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EFFECTS OF URBANIZATION ON THE SIZE AND SPATIAL DISTRIBUTION
OF WETLANDS IN NEW HAMPSHIRE

BY

KATIE JACQUES
B.S., University of New Hampshire, 1999

THESIS

Submitted to the University of New Hampshire
In Partial Fulfillment of
the Requirements for the Degree of

Master of Science
In
Natural Resources: Environmental Conservation

May, 2009

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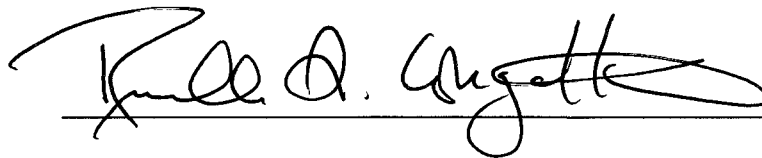
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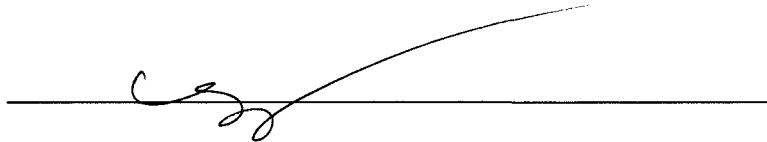
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ABSTRACT

EFFECTS OF URBANIZATION ON THE SIZE AND SPATIAL DISTRIBUTION OF WETLANDS IN NEW HAMPSHIRE

by

Katie Jacques

University of New Hampshire, May, 2009

This study investigates the effects of land use change in the form of urbanization on the size and spatial distribution of wetlands in New Hampshire. I predict that with increased urbanization, the number of wetlands lost will rise, causing an increase in landscape fragmentation. Aerial photography, US Geological Survey topographic maps, National Agriculture Imagery Program imagery, hydrography and National Wetlands Inventory data layers were analyzed using GIS tools along four urban-rural gradient transects 5km by 25km in size. Each study area transect included urban, suburban and rural areas. This study identified the relationships between the urbanization level and the size and spatial patterns of wetlands. A relationship between wetland distribution and urbanization as well as wetland size and urbanization was found for all study area transects. The results from this study suggest that wetland size and spatial distribution are being negatively affected by land use change within New Hampshire.

INTRODUCTION

The growth of urban and suburban areas has been a dominant demographic characteristic in the United States in past centuries (Ehrenfeld 2000). In 1989, 74 percent of the United States population (203 million people) resided in urban areas. Currently, 80 percent of the United States population (305 million people) lives in urban areas, surpassing the prediction originally made for 2025 (Fox 1987; Haub and Kent 2008). Urbanization endangers more species and is more geographically ubiquitous in the mainland United States than any other human activity (Czech et al. 2000). Species threatened by urbanization also tend to be threatened by agriculture, recreation, roads, and many other human impacts, emphasizing the impacts of urban sprawl (McKinney 2002). Urbanization is one of the major factors affecting wetlands today (Gibbs 2000).

Population Growth in New Hampshire

New Hampshire is witnessing a period of sustained and accelerated population transformation. Most of this growth is centered on urban areas (Stein et al 2000); yet rural communities are also undergoing dramatic changes both in numbers of people and in landscape composition. For four straight decades, New Hampshire has had the fastest growing population in New England (NH Office of Energy and Planning 2004). In 1970, the population of the state of New Hampshire was less than 740,000. Only 4 of New Hampshire's 259 communities were densely populated enough to be categorized as urban, 39 were suburban,

and 216 were rural. By 2003, New Hampshire's population had grown to more than 1.2 million, with densities increasing throughout the southern half of the state. Today, New Hampshire has 8 municipalities classified as urban, 78 are suburban, and 173 are rural. By 2025, the state's population is projected to be almost 1.6 million with 12 municipalities classified as urban, 89 suburban and 158 rural (NH Office of Energy and Planning 2004).

Urbanization

Urbanization is a direct result of population growth. Specifically, it is the physical growth of rural or natural land into urban areas as a result of population in-migration to an existing urban area (Azous and Horner 2001). Of the ecosystems affected by urbanization, wetlands are particularly vulnerable. Effects of urbanization on wetlands include direct destruction as well as degradation by suspended solids additions, hydrologic changes, and altered water quality (Darnell 1976). Urbanization was linked to wetland loss in almost all surveyed watersheds in a study by the US Department of Agriculture in 1997, and found responsible for upwards of 58 percent of total wetland loss in the United States (Ehrenfeld 2000). The shortage of land in urban areas often results in the destruction of small wetlands because they are among the few undeveloped areas remaining. Wetlands are also the least expensive sites to develop (Hall 1988). The challenge is to protect wetlands and their ecological condition given the pressures of development (Kentula et al. 2004). The spread of urbanization in the United States indicates that wetland ecosystems that are

influenced by urbanization can only become increasingly important for ecologists to study (McDonnell and Pickett 1990).

Wetlands

Wetlands are identified based upon three criteria; (1) the presence of plants adapted to survive in wet soil conditions, (2) the presence of water at or near the surface for more than two weeks during the growing season, and (3) the presence of hydric soils (Mitsch and Gosselink 1986). Wetlands perform ecological functions which are vitally important to the environmental and economic health of the nation and are impossible or costly to replace. Wetlands protect the quality of surface waters by retarding the erosive forces of moving water. They provide a natural means of flood control by reducing and delaying flood peaks, thereby protecting against the loss of life and property. Wetlands improve water quality by intercepting and filtering out waterborne sediments, excess nutrients, heavy metals and other pollutants (Mitsch and Gosselink 1986).

Wetlands are also sources of food, shelter, essential breeding, spawning, nesting and wintering habitats for fish and wildlife, including migratory birds, amphibians, endangered species and commercially and recreationally important species. Wetlands are unique because of their hydrologic conditions and their role as ecotones between terrestrial and aquatic systems (Mitsch and Gosselink 2000). Wetlands should be recognized as part of a complex, interrelated, hydrologic system (Azous and Horner 2001).

During the 1780s the conterminous United States contained an estimated 89 million hectares of wetlands (Dahl 1990). In 2004, there were an estimated

43.6 million ha of wetlands remaining in the conterminous United States. Three-fourths of the remaining wetlands in the continental United States are privately owned and only about 0.5 percent of these are under some form of conservation protection (Tiner 2003).

Wetlands are a significant landscape element, making up more than 5 percent of the total area in almost a third of the 2,123 watersheds in the contiguous United States (Heimlich 2003). Wetland losses vary throughout the country. Gross wetland losses from 1982 to 1992 were greatest in the United States along the east coast, Great Lakes, and Gulf Atlantic States (Heimlich 2003).

Wetland losses have varied over time. From the 1950s to the 1970s, approximately 11 million acres of wetlands were lost, while only 2 million were created. Agricultural development was responsible for 87 percent of the national loss of wetlands, while urbanization and development were responsible for 8 percent and 5 percent of the losses, respectively (Dahl 2000). From 1986-1997, urban development accounted for an estimated 30 percent of all losses, and 21 percent were attributed to rural development. Of this loss, 98 percent were freshwater wetlands. An estimated 36,000 hectares or 39 percent of lost wetland area were lost to urban development. In addition, 20,800 hectares or 22 percent were lost to rural development and 7,300 hectares or 8 percent of wetlands were lost through drainage or filling (Dahl 2006).

Wetlands are one of New Hampshire's most important ecosystems. Approximately 5 percent of New Hampshire's land area is identified as wetlands

(NH Office of Energy and Planning 2004). Wetlands provide critical functional roles in providing ecological services and resources held in the public trust, including flood protection, clean water and wildlife habitats. Wetlands and adjacent uplands provide essential habitat for wildlife, including food, cover, and travel if connected to other habitat. Protection of small wetlands and adjacent uplands is often important for achieving this connectivity. Wetlands support almost two-thirds of New Hampshire's wildlife in greatest need of conservation (NH Fish and Game Department 2005). State jurisdiction of wetlands in New Hampshire is found in RSA 482-A and NH Department of Environmental Services (DES) administrative rules Env-Wt 100-800 (New Hampshire DES 2008). Almost all activities that disturb the soils in a jurisdictional area, regardless of size or scale, in or on the banks of a surface water body or in a wetland require a permit from the state. Projects are classified according to their potential environmental impact – as minimum impact, minor impact, and major impact. The federal government also has jurisdiction over wetlands under Section 404 of the Clean Water Act. Section 404 review is administered by the Army Corps of Engineers, which coordinates review with the federal resource agencies – National Oceanic and Atmospheric Administration - National Marine Fisheries, and the US Fish and Wildlife Service. The Army Corps of Engineers has issued a Programmatic General Permit in New Hampshire, which means that most state wetlands permits are concurrently approved by the Army Corps of Engineers (NH DES 2008).

In addition to the state and federal wetland regulations in New Hampshire, municipalities can also designate wetlands as Prime wetlands. Prime wetlands are designated by a municipality according to the requirements of RSA 482-A: 15 and Chapter Env-Wt 700 of the DES administrative rules. The municipality chooses to evaluate the functions and values of the wetlands within its boundaries. If accepted, DES will classify all projects that are in or within 100 feet of a prime wetland as a major project. All major projects require a field inspection by DES and all prime wetland projects require a public hearing to be conducted by DES (NH DES 2008). Within New Hampshire, 8 towns that have more than 20 percent of their land area in wetlands have, on average, protected 13 percent of those wetlands. One hundred and fifty three communities have protected less than 20 percent of their wetlands, while 77 communities have protected less than 10 percent. Twenty-one percent of freshwater marshes and swamps, which account for 95 percent of all wetlands in New Hampshire and provide essential wildlife habitat, are protected throughout the state. Estuaries, which are among the most critical and sensitive wetlands, comprise about 2 percent of the wetlands in New Hampshire. Of those, only 23 percent are protected (NH Office of Energy and Planning 2004).

There is no definitive way to calculate the complete impact humans have had on the global extent of wetlands, but in heavily populated areas this impact ranges from significant to total (Mitsch and Gosselink 2000). Studies have been conducted on wetlands and the cumulative impacts that have occurred with regards to size, distribution, health, and function. Johnston (1994) found that,

because wetlands are not isolated but rather are components of larger landscapes, that cumulative impacts to wetlands only provide a partial picture. Gibbs (1998) found a direct relationship between human density and wetland density. He determined that as human density shifts from rural to urban, wetland distribution shifts from a clustered pattern to fewer and more isolated wetlands. Aggregate wetland areas also declined with increased human density.

Wetland size and spatial distribution in the landscape play important roles for species which rely on the composition of wetlands, therefore reinforcing the need for studies to be conducted to identify these spatial patterns (Gibbs 1995; Gibbs 1998). It is particularly important to understand the effects of human activities that fragment the landscape and thereby alter the size, shape, and spatial arrangement of these habitat types (Gibbs 1998). Habitat fragmentation is the separation of a landscape into various land uses (e.g., development, agriculture, etc.), resulting in numerous small, disconnected habitat patches (Harris 1984). Fragmentation eliminates habitat for those species requiring large unbroken blocks of specific habitat types. Gibbs (1993) simulated the loss of small isolated wetlands that are currently not protected by law, in an effort to determine how their loss might affect metapopulations structure of the organisms that rely on these wetlands. The loss of these wetlands resulted in declines in total wetland area and total wetland number. In addition there was an increase in the average distance between wetlands. Semlitsch and Bodie (1998) found that the majority of natural wetlands are small and that they are extremely valuable for maintaining biodiversity of wetland species.

Gradient analysis, developed in the context of vegetation analysis (Whittaker 1967), has been used to study the effects of urbanization on plant distribution (Whittaker 1967; Vitousek and Matson 1990) and ecosystem properties (McDonnell and Pickett 1990; McDonnell et al. 1997). Gradient analysis has been applied in vegetation studies to relate the abundance of various species in a plant community to various environmental gradients (Whittaker 1967). In addition, gradient analysis provides a useful tool for ecological studies of the spatially varying effects of urbanization (Ter Braak and Prentice 1988). Medley et al. (1995) conducted a study on forest landscape structure and found the approach to be a successful tool to guide management of natural areas along this gradient. The study of ecological systems along an urban rural gradient allows for examination of the influences of urban and natural environmental factors on ecosystem patterning. Human influences can be directly quantified along these gradients as well (McDonnell and Pickett 1990). Urban-gradient studies can compare wetland characteristics among watersheds with different levels of development. This technique is frequently applied when comparable prior data are not available for the watersheds of interest (Aichele 2005).

GIS Analysis

Utilizing Geographic Information System (GIS) tools to analyze the spatial distribution of wetlands is becoming increasingly popular (Tiner 2003; Kentula et al. 2004). GIS is a geospatial system that combines digital maps and tabular databases with the ability to manipulate, display, interpret, analyze, model and

store spatial data (Chang 2008). GIS has been used in various studies to quantify landscape characteristics of various ecosystems, including wetlands (Ehrenfeld 2000; Kentula et al. 2004; Luck and Wu 2002; Rubbo and Kiesecker 2005). In addition, studies have been performed (Luck and Wu 2002) utilizing GIS spatial statistical tools to analyze spatial patterns. Using GIS, the spatial distribution and size of wetlands can be interpreted, discovering patterns that link urbanization and development to the loss and fragmentation of the landscape.

Objectives

My research focused on identifying the relationship between land use change and the spatial distribution and size of wetlands in order to assess the impact land use change is having on wetlands in New Hampshire.

The objectives of this study were: (1) to determine the effect of different levels of land use change, defined as urban, suburban and rural, on the size of wetlands and (2) determine the effect of land use change on the spatial distribution of wetlands. More specifically, I asked whether the spatial distribution of wetlands varied with the distance from urban centers and if the size of wetlands varied along urban-rural gradients.

I tested the following hypotheses:

Ho₁: Spatial distribution of wetlands remains the same regardless of distance from urban centers.

Ho₂: Wetland size remains constant regardless of distance from urban centers.

I predict that closer to urban centers, the number of wetlands identified will be smaller. In rural areas, I expect more large and small wetlands than in the urban areas. I also predict there will be less clustered wetlands closer to urban centers, indicating an increase in habitat fragmentation.

Study Area

I evaluated the effects of land use change on wetland size and distribution along transects created using urban-rural gradient in New Hampshire. Each transect included an urban, suburban and rural area classified using definitions from the US Census Bureau (Table 1). The Census Bureau classification of "urban" consists of all territory, population, and housing units located within an urbanized area (UA) or an urban cluster (UC). It delineates UA and UC boundaries to encompass densely settled territory, which consists of: (1) core census block groups or blocks that have a population density of at least 1,000 people per square mile and (2) surrounding census blocks that have an overall density of at least 500 people per square mile. Suburban areas are classified as Micropolitan Statistical Area by the US Census Bureau; each micropolitan statistical area must have at least one urban cluster of at least 10,000 but less than 50,000 population count. The Census Bureau's classification of "rural" consists of all territory, population, and housing units located outside of UAs and UCs. Geographic entities, such as census tracts, counties, metropolitan areas, and the territory outside metropolitan areas, often are "split" between urban and rural territory, and the population and housing units they contain often are partly classified as urban and partly classified as rural (US Census 2002).

Each transect in this study extended out from an urban center into rural areas using a 5km wide by 25km long belt transect (Figure 1). Eight urban areas were identified in New Hampshire using the Census method. Of these eight, four urban areas were chosen, based on location relative to suburban and rural areas. Each urban area is located adjacent to areas classified as suburban, and those suburban areas are adjacent to rural areas. The four urban centers are: Concord, Manchester, Nashua, and Rochester. The creation of these transects adds an additional 8 towns to the study, when both suburban and rural areas are included. The four suburban areas are Hopkinton, Goffstown, Barrington and Hollis. The four rural areas are Henniker, Dunbarton, Brookline and Nottingham. Although these transects are consistent with political boundaries, they do not include the entire area of each town. The transect size and length were adapted from a previous study done by Medley et al. (1995) which focused on forest-landscape structure along urban to rural gradients from New York to Connecticut.

The Nashua and Manchester transects included additional towns to compose each of the study area transects. In the Nashua study area transect, a portion of both Hudson and Nashua were used to create the urban area for this transect. In addition, the rural area in this study area transect included a portion of both Brookline and Mason. In the Manchester study area transect, a portion of both Hooksett and Goffstown were used to create the suburban area for this transect. In addition, the rural area in this study area transect included a portion of both Dunbarton and Bow. All towns included in the study area transects were classified according to the Census method.

Table 1. US Census Bureau Urban Areas and Urban Clusters identified for New Hampshire.

Urban Areas	Population	Pop Density (sq mi)	Area (sq meters)
Boston, MA-NH-RI	96114	289266320	860.6
Dover--Rochester, NH-ME	73063	145804742	1297.8
Manchester, NH	143549	184043509	2020.1
Nashua, NH-MA	197119	356467231	1432.2
Porstmouth, NH-ME	41983	91411033	1189.5
Urban Clusters	Population	Pop Density (sq mi)	Area (sq meters)
Bellows Falls, VT--NH	551	448211	3184
Berlin, NH	11377	153335244	1921.5
Charlestown, NH	2625	6528784	1041.3
Claremont, NH	9188	13888818	1713.4
Concord, NH	46449	86297235	1394
Franklin, NH	10953	26132935	1085.5
Hillsborough, NH	3167	9204167	891.2
Jaffrey, NH	6475	17304536	969.1
Keene, NH	21436	30087127	1845.3
Laconia, NH	20302	47842504	1099.1
Lebanon, NH--VT	20819	58779147	917.3
Littleton, NH	3920	9820592	1033.8
Newmarket, NH	9256	22732932	1065.9
Newport, NH	3160	8141282	1005.3
Plymouth, NH	3957	5958750	1719.9
Raymond, NH	6751	18606060	939.7

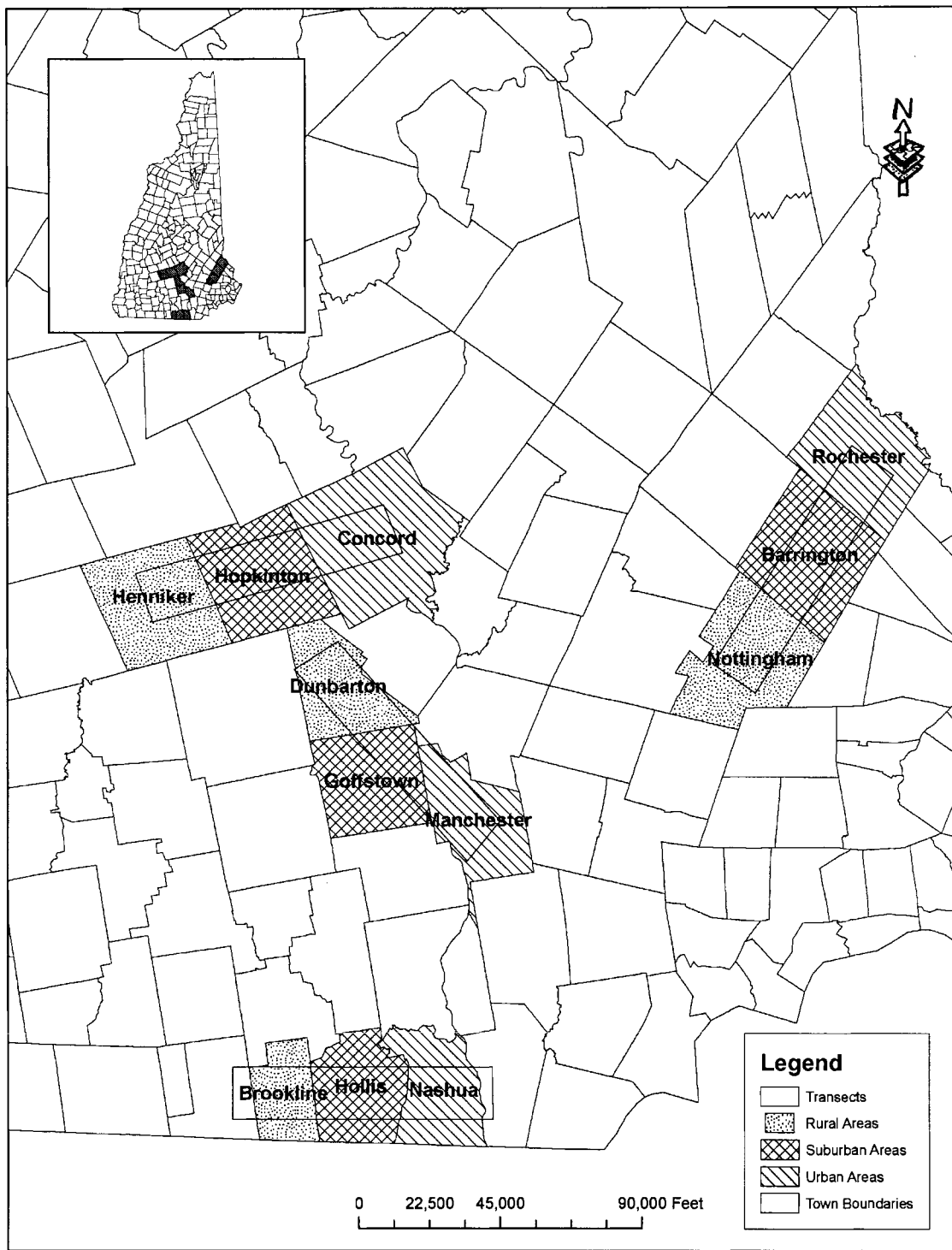


Figure 1. Study areas locating the 5 x 25 km urban-rural transects outlined within New Hampshire.

Concord Transect

Concord is located in central New Hampshire and contains 64 square miles of land area, 3.2 square miles of inland water area, and 636.2 persons per square mile of land area. From 1990-2000, Concord's population grew by 13 percent. It is the third largest city in New Hampshire (Economic & Labor Market Information Bureau 2002).

Rochester Transect

Rochester is located in southeastern New Hampshire and contains 44.8 square miles of land area, 0.6 square miles of inland water area, and 635 persons per square mile of land area. It is the fifth largest community in the state, with a population growth of 6.9 percent from 1990-2000 (Economic & Labor Market Information Bureau 2002).

Manchester Transect

Manchester is located in southern New Hampshire and contains 33 square miles of land area, 1.9 miles of inland water area, and 3238.7 persons per square mile of land area. It is the largest city in New Hampshire and had a 7.5 percent population growth from 1990-2000 (Economic & Labor Market Information Bureau 2002).

Nashua Transect

Nashua is located in southern New Hampshire and contains 30.8 square miles of land area, 1 square mile of inland water area, and 2816.4 persons per square mile of land area. It had an 8.7 percent increase in population from 1990-2000 (Economic & Labor Market Information Bureau 2002).

METHODS

To assess the size and spatial distribution of wetlands for the study area transects, accurate wetland data were required. Various types of data were available for the study area transects, including National Wetlands Inventory data, hydrography data, aerial photographs, and topographic maps. To obtain the most accurate and current wetland data layer for the wetland analysis, photointerpretation was conducted utilizing the available data layers listed above. Photointerpretation, for the purposes of this study, is defined as the interpretation of aerial imagery in combination with GIS data by using heads-up digitizing, to create a master wetland layer. The master wetland layer is needed to perform the spatial analysis on wetlands in the study area transect.

The data used for this analysis are listed below and separated into data types: raster and vector. Vector data is coordinate-based data that represents geographic features as points, lines, and polygons. Each point feature is represented as a single coordinate pair, while line and polygon features are represented as ordered lists of vertices. Attributes are associated with each vector feature, such as road names, area and perimeter calculations, or wetland classification (DeMers 2000). Raster data are spatial data that define space as an array of equally sized cells arranged in rows and columns, and comprised of single or multiple layers. Each cell contains an attribute value and location coordinates. Unlike a vector structure, which stores coordinates explicitly, raster coordinates are contained in the ordering of the matrix. Groups of cells that share the same value represent the same type of geographic feature (DeMers 2000).

Data Layers

Vector Data

National Wetlands Inventory (NWI) data were used in the creation of the wetland master data layer. In 1906, and again in 1922, the US Department of Agriculture inventoried the wetlands of the United States to identify those that could be drained and converted to other uses (Wilén and Tiner 1993). In 1954, the first nationwide wetland survey by the US Fish and Wildlife Service (FWS) covered about 40 percent of the conterminous United States and focused on wetlands important for waterfowl. After the earlier inventories, and in response to passage of the Emergency Wetlands Resources Act and its amendments, the FWS established the National Wetlands Inventory. The program is designed to (1) produce detailed maps on the characteristics and extent of the Nation's wetlands, (2) construct a national wetlands database, (3) disseminate wetland maps and digital data, (4) report results of State wetland inventories, (5) report to Congress every 10 years on the status and trends of the Nation's wetlands, and (6) assemble and distribute related maps, digital data, and reports. The National Wetlands Inventory has produced more than 50,800 maps covering 88 percent of the conterminous United States, 30 percent of Alaska, and all of Hawaii and the US Territories (Wilén et al. 2002). These data are available for New Hampshire through NH GRANIT (the central GIS data warehouse for NH) as supplied by the US Fish and Wildlife Service from 1983 at a 1:24000 scale. For the study area transects, the NWI data cover all urban, suburban and rural areas.

For the same study areas, hydrography data were also acquired and used to identify wetland locations. These data are part of the NH hydrography dataset, which is a feature-based database that interconnects and uniquely identifies stream segments or reaches that make up state's surface water systems. These data are produced by the US Geological Survey (USGS) in cooperation with the US Environmental Protection Agency (EPA). These data are available from NH GRANIT as supplied by the US Geological Survey and last updated in January 2006.

Political boundary data were also used to identify the town boundaries within New Hampshire. The political boundary layer provides a digital representation of the town boundaries mapped on standard 7.5-minute USGS quadrangles. The data were distributed by the USGS in digital line graphs (DLG) format and processed in ARC/INFO to generate the GRANIT data layer. The data were last updated in 1996 and is at a 1:24,000 scale.

US Census TIGER data from 2007 were used to spatially identify the urban, suburban and rural land areas within New Hampshire. The TIGER/Line shapefiles are extracts containing selected geographic and cartographic information from the Census Bureau's MAF/TIGER® (Master Address File/Topologically Integrated Geographic Encoding and Referencing) database. The MAF/TIGER database was developed at the Census Bureau to support a variety of geographic programs and operations including functions such as mapping, geocoding, and geographic reference files that are used in decennial and economic censuses and sample survey programs. Spatial data for

geographic features such as roads, railroads, rivers, and lakes, as well as legal and statistical geographic areas are included in the product. Other information about these features, such as the name, the type of feature, address ranges, and the geographic relationship to other features, also are included. The TIGER/Line shapefiles are made available to the public and are typically used to provide the digital map base for a Geographic Information System or for mapping software (US Census Bureau 2002).

Raster Data

I used Digital Orthophoto Quads (DOQs) to aid in the identification of wetlands for the study area transects. DOQs are digital images of aerial photographs with displacements from camera and terrain removed. DOQs combine image characteristics of a photograph with geometric qualities of a map. The DOQs used for this study were supplied by the USGS, and archived by NH GRANIT. These images are at a 1:12,000 scale, have a one meter ground resolution, are panchromatic, and were flown in April of 1998.

In addition, I used National Agricultural Imagery Program (NAIP) ortho imagery as a secondary source of wetland identification. The NAIP imagery was collected in 2003, making it more current than the 1998 DOQs noted above, and is also true color, aiding in the photointerpretation process. These images are at a 1:40,000 scale. NAIP imagery is orthorectified imagery provided by the National Agriculture Imagery Program. This imagery is acquired during the agricultural growing seasons in the continental US.

Topographic maps, in the form of a Digital Raster Graphic (DRG) were also used to identify wetland features. DRGs are scanned images of the USGS 7.5-minute quadrangle topographic maps at a 1:24,000 scale. Each image has a resolution of 250 dots per inch and used 13 colors. The USGS topographic maps are a type of map characterized by large scale detail and show a representation of relief using contour lines. Topographic maps show both natural and man-made features.

Base- Map Creation

To identify the existing wetlands for each study area transect, I used NWI, hydrography, NAIP, DOQs, DRGs, and political boundary data. I loaded data into ESRI ArcGIS Desktop v 9.1 (ESRI 2005) software and clipped each data layer was to the study area transect for each urban center using geoprocessing tools within the software. I used an ESRI personal geodatabase (PGDB) to organize the digital GIS data, and each layer created or used was imported to this personal geodatabase as an ESRI feature class, with the exception of the raster data. The choice of using the PGDB format enabled efficient organization of the GIS data used and developed in this project. I created base maps for each of the study area transects using all of the data layers.

Photointerpretation

A photointerpretation technique of heads-up digitizing was used to identify wetland areas on the raster datasets, including: DOQs, DRGs, and NAIP Imagery. On-screen digitizing is an interactive process in which a map is created using previously digitized or scanned information. This method is commonly called "heads-up" digitizing because the attention of the user is focused up on the screen, and not on a digitizing tablet. This technique may be used to trace features from a scanned map or image to create new layers or themes. Heads-up digitizing may also be employed in an editing session where there is enough information on the screen to accurately add new features without a reference image or map (DeMers 2000). The process of heads-up digitizing is similar to conventional digitizing. Rather than using a digitizer and a cursor, the user creates the map layer up on the screen with the mouse and typically with referenced information as a background.

Wetlands occur along a soil moisture continuum between permanently flooded, deepwater habitats and drier habitats that are not wet long enough to develop anaerobic conditions. They can be difficult to identify on the ground, from aerial photos, or DOQs (Tiner 1997). There are certain conditions that must be met in order to ensure that the photointerpretation process is successful. These conditions include: (1) quality and timing of photos, (2) ground referencing, (3) season, and (4) scale. The National Wetland Inventory program has mapped wetland from photos since 1906 and has found that leaf-off, color infrared aerial photography from early spring is best for detecting forested wetlands (Wilén and

Smith, 1996). To obtain the best interpretation of the wetlands from digital raster data, a combination of topographic maps, DOQ and NAIP imagery was used to create the base interpretation layer.

For the topographic maps, any area labeled with the standard topographic wetland symbol was digitized. The DOQ images were analyzed using training areas for the interpretation. These training areas were created using known wetland locations in the Manchester transect and represented both forested and non-forested wetlands and spanned all three urbanization levels. Scale and pixelization prevented the wetland identification in some areas, mostly impacting the identification of small wetlands, less than 1 acre in size. When the DOQ images became difficult to interpret, the NAIP imagery was used as a secondary reference. The scale of this imagery was larger than the DOQ imagery and the imagery was color, allowing for better identification of wetlands.

Wetland Identification

The wetland identification process was a multilayered process. A flow chart was created (Figure 2) to establish the process of identifying the wetlands. Initially, the topographic maps were used to digitize wetland locations. After the topographic data were digitized into a layer, both the DOQ and NAIP imagery were used to add additional wetland locations to the layer. This process established the creation of the 'master layer'. The master layer was compared to the hydrography and topographic layers. If the master layer, hydrography, and topographic layers all identified the area as a wetland, the master layer was compared to the NWI data. If the master layer and the NWI layer were in

agreement, no field check was conducted and the area was classified as a wetland. If all of the layers (master layer, hydrography and NWI) confirmed the area was a wetland, but the topographic map did not agree, the area was still classified a wetland. If only the master layer and NWI layer identified an area as a wetland, it was classified a wetland. If the master layer and the NWI data disagreed, a field check was conducted to confirm the presence and size of a wetland.

If an area required a field check and there was no public access available, at least 2 of the 3 data sources had to confirm the area a wetland. Areas with no access included private property or inaccessible terrain. Field checks were conducted twice in the data collection process. The first was in the Concord transect due to the master layer not agreeing with the NWI layer in the rural area of the study area transect. A field check confirmed that the area was a wetland. The second field check was in the Rochester transect in the suburban area. The master layer and the NWI layer were not in agreement. The field check identified the wetland as inaccessible. A secondary analysis was performed on the digital data, resulting in the area only being identified as a wetland from the NWI layer; therefore, it was not classified as a wetland.

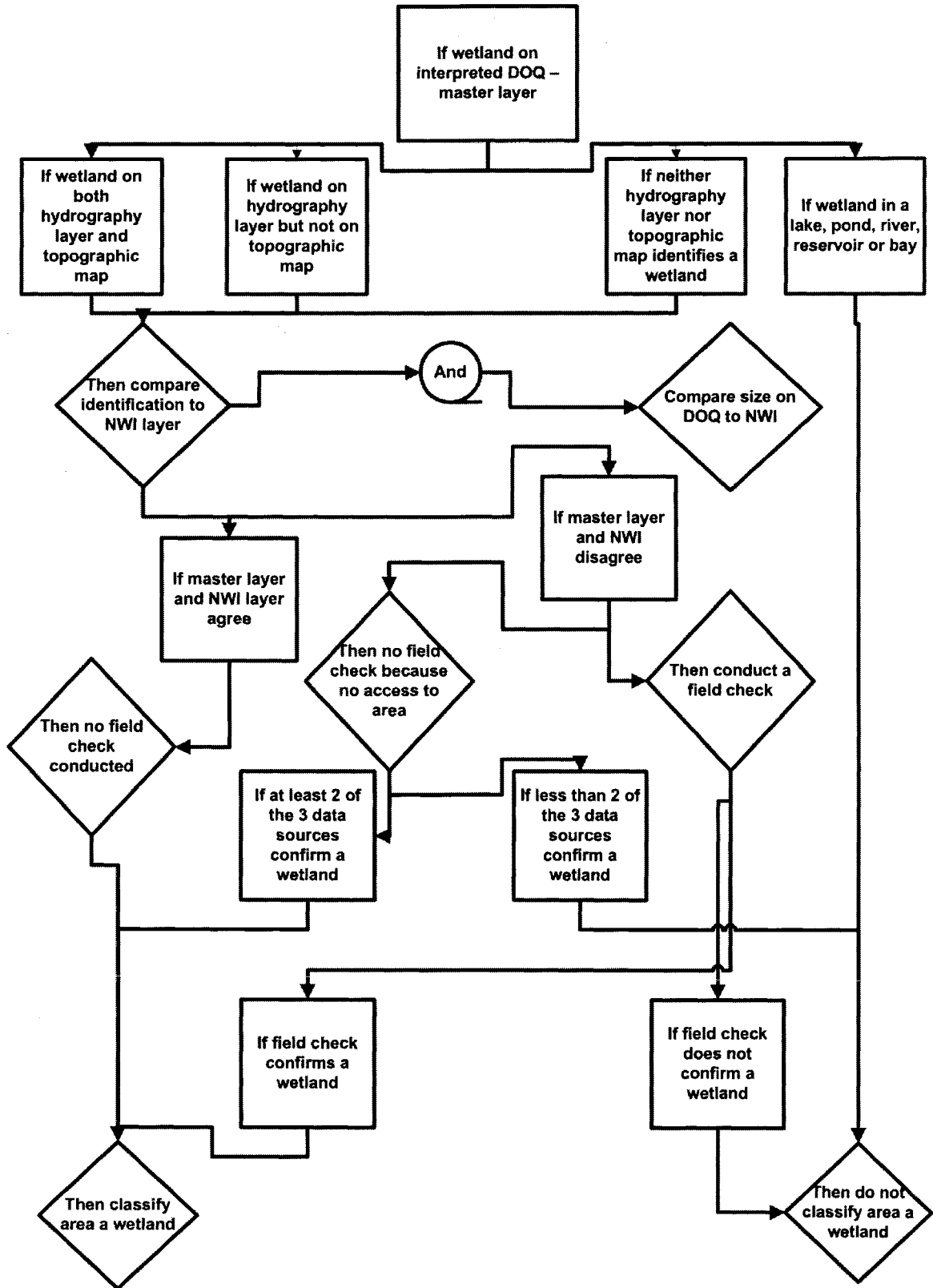


Figure 2. Flowchart for wetland identification process.

Analysis

The analysis for this study was broken up into two types, descriptive statistics and spatial statistics. I used descriptive statistics to conduct the analysis of the following: density of wetlands, percent of land area covered by wetlands, average size of wetlands, and size distribution of wetlands. These statistics were performed using Microsoft Excel (2003). The spatial statistics used in the analysis were: average nearest neighbor, standard deviational ellipse, and spatial autocorrelation. These statistics were performed using the ArcGIS Desktop software in conjunction with the Statistical Analyst extension (ESRI 2005).

Descriptive Statistics

To test the prediction that spatial distribution of wetlands is associated with urbanization level, I calculated the density of wetlands within each study area transect. Density of wetlands was calculated by tallying the total number of wetlands for each study area transect. This number was normalized by dividing the total number of wetlands by the total land area of each study area transect, to account for varying land areas for each of the four study area transects.

To estimate the abundance of wetlands within a study area transect, the percent of land area covered by wetlands for each study area transect was calculated. This number was calculated by dividing the total area of wetlands for each urbanization level within each study area transect by the total size of the urbanization level within each study area transect.

Average size of wetlands was calculated for each urbanization level within each study area transect to test the prediction that wetland size is associated with urbanization level. The average size of wetlands was determined by dividing the total area of wetlands per urbanization level within each study area transect by the total number of wetlands per urbanization level within each study area transect.

A graph depicting size range distribution of wetlands by urbanization level for each study area transect was created to provide a visual analysis of the distribution. Size ranges were calculated based on an adaptation from a similar study (Ekstein and Hygnstrom 1997) that found the number and total area of wetlands increased across a span of 43 years. The size ranges used in this temporal study were small (<1 ha), medium (2-10 ha) and large (>10 ha). These ranges were used to perform a chi-squared goodness of fit tests to check for similarities between years. I found on average, less than 30 wetlands per study area transect to be larger than 5 hectares, so I identified this as the largest wetland size range. In addition, I also found that on average, less than 30 wetlands per study area transect were smaller than 0.1 hectares, so I identified this as the smallest wetland size range. The middle three size ranges were then created based on average wetland size for the study area transects.

To test the predictions that a relationship exists between both the size of wetlands and urbanization level, as well as the number of wetlands and urbanization level, I tallied the number of wetlands per size range (<0.1, 0.1 < 0.5, 0.5 < 1.0, 1.0 < 5.0, and > 5.0). A chi-squared test of association was

performed (Zar 1999) to compare size distributions of wetlands among urbanization levels. A chi-squared test of association was also performed to compare the number of wetlands among the urbanization levels. This statistic provides a measure of how close the observed frequencies are to the frequencies that would be expected if the variables were independent (Agresti and Finlay 1986). A significance value of $p < 0.05$ was used.

Spatial Statistics

Spatial statistics are used to describe spatial patterns formed by geographic objects in one study area so they can be compared with patterns found in other study areas. The results of spatial statistical analysis can be used to describe forms, detect change and analyze how patterns can change over time (Wong and Lee 2005).

To assess the distribution of wetlands as they occur in each transect, I calculated the average nearest neighbor statistics for each urbanization level within each transect. The average nearest neighbor statistic was first introduced by two botanists, Clark and Evans (1954), to compare average distribution between nearest neighbors in a set of points to that of a random pattern for plant populations. The average nearest neighbor statistic measures the distance between each wetland centroid (center) and the nearest wetland's centroid location. It then averages all these nearest neighbor distances. The distribution of the wetlands are considered clustered if the average distance between wetlands is significantly less than the average for a hypothetical random distribution. If the average distance is significantly greater than a hypothetical

random distribution, they are considered dispersed (ESRI 2005). A centroid was created for each wetland area in order to perform this analysis. A Z score was calculated for each analysis. The Z score is a test of statistical significance that determines whether or not to reject the null hypothesis. Z scores are measures of standard deviation away from the mean. For example, if a procedure returns a Z score of +2.5 it is interpreted as +2.5 standard deviations away from the mean. In addition, a p-value was calculated for each analysis. A p-value is the probability of obtaining a result at least as extreme as the one that was actually observed, assuming that the null hypothesis is true. A p-value of $p < 0.05$ was used for this analysis. Both statistics are associated with the standard normal distribution. This distribution relates standard deviations with probabilities and allows significance and confidence to be attached to Z scores and p-values (Goodchild 1986). If the p-value is low, the less likely the result, assuming the null hypothesis, so the more significant the result.

To test the prediction that the number of wetlands is reduced by an increase in urbanization, wetland similarity (i.e. spatial autocorrelation) was measured using Moran's I Spatial Statistics for each study area transect. Spatial autocorrelation measures how similar or dissimilar neighboring points are in terms of a given attribute (Wong and Lee 2005). The associated attribute used for this analysis was urbanization level. Moran's I tool measures spatial autocorrelation based not only on feature locations or attribute values alone, but on both feature locations and feature values simultaneously (Cliff and Ord 1973). Given a set of features and an associated attribute, it evaluates whether the

pattern expressed is clustered, dispersed, or random. The tool calculates the Moran's I Index value and a Z score evaluating the significance of the index value. In general, a Moran's Index value near +1.0 indicates clustering, while an index value near -1.0 indicates dispersion (ESRI 2005). Moran's I Index is one method of performing spatial autocorrelation. With this method, the similarity of attribute values is defined as the difference between each value and the mean of all attribute values in question, versus a direct comparison as with the Geary Ratio method (Wong and Lee 2005). This study used the Moran's I Index method because the characteristics of its numeric distribution are more desirable than those of Geary's Ratio (Cliff and Ord 1973, 1981). Both a Z score and a p-value were calculated for each test to determine if the null hypothesis was not rejected. Therefore one can conclude there is no clustering of similar wetlands within each of the urbanization levels throughout the study area transects.

To characterize the spatial pattern of wetlands within each transect a standard deviational ellipse was calculated. The standard deviational ellipse shows a spatial spread of a set of point locations. It is used appropriately when spatial data don't conform to a circular pattern, but rather have a directional bias. Therefore using a standard distance circle will not fully reveal the bias of the spatial process. A logical extension of the standard distance circle is the standard deviational ellipse (Furfey 1927). The standard deviational ellipse measures the trend for wetland areas by calculating the standard distance separately in the x and y directions. These two measures define the axes of an ellipse encompassing the distribution of wetlands. The ellipse is referred to as the

standard deviational ellipse, since the method calculates the standard deviation of the x coordinates and y coordinates from the mean center to define the axes of the ellipse. The ellipse provides directional trends (i.e., whether features are farther from a specified point in one direction than in another direction) (ESRI 2005). One standard deviation was used to perform this analysis. A one standard deviational ellipse polygon will cover approximately 68 percent of the features, if the underlying spatial pattern of the features is concentrated in the center of the transect, with fewer features towards the periphery (spatial normal distribution). If the distribution is not spatially normal, the ellipse will not be concentrated in the center of the transect. This analysis was performed using the number of wetlands as the input value, not wetland size. Because the wetland data are polygons, centroids are used in the computations.

RESULTS

Wetland Identification

The development of the wetlands master layer ensured the number of wetlands were accurately identified for each study area transect and urbanization level (Table 2). In the Concord transect, a total of 177 wetlands were identified (51 were urban, 71 were suburban and 55 were rural). In the Rochester transect, a total of 262 wetlands were identified (33 were urban, 109 were suburban and 120 were rural). In the Manchester transect, 216 wetlands were identified (46 wetlands were identified as urban, 49 were suburban and 121 were rural). In the Nashua transect, 190 wetlands were identified (57 were identified as urban, 70 were suburban and 63 were rural).

Descriptive Statistics

Wetland density was highest in the rural area of each study area transect (Table 2). The highest density of wetlands for each study area transect was located within the largest size range identified for wetlands, >5 hectares (Figures 3-6).

The percent area covered by wetlands was highest in the rural areas for the Concord, Rochester, and Manchester transects, while in the Nashua transect it was highest in the suburban area (Table 3).

The average size of wetlands was largest in the rural area for the Concord, Rochester, and Manchester transects, while in the Nashua transect it was largest in the suburban area (Table 4).

The analysis of wetland size in relation to the distance from urban centers identified that the average size in the urban areas was less than that of the suburban and rural areas. There was a significant relationship within all four transects between the size of wetlands and the level of urbanization (Chi Squared test for association) (Table 5).

There were fewer wetlands found in urban areas as compared to suburban and rural areas. Rural and suburban areas contained the largest number of wetlands. For both the Manchester and Nashua transects, there was no significant relationship found between the number of wetlands and the urbanization level, while there was a significant relationship for both the Concord and Rochester transects (Chi Squared test for association) (Table 5).

Table 2. Density of wetlands per urbanization level for each study area transect.

Transect	Number of Wetlands	Total Size of Area (ha)	Density of Wetlands (# of Wets/ha)
Concord			
Urban	51	4110.49	0.0124
Suburban	71	5203.88	0.0136
Rural	55	3046.01	0.0181
Rochester			
Urban	33	2608.89	0.0126
Suburban	109	4173.81	0.0261
Rural	120	4191.81	0.0286
Manchester			
Urban	46	4323.82	0.0106
Suburban	49	2844.29	0.0172
Rural	121	4799.65	0.0252
Nashua			
Urban	57	4234.64	0.0135
Suburban	70	4407.35	0.0159
Rural	63	3929.04	0.0160

Table 3. Percent area covered by wetlands by urbanization level for each study area transect.

Transect	Total Size (ha)	Total size (ha) of wetlands	Percent Area Covered by Wetlands
Concord			
Urban	4110.49	78.35	1.91%
Suburban	5203.88	111.68	2.15%
Rural	3046.01	209.02	6.86%
Rochester			
Urban	2608.89	45.67	1.75%
Suburban	4173.81	153.98	3.69%
Rural	4191.81	177.45	4.23%
Manchester			
Urban	4323.82	26.84	0.62%
Suburban	2844.29	60.72	2.13%
Rural	4799.65	329.71	6.87%
Nashua			
Urban	4234.64	104.25	2.46%
Suburban	4407.35	268.51	6.09%
Rural	3929.04	208.50	5.31%

Table 4. Average size of wetlands in hectares by urbanization level for each study area transect.

Transect	Number of Wetands	Total size (ha) of wetlands	Average Size of Wetlands (ha)
Concord			
Urban	51	78.35	1.54
Suburban	71	111.68	1.57
Rural	55	209.02	3.80
Rochester			
Urban	33	45.67	1.38
Suburban	109	153.98	1.41
Rural	120	177.45	1.48
Manchester			
Urban	46	26.84	0.58
Suburban	49	60.72	1.24
Rural	121	329.71	2.72
Nashua			
Urban	57	104.25	1.83
Suburban	70	268.51	3.84
Rural	63	208.50	3.31

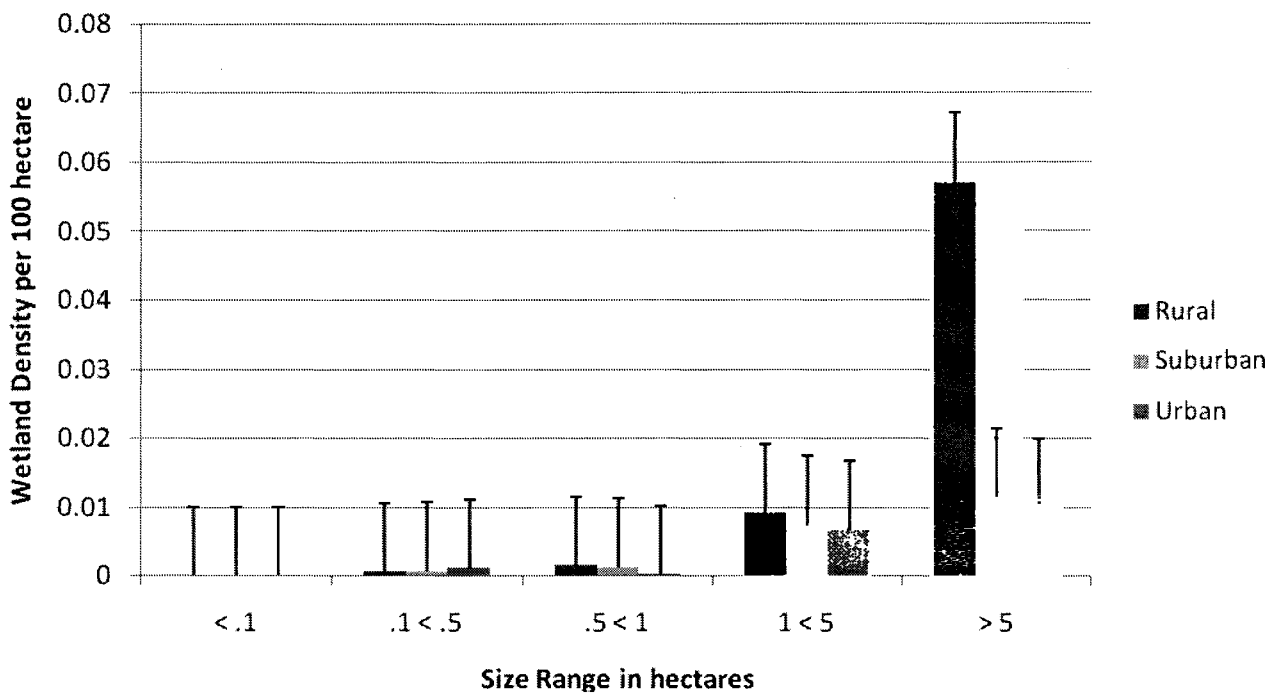


Figure 3. Density of wetlands by urbanization level and size range for the Concord transect.

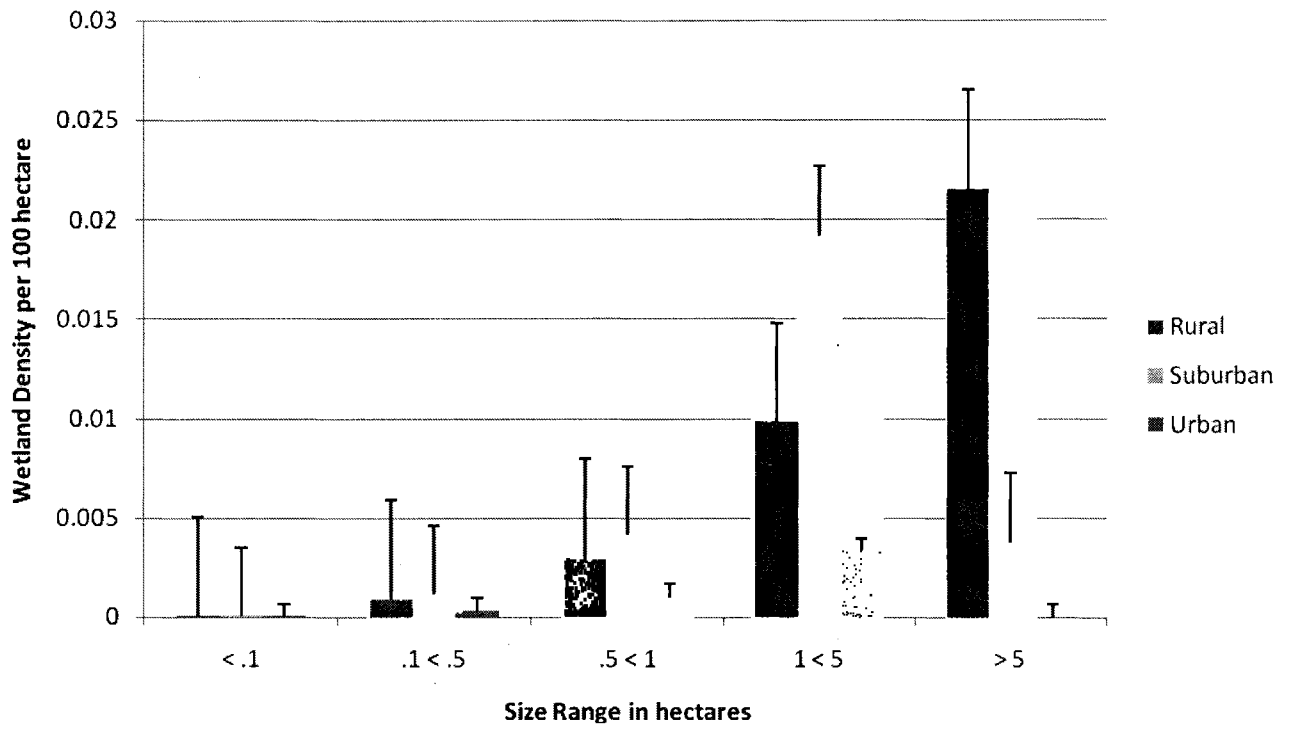


Figure 4. Density of wetlands by urbanization level and size range for the Rochester transect.

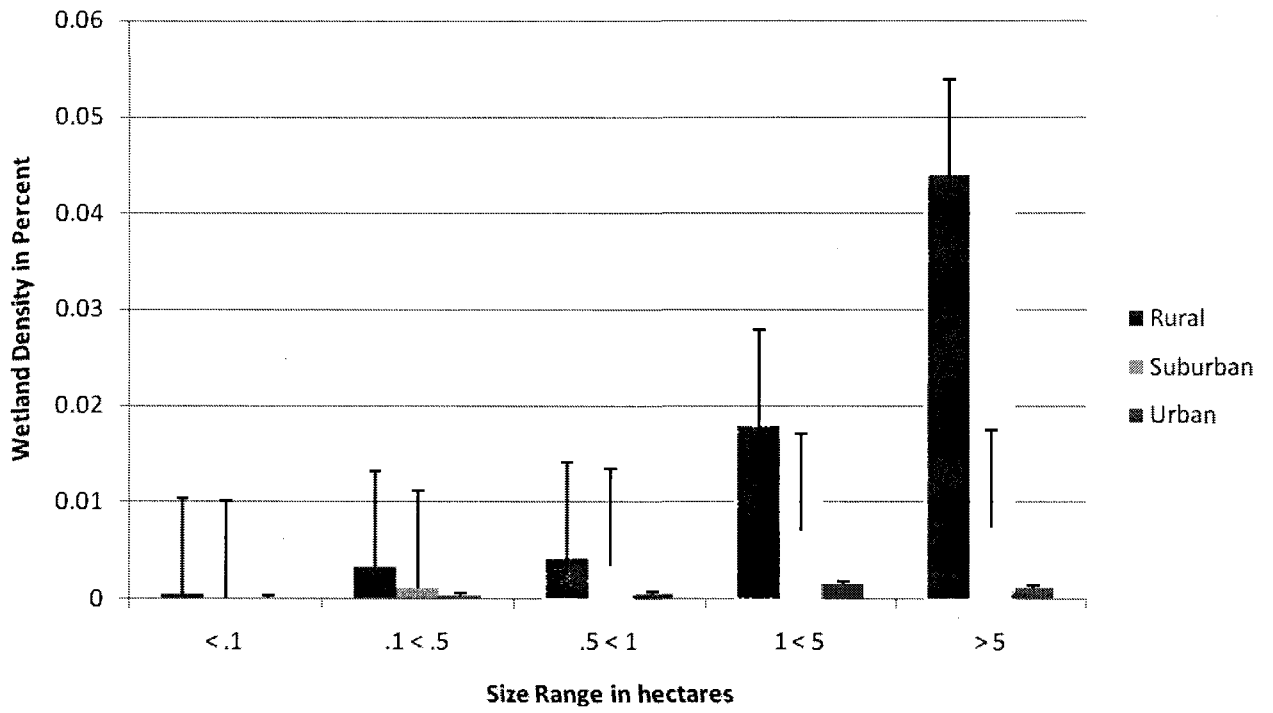


Figure 5. Density of wetlands by urbanization level and size range for the Manchester transect.

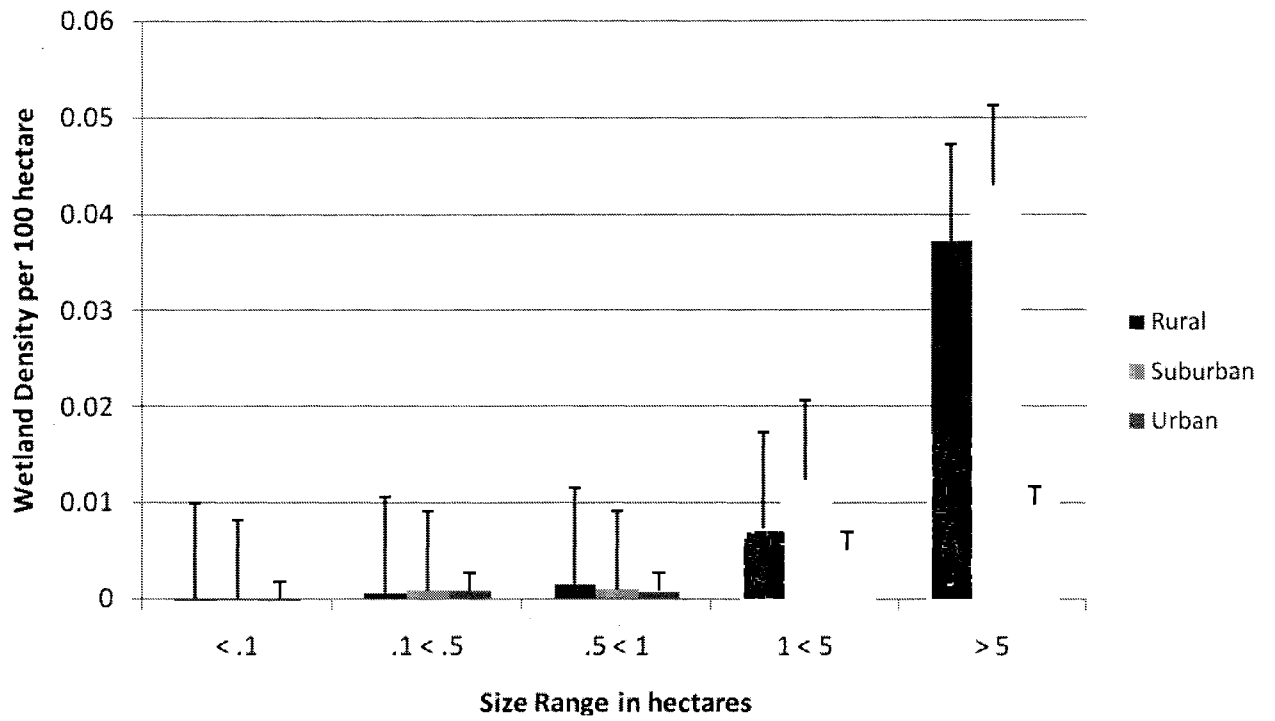


Figure 6. Wetland density by urbanization level and size range for the Nashua transect.

Table 5. Chi Squared test for association between the size of wetlands and urbanization level per transect and between the number of wetlands and urbanization level per transect. Test statistics in bold were significant at the 95% confidence interval.

Transect	Size of Wetlands χ^2
Concord	0.000001
Rochester	p< 0.000001
Manchester	0.007279
Nashua	0.031227
Transect	Number of Wetlands χ^2
Concord	0.004223
Rochester	p< 0.000001
Manchester	0.159318
Nashua	0.084907

Spatial Statistics

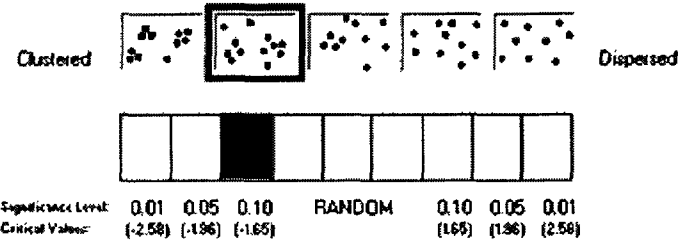
The average nearest neighbor spatial statistical analysis was performed to assess the distribution of wetlands as they occur in each transect by urbanization level. In the Concord transect, a clustered pattern was identified for all urbanization levels (Figure 7). In the Rochester transect, the suburban and rural areas exhibited a clustered pattern. The urban area showed a somewhat clustered pattern, but the pattern may be due to random chance with a Z score of -1.39 standard deviations (Figure 8). In the Manchester transect, all of the urbanization levels showed a clustered pattern (Figure 9). In the Nashua transect, only the urban area showed a clustered pattern. The suburban area did not show a clear pattern of clustering or dispersal of wetlands. In the rural area, a somewhat clustered pattern was identified but the pattern might be due to random chance, with a Z-score of -1.04 standard deviations (Figure 10).

Spatial autocorrelation (Moran's I) measurements of the number of wetlands within each urbanization level found all four transects have a Moran's Index of under +1.22 and exhibit a clustered pattern (Figures 11 - 14).

Standard deviational ellipses were calculated for each study area transect to identify the spatial pattern and directional distribution of the number of wetlands. In the Concord and Nashua transects, the ellipses were centered in the suburban area and extend to both the urban and rural areas, as defined by a spatial normal distribution (Figure 15). In the Rochester and Manchester transects, the ellipses were centered within the suburban and rural areas and

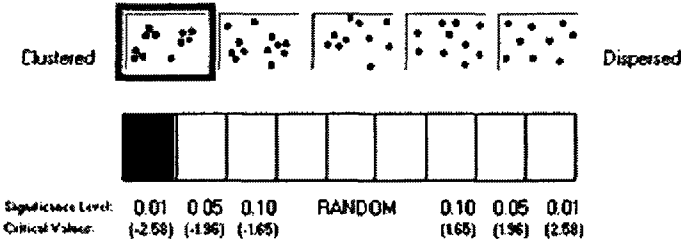
elongated. Therefore a spatial normal distribution was not found for these areas (Figure 15).

Observed Mean Distance / Expected Mean Distance = 0.86
 Z Score = -1.87 standard deviations



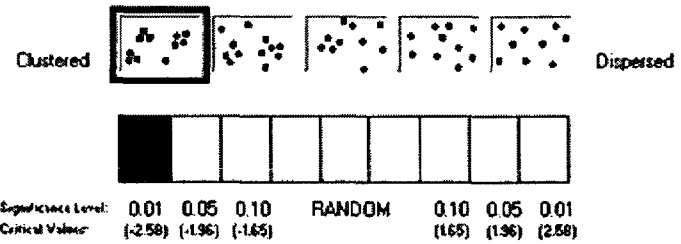
There is a 5-10% likelihood that this clustered pattern is the result of random chance.

Observed Mean Distance / Expected Mean Distance = 0.75
 Z Score = -4.09 standard deviations



There is less than 1% likelihood that this clustered pattern could be the result of random chance.

Observed Mean Distance / Expected Mean Distance = 0.7
 Z Score = -4.19 standard deviations



There is less than 1% likelihood that this clustered pattern could be the result of random chance.

Figure 7. Test for average nearest neighbor distance between wetlands for the Concord transect for each urbanization level. In order – Urban, Suburban, and Rural.

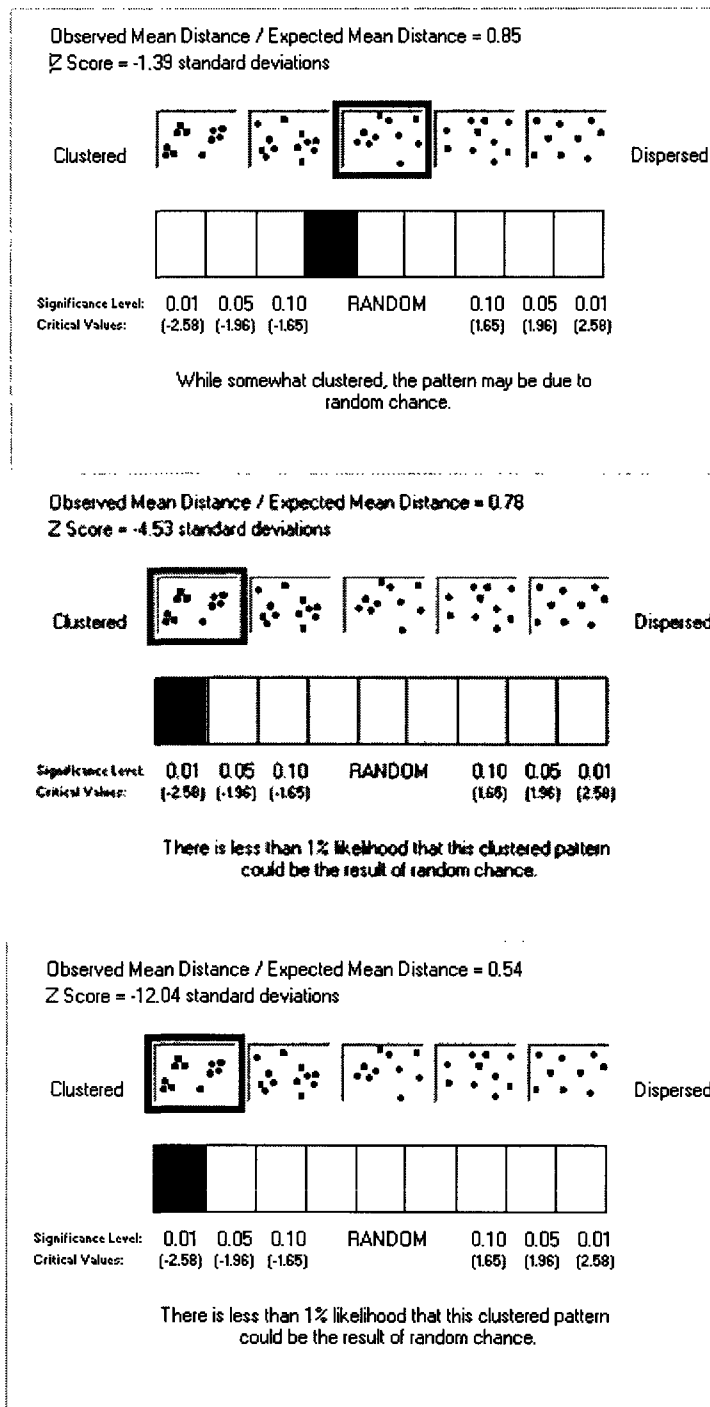


Figure 8. Test for average nearest neighbor distance between wetlands for the Rochester transect for each urbanization level. In order – Urban, Suburban, and Rural.

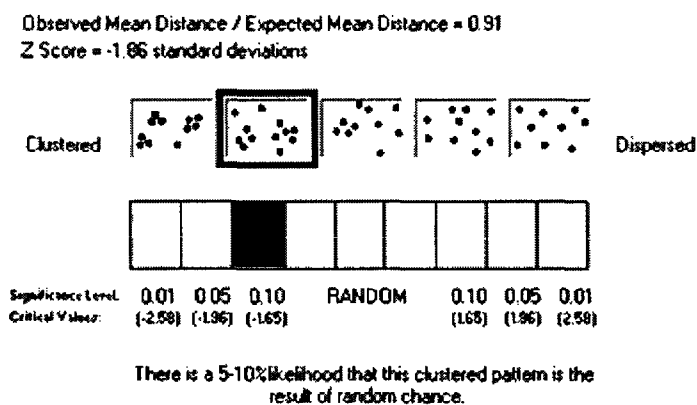
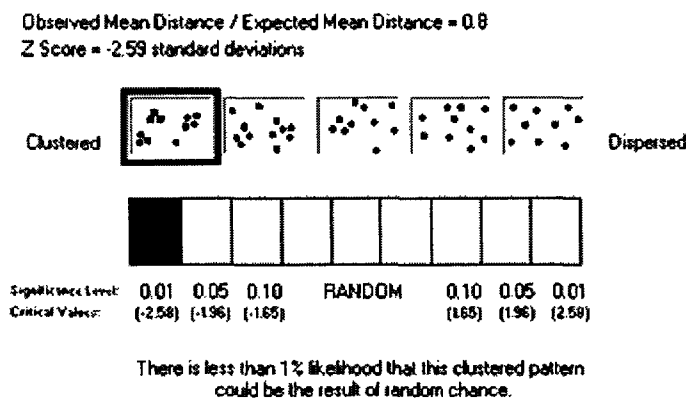
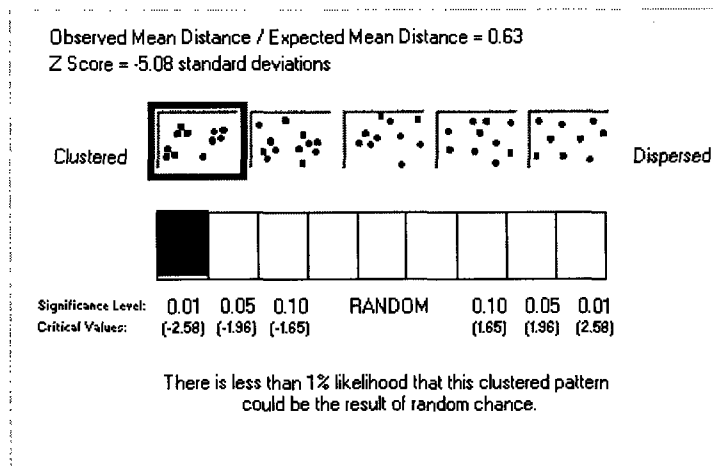
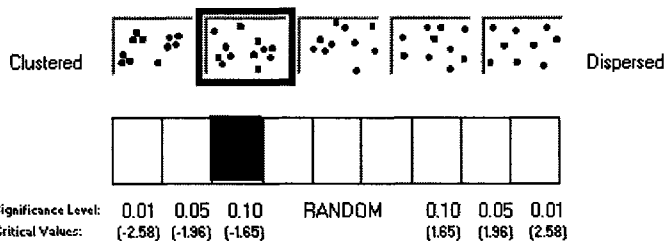


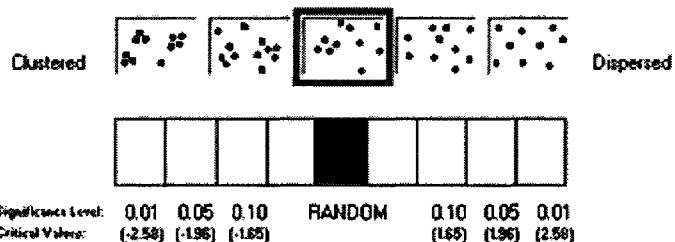
Figure 9. Test for average nearest neighbor distance between wetlands for the Manchester transect for each urbanization level. In order – Urban, Suburban, and Rural.

Observed Mean Distance / Expected Mean Distance = 0.87
 Z Score = -1.86 standard deviations



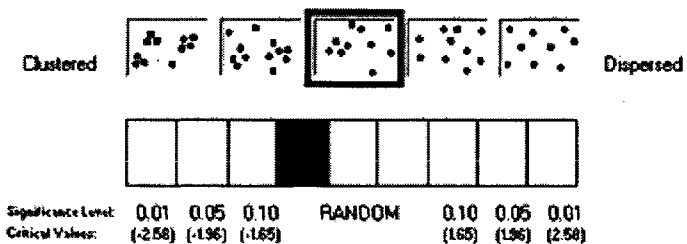
There is a 5-10% likelihood that this clustered pattern is the result of random chance.

Observed Mean Distance / Expected Mean Distance = 0.99
 Z Score = -0.19 standard deviations



The pattern is neither clustered nor dispersed.

Observed Mean Distance / Expected Mean Distance = 0.93
 Z Score = -1.04 standard deviations



While somewhat clustered, the pattern may be due to random chance.

Figure 10. Test for average nearest neighbor distance between wetlands for the Nashua transect for each urbanization level. In order – Urban, Suburban, and Rural.

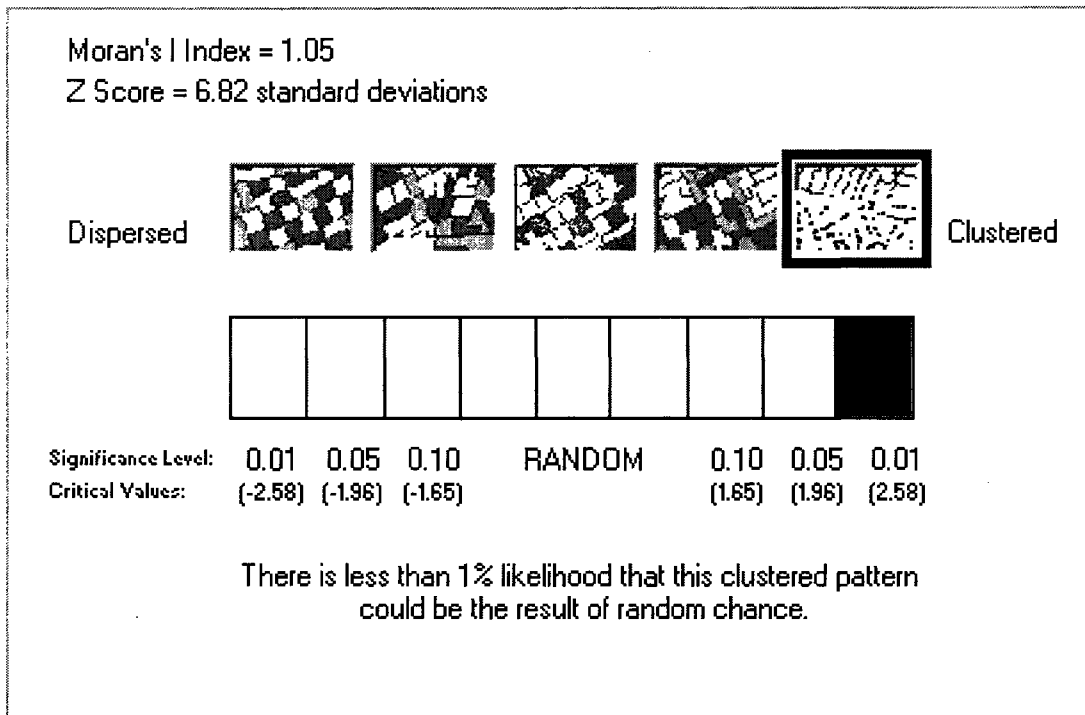


Figure 11. Spatial autocorrelation measurements (feature similarity) of the number of wetlands within each urbanization level (Moran's I) for the Concord transect.

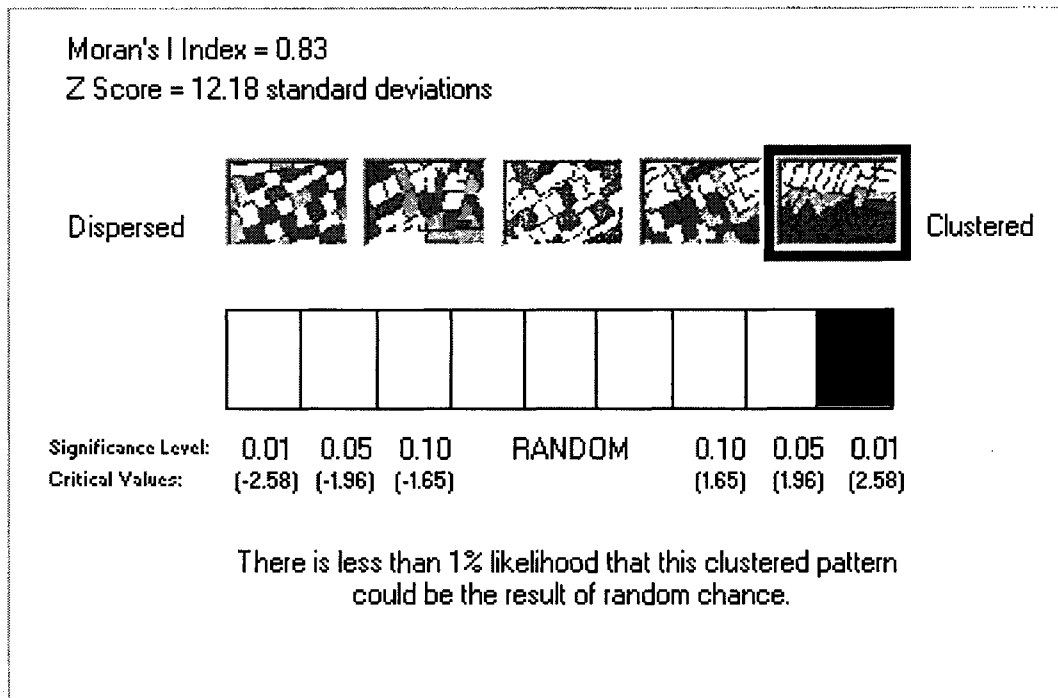


Figure 12. Spatial autocorrelation measurements (feature similarity) of the number of wetlands within each urbanization level (Moran's I) for the Rochester transect.

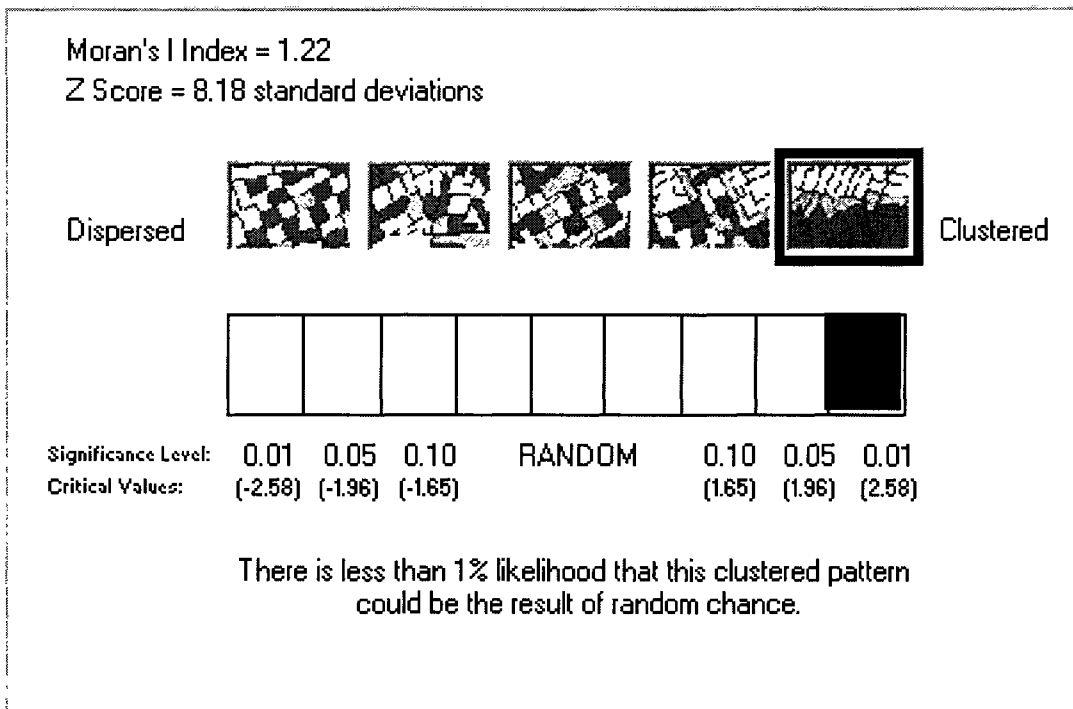


Figure 13. Spatial autocorrelation measurements (feature similarity) of the number of wetlands within each urbanization level (Moran's I) for the Manchester transect.

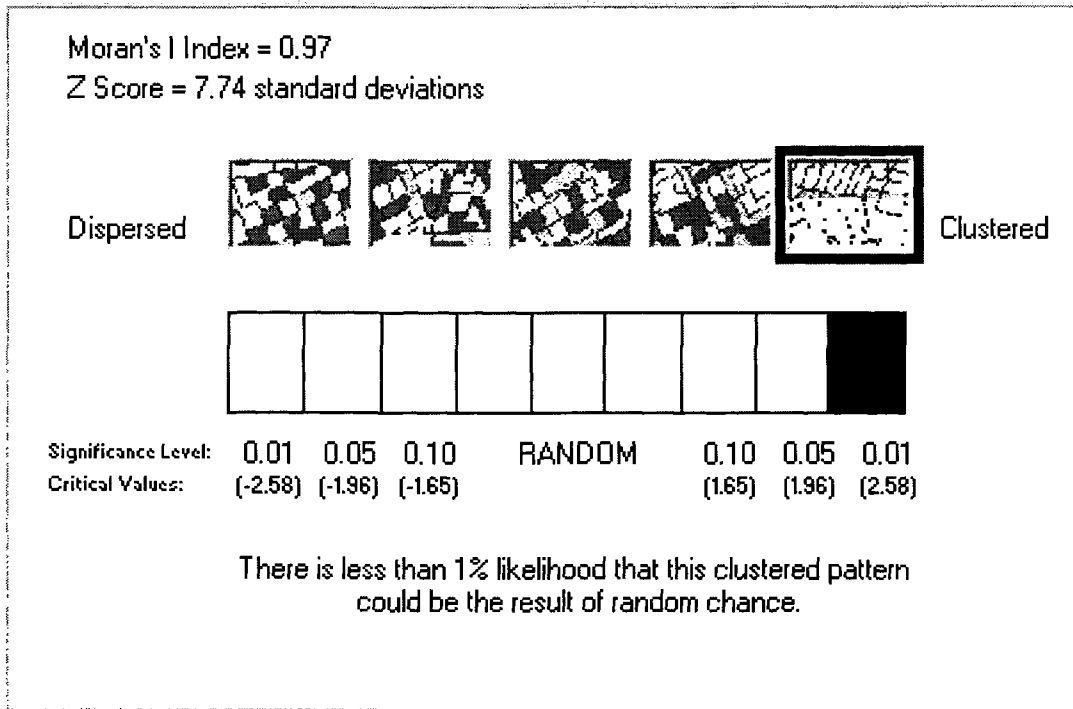


Figure 14. Spatial autocorrelation measurements (feature similarity) of the number of wetlands within each urbanization level (Moran's I) for the Nashua transect.

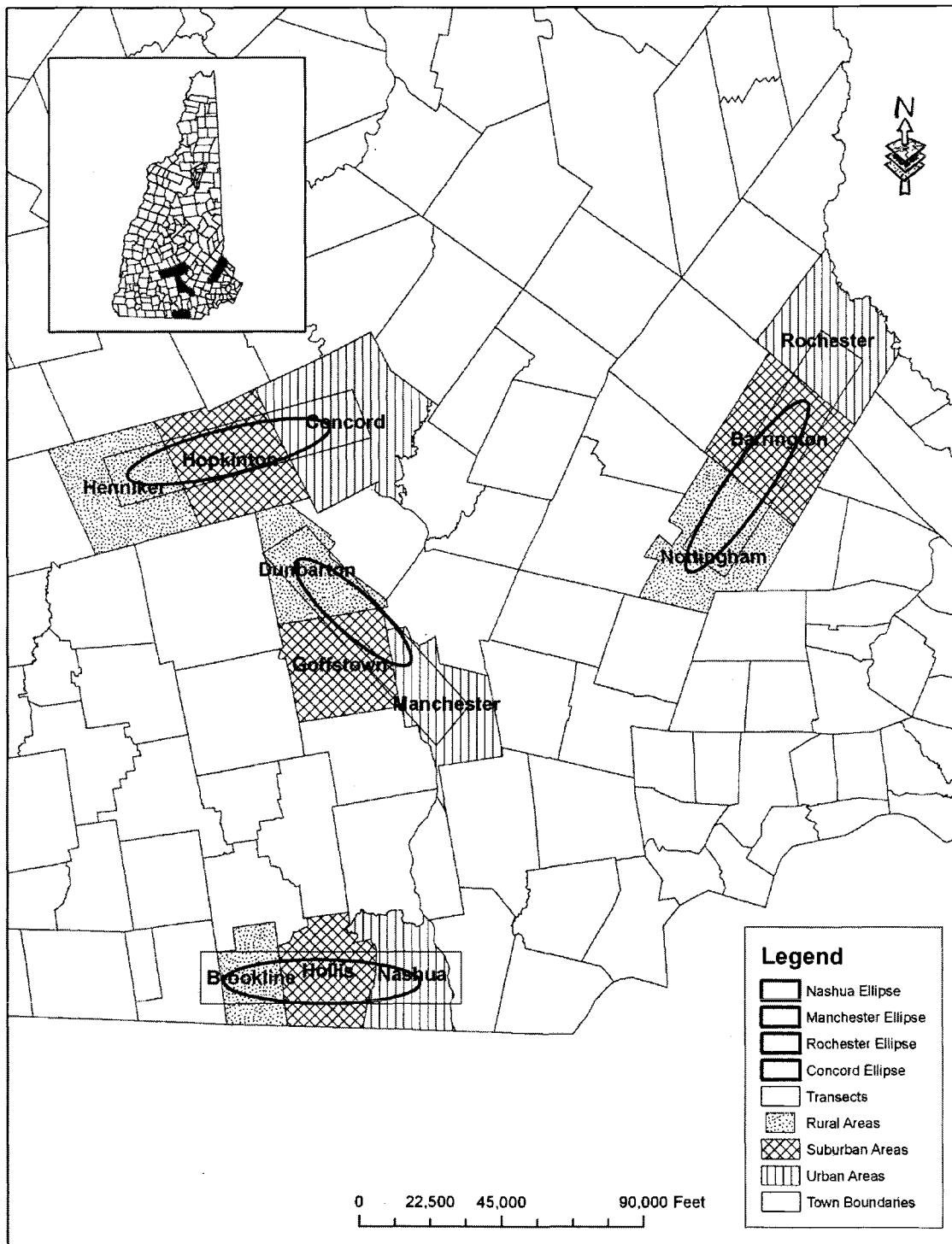


Figure 15. Standard deviational ellipse with 1 standard deviation, for each transect to identify spatial patterns.

DISCUSSION

Using an urban-rural gradient analysis, the results from this study suggest that land use change, in the form of urbanization, affects both the size, and spatial distribution of wetlands in New Hampshire.

My analysis showed the density of wetlands and the size of wetlands was smaller in urban areas than in suburban and rural areas along all study area transects. These results were expected since there is less development in rural areas coupled with less pressure to create commercial and residential development. In the future, the rural areas may succumb to development pressure, in a similar fashion to the current suburban areas. Urban sprawl, the spreading of a city and its suburbs over rural land at the fringe of an urban area (Kolankiewicz and Beck 2007), is a growing trend across the nation that most likely will affect New Hampshire in the future. Additional rural areas will become more inhabited based on proximity to urban areas. Wetland protection on a local and state level is essential to sustain the existing status of wetlands in New Hampshire and ensure the wetland dependent species the chance of survival. Additional wetland protection measures are also important from a community level (e.g. using Prime wetland designation or establishing conservation areas). Currently, 5 of the 12 communities analyzed in this study have designated Prime wetlands. Community growth plans also play an important role in determining how the landscape is affected by increases in urbanization. The NH Office of Energy and Planning is currently involved in a smart growth project, which

advises communities how to grow, while conserving and making the best use of vital natural and cultural resources. There are 8 smart growth principals, 3 of which address urbanization and natural resource protection and conservation. These principals are: maintaining traditional compact settlement patterns to efficiently use land, resources, and infrastructure investments; preserving New Hampshire's working landscape by sustaining farm and forest land and other rural resource lands to maintain contiguous tracts of open land and to minimize land use conflicts; and protecting environmental quality by minimizing impacts from human activities and planning for and maintaining natural areas that contribute to the health and quality of life of communities and people in New Hampshire (NH Office of Energy and Planning 2007). The smart growth principals can apply to various types of natural resources existing in New Hampshire, including wetlands.

The percent of land covered by wetlands in this study was generally highest in the suburban or rural areas. The urban areas were covered by less than 3 percent of wetlands in all of the study area transects, with Manchester having less than 1 percent of the land area in the transect covered by wetlands. Some species, such as waterfowl and amphibians, depend on a certain patch size to make the habitat suitable (Johnston 1994). Many wetland-associated mammals also have minimum home range requirements that limit the sizes of wetlands they can inhabit (Johnston 1994). Therefore, a decrease in average wetland size is as important to consider as cumulative area lost to urbanization and development in these transects. At the other end of the size spectrum,

Gibbs (2000) found that protection for small wetlands is essential to retain wetland densities minimally sufficient to sustain wetland biota. Goetz et al. (2000) found similar results in the Anacostia Watershed within parts of Maryland and D.C. They concluded that as urbanization increases in the Anacostia Watershed, 1) wetland area is decreasing; and 2) the land is being fragmented, causing an increase in wetland isolation.

In this study, the average size of wetlands was the largest in the rural areas. The exception was Nashua, where the suburban area had the largest average size. This exception could be explained by data patterns attributed to the demographic and landscape composition of the transect areas. All study area transects contained the three urbanization levels, but the population density differences between the four study area transects coupled with topography influenced the spatial pattern of the data. Nashua has the largest population of the four study area transects, an estimated 200,000 people, which was 30 percent higher than Manchester and over 60 percent higher than both Rochester and Concord (US Census Bureau 2002). The landscape composition of the Nashua study area transect differed from the other three study area transects in that the urban area included a portion of Hudson, NH, also classified as an urban area (US Census Bureau 2002). In the other three transect study areas, only one urban town was included in the study area transect. In addition, Hollis, the suburban area in the Nashua study area transect, has increased wetland protection measures compared to urban and suburban areas in the other study area transects. Specifically, a regulation imposing a 100 foot buffer is required

around all wetlands and surface waters. In addition, the Master Plan, created in 1998, identified 21 areas of potential Prime Wetland status to be given special protection (Hollis NH Master Plan 1998). Therefore, that is why Nashua differs from the other transects with regards to the average size of wetlands.

In this study, the average nearest neighbor analysis was used to show the mean distance between wetlands. In the Concord transect a clustered pattern was found for all of the urbanization levels. In addition, the urban area of the study area had the largest distance between wetlands. Similar results were found by Rubbo and Kiesecher (2005), who found clustering patterns for wetlands varied across urbanization levels, noting that the distance to the nearest wetland was lowest in rural areas and highest in urban. Clustering of wetlands is important to limit landscape fragmentation. Wetlands that are not clustered are less able to support viable populations of dependent species and are more susceptible to disturbance. In addition, species interactions, such as those between predators and prey, may be altered.

In the Rochester transect a clustered pattern was found in both the suburban and rural areas. In the urban area, wetlands were found to be somewhat clustered, but the pattern may be due to random chance. In addition, the largest distance between wetlands was found in the urban area, which supports Rubbo and Kiesecher's (2005) findings that the distance to the nearest wetland was lowest in rural areas and highest in urban areas.

In the Manchester transect all three urbanization levels were found to have a clustered pattern. The greatest distance between wetlands was found in

the rural area. The landscape composition of the rural area was a factor in these results. There was a large amount of land area where there was no surface water at all. These areas could be farms or forested areas where small wetlands were not able to be identified. Additional analysis could be performed on these areas to determine the cause of this large distance between wetlands.

In the Nashua study area transect, the largest distance between wetlands was found in the suburban area. In addition, only the urban area of the transect showed a clustered pattern. The majority of the suburban wetlands were extremely elongated in shape, which in comparison to the other three study area transects, was unique. The shape of these wetlands impacted the results of this analysis since it is performed by placing a centroid in the center of the polygon (wetland) area and then performing the nearest neighbor analysis. The suburban wetlands for this transect had both the largest percent of land area covered by wetlands as well as the largest average size of wetlands, indicating a strong wetland presence. Additional analysis could be conducted to determine if the distance between wetlands is due to the shape of the wetlands or is a result of fragmentation of the landscape.

Wetland similarity, measured using Moran's I spatial analysis tool, was used to show how the number of wetlands is reduced by an increase in urbanization level. This test identified a clustering pattern for all four of the study area transects. The clustering pattern shows that landscape fragmentation is not impacting the wetland mosaics as drastically as predicted in this study. This test was performed using the number of wetlands and not wetland size, therefore

prohibiting the conclusion that wetland size is impacted by urbanization level. However, the non spatial Chi Squared test did conclude that wetland size is being impacted by urbanization level for all four transects.

In this study, a standard deviational ellipse was calculated for each transect to identify spatial patterns of wetlands. If wetlands are exhibiting a spatial normal distribution, then the expectation would be that wetlands were concentrated in the center of the ellipse, with fewer wetlands to the edge. A spatial normal distribution pattern was found for both the Concord and Nashua study area transects. Both study area transects have similar counts of wetlands, with the largest number of wetlands in the suburban area and less in the urban and rural. The normal distribution pattern supports the hypothesis that a smaller number of wetlands are expected in the urban areas than the suburban. However, I did not predict such a small number of wetlands in the rural area. I expected the largest number of wetlands to be found in the rural areas. These findings are not necessarily an indication that development and urbanization are affecting these areas. Instead, they could be a predictor that there is less landscape fragmentation occurring. With less landscape fragmentation, larger patches of wetlands are possible, compared to smaller more isolated wetlands occurring where fragmentation is abundant.

Rochester and Manchester did not exhibit a normal distribution pattern, instead each having a unique spatial pattern. The Rochester study area transect ellipse was centered between the rural and suburban areas, and was non-existent in the urban area. The number of wetlands in Rochester were unique

compared to the other three study area transects. There were approximately 30 percent less wetlands identified in the urban area for this transect than the suburban and rural areas. In the other study area transects, the counts were more similar between the various urbanization levels. This unique pattern for Rochester could be due to less land area designated as wetlands within the city in general, not necessarily as a result of urbanization impacts. To more clearly analyze this pattern, a temporal analysis should be done to see if wetland loss to development and urbanization is truly the cause of this unique spatial pattern.

In the Manchester transect, the ellipse was skewed towards the rural and suburban areas with only a small portion of the ellipse in the urban area. Manchester's spatial pattern would be more similar to a normal distribution if the transect composition was not so unique. The suburban area in the Manchester transect was substantially smaller than both the urban and rural areas, whereas in Nashua and Concord, the suburban area was larger than the other two urbanization levels. The study area transects were created based on US Census data for population density, which is affected by political boundaries. The orientation of how the political boundaries of the cities and towns for the Manchester transect were unique in this study. There was no alternate way to compose the study area transect for Manchester to be used in this study.

Gibbs (2000) found similar patterns for wetland density as were found in this study for the Nashua and Concord study area transects. He found wetland density declined in urban areas compared to rural areas. The spatial patterns found in this analysis are supported by an observed increase in urban

development within New Hampshire. More wetlands are being lost in the urban areas due to the demand for housing and commercial properties. In addition, the standard deviational ellipse can be utilized as a prediction tool for where additional landscape fragmentation may spread, based on the direction of the ellipse.

When identifying wetlands for this study, small forested wetlands may have been underestimated. Kudray and Gale (2000) found that when evaluating NWI maps in heavily forested areas, the lowest level of accuracy occurred when identifying forested wetlands, which represent most of this study area. Stolt and Baker (1995) found the NWI often underestimated the size of wetlands. Dahl (1992) considers forested wetlands the most difficult wetland type to identify from aerial photographs. Additionally, evergreen forested wetlands are among the most difficult wetland type to identify due to canopy retention (Tiner 1990). Evergreen forests are common throughout New Hampshire. Despite these challenges, various studies (Swartwout et al. 1981, Crowley et al. 1998, Nichols 1994, Stolt and Baker 1995) have found that NWI maps correctly identify wetlands at an accuracy of over 90 percent. In addition, small wetlands, less than 0.1 hectare were difficult to identify due to the scale and format of the existing imagery and GIS data used for analysis. Gibbs (2000) found that larger wetlands were detected more reliably when identifying forested and non-forested wetlands. Regional evaluation of wetlands, such as this study, should be continued to further develop the NWI data and increase the interpretation accuracy for forested areas.

In conclusion, I found that the density of wetlands was lower closer to urban centers, which supports the hypotheses that the number of wetlands and the size of wetlands are impacted by urbanization. In addition, I concluded that there is a direct relationship between the percent of land cover of wetlands and urbanization. As wetland density and percent cover decreases, remaining wetlands may become less efficient at performing necessary functions including sediment and nutrient control, floodwater retention, groundwater recharge, and more. They may also not be able to meet minimum area requirements for some species and contain fewer habitat types/niches and therefore fewer species. Increases in fragmentation of the landscape may directly impact those populations dependant on particular species, particularly ones that are more susceptible to disturbance. Fragmentation may also influence species interactions, such as those between predators and prey.

I infer that, over time, there will be more large wetlands in rural areas. These patterns are due largely to settlement patterns, as well topography of the landscape. Future development will negatively impact wetland size and distribution within New Hampshire, particularly in suburban areas, where development is on the rise. I believe more small wetlands will be lost due to lack of regulations as well as the difficulty in identifying small wetlands using the techniques presented in this paper. Extensive field studies are required to adequately identify small wetlands, and limited resources for both state and local governments will inevitably prohibit these studies.

It is the intention of this study to determine how urbanization affects the size and spatial distribution of wetlands so that future studies may focus upon the effects of urbanization on wetlands on a regional scale. These data can be used to enhance the existing NWI data and assist in urban planning. Additional analysis should be conducted with higher resolution imagery, in true color, and flown in the spring to further develop these data for New Hampshire.

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