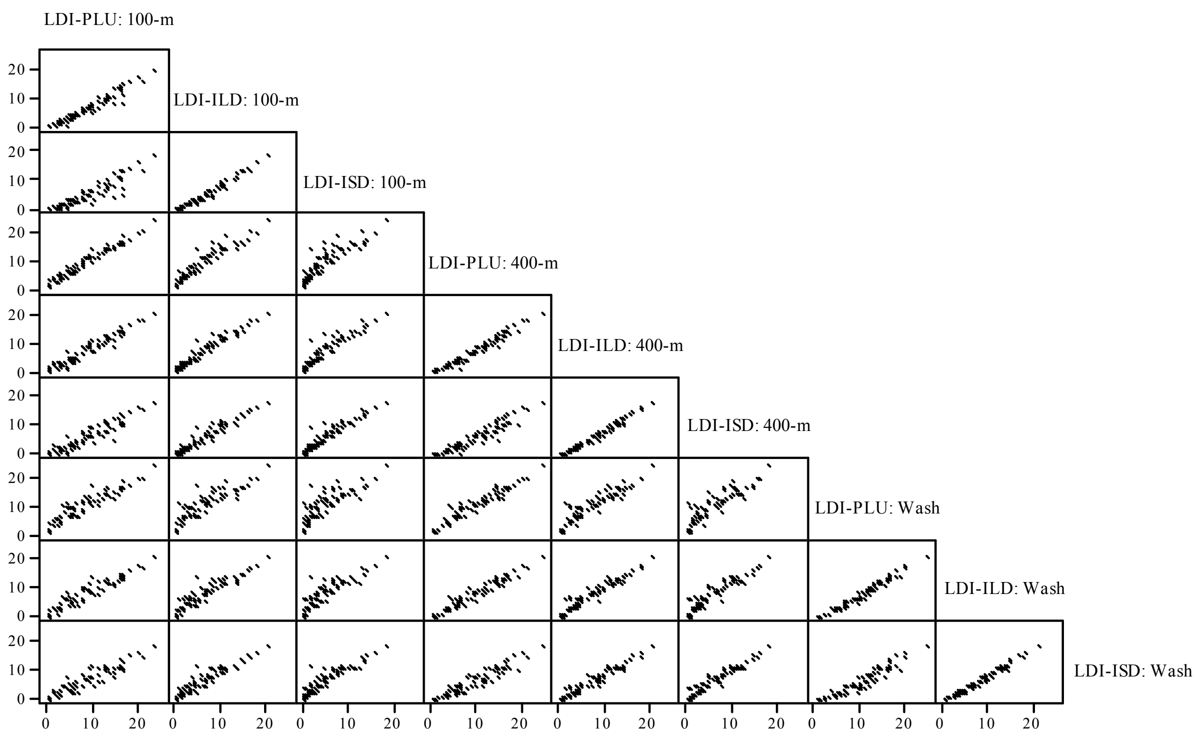
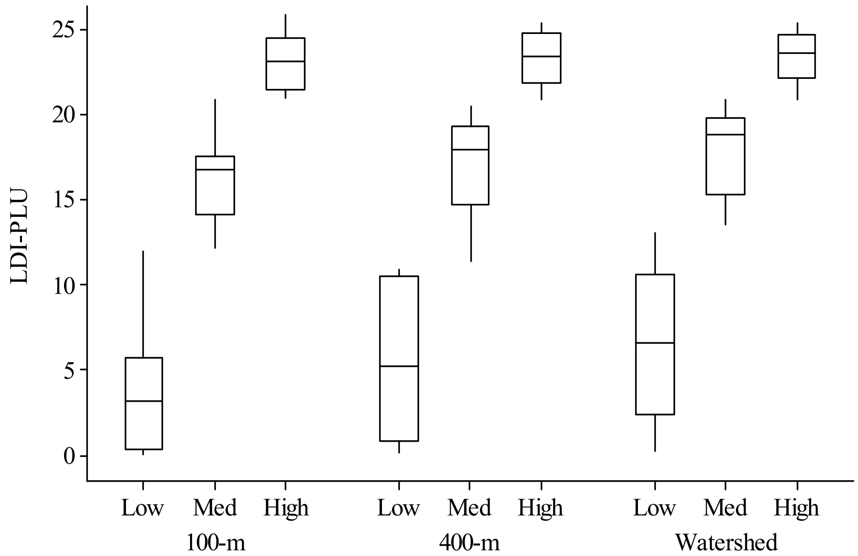
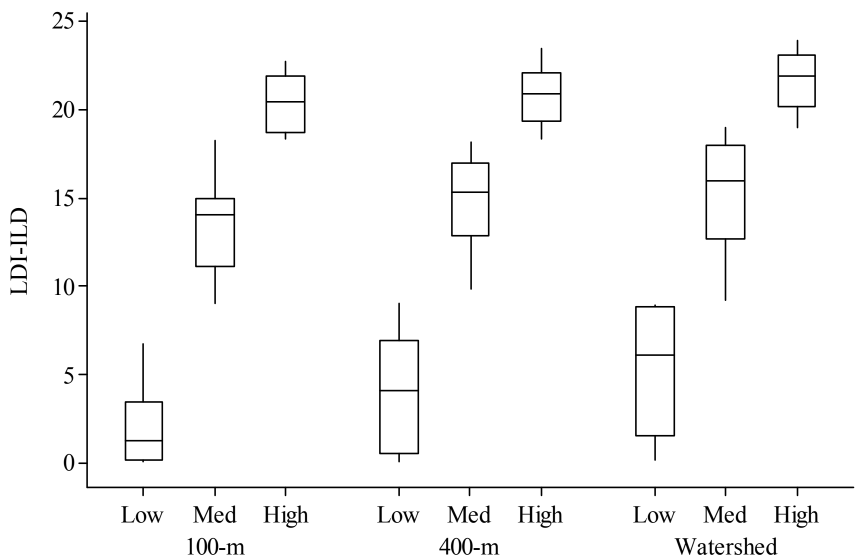


Figure 3-9. Matrix plot of the relationship between pairs of LDI scores calculated for three landscape extents (100-m, 400-m, and watershed) for the sample of streams. LDIs were calculated based on land- use type proportions in the landscape unit (LDI-PLU); and based on a linear (LDI-ILD) and inverse square (LDI-ISD) decrease with distance of development intensity.

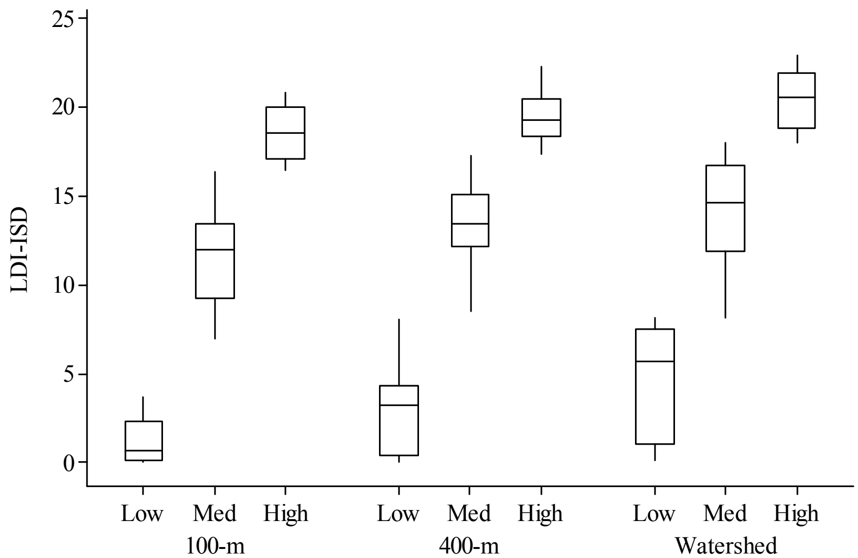


(a)



(b)

Figure 3-10. Comparison among LDI scores calculated for buffer areas of 100 and 400 meters from the sample lakes and for the entire drainage basin. LDI values were calculated based on (a) the proportion occupied by each land use type in the landscape unit – LDI-PLU, and assuming that the effect of development intensity on the landscape decreased (b) linearly with distance – LDI-ILD, and (c) in inverse-square with distance – LDI-ISD. Groups within extent category show lakes distribution for the first 25% (Low), the intermediate 50% (Med), and the higher 25% (High) of the data. There were no significant differences among extent categories (Kruskal-Wallis test, $p < 0.05$). Boxes delimit the 25th and 75th percentiles and solid lines indicate the median. Whiskers extend to the lowest and highest data values and asterisks show unusual observations.



(c)

Figure 3-10. Continued.

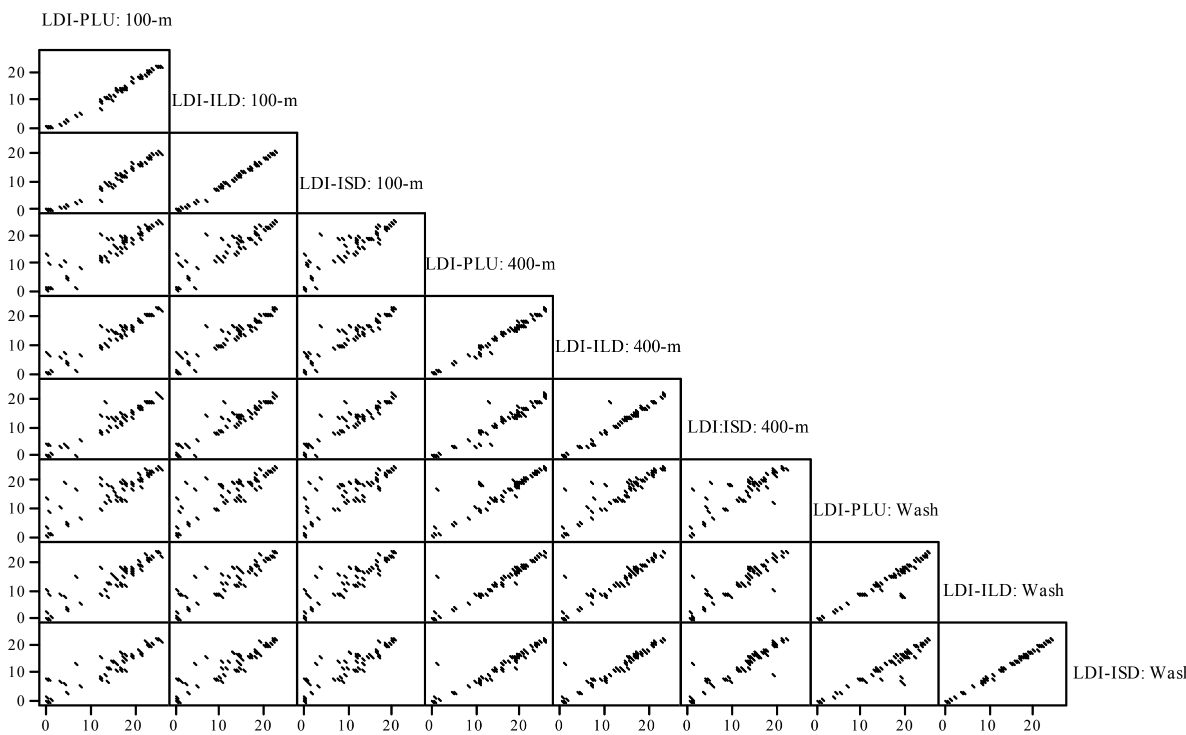


Figure 3-11. Matrix plot of the relationship between pairs of LDI scores calculated for three landscape extents (100-m, 400-m, and watershed) for the sample of lakes. LDIs were calculated based on land- use type proportions in the landscape unit (LDI-PLU); and based on a linear (LDI-ILD) and inverse square (LDI-ISD) decrease with distance of development intensity.

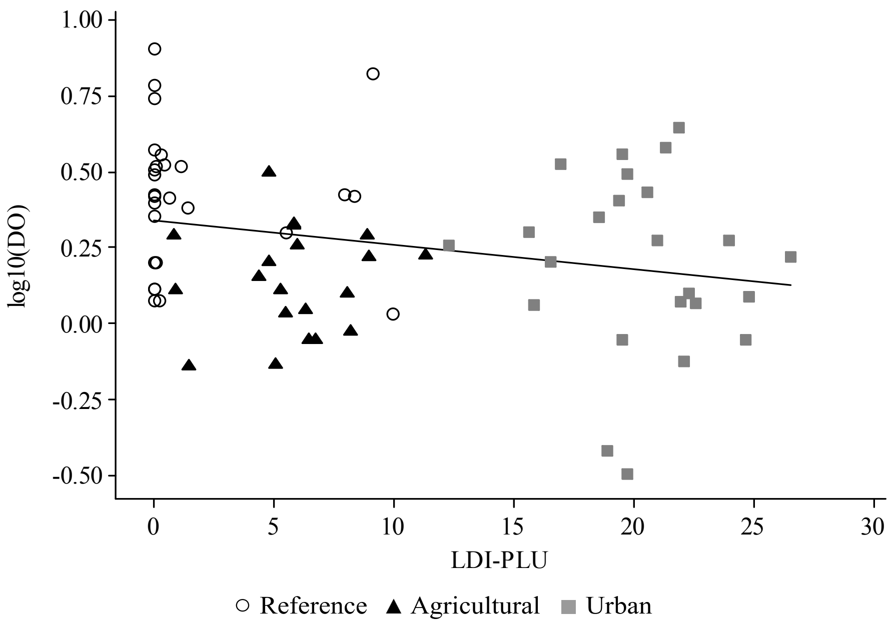


Figure 3-12. Variability in DO for the sample isolated forested wetlands explained by the LDI calculated at the 200-meter buffer. $Log_{10}(DO) = 0.338 - 0.0079(LDI\text{-}PLU)$; $r^2 = 0.069$, $p = 0.028$. Sample wetlands are designated by *a priori* land use category: reference, agricultural, or urban.

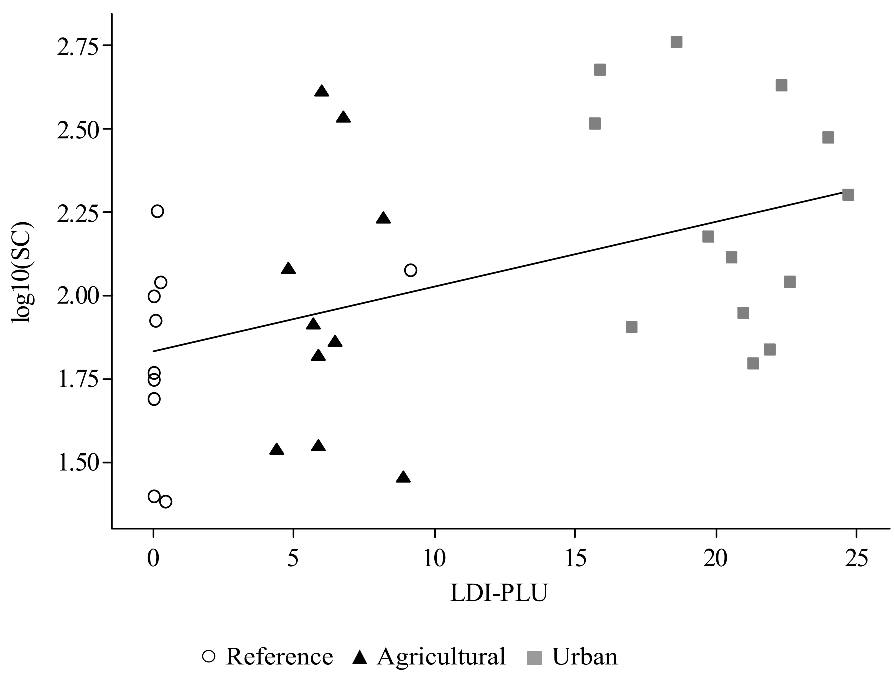


Figure 3-13. Variability in SC for the sample isolated forested wetlands explained by the LDI calculated at the 200-meter buffer. $Log_{10}(SC) = 1.83 + 0.0194(LDI\text{-}PLU)$; $r^2 = 0.205$, $p = 0.008$. Sample wetlands are designated by *a priori* land use category: reference, agricultural, or urban.

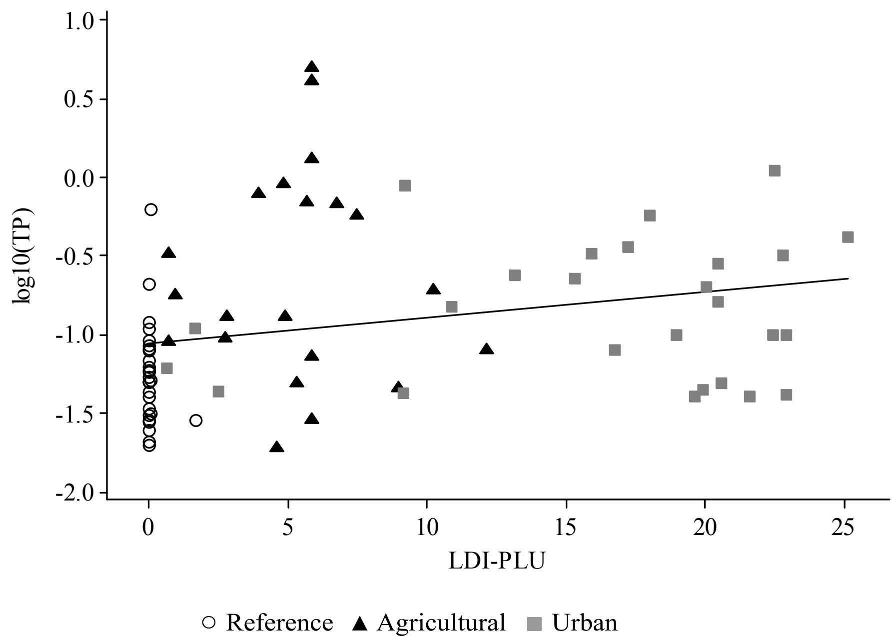


Figure 3-14. Variability in TP for the sample isolated forested wetlands explained by the LDI calculated for a spatial extent of 20 meters. $Log_{10}(TP) = - 1.06 + 0.0165(LDI\text{-}PLU)$; $r^2 = 0.065$, $p = 0.027$. Sample wetlands are designated by *a priori* land use category: reference, agricultural, or urban.

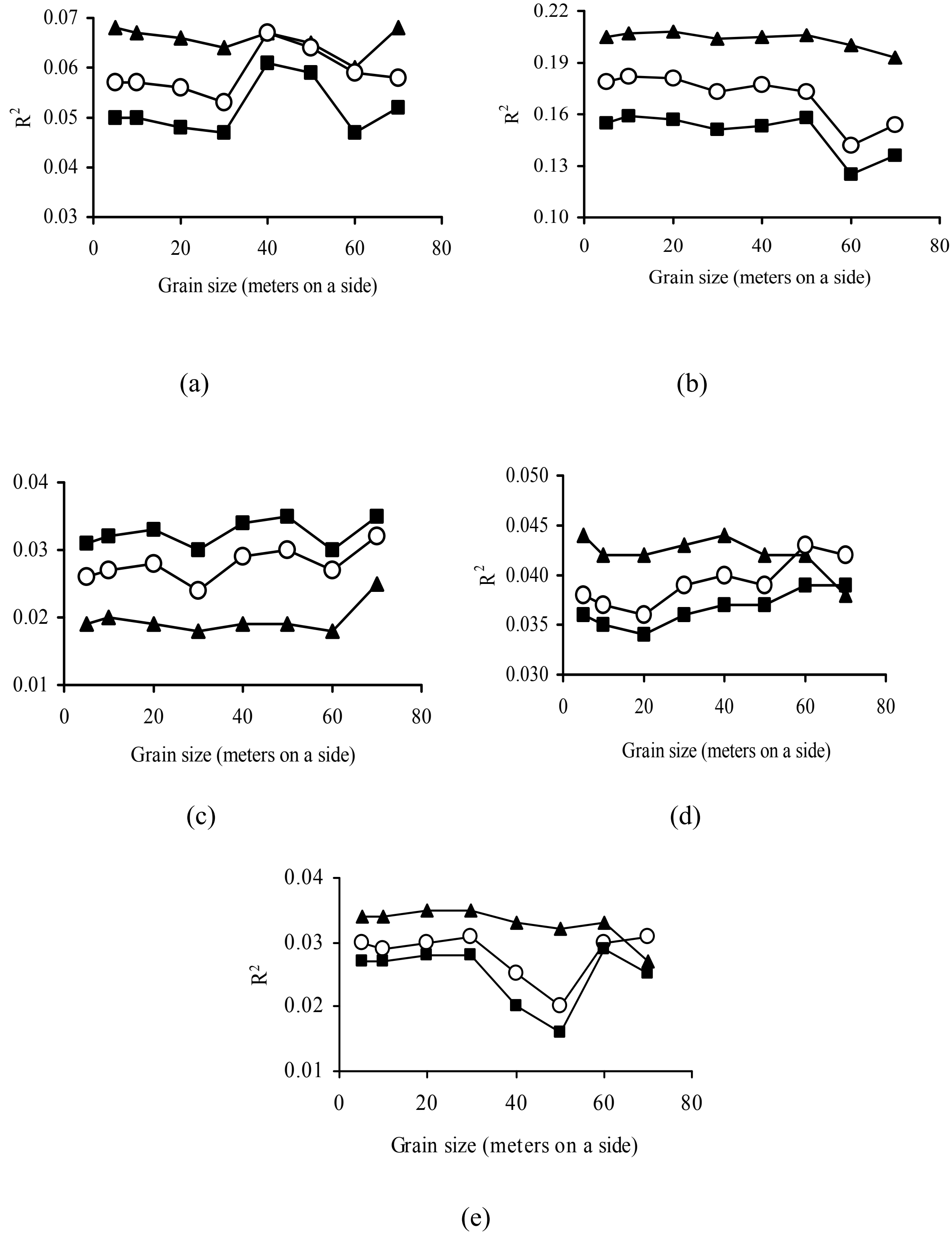


Figure 3-15. Regression results at several spatial scales showing how much of the variability (measured in r^2 values) in the water chemistry variables for the sample isolated forested wetlands was explained by the LDI: (a) $\log_{10}$DO, (b) $\log_{10}$SC, (c) $\log_{10}$TN, (d) $\log_{10}$TP, and (e) $\log_{10}$Turbidity. (–▲– LDI-PLU; –○–LDI-ILD; –■–LDI-ISD).

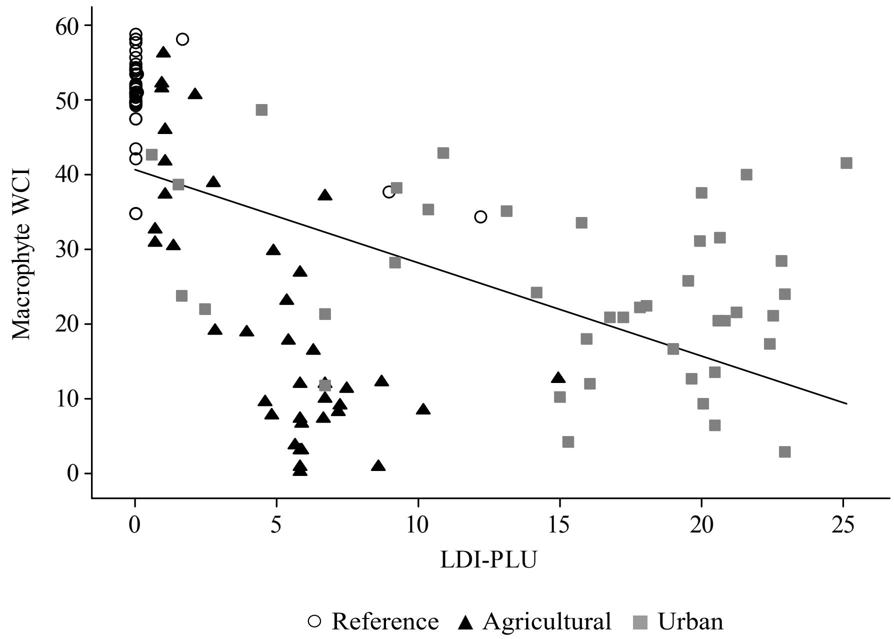


Figure 3-16. Variability in the macrophyte WCI explained by the LDI calculated for a buffer of 20-meters surrounding the sample isolated forested wetlands. Macrophyte WCI = 40.6 - 1.25(LDI-PLU); $r^2 = 0.296$, $p < 0.001$. Sample wetlands are designated by *a priori* land use category: reference, agricultural, or urban.

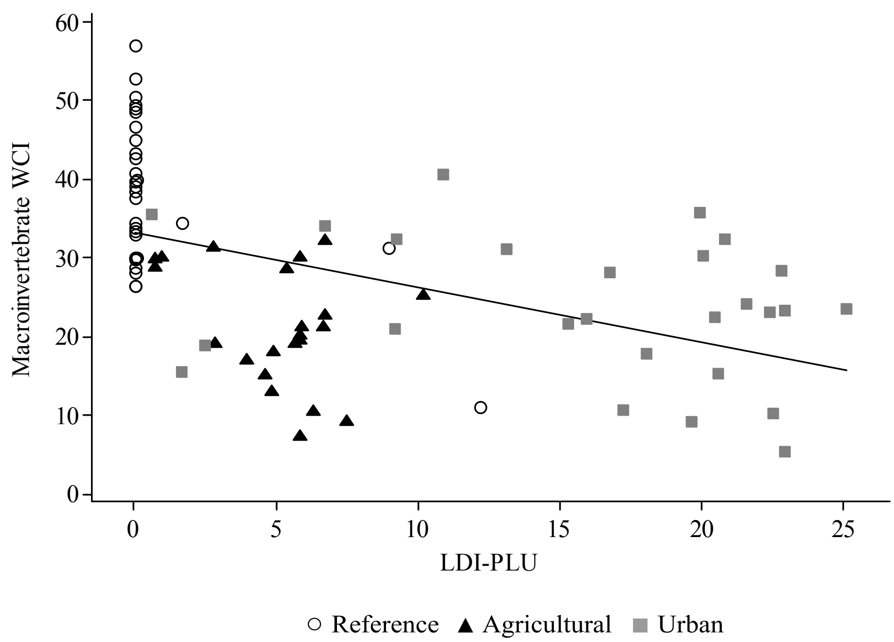


Figure 3-17. Variability in the macroinvertebrate WCI explained by the LDI calculated for a buffer of 20-meters surrounding the sample isolated forested wetlands. Macroinvertebrate WCI = 33.2 - 0.70(LDI-PLU); $r^2 = 0.239$, $p < 0.001$. Sample wetlands are designated by *a priori* land use category: reference, agricultural, or urban.

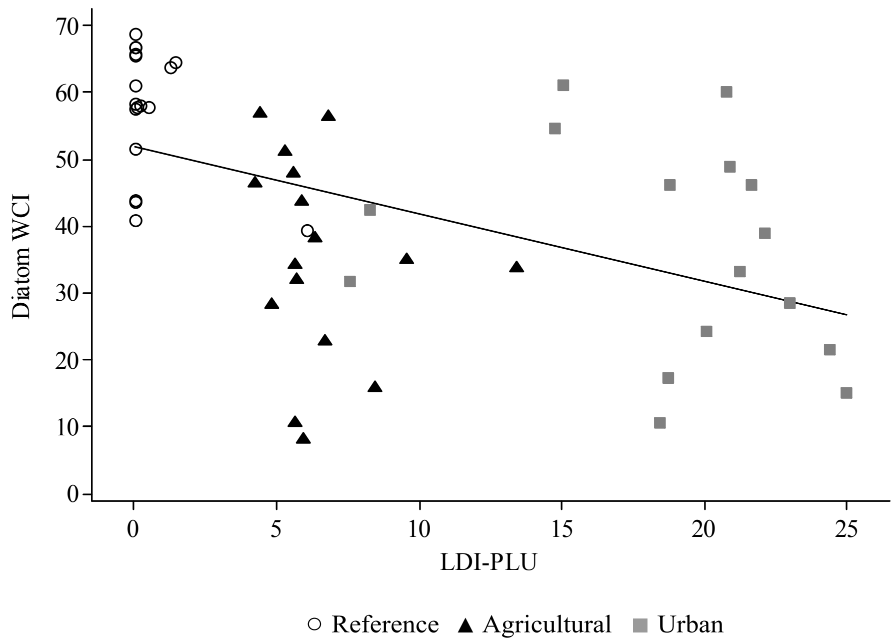


Figure 3-18. Variability in the diatom WCI explained by the LDI calculated for a buffer of 100-meters surrounding the sample isolated forested wetlands. Diatom WCI = 51.8 - 1.01(LDI-PLU); $r^2 = 0.242$, $p < 0.001$. Sample wetlands are designated by *a priori* land use category: reference, agricultural, or urban.

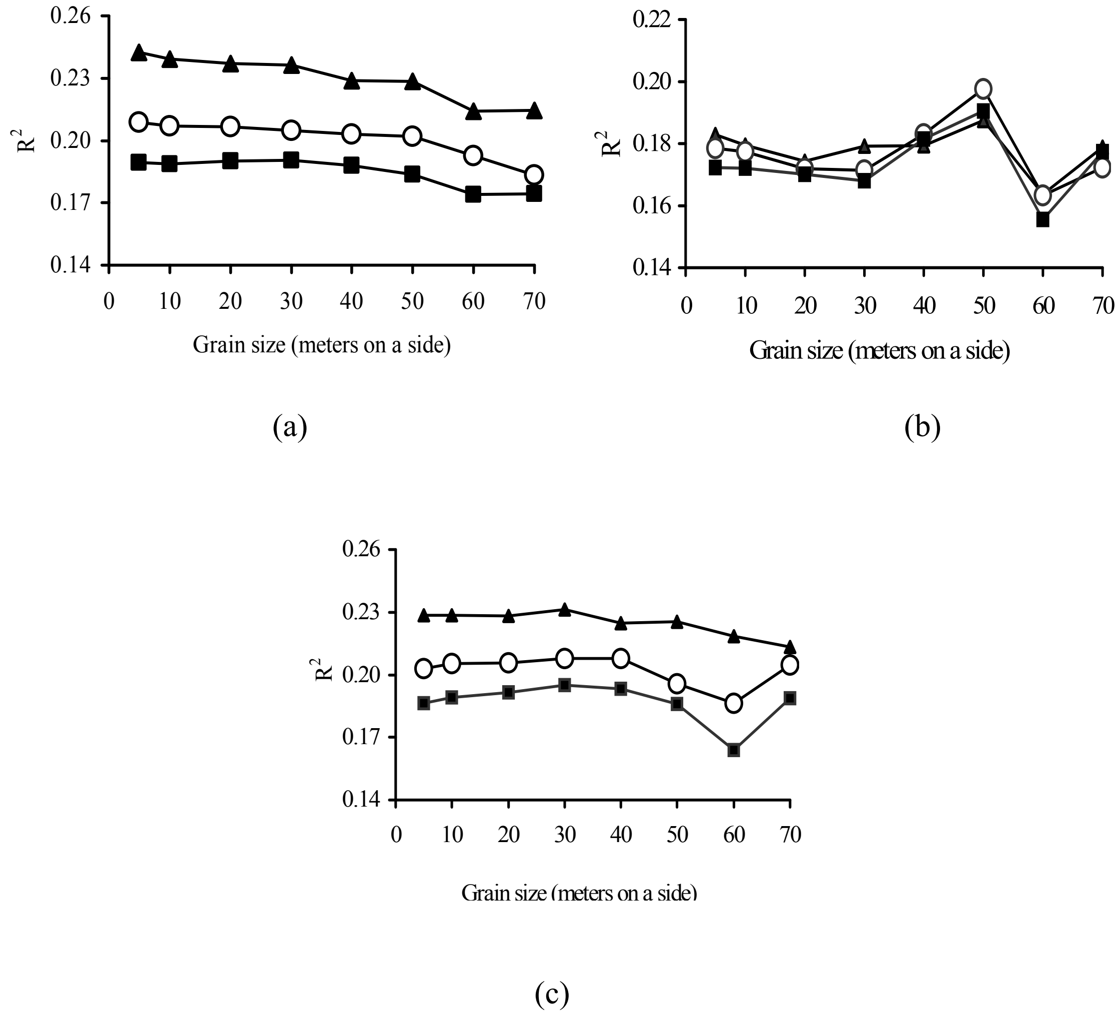


Figure 3-19. Regression results at several landscape grains showing how much of the variability (measured in r^2 values) in the WCI for the sample isolated forested wetlands was explained by the LDI: (a) macrophyte WCI, (b) macroinvertebrate WCI, and (c) diatom WCI. (–▲– LDI-PLU; –○–LDI-ILD; –■–LDI-ISD).

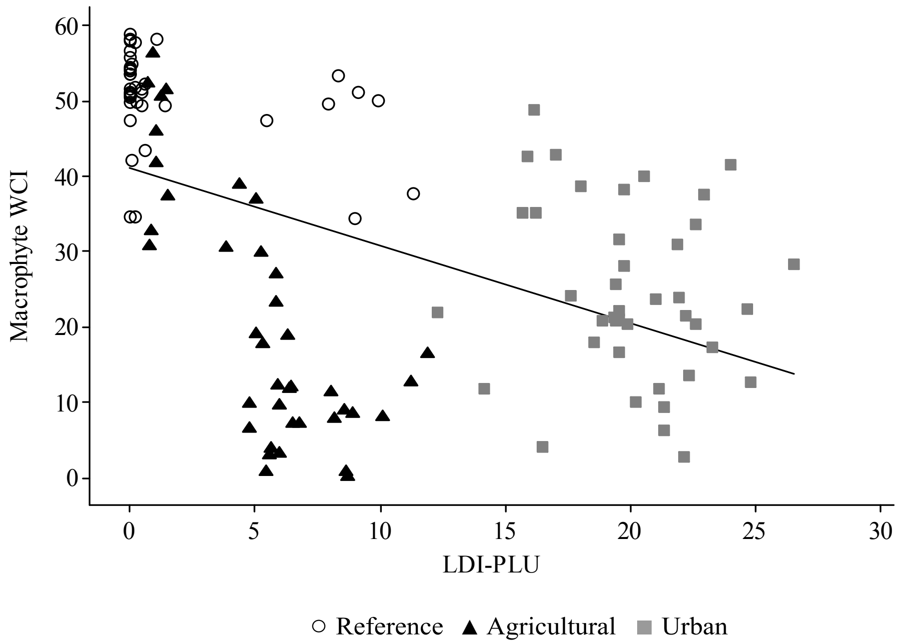


Figure 3-20. Variability in the macrophyte WCI explained by the LDI calculated at a grain size of 5 x 5 meters. Macrophyte WCI = 41.1 - 1.04(LDI-PLU); $r^2 = 0.243$, $p < 0.001$. Sample isolated forested wetlands are designated by *a priori* land use category: reference, agricultural, or urban.

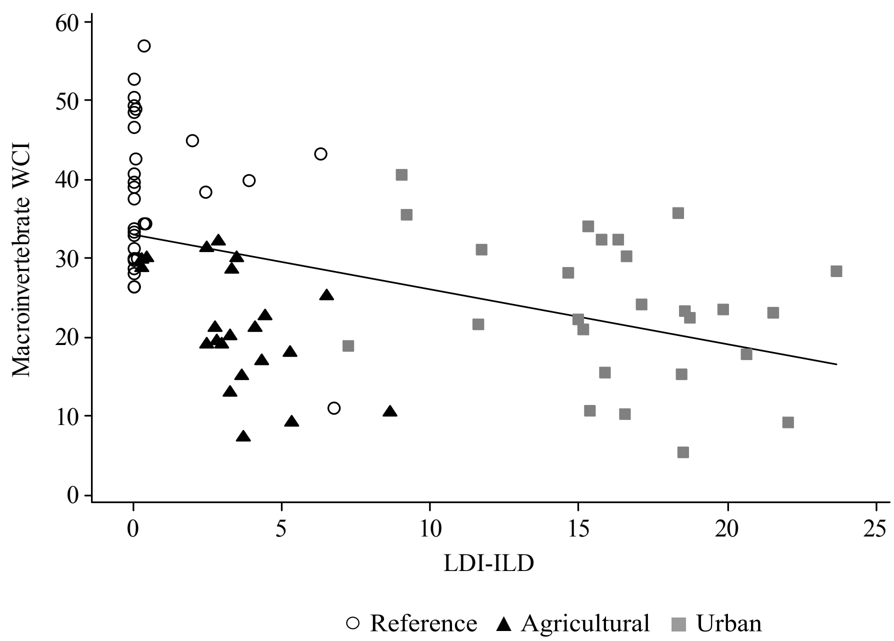


Figure 3-21. Variability in the macroinvertebrate WCI explained by the LDI calculated at a grain size of 50 x 50 meters. Macroinvertebrate WCI = 32.9 - 0.692(LDI-ILD); $r^2 = 0.198$, $p < 0.001$. Sample isolated forested wetlands are designated by *a priori* land use category: reference, agricultural, or urban.

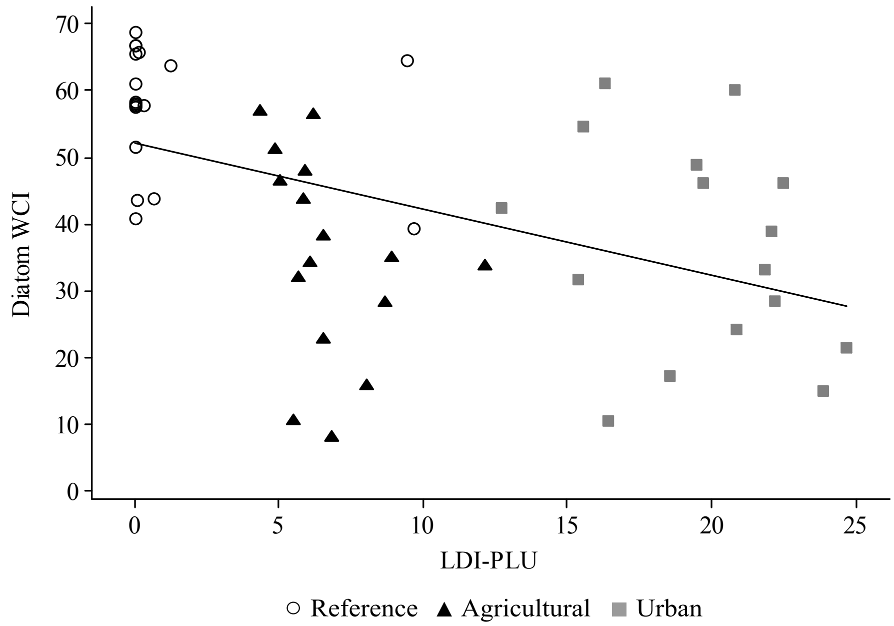


Figure 3-22. Variability in the diatom WCI explained by the LDI calculated at a grain size of 30 x 30 meters. Diatom WCI = 52.2 - 0.994 (LDI-PLU); $r^2 = 0.231$, $p < 0.001$. Sample isolated forested wetlands are designated by *a priori* land use category: reference, agricultural, or urban.

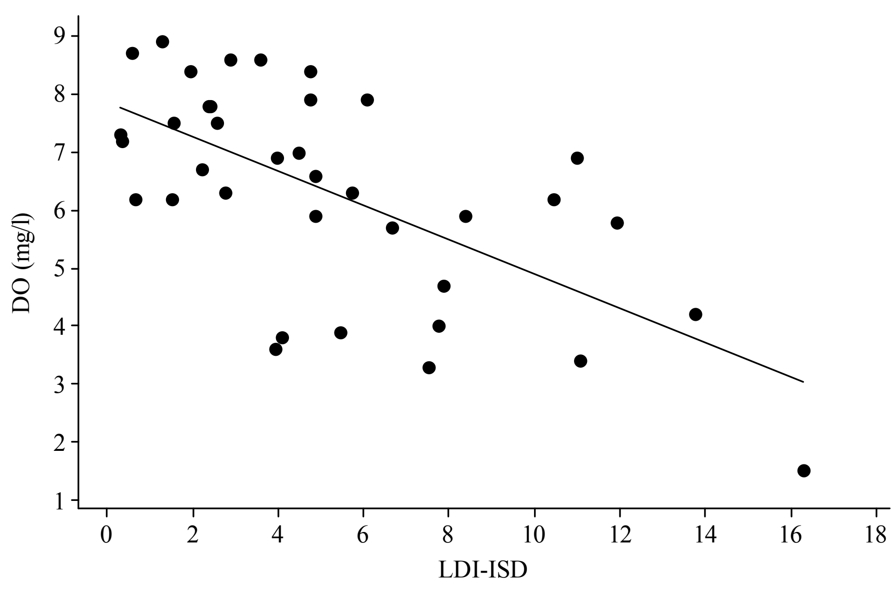


Figure 3-23. Variability in the concentration of DO for the sample streams explained by the LDI calculated for the watershed scale. DO = 7.85 - 0.296(LDI-ISD); $r^2 = 0.409$, $p < 0.001$.

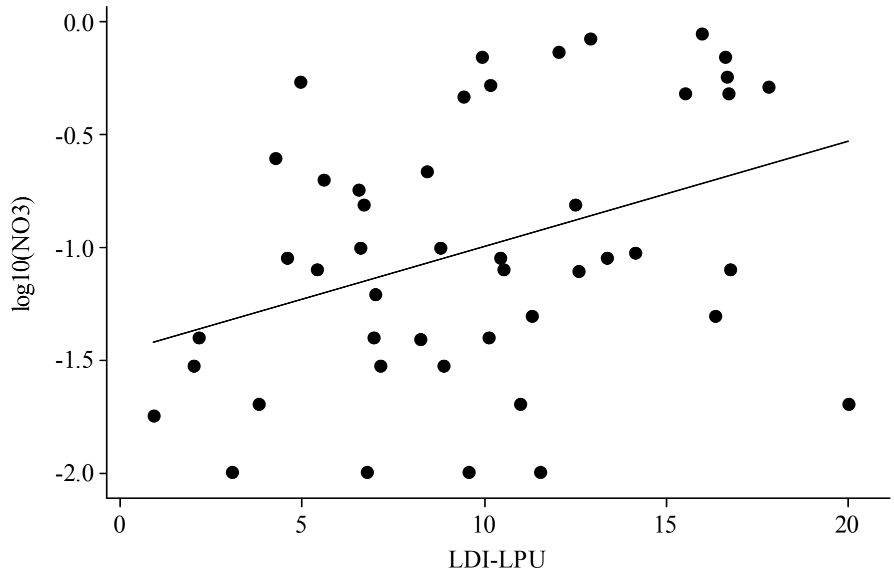


Figure 3-24. Variability in NO_3-N for the sample streams explained by the LDI calculated for the watershed scale. $Log_{10}(NO_3\text{-}N) = -1.46 + 0.0467$ (LDI-PLU); $r^2 = 0.139$, $p = 0.011$.

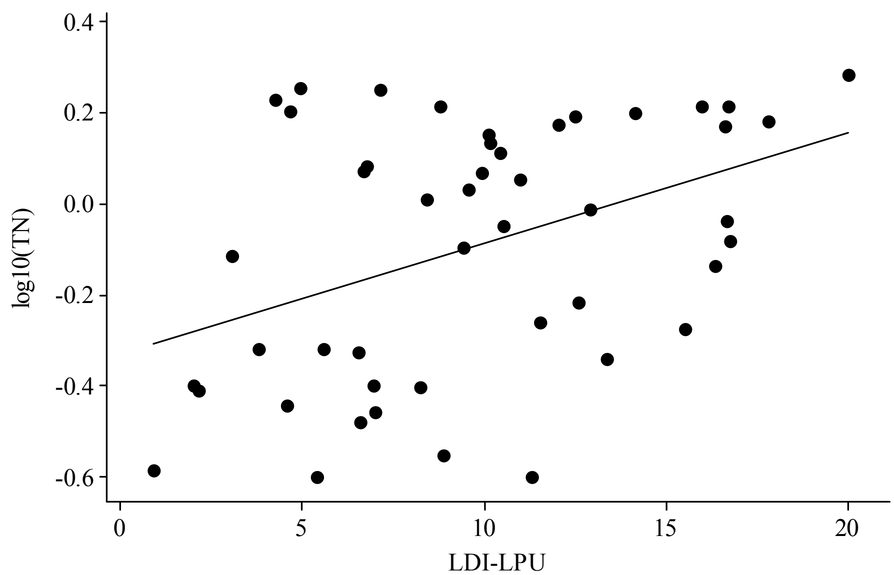


Figure 3-25. Variability in TN for the sample streams explained by the LDI calculated for the watershed scale. $Log_{10}(TN) = -0.330 + 0.0242$(LDI-PLU); $r^2 = 0.17$, $p = 0.004$.

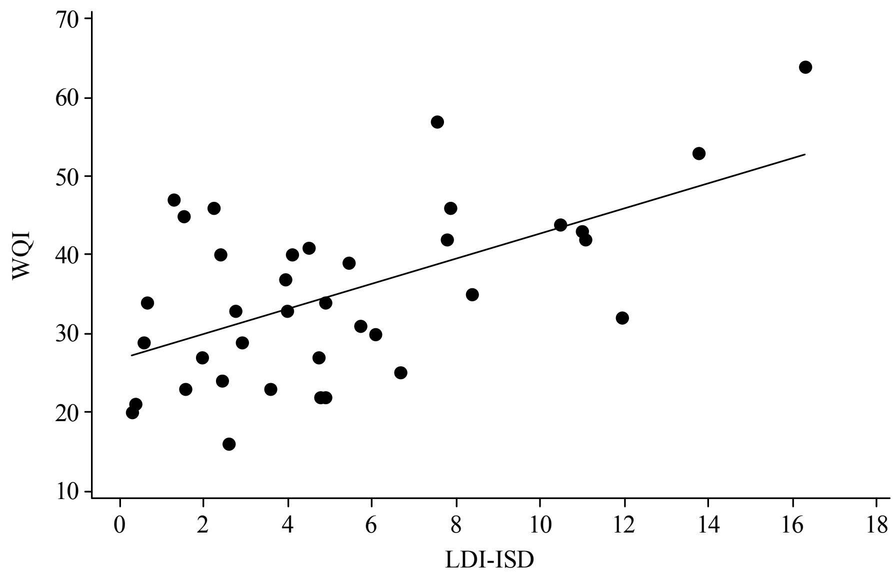


Figure 3-26. Variability in the WQI scores for the sample streams explained by the LDI calculated for the watershed scale. WQI = 26.7 + 1.60(LDI-ISD); $r^2 = 0.332$, $p < 0.001$.

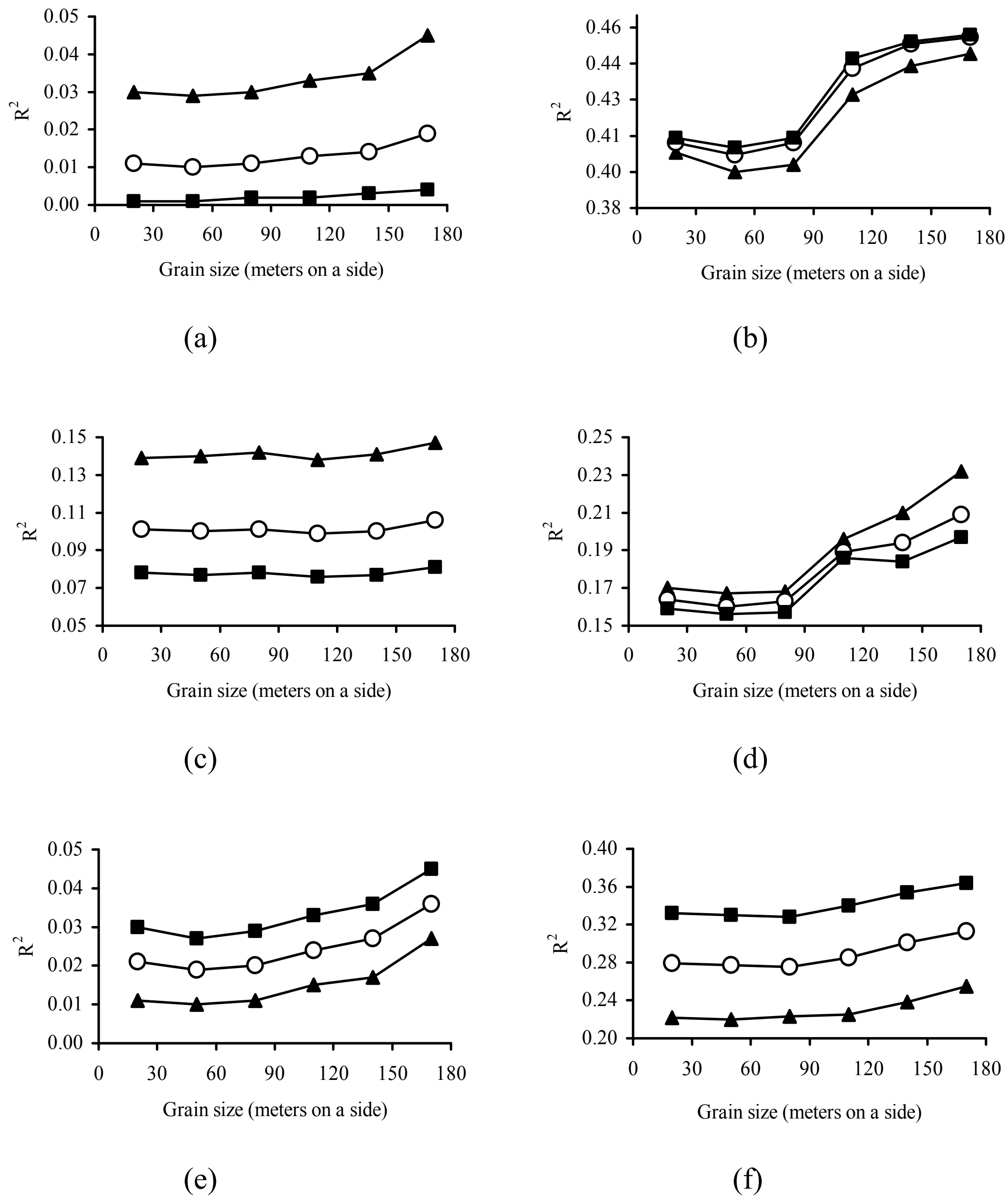


Figure 3-27. Regression results at several spatial scales showing how much of the variability (measured in r^2 values) in the water chemistry variables and the WQI for the sample streams was explained by the LDI: (a) Turbidity, (b) DO, (c) NO_3-N, (d) TN (e) TP, and (f) WQI. (–▲– LDI-PLU; –○–LDI-ILD; –■–LDI-ISD).

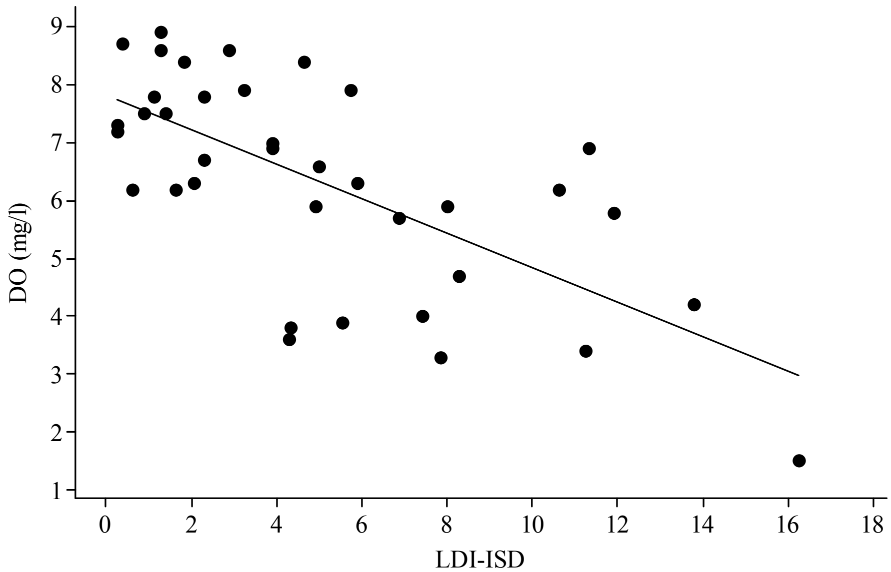


Figure 3-28. Variability in the concentration of DO for the sample streams explained by the LDI calculated at a grain size of 170 x170 meters. DO = 7.80 - 0.298(LDI-ISD); r^2 = 0.452, $p < 0.001$.

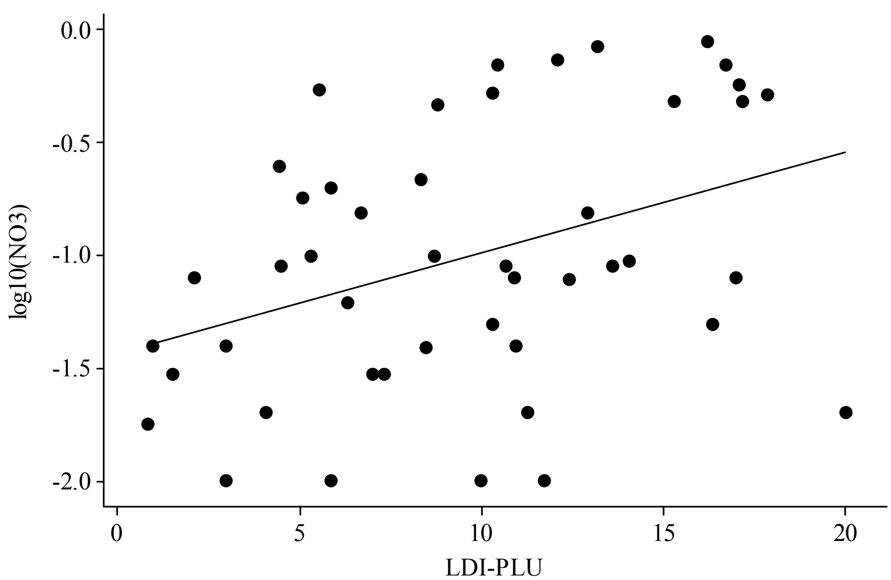


Figure 3-29. Variability in the concentration of NO_3-N for the sample streams explained by the LDI calculated at a grain size of 170 x 170 meters. $Log_{10}(NO_3\text{-}N) = -1.43 + 0.0447(LDI\text{-}PLU)$; $r^2 = 0.147$, $p = 0.008$.

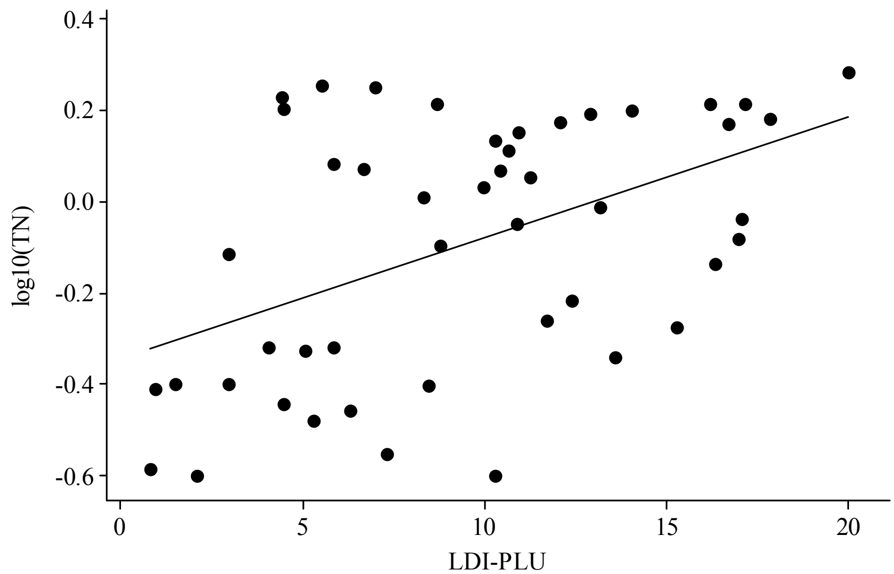


Figure 3-30. Variability in TN for the sample streams explained by the LDI calculated at a grain size of 170 x 170 meters. $Log_{10}(TN) = - 0.345 + 0.0264(LDI\text{-}PLU)$; $r^2 = 0.232$, $p = 0.001$.

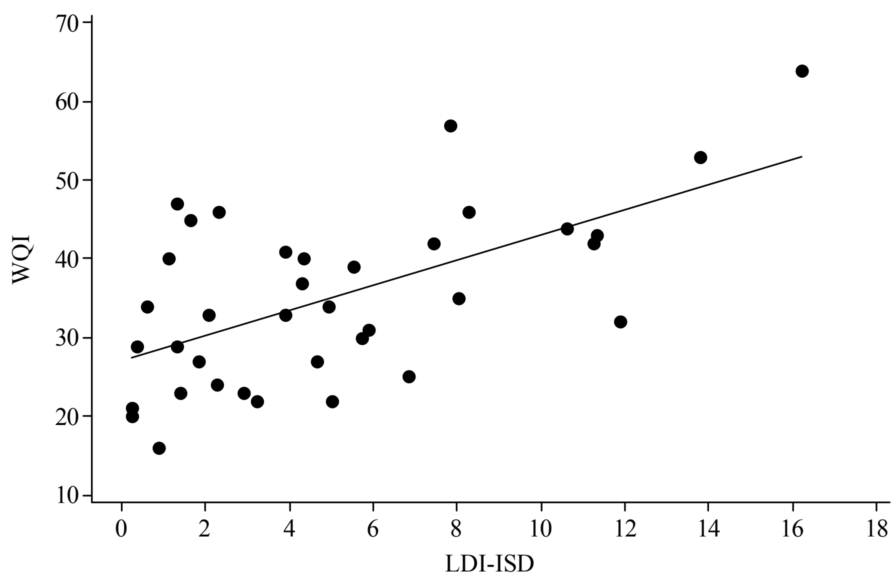


Figure 3-31. Variability in the WQI scores for the sample streams explained by the LDI calculated at a grain size of 170 x 170 meters. $WQI = 27.0 + 1.61(LDI\text{-}ISD)$; $r^2 = 0.364$, $p < 0.001$.

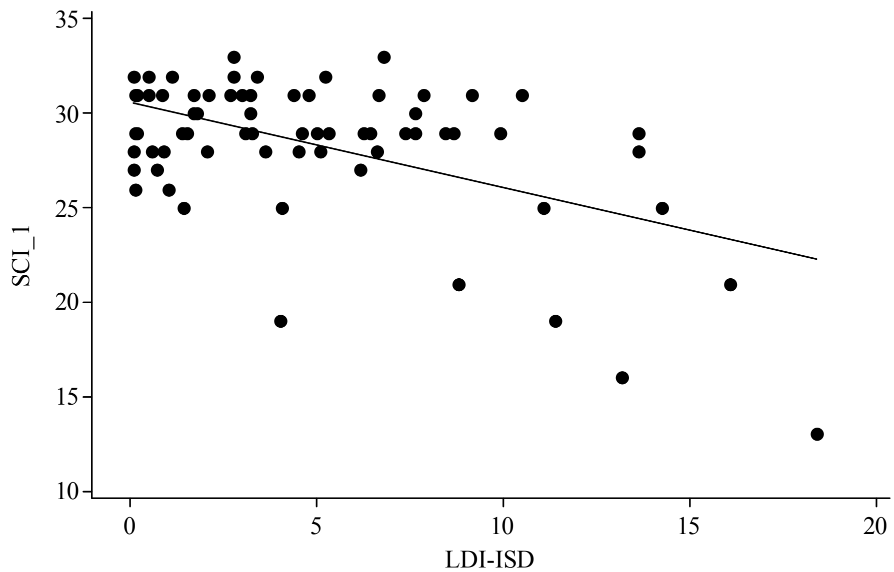


Figure 3-32. Variability in the SCI_1 for the sample streams explained by the LDI calculated for the 100-meter buffer. SC_1 = 30.6 - 0.450(LDI-ISD); $r^2 = 0.268$, $p < 0.001$.

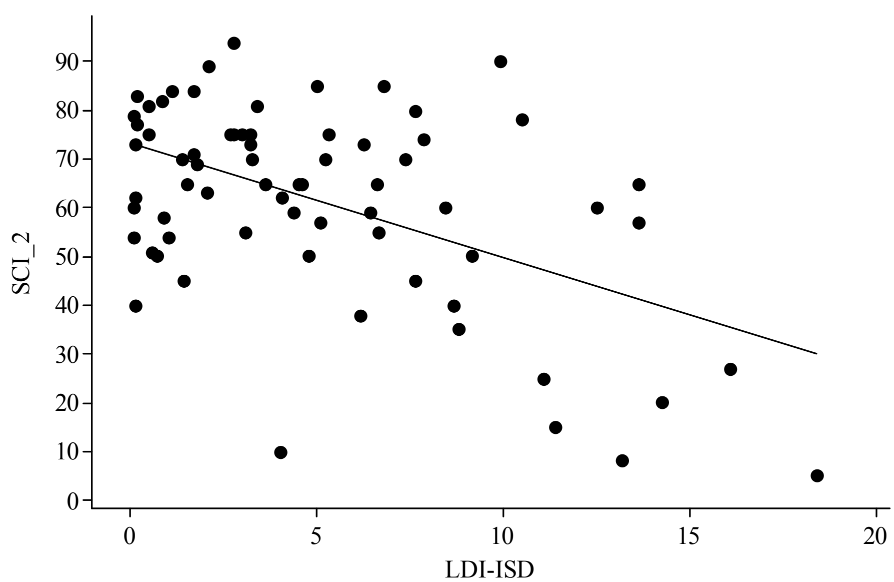
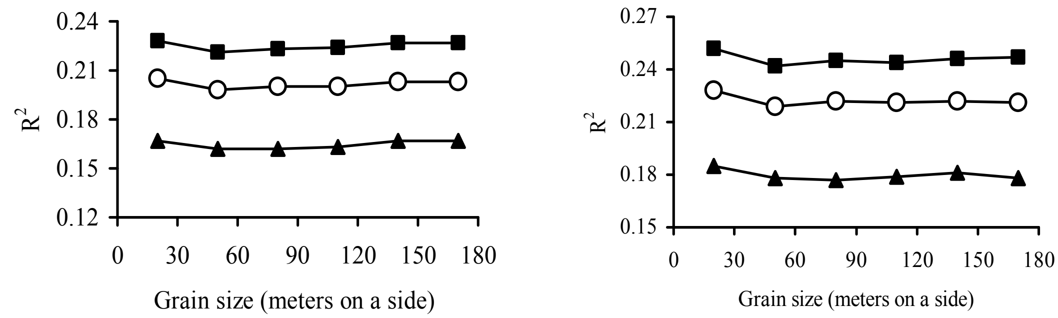


Figure 3-33. Variability in the SCI_2 for the sample streams explained by the LDI calculated for the 100-meter buffer. SCI_2 = 73.2 - 2.34(LDI-ISD); $r^2 = 0.261$, $p < 0.001$.



(a) (b)

Figure 3-34. Regression results at several spatial scales showing how much of the variability (measured in r^2 values) in the SCI for the sample streams was explained by the LDI: (a) SC_1, and (b) SCI_2. (–▲– LDI-PLU; –○–LDI-ILD; –■–LDI-ISD).

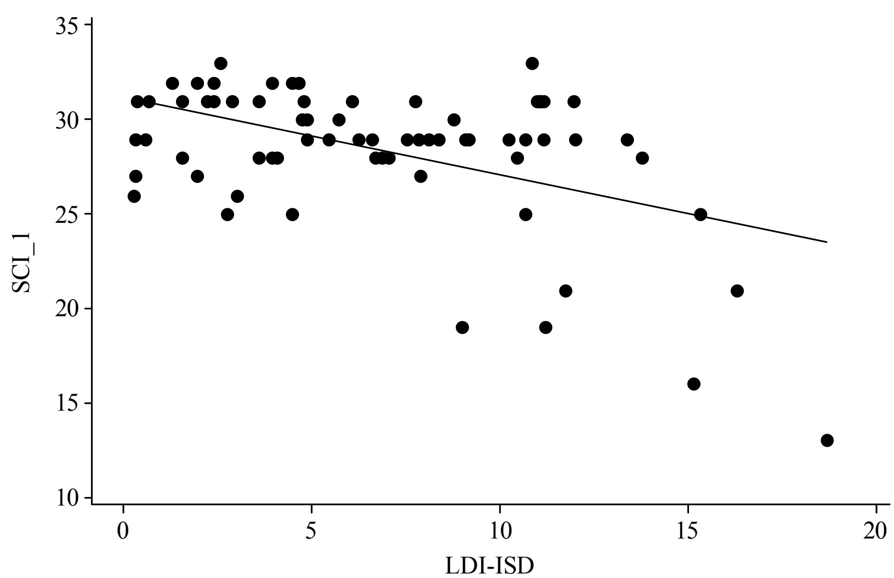


Figure 3-35. Variability in the SCI_1 for the sample streams explained by the LDI calculated at a grain size of 20 x 20 meters. SC_1 = 31.2 - 0.409(LDI-ISD); $r^2 = 0.228$, $p < 0.001$.

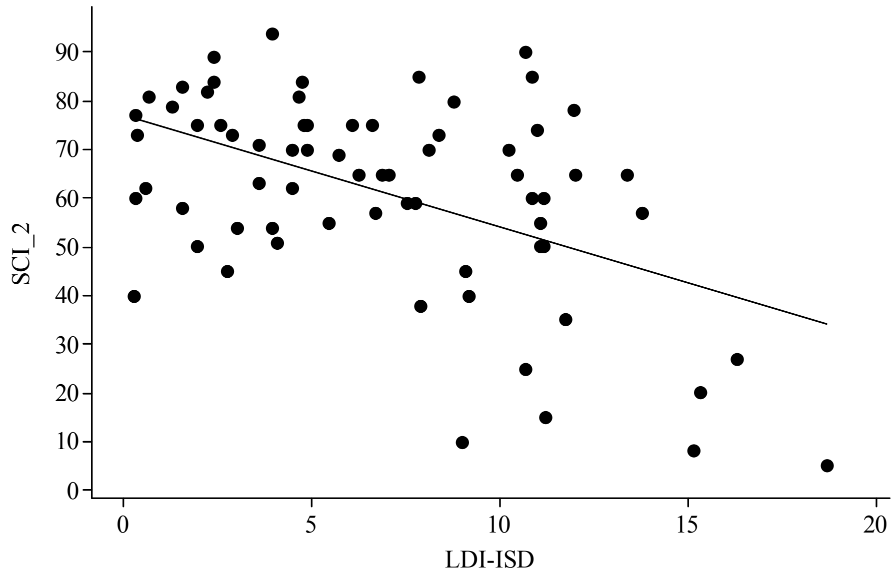


Figure 3-36. Variability in the SCI_2 for the sample streams explained by the LDI calculated at a grain size of 20 x 20 meters. SC_2 = 77.1 - 2.29(LDI-ISD); $r^2 = 0.252$, $p < 0.001$.

CHAPTER 4
DISCUSSION

Summary

Land use change may be the greatest threat to freshwater ecosystems worldwide. Since land development may result in changes in the ecological condition of freshwater ecosystems and the degradation of resources vital to human well-being, understanding how human behavior in the landscape affects freshwater ecosystems is a matter of critical importance. The problem may be most significant in places like Florida where rapid population growth and land development are the main driving forces of change in the landscape (Reynolds 1999). This dissertation evaluated how landscape-scale development intensity affects the ecological condition and water quality of isolated forested wetlands, streams, and lakes in Florida. A quantitative measure of Landscape Development Intensity (LDI) calculated based on the use of non-renewable energy use and several measures of landscape pattern were used as indicators of human activity. The objectives of this study were to (1) investigate spatial properties of indicators of landscape development intensity with changes in landscape scale and distance; (2) test the ability of indicators landscape development intensity to predict ecosystem condition at different landscape scales and considering land use distance; (3) statistically relate landscape pattern with indicators of ecosystem conditions and water quality at different landscape scales; and (4) evaluate how landscape pattern indicators may complement the landscape development intensity indicators in their ability to predict ecological condition. Accordingly, the major findings of this investigation are summarized as follows:

- Changes in landscape grain and extent had minor effects on the LDI. Grain size affected LDI scores, especially in the middle ranges of the LDI and for smaller landscapes (isolated forested wetlands). The effect of landscape grain on the LDI tended to become less important with increasing landscape area. LDI scores tended to increase with increasing spatial extent. Differences in LDI scores with changes in landscape scale were more noticeable at low and intermediate LDI ranges where differences in LDI scores are more likely to occur as developed lands were added with increasing area.

- In general, the LDI had a greater predictive ability for biological-based indices of ecological condition. The LDI calculated in closest proximity to the sample isolated forested wetlands and streams had the strongest predictive power, explaining up to 30% and 27% of variability, respectively. There was a lack of correlation between the LDI and indicators of lake condition, which may be attributed to the spatial variability and complex hydrology of Florida lakes.

- There were minor relationships between the LDI and water quality variables. For isolated forested wetlands and lakes small water quality sample size seemed to be a factor for poor correlations. Larger data samples for multiple years allowed for stronger associations for streams. Methods for calculating the LDI at the watershed scale and for coarser grain sizes had the strongest predictive power.

- The use of a distance-weighting functions provided little enhancement of the predictive power of the LDI. Only for streams, LDIs based on distance-weighting explained up to 7% more of the variance of biological indicators.

- Landscape pattern metrics were fairly associated to biological indicators of ecological condition and water quality for the freshwater ecosystems studied. Landscape pattern indices explained up to 44% of variability in biological indicators of ecological condition in isolated forested wetlands, and about 22% and 42% of the variability in biological indices of stream and lake condition, respectively. Pattern metrics were important factors in explaining the variability of water quality variables, especially for streams and lakes, which accounted for up to 60% and 39% in the variance in water quality, respectively.

- In general, using pattern indices with the LDI had a moderate effect on predictive power. For isolated forested wetlands, the strongest influences were for the macrophyte and macroinvertebrate WCIs with an additional 25% and 17% of the total variance explained at the most significant scales, respectively. For lakes, landscape pattern was an important factor in determining lake condition; together, the landscape indices explained up to 52% of the total variance in the LCI. Combining the LDI and the landscape pattern variables was useful in assessing the influence of human development on water quality, especially for streams.

Spatial Properties of the LDI

Effects of Changing Grain Size on the LDI

Landscape indices allow the quantification of landscape attributes and provide a direct means to assess how landscapes may affect ecological systems. Their interpretation and usefulness is even more relevant when the sensitivity of landscape indices to changes in scale is well comprehended. In this study a Landscape Development Intensity Index (LDI) was developed using land use data surrounding various freshwaters systems, and was systematically investigated as to how the index varied with changes in landscape grain and extent. Important spatial properties of the LDI were described through this work, enhancing the usefulness of the LDI as a measure of land use intensity. The effect of cell aggregation (increase in landscape grain), which may result in the elimination of patch types, had more influence on the LDI scores of the smaller landscapes (isolated forested wetlands) than on larger landscapes (streams). More variability in LDI scores was observed when the LDI was quantified for landscapes surrounding isolated forested wetlands than for landscapes surrounding streams (see Figures 3-1 through 3-5). LDI scores were also more variable among landscapes that were more heterogeneous in their land use composition (mix of low- to high-intensity land uses). These results suggest that the grain size at which the LDI is calculated influences the result. It also suggests that the intensity of land use measured at different spatial scales may not be comparable.

That the LDI is scale dependent is a logical outcome provided that the LDI is derived using land-use data, which when aggregated into coarser grain data suffers from the elimination of the less common land use types (Turner et al. 1989). Despite this, two important findings about the properties of the LDI resulted from this study. First, the LDI is very sensitive to the presence or absence of urban land-use types in the landscape. Since the development intensity of urban lands, measured as non-renewable areal empower density, is at least an order of magnitude greater than other land uses classes like agricultural and natural lands, the presence of even a small area of urban lands may result in a high LDI score for a given landscape that otherwise may appear less developed. Second, for the isolated forested wetlands calculating the LDI at a grain size of 5 x 5 meters may be most appropriate (refer to Figure 3-2). The calculation of the LDI at coarser grain sizes may result in the elimination of land use patches that have strong influence on the condition of these systems. In doing so, the causes of ecosystem degradation related to land use may be obscured. For streams, the behavior of the LDI when calculated at different grain sizes suggests that differences in LDI scores are minimal for the finest scales considered (Figure 3-5, Appendix M) and that calculating the LDI at grain sizes between 20 x 20- to 80 x 80-meters will preserve land use patches that have strong influence on the condition of these systems, especially for small watersheds.

It must be noted that in this study only one of several aggregation methods for spatial data was used. The data were rescaled based on the most frequently occurring cell value, which may eliminate patch types with aggregation. This change may have had an effect on the LDI score for different grain sizes. The use of other aggregation methods may lead to different conclusions, since different aggregation methods may produce different results when the spatial data are rescaled (Bian and Butler 1999; Turner et al. 2001; Wu 2004).

Effects of Changes in Extent on the LDI

The LDI is also sensitive to changes in landscape extent (see Figures 3-6 through 3-11). Considering that a change in spatial extent while holding the grain constant usually results in greater spatial heterogeneity as new patch types are added to the landscape under investigation (Wiens 1989), the increase in extent most likely resulted in the addition of urban lands and an increase in LDI scores; thus, the largest differences among LDI scores were observed between landscapes that presented low LDI scores at small extents and high LDI scores at broad extents.

Since the results of this study suggested that the spatial extent over which the LDI is calculated influences the outcome, the ability to extrapolate development intensity values across different extents is limited. The implications of these results are important when analyzing the development patterns of watersheds using the LDI and how the land use within them may affect freshwater ecosystems. For largely urbanized watersheds, which were more characteristic of the lakes analyzed in this study, the difference among extents may not be relevant as LDI scores tend to be similar regardless of changes in spatial extent. This might also be the case for watersheds where developed lands are found in the near vicinity of the freshwaters systems studied as once included in the smaller extents, the influence of urban lands on the LDI score for the broader extents may still be large because of the high non-renewable empower density of these type of lands. When this is the case, considering just the smaller spatial extents to characterize the development intensity of a landscape surrounding a freshwater system may be sufficient as the variability in LDI scores tends to be small with increasing extent. Where landscapes are more heterogeneous in their land use composition and undeveloped lands tend to be more common in the near vicinity of the freshwater systems studied, the effect of spatial extent on the LDI cannot be ignored. This was the case for the landscape surrounding the streams analyzed in this study, which tended to be surrounded by natural lands (floodplain effect) with their influence on the LDI decreasing with increasing extent. It is important to point out the drainage basins for streams were larger compared to those of the sample lakes, allowing for less extent overlap and more variability in land use types. This suggests that the size of the drainage basin is also important in determining LDI scores. However, the effect of watershed size on the LDI remains a matter for future research, as it was not quantitatively analyzed in this study.

Distance-Weighting Factors

Several spatial aspects of the LDI related to land-use distance were also described. Distance-weighting was effective at emphasizing the value of the development intensity of nearby lands over that of more distant lands, particularly at the intermediate range of LDI values where landscapes were more heterogeneous in terms of the different lands use types present and where the presence of urban lands may have the most influence on LDI scores. Another noted effect of distance-weighting on the LDI at the intermediate range of LDI values was that the LDI was less variable with changes in landscape scale because distance-weighting allowed reducing the effect that methods of cell aggregation may have on LDI scores and by reducing the influence of developed lands that are added when the area of analysis is increased.

The LDI in its three forms was also highly correlated (see Tables 3-5, 3-6, and 3-7 and Figures 3-7, 3-9, and 3-11), suggesting that all forms of the LDI provided very similar information about the land use intensity when calculated at the same landscape extent. Accordingly, either form of the LDI can be used to describe the intensity of human development of the lands surrounding freshwater systems. However, the LDI calculated using distance-weighted factors allows distinguishing between patterns of development within buffers and whole watersheds, which can also be highly correlated, especially for small watersheds where the extent overlap can be considerable. Possible applications of emphasizing the land uses within buffers over entire watersheds include giving more value to the presence of natural lands for their role in mitigating impacts or weighting more heavily the presence of contiguous patches of developed lands along water bodies to give emphasis to their potential negative effect on their ecological condition and water quality.

Land Use Intensity and Ecosystem Condition

Biological Indices

The LDI served as a measure to predict the condition of isolated forested wetlands and streams in spite of the inherent complexity of these systems. For the isolated forested wetlands, the LDI was significantly related to the macrophyte WCI, the macroinvertebrate WCI, and the diatom WCI (see Tables 3-10 and 3-11). Similarly, the LDI was significantly associated with both forms of the SCI (see Tables 3-14 and 3-15). In the assessment of the ecological condition of aquatic ecosystems, biological indicators are believed to be useful in determining the condition of freshwater ecosystems since biological communities are affected by a wide range of environmental factors and integrate the effect of human disturbances over time (Karr and Chu 1999; Karr and Chu 2000; Adams 2002). Accordingly, the significant relationship between the LDI and measures of biotic condition for the isolated forested wetlands and streams seem to indicate that the LDI is an effective predictor of the various human factors that may affect the condition of freshwater systems as reflected by the response of the biotic components of the systems investigated to land use intensity.

Despite the significant association between the biological indices tested and the LDI, the relationships reported were not strong. This suggests that factors other than land use intensity were in part responsible for the variability in the biological indices tested. Reiss (2004) reported that given the wide latitudinal and longitudinal range of Florida there were differences in the biological composition of the assemblages used in developing the WCI for Florida. Reiss argued that the development of WCIs for specific regions may improve the state-wide WCI since sources of environmental variability that may account for some of the differences found among the biological composition of the three assemblages of organisms used in developing the WCI may be reduced. Other studies have also reported that biological indicators used to assess the level of wetland degradation by human activities can be highly influenced by natural factors in determining the composition of wetlands' biological communities (Wilcox et al. 2002; Tangen et al. 2003).

Biological differences among regions for Florida's streams have been attributed mostly to topography, water velocity, and water chemistry characteristics (Barbour et al. 1996a; Barbour 1996b). The weak correlation between the LDI and the state-wide SCI suggests that such natural variables may have a stronger effect on the biological composition of Florida's streams than the intensity of human development. Natural factors have also been reported to have a stronger influence on some streams' biological communities than anthropogenic landscape variables (see for example Arbuckle and Downing 2002, and Wang et al. 2003). As suggested for the isolated forested wetlands, the development of biological indices for the assessment of the ecological condition of streams for individual bioregions may result in the reduction of sources of non-anthropogenic variability, and will possibly allow for stronger predictions of the effect of land use intensity on streams condition in Florida.

For lakes, the LDI and the LCI correlated very poorly (see Tables 3-16 and 3-17). The reasons for this poor correlation may be related to the complexity of the hydrological characteristics of Florida's lakes, most of which are classified as seepage lakes. In developing the LCI, Gerritsen et al. (2000) investigated the relationship between the biological condition of lakes and the proportion of land uses within their watersheds represented as equidistant buffers from the lakeshores. Poor relationships were found among the variables tested. Gerritsen et al. (2000) pointed out the difficulty in defining the contributing drainage basins in Florida's lakes due to their complex groundwater connections, and suggested that this factor could be in part responsible for the lack of association between changes in land use and lake condition. Additional factors may also be more important than human influence in determining the condition of the state's lakes. The classification of Florida's lakes proposed by Griffith et al. (1997) included 47 lake regions based on soil and sediment types, lake origin, water chemistry, and hydrology. Perhaps, an analysis based on individual lake regions may result in the reduction of some of the variability of the LCI due to factors other than those of anthropogenic origin.

Gradients of Change and Thresholds

The relationship between the LDI and the indices of biological integrity for isolated forested wetlands indicated non-linear patterns. The relationship between the LDI and the WCIs showed clear differences in WCI scores among the isolated forested wetlands with low LDI values and isolated forested wetlands with intermediate to high LDI values (see Figures 3-16, 3-17, and 3-18). WCI scores for isolated forested wetlands with intermediate to high LDI values were approximately within the same range, suggesting that there were minimal differences in the macrophyte, macroinvertebrate, and diatom community compositions among the sample isolated forested wetlands. Reiss (2004, 2006) noted, after analyzing the relationships between the WCIs and a slightly different version of the LDI, that there may be a convergence of species among some of the isolated forested wetlands with intermediate LDI scores (mostly agricultural sites) and isolated forested wetlands with high LDI scores (mostly urban isolated forested wetlands), despite the fact that the human influences were different for each type of wetland.

The LDI incorporates land use intensity estimates from multiple land use types as measured by the use of non-renewable energies in each land use type. Energy flows such as electricity or energy storages, such as construction materials (buildings), help to define the differences between the energy usages of an urban land from other land uses, such as agriculture. These types of flows make urban lands more energy-intense than areas with other types of land uses. However, the use of high energy-intense resources like electricity in the landscape may have a smaller effect on ecological systems than other less intense energy flows. This observation was also made by Surdick (2005) in explaining the variability observed in the strength of the relationship between land use intensity, as measured through the LDI, and the avian and amphibian species composition of isolated forested wetlands. The position of the urban isolated forested wetlands along the gradient of human disturbance observed in this study was the result of the higher energy usage in the landscapes surrounding these wetlands. However, the response of the biological assemblages analyzed to anthropogenic activities seemed to be the result of an energy usage that was related to less energy-intense lands, such as those that are characteristic of agricultural lands. Testing the LDI with other wetland data for different regions in which sites are selected to represent the whole range of the development gradient may provide additional insight into the nature of the relationship between land use intensity and ecological condition, as well as the effect of highly intense energy flow on biological communities.

For streams, the relationships between variables were non-linear, and suggested a threshold behavior with sites reporting low SCI values approximately mid-way on the LDI scale (see Figures 3-36 and 3-36). Species' responses to environmental gradients are usually non-linear (McCune and Grace 2002), as are responses of stream condition to gradients of human disturbance (Allan 2004). Accordingly, results from this dissertation seemed to indicate that streams may remain in relatively good condition until their drainage basins become highly developed. Only until these levels of development are reached will their biological communities show evidence of degradation. However, other studies have reported a decline in the condition of biological communities of streams with relatively low levels of urban development (Wang et al. 2000; Paul and Meyer 2001), and for agricultural landscapes (Wang 1997; Fitzpatrick et al. 2001). It appears that the relationship between land use intensity and streams condition seems too complex to be explained solely based on one threshold, or to be able to differentiate among types of developed lands that may be more compatible for preserving healthy streams. Despite this complexity, this study demonstrates that streams' biological communities are adversely affected by increasing land development.

Water Quality

With the exception of some water chemistry variables for streams, the water quality of the freshwater systems studied were generally poorly associated with the development intensity of their surrounding lands (see Tables 3-8, 3-9, 3-12 and 3-13). The assessment of the condition of aquatic ecosystems based on a chemical criterion has been recognized by some authors as being of limited use, since it assumes that ecological degradation is the result of chemical contamination alone (Barbour et al. 1996a; Karr and Chu 1999; USEPA 2002b). In addition to chemical-based degradation, human actions can cause the alteration of hydrological, physical, and biological factors that control the structure and functionality of aquatic ecosystems (Karr 1999). Since the LDI represents the combined actions of several human actions that may be agents of ecosystem degradation (air and water pollutants, physical damage, changes in the suite of environmental conditions such as groundwater levels and increased flooding) (Brown and Vivas 2005), the poor correlation between the water chemistry variables tested and the LDI can be partially attributed to the limitation of water chemistry variables in integrating the multiple human factors that may affect the condition of freshwater systems.

The water chemistry data available for streams consisted of a larger number of samples for multiple years than the water chemistry data for lakes and isolated forested wetlands, many of which were based on one grab sample. It will seem that the larger water quality data sets for streams allowed for a better integration of the cumulative effect of human actions than the water quality data sets for lakes and isolated forested wetlands. Poor correlation between the LDI and water quality for lakes and isolated forested wetlands could be partially explained by the fact that water quality assessments based on grab samples may only reflect a temporary condition since the unusual concentration of chemicals in the water may be the result of a one-time pollution event instead of the effect of stressors over time (USEPA 2002b). Furthermore, the water chemical characteristics of most aquatic systems may change quickly as many of the chemical constituents present in the water column are altered by biological and physical processes (Barbour et al. 1996a; Brönmark and Hannon 1998; USEPA 2002b). Results from this study suggest that large sampling efforts may be required to account for the different anthropogenic factors that may contribute to determine the chemical composition of the water column of freshwater systems. This constitutes an important limitation to using a chemical approach in the evaluation of the ecological condition of aquatic ecosystems, as extended sampling can be time-consuming and costly, especially for studies at a regional level (Smith et al. 1997).

Other factors may also have contributed to the lack of correlation between the intensity of land use and the water quality variables for the systems under investigation. For example, Devito et al. (2000) noted that in areas with a complex hydrology and geology, the landscape variables alone may not be good predictors of the variability in water quality of lakes as a consequence of human disturbance. In Florida, most of the lakes are seepage lakes with groundwater-dominating water flows, with their chemical composition closely related to the state's geological structure (Canfield and Hoyer 1988; Brenner et al. 1990) and largely determining nutrient budgets (Deevey 1988). Accordingly, it could be that contributing areas defined in this study for the sample lakes based on surface drainages were not representative of the flows that would determine the water chemistry composition of these systems. This possible situation points to the need to analyze the relationship between human disturbance and lake condition based on the distribution of lakes by ecoregions or other land category that will allow the grouping of lakes based on their ecological similarities and controlling for sources of natural variability.

Watershed size may also affect the water chemistry composition of freshwater systems. For example, low concentrations of nutrients are more common for lakes with smaller drainage basins (Brönmark and Hannon 1998; McDowell et al. 2004). Watershed size was not evaluated as a source of variability in this research; however, it was observed that the sizes of watersheds for the sample lakes and streams were very variable (see Table 3-3). Future research should test for potential dependence of lake condition on watershed size.

Correlations with Changes in Grain Size

Biological indices

This study revealed that the effect of landscape grain on the relationships between biological indicators of ecosystem condition and the LDI was small. For the isolated forested wetlands, slightly more of the variability in the macrophyte WCI and the diatom WCI was explained at the finer and intermediate grain sizes (5 x 5-meter to 30 x 30-meter) (see Table 3-11 and Figure 3-19). For the macroinvertebrate WCI, a slightly larger proportion of the total variance was explained at a coarser grain size (50 x 50-meter scale). Considering that as the grain becomes larger the spatial variance in the whole landscape study decreases (Wiens 1989), these results seem to suggest that macrophytes and diatoms are more affected by more local or fine-grained variations in driving energies associated with human development than macroinvertebrates. Perhaps this is due to the fact that macrophytes and diatoms have no mobility or depend on physical factors for movement and finer-scale events may affect them more directly. On the other hand, macroinvertebrates can move away from sources of disturbance and may be affected more by stressors that are more widespread.

For streams, the effect of grain size on the relationship between land use intensity and the SCI was minimal (see Table 3-15 and Figure 3-34). It appears that the response of stream macroinvertebrates to the intensity of human development is independent of landscape grain, at least within the range of grain sizes tested. This is in contrast to what was observed for the isolated forested wetlands, suggesting that the scale-dependency of the relationship between land use intensity and ecosystem condition differs for different freshwaters systems, and limiting the establishment of generalizations about system response to land use intensity with changes in landscape grain. Differences in the response observed for the two types of ecosystems to the influence of land use intensity could be attributed to differences in patterns of landscape development as well as to differences in the structure and composition of their macroinvertebrates' communities.

Water quality

This study also showed that the effect of landscape grain on the relationships between water quality variables and the LDI was small. For the isolated forested wetlands, the LDI was only significantly related to DO and SC (Table 3-9 and Figure 3-15). Since information at different grain sizes did not represent major differences in predictability (higher or lower r^2 values), it would appear that to predict the impact of human development on the water chemistry composition for small wetlands systems with small hydrological contributing areas, this relationship could be assessed at any scale within the range of grains sizes tested here. However, since the correlation between the water quality variables and the LDI were weak and only statistically significant for two variables, conclusive statements on how land use intensity affects the condition of isolated forested wetlands as viewed by their water quality are not possible. Perhaps using a larger dataset of water chemistry for wetlands, consisting of multiple measurements for each wetland sampled, might provide additional information about this relationship with changes in scale.

For streams, significant associations were found between the LDI and DO, NO_3-N, TN, and the WQI (see Table 3-13 and Figure 3-27). In all cases, the LDI explained more of the variability in the response values at the coarser grain size (170 x 170 meters), suggesting that the effect of land use intensity on the water chemistry composition of streams is highest when spatial variance is reduced. These results have an important implication for studies at a regional level because of the widespread nature of the problem related to land use and non-point sources of pollution. Additionally, since regional-scale land-use data are usually coarse-grained, they may be more suitable than fined-grained data for studying this phenomenon.

Correlations with Changes in Extent

Biological indices

Landscape extent was an important factor in determining the response of different biological communities of the sample isolated forested wetlands to landscape development intensity. The strongest relationship between land use intensity and the community composition of macrophytes and macroinvertebrates for the isolated forested wetlands was reported for the smallest extent tested (20-meter buffers) (see Table 3-10, Figure 3-16, and Figure 3-17). It appears that macrophytes and macroinvertebrates are more likely to be affected by human activities within the immediate vicinity of the isolated forested wetlands, suggesting that maintaining the natural lands around the first 20-meters surrounding isolated forested wetlands is critical for securing the ecological condition of these systems. However, it also seems that human activities on larger scales also have the potential to alter the ecosystem condition of the isolated forested wetlands, as implied by the strongest relationship found between land use intensity and the diatom WCI for the 100-meter buffer scale (see Table 3-10 and Figure 3-18). These findings, as well as those reported for the response of the WCIs to land use intensity with changes in landscape grain, suggest that the assessment of ecosystem condition requires a multiple-scale approach since, as it has been noted, one scale of analysis alone may only provide a limited understanding of the effects of human activities on the integrity of ecological systems (King 1993; Karr 1994; Allan 2004). Additionally, support is provided for Reiss's (2004) proposition of the use of a multi-metric multi-assemblage approach over a single-assemblage approach for determining the ecological condition of isolated forested wetlands. Although this study seems to indicate that the condition of these wetlands systems can be assessed considering only the lands nearest to the study wetlands (within 100 meters), it will still be of interest to investigate how the lands beyond 200 meters might affect the condition of the isolated forested wetlands. Also, using elevation data with fine resolution when they becomes available for the entire state will allow delineating more precisely the hydrologic contributing areas to these small systems, perhaps allowing for new insights into this relationship.

For streams, the two forms of the SCI for Florida were most significantly associated with the LDI at the 100-meter buffer scale (see Table 3-14). This suggests that changes in development intensity in the lands immediately surrounding the sample streams may be enough to alter their ecological condition. It also points to the importance of riparian buffers for maintaining healthy streams. Other studies have also documented that local lands may have a stronger effect on stream macroinvertebrate assemblages than more distant lands (Sponseller et al. 2001; Townsend et al. 2004). However, small differences in the relationship between the LDI and the SCI_2 at the 100-meter buffer scale and the results for the watershed scale imply that both local and watershed-wide development may affect the community composition of macroinvertebrates in streams. Morley and Karr (2002) have suggested that this might be the case, while other studies have reported that macroinvertebrate communities are more impacted by land use at the watershed scale (Richards et al. 1996; Wang et al. 1997). Despite differences among studies that seem to indicate that there is no single best landscape at which the effect of human development on stream macroinvertebrates should be analyzed and that efforts directed to reduce the impact of land use intensity on streams should consider multiple-scale management strategies, these study indicates that for Florida streams the effect of land use intensity in their nearest lands have the strongest effect on their macroinvertebrate communities.

Water quality

Differences were revealed on how landscape development intensity affects the water chemistry characteristics of the sample isolated forested wetlands with changes in landscape extent. For the isolated forested wetlands, significant relationships were found between the LDI and DO, SC, and TP when changes in the spatial extent were considered (see Table 3-8). The LDI explained more of the variance of the concentration of DO at the broadest scale (200-meter buffer). Similarly, for SC more of the variability was explained at the 200-meter buffer scale. For TP, the LDI explained more proportions of the variance at the smallest extent (20-meter buffer scale). These results initially suggest that the effect of land use intensity on the isolated forested wetlands' water quality operate across scales, varying depending on the water chemistry variable considered. However, as was mentioned before, when referring to the results from this dissertation regarding the relationship between the LDI and water quality, the use of a larger dataset for water chemistry variable for the isolated forested wetlands would have been useful to confirm these initial findings.

When an effort was done to compare the results discussed here to those of similar investigations, only one study was found that has analyzed the influence of human development of adjacent lands on the water chemistry composition of wetlands. Houlahan and Findlay (2004) reported that the effect of the surrounding land uses on the composition of the water chemistry (nitrogen and phosphorus) of a sample of wetlands in Ontario, Canada, may extend to distances of up to 4,000 meters from the wetlands' edge. Accordingly, it appears that the optimum distance or extent for most accurately predicting the variability of the water chemistry is dependent on the wetland type and varies for each variable considered. Houlahan and Findlay (2004) also suggested that large areas with a large coverage of natural lands surrounding wetlands are required to prevent the impact of human development on their water quality. The results provided herein seem to indicate that for small isolated wetland systems, and specifically for phosphorus concentrations, only a narrow strip of natural lands adjacent to the wetlands may be adequate. However, it will still be useful to investigate beyond 200 meters in order to gain more understanding of the influence of human activities on the condition of the isolated forested wetlands at larger scales.

For Florida's streams the variability in the concentrations of DO, NO_3-N, TN, and for the WQI were best predicted by the LDI at the watershed scale (see Table 3-12). This is in agreement with other studies that have reported that the influence of land use on the chemical condition of streams is best explained at the watershed scale (Hunsaker and Levine 1995; Scott et al. 2002; Strayer et al. 2003). Together these results suggest that changes induced by watershed-scale development are more important in determining the water chemistry composition of streams than nearby lands and that studies aiming at analyzing the cumulative impacts of land use intensity on streams' based on water quality assessments should be focused on the watershed scale. Yet, other studies have shown that the lands nearest streams may have a stronger influence on the chemical composition of these systems (Richards et al. 1996; Johnson et al. 1997; Tufford et al. 1998). Provided that the water quality data used in this dissertation appears representative of a wide variety of factors that may determine the water chemistry of the sample streams as well as their cumulative impact, and that the variability of water quality variables was consistently predicted by the LDI at the watershed scale, this constitutes an important finding of this study.

Land Use Intensity and Distance-Weighting

Considering that the LDI calculated based on distance-weights explained up to 7% more of the variance in stream condition as measure by the SCI than the LDI calculated based only on land use proportions (see Tables 3-14 and 3-15), it will seem that the effect of distance of land use is only a critical factor in determining the effect of land use intensity on the ecological condition of these systems. On the other hand, the effect of distance of land use had a limited effect on the ecosystem condition of the isolated forested wetlands as the distance-weighted LDI less of the variability in the biological indices for these systems than the LDI based only on land use (see Tables 3-10 and 3-11). Distance-weighting was also of limited use when relating the LDI to water quality variables. The distance-weighted LDI only explained more of the variance in DO and the WQI for streams (Table 3-12). Other significant relationships between land use intensity and water quality variables for streams and isolated forested wetlands were stronger when the LDI-PLU was used. Accordingly, it appears that the distance of land use may have different effects on the chemical composition of different freshwater systems and depending on the response variable. Differences in the effect of land use intensity based on distance-weighting for wetlands and streams also seemed to suggest that watershed size may play a role in the effect of land use on ecosystem condition.

The use of land-use distance weighing has received little attention in the literature despite being suggested by O'Neill et al. (1997) as a way to further refine landscape indicators of ecological integrity. Strayer et al. (2003) have reported that the spatial arrangement of land use is more important than non-spatially explicit landscape measures in small watersheds for predicting ecosystems condition, and King et al. (2005) has provided similar evidence after using distance-weighting of land cover for watersheds of different sizes to assess the condition of streams in the Coastal Plain of Maryland. However, the results of this dissertation suggest the opposite since measures of land use intensity of the hydrological contributing areas for the sample isolated forested wetlands based on land use proportions alone consistently correlated stronger with water quality variables and the WCIs than distance-weighing land use intensity measures. On the other hand, for streams and their larger watersheds, the response to the effect of distance-weighting was variable; suggesting that at broader scales the distance-weighted LDI may be more useful for assessing the water chemistry composition of freshwater systems. Contrasting results between this and other research call for further investigation of the benefits and limitations of the distance-weighting approach in freshwater condition assessment studies.

Landscape Pattern and Ecosystem Condition

Correlations with Changes in Scale

Water quality

Isolated forested wetlands. Landscape pattern was a poor predictor of water quality for the isolated forested wetlands. Pattern metrics were only significantly related to the concentrations of TP (see Table 3-24). Agricultural land uses as well as the distance between patches of the same type were metrics that were significantly associated to TP at the coarsest grain size tested (30 x 30 meters). The lack of correlation between landscape pattern metrics and water quality variables could be attributed once more to the fact that water chemistry measurements were based on a single water sample rather than the inadequacy of landscape pattern metrics to predict water quality. The disadvantages of basing water quality assessment on grab samples have already been discussed. However, the limitations of pattern metrics to accurately represent landscape pattern also needs to be emphasized. Some pattern metrics may give erroneous measurements at very small extents or some cannot be computed at all because they are dependent on the number of patch types present (McGarigal and Marks 1995; McGarigal et al. 2002). This certainly represents a limitation of pattern metrics. In this study, testing the relationship between landscape pattern metrics and water quality variables of isolated forested wetlands with changes in landscape extent was not possible since only the largest extent could be considered as few patches tend to remain at spatial extents smaller than 200 meters surrounding the isolated forested wetlands, thereby leaving the question about how landscape pattern influences the condition of small isolated forested wetland with changes in landscape extent wide open. However, at small spatial extents simple measurements such as land use proportions may be useful in predicting how land use intensity affects the water quality of small wetland systems. Evidence in this direction has been provided by Lane and Brown (2006), who effectively used landscape measures of percent agriculture, percent urban, percent natural lands for 100–meter buffers surrounding small herbaceous wetlands in Florida to assess the ecological condition of these systems.

Streams. For streams, landscape pattern metrics were useful in predicting changes in water quality related to land use. Landscape pattern metrics were significantly associated to DO, NO_3-N, TN, TP, and the WQI when relationships were assessed at different landscape scales (see Tables 3-36 and 3-37). The water chemistry composition of streams varied along a land use diversity gradient ranging from a landscape with few land-use types among which forests were common, to landscapes richer in land use types where agriculture was more prevalent. Water quality conditions were usually better for forested watersheds than for watersheds where agriculture lands were more common. The relationship between landscape pattern metrics and water chemistry varied with grain size and for each variable considered. Additionally, the relative importance of landscape pattern factors was also variable among variables. Based on the results presented herein, it appears that the influence of land use on the water quality operates across multiple landscape grains, depending on the water chemistry variable of interest. Accordingly, it seems that the assessment of the ecosystem condition of freshwater systems using a chemical criterion will be incomplete if it relies only on one or few variables and if the effect of landscape grain is not considered, as different water chemistry variables are affected differently by land use and at different spatial scales. Very few studies have reported on the relationship discussed here. When this has been the case, the use of different grain sizes has been the result of the availability of spatial data at different resolution scales to compare different landscapes (Hunsaker and Levine 1995), rather than a systematic effort to assess how changes in grain size determines the predictive power of landscape pattern metrics in assessing stream condition. Including the analysis of the effect of change sin landscape grain in land-water studies for streams is a necessary step for the understanding of how landscape pattern influences stream condition. Not doing so may lead to erroneous conclusion about the scales at which water quality is controlled by land use.

With changes in spatial extent, the landscape pattern metrics explained more of the variability in DO at the 100-meter buffer scale. Streams with adjacent lands with high presence of forests and wetlands presented higher concentrations of DO than streams where adjacent lands were more fragmented and presented higher proportions of agricultural and urban lands. This is consistent with previous studies that have reported that the concentration of DO in streams decreases with increasing landscape disturbance levels (Young and Huryn 1999; Mulholland et al. 2005). However, there seem to be no previous studies that considered the spatial scales at which land use has the greatest influence on DO in streams. Mulholland et al. (2005) suggested that changes in DO in streams should be analyzed at the watershed scale since stream metabolism, the process that together with diffusion determines the oxygen concentrations in streams (Allan 1995; Young and Huryn 1999), is affected by watershed-wide variables. However, since differences in vegetation in adjacent lands (reduction in forest cover) can influence DO concentrations in streams (Findlay et al. 2001), land in the vicinity of streams may also play an important role in regulating DO concentrations as suggested by the result presented here.

For nutrients, the landscape pattern metrics explained more of the variability at the watershed scale. Previous studies have also established that inorganic nitrogen (Johnson et al 1997; Sponseller et al. 2001; Griffith 2002) and TN (Hunsaker and Levine 1995; Jones et al. 2001; Sponseller et al. 2001) are more related to watershed-scale land use patterns. However, other investigations have also reported that the relationship between landscape pattern and nitrogen is best observed at more local scales (Johnson et al 1997; Tufford et al. 1998). Yet, Brett et al. (2005) found no significant relationships between land development and the concentration of inorganic nitrogen at the watershed scale. Previous studies have also reported that TP in streams is controlled by human activities at the watershed scale (Hunsaker and Levine 1995; Brett et al. 2005). However, more local scales seem also important (Tufford et al. 1998; Johnson et al. 1997) and others (Sponseller et al. 2001; Tufford et al. 2003) have found no relationship at all. The lack of agreement among studies in relating nutrients (nitrogen and phosphorus) to land use with changes in landscape extent may be attributed to the complexity of the phenomenon under investigation. Physical, chemical, and biological variables related to land use make it difficult to find patterns that allow the consistent description of nutrient pathways over a wide range of landscapes (Townsend and Riley 1999; McDowell et al. 2004). Differences among studies might also have to do with differences in classification systems used and the number of land use/land cover classes considered. Despite these differences and limitations, the results from this dissertation are a contribution to establishing a relationship between landscape pattern and water quality for Florida's streams. Landscape pattern metrics were able to explain up to 60% of the variability of TN and up to 44% of the variability of TP, providing evidence of the link between land use and stream condition. Additionally, since in this study the land-use classification system used was the FLUCCS, which is widely used by state agencies and research institutions in ecological assessment studies, uncertainties regarding the usefulness the land use/land cover classification system and the number of land use classes considered were minimized.

Lakes. Landscape pattern metrics were useful in determining differences in the concentrations of nutrient in lakes with watersheds with varying patterns of development. Landscape pattern metrics were significantly associated with TN and TP with changes in grain size. Relationships were best explained at the 20 x 20-meter scale in both cases (see Table 3-49). For different landscape extents, landscape pattern metrics were significantly associated to TKN, TN, and TP with all relationships were best explained for the 400-meter buffer (see Table 3-50). Lakes within watersheds with higher diversity of patch types (a mix of natural, agricultural, and urban lands) tended to have lower concentrations of nutrients than lakes within watersheds where patch diversity was low and where urban or agricultural lands were common.

Considering that excess phosphorus and nitrogen that result from agricultural and urban land use is the most common cause of concern regarding the eutrophication of aquatic systems, landscape pattern metrics proved to be effective in linking human activities in the landscape with the condition of Florida lakes. The usefulness of pattern metrics is even more relevant since the hydrological complexity of Florida lakes makes it difficult to establish a relationship between human disturbance and water quality based solely on landscape variables. Despite these results, testing the ability of landscape pattern metrics with larger water quality datasets would be to further evidence the usefulness of pattern metrics to predict the water quality of Florida lakes.

Biological indicators

Isolated forested wetlands. Landscape pattern metrics were fair predictors of the ecological condition of the isolated forested wetlands as measured by the macrophyte WCI and macroinvertebrate WCI (see Table 3-24). For the macrophyte WCI, more of the variability was explained at the 10 x 10-meter resolution scale, with the complexity of patch types' shapes and forest lands being the most important explanatory factors. In both cases the proportion of agricultural land use was negatively correlated with the patch types shapes and the percent of forests, suggesting that among the land use types present in the different landscapes, agriculture may be a determining factor for wetland impairment. These results are consistent with other studies that have suggested that agricultural land use is an important factor in determining the level of impairment of wetland systems when related to different assemblages of wetland vegetation (Crosbie and Chow-Fraser 1999; Galatowitsch et al. 2000; Lopez et al. 2002) as well as forest cover (Houlahan et al. 2006). Urban land use has also been reported to affect vegetation communities in wetlands (Galatowitsch et al. 2000; Lopez et al. 2002); however, urban lands were not found to be an important factor in this research. Of interest was the fact that the influence of land development on the macrophytes WCI was most notable at a fine landscape grain when pattern metrics were used as an indicator of human activity. A similar result was reported when the LDI was used, providing support to the idea that because macrophytes cannot escape the direct effect of distance, finer-scale events may affect them more directly.

For the macroinvertebrate WCI, the relationship between the landscape pattern metrics was only significant at the 20 x 20-meter resolution scale. Urban land use was the most important defining factor for wetland impairment. Few studies have reported on the influence of landscape scale development on wetlands macroinvertebrate communities, despite that fact that aquatic macroinvertebrates have been suggested as potential indicators of ecological integrity in wetlands (Adamus 1996; USEPA 2002a). Mensing et al. (1998) found no indication that landscape scale disturbances, when measured along a disturbance gradient that included urban lands, affected aquatic macroinvertebrate communities in riparian wetlands of northern temperate landscapes. Other studies have also reported on the lack of correlation between land use and macroinvertebrates in wetlands (Steinman et al. 2003; Tangen et al. 2003). Yet, Euliss and Mushet (1999) found that agricultural lands had a significant influence on macroinvertebrate assemblages for wetlands in the Prairie Pothole region. A disagreement between the results on the grain size at which the influence of land development on the macroinvertebrate is most significant, seemed apparent between the pattern metrics and the LDI. According to the latter, the results indicated that the influence of land development on the macroinvertebrate was best observed at coarser grain sizes; for the former an intermediate scale seemed most important. Unfortunately pattern metrics could not be calculated beyond a grain size of 30 x 30 meters, thus limiting the possibility of comparison of results. Therefore, multiple spatial scales might need to be considered when assessing how land development affects the community of macroinvertebrates for isolated forested wetlands as the evidence provided herein is not conclusive about the scale at which macroinvertebrates are most affected by human disturbances.

Previous studies have also reported, as is reported in this dissertation, on the importance of the landscape extent at which adjacent land use may have the largest influence on wetlands. Mensing et al. (1998) found that for riparian wetlands, herbaceous vegetation was more affected by disturbance at local scales (less than 500 meters), while shrub communities responded to disturbance at intermediate scales (500 and 1,000 meters). Galatowitsch et al. (2000) also observed that the vegetation of wet meadows (herbaceous communities) was most affected by human activities at less than 500 meters from the wetlands. Houlahan et al. (2006) found that the highest effect of adjacent land use to the species richness on forest species was within 250 to 300 meters from temperate wetlands. For macroinvertebrates, Mensing et al. (1998) found that these responded to disturbance at local scales (less than 500 meters). Although the effect of human activities in the landscape on the sample isolated forested wetlands was not assessed in this study beyond 200 meters from the wetlands' edge, the results presented herein together with the results from other studies suggest that in the assessment of wetland condition using vegetation and macroinvertebrate as indicators, the effects of human disturbances on wetlands can be effectively assessed at relatively small spatial extents.

For diatoms, the lack of correlation between landscape pattern metrics and the diatom WCI implies that the response of diatoms to human disturbance may be controlled at spatial scales different to the one that was considered here. For example, Lane and Brown (2006) found a fair association between land use proportions and diatom assemblages when measured within 100 meters from isolated depressional marshes in Florida. For streams, Pan et al. (1999) suggested that the correspondence between diatoms and landscape pattern can extend to the watershed scale. Testing the relationship between landscape pattern and condition diatom assemblages in wetlands at multiple scales may provide additional information about the spatial scales at which land development affect diatom communities. However, the limitation of using landscape pattern metrics at very fine extents will always exist. Perhaps simple land use proportions may suffice to analyze this relationship at very small extents.

Streams. No significant relationships between the landscape pattern variables and the SCI for Florida were reported for different grain sizes (see Table 3-36). The lack of association between variables can be attributed to the fact that variations in grain size were analyzed only at the watershed scale, which was also statistically not significantly related to the SCI. Landscape pattern variables were more strongly related to the SCI at the 100-meter spatial scale (see Table 3-37). Accordingly, human activities in the landscape seem to have greater significance in determining the composition of macroinvertebrate assemblages at smaller spatial extents. This is consistent with other studies (Lammert and Allan 1999; Sponseller et al. 2001; Roy et al. 2003; Townsend et al. 2003; Townsend et al. 2004) and with the results reported in this work when the LDI was used as measure of human activity. However, differences also exist between this investigation and what has been reported elsewhere. Although in this investigation the proportion of urban lands was not a very important factor in determining the variability the SCI, it did have some influence on the composition of the macroinvertebrates assemblages. Urban lands have been reported to have more influence on stream macroinvertebrates at the watershed scale than at more local scales (Morley and Karr 2002; Roy et al 2003). Additionally, Richards et al. (1996) suggested that all together land use at the catchments scale, rather than at local scales (100-meters buffers), is more important in determining the condition of stream assemblages including macroinvertebrates. Similarities and differences between this work and other studies suggest that land development affects the condition of streams at both local and basin-wide scales, and further studies of this relationship should incorporate analyses at multiple landscape extents. However, the results from this work indicate that for Florida's streams the response of macroinvertebrates to human disturbance is controlled locally.

Lakes. Landscape pattern metrics were a fair predictor of the ecological condition of lakes as measured by the LCI (see Table 3-49). More of the variability in lake condition was explained at finer resolution scales (20 x 20 meters and 40 x 40 meters). When different spatial extents were analyzed, more of the variability in lake condition was explained at the 400-meter scale (see Table 3-50). Results showed that the diversity of patch types had a positive influence on macroinvertebrate communities. Higher levels of impairment of the macroinvertebrate communities of lakes were associated with low diversity of patch types where large urban or agricultural patches were common in the landscape.

Although macroinvertebrates have been identified as potential indicators of lake condition (USEPA 1998), few studies have reported on the influence of land use on macroinvertebrates in lakes and none seem to have considered the scale(s) at which such a relationship is best predicted. Blocksom et al. (2002) found that macroinvertebrate assemblages were correlated to land use, with increased levels of impairment in lakes more strongly associated with urban lands, while the proportion of forests in lakes' watersheds was associated with less impaired conditions. Lewis et al. (2001) also provided evidence on the relationship between land use at the watershed scale and the condition of lakes based on macroinvertebrate data. The fact that the LCI was not significantly related to the LDI, as reported earlier in this dissertation, adds more uncertainty as to how human disturbance impacts lake condition. Of interest is to note that landscape patterns of development for lakes and streams were different, with the former presenting higher levels of urbanization and less buffering by natural lands. Such differences may help to explain the contrast observed among the spatial extents at which land use seems to control the ecological condition of these aquatic systems. Altogether, the finding of this work as well as the little evidence available from other studies initially indicates that land use may affect lake condition at multiple scales; however, more research is needed in order to produce more conclusive statements on this matter.

Land Use Intensity, Landscape Pattern, and Ecosystem Condition

When the LDI and pattern metrics were used together in multiple regression analysis as predictor variables, different proportions of the remaining variance of the indicators of ecological condition and water quality variables initially explained by the LDI alone, was additionally accounted for. The results varied for each dependent variable and for each type of freshwater system investigated.

The effect of the pattern metrics on the relationship between the LDI and the water quality variables for the isolated forested wetlands was limited. More of the variability in the water quality measurements was only explained for TP concentrations (see Table 3-51). Stronger relationships were reported for the macrophyte WCI and the macroinvertebrate WCI. These results emphasize the need to focus on the use of biological indicators of ecosystem condition over water chemistry indicators. However, since landscape pattern metrics can be constrained by the scale of analysis for very fine extents, the LDI alone may be a better assessment tool of wetlands' ecosystem condition than it would be when used together with measures of landscape pattern. At fine extents simple metrics such as land use proportions may be useful when used together with the LDI. However, care must be used since land use proportions and the LDI can be highly correlated.

Multiple regression analysis revealed that combining the LDI and the landscape pattern variables was useful in assessing the influence of human development on the water quality variables for streams. Stronger relationships were observed for DO, TN, TP, and the WQI (see Tables 3-52 and 3-53). That the combined predictive power of the two types of landscape pattern metrics was more noticeable for streams can be attributed once again to the fact that the water chemistry data for these systems were more robust in terms of the number of independent samples included, and perhaps allowing for a better characterization of the streams' water chemistry composition. Of interest was the fact that the landscape pattern metrics did not help to improve the relationship between the LDI and the SCI. Although the landscape metrics explained a relatively small proportion of the variance in the SCI, it still can be argued that indicators of stream condition based on assemblages of macroinvertebrates are useful since macroinvertebrates communities can be negatively impacted at high levels of development intensity.

The analysis of both landscape intensity and landscape pattern variables showed that when used together in multiple factor models, slightly better relationships with indicators of ecosystem condition were observed for lakes (see Table 3-54 and 3-55). Provided that the LDI alone was not significantly related to any of the water quality variables for lakes, the relative contribution of landscape pattern metrics in explaining the variability in the water quality variables for lakes suggest that the combined effect of both types of landscape indices may be useful in ecosystem condition assessment efforts for this type of systems. However, problems with collinearity were observed in the factor models for TN and TP. This was attributed to the fact that the LDI was highly correlated to the proportion of urban land use in the surrounding landscapes to the lakes. Thus, testing for high correlation between the LDI and proportions of land use before using these metrics together is desirable.

The LDI accounted for a proportion of the variability of some of the indicators of ecosystems' condition and water quality tested in this study, while the landscape pattern metrics explained an additional proportion of the variability of these same variables and in some cases of other variables not explained by the LDI. This suggests that although both groups of landscape indices are measures of human activity in the landscape, different attributes of the land use are being quantified. Therefore, both types of landscape indicators are complementary and can be used together to improve the ability to predict how landscape-level human disturbances may impact freshwaters systems.

Limitations and Further Research

A major limitation to this study was the small sample size of the streams and lakes studied as well as the small sample size of water chemistry measurements for the isolated forested wetlands and lakes. A larger sample size of streams and lakes would have allowed including more drainage basins at different levels of development intensity that could have improved the accuracy of the relationship of human development and freshwater ecosystem condition, and would possibly have helped to identify critical thresholds. It would also have allowed an analysis by ecoregions or bioregions, providing a spatial framework within which aspects of this relationship could have been more clearly described. A larger sample size of water chemistry measurements for the isolated forested wetlands and lakes could have permitted accounting for some of the variability related to the multiple environmental factors that determine the water chemistry composition of these systems.

The seasonal or yearly variations in both water chemistry and biological assemblages were not analyzed for any of the systems studied, even though the temporal aspect of environmental variability is an important factor in determining the chemical composition as well as the structure of biological communities in freshwater systems (Cattaneo and Prairie 1995; Cyr et al. 2004). By doing so, aspects of variability of ecosystem condition could have been explained. Some temporal disconnections also existed between the land use data used to calculate the LDI and the data used as indicators of ecosystem condition. The date the land use data were developed did not always agree with the date of the biological and water chemistry sampling. For the sample isolated forested wetlands, the land use data were developed using aerial photographs and efforts were made to ground truth the data. However, this was not the case for the sample streams and lakes since the land use data used were datasets generated by others and corresponded to a prior period, and covered large areas throughout Florida.

The analysis of the landscape scales (grain and extent) at which the effect of human development was described was constrained by some spatial attributes of the systems under investigation. Grain size was limited by the extent of the drainage basins for each system. The isolated forested wetlands analyses were limited to the use of buffers as surrogates for real hydrological contributing areas. Isolated forested wetlands can be part of larger watersheds and subject to hydrological exchanges with other freshwater systems not included in buffers. For Florida's lakes, most of which are seepage systems, the identification of the contributing drainage basins was limited to topographic flows, ignoring subsurface exchanges that may strongly influence lake condition. Although these limitations are technically difficult to overcome, they constitute examples of the complexity of the systems investigated and call for the need to consider these variables when interpreting the relationship between land use and ecosystem condition.

Finally, the interpretation of landscape pattern indices was challenging. This difficulty has been recognized by other authors (Griffith et al. 2002; Li and Wu 2004). Perhaps using simple and a few well-tested metrics would have simplified the understanding of how landscape pattern influences ecosystem condition and can complement the LDI as predictor variables of impact.

Conclusions

Changes in the ecological condition and water quality of isolated forested wetlands were linked to land use intensity, as measured by the landscape development intensity index (LDI). The LDI was developed as an index of human activity based on a development intensity measure that is derived from non-renewable energy use in the surrounding landscape and was used as a measure of human-induced impacts on ecological systems. Accordingly, the LDI may be used as an effective land use-based assessment index that allows predicting the condition of freshwater systems, while the areal empower density of land use allows describing patterns of landscape development which may aid in land use planning directed to minimizing anthropogenic influences on ecological systems.

The study of the spatial properties of the LDI revealed that the LDI is scale-dependent, varying with changes in both landscape grain and extent. Changes in landscape grain affected LDI scores, especially in its middle ranges of values and for smaller landscapes; while changes in landscape extent were more noticeable at low and intermediate LDI ranges where differences in LDI scores are more likely to occur as developed lands were added with increasing area. The understanding of the sensitivity of the LDI to changes in spatial scale is an important consideration for future applications of the LDI.

Greater correlations between the LDI and biological indicators suggest that biological communities may integrate a wide range of human disturbances and may be more effective indicators of ecological condition. The limited correlation between the LDI and water quality draw attention to the limitations of using a chemical criterion to assess the condition of freshwater systems. Although a significant level of association was found between the LDI and some water chemistry variables, as in the case of the sample streams; in order to assess the condition of freshwater systems using a chemical criterion, large sampling efforts may be required to account for the environmental factors that determine the water chemical composition of freshwater systems and may only provide a partial understanding of how humans may impact aquatic systems.

Although the overall effect of changes in landscape scale (grain and extent) on the LDI's predictive power of ecosystem condition at the scales tested was small, there is no one unique spatial scale at which the relationship between human development and ecological condition can be best assessed. Rather, multiple indicators analyzed at multiple spatial scales should be considered when analyzing this relationship. Despite this, the land nearest to the isolated forested wetlands and streams studied seemed to have the greatest effect on their ecological condition, as suggested by the response of biological indicators to land use intensity.

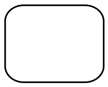
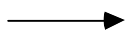
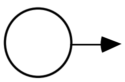
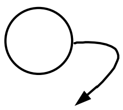
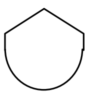
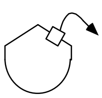
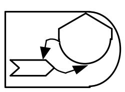
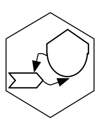
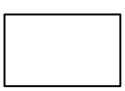
The use of distance-weighting functions provided little enhancement of the predictive power of the LDI, especially for freshwater systems with very small drainage areas; however, distance-weighting became more important as drainage sizes increased. At broader extents distance-weighting may allow distinction between the effect of land use intensity within buffers and whole watersheds, which may be useful for highlighting the importance of natural lands within floodplains and their positive influence on ecological condition.

Landscape pattern metrics were fair predictors of the condition and water quality for isolated forested wetlands, streams, and lakes. Differences among the variables that were best explained by the landscape pattern metrics and the LDI indicate that both types of landscape indices can be used together to enhance the predictive power of landscape indices for assessing the condition of freshwater systems.

Florida's increasing human population will continue to demand intensification in land use with the inevitable conversion of some of the remaining natural lands to agricultural and urban uses. Identifying patterns of development that will minimize the impact on the state's freshwater systems remains imperative. The LDI and metrics of landscape pattern are analytical tools that can aid in the assessment and management of entire landscapes, a necessary approach in order to ensure the persistence of healthy isolated forested wetlands, streams, and lakes throughout the state. A more complete understanding as to how the LDI can be used to predict the condition of freshwaters systems could include an analysis that considers a larger system's sample size as well as temporal variations in water chemistry and biotic integrity measures.

APPENDIX A
ENERGY CIRCUIT LANGUAGE

Table A-1. Primary symbols of the energy circuit diagramming.

Symbol	Name	Description
	System boundary	Defines the system being diagrammed. Lines that cross the system boundary indicate inflows and outflows of the system.
	Energy circuit	A pathway with a flow proportional to the quantity in the storage or source upstream.
	Source	A forcing function or outside source of energy delivering forces according to a program controlled from outside.
	Flow limited source	Outside source of energy with a flow that is externally controlled.
	Storage tank	A compartment of energy storage within the system storing a quantity as the balance of inflows and outflows.
	Sensor	The sensor (small square box on storage) suggests the storage tank controls some other flow but does not supply the main energy for it.
	Producer	Unit that collects and transforms low-quality energy under the control of high-quality flows.
	Consumer	Unit that transforms energy quality, stores it, and feeds it back autocatalytically to improve inflow.
	Box	Miscellaneous symbol to use for whatever unit or function is needed.
	Heat sink	Dispersion of potential energy into heat that accompanies all real transformation processes and storages. Dispersed energy is no longer available to the system.

APPENDIX B
LAND USE/LAND COVER CLASSIFICATION SYSTEM

Table B-1. FLUCCS categories and corresponding land use intensity classes.

FLUCCS Code			FLUCCS Description	Land Use Intensity Description (LI=Low Intensity, MI=Middle Intensity, HI=High Intensity)
LI	LII	LIII		
100			Urban and Built-up	
	110		Residential, Low Density <Less than two dwelling units per acre>	LI-Single Family Residential
		111	Low Density Residential – Fixed Single Family Units	LI-Single Family Residential
		112	Low Density Residential – Mobile Home Units	LI-Single Family Residential
		113	Low Density Residential – Mixed Units <Fixed and mobile home units>	LI-Single Family Residential
		114	Ranchettes – Fixed Single Family Units	LI-Single Family Residential
		115	Ranchettes – Mobile Units	LI-Single Family Residential
		116	Ranchettes – Mixed Units	LI-Single Family Residential
		119	Low Density Under Construction	LI-Single Family Residential
	120		Residential, Medium Density <Two – five dwelling units per acre>	MI-Single Family Residential
		121	Medium Density Residential – Fixed Single Family Units	MI-Single Family Residential
		122	Medium Density Residential – Mobile Home Units	MI-Single Family Residential
		123	Medium Density Residential – Mixed Units <Fixed and mobile home units>	MI-Single Family Residential
		129	Medium Density Under Construction	MI-Single Family Residential
		130	Residential, High Density	LI-Multifamily Residential
		131	High Density Residential – Fixed Single Family Units <Six or more dwelling units per acre>	HI-Single Family Residential
		132	High Density Residential – Mobile Home Units <Six or more dwelling units per acre>	HI-Single Family Residential
		133	Multiple Dwelling Units – Low Rise <Two stories or less>	LI-Multifamily Residential
		134	Multiple Dwelling Units – High Rise <Three stories or more>	HI-Multifamily Residential
		135	High Density Residential – Mixed Units <Fixed and mobile home units>	HI-Single Family Residential
		139	High Density Under Construction	HI-Single Family Residential
	140		Commercial and Services	LI-Commercial
		141	Retail Sales and Services	HI-Commercial
		1411	Shopping Center	HI-Commercial
		142	Wholesale Sales and Services <excluding warehouses associated with industrial use>	LI-Commercial
		143	Professional Services	LI-Commercial
		144	Cultural and Entertainment	Institutional
		145	Tourist Services	LI-Commercial
		193	Urban Land in Transition Without Positive Indicators of Intended Activity	MI-Open Space / Recreational
		194	Other Open Land	MI-Open Space / Recreational
200			Agriculture	

Table B-1. Continued.

FLUCCS Code LI	LII	LIII	FLUCCS Description	Land Use Intensity Description (LI=Low Intensity, MI=Middle Intensity, HI=High Intensity)
	210		Pastures and Fields	LI-Pasture
		211	Improved Pastures	HI-Pasture
		212	Unimproved Pastures	LI-Pasture
		213	Woodland Pastures	LI-Pasture
		214	Row Crops	Row Crops
		215	Field Crops	Row Crops
	220		Tree Crops	Tree Crops
		221	Tree Crops Groves	Tree Crops
		222	Fruit Orchards	Tree Crops
		223	Other Groves	Tree Crops
	230		Feeding Operations	HI-Agriculture
		231	Cattle Feeding Operations	HI-Agriculture
		232	Poultry Feeding Operations	HI-Agriculture
		233	Swine Feeding Operations	HI-Agriculture
	240		Nurseries and Vineyards	Tree Crops
		241	Tree Nurseries	Tree Crops
		242	Sod Farms	Tree Crops
		243	Ornamental Nurseries	Tree Crops
		244	Vineyards	Tree Crops
		245	Floriculture	Tree Crops
		246	Timber Nursery	Tree Crops
	250		Specialty Farms	Tree Crops
		251	Horse Farms	HI-Agriculture
		252	Dairies	HI-Agriculture
		253	Kennels	HI-Agriculture
		254	Aquaculture	HI-Agriculture
		259	Other Specialty Farms	HI-Agriculture
	260		Other Open Lands	Rangeland
		261	Fallow Cropland	Rangeland
		262	Old Field	Rangeland
300		300	Rangeland	
	310		Herbaceous	Rangeland
	320		Shrub and Brushland	Rangeland
		321	Palmetto Prairies	Rangeland
		322	Coastal Scrub	Rangeland
		329	Other Shrubs and Brush	Rangeland
	330		Mixed Rangeland	Rangeland
400			Upland Forests	
	410		Upland Coniferous Forests	Natural Land / Open Water
		411	Pine Flatwoods or Mesic Flatwoods	Natural Land / Open Water
		412	Longleaf Pine-Xeric Oak or Longleaf Sandhill	Natural Land / Open Water
		413	Sand Pine or Sand Pine Scrub	Natural Land / Open Water
		414	Pine - Mesic Oak	Natural Land / Open Water
		419	Hunting Plantation Woodlands	Pine Plantation
	420		Upland Hardwood Forests	Natural Land / Open Water
		421	Oak Sandhill	Natural Land / Open Water

Table B-1. Continued.

FLUCCS Code LI	LII	LIII	FLUCCS Description	Land Use Intensity Description (LI=Low Intensity, MI=Middle Intensity, HI=High Intensity)
		422	Brazilian Pepper	Natural Land / Open Water
		423	Oak - Pine - Hickory	Natural Land / Open Water
		424	Melaleuca	Natural Land / Open Water
		425	Temperate Hardwood	Natural Land / Open Water
		426	Tropical Hardwoods	Natural Land / Open Water
		427	Live Oak	Natural Land / Open Water
		428	Cabbage Palm	Natural Land / Open Water
		429	Wax Myrtle - Willow	Natural Land / Open Water
	430		Upland Hardwood Forests	Natural Land / Open Water
		431	Beech - Magnolia	Natural Land / Open Water
		432	Oak Scrub	Natural Land / Open Water
		433	Western Everglades Hardwoods	Natural Land / Open Water
		434	Hardwood - Conifer Mixed	Natural Land / Open Water
		435	Dead Trees	Natural Land / Open Water
		437	Australian Pine	Natural Land / Open Water
		438	Mixed Hardwoods	Natural Land / Open Water
		439	Maritime Hammock	Natural Land / Open Water
	440		Tree Plantations	Pine Plantation
		441	Pine Plantations	Pine Plantation
		442	Hardwood Plantations	Pine Plantation
		443	Forest Regeneration	Pine Plantation
		444	Experimental Tree Plots	Pine Plantation
		445	Seed Tree Plantations	Pine Plantation
500			Water	
	510		Streams and Waterways	Natural Land / Open Water
	520		Lakes	Natural Land / Open Water
		521	Lakes Larger Than 500 Acres (202 Hectares)	Natural Land / Open Water
		522	Lakes Larger Than 100 Acres (40 Hectares), but Less Than 500 Acres	Natural Land / Open Water
		523	Lakes Larger Than 10 Acres (4 Hectares), but Less Than 100 Acres	Natural Land / Open Water
		524	Lakes Less Than 10 Acres (4 hectares) Which are Dominant Features	Natural Land / Open Water
	530		Reservoirs	MI-Open Space / Recreational
		531	Reservoirs Larger Than 500 Acres (202 Hectares)	MI-Open Space / Recreational
		532	Reservoirs Larger Than 100 Acres (40 Hectares), but Less Than 500 Acres	MI-Open Space / Recreational
		533	Reservoirs Larger Than 10 Acres (4 Hectares), but Less Than 100 Acres	MI-Open Space / Recreational
		534	Reservoirs less than 10 Acres (4 Hectares) which are dominant features	MI-Open Space / Recreational
	540		Bays and Estuaries	Natural Land / Open Water
		541	Embayments Opening Directly into the Gulf of Mexico or the Atlantic Ocean	Natural Land / Open Water
		542	Embayments Not Opening Directly into the Gulf of Mexico or the Atlantic Ocean	Natural Land / Open Water
	550		Major Springs	Natural Land / Open Water

Table B-1. Continued.

FLUCCS Code LI	LII	LIII	FLUCCS Description	Land Use Intensity Description (LI=Low Intensity, MI=Middle Intensity, HI=High Intensity)
	560		Slough Waters	Natural Land / Open Water
600			Wetlands	
	610		Wetland Hardwood Forests	Natural Land / Open Water
		611	Bay Swamps	Natural Land / Open Water
		612	Mangrove Swamps	Natural Land / Open Water
		613	Gum Swamps	Natural Land / Open Water
		614	Shrub Swamps	Natural Land / Open Water
		615	Bottomland Hardwood Forest	Natural Land / Open Water
		616	Inland Ponds and Sloughs	Natural Land / Open Water
		617	Mixed Wetland Hardwoods	Natural Land / Open Water
	620		Wetland Coniferous Forests	Natural Land / Open Water
		621	Cypress	Natural Land / Open Water
		622	Wet Flatwoods	Natural Land / Open Water
		623	Atlantic White Cedar	Natural Land / Open Water
		624	Cypress - Pine - Cabbage Palm	Natural Land / Open Water
	630		R Wetland Mixed Forest	Natural Land / Open Water
		631	Hydric Hammock	Natural Land / Open Water
		632	Tidal Swamp	Natural Land / Open Water
	640		Vegetated Non-forested Wetlands	Natural Land / Open Water
		641	Freshwater Marshes	Natural Land / Open Water
		642	Salt marshes	Natural Land / Open Water
		643	Wet Prairies	Natural Land / Open Water
		644	Emergent Aquatic Vegetation	Natural Land / Open Water
		645	Submergent Aquatic Vegetation	Natural Land / Open Water
		6451	Hydrilla	Natural Land / Open Water
		646	Mixed Scrub-Shrub Wetland	Natural Land / Open Water
	650		Non-vegetated	Natural Land / Open Water
		651	Salt Barrens	Natural Land / Open Water
		652	Intertidal Areas	Natural Land / Open Water
		653	Inland Shores/Ephemeral Ponds	Natural Land / Open Water
		654	Oyster Bars	Natural Land / Open Water
	660		Cut over Wetlands	Natural Land / Open Water
700			Barren Land	
	710		Beaches	Natural Land / Open Water
	720		Sand Other Than Beaches	Natural Land / Open Water
	730		Exposed Rock	Natural Land / Open Water
		731	Exposed Rock with Marsh Grasses	Natural Land / Open Water
	740		Disturbed Lands	MI-Open Space / Recreational
		741	Rural Land in Transition Without Positive Indicators of Intended Activity	MI-Open Space / Recreational
		742	Borrow Areas	MI-Open Space / Recreational
		743	Spoil Areas	MI-Open Space / Recreational
		744	Fill Areas	MI-Open Space / Recreational
		745	Burned Areas	MI-Open Space / Recreational
800			Transportation, Communication and Utilities	
	810		Transportation	LI-Transportation

Table B-1. Continued.

FLUCCS Code LI	LII	LIII	FLUCCS Description	Land Use Intensity Description (LI=Low Intensity, MI=Middle Intensity, HI=High Intensity)
		811	Airports	HI-Transportation
		812	Railroads	LI-Transportation
		813	Bus and Truck Terminals	HI-Transportation
		814	Roads and Highways	HI-Transportation
		815	Port Facilities	HI-Transportation
		816	Canals and Locks	HI-Transportation
		817	Oil, Water, or Gas Long Distance Transmission Line	HI-Transportation
		818	Auto Parking Facilities (Highway Rest Areas)	HI-Transportation
		819	Transportation Facilities Under Construction	HI-Transportation
	820		Communications	Industrial
		821	Transmission Towers	Industrial
		822	Communication Facilities	Industrial
		829	Communication Facilities Under Construction	Industrial
	830		Utilities	Industrial
		831	Electrical Power Facilities	Industrial
		832	Electrical Power Transmission Lines	Industrial
		833	Water Supply Plants	Industrial
		834	Sewage Treatment	Industrial
		835	Solid Waste Disposal	Industrial
		839	Utilities Under Construction	Industrial
900			Special Classifications	Natural Land / Open Water
	910		Vegetative	Natural Land / Open Water
		911	Sea Grass	Natural Land / Open Water

APPENDIX C
SUMMARY OF EMERGY EVALUATIONS FOR LAND USES

Table C-1. Non-renewable and purchased empower density for urban land uses according to M. T. Brown[a] (units: E14 sej/ha/yr).

Land use	Fuel	Goods & services	Total
Single family residential (low-density)	290.33	1013.26	1303.59
Single family residential (med-density)	467.34	1685.33	2152.67
Single family residential (high-density)	454.93	1914.86	2369.80
Multi-family residential (low rise: 2 stories)	1943.81	7349.26	9293.07
Multi-family residential (high rise: 4 stories)	2568.31	10256.70	12825.02
Mobile home medium density	500.43	2247.79	2748.22
Mobile home high density	949.16	4137.84	5086.99
Commercial strip	2812.32	1823.87	4636.20
Commercial mall	13565.32	8486.60	22051.91
Industrial	3143.18	2266.40	5409.58
Central business district (2 stories)	9843.13	6307.05	16150.17
Central business district (4 stories)	17866.52	11534.66	29401.17
Universities (Institutional)	1207.64	2828.87	4036.51

[a] Brown (1980).

Table C-2. Non-renewable and purchased empower density for urban land uses according to N. Parker[a] (units: E14 sej/ha/yr).

Land use	Earth loss	Electricity	Fuel	Total
Single family residential (low-density)	5.83	820.04	17.47	843.34
Single family residential (med-density)	5.83	2139.02	40.80	2185.65
Multi-family residential (low rise)	5.83	5335.20	143.60	5484.63
Commercial strip	8.74	2494.70	379.00	2882.44
Commercial mall	8.74	2884.96	379.00	3272.70
Industrial	5.83	4626.84	379.00	5011.67
Highway	5.83	-	4075.50	4081.33

[a]Parker (1998).

Table C-3. Non-renewable and purchased empower density for agricultural land uses according to S. Brandt-Williams[a] (units: E13 sej/ha/yr).

Land use	Net Topsoil Loss	Fuel	Electricity	Labor	Lime	Potash	Pesticides	Phosphate	Nitrogen	Services	Subtotal[b]	Total[c]
Potatoes	95.29	194.21	36.68	61.00	94.92	30.06	86.94	145.82	192.38	435.41	937.30	1372.70
Sugarcane	95.29	62.57	0.00	6.00	0.00	27.45	4.94	38.97	0.00	453.60	235.22	688.82
Tomatoes	0.78	817.36	0.00	381.00	552.72	25.76	400.68	170.13	192.38	1199.42	2540.81	3740.23
Watermelon	95.29	229.66	0.00	178.00	0.00	13.76	95.51	97.22	115.94	287.53	825.37	1112.90
Green beans	95.29	215.15	44.22	28.00	94.92	12.90	30.74	73.00	96.19	512.08	690.41	1202.49
Lettuce	95.29	291.14	0.00	172.00	0.00	34.35	111.64	97.22	192.38	451.84	994.01	1445.84
Cucumber	95.29	242.96	0.00	285.00	94.92	27.45	123.48	155.37	192.38	410.76	1216.85	1627.61
Cotton	1020.14	107.58	8.48	40.00	94.92	13.76	12.52	58.42	77.04	123.08	1432.85	1555.92
Cabbage	95.29	193.20	36.68	91.00	94.92	34.35	16.63	170.13	192.38	121.31	924.57	1045.88
Corn[d]	526.89	90.01	21.10	6.00	62.66	20.70	4.26	77.95	231.03	132.75	1040.59	1173.34
Corn[e]	302.68	138.31	0.00	113.00	0.00	25.76	27.97	145.82	192.38	212.50	945.93	1158.43
Pepper	95.29	690.64	20.13	728.00	0.00	31.83	330.12	194.75	178.24	577.80	2269.00	2846.80
Oranges	7.85	221.01	12.58	120.00	40.32	43.55	45.11	41.58	121.95	121.36	653.94	775.31
Pasture[f]	0.78	27.31	5.95	2.00	62.69	6.71	0.00	27.27	62.63	6.13	195.34	201.47
Beef[g]	1.00	133.00	0.00	37.00	93.00	13.00	27.00	28.00	125.00	136.00	457.00	593.00
Milk[h]	95.00	194.00	135.00	57.00	156.00	28.00	6.00	124.00	205.00	1177.00	1000.00	2177.00

[a] Brandt-Williams (2001)
[b]Without services; [c]With services.
[d]Grain; [e]Sweet; [f]Bahia; [g]2 steers/ha; [h]Per cow/yr.

APPENDIX D
WATER CHEMISTRY DATA FOR THE SAMPLE FRESHWATER SYSTEMS

Table D-1. Water chemistry variables considered for 75 sample isolated forested wetlands (x = variable measured).

Site code	Turbidity	Specific conductance	Total nitrogen	Total phosphorus	Dissolved oxygen	Site code	Turbidity	Specific conductance	Total nitrogen	Total phosphorus	Dissolved oxygen
SA2	x	x	x	x	x	CR3	x	x	x	x	x
SA3	x	x	x	x	x	CR4	x	x	x	x	x
SA4	x		x	x		CR5	x		x	x	x
SA5	x		x	x	x	CR6	x		x	x	x
SA6	x	x	x	x		CR8	x		x	x	x
SA7	x		x	x	x	CR9	x			x	x
SA8	x		x	x	x	CR10	x		x	x	x
SA9	x			x	x	CR11	x		x	x	x
SR1	x	x	x	x	x	CU1	x	x	x	x	x
SR2	x	x	x	x	x	CU3	x	x	x	x	x
SR3	x	x	x	x	x	CU5	x	x	x	x	x
SR4	x		x	x	x	CU6	x	x	x	x	x
SR5	x		x	x	x	CU7	x		x	x	x
SR7	x		x	x	x	CU8	x			x	x
SR8	x			x	x	CU9	x			x	x
SR9	x		x	x	x	CU10	x			x	x
SU1	x	x	x	x	x	NA6	x		x	x	x
SU2	x	x	x	x	x	NA10	x			x	x
SU3	x	x	x	x	x	NA11	x			x	x
SU4	x		x	x	x	NR2	x	x	x	x	x
SU5	x		x	x	x	NR3	x	x	x	x	x
SU6	x	x	x	x	x	NR4	x	x	x	x	x
SU7	x		x	x	x	NR6	x		x	x	x
SU8	x			x	x	NR8	x		x	x	x
CA2	x		x	x	x	NR9	x			x	x
CA3	x	x	x	x	x	NU2	x	x	x	x	x
CA4	x	x	x	x	x	NU4	x	x	x	x	x
CA5	x	x	x	x	x	NU5	x	x	x	x	x
CA7	x			x	x	NU6	x		x	x	x
CA8	x		x	x	x	NU10	x		x	x	
CR1	x		x	x	x	PA2	x	x	x	x	x
PA3	x	x	x	x	x	PR8	x		x	x	x
PA5	x	x	x	x	x	PU1	x	x	x	x	x
PA6	x	x	x	x	x	PU3	x	x	x	x	x
PR4	x	x	x	x	x	PU4	x		x	x	x
PR5	x	x	x	x	x	PU6	x		x	x	x
PR6	x		x	x	x	PU10	x			x	
PR7	x		x	x	x						

Table D-2. Water chemistry variables considered for 47 STORET stream stations (x = data available).

STORET Station #	Data Source	Period sampled	# of samples	Turbidity	DO[a]	NO_3[b]	TN[c]	TP[d]	WQI[e]
19010099	305(b) report	93-94	18	x	x	x	x	x	x
20010454	305(b) report	93-95	8	x	x	x	x	x	x
20010455	305(b) report	93-94	6	x	x	x	x	x	x
20020004	305(b) report	94-95	5	x	x	x	x	x	x
20020012	305(b) report	90-95	30	x	x	x	x	x	x
20020317	305(b) report	90-94	10	x	x	x	x	x	x
20020404	305(b) report	93-94	7	x	x	x	x	x	x
20030342	STORET	95-96	2			x	x	x	
20030419	STORET	94-95	2			x	x	x	
20030437	STORET	94-96	3			x	x	x	
21010018	305(b) report	94-94	8	x	x	x	x	x	x
22020049	305(b) report	93-94	8	x	x	x	x	x	x
22020062	STORET	94-96	4			x	x	x	
22030062	305(b) report	93-93	6	x	x	x	x	x	x
23010464	305(b) report	93-95	7	x	x	x	x	x	x
24010002	305(b) report	93-94	6	x	x	x	x	x	x
24020134	305(b) report	94-95	3	x	x	x	x	x	x
24030013	305(b) report	93-95	7	x	x	x	x	x	x
24030044	305(b) report	93-94	6	x	x	x	x	x	x
25020014	305(b) report	93-95	7	x	x	x	x	x	x
25020111	305(b) report	90-94	32	x	x	x	x	x	x
26010029	305(b) report	92-94	4	x	x	x	x	x	x
26010430	STORET	95-96	7			x	x	x	
26010593	305(b) report	94-94	4	x	x	x	x	x	x
26010972	STORET	94-95	2			x	x	x	
26011019	305(b) report	93-94	6	x	x	x	x	x	x
26011020	305(b) report	93-94	6	x	x	x	x	x	x
28010223	305(b) report	93-95	344	x	x	x	x	x	x
28010224	305(b) report	93-95	11	x	x	x	x	x	x
28010239	305(b) report	94-95	3	x	x	x	x	x	x
28010608	305(b) report	93-95	365	x	x	x	x	x	x
28020147	STORET	94-96	2			x	x	x	
28020148	305(b) report	92-94	7	x	x	x	x	x	x
28020221	305(b) report	93-94	6	x	x	x	x	x	x
31010050	305(b) report	93-94	6	x	x	x	x	x	x
31010051	305(b) report	93-94	5	x	x	x	x	x	x
31020038	305(b) report	92-94	10	x	x	x	x	x	x
31020040	305(b) report	93-94	9	x	x	x	x	x	x
32010021	305(b) report	92-94	9	x	x	x	x	x	x
32020063	305(b) report	93-94	6	x	x	x	x	x	x
32030023	305(b) report	93-94	8	x	x	x	x	x	x
32030024	305(b) report	93-94	9	x	x	x	x	x	x
33010054	STORET	92-95	8			x	x	x	
33010065	STORET	95-96	2			x	x	x	
33010068	STORET	95-96	2			x	x	x	
33040014	305(b) report	93-94	7	x	x	x	x	x	x
33040015	305(b) report	93-94	7	x	x	x	x	x	x

[a]DO = Dissolved oxygen; [b]NO_3 = Nitrate nitrogen; [c]TN = Total nitrogen, calculated from STORET data; [d]TP = Total phosphorus; [e]WQI = Water Quality Index.

Table D-3. Water chemistry variables considered for 54 STORET lake stations. All data provided by FDEP (R. Frydenborg 2005, Environmental Assessment Section, Bureau of Laboratories personal communication) (x = data available).

STORET Station #	Period sampled	# of samples	Ammonia N[a]	NO_3/NO_2[b]	TKN[c]	TN[d]	TP[e]
20010048	2000	1	x	x	x	x	x
20010110	1998	1	x	x	x	x	x
20010222	1998	1	x	x	x	x	x
20010299	1997	1	x	x	x	x	x
20010311	1998	1	x	x	x	x	x
20010334	1998	1	x	x	x	x	x
20010336	1998	1	x	x	x	x	x
20010337	1998	1	x	x	x	x	x
20020014	1996-1997	2	x	x	x	x	x
20020015	1996-1998	2	x	x	x	x	x
20020062	1997	1	x	x	x	x	x
20020064	1998-2000	2	x	x	x	x	x
20020065	1998-2000	3	x	x			
20020066	1998	1	x	x	x	x	x
20030417	1998	1	x	x	x	x	x
20030438	1998	1	x	x	x	x	x
23010434	1998	1	x	x	x	x	x
23010435	1997	1	x	x	x	x	x
25010079	1997	2	x	x	x	x	x
25020552	1998	2	x	x	x	x	x
25020554	1999	2	x	x	x	x	x
26010032	1996-1998	2	x	x	x	x	x
26010037	1998	1	x	x	x	x	x
26010039	1998	1	x	x	x	x	x
26010040	1997	1	x	x	x	x	x
26010105	2000	1	x	x	x	x	x
26010116	1997	1	x	x	x	x	x
26010303	1998	2	x	x	x	x	x
26010304	1998	2	x	x	x	x	x
26010325	1999	2	x	x	x	x	x
26010326	1999	2	x	x	x	x	x
26010327	2000	2	x	x	x	x	x
26010331	1998	2	x	x	x	x	x
26010526	2000	2	x	x	x	x	x
26010528	2000	2	x	x	x	x	x
26010531	2000	2	x	x	x	x	x
26010556	1999	2	x	x	x	x	x
26010585	1999	2	x	x	x	x	x
26010591	1999	2	x	x	x	x	x
26010605	1998	2	x	x	x	x	x
26010644	1999	2	x	x	x	x	x
26010645	1997	2	x	x	x	x	x
26010646	1997	2	x	x	x	x	x
26010647	1997	2	x	x	x	x	x
26010648	1997	2	x	x	x	x	x
28020242	1998	2	x	x	x	x	x
28030068	1997	2	x	x	x	x	x

Table D-3. Continued.

STORET Station #	Period sampled	# of samples	Ammonia N[a]	NO_3/NO_2[b]	TKN[c]	TN[d]	TP[e]
32010038	1997-1998	2	x	x	x	x	x
32020113	1997-1999	2	x	x	x	x	x
32030081	1998-1999	2	x	x	x	x	x
33010064	1997-1998	2	x	x	x	x	x
33020097	1998-1999	2	x	x	x	x	x
33020098	1998-1999	2	x	x	x	x	x
33030057	1996-1998	3	x	x	x	x	x

[a]Ammonia N = Ammonia nitrogen; [b] NO_3/NO_2 = Nitrite-nitrate nitrogen; [c]TKN = Total Kjeldahl nitrogen; [d]TN = Total nitrogen; [e]TP = Total phosphorus.

APPENDIX E
WETLAND CONDITION INDEX

Table E-1. Metric composition of the WCI including diatoms WCI, macrophytes WCI, and macroinvertebrates WCI (Source: Reiss 2004).

Diatoms	Macrophytes	Macroinvertebrates
% Tolerant Indicator Species	% Tolerant Indicator Species	% Tolerant Indicator Species
% Sensitive Indicator Species	% Sensitive Indicator Species	% Sensitive Indicator Species
Pollution class 1[a]	Modified FQI[f]	Florida Index[g]
Nitrogen class 3[b]	% Exotic species	% Mollusca
Saprobity class 4[c]	% Native perennial	% Noteridae
pH class 3[d]	% Wetland status species	% Scrapers
Dissolved oxygen class 1[e]		

[a] Very tolerant to pollution; [b] Need periodically elevated concentration of organically bound nitrogen; [c] inhabit aquatic environments with an oxygen saturation between 10-25% and a biological oxygen demand of approximately 13-22 mg/L; [d] Mainly occurring at pH values close to 7; [e] requiring continuously high dissolved oxygen concentrations near 100%; [f] Modified Floristic Quality Index; [g] Weighted sum of intolerant taxa, which are classed as 1 (least tolerant) or 2 (intolerant).

Table E-2.WCI scores for 118 wetlands based on three assemblages including diatoms, macrophytes, and macroinvertebrates (Source: Reiss 2004).

Site code	Diatom WCI	Macrophyte WCI	Macroinvertebrate WCI	Site code	Diatom WCI	Macrophyte WCI	Macroinvertebrate WCI
PA1	-	30.4	-	CA1	-	8.9	-
PA2	38.1	11.9	30.1	CA2	10.6	0.7	19.4
PA3	34.9	8.3	25.1	CA3	7.9	7.1	20.0
PA4	-	12.6	-	CA4	56.9	38.8	31.3
PA5	51.1	6.5	21.2	CA5	43.6	26.9	7.2
PA6	28.2	7.7	12.9	CA6	22.7	7.1	21.1
PA7	-	17.7	-	CA7	-	9.8	32.1
PA8	-	50.6	-	CA8	-	37.7	31.3
PA9	-	12.1	-	CA9	-	11.8	22.6
PA10	-	41.7	-	CR1	-	51.0	-
PR1	61.1	55.9	37.6	CR2	-	49.9	-
PR2	-	50.5	-	CR3	57.7	47.6	33.9
PR3	-	49.5	-	CR4	57.8	51.2	48.9
PR4	64.5	51.2	40.0	CR5	43.8	43.5	29.7
PR5	58.0	53.6	30.0	CR6	65.5	54.6	50.4
PR6	63.9	58.4	34.4	CR7	-	51.7	-
PR7	-	34.8	26.5	CR8	-	54.3	28.8
PR8	-	53.6	40.7	CR9	-	49.4	34.4
PU1	-	6.2	-	CR10	-	53.5	45.0

Table E-2. Continued.

Site code	Diatom WCI	Macrophyte WCI	Macroinvertebrate WCI	Site code	Diatom WCI	Macrophyte WCI	Macroinvertebrate WCI
PU2	-	31.5	-	CR11	-	59.0	49.5
PU3	33.1	31.0	35.7	CU1	61.1	42.9	40.6
PU4	10.5	4.0	21.6	CU2	-	10.0	-
PU5	-	22.1	-	CU3	28.5	13.5	22.3
PU6	-	16.5	-	CU4	-	21.4	-
PU7	-	24.1	-	CU5	21.5	22.3	17.8
PU8	-	33.6	-	CU6	15.1	41.5	23.4
PU9	-	48.8	-	CU7	-	20.7	10.6
PU10	-	9.2	30.2	CU8	-	21.1	10.1
NA1	-	0.0	-	CU9	-	28.3	28.3
NA2	-	3.0	-	CU10	-	38.3	32.3
NA3	-	56.4	-	CU11	-	21.3	34.1
NA4	33.8	16.3	10.4	SA1	-	0.7	-
NA5	-	2.9	-	SA2	34.1	9.4	15.0
NA6	56.3	18.8	16.9	SA3	47.9	23.1	28.6
NA7	-	37.0	-	SA4	15.8	11.3	9.1
NA8	-	46.0	-	SA5	46.3	18.9	19.0
NA9	-	37.3	-	SA6	31.9	3.7	19.0
NA10	-	51.5	30.0	SA7	-	30.8	29.8
NA11	-	32.6	28.7	SA8	-	34.5	11.0
NA12	-	8.0	-	SA9	-	29.8	17.9
NR1	-	52.0	-	SR1	66.8	54.1	33.4
NR2	65.8	34.8	30.0	SR2	68.9	50.8	46.6
NR3	66.8	58.2	52.8	SR3	51.6	51.2	26.4
NR4	58.3	42.2	39.8	SR4	43.7	57.9	28.2
NR5	-	52.3	-	SR5	39.4	49.8	38.4
NR6	57.9	55.0	48.6	SR6	41.0	51.8	39.0
NR7	-	52.3	-	SR7	-	49.9	42.7
NR8	-	58.4	30.0	SR8	-	47.5	57.0
NR9	-	56.7	33.0	SR9	-	50.1	43.4
NU1	-	35.2	-	SU1	17.2	17.8	22.1
NU2	24.1	23.7	15.5	SU2	46.2	20.3	15.2
NU3	-	25.6	-	SU3	31.7	42.6	35.4
NU4	54.5	35.1	31.0	SU4	42.3	21.8	18.9
NU5	60.0	40.1	24.0	SU5	38.9	23.9	5.3
NU6	48.8	20.7	28.0	SU6	46.1	28.1	21.0
NU7	-	11.8	-	SU7	-	12.5	9.1
NU8	-	38.6	-	SU8	-	2.7	23.3
NU9	-	37.5	-	SU9	-	20.4	32.3
NU10	-	17.2	23.0	SU10	-	11.7	-

APPENDIX F
STREAM CONDITION INDEX

Table F-1. Macroinvertebrate metric composition of the SCI defined by Barbour and colleagues[a].

Core Metrics	Description
Total taxa	Measures the overall variety of macroinvertebrates.
EPT taxa	Sum of the number of taxa of the orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies).
Chironomidae taxa	Number of unique taxa of chiromids (midges).
% Dominant taxon	Relative abundance of the most abundant taxon.
% Diptera	Relative abundance of individuals classed as dipterans (true fly larvae).
Florida index	Weighted sum of intolerant taxa, classified as 1 (least tolerant) and 2 (intolerant). Florida index = 2 X class 1 taxa + 1 X class 2 taxa.
% Filterers	Relative abundance of the sample that filters suspended detritus.

[a]Barbour et al (1996b).

Table F-2. Macroinvertebrate metric composition of the SCI defined by S. Fore[a].

Core Metrics	Description
Total taxa	Measures the overall variety of macroinvertebrates.
Ephemeroptera taxa	Number of unique taxa found within the order Ephemeroptera (mayflies).
Trichoptera taxa	Number of unique taxa found within the order Trichoptera (caddisflies).
% Filterers	Relative abundance of the filterer functional feeding group.
Long-lived taxa	Number of unique taxa which requires more than a year to complete their life cycles.
Clinger taxa	Number of unique taxa that attaches to substrates.
% Dominance	Relative abundance of the most abundant taxon.
% Tanytarsini	Relative abundance of the Tanytarsini tribe of the Chironimid (midges) family.
Sensitive taxa	Number of unique taxa sensitive to human disturbance.
% Very tolerant	Relative abundance of taxa very tolerant to human disturbance.

[a]Fore (2004)

Table F-3. SCI scores for 69 streams for the macroinvertebrate assemblage. (Source: R. Frydenborg 2005, FDEP, Environmental Assessment Section, Bureau of Laboratories, personal communication).

Site code	STORET station #	# of Samples	SCI_1[a] Score	SCI_2[b] Score	Site code	STORET station #	# of Samples	SCI_1 Score	SCI_2 Score
S1	19010042	3	29	77	S36	25020014	6	28	58
S2	19010099	5	29	73	S37	25020111	5	31	82
S3	19020027	1	29	70	S38	26010029	3	21	27
S4	20010454	5	27	60	S39	26010430	3	28	63
S5	20010455	5	29	55	S40	26010593	5	32	75
S6	20020004	4	32	94	S41	26010972	2	30	80
S7	20020012	7	30	69	S42	26011019	5	29	70
S8	20020317	5	28	57	S43	26011020	5	30	75
S9	20020404	6	31	89	S44	28010223	7	28	51
S10	20020424	1	19	10	S45	28010224	8	31	50
S11	20030263	1	29	60	S46	28010232	1	19	15
S12	20030264	1	29	65	S47	28010239	5	29	59
S13	20030265	1	25	25	S48	28010608	8	27	38
S14	20030340	1	29	75	S48	28020147	2	32	70
S15	20030341	1	29	65	S50	28020148	5	31	78
S16	20030342	1	29	40	S51	28020221	6	31	81
S17	20030419	2	28	65	S52	28020232	1	29	45
S18	20030437	3	28	65	S53	28020233	1	25	20
S19	20030549	1	29	85	S54	28020234	1	-	60
S20	20030550	1	21	35	S55	31010050	7	32	79
S21	21010018	3	25	62	S56	31010051	8	32	84
S22	21010032	2	26	40	S57	31020037	1	27	50
S23	22020010	1	31	50	S58	31020038	1	25	45
S24	22020049	7	29	62	S59	31020040	6	31	71
S25	22020062	5	26	54	S60	32010021	6	31	75
S26	22020077	1	29	70	S61	32020030	2	16	8
S27	22020093	1	31	55	S62	32020063	6	31	73
S28	22030062	4	31	59	S63	32030023	6	31	75
S29	22030064	1	13	5	S64	32030024	5	33	75
S30	23010464	7	28	54	S65	33010054	6	32	81
S31	24010002	5	30	84	S66	33010065	1	33	85
S32	24020134	4	31	74	S67	33010068	1	29	65
S33	24030013	7	28	57	S68	33040014	6	31	73
S34	24030044	5	28	65	S69	33040015	6	31	83
S35	24030142	1	29	90					

[a]SCI defined by Barbour et al. (1996b).

[b]SCI defined by Fore (2004).

APPENDIX G
LAKE CONDITION INDEX

Table G-1. Macroinvertebrate metric composition of the LCI (source: Gerritsen et al. 2000).

Core Metrics	Description
Total taxa	Measures the overall variety of macroinvertebrates.
EOT taxa	Sum of the number of taxa of the orders Ephemeroptera (mayflies), Odonata (dragonflies and damselflies), and Trichoptera (caddisflies).
% EOT	Relative abundance of individuals classed as mayflies, dragonflies and damselflies, and caddisflies.
Hulbert Index	Macroinvertebrate component of the Hulbert's Lake Condition Index.
Shannon-Wiener diversity	Measure of the general diversity and composition of macroinvertebrates (considers both richness and evenness).
% Diptera	Relative abundance of individuals classed as dipterans (true fly larvae).

Table G-2. LCI scores for 54 lakes for the macroinvertebrate assemblage (source: R. Frydenborg 2005, FDEP, Environmental Assessment Section, Bureau of Laboratories, personal communication).

STORET station #	# of Samples	LCI score	STORET station #	# of Samples	LCI score
20010048	-	-	26010303	2	13.94
20010110	1	34.39	26010304	2	52.60
20010222	1	24.89	26010325	2	66.65
20010299	1	42.43	26010326	2	25.07
20010311	1	18.48	26010327	2	46.97
20010334	1	37.34	26010331	2	66.09
20010336	1	22.99	26010526	2	75.57
20010337	1	11.74	26010528	2	72.34
20020014	1	49.18	26010531	2	69.21
20020015	1	35.91	26010556	2	61.81
20020062	1	21.49	26010585	2	53.42
20020064	2	65.36	26010591	2	31.89
20020065	3	54.34	26010605	2	55.56
20020066	1	36.54	26010644	2	38.13
20030417	1	87.96	26010645	1	38.15
20030438	1	57.64	26010646	1	41.38
23010434	1	51.66	26010647	2	24.25

Table G-2. Continued.

STORET station #	# of Samples	LCI score	STORET station #	# of Samples	LCI score
23010435	1	54.74	26010648	2	36.27
25010079	2	58.47	28020242	2	26.27
25020552	2	9.68	28030068	2	58.95
25020554	2	43.85	32010038	2	30.28
26010032	1	78.53	32020113	2	49.06
26010037	1	44.33	32030081	2	43.81
26010039	1	44.32	33010064	2	26.67
26010040	1	16.29	33020097	2	37.57
26010105	1	37.71	33020098	2	64.30
26010116	1	25.64	33030057	2	35.56

APPENDIX H
MFWORKS SCRIPTS

Script 1: Land use proportion LDI (regardless of distance from study aquatic system).

```
Recode_map= Recode Empower_map Assigning 1 To 0...15000;
Total_area_map= Measure Recode_map Hectares Ignore VOID;
LU_area_map= Measure Empower_map Hectares;
Fraction_map= LU_area_map/Total_area_map;
LU_empower_map= Fraction_map*Empower_map;
Cell_measure_map= Measure LU_empower_map Cells;
New_fraction_map= (LU_empower_map/Cell_measure_map)*100000000;
Trunk_map= Trunc(New_fraction_map);
New_trunc_map= Trunc(Total_area_map);
Total_score_map= Score New_trunc_map By Trunc_map Total;
Float_total_score_map= Float(Total_score_map);
Aw_final_value_map= Float_total_score_map/1000000;
Save Aw_final_value_map;
```

Script 2: Inverse linear distance LDI (linear decrease with distance from study aquatic system).

```
Mask_map= (Empower_map*0)+1;
Recode_mask_map= Recode Mask_map Assigning 9999999 To VOID CarryOver;
Spread_map= Spread Seed_map To 100000 In Recode_mask_map;
Mask_all_map= Recode Mask_map Assigning 1 to 100000000.00000 CarryOver;
Trunc_mask_all_map= Trunc(Mask_all_map);
Float_spread_map= Float(Spread_map);
Max_spread_value_map= Score Trunk_mask_all_map By Float_spread_map Maximum;
Inverse_distance_map= (Spread_map- Max_spread_value_map)*-1;
Norm_distance_map= Inverse_distance_map/Max_spread_value_map;
Ldw_empower_map= Norm_distance_map*Empower_map;
Trunc_mask_map= Trunc(Mask_map);
Ldw_final_value_map= Score Trunk_mask_map By Ldw_empower_map Average;
Save Ldw_final_value_map;
```

Script 3: Inverse square distance LDI (square decrease with distance from study aquatic system).

```
Mask_map= (Empower_map*0)+1;
Recode_maskmap= Recode Mask_map Assigning 9999999 To VOID CarryOver;
Spread_map= Spread Seed_map To 100000 In Recode_mask;
Mask_all_map= Recode Mask_map Assigning 1 to 100000000.00000 CarryOver;
Trunk_mask_all_map= Trunc(Mask_all_map);
Float_spread_map= Float(Spread_map);
Max_spread_value_map= Score Trunk_mask_all_map By Float_spread_map Maximum;
Inverse_distance_map= (Spread_map- Max_spread_value_map)*-1;
Square_distance_map= Distance_map*Distance_map;
```

```
Norm_distance_map= Square_distance_map/
(Max_spread_value_map*Max_spread_value_map);
Sqdw_empower_map= Norm_distance_map* Empower_map;
Trunk_mask_map= Trunc(Mask_map);
Sqdw_final_value_map= Score Trunk_mask_map By Sqdw_empower_map;
Save Sqdw_final_value_map;
```

APPENDIX I
LAND USE/LAND COVER SURROUNDING THE ISOLATED FORESTED WETLANDS

Table I-1. Characteristics of the land use/land cover surrounding the isolated forested wetlands (n = 118). Categories defined according to Level 1 of the FLUCCS classification scheme. Blank spaces denote a value of zero.

Site Code	% Urban	% Agriculture	% Rangeland	% Forest	% Water	% Wetland	% Transportation
CA1		94.6			1.7	3.7	
CA2		86.9			1.6	11.5	
CA3		84.1		0.4	1.0	12.5	2.0
CA4		84.7				15.3	
CA5		98.6			1.4		
CA6		94.1			2.1	3.8	
CA7		51.9		16.5		27.8	3.8
CA8	0.8			72.3		18.6	8.3
CA9		97.7				2.3	
CR1				89.8		10.2	
CR10				98.1			1.9
CR11				12.0	0.3	87.6	
CR2				97.3		2.7	
CR3				58.7		41.3	
CR4				76.8		20.4	2.8
CR5				95.8	2.0		2.2
CR6				63.0		37.0	
CR7				67.0		29.3	3.6
CR8				92.2		4.3	3.5
CR9				89.7			3.1
CU1	16.8			62.6	0.5		20.1
CU10	96.4						3.6
CU11	96.2			2.1			1.7
CU2	78.4				21.6		
CU3	75.0			11.3	0.8		12.9
CU4	52.4	6.7		24.5	0.3		16.1
CU5	40.2				2.4	7.1	50.2
CU6	86.1				9.2	1.7	2.9
CU7	71.9			15.7	5.2		7.3
CU8	23.8			56.3		2.9	17.0
CU9	56.6			3.5	2.7		37.2
NA1		87.9			0.7	7.4	3.9
NA10				91.2		0.5	8.3
NA11		86.4		2.2	0.5	9.2	1.7

Table I-1. Continued.

Site Code	% Urban	% Agriculture	% Rangeland	% Forest	% Water	% Wetland	% Transportation
NA12		64.5	15.1		0.2	17.0	3.2
NA2		93.7		3.8			2.6
NA3				70.4		26.6	2.9
NA4		88.0			2.6	3.9	5.5
NA5		86.3		2.6	4.4	6.7	
NA6		79.9	3.7	8.8	4.1	3.6	
NA7		59.1				40.9	
NA8				99.5		0.5	
NA9				85.1	1.3	9.1	4.5
NR1				97.6		1.0	1.4
NR2				89.7		7.2	3.1
NR3				82.3		17.7	
NR4				81.3		16.1	2.5
NR5				96.5			3.5
NR6				84.5		9.8	5.7
NR7				97.7		1.9	0.4
NR8				98.6			1.4
NR9				93.1		5.2	1.7
NU1	26.3	9.7		49.0	1.7	2.3	11.0
NU10	87.0			7.0	0.4		5.5
NU2	73.3			22.3			4.4
NU3	39.7			53.1		1.0	6.2
NU4	51.2			33.2	2.4	3.0	10.1
NU5	69.9				12.2	1.8	16.1
NU6	54.3			40.0			5.6
NU7	76.9			15.6		1.5	6.0
NU8	58.8			26.2	8.4		6.5
NU9	77.1			17.5			5.4
PA1		49.7	48.9				1.5
PA10				97.4			2.6
PA2	0.4	71.2		15.2	10.7	2.5	
PA3	14.5	83.3			0.8		1.4
PA4	2.2	90.7			1.5		5.6
PA5		66.2			2.7	31.1	
PA6	0.3	62.9		25.2	3.1	4.3	4.2
PA7		80.1		7.0	0.9	12.0	
PA8				98.2			1.8
PA9		43.2		53.8	3.1		
PR1				64.4		33.1	2.5
PR2				7.7	0.4	91.8	
PR3				89.7		7.2	3.1
PR4	2.9			90.7			6.5
PR5				77.2		18.6	4.2
PR6				81.3		13.9	4.9

Table I-1. Continued.

Site Code	% Urban	% Agriculture	% Rangeland	% Forest	% Water	% Wetland	% Transportation
PR7				98.5		1.5	
PR8				84.5		14.2	1.3
PU1	77.2			12.8			10.0
PU10	91.4			3.4			5.2
PU2	62.3	2.4		18.5		7.6	9.3
PU3	84.3			5.7			10.1
PU4	79.3			16.0			4.7
PU5	40.3			32.7	1.1	17.7	8.2
PU6	25.1			36.2	0.7	28.5	9.4
PU7	68.7	20.0		11.3			
PU8	87.8			5.9			6.3
PU9	83.0			14.1			2.9
SA1		96.1			3.9		
SA2		76.0			5.4	18.7	
SA3		60.4			15.5	24.1	
SA4		77.0		0.1	10.9	11.2	0.7
SA5		76.6	14.7	8.7			
SA6		93.5		3.7	0.9	1.8	
SA7			98.2			1.8	
SA8		11.7		84.3			3.9
SA9		99.9			0.1		
SR1				77.9		22.1	
SR2				54.2		45.8	
SR3				78.7		20.7	0.6
SR4				13.4		85.2	1.4
SR5				14.6		78.4	7.0
SR6						100.0	
SR7				69.4		29.1	1.6
SR8				56.9		36.4	6.7
SR9	14.5			66.8		15.1	3.6
SU1	51.3			25.6	5.3		17.8
SU10	77.7			3.3	1.7	4.0	13.3
SU2	48.8			24.8		12.5	13.9
SU3	17.6				4.2	50.5	27.7
SU4	85.9			1.3			12.7
SU5	53.2			43.1	0.5		3.3
SU6	46.9	21.1		22.0	7.0		3.1
SU7	67.5				2.8	20.3	9.4
SU8	84.1				2.4		13.4
SU9	77.6				16.8	3.7	2.0

APPENDIX J
LAND USE/LAND COVER SURROUNDING STREAMS

Table J-1. Characteristics of the land use/land cover surrounding the sample streams (n = 69). Categories defined according to Level 1 of the FLUCCS classification scheme. Blank spaces denote a value of zero.

Site code	% Urban	% Agriculture	% Rangeland	% Forest	% Water	% Wetland	% Barren land	% Transportation
S1		0.1		62.0		37.8		
S2	6.1	5.9	10.6	56.9	0.3	16.7	0.4	3.1
S3	6.7	12.4	1.8	51.5	0.4	27.1		0.1
S4	0.2		0.3	90.3	0.4	8.7		0.1
S5	10.0	12.7	4.3	39.5	7.7	25.2	0.6	0.1
S6	10.9	3.3	0.8	49.9	11.2	23.0	0.6	0.2
S7	9.3	9.3	2.2	49.3	6.5	23.0	0.2	0.2
S8	12.6	4.3	1.9	66.4	0.8	13.1		0.9
S9	3.4	16.3	1.7	33.1	10.2	34.8	0.1	0.3
S10	17.9	11.8	3.2	30.0	3.0	33.3	0.4	0.4
S11	9.4	0.4	2.5	59.2	1.1	22.9		4.4
S12	2.5	4.4	7.1	50.5	0.2	20.7	0.1	14.6
S13	2.5	3.6	5.9	54.7	0.1	20.8	0.1	12.3
S14	4.0	0.4	0.5	63.6	0.7	29.4		1.5
S15	5.9	2.3	1.8	67.0	0.3	20.7		2.0
S16	5.5	2.6	3.3	62.2	0.3	20.3		5.9
S17	10.8		8.1	60.9	4.3	15.3	0.3	0.3
S18	7.1	2.3	2.3	63.9	1.9	19.6	0.1	2.8
S19	5.4	2.4	1.7	68.4	0.3	19.6		2.2
S20	9.8	0.4	1.7	60.0	1.2	22.8		4.1
S21	2.1	1.9	1.1	71.0	0.1	22.8	0.2	0.7
S22	0.2	1.7	0.1	56.2	0.1	41.9		
S23	11.2	17.0	0.7	65.3	1.4	3.4	0.1	0.8
S24		2.6	0.7	85.6		10.8		0.1
S25	0.4		4.8	85.6		9.1		
S26	39.7			47.3				13.0
S27	10.5	20.0	0.4	63.3	1.6	3.4	0.1	0.7
S28	28.8	4.2	3.2	56.7		5.1	0.2	1.7
S29	99.4							0.6
S30	6.9	30.2	13.3	16.2	0.5	32.4	0.1	0.5

Table J-1. Continued.

Site code	% Urban	% Agriculture	% Rangeland	% Forest	% Water	% Wetland	% Barren land	% Transportation
S31	1.4	27.3	41.7	18.2	0.3	10.7		0.4
S32	16.9	51.6	4.5	12.6	1.9	12.4		0.1
S33	25.3	25.4	14.3	10.6	0.8	21.9		1.7
S34	23.4	36.1	8.7	9.7	1.0	19.9		1.3
S35	17.1	21.3	18.4	12.5	0.8	27.4		2.5
S36		68.8	6.2	7.2	0.2	17.7		
S37	0.5	48.6	16.2	15.9	0.1	18.6		0.1
S38	45.3	24.0	2.8	8.5	7.7	11.4		0.2
S39	2.0	75.9	4.8	4.7	1.8	10.6	0.2	
S40	0.9	42.2	11.9	20.7	0.3	23.9		0.1
S41	9.8	36.6	0.4	7.7	2.5	39.4	0.9	2.6
S42	6.1	41.1	8.5	12.1	14.6	17.2		0.4
S43	10.3	53.1	1.6	14.5	6.4	13.7		0.3
S44	6.5	4.6	1.5	51.8	0.7	32.5	2.3	
S45	70.0	0.6	0.6	21.4	0.9	6.6		
S46	10.2	65.6	0.3	16.3	2.1	2.8		2.7
S47	4.3	68.5	2.8	13.0	1.7	7.5	0.7	1.4
S48	5.1	63.4	3.0	16.2	1.6	8.7	0.7	1.3
S48	27.2	22.3	6.1	21.6	0.5	21.5		0.8
S50	65.7	4.7	5.9	9.1	2.0	8.3	3.2	1.1
S51	0.1	21.0	3.3	49.6		25.8		0.1
S52	13.2	25.5	9.4	27.9	0.1	21.3	1.8	0.7
S53	45.9	14.1	3.6	17.5	0.9	9.0	4.1	5.0
S54	14.6	24.5	0.8	14.8	0.9	37.0	6.2	1.2
S55	2.2	2.1	4.8	89.7	0.3	0.9		
S56	0.4	1.6	3.3	93.4		0.8		0.6
S57	1.8	19.6	20.6	49.8	0.3	7.8		0.1
S58	3.4	38.4	0.8	41.6	0.5	14.4	0.2	0.7
S59	3.0	7.7	17.2	55.9	0.6	15.0		0.5
S60	6.3	2.9	4.0	79.5	0.5	5.3	0.1	1.5
S61	41.9	30.7	2.3	20.4	0.2	4.4		
S62				76.8		23.1		
S63	12.4	3.1	12.7	58.4	2.9	9.5		1.1
S64	0.1	0.2	0.1	91.4		7.0		1.3
S65	2.1	23.7	0.3	61.2	0.2	12.0		0.4
S66	19.3	4.0		56.6	0.5	13.9		5.6
S67	25.4	12.8	0.7	53.8	1.3	3.7		2.4
S68	1.3	19.2	1.9	64.5	0.8	11.6		0.6
S69	1.3	26.4	4.1	51.9	1.3	14.8		0.1

APPENDIX K
LAND USE/LAND COVER SURROUNDING LAKES

Table K-1. Characteristics of the land use/land cover surrounding the sample lakes (n = 54). Categories defined according to Level 1 of the FLUCCS classification scheme. Blank spaces denote a value of zero.

Site code	% Urban	% Agriculture	% Rangeland	% Forest	% Water	% Wetland	% Barren land	% Transportation
L1	99.83				0.17			
L2			32.73	3.44	17.49	46.33		
L3	86.99			2.88	0.34	1.04		8.75
L4	93.37				0.69			5.94
L5	30.32		2.72		0.28	1.98		64.70
L6	87.91	0.10		0.75	0.80	2.81		7.64
L7	88.02					1.40		10.58
L8	89.95			0.12		6.60		3.34
L9		6.44	43.50	29.92		20.14		
L10	0.84	24.93	48.32			25.90		
L11	9.88	21.77		17.52		50.83		
L12	45.44	22.10	10.78	21.69				
L13	10.82	58.02	2.75	24.11		4.29		
L14	59.54	17.04	8.51	5.21		7.70		2.01
L15	32.48		3.57	45.13	0.08	18.05	0.08	0.61
L16	6.06		22.48	46.54	4.34	19.97	0.62	
L17	37.35	24.37	0.25	9.86	2.57	25.59		0.02
L18	37.35	24.37	0.25	9.86	2.57	25.59		0.02
L19	0.40	0.70	39.55	31.84	0.00	22.89	0.03	4.59
L20	100.00							
L21	90.73			3.31	1.05			3.56
L22	20.80	38.22	0.64	9.04	8.14	22.71	0.11	0.34
L23	15.42	21.21		39.56	0.22	23.08		0.49
L24	10.48		27.56	16.43	0.58	44.84	0.10	
L25		40.44		5.89	0.14	53.53		
L26	96.13				0.97			2.90
L27	52.63	33.04	0.42		1.42	5.99		6.50
L28	35.19	54.48		3.93		6.40		
L29	63.19	20.36	4.73	3.46	2.95	3.56		1.75
L30	64.94	32.90			0.48	0.83		0.85
L31	13.86	67.51	6.13	8.85		3.65		
L32	44.99	25.09	14.58	1.66	13.19	0.48		

Table K-1. Continued.

Site code	% Urban	% Agriculture	% Rangeland	% Forest	% Water	% Wetland	% Barren land	% Transportation
L33	36.48	35.52	1.53	18.77		7.71		
L34	67.31	10.51	0.68	5.59	10.25	3.08		2.58
L35	67.31	10.51	0.68	5.59	10.25	3.08		2.58
L36	67.31	10.51	0.68	5.59	10.25	3.08		2.58
L37	62.67	11.03	2.20	12.68	2.19	6.40		2.84
L38	98.42				0.55	1.04		
L39	47.27	42.00	0.90	4.97		4.34		0.53
L40	50.79	49.21						
L41	30.33	25.81	0.87	25.01	1.39	13.90		2.69
L42	49.96	6.08	6.97	7.02	0.20	29.78		
L43	26.24	17.99	23.98	17.35	0.95	13.49		
L44	42.04	44.28		13.68				
L45	18.73	73.35		7.69		0.23		
L46	83.83							16.17
L47	75.21	0.54	2.86	12.26		6.80		2.33
L48	2.35	53.33		29.25		15.06		
L49	29.16		26.06	35.64	0.38	8.19		0.57
L50	77.35			5.93	0.44	1.96		14.31
L51	87.22	2.01		4.98		1.74		4.06
L52	11.48		7.10	78.11	0.41	2.32		0.58
L53				61.96	5.38	32.67		
L54	3.98			75.10		20.83	0.09	

APPENDIX L
LDI SCORES FOR THE ISOLATED FORESTED WETLANDS

Table L-1. LDI scores calculated for eight different grain sizes (units: meters on a side) and based on the area occupied by each land use type in the landscape unit.

Site Code	5-m	10-m	20-m	30-m	40-m	50-m	60-m	70-m	Mean	SD
SA1	8.67	8.69	8.69	8.72	8.73	8.73	8.73	8.73	8.71	0.02
SA2	6.00	6.04	6.03	6.06	5.99	5.96	6.12	6.03	6.03	0.05
SA3	5.88	5.95	5.89	5.91	5.88	5.94	5.59	6.05	5.89	0.13
SA4	8.08	8.11	8.07	8.06	8.10	8.06	7.92	8.03	8.05	0.06
SA5	5.08	5.13	5.12	5.06	4.99	5.13	5.02	5.04	5.07	0.05
SA6	5.68	5.69	5.65	5.67	5.67	5.66	5.67	5.61	5.66	0.02
SA7	0.81	0.86	0.87	0.89	0.81	0.70	0.71	0.71	0.80	0.08
SA8	8.99	10.37	9.38	5.50	8.72	8.44	8.06	9.56	8.63	1.45
SA9	5.27	5.28	5.26	5.26	5.31	5.28	5.29	5.29	5.28	0.02
SR1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SR2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SR3	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
SR4	0.20	0.33	0.14	0.08	0.00	0.43	0.00	0.00	0.15	0.16
SR5	7.90	9.36	9.72	9.66	7.68	7.93	6.72	7.76	8.34	1.10
SR6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SR7	0.26	0.25	0.08	0.09	0.32	0.49	0.68	0.49	0.33	0.21
SR8	5.47	6.19	6.74	4.84	6.40	1.39	6.79	2.27	5.01	2.08
SR9	9.93	10.23	10.76	10.84	11.72	11.94	12.11	12.94	11.31	1.03
SU1	18.58	18.69	18.69	18.53	18.44	18.73	18.13	18.72	18.56	0.20
SU10	14.16	15.10	14.10	12.72	8.39	9.98	8.58	9.09	11.52	2.79
SU2	22.63	22.82	22.85	22.47	22.34	22.25	22.97	22.83	22.65	0.27
SU3	15.88	16.55	16.61	15.37	15.56	15.60	15.63	14.99	15.77	0.56
SU4	12.29	12.74	12.66	12.71	12.77	12.53	11.57	12.74	12.50	0.41
SU5	21.98	22.16	22.01	22.06	22.07	22.23	21.95	22.55	22.13	0.19
SU6	19.74	19.87	19.77	19.73	19.65	19.51	19.20	19.97	19.68	0.24
SU7	24.81	24.95	25.03	25.31	24.89	24.95	24.97	25.04	24.99	0.15
SU8	22.12	22.18	22.17	22.08	21.90	22.25	22.03	21.77	22.06	0.16
SU9	19.89	20.01	20.02	19.65	19.74	19.99	19.70	19.55	19.82	0.18
CA1	8.57	8.60	8.59	8.56	8.60	8.65	8.67	8.57	8.60	0.04
CA2	5.49	5.52	5.50	5.50	5.50	5.49	5.58	5.50	5.51	0.03
CA3	6.76	6.88	6.85	6.86	6.79	6.69	7.06	6.74	6.83	0.11
CA4	4.40	4.40	4.38	4.35	4.39	4.38	4.37	4.50	4.40	0.04
CA5	5.86	5.86	5.85	5.85	5.85	5.85	5.85	5.85	5.85	0.00
CA6	6.52	6.53	6.52	6.52	6.52	6.52	6.55	6.53	6.53	0.01

Table L-1. Continued.

Site Code	5-m	10-m	20-m	30-m	40-m	50-m	60-m	70-m	Mean	SD
CA7	4.77	4.87	4.86	4.88	4.75	5.11	5.04	5.50	4.97	0.25
CA8	11.33	12.26	11.36	9.62	8.84	7.48	9.39	10.72	10.12	1.57
CA9	6.42	6.43	6.41	6.37	6.39	6.38	6.42	6.39	6.40	0.02
CR1	0.00	0.48	0.46	0.47	0.48	0.47	0.48	0.48	0.42	0.17
CR10	8.34	9.04	8.82	7.97	6.13	8.93	8.85	7.40	8.18	1.00
CR11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CR2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CR3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CR4	0.44	0.51	0.47	0.33	0.43	0.46	0.63	0.86	0.52	0.16
CR5	0.62	0.78	0.72	0.63	0.70	0.22	0.33	0.45	0.56	0.20
CR6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CR7	0.49	0.61	0.59	0.48	0.51	0.39	0.80	0.74	0.58	0.14
CR8	0.02	0.03	0.01	0.00	0.01	0.02	0.03	0.04	0.02	0.01
CR9	1.39	1.51	1.59	1.89	1.81	2.22	2.38	2.18	1.87	0.36
CU1	17.00	17.35	17.31	16.33	16.39	16.15	16.26	15.62	16.55	0.61
CU10	19.74	19.90	19.81	19.64	19.89	19.83	19.78	20.08	19.83	0.13
CU11	19.39	19.56	19.54	19.52	19.56	19.41	19.16	19.41	19.44	0.14
CU2	20.24	20.31	20.33	20.49	20.36	20.47	20.39	20.24	20.35	0.09
CU3	22.33	22.38	22.20	22.22	22.09	22.18	22.22	22.00	22.20	0.12
CU4	22.21	22.35	22.38	22.48	22.26	22.53	22.24	22.81	22.41	0.20
CU5	24.71	24.78	24.73	24.70	24.84	24.62	24.61	24.57	24.70	0.09
CU6	23.98	24.03	24.00	23.90	23.94	23.59	23.78	24.34	23.95	0.21
CU7	18.90	19.00	18.71	18.67	18.42	18.33	18.26	18.76	18.63	0.27
CU8	19.56	19.74	19.56	19.64	19.48	19.13	19.02	19.69	19.48	0.26
CU9	26.55	26.63	26.58	26.63	26.46	26.55	26.46	26.71	26.57	0.09
NA1	8.73	9.32	8.52	6.14	6.07	6.12	6.08	6.11	7.14	1.44
NA10	1.45	1.48	1.49	0.32	1.06	1.06	1.08	1.07	1.13	0.38
NA11	0.90	1.01	0.76	0.62	0.62	0.62	0.62	0.62	0.72	0.15
NA12	10.10	10.75	10.91	9.73	10.17	9.29	6.40	6.78	9.27	1.73
NA2	5.96	5.97	5.93	5.91	5.87	5.91	5.94	5.89	5.92	0.03
NA3	0.95	0.96	0.96	0.96	0.97	0.97	0.97	0.96	0.96	0.01
NA4	11.88	12.00	11.67	12.13	10.86	11.69	7.83	7.80	10.73	1.84
NA5	5.61	4.76	4.72	4.66	4.68	4.62	4.64	4.70	4.80	0.33
NA6	6.32	6.34	6.28	6.20	6.22	6.15	6.29	6.13	6.24	0.08
NA7	5.09	5.12	5.10	4.99	4.91	4.91	5.02	4.79	4.99	0.12
NA8	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	0.00
NA9	1.54	1.75	1.29	1.06	1.01	1.02	1.24	1.04	1.24	0.27
NR1	0.21	0.26	0.00	0.00	0.15	0.25	0.34	0.00	0.15	0.14
NR2	0.21	0.35	0.12	0.16	0.34	0.30	0.38	1.59	0.43	0.48
NR3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NR4	0.10	0.15	0.06	0.01	0.14	0.02	0.00	0.04	0.07	0.06
NR5	0.59	0.67	0.61	0.54	0.29	0.00	0.33	0.43	0.43	0.22

Table L-1. Continued.

Site Code	5-m	10-m	20-m	30-m	40-m	50-m	60-m	70-m	Mean	SD
NR6	0.10	0.15	0.06	0.01	0.14	0.02	0.04	0.04	0.07	0.05
NR7	0.72	0.70	0.67	0.68	0.70	0.68	0.65	0.73	0.69	0.03
NR8	0.01	0.01	0.00	0.01	0.02	0.04	0.05	0.05	0.02	0.02
NR9	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01
NU1	16.26	16.63	16.55	16.29	16.33	15.54	15.26	16.05	16.11	0.48
NU10	23.25	23.24	23.16	23.09	22.91	23.42	23.14	23.00	23.15	0.16
NU2	20.99	21.08	20.96	20.86	20.68	20.60	21.05	21.03	20.91	0.18
NU3	19.44	19.47	19.56	19.36	19.30	18.79	19.51	18.75	19.27	0.32
NU4	15.68	15.79	16.15	15.54	15.89	15.90	15.32	14.97	15.65	0.37
NU5	20.56	20.72	20.71	20.81	20.65	20.46	20.51	20.72	20.64	0.12
NU6	19.43	19.51	19.62	19.46	18.95	19.12	19.11	19.29	19.31	0.23
NU7	21.12	21.27	21.35	21.27	21.08	21.35	21.34	21.38	21.27	0.11
NU8	18.00	18.15	18.13	17.99	18.15	17.88	18.23	18.42	18.12	0.17
NU9	22.96	23.04	23.02	23.04	22.86	23.12	22.93	22.68	22.96	0.14
PA1	3.88	4.58	5.42	5.55	5.90	2.07	2.31	2.30	4.17	1.87
PA10	1.07	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	0.00
PA2	6.48	6.52	6.52	6.56	6.45	6.57	6.44	6.68	6.53	0.08
PA3	8.91	8.96	8.96	8.93	8.96	8.85	8.85	8.80	8.90	0.06
PA4	11.24	11.84	11.78	10.86	9.84	9.02	9.11	9.27	10.37	1.20
PA5	4.82	4.88	4.87	4.88	4.90	4.87	4.70	4.87	4.85	0.06
PA6	8.20	8.47	8.55	8.71	7.80	7.83	6.92	3.92	7.55	1.57
PA7	5.30	5.33	5.30	5.26	5.40	5.29	5.32	5.15	5.29	0.07
PA8	1.24	1.33	1.18	1.03	1.01	1.03	1.02	1.02	1.11	0.12
PA9	5.93	6.00	5.78	5.83	5.75	5.46	5.45	5.66	5.73	0.20
PR1	0.02	0.02	0.01	0.00	0.02	0.02	0.04	0.05	0.02	0.02
PR2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PR3	0.50	0.63	0.58	0.31	0.14	0.22	0.59	0.46	0.43	0.18
PR4	9.12	9.37	9.09	9.44	9.40	9.73	9.65	8.24	9.25	0.47
PR5	0.03	0.04	0.01	0.01	0.02	0.03	0.05	0.07	0.03	0.02
PR6	1.10	1.21	1.19	1.21	1.50	1.04	0.82	1.56	1.20	0.24
PR7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PR8	0.01	0.02	0.00	0.00	0.01	0.02	0.01	0.04	0.01	0.01
PU1	21.33	21.61	21.56	21.61	21.44	21.34	21.56	20.83	21.41	0.26
PU10	21.33	21.46	21.30	21.18	21.12	21.15	20.94	21.15	21.20	0.16
PU2	19.54	19.67	19.67	19.58	19.47	19.25	19.47	19.29	19.49	0.16
PU3	21.90	21.96	22.01	21.87	21.74	22.08	21.79	21.91	21.91	0.11
PU4	16.53	16.88	16.71	16.40	15.94	15.65	15.34	15.86	16.16	0.55
PU5	19.59	19.73	19.62	19.72	19.70	19.16	19.48	18.70	19.46	0.36
PU6	19.55	19.79	19.49	19.64	19.98	19.24	19.22	19.72	19.58	0.26
PU7	17.64	17.75	17.79	17.70	17.80	17.87	17.57	17.97	17.76	0.13
PU8	22.61	22.77	22.74	22.71	23.14	22.81	23.66	23.80	23.03	0.46
PU9	16.15	16.45	16.06	16.26	16.08	16.20	16.74	16.49	16.30	0.24

Table L-2. LDI scores calculated for eight different spatial resolutions (units in meters) and assuming that the effect of development intensity on the landscape decreases linearly with distance.

Site code	5-m	10-m	20-m	30-m	40-m	50-m	60-m	70-m	Mean	SD
SA1	5.63	5.65	5.78	5.98	6.17	6.02	5.19	4.99	5.68	0.41
SA2	3.31	3.36	3.31	3.30	3.46	3.63	2.73	3.14	3.28	0.26
SA3	3.23	3.14	3.29	3.48	3.61	3.32	2.57	2.64	3.16	0.37
SA4	5.47	5.51	5.49	5.49	5.10	5.29	4.70	4.83	5.24	0.32
SA5	2.54	2.69	2.69	2.56	2.98	2.44	1.88	1.74	2.44	0.42
SA6	3.37	3.42	3.40	3.42	3.62	2.95	2.84	3.65	3.33	0.29
SA7	0.31	0.30	0.34	0.30	0.35	0.27	0.24	0.30	0.30	0.03
SA8	6.36	7.68	6.99	1.77	5.87	6.72	0.15	6.72	5.28	2.75
SA9	2.97	3.01	3.02	3.09	3.24	5.28	2.46	2.42	3.19	0.90
SR1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SR2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SR3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SR4	0.02	0.05	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.02
SR5	4.60	5.64	6.24	6.70	3.19	2.37	0.00	4.24	4.12	2.22
SR6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SR7	0.11	0.09	0.02	0.01	0.03	0.06	0.12	0.17	0.08	0.05
SR8	0.96	1.09	1.87	0.67	2.67	0.34	0.10	0.66	1.04	0.85
SR9	4.66	4.76	5.51	5.93	7.07	6.29	5.48	6.43	5.76	0.83
SU1	14.92	15.09	15.21	14.99	14.72	14.98	13.10	15.77	14.85	0.77
SU10	10.78	11.75	10.75	8.64	3.36	5.24	5.31	3.29	7.39	3.49
SU2	18.35	18.48	18.85	18.54	19.18	18.48	17.39	17.32	18.32	0.65
SU3	10.10	11.00	10.73	8.95	10.06	9.21	8.05	7.09	9.40	1.35
SU4	7.29	7.97	7.84	8.01	8.54	7.22	4.98	8.71	7.57	1.17
SU5	18.32	18.45	18.27	18.52	18.68	18.49	18.89	17.45	18.38	0.42
SU6	15.60	15.48	15.51	15.88	15.51	15.17	13.42	16.62	15.40	0.91
SU7	20.40	20.65	20.75	20.77	20.85	22.03	18.76	19.50	20.46	0.97
SU8	18.49	18.57	18.51	18.99	18.63	18.57	19.01	18.10	18.61	0.29
SU9	16.40	16.46	16.77	16.39	17.14	16.34	16.81	16.87	16.65	0.29
CA1	5.58	5.61	5.64	5.38	5.43	6.02	5.99	4.67	5.54	0.42
CA2	3.08	3.11	3.08	3.38	3.25	2.78	3.35	2.44	3.06	0.31
CA3	3.62	3.67	3.81	3.88	4.25	3.22	3.21	3.97	3.70	0.36
CA4	2.43	2.49	2.52	2.32	2.41	2.43	2.65	2.84	2.51	0.16
CA5	3.49	3.51	3.48	3.80	3.79	3.69	2.96	3.76	3.56	0.28
CA6	4.02	4.00	4.17	4.10	4.39	4.09	3.66	4.53	4.12	0.26
CA7	2.97	3.02	2.97	3.16	2.92	2.83	2.76	3.35	3.00	0.18
CA8	8.58	9.47	8.56	6.47	6.75	0.00	3.31	4.16	5.91	3.22
CA9	4.06	4.11	4.14	4.08	4.44	4.40	3.79	4.11	4.14	0.21
CR1	0.00	0.20	0.19	0.20	0.20	0.22	0.15	0.22	0.17	0.07
CR10	5.92	6.52	5.93	5.89	1.18	1.96	0.01	3.98	3.92	2.54
CR11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table L-2. Continued.

Site Code	5-m	10-m	20-m	30-m	40-m	50-m	60-m	70-m	Mean	SD
CR2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CR3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CR4	0.19	0.22	0.19	0.05	0.03	0.06	0.00	0.31	0.13	0.11
CR5	0.20	0.25	0.25	0.19	0.15	0.00	0.00	0.16	0.15	0.10
CR6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CR7	0.18	0.22	0.22	0.19	0.00	0.00	0.00	0.26	0.14	0.11
CR8	0.01	0.14	0.05	0.00	0.00	0.01	0.01	0.02	0.03	0.05
CR9	0.37	0.41	0.40	0.54	0.21	0.30	0.37	0.00	0.33	0.16
CU1	12.46	13.09	12.82	11.28	11.69	9.01	10.88	10.65	11.48	1.34
CU10	14.99	15.28	14.88	14.91	15.59	15.78	13.13	15.54	15.01	0.83
CU11	14.47	14.75	14.91	14.27	15.49	15.30	12.61	13.65	14.43	0.94
CU2	15.61	15.51	15.72	16.52	16.08	16.55	14.51	15.88	15.80	0.65
CU3	19.04	19.21	19.05	19.15	19.20	18.71	18.21	19.60	19.02	0.41
CU4	18.07	18.41	18.46	19.27	18.68	17.68	17.14	18.83	18.32	0.68
CU5	20.83	20.97	20.99	20.69	20.59	20.65	19.77	21.22	20.71	0.44
CU6	20.60	20.67	20.95	20.78	20.67	19.84	20.10	21.62	20.65	0.54
CU7	15.69	15.63	15.59	15.52	15.48	15.34	14.20	16.28	15.47	0.58
CU8	16.51	16.85	16.83	16.48	16.17	16.55	15.53	15.42	16.29	0.55
CU9	22.86	23.02	22.93	23.61	23.15	23.66	21.52	23.75	23.06	0.71
NA1	4.97	5.43	5.00	3.54	3.36	3.96	2.81	3.70	4.10	0.93
NA10	0.70	0.74	0.75	0.53	0.49	0.45	0.40	0.56	0.58	0.14
NA11	0.42	0.49	0.33	0.29	0.26	0.24	0.23	0.28	0.32	0.09
NA12	7.32	7.86	8.37	6.56	7.58	6.27	3.19	3.54	6.34	1.96
NA2	3.51	3.61	3.57	3.50	3.84	3.51	3.89	2.99	3.55	0.27
NA3	0.43	0.44	0.45	0.43	0.48	0.41	0.34	0.41	0.42	0.04
NA4	8.87	8.95	8.48	9.14	7.83	8.64	3.97	4.81	7.59	2.02
NA5	3.27	2.68	2.64	2.68	2.74	2.34	2.05	2.31	2.59	0.37
NA6	3.97	3.97	3.93	4.13	4.17	4.28	3.60	4.09	4.02	0.21
NA7	3.19	3.29	3.32	3.34	3.31	3.07	2.83	3.05	3.18	0.18
NA8	0.48	0.48	0.48	0.48	0.53	0.47	0.37	0.45	0.47	0.05
NA9	0.77	0.88	0.59	0.46	0.52	0.46	0.36	0.51	0.57	0.17
NR1	0.11	0.14	0.00	0.00	0.00	0.25	0.34	0.00	0.11	0.13
NR2	0.05	0.09	0.03	0.03	0.06	0.11	0.01	0.49	0.11	0.16
NR3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NR4	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NR5	0.22	0.24	0.27	0.22	0.09	0.00	0.00	0.15	0.15	0.11
NR6	0.04	0.05	0.02	0.00	0.00	0.00	0.01	0.02	0.02	0.02
NR7	0.37	0.35	0.33	0.33	0.32	0.29	0.24	0.42	0.33	0.05
NR8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NR9	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NU1	12.47	12.91	12.61	13.02	12.61	11.55	11.40	10.94	12.19	0.78
NU10	20.40	20.51	20.65	20.64	20.30	21.56	21.22	20.70	20.75	0.43

Table L-2. Continued.

Site Code	5-m	10-m	20-m	30-m	40-m	50-m	60-m	70-m	Mean	SD
NU2	17.08	17.22	17.06	17.06	16.46	15.90	15.82	17.00	16.70	0.56
NU3	16.60	16.70	16.80	16.83	16.56	16.42	16.59	16.18	16.59	0.21
NU4	11.54	11.65	11.94	11.90	10.99	11.71	10.58	10.24	11.32	0.64
NU5	16.68	16.75	16.79	16.98	17.29	17.12	15.72	17.61	16.87	0.56
NU6	15.85	15.86	16.29	16.00	14.41	14.62	14.36	15.42	15.35	0.77
NU7	16.59	16.82	16.89	16.87	15.86	15.62	14.95	17.76	16.42	0.89
NU8	13.67	13.83	13.90	13.92	13.83	13.05	12.63	15.26	13.76	0.77
NU9	19.30	19.48	19.61	19.27	19.91	19.96	18.39	19.40	19.41	0.49
PA1	1.24	1.44	1.87	1.57	0.90	0.76	0.78	0.74	1.16	0.43
PA10	0.45	0.48	0.47	0.47	0.50	0.41	0.52	0.52	0.48	0.04
PA2	3.71	3.90	3.90	3.95	3.64	3.44	4.08	3.29	3.74	0.27
PA3	6.10	6.13	6.32	6.40	5.82	6.50	5.56	6.50	6.17	0.34
PA4	8.61	9.31	9.39	8.89	7.55	6.68	5.99	6.95	7.92	1.30
PA5	2.71	2.82	2.88	2.65	2.97	2.72	2.28	2.45	2.69	0.23
PA6	4.21	4.46	4.23	4.78	4.05	3.24	2.13	2.56	3.71	0.95
PA7	3.21	3.24	3.24	3.21	3.06	2.85	2.82	3.34	3.12	0.19
PA8	0.57	0.63	0.53	0.47	0.47	0.52	0.36	0.46	0.50	0.08
PA9	4.34	4.41	4.24	4.43	4.38	4.37	3.68	4.39	4.28	0.25
PR1	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.03	0.01	0.01
PR2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PR3	0.22	0.27	0.29	0.11	0.00	0.00	0.00	0.00	0.11	0.13
PR4	4.46	4.53	4.29	5.32	2.60	3.85	0.19	0.40	3.21	1.95
PR5	0.01	0.02	0.00	0.00	0.00	0.01	0.02	0.04	0.01	0.01
PR6	0.57	0.64	0.66	0.64	0.86	0.39	0.16	0.79	0.59	0.22
PR7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PR8	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
PU1	17.49	17.84	17.75	18.52	17.77	17.75	18.42	17.38	17.86	0.41
PU10	17.83	18.01	17.77	17.93	17.77	16.58	16.05	17.76	17.46	0.73
PU2	16.14	16.34	16.53	16.21	16.16	15.98	15.25	14.84	15.93	0.58
PU3	17.99	18.12	18.43	18.04	18.16	18.33	18.56	18.81	18.31	0.28
PU4	13.35	13.70	13.79	13.38	12.78	11.62	10.54	13.17	12.79	1.14
PU5	15.66	15.89	15.79	16.14	15.86	16.11	16.19	14.36	15.75	0.59
PU6	16.14	16.35	16.46	15.93	16.81	16.26	15.53	16.35	16.23	0.38
PU7	13.00	13.19	13.24	13.27	13.98	13.78	10.72	14.24	13.18	1.08
PU8	17.41	17.90	17.55	18.18	18.77	19.53	17.43	17.61	18.05	0.75
PU9	11.58	11.96	11.67	11.52	10.77	10.99	10.08	11.75	11.29	0.63

Table L-3. LDI scores calculated for eight different spatial resolutions (units in meters) and assuming that the effect of development intensity on the landscape decreases in inverse-square with distance.

Site code	5-m	10-m	20-m	30-m	40-m	50-m	60-m	70-m	Mean	SD
SA1	4.05	4.13	4.28	4.55	4.71	4.69	3.99	4.18	4.32	0.29
SA2	2.06	2.11	2.06	2.19	2.21	2.39	1.79	2.09	2.11	0.17
SA3	1.99	1.94	2.11	2.34	2.44	2.07	1.70	1.97	2.07	0.23
SA4	4.03	4.10	4.12	4.23	3.88	4.09	3.62	4.07	4.02	0.19
SA5	1.49	1.61	1.61	1.55	1.90	1.53	1.12	1.19	1.50	0.25
SA6	2.26	2.33	2.36	2.44	2.58	2.04	2.03	2.65	2.34	0.23
SA7	0.17	0.16	0.19	0.18	0.19	0.16	0.15	0.18	0.17	0.01
SA8	4.87	6.08	5.93	0.68	4.93	6.05	0.05	6.72	4.41	2.58
SA9	1.92	1.98	2.02	2.13	2.21	1.81	1.67	1.88	1.95	0.17
SR1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SR2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SR3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SR4	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SR5	2.59	3.29	3.96	4.54	1.62	0.82	0.00	1.91	2.34	1.55
SR6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SR7	0.05	0.04	0.00	0.00	0.01	0.02	0.04	0.06	0.03	0.02
SR8	0.13	0.15	0.36	0.12	0.93	0.12	0.04	0.23	0.26	0.29
SR9	1.91	1.98	2.50	2.94	3.95	3.65	2.66	3.29	2.86	0.74
SU1	12.44	12.64	12.93	12.83	12.48	12.78	11.04	13.58	12.59	0.72
SU10	8.61	9.56	8.66	6.64	2.64	3.24	3.44	2.57	5.67	3.01
SU2	15.65	15.85	16.26	16.25	16.82	15.77	15.04	15.84	15.93	0.52
SU3	6.14	7.15	6.87	5.30	6.09	6.05	4.48	3.78	5.73	1.15
SU4	4.26	4.89	4.81	5.12	5.69	4.61	2.93	5.81	4.76	0.91
SU5	15.66	16.04	15.96	16.29	16.46	16.11	16.61	16.06	16.15	0.30
SU6	12.64	12.59	12.62	13.39	12.56	12.06	10.39	14.08	12.54	1.07
SU7	17.37	17.71	17.87	18.18	17.93	19.76	15.87	16.79	17.69	1.13
SU8	16.15	16.28	16.24	16.91	16.46	16.48	16.97	16.17	16.46	0.32
SU9	14.22	14.35	14.75	14.56	15.40	14.35	14.93	15.01	14.70	0.40
CA1	3.94	4.00	4.08	3.90	4.02	4.46	4.43	3.77	4.08	0.25
CA2	1.97	2.01	2.01	2.28	2.14	1.80	2.15	1.86	2.03	0.16
CA3	2.24	2.30	2.41	2.54	2.85	2.03	2.03	2.58	2.37	0.28
CA4	1.55	1.62	1.67	1.53	1.81	1.66	1.78	2.08	1.71	0.18
CA5	2.35	2.39	2.39	2.71	2.71	2.58	2.13	2.79	2.51	0.23
CA6	2.80	2.82	3.01	3.03	3.25	3.06	2.75	3.56	3.03	0.27
CA7	2.14	2.18	2.17	2.40	2.11	2.13	2.15	2.47	2.22	0.14
CA8	7.15	8.06	7.39	5.23	6.67	0.00	3.31	4.16	5.25	2.69
CA9	2.87	2.93	3.03	3.03	3.37	3.32	2.92	3.14	3.08	0.19
CR1	0.00	0.11	0.10	0.12	0.11	0.13	0.09	0.14	0.10	0.04
CR10	4.48	5.06	4.61	4.54	0.27	0.59	0.01	1.77	2.66	2.21
CR11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table L-3. Continued.

Site Code	5-m	10-m	20-m	30-m	40-m	50-m	60-m	70-m	Mean	SD
CR2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CR3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CR4	0.10	0.12	0.11	0.01	0.01	0.01	0.00	0.10	0.06	0.05
CR5	0.07	0.09	0.09	0.06	0.05	0.00	0.00	0.05	0.05	0.04
CR6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CR7	0.08	0.10	0.10	0.11	0.00	0.00	0.00	0.09	0.06	0.05
CR8	0.09	0.01	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.03
CR9	0.11	0.12	0.12	0.18	0.04	0.08	0.13	0.00	0.10	0.05
CU1	9.66	10.34	9.95	8.01	8.17	5.64	9.01	7.41	8.53	1.55
CU10	11.71	12.08	11.50	11.85	12.50	12.74	9.96	12.98	11.92	0.94
CU11	10.83	11.19	11.53	10.67	12.30	12.12	9.09	9.74	10.93	1.11
CU2	12.56	12.51	12.82	14.00	13.24	13.76	12.03	12.98	12.99	0.66
CU3	16.86	17.09	16.97	17.22	17.21	16.79	16.38	18.07	17.07	0.49
CU4	15.63	16.01	16.16	17.10	16.53	15.65	15.37	16.84	16.16	0.62
CU5	18.18	18.40	18.54	18.24	18.15	18.29	17.64	19.07	18.31	0.40
CU6	18.45	18.62	19.04	18.93	18.91	17.88	18.35	20.11	18.79	0.66
CU7	13.48	13.45	13.50	13.55	13.32	13.25	12.28	14.70	13.44	0.66
CU8	14.68	15.09	15.24	14.86	14.66	14.98	14.53	13.46	14.69	0.55
CU9	20.36	20.61	20.57	21.47	20.88	21.56	19.27	21.90	20.83	0.83
NA1	2.92	3.20	3.06	2.37	2.27	2.74	1.92	2.59	2.63	0.43
NA10	0.43	0.47	0.48	0.32	0.32	0.28	0.26	0.37	0.37	0.08
NA11	0.24	0.29	0.20	0.19	0.17	0.15	0.15	0.18	0.20	0.05
NA12	5.78	6.30	6.86	4.91	6.10	4.47	2.24	2.94	4.95	1.65
NA2	2.36	2.46	2.46	2.46	2.78	2.54	2.77	2.40	2.53	0.16
NA3	0.25	0.27	0.27	0.27	0.30	0.26	0.22	0.25	0.26	0.02
NA4	6.95	7.00	6.48	7.38	5.77	6.67	2.71	3.38	5.79	1.77
NA5	2.18	1.76	1.76	1.84	1.83	1.59	1.41	1.53	1.74	0.24
NA6	2.75	2.77	2.78	2.97	3.00	3.20	2.66	3.12	2.91	0.19
NA7	2.25	2.37	2.42	2.51	2.46	2.26	2.07	2.31	2.33	0.14
NA8	0.27	0.28	0.29	0.29	0.32	0.29	0.23	0.27	0.28	0.03
NA9	0.48	0.55	0.35	0.29	0.33	0.27	0.23	0.33	0.35	0.11
NR1	0.07	0.09	0.00	0.00	0.00	0.25	0.34	0.00	0.09	0.13
NR2	0.02	0.03	0.01	0.01	0.01	0.05	0.00	0.17	0.04	0.06
NR3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NR4	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NR5	0.09	0.10	0.13	0.09	0.03	0.00	0.00	0.05	0.06	0.05
NR6	0.02	0.02	0.01	0.00	0.00	0.00	0.01	0.02	0.01	0.01
NR7	0.24	0.22	0.22	0.22	0.21	0.19	0.16	0.29	0.22	0.04
NR8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NR9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NU1	10.00	10.48	10.23	10.71	10.10	8.98	8.69	9.21	9.80	0.74
NU10	18.43	18.65	18.98	19.06	18.70	20.21	19.93	19.09	19.13	0.63

Table L-3. Continued.

Site Code	5-m	10-m	20-m	30-m	40-m	50-m	60-m	70-m	Mean	SD
NU2	14.24	14.44	14.30	14.49	13.88	13.12	13.01	14.47	13.99	0.60
NU3	14.65	14.85	14.96	15.20	14.55	14.82	15.06	14.32	14.80	0.28
NU4	8.92	9.03	9.33	9.49	8.67	9.67	8.67	7.99	8.97	0.54
NU5	14.45	14.58	14.59	14.96	15.22	15.05	14.07	15.81	14.84	0.54
NU6	13.58	13.64	14.14	13.98	11.98	12.26	12.17	14.29	13.25	0.96
NU7	13.59	13.90	14.00	14.28	13.12	12.76	12.34	15.49	13.68	0.98
NU8	10.58	10.77	10.97	11.21	11.04	10.19	9.69	13.06	10.94	0.99
NU9	16.87	17.12	17.39	17.07	17.83	18.03	16.38	17.23	17.24	0.52
PA1	0.60	0.66	0.77	0.68	0.55	0.44	0.52	0.54	0.59	0.10
PA10	0.26	0.28	0.27	0.28	0.29	0.24	0.30	0.33	0.28	0.03
PA2	2.44	2.63	2.67	2.75	2.56	2.34	2.76	2.59	2.59	0.15
PA3	4.64	4.73	4.96	5.12	4.62	5.13	4.51	5.38	4.89	0.31
PA4	7.12	7.84	7.96	7.85	6.29	5.22	4.74	5.55	6.57	1.29
PA5	1.81	1.90	2.01	1.84	2.05	1.91	1.65	1.71	1.86	0.14
PA6	2.26	2.42	2.27	2.72	2.23	1.89	1.53	1.90	2.15	0.37
PA7	2.18	2.23	2.27	2.29	2.19	2.03	2.08	2.47	2.22	0.14
PA8	0.34	0.39	0.32	0.29	0.28	0.32	0.23	0.29	0.31	0.05
PA9	3.35	3.43	3.31	3.60	3.52	3.61	2.87	3.59	3.41	0.25
PR1	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.02	0.01	0.01
PR2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PR3	0.11	0.14	0.16	0.05	0.00	0.00	0.00	0.00	0.06	0.07
PR4	1.92	2.00	1.75	2.72	0.74	1.38	0.09	0.23	1.35	0.92
PR5	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.02	0.01	0.01
PR6	0.37	0.42	0.46	0.43	0.65	0.22	0.10	0.56	0.40	0.18
PR7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PR8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PU1	15.18	15.63	15.63	16.46	15.50	15.48	16.29	15.45	15.70	0.44
PU10	15.56	15.79	15.58	15.97	15.51	14.18	14.04	15.92	15.32	0.77
PU2	14.00	14.26	14.61	14.37	14.34	14.26	13.56	13.67	14.13	0.36
PU3	15.34	15.55	16.04	15.64	15.93	16.10	16.31	16.80	15.96	0.46
PU4	11.30	11.68	11.93	11.59	10.78	9.57	8.36	11.29	10.81	1.23
PU5	13.08	13.39	13.43	13.78	13.43	13.95	13.88	11.63	13.32	0.74
PU6	13.99	14.20	14.46	14.02	14.84	14.64	14.20	14.84	14.40	0.35
PU7	9.93	10.21	10.34	10.50	11.30	10.89	7.99	11.66	10.35	1.11
PU8	14.00	14.60	14.19	14.95	15.59	16.97	14.64	14.44	14.92	0.96
PU9	8.46	8.86	8.78	8.66	7.92	8.28	7.21	9.13	8.41	0.61

APPENDIX M
LDI SCORES FOR STREAMS

Table M-1. LDI scores calculated for six different grain sizes (units: meters on a side) and based on the area occupied by each land use type in the drainage basin unit.

Site code	20-m	50-m	80-m	110-m	140-m	170-m	Mean	SD
S1	0.76	0.79	0.92	0.93	0.80	0.99	0.86	0.09
S2	11.52	12.09	12.19	12.09	11.88	11.70	11.91	0.26
S3	9.80	10.23	10.31	10.49	10.48	10.02	10.22	0.27
S4	2.01	2.14	1.93	1.67	1.62	1.50	1.81	0.25
S5	8.79	9.00	9.09	8.80	8.71	8.67	8.84	0.17
S6	10.13	10.42	10.27	10.40	10.11	10.92	10.37	0.30
S7	9.91	10.20	10.26	10.20	10.19	10.40	10.19	0.16
S8	12.90	13.10	13.30	13.07	12.92	13.16	13.07	0.15
S9	7.14	7.43	7.44	7.27	7.04	7.00	7.22	0.19
S10	12.21	12.35	12.40	12.28	12.31	12.23	12.30	0.07
S11	14.34	14.67	14.77	14.46	14.44	14.33	14.50	0.18
S12	16.74	16.83	16.92	16.94	16.85	16.86	16.85	0.07
S13	16.07	16.26	16.30	16.22	16.05	16.38	16.21	0.13
S14	10.93	11.41	11.50	11.21	11.09	11.27	11.24	0.21
S15	11.50	11.90	11.94	12.02	11.86	12.03	11.87	0.20
S16	14.13	14.33	14.33	14.17	14.08	14.05	14.18	0.12
S17	13.38	13.53	13.53	13.44	13.45	13.56	13.48	0.07
S18	12.59	12.83	12.81	12.61	12.46	12.37	12.61	0.18
S19	11.92	12.35	12.37	12.48	12.35	12.46	12.32	0.21
S20	14.30	14.67	14.77	14.53	14.53	14.41	14.53	0.17
S21	6.77	7.17	7.01	6.53	6.02	5.83	6.55	0.54
S22	1.08	1.15	1.12	1.15	1.10	1.09	1.12	0.03
S23	14.29	14.59	14.56	14.25	14.12	14.35	14.36	0.18
S24	2.13	2.46	3.20	1.53	1.19	0.96	1.91	0.85
S25	3.77	3.88	3.86	3.85	4.03	4.07	3.91	0.12
S26	19.00	19.47	19.78	19.78	19.54	19.75	19.55	0.30
S27	13.93	14.26	14.30	14.05	13.89	14.18	14.10	0.17
S28	15.54	15.71	15.72	15.46	15.34	15.27	15.51	0.19
S29	25.03	25.06	24.99	25.08	25.09	25.14	25.06	0.05
S30	11.00	11.26	11.31	11.18	11.05	11.25	11.17	0.12
S31	8.40	8.75	9.12	8.36	8.16	8.33	8.52	0.35

Table M-1. Continued.

Site code	20-m	50-m	80-m	110-m	140-m	170-m	Mean	SD
S32	16.69	16.93	17.03	17.06	17.08	17.15	16.99	0.16
S33	16.64	16.80	16.85	16.74	16.71	16.71	16.74	0.07
S34	15.97	16.18	16.23	16.13	16.13	16.18	16.14	0.09
S35	14.70	14.94	14.91	14.89	14.87	14.94	14.87	0.09
S36	4.24	4.35	4.37	4.40	4.39	4.42	4.36	0.06
S37	4.92	5.28	5.35	5.36	5.38	5.50	5.30	0.20
S38	20.01	20.03	20.02	20.01	20.00	19.98	20.01	0.02
S39	6.68	6.84	6.80	6.61	6.64	6.66	6.70	0.09
S40	4.66	4.87	4.88	4.68	4.56	4.45	4.68	0.17
S41	12.48	12.83	12.96	12.87	12.86	12.89	12.82	0.17
S42	10.17	10.38	10.47	10.32	10.30	10.30	10.32	0.10
S43	12.05	12.19	12.19	12.17	11.74	12.08	12.07	0.17
S44	9.56	9.86	10.06	10.13	10.21	9.98	9.96	0.23
S45	16.76	16.87	16.95	16.94	16.91	16.97	16.90	0.08
S46	14.31	14.52	14.58	14.47	14.20	14.17	14.37	0.17
S47	10.44	10.72	10.80	10.71	10.68	10.64	10.66	0.12
S48	10.53	10.84	10.94	10.87	10.85	10.86	10.81	0.14
S48	8.24	8.44	8.22	8.95	7.84	8.46	8.36	0.37
S50	16.33	16.44	16.47	16.46	16.35	16.33	16.40	0.07
S51	3.06	3.19	3.18	3.17	2.99	2.94	3.09	0.11
S52	12.90	13.07	13.08	13.01	12.87	12.83	12.96	0.11
S53	18.09	18.35	18.32	18.34	18.30	18.24	18.27	0.10
S54	12.88	13.13	13.16	13.28	13.44	13.37	13.21	0.20
S55	4.57	4.73	4.78	4.40	4.71	4.47	4.61	0.15
S56	5.41	5.85	5.70	3.32	2.28	2.10	4.11	1.75
S57	6.55	7.01	7.06	7.08	6.04	5.33	6.51	0.71
S58	9.43	9.67	9.63	9.37	9.17	8.77	9.34	0.33
S59	6.56	6.92	6.26	5.52	5.34	5.06	5.94	0.74
S60	11.30	11.66	11.69	11.27	11.07	10.28	11.21	0.51
S61	20.28	20.43	20.60	20.40	20.22	20.14	20.35	0.16
S62	0.90	1.12	1.35	0.78	0.78	0.80	0.95	0.23
S63	8.89	9.22	9.01	8.27	7.91	7.30	8.43	0.74
S64	6.93	7.16	7.09	6.81	5.82	2.95	6.12	1.63
S65	6.98	7.29	7.53	6.97	6.59	6.29	6.94	0.45
S66	16.68	17.04	17.10	17.22	17.27	17.05	17.06	0.21
S67	17.83	18.15	18.15	18.13	18.08	17.85	18.03	0.15
S68	6.58	7.03	7.22	6.05	5.31	5.30	6.25	0.83
S69	5.59	6.05	6.26	5.90	5.83	5.86	5.91	0.22

Table M-2. LDI scores calculated for six different grain sizes (units: meters on a side) and assuming that the effect of development intensity on the landscape decreases linearly with distance.

Site code	20-m	50-m	80-m	110-m	140-m	170-m	Mean	SD
S1	0.41	0.43	0.54	0.53	0.43	0.62	0.49	0.08
S2	9.61	10.11	10.17	10.00	9.73	9.39	9.84	0.31
S3	8.84	9.30	9.36	9.53	9.56	9.02	9.27	0.28
S4	0.71	0.74	0.69	0.62	0.57	0.54	0.65	0.08
S5	6.54	6.69	6.78	6.68	6.56	6.58	6.64	0.09
S6	6.31	6.56	6.49	6.49	6.22	6.33	6.40	0.13
S7	6.98	7.22	7.24	7.07	6.64	7.12	7.05	0.22
S8	9.52	9.66	9.87	9.68	9.59	9.73	9.67	0.12
S9	4.10	4.30	4.28	4.13	3.96	3.90	4.11	0.16
S10	10.46	10.58	10.63	10.51	10.55	10.48	10.54	0.06
S11	12.40	12.66	12.84	12.49	12.72	12.44	12.59	0.18
S12	14.87	14.94	14.98	15.02	14.97	15.00	14.96	0.05
S13	13.16	13.28	13.27	13.26	13.05	13.42	13.24	0.12
S14	7.99	8.53	8.47	8.45	8.22	8.82	8.41	0.28
S15	8.43	8.73	8.81	8.90	8.79	8.89	8.76	0.17
S16	11.43	11.58	11.59	11.44	11.39	11.36	11.46	0.10
S17	9.87	10.01	9.97	9.88	9.89	9.96	9.93	0.06
S18	9.45	9.68	9.63	9.46	9.29	9.24	9.46	0.18
S19	9.59	9.99	10.03	10.12	10.02	10.25	10.00	0.22
S20	12.67	12.99	13.16	12.93	13.14	12.92	12.97	0.18
S21	5.43	5.77	5.58	5.30	4.91	4.69	5.28	0.41
S22	0.49	0.52	0.51	0.51	0.50	0.50	0.50	0.01
S23	12.43	12.69	12.65	12.43	12.34	12.52	12.51	0.14
S24	1.06	1.19	1.55	0.82	0.67	0.54	0.97	0.37
S25	3.33	3.43	3.42	3.40	3.61	3.67	3.48	0.13
S26	14.03	14.45	14.64	15.26	15.55	15.28	14.87	0.58
S27	12.15	12.45	12.54	12.32	12.16	12.51	12.36	0.17
S28	10.83	11.00	11.04	10.68	10.69	10.47	10.79	0.22
S29	21.24	21.20	21.28	20.97	21.27	21.31	21.21	0.12
S30	6.37	6.65	6.63	6.62	6.58	6.73	6.60	0.12
S31	6.43	6.68	7.01	6.32	6.15	6.31	6.48	0.31
S32	13.69	13.94	14.02	14.02	14.08	14.08	13.97	0.15
S33	14.97	15.11	15.16	15.01	15.00	15.00	15.04	0.08
S34	12.68	12.86	12.91	12.81	12.79	12.85	12.82	0.08
S35	12.15	12.36	12.30	12.31	12.24	12.30	12.28	0.07
S36	2.43	2.47	2.50	2.50	2.50	2.53	2.49	0.04
S37	2.97	3.13	3.09	3.05	3.02	3.06	3.05	0.06

Table M-2. Continued.

Site code	20-m	50-m	80-m	110-m	140-m	170-m	Mean	SD
S38	17.99	18.01	18.00	17.99	17.98	17.96	17.99	0.02
S39	4.80	4.97	4.93	4.69	4.67	4.69	4.79	0.13
S40	2.93	3.04	3.04	2.88	2.81	2.76	2.91	0.12
S41	10.36	10.73	10.83	10.72	10.71	10.59	10.66	0.16
S42	7.14	7.31	7.40	7.25	7.21	7.22	7.25	0.09
S43	7.77	7.86	7.85	7.90	7.56	7.83	7.79	0.12
S44	6.54	6.80	7.00	7.10	7.04	6.88	6.89	0.20
S45	13.45	13.58	13.68	13.63	13.61	13.58	13.59	0.08
S46	12.57	12.78	12.87	12.80	12.53	12.53	12.68	0.16
S47	8.60	8.87	8.98	8.89	8.88	8.84	8.84	0.13
S48	8.86	9.15	9.28	9.19	9.19	9.23	9.15	0.15
S48	5.87	5.97	5.85	6.32	6.08	6.83	6.15	0.37
S50	13.96	14.08	14.09	14.07	13.96	13.92	14.01	0.07
S51	1.29	1.37	1.31	1.28	1.21	1.21	1.28	0.06
S52	10.82	11.02	11.04	10.94	10.79	10.74	10.89	0.13
S53	16.53	16.81	16.79	16.77	16.80	16.75	16.74	0.10
S54	11.75	12.00	12.03	12.17	12.29	12.25	12.08	0.20
S55	2.36	2.47	2.49	2.27	2.43	2.31	2.39	0.09
S56	3.37	3.71	3.21	1.96	1.64	1.46	2.56	0.98
S57	3.58	3.96	3.92	3.94	3.22	3.02	3.61	0.40
S58	5.18	5.37	5.27	5.06	4.81	4.30	5.00	0.39
S59	4.56	4.85	4.37	3.90	3.75	3.65	4.18	0.48
S60	8.24	8.49	8.51	8.06	7.96	7.87	8.19	0.27
S61	17.53	17.66	17.85	17.70	17.57	17.32	17.61	0.18
S62	0.52	0.73	0.95	0.39	0.38	0.40	0.56	0.23
S63	6.53	6.82	6.63	5.87	5.44	4.88	6.03	0.76
S64	4.24	4.43	4.42	4.03	3.31	1.45	3.65	1.15
S65	5.55	5.84	6.10	5.41	5.08	4.80	5.46	0.48
S66	13.42	13.82	13.81	13.84	13.98	13.67	13.76	0.19
S67	14.06	14.43	14.38	14.46	14.28	14.27	14.31	0.15
S68	4.10	4.44	4.63	3.09	2.57	2.41	3.54	0.97
S69	2.65	2.90	2.99	2.88	2.85	2.62	2.82	0.15

Table M-3. LDI scores calculated for six different grain sizes (units: meters on a side) and assuming that the effect of development intensity on the landscape decreases in inverse square with distance.

Site code	20-m	50-m	80-m	110-m	140-m	170-m	Mean	SD
S1	0.28	0.29	0.39	0.36	0.29	0.47	0.35	0.07
S2	8.36	8.83	8.88	8.68	8.44	8.01	8.53	0.33
S3	8.09	8.57	8.61	8.76	8.83	8.23	8.52	0.29
S4	0.28	0.29	0.28	0.26	0.24	0.24	0.26	0.02
S5	5.43	5.57	5.65	5.59	5.47	5.51	5.54	0.08
S6	3.95	4.19	4.12	4.10	3.76	3.89	4.00	0.16
S7	5.72	5.95	5.96	5.80	5.33	5.88	5.77	0.23
S8	6.67	6.78	6.96	6.83	6.79	6.84	6.81	0.10
S9	2.40	2.54	2.51	2.41	2.30	2.27	2.40	0.11
S10	9.00	9.11	9.14	9.04	9.09	9.03	9.07	0.06
S11	11.17	11.39	11.61	11.24	11.58	11.17	11.36	0.20
S12	13.35	13.42	13.45	13.52	13.49	13.50	13.46	0.06
S13	10.67	10.77	10.74	10.78	10.52	10.95	10.74	0.14
S14	6.58	7.09	7.04	7.11	6.82	7.54	7.03	0.32
S15	6.23	6.46	6.57	6.68	6.59	6.66	6.53	0.17
S16	9.17	9.30	9.31	9.18	9.18	9.14	9.21	0.07
S17	6.86	6.98	6.91	6.83	6.84	6.86	6.88	0.06
S18	7.01	7.21	7.16	7.01	6.87	6.82	7.01	0.16
S19	7.81	8.19	8.26	8.35	8.27	8.51	8.23	0.24
S20	11.74	12.03	12.22	12.01	12.29	12.00	12.05	0.19
S21	4.46	4.76	4.55	4.43	4.12	3.90	4.37	0.31
S22	0.25	0.26	0.26	0.26	0.26	0.26	0.26	0.00
S23	11.14	11.38	11.32	11.20	11.14	11.26	11.24	0.10
S24	0.55	0.61	0.75	0.48	0.42	0.36	0.53	0.14
S25	3.01	3.11	3.12	3.08	3.32	3.40	3.17	0.15
S26	10.20	10.67	10.91	12.27	12.45	12.17	11.45	0.96
S27	11.06	11.36	11.46	11.31	11.16	11.50	11.31	0.17
S28	7.76	7.93	7.98	7.59	7.71	7.41	7.73	0.21
S29	18.70	18.75	18.89	18.58	19.07	19.28	18.88	0.26
S30	3.94	4.22	4.08	4.22	4.19	4.28	4.16	0.12
S31	4.73	4.94	5.22	4.62	4.49	4.63	4.77	0.26
S32	10.99	11.24	11.31	11.28	11.38	11.32	11.25	0.14
S33	13.77	13.90	13.96	13.78	13.77	13.77	13.83	0.08
S34	10.45	10.63	10.67	10.58	10.55	10.61	10.58	0.08
S35	10.68	10.88	10.83	10.83	10.75	10.82	10.80	0.07
S36	1.52	1.55	1.57	1.58	1.58	1.60	1.57	0.03
S37	2.21	2.34	2.30	2.28	2.27	2.29	2.28	0.04

Table M-3. Continued.

Site code	20-m	50-m	80-m	110-m	140-m	170-m	Mean	SD
S38	16.28	16.28	16.27	16.26	16.26	16.23	16.26	0.02
S39	3.57	3.73	3.69	3.45	3.40	3.42	3.54	0.14
S40	1.92	2.00	2.00	1.88	1.84	1.80	1.91	0.08
S41	8.76	9.13	9.21	9.10	9.07	8.88	9.03	0.17
S42	4.86	5.00	5.08	4.95	4.89	4.91	4.95	0.08
S43	4.87	4.94	4.94	5.01	4.81	4.98	4.93	0.07
S44	4.08	4.27	4.46	4.57	4.41	4.31	4.35	0.17
S45	11.08	11.24	11.35	11.28	11.31	11.25	11.25	0.09
S46	11.18	11.40	11.52	11.47	11.22	11.26	11.34	0.14
S47	7.53	7.79	7.94	7.85	7.86	7.82	7.80	0.14
S48	7.86	8.15	8.30	8.20	8.21	8.25	8.16	0.15
S48	4.44	4.53	4.48	4.76	5.18	6.00	4.90	0.61
S50	11.93	12.06	12.06	12.03	11.91	11.89	11.98	0.08
S51	0.63	0.69	0.63	0.60	0.58	0.59	0.62	0.04
S52	9.08	9.29	9.33	9.20	9.04	8.99	9.15	0.14
S53	15.33	15.63	15.62	15.59	15.66	15.63	15.58	0.12
S54	10.82	11.08	11.10	11.27	11.36	11.34	11.16	0.20
S55	1.26	1.34	1.37	1.24	1.31	1.28	1.30	0.05
S56	2.37	2.67	2.22	1.31	1.30	1.11	1.83	0.67
S57	1.94	2.22	2.14	2.20	1.75	1.75	2.00	0.22
S58	2.75	2.88	2.79	2.65	2.45	2.05	2.60	0.30
S59	3.58	3.83	3.45	3.07	2.98	2.88	3.30	0.38
S60	6.05	6.26	6.27	5.83	5.77	5.72	5.98	0.24
S61	15.16	15.30	15.49	15.41	15.33	14.98	15.28	0.18
S62	0.35	0.54	0.75	0.22	0.22	0.23	0.39	0.22
S63	4.76	5.01	4.85	4.11	3.65	3.22	4.27	0.73
S64	2.56	2.72	2.74	2.42	2.01	0.88	2.22	0.71
S65	4.62	4.89	5.13	4.36	4.03	3.78	4.47	0.51
S66	10.86	11.27	11.22	11.22	11.37	11.06	11.17	0.18
S67	11.98	12.43	12.34	12.49	12.25	12.41	12.32	0.18
S68	2.88	3.18	3.35	1.90	1.55	1.28	2.36	0.89
S69	1.55	1.68	1.73	1.72	1.78	1.37	1.64	0.15

APPENDIX N
DESCRIPTIVE STATISTICS FOR LANDSCAPE PATTERN METRICS

Table N-1. Isolated forested wetlands (n = 51): summary statistics and transformation information for landscape pattern metrics calculated at different grain sizes (meters on a side). Summary statistics expressed in untransformed values (refer to Table 2-7 for units and metrics names).

Grain size	Metric (acronym)	Mean	SD	Min	Max	Transformation	AD[a] statistics	p
5-m	PLAND_Urb	47.03	34.30	0.00	96.38	arcsine sqrt	2.83	<0.005
	PLAND_Ag	13.71	27.59	0.00	87.93	arcsine sqrt	10.17	<0.005
	PLAND_For	18.22	20.34	0.00	85.08	arcsine sqrt	0.85	0.027
	PLAND_Wet	10.15	17.14	0.00	85.17	arcsine sqrt	3.41	<0.005
	PD	70.29	28.70	22.42	151.71	log10	0.30	0.575
	ED	313.94	64.49	207.40	468.66	sqrt	0.54	0.155
	AREA_MN	1.69	0.79	0.66	4.46	log10	0.30	0.575
	AREA_CV	119.44	35.57	35.73	207.92		0.71	0.062
	SHAPE_MN	1.77	0.24	1.37	2.28	sqrt	0.61	0.109
	FRAC_MN	1.12	0.03	1.07	1.19		0.49	0.218
	ENN_MN	47.70	34.79	0.00	145.10	sqrt	0.32	0.517
	CONTAG	56.42	6.60	42.17	71.99		0.21	0.842
	IJI[a]	67.88	10.81	31.00	95.56	arcsine sqrt	4.27	<0.005
	PR	6.51	2.11	2.00	12.00	sqrt	1.06	0.008
	PRD	35.59	11.26	11.45	62.79		0.15	0.956
	SHDI	1.36	0.37	0.55	2.26		0.32	0.528
	SHEI	0.75	0.12	0.40	0.98		0.48	0.222
10-m	PLAND_Urb	47.04	34.33	0.00	96.67	arcsine sqrt	2.80	<0.005
	PLAND_Ag	13.69	27.55	0.00	87.68	arcsine sqrt	10.18	<0.005
	PLAND_For	18.21	20.32	0.00	85.18	arcsine sqrt	0.84	0.028
	PLAND_Wet	10.11	17.13	0.00	85.20	arcsine sqrt	3.41	<0.005
	PD	73.35	31.21	22.88	146.08	log10	0.17	0.927
	ED	303.98	59.58	203.03	446.28	sqrt	0.54	0.156
	AREA_MN	1.64	0.77	0.68	4.37	log10	0.17	0.927
	AREA_CV	137.06	62.71	67.25	333.68	log10	0.90	0.020
	SHAPE_MN	1.63	0.21	1.22	2.24		0.52	0.184
	FRAC_MN	1.10	0.02	1.04	1.16		0.38	0.384
	ENN_MN	56.38	31.37	0.00	133.31	sqrt	0.60	0.116
	CONTAG	52.39	7.15	34.68	68.67		0.28	0.618
	IJI[a]	68.00	10.83	29.59	95.23	arcsin sqrt	4.01	<0.005
	PR	6.51	2.11	2.00	12.00	sqrt	1.06	0.008
	PRD	35.59	11.29	11.44	62.73		0.14	0.971
	SHDI	1.36	0.37	0.55	2.25		0.33	0.506

Table N-1. Continued.

Grain size	Metric (acronym)	Mean	SD	Min	Max	Transformation	AD[a] statistics	p
	SHEI	0.75	0.12	0.40	0.98		0.39	0.363
20-m	PLAND_Urb	47.02	34.28	0.00	96.85	arcsine sqrt	2.85	<0.005
	PLAND_Ag	13.72	27.60	0.00	87.38	arcsine sqrt	10.13	<0.005
	PLAND_For	18.26	20.41	0.00	86.18	arcsine sqrt	0.85	0.027
	PLAND_Wet	10.18	17.16	0.00	85.50	arcsine sqrt	3.44	<0.005
	PD	72.30	30.17	23.04	151.84		0.73	0.055
	ED	276.65	47.28	205.62	395.02		0.71	0.061
	AREA_MN	1.67	0.80	0.66	4.34	log10	0.41	0.339
	AREA_CV	146.88	65.92	48.30	390.72	log10	0.18	0.912
	SHAPE_MN	1.38	0.12	1.13	1.70		0.43	0.295
	FRAC_MN	1.07	0.02	1.03	1.11		0.38	0.384
	ENN_MN	74.31	37.89	0.00	221.02	sqrt	3.16	<0.005
	CONTAG	46.76	7.94	25.19	62.64		0.36	0.446
	IJI[b]	69.41	11.63	30.39	95.64	arcsine sqrt	3.76	<0.005
	PR	6.35	2.11	2.00	12.00	sqrt	1.01	0.010
	PRD	34.64	10.94	11.52	62.50		0.28	0.636
	SHDI	1.35	0.37	0.49	2.23		0.31	0.548
	SHEI	0.75	0.12	0.45	0.98		0.46	0.248
30-m	PLAND_Urb	46.92	34.56	0.00	95.21	arcsine sqrt	2.65	<0.005
	PLAND_Ag	13.77	27.57	0.00	85.71	arcsine sqrt	10.12	<0.005
	PLAND_For	18.27	20.37	0.00	84.02	arcsine sqrt	0.85	0.027
	PLAND_Wet	10.11	17.32	0.00	85.22	arcsine sqrt	2.54	<0.005
	PD	63.23	25.18	22.45	136.66		0.60	0.116
	ED	257.26	40.51	187.91	353.04		0.71	0.059
	AREA_MN	1.85	0.80	0.73	4.46	log10	0.21	0.865
	AREA_CV	133.38	50.62	56.30	327.78	log10	0.27	0.664
	SHAPE_MN	1.30	0.10	1.12	1.69		0.46	0.253
	FRAC_MN	1.06	0.02	1.02	1.11		0.42	0.313
	ENN_MN	101.87	57.27	0.00	369.93	sqrt	3.05	<0.005
	CONTAG	42.77	9.28	18.20	66.16		0.28	0.645
	IJI[a]	69.87	11.51	25.02	95.78	arcsine sqrt	3.76	<0.005
	PR	6.31	2.04	2.00	12.00		0.62	0.099
	PRD	34.43	10.95	11.22	63.19		0.24	0.780
	SHDI	0.66	0.13	0.28	0.87		0.33	0.504
	SHEI	0.75	0.13	0.39	0.97		0.56	0.145

[a] The Anderson-Darling test was used to determine whether the metrics' scores were normally distributed; if $p < 0.05$ the data did not follow a normal distribution.

Table N-2. Streams (n = 68): summary statistics and transformation information for landscape pattern metrics calculated at four different grain sizes (meters on a side). Summary statistics are expressed in untransformed values (refer to Table 2-7 for units and metrics' names).

Grain size	Metric (acronym)	Mean	SD	Min	Max	Transformation	AD[a] statistic	p
20-m	PLAND_Urb	12.97	18.20	0.00	99.44	arcsine sqrt	8.35	<0.005
	PLAND_Ag	18.11	20.17	0.00	75.90	arcsine sqrt	4.25	<0.005
	PLAND_For	43.44	25.59	0.00	93.39	arcsine sqrt	1.58	<0.005
	PLAND_Wet	16.87	10.34	0.00	41.88		0.48	0.222
	PD	7.75	3.46	1.92	16.85		0.47	0.235
	ED	84.30	20.08	34.18	137.14		0.20	0.868
	AREA_MN	16.58	10.05	5.93	52.21	log10	1.00	0.012
	AREA_CV	505.92	291.07	104.36	1656.25	log10	0.21	0.861
	SHAPE_MN	1.61	0.16	1.33	2.27	sqrt	1.65	<0.005
	FRAC_MN	1.08	0.01	1.05	1.11		0.69	0.067
	ENN_MN	421.99	152.70	0.00	816.68	sqrt	1.39	<0.005
	CONTAG	63.67	5.53	50.43	79.63		0.97	0.842
	IJI	59.76	8.11	32.16	71.64	arcsine sqrt	0.81	0.035
	PR	32.53	16.24	5.00	70.00	sqrt	0.41	0.340
	PRD	0.96	1.54	0.07	7.74	log10	0.56	0.141
	SHDI	2.06	0.50	0.80	3.13		0.28	0.528
	SHEI	0.61	0.10	0.35	0.83		0.63	0.222
50-m	PLAND_Urb	12.97	18.22	0.00	99.60	arcsine sqrt	8.40	<0.005
	PLAND_Ag	18.11	20.18	0.00	75.90	arcsine sqrt	4.25	<0.005
	PLAND_For	43.45	25.61	0.00	93.48	arcsine sqrt	1.58	<0.005
	PLAND_Wet	16.87	10.32	0.00	41.59		0.48	0.222
	PD	7.68	3.14	2.27	19.48		0.40	0.360
	ED	78.74	17.77	35.03	131.82		0.35	0.456
	AREA_MN	15.82	8.27	5.13	44.10	log10	0.98	0.013
	AREA_CV	566.46	321.10	104.03	1689.04	log10	0.37	0.418
	SHAPE_MN	1.44	0.12	1.27	1.85	sqrt	1.46	<0.005
	FRAC_MN	1.06	0.01	1.04	1.09		0.41	0.343
	ENN_MN	438.96	141.13	0.00	797.28	sqrt	1.93	<0.005
	CONTAG	58.06	6.10	42.19	72.30		0.23	0.802
	IJI	59.73	8.26	30.43	72.06	arcsin sqrt	0.69	0.068
	PR	32.21	16.11	5.00	70.00	sqrt	0.41	0.330
	PRD	0.93	1.47	0.07	8.03	log10	0.59	0.118
	SHDI	2.07	0.49	0.80	3.13		0.32	0.522
	SHEI	0.62	0.09	0.36	0.83		0.23	0.790

Table N-2. Continued.

Grain size	Metric (acronym)	Mean	SD	Min	Max	Transformation	AD[a] statistic	P
80-m	PLAND_Urb	12.97	18.22	0.00	99.60	arcsine sqrt	8.59	<0.005
	PLAND_Ag	18.11	20.18	0.00	75.90	arcsine sqrt	4.26	<0.005
	PLAND_For	43.45	25.61	0.00	93.48	arcsine sqrt	1.59	0.027
	PLAND_Wet	16.87	10.32	0.00	41.59		0.48	0.222
	PD	6.91	2.68	2.34	17.65		0.46	0.259
	ED	72.55	16.29	32.81	119.83		0.40	0.357
	AREA_MN	16.97	7.69	5.67	42.65	log10	0.71	0.061
	AREA_CV	559.4	313.9	81.38	1582.3	log10	0.45	0.272
	SHAPE_MN	1.34	0.09	1.20	1.67	sqrt	1.87	<0.005
	FRAC_MN	1.05	0.01	1.04	1.07		1.13	<0.005
	ENN_MN	511.9	155.0	0.00	870.48	sqrt	1.89	<0.005
	CONTAG	54.17	6.64	36.63	69.11		0.21	0.855
	IJI	60.28	8.46	30.83	83.07	arcsine sqrt	0.63	0.095
	PR	31.72	16.21	4.00	69.00	sqrt	0.44	0.276
	PRD	0.89	1.32	0.07	6.89	log10	0.68	0.075
	SHDI	2.07	0.49	0.82	2.13		0.32	0.523
	SHEI	0.62	0.09	0.37	0.85		0.20	0.875
110-m	PLAND_Urb	13.02	18.27	0.00	100.00	arcsine sqrt	8.60	<0.005
	PLAND_Ag	18.18	20.19	0.00	75.42	arcsine sqrt	4.21	<0.005
	PLAND_For	43.44	25.64	0.00	93.43	arcsine sqrt	1.64	0.027
	PLAND_Wet	16.30	10.20	0.00	41.89		0.39	0.336
	PD	5.86	2.09	1.98	14.35		0.38	0.393
	ED	65.81	14.60	30.23	108.13		0.65	0.085
	AREA_MN	19.66	8.59	6.97	50.39	log10	0.97	0.014
	AREA_CV	530.1	297.0	78.50	1796.7	log10	0.52	0.181
	SHAPE_MN	1.28	0.07	1.18	1.59	sqrt	2.21	<0.005
	FRAC_MN	1.04	0.01	1.03	1.06		1.11	<0.005
	ENN_MN	607.7	173.1	0.00	1022.3	sqrt	2.16	<0.005
	CONTAG	51.44	7.34	32.42	68.14		0.21	0.852
	IJI	60.37	8.35	29.38	74.01	arcsine sqrt	0.59	0.118
	PR	31.04	16.25	4.00	69.00	sqrt	0.46	0.256
	PRD	0.85	1.23	0.07	6.48	log10	0.67	0.075
	SHDI	2.07	0.49	0.80	3.12		0.33	0.508
	SHEI	0.63	0.10	0.37	0.86		0.26	0.716

[a]The Anderson-Darling test was used to determine whether the metrics' scores were normally distributed; if $p < 0.05$ the data did not follow a normal distribution.

Table N-3. Streams (n = 63): summary statistics and transformation information for landscape pattern metrics calculated at three different spatial extents (units in meters). Summary statistics are expressed in untransformed values (refer to Table 2-7 for units and metrics names).

Buffer size	Metric (acronym)	Mean	SD	Min	Max	Transform	AD[a] statistic	p
100-m	PLAND_Urb	8.43	13.63	0.05	59.28	arcsine sqrt	3.14	<0.005
	PLAND_Ag	13.75	18.82	0.32	76.66	arcsine sqrt	2.42	<0.005
	PLAND_For	37.44	23.80	3.84	94.81	arcsine sqrt	0.58	0.128
	PLAND_Wet	34.83	16.48	0.43	69.15		0.35	0.463
	PD	24.15	6.29	10.33	36.14		0.25	0.736
	ED	213.20	23.85	166.44	263.37		0.62	0.104
	AREA_MN	4.49	1.49	2.77	9.68	log10	0.98	0.013
	AREA_CV	322.50	150.88	95.44	729.32	log10	0.20	0.868
	SHAPE_MN	1.62	0.14	1.38	2.17		0.65	0.084
	FRAC_MN	1.09	0.01	1.07	1.12		0.48	0.231
	ENN_MN	449.96	220.82	103.08	952.56	sqrt	0.32	0.517
	CONTAG	59.91	5.70	45.09	71.98	arcsine sqrt	0.86	0.025
	IJI	56.43	8.43	21.88	74.31	arcsine sqrt	1.55	<0.005
	PR	21.10	8.49	5.00	39		0.48	0.223
	PRD	3.45	3.89	0.65	27.64	log10	0.45	0.261
	SHDI	1.89	0.42	0.80	2.87		0.20	0.881
	SHEI	0.64	0.10	0.45	0.89		0.63	0.098
400-m	PLAND_Urb	8.87	13.30	0.00	64.17	arcsine sqrt	2.03	<0.005
	PLAND_Ag	15.70	19.67	0.00	77.10	arcsine sqrt	1.67	<0.005
	PLAND_For	44.28	25.02	4.71	93.90	arcsine sqrt	1.24	<0.005
	PLAND_Wet	22.50	12.52	1.22	49.33		0.64	0.090
	PD	10.07	3.72	3.83	21.34	sqrt	0.67	0.075
	ED	106.96	16.87	64.68	142.25		0.33	0.504
	AREA_MN	11.53	5.09	4.69	26.12	log10	1.14	<0.005
	AREA_CV	345.77	142.51	116.12	720.12	log10	0.49	0.216
	SHAPE_MN	1.61	0.14	1.40	2.10		0.72	0.057
	FRAC_MN	1.08	0.01	1.06	1.11		0.20	0.876
	ENN_MN	472.16	180.22	219.39	946.48	sqrt	0.94	0.016
	CONTAG	61.83	5.18	48.71	75.03		0.35	0.466
	IJI	59.36	7.60	29.74	71.76	arcsin sqrt	0.99	0.012
	PR	26.08	10.41	8.00	50.00	sqrt	0.38	0.386
	PRD	1.27	1.48	0.25	10.08	log10	0.79	0.039
	SHDI	2.02	0.42	0.86	2.94		0.24	0.772
	SHEI	0.63	0.09	0.41	0.86		0.36	0.430

Table N-3. Continued.

Buffer size	Metric (acronym)	Mean	SD	Min	Max	Transform	AD[a] statistic	p
Wash[b]	PLAND_Urb	12.97	18.22	0.00	99.60	arcsine sqrt	5.44	<0.005
	PLAND_Ag	18.11	20.18	0.00	75.90	arcsine sqrt	4.03	<0.005
	PLAND_For	43.45	25.61	0.00	93.48	arcsine sqrt	1.53	<0.005
	PLAND_Wet	16.87	10.32	0.00	41.59		0.44	0.277
	PD	6.91	2.68	2.34	17.65		0.42	0.316
	ED	72.55	16.29	32.81	119.83		0.31	0.541
	AREA_MN	16.97	7.69	5.67	42.65	log10	1.27	<0.005
	AREA_CV	559.4	313.9	81.38	1582.3	log10	0.16	0.943
	SHAPE_MN	1.34	0.09	1.20	1.67	sqrt	1.75	<0.005
	FRAC_MN	1.05	0.01	1.04	1.07		0.78	0.040
	ENN_MN	511.9	155.0	0.00	870.48	sqrt	1.10	<0.005
	CONTAG	54.17	6.64	36.63	69.11		0.15	0.963
	IJI	60.28	8.46	30.83	83.07	arcsine sqrt	0.70	0.039
	PR	31.72	16.21	4.00	69.00	sqrt	0.46	0.254
	PRD	0.89	1.32	0.07	6.89	log10	0.39	0.378
	SHDI	2.07	0.49	0.82	2.13		0.59	0.122
	SHEI	0.62	0.09	0.37	0.85		0.29	0.614

[a] The Anderson-Darling test was used to determine whether the metrics' scores were normally distributed; if $p < 0.05$ the data did not follow a normal distribution.

[b]Wash = watershed.

Table N-4. Lakes (n = 48): summary statistics and transformation information for landscape pattern metrics calculated at four different grain sizes (meters on as side). Summary statistics expressed in untransformed values (refer to Table 2-7 for units and metrics names).

Grain size	Metric (acronym)	Mean	SD	Min	Max	Transformation	AD[a] statistic	p
20-m	PLAND_Urb	45.60	30.23	0.40	99.83	arcsine sqrt	0.23	0.801
	PLAND_Ag	26.40	19.29	0.10	73.35	arcsine sqrt	1.82	<0.005
	PLAND_For	17.92	18.61	0.12	78.11	arcsine sqrt	0.88	0.022
	PLAND_Wet	13.85	14.51	0.23	53.53	arcsine sqrt	0.96	0.014
	PD	20.05	9.05	5.87	39.40	log10	0.32	0.520
	ED	74.90	20.41	29.31	127.08		0.26	0.697
	AREA_MN	6.24	3.26	2.54	17.03	log10	0.32	0.520
	AREA_CV	225.76	76.04	91.54	413.90		0.55	0.153
	SHAPE_MN	1.54	0.13	1.26	1.81		0.52	0.182
	FRAC_MN	1.08	0.01	1.04	1.12		0.28	0.619
	ENN_MN	299.29	167.33	85.32	852.98	sqrt	0.37	0.422
	CONTAG	58.19	6.88	45.74	74.39		0.35	0.458
	IJI	65.38	7.14	43.16	75.22	arcsine sqrt	1.59	<0.005
	PR	12.10	4.82	5.00	24.00	sqrt	0.99	0.012
	PRD	6.11	4.37	0.90	21.77	log10	0.69	0.067
	SHDI	1.67	0.42	0.88	2.33	sqrt	1.33	0.002
	SHEI	0.69	0.11	0.41	0.88		0.56	0.139
40-m	PLAND_Urb	46.13	30.35	0.39	99.89	arcsine sqrt	0.24	0.756
	PLAND_Ag	25.88	19.76	0.18	73.21	arcsine sqrt	1.80	<0.005
	PLAND_For	17.85	18.59	0.15	77.75	arcsine sqrt	0.90	0.020
	PLAND_Wet	13.74	14.47	0.21	53.45	arcsine sqrt	1.02	0.010
	PD	18.44	8.48	4.47	43.60		0.54	0.157
	ED	68.03	18.63	28.42	110.47		0.19	0.890
	AREA_MN	6.85	3.81	2.29	22.36	log10	0.33	0.506
	AREA_CV	214.37	68.61	104.07	378.14		0.56	0.139
	SHAPE_MN	1.43	0.11	1.27	1.70		0.54	0.161
	FRAC_MN	1.06	0.01	1.04	1.09		0.38	0.399
	ENN_MN	335.29	162.12	108.08	924.10	sqrt	0.86	0.026
	CONTAG	53.29	7.79	37.60	71.56		0.26	0.715
	IJI	65.87	7.09	45.87	82.17	arcsine sqrt	1.15	0.005
	PR	11.94	4.81	5.00	24.00	sqrt	0.84	0.028
	PRD	5.99	4.17	0.89	18.94	log10	0.68	0.071
	SHDI	1.67	0.42	0.88	2.33	sqrt	1.35	0.001
	SHEI	0.69	0.11	0.41	0.89		0.48	0.228
60-m	PLAND_Urb	45.52	30.02	0.43	100.00	arcsine sqrt	0.22	0.833
	PLAND_Ag	26.46	19.26	0.10	73.78	arcsine sqrt	1.84	<0.005
	PLAND_For	18.42	18.64	0.90	78.40	arcsine sqrt	0.93	0.017
	PLAND_Wet	13.88	14.40	0.35	53.59	arcsine sqrt	0.87	0.024

Table N-4. Continued.

Grain size	Metric (acronym)	Mean	SD	Min	Max	Transformation	AD[a] statistic	p
	PD	17.21	7.93	4.46	41.40		0.65	0.086
	ED	61.01	16.05	27.50	95.91		0.32	0.533
	AREA_MN	7.28	3.95	2.42	22.42	log10	0.29	0.591
	AREA_CV	205.93	65.69	110.05	346.18	log10	0.43	0.303
	SHAPE_MN	1.34	0.10	1.12	1.61		0.26	0.708
	FRAC_MN	1.05	0.01	1.03	1.08		0.26	0.682
	ENN_MN	369.24	152.63	153.45	977.69	sqrt	0.41	0.338
	CONTAG	49.15	8.04	33.16	69.63		0.25	0.722
	IJI	67.35	6.20	48.97	81.31	arcsine sqrt	1.21	0.003
	PR	11.58	4.88	4.00	24.00	sqrt	0.71	0.060
	PRD	5.75	3.99	0.89	18.73	log10	0.67	0.074
	SHDI	1.67	0.42	0.88	2.33	sqrt	1.32	0.002
	SHEI	0.70	0.11	0.41	0.93		0.39	0.380
80-m	PLAND_Urb	45.59	30.32	0.38	100.00	arcsine sqrt	0.21	0.860
	PLAND_Ag	27.17	18.95	0.72	72.05	arcsine sqrt	1.81	<0.005
	PLAND_For	18.59	18.71	0.69	78.65	arcsine sqrt	0.90	0.020
	PLAND_Wet	14.78	14.42	1.02	53.05	arcsine sqrt	0.93	0.017
	PD	15.98	7.23	4.57	37.01	log10	0.37	0.420
	ED	54.64	16.10	24.55	107.92		0.36	0.427
	AREA_MN	7.71	3.95	2.70	21.90	log10	0.37	0.420
	AREA_CV	195.12	64.58	67.00	357.05		0.59	0.119
	SHAPE_MN	1.27	0.09	1.06	1.54	sqrt	0.87	0.023
	FRAC_MN	1.04	0.01	1.01	1.07		0.59	0.118
	ENN_MN	413.09	161.34	178.48	949.38		0.68	0.072
	CONTAG	46.83	8.59	29.60	68.85		0.23	0.784
	IJI	67.42	6.18	51.58	79.14		0.59	0.118
	PR	11.42	4.81	4.00	24.00	sqrt	0.79	0.038
	PRD	5.71	3.97	0.79	17.69	log10	0.58	0.123
	SHDI	1.67	0.42	0.86	2.33	sqrt	1.26	0.002
	SHEI	0.70	0.11	0.41	0.95		0.23	0.790

[a] The Anderson-Darling test was used to determine whether the metrics' scores were normally distributed; if $p < 0.05$ the data did not follow a normal distribution.

Table N-5. Lakes (n =44): summary statistics and transformation information for landscape pattern metrics calculated at different spatial extents (units in meters). Summary statistics expressed in untransformed values (refer to Table 2-7 for units and metrics' names).

Buffer size	Metric (acronym)	Mean	SD	Min	Max	Transformation	AD[a] statistic	p
100-m	PLAND_Urb	45.62	28.89	0.66	99.78	arcsine sqrt	0.393	0.363
	PLAND_Ag	22.53	17.41	0.41	55.12	arcsine sqrt	3.320	<0.001
	PLAND_For	16.69	18.48	0.14	80.98	arcsine sqrt	1.868	<0.001
	PLAND_Wet	17.41	16.47	0.13	64.83	arcsine sqrt	0.619	0.100
	PD	51.00	23.05	15.82	122.03	sqrt	0.616	0.102
	ED	85.10	40.54	15.58	205.18		0.592	0.118
	AREA_MN	2.37	1.07	0.82	6.32		0.717	0.057
	AREA_CV	168.37	63.23	72.00	383.34	log10	0.308	0.547
	SHAPE_MN	1.61	0.21	1.36	2.21	sqrt	1.382	0.001
	FRAC_MN	1.09	0.02	1.05	1.15		0.543	0.154
	ENN_MN	232.14	132.89	0.00	597.82	sqrt	0.287	0.607
	CONTAG	55.35	11.01	30.09	83.00		0.228	0.800
	IJI	59.50	10.36	17.62	76.86		0.709	0.060
	PR	8.27	3.69	3.00	19.00	sqrt	0.472	0.233
	PRD	16.91	9.16	2.85	35.55		0.375	0.399
	SHDI	1.40	0.41	0.40	2.08		0.498	0.200
	SHEI	0.70	0.16	0.25	0.93		0.637	0.091
400-m	PLAND_Urb	45.62	28.89	0.66	99.78		0.574	0.128
	PLAND_Ag	22.53	17.41	0.41	55.12	arcsine sqrt	1.831	<0.001
	PLAND_For	16.69	18.48	0.14	80.98	arcsine sqrt	0.931	0.017
	PLAND_Wet	17.41	16.47	0.13	64.83	arcsine sqrt	0.611	0.105
	PD	24.19	9.99	8.41	47.28	sqrt	0.413	0.325
	ED	78.26	21.96	24.12	126.64		0.163	0.940
	AREA_MN	4.92	2.19	2.12	11.88	log10	0.306	0.553
	AREA_CV	201.05	62.06	98.00	419.74		0.584	0.121
	SHAPE_MN	1.54	0.14	1.34	1.91		0.617	0.102
	FRAC_MN	1.08	0.02	1.05	1.13		0.675	0.073
	ENN_MN	297.03	167.28	91.24	769.25	sqrt	0.477	0.226
	CONTAG	57.50	7.23	44.52	74.44		0.333	0.502
	IJI	63.13	8.43	32.17	73.59	arcsine sqrt	1.410	0.001
	PR	11.11	3.87	5.00	20.00	sqrt	0.643	0.088
	PRD	7.90	4.82	1.59	26.01	log10	0.514	0.183
	SHDI	1.63	0.39	0.74	2.27		0.521	0.176
	SHEI	0.69	0.12	0.42	0.89		0.339	0.486
Wash[b]	PLAND_Urb	45.00	30.01	0.40	99.83		0.728	0.053
	PLAND_Ag	23.85	17.68	0.10	67.51	arcsine sqrt	1.786	<0.001
	PLAND_For	18.90	19.06	0.12	78.11	arcsine sqrt	0.693	0.066
	PLAND_Wet	13.43	13.35	0.48	50.83	arcsine sqrt	0.780	0.039

Table N-5. Continued.

Buffer size	Metric (acronym)	Mean	SD	Min	Max	Transformation	AD[a] statistic	p
	PD	20.34	9.27	5.87	39.40		0.693	0.065
	ED	75.18	20.91	29.31	127.08		0.249	0.732
	AREA_MN	6.20	3.33	2.54	17.03	log10	0.326	0.511
	AREA_CV	225.83	76.05	91.54	413.90		0.675	0.073
	SHAPE_MN	1.54	0.13	1.26	1.81		0.654	0.082
	FRAC_MN	1.08	0.01	1.04	1.12		0.361	0.431
	ENN_MN	292.07	164.71	85.32	852.98	sqrt	0.354	0.449
	CONTAG	57.98	7.11	45.74	74.39		0.428	0.299
	IJI	65.17	7.27	43.16	75.22	arcsine sqrt	1.622	<0.001
	PR	12.05	4.88	5.00	24.00	sqrt	0.927	0.017
	PRD	6.11	4.55	0.90	21.77	log10	0.574	0.128
	SHDI	1.67	0.43	0.88	2.33	sqrt	1.346	0.002
	SHEI	0.69	0.12	0.41	0.88		0.723	0.055

[a] The Anderson-Darling test was used to determine whether the metrics' scores were normally distributed; if $p < 0.05$ the data did not follow a normal distribution.
[b]Wash = Watershed.

APPENDIX O
LANDSCAPE INDICES AND INDICATORS OF ECOSYSTEM CONDITION

Table O-1. Multiple regression models at four grain sizes for the sample isolated forested wetlands: coefficients of determination, probabilities, and change in the amount of variability (ΔR^2) in indicators of ecosystems condition (α – level of 0.05).

Dependent Variable	Independent Variables	R^2 (adj)	p	ΔR^2
5 x 5-meters				
Water chemistry				
Log_{10}(DO)	LDI-PLU; URB; HETER; SHAPE; AG; FOR	0.00	0.539	-0.07
	LDI-ILD; URB; HETER; SHAPE; AG; FOR	0.00	0.534	-0.06
	LDI-ISD; URB; HETER; SHAPE; AG; FOR	0.00	0.526	-0.05
Log_{10}(SC)	LDI-PLU; URB; HETER; SHAPE; AG; FOR	0.09	0.355	-0.12
	LDI-ILD; URB; HETER; SHAPE; AG; FOR	0.08	0.364	-0.10
	LDI-ISD; URB; HETER; SHAPE; AG; FOR	0.08	0.368	-0.08
Log_{10}(TN)	LDI-PLU; URB; HETER; SHAPE; AG; FOR	0.00	0.521	-0.02
	LDI-ILD; URB; HETER; SHAPE; AG; FOR	0.00	0.523	-0.03
	LDI-ISD; URB; HETER; SHAPE; AG; FOR	0.00	0.519	-0.03
Log_{10}(TP)	LDI-PLU; URB; HETER; SHAPE; AG; FOR	0.16	0.104	0.12
	LDI-ILD; URB; HETER; SHAPE; AG; FOR	0.16	0.111	0.12
	LDI-ISD; URB; HETER; SHAPE; AG; FOR	0.15	0.124	0.11
Log_{10}(Turbidity)	LDI-PLU; URB; HETER; SHAPE; AG; FOR	0.00	0.640	-0.03
	LDI-ILD; URB; HETER; SHAPE; AG; FOR	0.00	0.683	-0.03
	LDI-ISD; URB; HETER; SHAPE; AG; FOR	0.00	0.717	-0.03
WCI				
Macroinvertebrates	LDI-PLU; URB; HETER; SHAPE; AG; FOR	0.23	0.050	0.05
Diatoms	LDI-PLU; URB; HETER; SHAPE; AG; FOR	0.07	0.332	-0.15
	LDI-ILD; URB; HETER; SHAPE; AG; FOR	0.08	0.321	-0.12
	LDI-ISD; URB; HETER; SHAPE; AG; FOR	0.08	0.318	-1.78
10 x 10-meters				
Water chemistry				
Log_{10}(DO)	LDI-PLU; URB; HETER; CONTAG; AG; FOR; ENN	0.00	0.704	-0.07
	LDI-ILD; URB; HETER; CONTAG; AG; FOR; ENN	0.00	0.712	-0.06
	LDI-ISD; URB; HETER; CONTAG; AG; FOR; ENN	0.00	0.716	-0.05
Log_{10}(SC)	LDI-PLU; URB; HETER; CONTAG; AG; FOR; ENN	0.03	0.447	-0.17
	LDI-ILD; URB; HETER; CONTAG; AG; FOR; ENN	0.01	0.477	-0.17
	LDI-ISD; URB; HETER; CONTAG; AG; FOR; ENN	0.00	0.488	-0.16
Log_{10}(TN)	LDI-PLU; URB; HETER; CONTAG; AG; FOR; ENN	0.03	0.369	0.01
	LDI-ILD; URB; HETER; CONTAG; AG; FOR; ENN	0.03	0.371	0.00
	LDI-ISD; URB; HETER; CONTAG; AG; FOR; ENN	0.03	0.373	0.00
Log_{10}(Turbidity)	LDI-PLU; URB; HETER; CONTAG; AG; FOR; ENN	0.00	0.782	-0.03
	LDI-ILD; URB; HETER; CONTAG; AG; FOR; ENN	0.00	0.807	-0.03
	LDI-ISD; URB; HETER; CONTAG; AG; FOR; ENN	0.00	0.830	-0.03
WCI				
Macroinvertebrates	LDI-PLU; URB; HETER; CONTAG; AG; FOR; ENN	0.21	0.077	0.03
	LDI-ILD; URB; HETER; CONTAG; AG; FOR; ENN	0.24	0.060	0.06
Diatoms	LDI-PLU; URB; HETER; CONTAG; AG; FOR; ENN	0.01	0.448	-0.22
	LDI-ILD; URB; HETER; CONTAG; AG; FOR; ENN	0.03	0.429	-0.18

Table O-1. Continued.

Dependent Variable	Independent Variables	R^2 (adj)	p	ΔR^2
	LDI-ISD; URB; HETER; CONTAG; AG; FOR; ENN	0.03	0.431	-0.16
20 x 20-meters				
Water chemistry				
Log_{10}(DO)	LDI-PLU; DIVERS; HETER; CONTAG; AG; SHAPE; FOR	0.00	0.643	-0.07
	LDI-ILD; DIVERS; HETER; CONTAG; AG; SHAPE; FOR	0.00	0.624	-0.06
	LDI-ISD; DIVERS; HETER; CONTAG; AG; SHAPE; FOR	0.00	0.604	-0.05
Log_{10}(SC)	LDI-PLU; DIVERS; HETER; CONTAG; AG; SHAPE; FOR	0.01	0.473	-0.15
	LDI-ILD; DIVERS; HETER; CONTAG; AG; SHAPE; FOR	0.01	0.481	-0.17
	LDI-ISD; DIVERS; HETER; CONTAG; AG; SHAPE; FOR	0.00	0.485	-0.16
Log_{10}(TN)	LDI-PLU; DIVERS; HETER; CONTAG; AG; SHAPE; FOR	0.00	0.491	-0.02
	LDI-PLU; DIVERS; HETER; CONTAG; AG; SHAPE; FOR	0.00	0.502	-0.03
	LDI-ILD; DIVERS; HETER; CONTAG; AG; SHAPE; FOR	0.00	0.507	-0.03
Log_{10}(Turbidity)	LDI-PLU; DIVERS; HETER; CONTAG; AG; SHAPE; FOR	0.00	0.826	-0.04
	LDI-ILD; DIVERS; HETER; CONTAG; AG; SHAPE; FOR	0.00	0.840	-0.03
	LDI-ISD; DIVERS; HETER; CONTAG; AG; SHAPE; FOR	0.00	0.839	-0.03
WCI				
Diatoms	LDI-PLU; DIVERS; HETER; CONTAG; AG; SHAPE; FOR	0.02	0.444	-0.21
	LDI-ILD; DIVERS; HETER; CONTAG; AG; SHAPE; FOR	0.02	0.435	-0.18
	LDI-ISD; DIVERS; HETER; CONTAG; AG; SHAPE; FOR	0.03	0.431	-0.17
30 x 30-meters				
Water chemistry				
Log_{10}(DO)	LDI-PLU; DIVERS; HETER; URB/WET; AG; SHAPE; FOR	0.00	0.727	-0.06
	LDI-ILD; DIVERS; HETER; URB/WET; AG; SHAPE; FOR	0.00	0.697	-0.05
	LDI-ISD; DIVERS; HETER; URB/WET; AG; SHAPE; FOR	0.00	0.672	-0.05
Log_{10}(SC)	LDI-PLU; DIVERS; HETER; URB/WET; AG; SHAPE; FOR	0.03	0.454	-0.18
	LDI-ILD; DIVERS; HETER; URB/WET; AG; SHAPE; FOR	0.02	0.459	-0.15
	LDI-ISD; DIVERS; HETER; URB/WET; AG; SHAPE; FOR	0.03	0.454	-0.12
Log_{10}(TN)	LDI-PLU; DIVERS; HETER; URB/WET; AG; SHAPE; FOR	0.14	0.150	0.12
	LDI-PLU; DIVERS; HETER; URB/WET; AG; SHAPE; FOR	0.14	0.155	0.11
	DIVERS; HETER; URB/WET; AG; SHAPE; FOR; LDI-ILD	0.14	0.156	0.11
Log_{10}(Turbidity)	LDI-PLU; DIVERS; HETER; URB/WET; AG; SHAPE; FOR	0.00	0.665	-0.04
	LDI-ILD; DIVERS; HETER; URB/WET; AG; SHAPE; FOR	0.00	0.679	-0.03
	LDI-ISD; DIVERS; HETER; URB/WET; AG; SHAPE; FOR	0.00	0.689	-0.03
WCI				
Diatoms	LDI-PLU; DIVERS; HETER; URB/WET; AG; SHAPE; FOR	0.07	0.369	-0.17
	LDI-ILD; DIVERS; HETER; URB/WET; AG; SHAPE; FOR	0.07	0.364	-0.14
	LDI-ISD; DIVERS; HETER; URB/WET; AG; SHAPE; FOR	0.07	0.360	-0.13

Table O-2. Multiple regression models at four grain sizes for the sample streams: coefficients of determination, probabilities, and change in the amount of variability (ΔR^2) in indicators of ecosystems condition (α – level of 0.05).

Dependent Variable	Independent Variables	R^2 (adj)	p	ΔR^2
20 x 20-meters				
Water chemistry				
Log_{10}(Turbidity)	LDI-PLU; DIVERS1; DIVERS2; WET; DIST	0.00	0.798	-0.03
	LDI-ILD; DIVERS1; DIVERS2; WET; DIST	0.00	0.753	-0.01
	LDI-ISD; DIVERS1; DIVERS2; WET; DIST	0.00	0.643	0.00
Log_{10}(NO_3-N)	LDI-PLU; DIVERS1; DIVERS2; WET; DIST	0.12	0.079	-0.02
	LDI-ILD; DIVERS1; DIVERS2; WET; DIST	0.10	0.098	0.00
	LDI-ISD; DIVERS1; DIVERS2; WET; DIST	0.10	0.103	0.02
SCI				
SC_1	LDI-PLU; DIVERS1; DIVERS2; WET; DIST	0.04	0.204	-0.13
	LDI-ILD; DIVERS1; DIVERS2; WET; DIST	0.07	0.086	-0.13
	LDI-ISD; DIVERS1; DIVERS2; WET; DIST	0.09	0.051	-0.13
SC_2	LDI-PLU; DIVERS1; DIVERS2; WET; DIST	0.09	0.058	-0.10
50 x 50-meters				
Water chemistry				
Log_{10} (Turbidity)	LDI-PLU; DIVERS1; DIVERS2; WET; SHAPE	0.00	0.871	-0.03
	LDI-ILD; DIVERS1; DIVERS2; WET; SHAPE	0.00	0.861	-0.01
	LDI-ISD; DIVERS1; DIVERS2; WET; SHAPE	0.00	0.787	0.00
Log_{10}(NO_3-N)	LDI-PLU; DIVERS1; DIVERS2; WET; SHAPE	0.13	0.066	-0.01
	LDI-ILD; DIVERS1; DIVERS2; WET; SHAPE	0.11	0.085	0.01
	LDI-ISD; DIVERS1; DIVERS2; WET; SHAPE	0.11	0.092	0.03
SCI				
SC_1	LDI-PLU; DIVERS1; DIVERS2; WET; SHAPE	0.04	0.082	-0.12
	LDI-ILD; DIVERS1; DIVERS2; WET; SHAPE	0.08	0.066	-0.12
	LDI-ISD; DIVERS1; DIVERS2; WET; SHAPE	0.10	0.050	-0.13
SC_2	LDI-PLU; DIVERS1; DIVERS2; WET; SHAPE	0.08	0.064	-0.10
80 x 80-meters				
Water chemistry				
Log10(Turbidity)	LDI-PLU; DIVERS1; DIVERS2; URB; SHAPE	0.00	0.852	-0.30
	LDI-ILD; DIVERS1; DIVERS2; URB; SHAPE	0.00	0.824	-0.01
	LDI-ISD; DIVERS1; DIVERS2; URB; SHAPE	0.00	0.731	0.00
Log_{10}(NO_3-N)	LDI-PLU; DIVERS1; DIVERS2; URB; SHAPE	0.13	0.061	-0.01
	LDI-ILD; DIVERS1; DIVERS2; URB; SHAPE	0.11	0.089	0.01
	LDI-ISD; DIVERS1; DIVERS2; URB; SHAPE	0.10	0.101	0.02
SCI				
SC_1	LDI-PLU; DIVERS1; DIVERS2; URB; SHAPE	0.04	0.072	-0.12
	LDI-ILD; DIVERS1; DIVERS2; URB; SHAPE	0.08	0.058	-0.12
SC_2	LDI-PLU; DIVERS1; DIVERS2; URB; SHAPE	0.08	0.081	-0.10
110 x 110-meters				
Water chemistry				
Log10(Turbidity)	LDI-PLU; DIVERS1; DIVERS2; URB; SHAPE	0.00	0.813	-0.03
	LDI-ILD; DIVERS1; DIVERS2; URB; SHAPE	0.00	0.810	-0.01
	LDI-ISD; DIVERS1; DIVERS2; URB; SHAPE	0.00	0.720	0.00

Table O-2. Continued.

Dependent Variable	Independent Variables	R^2 (adj)	p	ΔR^2
$Log_{10}(NO_3\text{-}N)$	LDI-PLU; DIVERS1; DIVERS2; URB; SHAPE	0.13	0.061	-0.01
	LDI-ILD; DIVERS1; DIVERS2; URB; SHAPE	0.12	0.081	0.02
	LDI-ISD; DIVERS1; DIVERS2; URB; SHAPE	0.11	0.090	0.03
SCI				
SC_1	LDI-PLU; DIVERS1; DIVERS2; URB; SHAPE	0.04	0.208	-0.13
	LDI-ILD; DIVERS1; DIVERS2; URB; SHAPE	0.08	0.080	-0.12
SC_2	LDI-PLU; DIVERS1; DIVERS2; URB; SHAPE	0.08	0.080	-0.10

Table O-3. Multiple regression models at three spatial extents for the sample streams: coefficients of determination, probabilities, and change in the amount of variability (ΔR^2) in indicators of ecosystems condition (α – level of 0.05).

Dependent Variable	Independent Variables	R^2 (adj)	p	ΔR^2
100-meter				
Water chemistry				
$Log_{10}(NO_3$-N)	LDI-PLU; DIVERS; SIZE; WET; HETER	0.01	0.390	-0.06
	LDI-ILD; DIVERS; SIZE; WET; HETER	0.00	0.650	-0.04
	LDI-ISD; DIVERS; SIZE; WET; HETER	0.00	0.687	-0.01
400-meter				
Water chemistry				
Log10(Turbidity)	LDI-PLU; DIVERS; HETER; WET; AG	0.00	0.795	-0.02
	LDI-ILD; DIVERS; HETER; WET; AG	0.00	0.535	0.00
	LDI-ISD; DIVERS; HETER; WET; AG	0.04	0.315	0.03
$Log_{10}(NO_3$-N)	LDI-PLU; DIVERS; HETER; WET; AG	0.08	0.164	-0.01
	LDI-ILD; DIVERS; HETER; WET; AG	0.06	0.202	-0.01
	LDI-ISD; DIVERS; HETER; WET; AG	0.05	0.229	0.01
SCI				
SC_1	LDI-PLU; DIVERS; HETER; WET; AG	0.07	0.102	-0.10
	LDI-ILD; DIVERS; HETER; WET; AG	0.09	0.060	-0.11
Watershed				
Water chemistry				
Log10(Turbidity)	LDI-PLU; DIVERS; HETER; WET; AG	0.00	0.951	-0.03
	LDI-ILD; DIVERS; HETER; WET; AG	0.00	0.949	-0.01
	LDI-ISD; DIVERS; HETER; WET; AG	0.00	0.904	0.00
$Log_{10}(NO_3$-N)	LDI-PLU; DIVERS; HETER; WET; AG	0.22	0.052	0.08
	LDI-ILD; DIVERS; HETER; WET; AG	0.22	0.067	0.12
	LDI-ISD; DIVERS; HETER; WET; AG	0.22	0.070	0.14
SCI				
SC_1	LDI-PLU; DIVERS; HETER; WET; AG	0.05	0.136	-0.12
	LDI-ILD; DIVERS; HETER; WET; AG	0.08	0.070	-0.13
SC_2	LDI-PLU; DIVERS; HETER; WET; AG	0.09	0.053	-0.10

Table O-4. Multiple regression models at four grain sizes for the sample lakes: coefficients of determination, probabilities, and change in the amount of variability (ΔR^2) in indicators of ecosystems condition (α – level of 0.05).

Dependent Variable	Independent Variables	R^2 (adj)	p	ΔR^2
20 x 20-meters				
Water chemistry				
Log_{10}(Ammonia-N)	LDI-PLU; DIVERS1; DIVERS2; URB/SIZE; WET; AG	0.00	0.443	-0.01
	LDI-ILD; DIVERS1; DIVERS2; URB/SIZE; WET; AG	0.00	0.643	-0.04
	LDI-ISD; DIVERS1; DIVERS2; URB/SIZE; WET; AG	0.00	0.642	-0.04
Log_{10}(NO_3/NO_2-N)	LDI-PLU; DIVERS1; DIVERS2; URB/SIZE; WET; AG	0.07	0.182	0.06
	LDI-ILD; DIVERS1; DIVERS2; URB/SIZE; WET; AG	0.01	0.416	0.00
	LDI-ISD; DIVERS1; DIVERS2; URB/SIZE; WET; AG	0.02	0.359	0.01
Log_{10}(TKN)	LDI-PLU; DIVERS1; DIVERS2; URB/SIZE; WET; AG	0.12	0.077	0.12
	LDI-ILD; DIVERS1; DIVERS2; URB/SIZE; WET; AG	0.08	0.156	0.07
	LDI-ISD; DIVERS1; DIVERS2; URB/SIZE; WET; AG	0.08	0.153	0.07
40 x 40-meters				
Water chemistry				
Log_{10}(Ammonia-N)	LDI-PLU; DIVERS1; DIVERS2; URB; AG; SIZE	0.00	0.650	-0.02
	LDI-ILD; DIVERS1; DIVERS2; URB; AG; SIZE	0.00	0.601	-0.04
	LDI-ISD; DIVERS1; DIVERS2; URB; AG; SIZE	0.00	0.311	-0.04
Log_{10}(NO_3/NO_2-N)	LDI-PLU; DIVERS1; DIVERS2; URB; AG; SIZE	0.07	0.176	0.07
	LDI-ILD; DIVERS1; DIVERS2; URB; AG; SIZE	0.00	0.436	0.00
	LDI-ISD; DIVERS1; DIVERS2; URB; AG; SIZE	0.00	0.460	0.00
Log_{10}(TKN)	LDI-PLU; DIVERS1; DIVERS2; URB; AG; SIZE	0.06	0.194	0.06
	LDI-ILD; DIVERS1; DIVERS2; URB; AG; SIZE	0.06	0.214	0.04
	LDI-ISD; DIVERS1; DIVERS2; URB; AG; SIZE	0.04	0.273	0.03
60 x 60-meters				
Water chemistry				
Log_{10}(Ammonia-N)	LDI-PLU; DIVERS1; DIVERS2; URB; AG; SIZE	0.00	0.439	0.00
	LDI-ILD; DIVERS1; DIVERS2; URB; AG; SIZE	0.00	0.550	0.00
	LDI-ISD; DIVERS1; DIVERS2; URB; AG; SIZE	0.00	0.482	0.00
Log_{10}(NO_3/NO_2-N)	LDI-PLU; DIVERS1; DIVERS2; URB; AG; SIZE	0.13	0.063	0.13
	LDI-ILD; DIVERS1; DIVERS2; URB; AG; SIZE	0.07	0.165	0.07
	LDI-ISD; DIVERS1; DIVERS2; URB; AG; SIZE	0.13	0.071	0.13
Log_{10}(TKN)	LDI-PLU; DIVERS1; DIVERS2; URB; AG; SIZE	0.00	0.456	0.00
	LDI-ILD; DIVERS1; DIVERS2; URB; AG; SIZE	0.00	0.535	0.00
	LDI-ISD; DIVERS1; DIVERS2; URB; AG; SIZE	0.04	0.257	0.04
Log_{10}(TP)	LDI-PLU; DIVERS1; DIVERS2; URB; AG; SIZE	0.10	0.114	0.10
	LDI-ILD; DIVERS1; DIVERS2; URB; AG; SIZE	0.10	0.117	0.10
	LDI-ISD; DIVERS1; DIVERS2; URB; AG; SIZE	0.11	0.090	0.11
80 x 80-meters				
Water chemistry				
Log_{10}(Ammonia-N)	LDI-PLU; DIVERS1; HETER; URB; AG; SIZE	0.00	0.517	0.00
	LDI-ILD; DIVERS1; HETER; URB; AG; SIZE	0.00	0.516	0.00
	LDI-ISD; DIVERS1; HETER; URB; AG; SIZE	0.00	0.227	0.00
Log_{10}(NO_3/NO_2-N)	LDI-PLU; DIVERS1; HETER; URB; AG; SIZE	0.14	0.058	0.14
	LDI-ILD; DIVERS1; HETER; URB; AG; SIZE	0.13	0.710	0.13
	LDI-ISD; DIVERS1; HETER; URB; AG; SIZE	0.14	0.059	0.14

Table O-4. Continued.

Dependent Variable	Independent Variables	R^2 (adj)	p	ΔR^2
Log_{10}(TKN)	LDI-PLU; DIVERS1; HETER; URB; AG; SIZE	0.07	0.175	0.07
	LDI-ILD; DIVERS1; HETER; URB; AG; SIZE	0.04	0.267	0.04
	LDI-ISD; DIVERS1; HETER; URB; AG; SIZE	0.04	0.125	0.04
Log_{10}(TP)	LDI-PLU; DIVERS1; HETER; URB; AG; SIZE	0.12	0.085	0.12
	LDI-ILD; DIVERS1; HETER; URB; AG; SIZE	0.12	0.084	0.12
	LDI-ISD; DIVERS1; HETER; URB; AG; SIZE	0.11	0.095	0.11

Table O-5. Multiple regression models at three spatial extents for the sample lakes: coefficients of determination, probabilities, and change in the amount of variability (ΔR^2) in indicators of ecosystems condition (α – level of 0.05).

Dependent Variable	Independent Variables	R^2 (adj)	p	ΔR^2
100-meter				
Water chemistry				
Log_{10}(Ammonia-N)	LDI-PLU; DIVERS1; DIVERS2; URB; SHAPE; FOR	0.00	0.596	0.00
	LDI-ILD; DIVERS1; DIVERS2; URB; SHAPE; FOR	0.00	0.578	0.00
	LDI-ISD; DIVERS1; DIVERS2; URB; SHAPE; FOR	0.00	0.576	0.00
$Log_{10}(NO_3/NO_2$-N)	LDI-PLU; DIVERS1; DIVERS2; URB; SHAPE; FOR	0.08	0.174	0.08
	LDI-ILD; DIVERS1; DIVERS2; URB; SHAPE; FOR	0.11	0.108	0.11
	LDI-ISD; DIVERS1; DIVERS2; URB; SHAPE; FOR	0.13	0.080	0.13
Log_{10}(TKN)	LDI-PLU; DIVERS1; DIVERS2; URB; SHAPE; FOR	0.00	0.554	0.00
	LDI-ILD; DIVERS1; DIVERS2; URB; SHAPE; FOR	0.00	0.604	0.00
	LDI-ISD; DIVERS1; DIVERS2; URB; SHAPE; FOR	0.00	0.660	0.00
Log_{10}(TN)	LDI-PLU; DIVERS1; DIVERS2; URB; SHAPE; FOR	0.00	0.647	0.00
	LDI-ILD; DIVERS1; DIVERS2; URB; SHAPE; FOR	0.00	0.669	0.00
	LDI-ISD; DIVERS1; DIVERS2; URB; SHAPE; FOR	0.00	0.655	0.00
Log_{10}(TP)	LDI-PLU; DIVERS1; DIVERS2; URB; SHAPE; FOR	0.07	0.189	0.07
	LDI-ILD; DIVERS1; DIVERS2; URB; SHAPE; FOR	0.08	0.169	0.08
	LDI-ISD; DIVERS1; DIVERS2; URB; SHAPE; FOR	0.09	0.159	0.09
400-meter				
Water chemistry				
Log_{10}(Ammonia-N)	LDI-PLU; DIVERS1; DIVERS2; WET; HETER; AG	0.03	0.315	0.03
	LDI-ILD; DIVERS1; DIVERS2; WET; HETER; AG	0.03	0.308	0.03
	LDI-ISD; DIVERS1; DIVERS2; WET; HETER; AG	0.03	0.311	0.03
$Log_{10}(NO_3/NO_2$-N)	LDI-PLU; DIVERS1; DIVERS2; WET; HETER; AG	0.00	0.454	0.00
	LDI-ILD; DIVERS1; DIVERS2; URB; HETER; AG	0.01	0.392	0.01
	LDI-ISD; DIVERS1; DIVERS2; URB; HETER; AG	0.01	0.399	0.01
Watershed				
Water chemistry				
Log_{10}(Ammonia-N)	LDI-PLU; DIVERS1; DIVERS2; URB; HETER; AG	0.10	0.120	0.10
	LDI-ILD; DIVERS1; DIVERS2; URB; HETER; AG	0.06	0.220	0.06
	LDI-ISD DIVERS1; DIVERS2; URB; HETER; AG	0.06	0.227	0.06
$Log_{10}(NO_3/NO_2$-N)	LDI-ILD; DIVERS1; DIVERS2; URB; HETER; AG	0.06	0.219	0.06
	LDI-ISD DIVERS1; DIVERS2; URB; HETER; AG	0.07	0.197	0.07
Log_{10}(TKN)	LDI-PLU; DIVERS1; DIVERS2; URB; HETER; AG	0.13	0.091	0.13
	LDI-ILD; DIVERS1; DIVERS2; URB; HETER; AG	0.10	0.132	0.10
	LDI-ISD DIVERS1; DIVERS2; URB; HETER; AG	0.10	0.125	0.10
Log_{10}(TP)	LDI-PLU; DIVERS1; DIVERS2; URB; HETER; AG	0.13	0.083	0.13
	LDI-ILD; DIVERS1; DIVERS2; URB; HETER; AG	0.11	0.111	0.11
	LDI-ISD DIVERS1; DIVERS2; URB; HETER; AG	0.12	0.106	0.12

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BIOGRAPHICAL SKETCH

Manuel Benjamin Vivas was born in Bogotá, Colombia. He graduated from Universidad de los Andes in 1988 after having earned a degree in biology. He earned a Master of Arts degree from the Center for Latin American Studies/Tropical Conservation Development Program at the University of Florida in 1998. In January 2000, Benjamin enrolled in the Ph.D. program in Systems Ecology through the Center for Wetlands, Department of Environmental Engineering Sciences, University of Florida, under the tutelage of Dr. Mark T. Brown.

During his professional career in the fields of natural resource management and conservation science, Benjamin has served in various positions of project management and consultancy in environmental non-governmental organizations. He is well-versed in ecoregional planning and national parks management, and has worked in close collaboration with a variety of stakeholders to define strategies for conservation and natural resources management in South America.

Benjamin is married to Sara Vivas, and is the proud father of Sofía Manuela. He enjoys cycling, fishing, Latin American literature, and classical music.