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

Katie Jacques, Research Assistant
Russell G. Congalton, Professor
Kimberly Babbitt, Associate Professor
Department of Natural Resources
University of New Hampshire
Durham, NH 03824
katielynn_1@yahoo.com
russ.congalton@unh.edu
kbabbitt@cisunix.unh.edu

ABSTRACT

The spatial and size patterns of wetlands were examined along four urban-rural transect of 5 km by 25 km sections in New Hampshire. Each transect included urban, suburban and rural areas of proportional size. This study identified the relationships between the urbanization level and these spatial patterns of wetlands. These analyses indicated a direct correlation between the urbanization level and distribution and size patterns of wetlands in New Hampshire. These findings are intended to assist in urban planning for the state of New Hampshire.

INTRODUCTION

New Hampshire is witnessing a period of sustained and accelerated population growth. Most of this growth is centered on urban areas (Stein et al 2000); yet rural communities are undergoing dramatic changes both in numbers of people and in landscape composition. In 1989, 74% of the United States population (203 million people) resided in urban areas and that number is expected to increase over time (Fox 1987). 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, 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. In 2025, the state's population is projected to be almost 1.6 million. 12 municipalities will be classified as urban, 89 will be suburban, and 158 will be rural (NH Office of Energy and Planning, Theobald 2003). Urbanization and development are factors that can influence trends in landscape composition, such as fragmentation, in both urban and rural areas. In addition, human threats on wetlands are becoming more evident in practices such as filling, developing and dredging. It is believed that wetlands are among America's most valuable and threatened natural resources. This research focuses on identifying the relationship between urbanization and the spatial distribution and size of wetlands in order to assess the impact urbanization is having on wetlands in New Hampshire.

Background

Wetlands are identified based upon three criteria; the presence of plants adapted to survive in wet soil conditions, the presence of water at or near the surface for more than two weeks during the growing season, and the presence of hydric soils (NH Department of Environmental Science 2002). Wetlands, in their natural state, perform ecological functions that are vitally important to the environment and economic health of the nation and 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 providing damage protection by reducing 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.

Wetlands are also sources of food, shelter, essential breeding, spawning, nesting and wintering habitats for fish and wildlife. These include migratory birds, endangered species and commercially and recreationally important species. Wetlands need to be recognized as part of a complex, interrelated, hydrologic system.

During the 1780s the conterminous United States contained an estimated 221 million acres of wetlands. Over a 200-year period, wetlands have been drained, dredged, filled, leveled and flooded. Twenty-two states have lost 50 percent or more of their original wetlands since the 1780's (Dahl 1990). At the time of the nation's settlement, wetlands represented approximately 221 million acres (89.5 million ha) of the land area in the lower 48 states (Dahl 2000). By 1997, only 105.5 million acres (42.7 million ha) remained, leaving just 47.7 percent of the original wetland acreage (Dahl 2000). Wetlands now occupy about 5.5 percent of the land surface of the lower 48 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, 1984).

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. From 1986-1997, urban development accounted for an estimated 30 percent of all losses, and 21 percent attributed to rural development. Of this loss, ninety-eight percent were found to be freshwater wetlands (USFWS 2000).

Digital maps of wetlands, developed for much of the United States under the authority of the U.S. Fish and Wildlife Service's National Wetland Inventory (NWI), are available and provide an opportunity for examining human effects on the composition of wetland mosaics. Geographic Information Systems (GIS) can assist in locating wetlands by using the NWI data layer. 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. Using GIS, the spatial distribution of wetlands can be interpreted, showing patterns that link urbanization and development to the loss and fragmentation of wetlands. Area, although significant to asses size of the wetland, is not the only factor in determining the importance of both large and small wetlands. The number of individual wetlands is vital because it addresses the abundance and distribution of individual wetland populations (Richlefs & Schluter 1993).

Literature Review

With development and urbanization on the rise throughout most of the United States, it is becoming increasingly important to assess the natural resources that exist throughout various ecosystems. Of these various ecosystems there is one type that stands apart – wetlands. Wetlands are unique because of their hydrologic conditions and their role as ecotones between terrestrial and aquatic systems (Mitsch and Gosselink 2000). Throughout history, wetlands have been both embraced as well as shunned by human populations. There is no definitive way to calculate the complete impact humans have had on the global extent of wetlands, but in heavily populated areas it has been observed that 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 reference to size, distribution, health, and function. Johnston (1994) found that because wetlands are not isolated, and rather that they are components of larger landscapes, that cumulative impacts to wetlands only provide a partial picture. Studies conducted on wetland density have shown that a direct relationship does exist between human density and wetland density, and that as human density shifts from rural to urban, wetland distribution shifts from clustered to fewer and more isolated wetlands (Gibbs 1998). Wetland size and proximity 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.

Gradient analysis has been applied to 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 a successful tool for the 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).

Objectives

The objectives for this study were to examine the spatial relationships between wetlands and urbanization levels throughout New Hampshire, as well as identify the effects these levels have on the size of wetlands. More specifically, this project investigated if the spatial distribution of wetlands changed based on the distance from an urban center and if the size of wetlands increased as one moves along an urban-rural gradient. We hypothesized that there is a direct correlation between distance from an urban center and the size and distribution of wetlands. We

predicted that as you move away from the urban center, the quantity of wetlands will increase, as well as the spatial distance between wetlands.

METHODS

Study Area

This study evaluates wetland size and distribution for four locales in New Hampshire encompassing an urban, suburban and rural area, which when grouped together compose a transect for the study area. For the purposes of this study, urban, suburban and rural are classified using definitions from the New Hampshire Minimum Impact Development method (New Hampshire Minimum Impact Development Partnership, 2001). Urban areas are identified as cities that contain 10000-20000+ housing units, suburban areas are identified as cities and towns with 2,000-9,999 housing units and rural areas are identified as towns with up to 1,999 housing units. Eight urban areas were identified within New Hampshire, and from these, four were chosen. These include: Concord, Manchester, Nashua and Rochester. These four areas were chosen due their geographic location in relation to both suburban and rural areas, thus allowing the transects to include a representative area from each urbanization level. The study area for each transect extends out from the urban centers into rural areas using a 5km wide by 25km long belt transect (Figure 1).

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. 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. 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, and has the second highest opulation increase (8.7 percent). 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).

The study area extends out from the urban centers into rural areas using
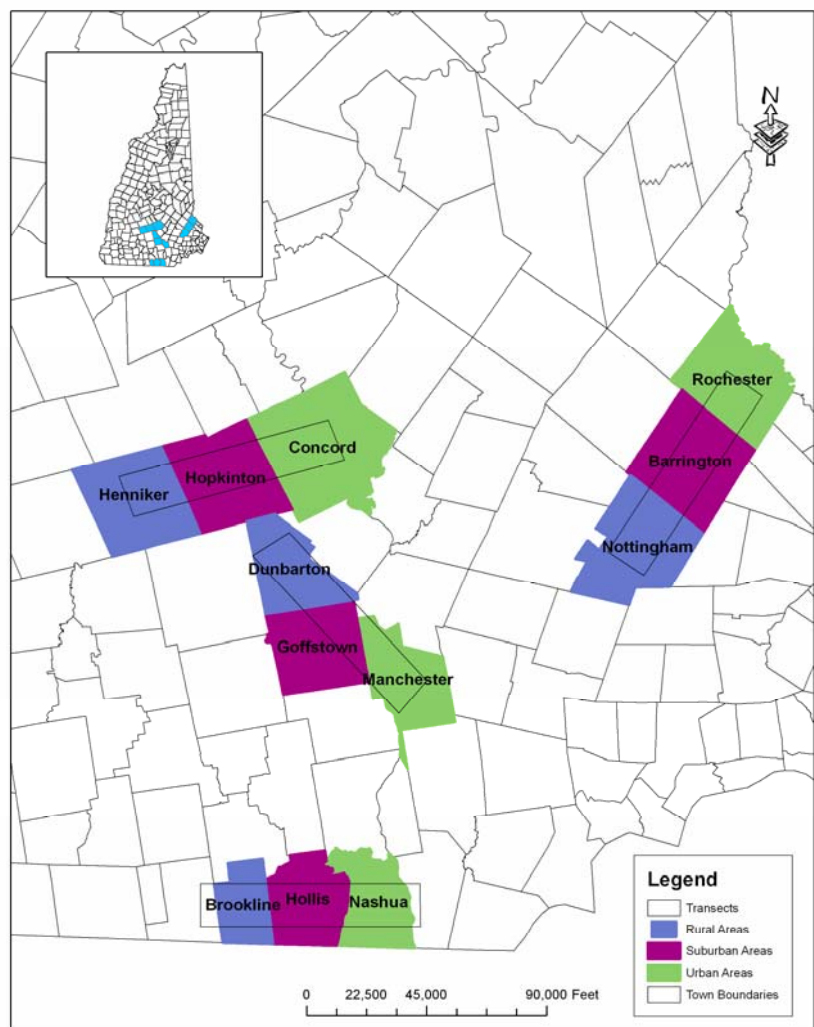
Figure 1. Study areas with the 5 x 25 km urban-rural transects outlined within New Hampshire.

a 5km wide by 25km long belt transect. The creation of these transects adds an additional 8 towns to the study area with both suburban and rural areas 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.

Data Acquisition

This project required the acquisition of Nation Wetlands Inventory (NWI) data covering the following urban, suburban and rural areas: Concord, Manchester, Nashua, Rochester, Hopkinton, Goffstown, Barrington, Hollis, Henniker, Dunbarton, Brookline, and Nottingham. These data are available through NH GRANIT as supplied by the US Fish and Wildlife Service from 1983. For the same study areas, hydrography data were also acquired, which are available from NH GRANIT as supplied by the US Geological Survey and last updated in January 2006. Political boundary data for the state of New Hampshire were also acquired from NH GRANIT. These data were supplied by the US Geological Survey, last updated in June 1996. Digital Orthophoto Quads (DOQs) were also used to aid in the analysis of wetlands for the designated areas. The DOQs were flown in April of 1998 at a scale of 1:12000 and are panchromatic. In addition, National Agricultural Imagery Program (NAIP) ortho-imagery was used. This imagery is acquired during the agricultural growing seasons in the continental US. The data are from 2003 and are at a scale of 1:40,000 in true color. Topographic maps, in the form of a Digital Raster Graphic (DRG) were also used at a scale of 1:24000.

Base- Map Creation

In order to identify the existing wetlands for the study areas, NWI, hydrography, NAIP, DOQs, DRGs, NHDOT roads, and political boundary data were used. The NWI, hydrography, NHDOT roads, and political boundary data are all vector data types. All of the data were loaded into ESRI ArcGIS Desktop v 9.1 software and each data type was clipped to the study area transect for each urban center using geoprocessing tools within the software. An ESRI personal geodatabase (PGDB) was used 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. Base maps were created for each of the study area transects using all of the data types.

Photointerpretation Techniques

Photointerpretation techniques were used to identify wetland areas on the raster datasets. 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. There are certain conditions that must be met in order to make the photo interpretation process successful such as quality and timing of photos, ground referencing, season and scale. In order to obtain the best interpretation of the wetlands from digital raster data, a combination of topographic maps, DOQ and NAIP imagery were used to create the base interpretation layer.

For the topographic maps, any area with the standard wetland symbol was digitized. The DOQ images were analyzed using training areas for the interpretation that incorporated issues of the scale and pixelization. These areas represented both forested and non-forested wetlands and spanned all three urbanization levels. When the DOQ images became difficult to interpret, the NAIP imagery was used as a secondary reference.

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 feature class, both the DOQ and NAIP imagery was used to add additional wetland polygon locations to the feature class. This established the creation of the 'boss layer'. The boss layer was then used as a data source for a model to run an intersect analysis. The first time this analysis was run using the hydrography data layer, then the resulting layer was used to run another intersect analysis this time with the NWI data. The first intersect layer is referred to as intersect 1, and the second intersect layer is referred to as the final intersect. To locate areas where field checks needed to be conducted, the NWI and hydrography data were subtracted from the final intersect layer to identify those areas.
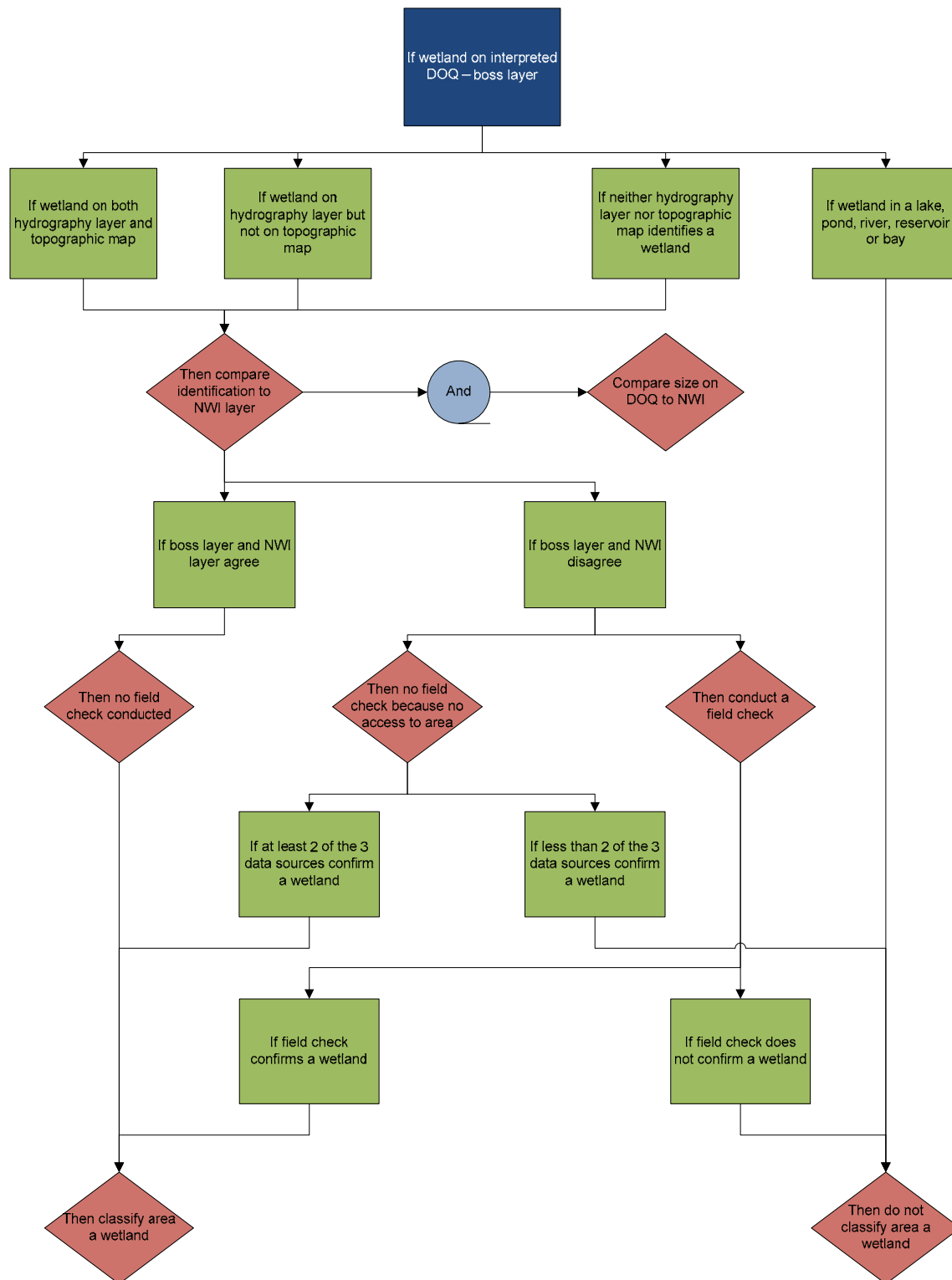
Figure 2. Flowchart for identifying the wetland identification process.

Field checks were conducted twice in the data collection process. The first was in the Concord transect due to the fact that the boss layer (the photointerpreted DOQ layer in conjuction with the hydrograpy layer and topographic map) did not agree with the NWI layer in the rural area of the transect. After the field check was conducted, it was found that the area was considered a wetland. The second field check was in the Rochester transect in the suburban area, again due to the fact of the boss layer and the NWI layer not being in agreement to the site being classified a wetland, and it was found be 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.
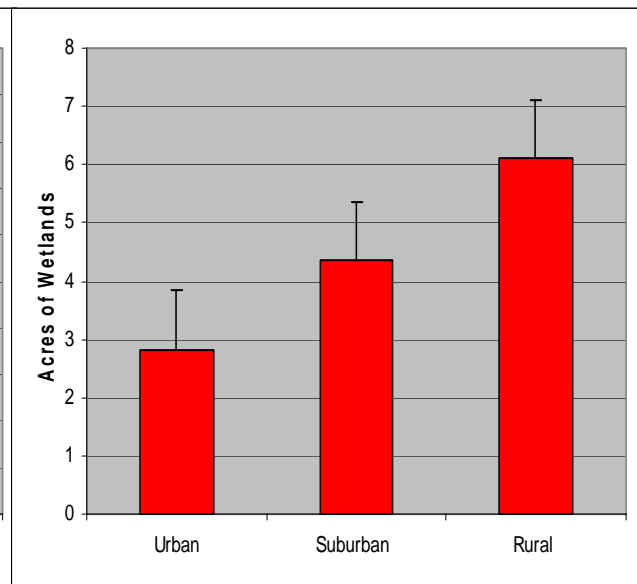
Statistical Analysis

To test the hypotheses that wetland size and distribution are affected by urbanization and development along urban-rural transects, we calculated the total amount of wetlands for each urbanization level using the statistical tools for attribute tables within the ArcGIS software. To assess size, we calculated the total area that wetlands cover on the ground in each urbanization level. In addition, the average wetland size for each urbanization level was computed. The results were tabulated and charted using Microsoft Excel. Additionally, pivot tables and bar graphs were created for each transect to assess both the quantity of wetlands and the acreage of wetlands by urban level and size category. To identify if there were significant relationships between both the size of wetlands and urbanization level as well as the number of wetlands and urbanization level a Chi Squared test for significance was employed. To assess the distribution of wetlands as they occur in each transect, we used average nearest neighbor spatial statistics within the ArcGIS 9.1 software. To identify the spatial pattern of wetlands within each transect a standard deviational ellipse was calculated within the ArcGIS 9.1 software. Lastly, the spatial autocorrelation was measured using Moran's I Spatial Statistics for each transect encompassing all three urbanization levels.

RESULTS

Wetlands were studied from four transect areas within New Hampshire. The average number of wetlands was found to be highest in the rural transects (Figure 3). The average size of wetlands was also found to be highest in the rural transect (Figure 4).
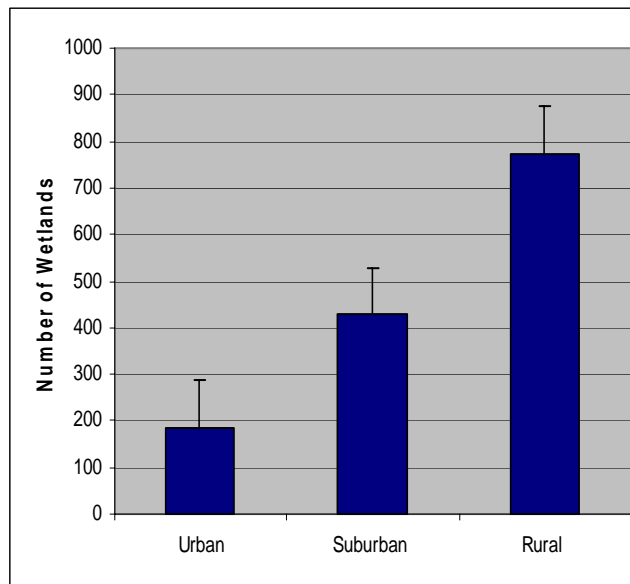
Figure 3. Average Number of Wetland by Urbanization   **Figure 4.** Average Size of Wetland by Urbanization

Within all four of the transects, there was a significant relationship found be between the size of wetlands and the level of urbanization (Table 1). There was no significant relationship found between the number of wetlands and

the urbanization level in both the Manchester and Nashua transects, while there was a significant relationship found in both the Concord and Rochester transects (Table 1).

Table 1. Chi Squared test for association between size of wetlands and the number of wetlands per transect. Variables in bold were significant.

TRANSECT	SIZE OF WETLANDS X^2	NUMBER OF WETLANDS X^2
Concord	**0.000053%**	**0.422293%**
Manchester	**0.727865%**	15.931797%
Nashua	**3.122655%**	8.490747%
Rochester	**0.000000%**	**0.000000%**

Spatial Statistics

The average nearest neighbor spatial statistical calculations found the Rochester, Concord and Manchester transects exhibited a clustered pattern, while the Nashua transect was found to be somewhat clustered (Figure 5). This test measures the distance between each feature centroid and its nearest neighbor's centroid location. It then averages all these nearest neighbor distances. If the average distance is less than the average for a hypothetical random distribution, the distribution of the features being analyzed are considered clustered. If the average distance is greater than a hypothetical random distribution, the features are considered dispersed.
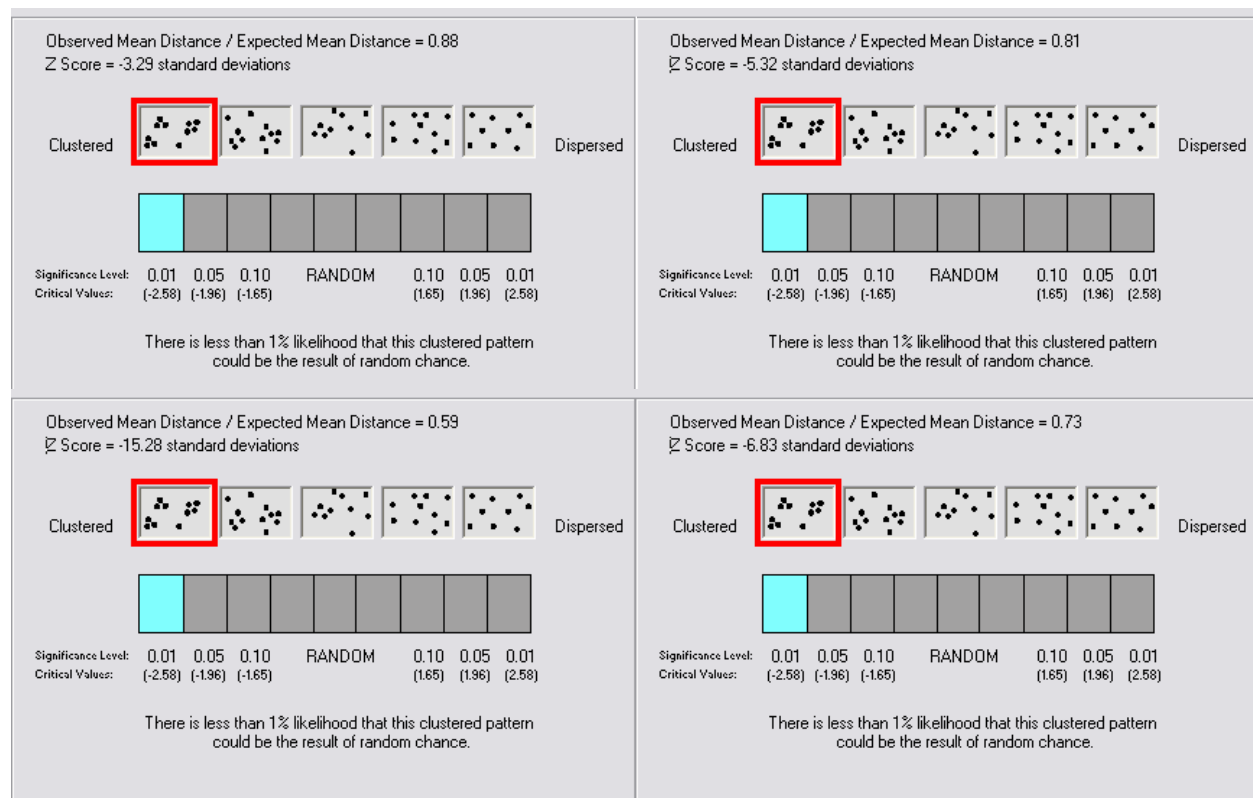

Figure 5. Average nearest neighbor distance measurements for each transect. In clockwise order: Nashua, Manchester, Rochester, Concord.

A standard deviational ellipse was calculated and drawn for each transect to identify the spatial pattern of wetland features. In the Rochester transect, the ellipse was centered within the suburban and rural areas. In the Concord transect, the ellipse was centered in the suburban area and partially within both the urban and rural areas.

In the Manchester transect, the ellipse was centered within the suburban and rural areas. In the Nashua transect, the ellipse was centered in the rural area.

Spatial autocorrelation (Moran's I) was performed for each transect. This 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. All four transects were found to have a clustered pattern (Figure 6).
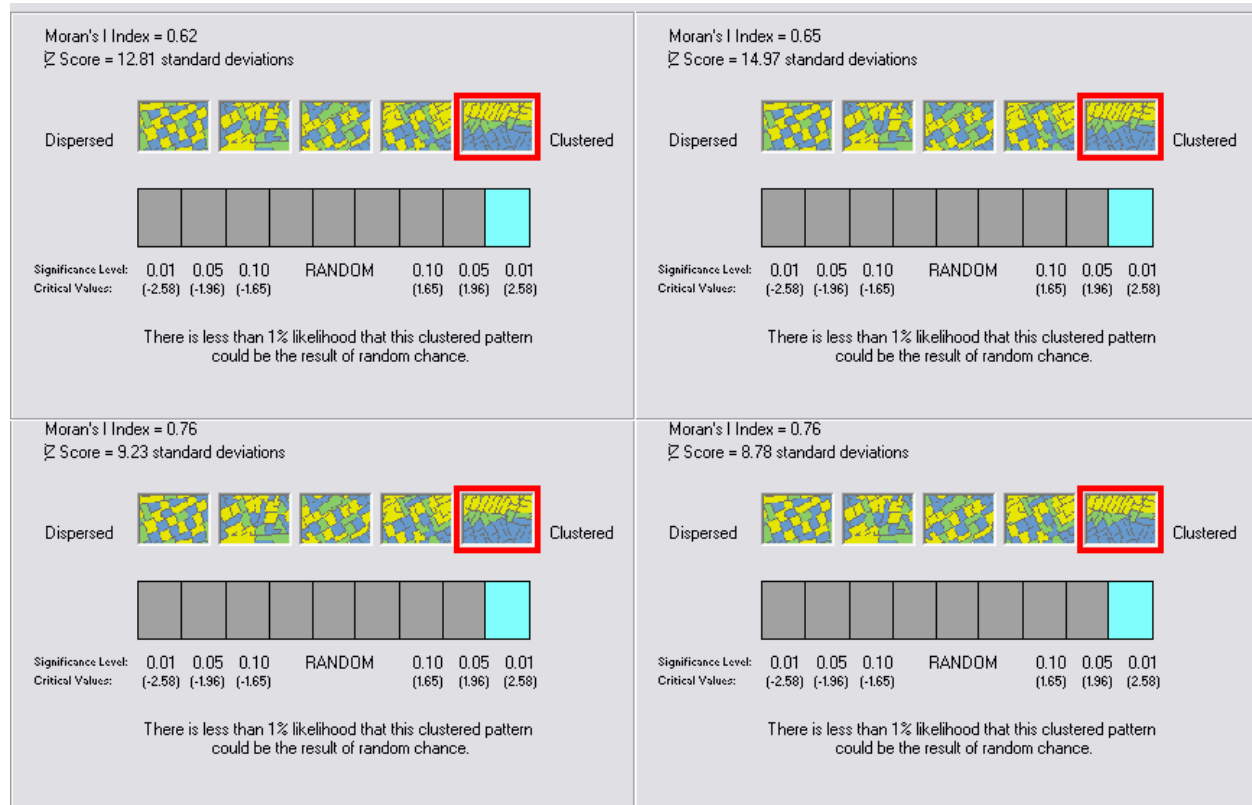
Figure 6. Spatial autocorrelation measurements for each transect. In clockwise order: Nashua, Rochester, Manchester, Concord.

DISCUSSION

The findings for this study suggest that urbanization is affecting both the size and spatial distribution of wetlands in New Hampshire. Wetland acreage was found to increase as you move away from the urban core. A similar trend was identified for the quantity of wetlands found. A higher number of wetlands were found when averaging the data for the rural areas, in comparison to both the suburban and rural.

A pattern was identified for the urban levels that the urban areas contained the least amount of wetlands. This discovery was expected and was due largely to the fact that most of the landscape for the urban areas was impervious and contained existing development, leaving little area for wetlands to exist. The total acreage of wetlands identified for each urban center varied. For both the Manchester and Rochester urban centers, the total area was approximately 16 hectares, while both the Concord and Nashua urban centers had total area of over 75 hectares. This could be attributed to the landscape parameters of the urban areas, as well as the fact that Manchester is ranked the largest NH city with respect to population density, while Rochester, although ranked below both Concord and Nashua, only contains 0.6 square miles of inland water, accounting for the dramatically lower number of wetlands identified in this area.

Trends were identified with respect to wetland size range over the varying urban levels. Within the Manchester transect, the number of wetlands for rural areas were the highest across all ranges, while very few wetlands of > 5 hectare were located in the urban area. Additionally, there were a large number of small wetlands (< .1 hectare) identified in the rural area. This finding caused us to question what was affecting the wetlands in this rural area to cause such fragmentation; this could be due to an increase in the number of developments which in turn generate new roads, as well as the extensive stream network that exists in this urban area. This concept of wetland fragmentation can also adversely affect the species which inhabit wetlands throughout the state. Some species depend on a certain patch size in order to make the habitat suitable, such as waterfowl. Many wetland-associated mammals also have minimum home range requirements that limit the sizes of wetlands they can inhabit. Therefore, a decrease in average area of individual wetlands is as important to consider as cumulative area lost to urbanization and development in these areas (Johnston 1994). Another study by Gibbs in 2000 found that a minimum wetland density is required to sustain wetland biota. A correlation between increased human population and loss of wetland density and proximity was identified in his study.

Within the Rochester transect, a high quantity of suburban wetlands were found within each size range except in the > 5 hectare range. Additionally, rural wetlands had lesser quantities in all ranges except the > 5 hectare range, and there were no urban wetlands found with a size range of > 5 hectare. These results represent the expected results for the various transect areas. A contributing factor to these normal findings could be that Rochester is one of the less dense urban areas and has not yet experienced the residential growth that most other urban transect areas are currently going through.

Within the Concord transect, a large number of urban wetlands were found within the 0.1 <0 .5 hectare range, as well as the 1 < 5 hectare range. Although the high numbers of wetlands existing in the 1 < 5 hectare range may at first appear to be out of character, one must consider that Concord has a major river running through its borders, creating the ideal environment for riverine wetlands to exist. Other trends noticed in the Concord transect was a fairly large amount of suburban wetlands found throughout the various urban levels.

Lastly, in the Nashua transect, a large number of suburban wetlands were found to have an area range of 1 < 5 hectares. However, rural wetlands were found to increase in quantity as you move along the size intervals.

Some anomalies in data patterns can be attributed to the demographic and landscape composition of the transect areas. All contained the varying urban levels, but the population density differences between the four areas coupled with the terrain are thought to have caused a disconnect in the spatial pattern of the data. Additionally, the interpretation of the wetland layer used for analysis and quantification for each transect area was partially based on the NWI data. Stolt and Baker (1995) found in validation studies that a substantial number of wetlands were overlooked by interpreters of aerial photos used to delineate wetlands. This in turn, caused inaccuracies to the dataset and contributes to some of the inconsistent spatial patterns identified for the various transect areas.

Kudray and Gale (2000) found that when evaluating NWI maps in heavily forested areas, like NH, the lowest level of accuracy was achieved in identifying forested wetlands. 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 wetland is among the most difficult forested wetland to identify due to canopy retention (Tiner 1990). 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. 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, this study did find obvious spatial patterns for both the number of wetlands within an urban-rural gradient, as well as size of wetlands along this gradient. It is the intention of this study to open up future studies of the effects of urbanization on wetlands on a regional scale. Temporal studies should be conducted to analyze the spatial pattern of wetland loss within the New Hampshire community. Additional analysis should also be made with higher resolution imagery in true color and flown in the spring to further develop these data for New Hampshire. These future studies should help policy makers create additional regulations for the protection of wetlands.

REFERENCES

Berry, B. J. L. (1991). *The Human Consequences of Urbanization*. New York; St. Martin's Press.

Cliff, A. D., and J. K. Ord, (1973). *Spatial Autocorrelation*. Pion, London.

Crowley, S., C. O'Brien, and S. Shea, (1998). Results of the wetland study and the 1988 draft wetland rules: Agency of Natural Resources, Division of Water Quality, Waterbury, VT.

Dahl, T. E., and C. E. Johnson, (1991). Status and trends of wetlands in the conterminous United States, Mid-1970's to Mid-1980's. US Department of the Interior, Fish and Wildlife Service, Washington, D. C. 28 pages.

Dahl, T. E. (1990). Wetlands Losses in the United States 1780's to 1980's. US Fish and Wildlife Service, National Wetlands Inventory Project, Washington, DC 21 pp.

Dahl, T. E. (1992). Wetland status and trends-the link to remote sensing: p. 221-230. In Proceedings of Remote Sensing & Natural Resource Management, the Fourth Forest Service Remote Sensing Applications Conference, Orlando, FL.

Dahl, T. E. (2000). Status and Trends of Wetlands in the Conterminous United States 1986 to 1997, Washington, D.C.: U.S. Department of the Interior, U.S. Fish and Wildlife Service.

Economic & Labor Market Information Bureau, NH Employment Security. 2002.

ESRI, (2005). ArcGIS Desktop version 9.1. Environmental Systems Research Institute, Inc., Redlands, CA.

Fox, R. (1987). Populations images. United Nations Fund for Population Activities.

Foulis, D. B., J. A. Eaton, and R. W. Tiner, (1994). Wetland trends for selected areas of the Gulf of Maine, from York, Maine to Rowley, Massachusetts (1977 to 1985-86): US Fish and Wildlife Service Region 5 and Gulf of Maine Project.

Gibbs, James P. (1993). Importance of small wetlands for the persistence of local populations of wetland-associated animals: *Wetlands*. 13/1: 25-31.

Gibbs, James P. (1998). Distribution of woodland amphibians along a forest fragmentation gradient. *Landscape Ecology* 13: 263-268.

Gibbs, James P. (2000). Wetland Loss and Biodiversity Conservation: *Conservation Biology*. 14: 314-317. Hershey, R. R. and W. A. Befort, (1995). Aerial photo guide to New England forest cover types. USDA Forest Service.

Johnston, Carol A. (1994). Cumulative Impacts to Wetlands: *Wetlands*. 14/1: 49-55.

Luck, M. and J. Wu., (2002). A gradient analysis of urban landscape pattern: a case study from the Phoenix metropolitan region, Arizona, USA: *Landscape Ecology*. 17: 327-339.

McDonnell, M. J., and S. T. A. Pickett, (1990). Ecosystem Structure and Function along Urban-Rural Gradients: An Unexploited Opportunity for Ecology: *Ecology*. 71/4:1232-1237.

McDonnell, M. J., S. Pickett, P. Groffman, P. Bohlen, R. Pouyat, W. Zipperer, R. Parmelee, M. Carreiro, and K. Medley, (1997). Ecosystem processes along an urban-to-rural gradient: *Urban Ecosystems*. 1: 21-36.

McKinney, Michael L. (2002). Urbanization, biodiversity, and conservation: *BioScience*. 52/10: 883-890.

Medley, K. E., M. J. McDonnell, and S. T. A. Pickett, (1995). Forest-Landscape Structure along an Urban-To-Rural Gradient: *Professional Geographer*. 47/2:159-168.

Mitsch, W.J. and J.G. Gosselink, (1986). *Wetlands.* New York, NY. Van Nostrand Reinhold Company Inc.

Moller, T. R., and C. P. Rordam, (1985). Species numbers of vascular plants in relation to area, isolation, and age of ponds in Denmark: *Oikos*. 45:8-16.

NH DES Wetlands Bureau, (2002). Clues to Identifying Forested Wetlands: www.des.state.nh.us/factsheets/wetlands/wb-14.htm. 1-3.

NH GRANIT (2006).

New Hampshire Minimum Impact Development Partnership, (2001). Maintaining Choices in Community Character: www.nhmid.org/maint.htm. 1-8.

NH Office of Energy and Planning, (2005). New Hampshire's Changing Landscape Report. Prepared by the Society for the Protection of New Hampshire Forests.

Nichols, C. (1994). Map accuracy of National Wetlands Inventory Maps for areas subject to Maine Land Use Regulation Commission Jurisdiction: U.S. Fish and Wildlife Service, Hadley, ME. Ecological Services Report R5-94/6.

Richlefs, R. E., and D. Schluter, (1993). Species diversity in ecological communities; historical and geographical perspectives. University of Chicago Press, Chicago, IL.

Rodrigue, Paul, S. Davis, NRCS Mississippi, and Wetland Science Institute. Aerial photography interpretation for wetland determination: USDA and NRCS.

Sjogren, P. (1991). Extinction and isolation gradients in metapopulations; the case of the pool frog (*Rana lessonae*): *Biological Journal of the Linnaean Society*. 42:135-147.

Stolt, M. H., and J. C. Baker, (1995). Evaluation of National Wetland Inventory Maps to inventory wetlands in the southern Blue Ridge of Virginia: *Wetlands*. 15 346-353.

Swartwout, D. J., W. P. MacConnell, and J. T. Finn, (1981). An evaluation of the National Wetlands Inventory in Massachusetts: p. 685-691. In Proceedings of the In-Place Resource Inventory Workshop, Orono, ME.

Ter Braak, C.J.F., and Prentice, I.C. (1988). A theory of gradient analysis. Adv. Ecol. Res. No. 18. pp. 271.317.

Tiner, R. W. Jr. (1990). Use of high-altitude aerial photography for inventorying forested wetlands in the United States: *Forest Ecology and Management*. 33/34: 593-604.

Tiner, R. W. (1997). NWI Maps: What they tell us: *National Wetlands Newsletter*. 7-12.

Tiner, R. W., H. C. Bergquist, G. P. DeAlessio, and M. J. Starr. 2002. Geographically Isolated Wetlands: A preliminary assessment of their characteristics and status in selected areas of the United States. US Department of the Interior, Fish and Wildlife Service, Northeast Region, Hadley, MA.

Tinner, R. W. (2003). Geographically isolated wetlands of the United States: *Wetlands*. 23/3: 494-516.

US Fish and Wildlife Service. 1984. Wetlands of the United States: Current Status and Recent Trends.
Whittaker R. H. (1967). Gradient analysis of vegetation. – *Biol*. Rev. 42: 207–264.

Wilen B. O. and M. K. Bates. 1995. The US fish and wildlife service's national wetlands inventory project: *Vegetario*. 118: 153-169.