

FROM BRAY-CURTIS ORDINATION TO MARKOV CHAIN MONTE CARLO
SIMULATION: ASSESSING ANTHROPOGENICALLY-INDUCED AND/OR
CLIMATICALLY-INDUCED CHANGES IN ARBOREAL ECOSYSTEMS

A Dissertation
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

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In Partial Fulfillment
for the Degree of
DOCTOR OF PHILOSOPHY

Major Program:
Environmental and Conservation Sciences

January 2013

Fargo, North Dakota

North Dakota State University
Graduate School

Title

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ABSTRACT

Mapping forest resources is useful for identifying threat patterns and monitoring changes associated with landscapes. Remote Sensing and Geographic Information Science techniques are effective tools used to identify and forecast forest resource threats such as exotic plant invasion, vulnerability to climate change, and land-use/cover change. This research focused on mapping abundance and distribution of Russian-olive using soil and land-use/cover data, evaluating historic land-use/cover change using mappable water-related indices addressing the primary loss of riparian arboreal ecosystems, and detecting year-to-year land-cover changes on forest conversion processes. Digital image processing techniques were used to detect the changes of arboreal ecosystems using ArcGIS ArcInfo[®] 9.3, ENVI[®], and ENVI[®] EX platforms.

Research results showed that Russian-olive at the inundated habitats of the Missouri River is abundant compared to terrestrial habitats in the Bismarck-Mandan Wildland Urban Interface. This could be a consequence of habitat quality of the floodplain, such as its silt loam and silty clay soil type, which favors Russian-olive regeneration. Russian-olive has close assemblage with cottonwood (*Populus deltoides*) and buffaloberry (*Shepherdia argentea*) trees at the lower elevations. In addition, the Russian-olive-cottonwood association correlated with low nitrogen, low pH, and high Fe, while Russian-olive- buffaloberry association occurred in highly eroded areas.

The Devils Lake sub-watershed was selected to demonstrate how both land-use/cover modification and climatic variability have caused the vulnerability of arboreal ecosystems on the fringe to such changes. Land-cover change showed that the forest acreage declined from 9% to 1%, water extent increased from 13% to 25%, and cropland extent increased from 34% to 39% between 1992 and 2006. In addition, stochastic modeling was adapted to simulate how land-use/cover change influenced forest conversion to non-forested lands at the urban-

wildland fringes in Cass County. The analysis yielded two distinct statistical groups of transition probabilities for forest to non-forest, with high transition probability of unchanged forest ($0.54 \leq P_{ff} \leq 0.68$) from 2006 to 2011. Generally, the land-uses, such as row crops, showed an increasing trend, while grains, hay, seeds, and other crops showed a declining trend. This information is vital to forest managers for implementing restoration and conservation practices in arboreal ecosystems.

ACKNOWLEDGEMENTS

I owe my deepest gratitude to many people whose efforts allowed me to achieve my dream of succeeding in graduate school. First and foremost, I am deeply indebted to my major advisor, Dr. Peter Oduor, for guidance, challenges, encouragement, and support during my study. I am extremely indebted to Dr. Peter Oduor for strengthening my knowledge of Geographic Information Science and Remote Sensing through the courses he taught. I would like to thank my committee members: Drs. Gary Clambey, Joseph Zeleznik, Deying Li, and Saleem Shaik for their dutiful service including guidance, critiques of my work, and encouragement. I am grateful to Dr. Gary Clambey for improving my knowledge on Ecological Processes through his course, which helped me to develop my research. My special thanks to Dr. Joseph Zeleznik for taking me to the field and expanding my field knowledge.

My special thanks to Dr. Shawn DeKeyser for help in identification of plants and providing me an opportunity to use the herbarium at NDSU. I would also like to thank Curt Doetkott for assistance with statistical analyses. Special thanks to Dr. Craig Stockwell, Director of Environmental and Conservation Science Program, and Dr. Bernhardt Saini-Eidukat, Chair, Dept. of Geosciences, for their support. I'm grateful from the bottom of my heart to all the members of the Center for Writers, who helped me to improve my writing skills. I would like to pass my special thanks to Jessica Ebert for her valuable input.

I owe thanks to my colleagues Anthony Wamono, Mohammad Anar, Deidra Lies, and Papia Rozario for their enormous support during my studies. I am very thankful to Shawn Goodchild and Anthony Wamono for helping me in numerous ways with my field work. I would like to thank Dr. Janaka Kuruppuarachchi and Udhara Munasinghe for presenting a part of this work at the 4th International Conference on Geo-Information Technology for Natural Disaster Management. My special thanks go to Sujana Henkanathgedara and his

family for helping me settle in during my first year in Fargo. Thanks to all administrative staff of the Department of Geosciences: Suzy Schmoll, Rita Slator, Phyllis Murray, Ashley Anderson, and Nancy Suttle for their immense support during my studies.

This project was funded by the United States Department of Agriculture Forest Service award #10-DG-11010000-011 and Catalog of Federal Domestic Assistance (CFDA) Cooperative Forestry #10.664. In addition, I received funding through the NDSU Department of Geosciences for a teaching assistantship (2011-2012). I would like to thank the following institutions for travel grants: Research, Creative Activities & Tech Transfer (RCATT), Department of Geosciences, Environmental and Conservation Sciences Program, and the College of Science & Mathematics. I would also like to acknowledge the North Dakota View Scholarship and Alexander Goetz Instrument Support Program that funded parts of my research.

I am extremely indebted to my loving parents for giving me the encouragement to make my opportunity here a success. I am thankful to my sister, brother in-law, and their loving children, Tharindu and Chapa, for taking care of my parents and giving me the courage to reach the end of this journey. I recall memories of my late, loving aunt, Mrs. Sumitra Jayaseeli, and also Rev. Batuwatte Sirinanda, who were willing to guide me to the top of this summit. Last, but not least, I would like to express my deepest appreciation to Prof. C. V. S. Gunatilleke for building my capacity during my master's program, which ultimately allowed me to pursue a doctoral degree program at NDSU.

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CHAPTER 1. GENERAL INTRODUCTION

1.1. North Dakota Forests

Historically, North Dakota has been characterized as a prairie land due to its topographic features, soils and climate (Kotchman 2010). North Dakota has relatively few densely forested areas that fall under the purview of the North Dakota Forest Service. The densely forested areas that are found in North Dakota consist of upland forests, riparian forests, rural plantings, and community forests (Kotchman 2010). Most historical forest land existed in the Turtle Mountains, Killdeer Mountains, Pembina Hills, and the Devils Lake area and along major riparian corridors. Basically, North Dakota's forests can be separated into four geographical watershed units *viz.*, Missouri River, Devils Lake/James River, Red River and Souris River (Haugen et al. 2009). These four watershed units harbor over twenty riverine systems (Meehan et al. 2011).

1.2. Riparian Forest

North Dakota riparian forests are critically important, because more than half of the state's woodland is located in riparian ecosystems (Meehan et al. 2011). Also Keammerer et al. (1975) reported that the deciduous forests in North Dakota are mainly confined to the floodplains of major rivers such as the Red River, the Sheyenne, the James, and the Missouri Rivers (Reily and Johnson 1982). Therefore, riparian forests are rich in plant diversity. For example, Keammerer et al. (1975) recorded 220 plant species belonging to 152 genera and 54 families of the Missouri River bottomland forest. The leading trees in the riparian habitats include cottonwood (*Populus deltoides*), peach-leaved willow (*Salix amygdaloides*), boxelder (*Acer negundo*), green ash (*Fraxinus pennsylvanica*), American elm (*Ulmus americana*) and bur oak (*Quercus macrocarpa*) (Keammerer et al. 1975; Killingbeck and Wali 1978; Reily and Johnson 1982). The association of those plants at the riparian habitats, is strongly related to stand age and horizontal and vertical position on the floodplain (Johnson et al. 1976). For

example, cottonwood and peachleaf willow occur in low terraces as young stands proximal to the floodplain (Johnson 1971), while ash-boxelder-elm-bur oak occur in high terraces as old stands near the edge of the floodplain (Johnson et al. 1976).

This high biodiversity along the riparian habitats in North Dakota is vulnerable to human activities, however. Human-induced environmental changes such as dam construction have caused substantial ecological alteration of the riparian ecosystem. For example, seven massive dams constructed along the Missouri River have caused significant vegetation loss of the bottomland forest. The upper Missouri River vegetation was destroyed due to inundation by the reservoirs and downstream riparian habitats were converted into farmland (NRC 2002). Dams prevent natural flooding and alluvial soil deposition on the floodplain. The absence of natural flooding and alluvial soil deposition is a barrier to the regeneration of many plants such as cottonwood and willow (Auble and Scott 1998; Katz and Shafroth 2003). Moreover, dams decrease the lateral channel meandering, which impedes the recruitment of pioneer forest communities such as cottonwood-willow (NRC 2002).

1.3. Exotic Plants Invasion

Climatic change affects riparian forest health and may alter the ecological processes of riparian ecosystems. Flooding is an example of climate change that causes a reduction in the vigor of riparian trees and forest dieback is a consequence. However, exotic plants are more resistant to such climatic variability because of their plastic biological attributes such as adaptation to saline soil condition and tolerance to inundation conditions. Russian-olive and saltcedar (*Tamarix ramosissima*) are good examples of riparian invaders that were widely distributed in the western United States (Olson and Knopf 1986; Friedman et al. 2005). Those two non-native plants were also reported in riparian ecosystems of North Dakota (Friedman et al. 2005). Unlike native plants, Russian-olive can establish well along eroded ditch banks, because it can fix nitrogen using symbiotic bacteria (Bertrand and Lalonde 1985; Lesica and

Miles 2001). In addition, Russian-olive seedlings can tolerate shade and grow under the cottonwood canopy (Lesica and Miles 1999).

According to regional surveys conducted on Russian-olive distribution within the US along rivers and irrigation canals, Russian-olive creates problems for restoration of riparian forests, because it can compete well with native plants, and it can replace native trees such as cottonwood (Lesica and Miles 1999). Therefore, understanding land-use and land-cover changes such as Russian-olive invasion in riparian forests in North Dakota is critically important for long term forest management and policy decisions.

1.4. Land-use/Cover Change

Changes in land-use / land-cover (LULC) may cause significant environmental consequences such as deforestation, biodiversity loss, climatic change and natural disturbance (Falcucci et al. 2007; Lima et al. 2012; Madurapperuma et al. 2012). Conversion of forest lands to agricultural lands has been identified as the major form of land-cover modification (Matson et al. 1997). For example, in North Dakota 90% of formerly forested lands are utilized for farming and ranching (NASS 2012; Oduor et al. 2012). Therefore, transition of forest lands into more agricultural lands is a common practice in North Dakota and could create environmental problems such as water pollution and soil erosion. Federal agencies have developed land management policies to mitigate these environmental issues. For example, non-point source pollution is a result of agricultural land intensification, so landowners should adopt best management practices to reduce environmental pollution.

In addition, certain areas in North Dakota are identified as soil conservation districts with the purpose of reducing erosion, improving water quality, improving air quality and enhancing wildlife under the state Conservation Reserve Program (CRP). North Dakota enrolled three million acres (9% of the total acres at the national level) in this program. The

north and north-central regions of North Dakota have the largest portion of CRP acres enrolled within the state (USDA 1992; Kotchman 2010).

North Dakota Forest Service statistics reveal that 70% of the forest lands in North Dakota belong to private owners (Haugen et al. 2009). Essentially, ecological interconnections between public and private lands are important in the form of ecosystem management (Nie and Miller 2008). A partnership between the federal government and private stakeholders to manage forest resources in North Dakota is crucial.

1.5. Remote Sensing and GIS

Remote Sensing (RS) and Geographic Information Systems (GIS) offer a useful glimpse in understanding how land-use and land-cover change over time and space. RS and GIS help people to understand the relationships between anthropogenic and natural phenomena and to make proper land management decisions (Kamusoko and Aniya 2006). For example, future flooding scenarios can be predicted using hydrological and geographic information, which may reduce risks associated with flooding (Cummings et al. 2012). Another wide application of RS and GIS is the simulation modeling for the transition of forests into non-forested lands (Madurapperuma et al. 2011; Oduor et al. 2012; Brown et al. 2000).

The Markov Random Fields (MRF) model is commonly used to predict how land-use and land-cover transition will occur from one state (forest) to another (non-forest land) over time (Modal and Southworth 2010; Oduor et al. 2012). MRF simulation may be useful in shaping policy decisions. For example, Oduor et al. (2012) used a MRF model to establish conservation priority for areas prone to forest conversion. Furthermore, their findings proved useful to federal agencies in elucidating areas which would most benefit from forest stewardship programs. Similarly, Ramos et al. (2008) used MRF to predict future tree composition using two indicator tree species, which are affected most by fragmentation.

Also, they evaluated the effectiveness of different land management practices through calculating the future stable stand composition of those two indicator species.

1.6. Organization of Dissertation

This dissertation consists of six chapters including a general introduction, four chapters which stem from published papers and the last chapter on conclusions and future directions. Paper 1 discusses the use of GIS and RS in identifying the factors that correlate or contribute to the distribution of Russian-olive at the Bismarck-Mandan Wildland Urban Interface (BMWUI). The paper also highlights the relationships between soil characteristics and Russian-olive occurrence within the BMWUI and which land-use and land-cover types contribute more for Russian-olive distribution. Moreover, the results show that Russian-olive occurrence is much higher in the riparian habitats than upland terrestrial ecosystems. Therefore, Paper 2 explains further how Russian-olive associates with native plants within riparian habitats from Lake Sakakawea to the Oahe Reservoir using *in-situ* data. The phytosociology of native and exotic plants in relation to soil chemical properties is discussed in detail. Paper 3 describes how land-use/cover change and climatic variability influence the sustainability of an arboreal ecosystem within the Devils Lake watershed. Paper 4 discusses factors which correlate or contribute to land-use and land-cover change in Cass County, North Dakota using multivariate analysis and multi-temporal landsat data. The final chapter of this dissertation is the conclusion. The purpose of this chapter is to summarize and synthesize the major findings of the four main chapters.

This study integrates Geographic Information Systems and Remote Sensing techniques to model the distribution of an invasive species across riparian habitats, a necessary step in developing geospatial arboreal continuity to manage riparian forest resources in North Dakota. Also understanding land-use and land-cover change and climatic variability, which may affect arboreal ecosystem, is key to making better management

decisions. For example, prior to riparian forest restoration, it is beneficial to know which land-use practices are promising for conversion of forest lands to non-forested areas. In addition, forest conversion trends can be identified using stochastic analyses, for example, Markov Chain Monte Carlo simulation, which could be useful to design strategic forest resource management plans.

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CHAPTER 2. UNDERSTANDING FACTORS THAT CORRELATE OR CONTRIBUTE TO EXOTIC RUSSIAN-OLIVE INVASION AT A WILDLAND- URBAN INTERFACE ECOSYSTEM*

2.1. Abstract

Understanding the ecological distribution range of exotic trees in an arboreal ecosystem is essential to managing natural forest resources sustainably. Forest resource mapping can be applied as a powerful tool in the identification of forest resource threat patterns, and in monitoring ongoing changes associated with a landscape. This study offers an insight on Russian-olive and its impact on a spatially bound ecosystem, namely, the Bismarck–Mandan Wildland–Urban Interface (BMWUI). Data from the National Agricultural Imagery Program collected in 2005 and 2010 and *in-situ* reference data were used to estimate the potential distribution of Russian-olive using ArcGIS ArcInfo® 9.3 (ESRI, Redlands, CA). Russian-olive plants are discernible on aerial photographs with a fine spatial resolution because of silvery gray-green leaves in the upper strata of their canopies. Results showed that Russian-olive occupied 110 ha (272 acres) in BMWUI in 2005 and of that, 13 ha (12%) was in inundated habitats. In addition, Russian-olive in 2010 covered 125 ha within the BMWUI and of that, 25 ha (20%) was in inundated habitats. Russian-olive showed a close association with the silt loam and silty clay soil type, which occurs along the Missouri River floodplain. Our findings revealed that the species is well established in riparian habitats and other open habitats such as roadside and agricultural lands. There is a greater likelihood of lateral spread of Russian-olive throughout the BMWUI that may require active management to avert undesirable conservation impacts.

*This material in this chapter was Co-authored by Buddhika D. Madurapperuma, , Peter G. Oduor, Mohammad J. Anar, and Larry A. Kotchman (Published in *Invasive Plant Science and Management*, 6: 130-139. <http://dx.doi.org/10.1614/IPSM-D-12-00021.1>).

2.2. Introduction

Anthropogenic land-use and land-cover change are two of the main driving forces of establishment or rooting of exotic plants. When nonnative plants colonize a new environment they may eliminate a functional group or keystone species. Their colonization can alter ecosystem functions, such as hydrologic and biogeochemical cycling. Hoffman et al. (2008) suggested that hydrology with anthropogenic activities aid the establishment and spread of invasive plants in riparian habitats. For example, anthropogenic processes such as clearing of riparian forest have promoted saltcedar (*Tamarix ramosissima*) and Russian-olive (*Elaeagnus angustifolia*) invasion and proliferation (Friedman et al. 2005). Management of such species requires knowledge of their current and potential future distribution, their abundance in different ecosystems, and the ecological conditions that favor or hinder their spread or persistence (Nagler et al. 2011).

Russian-olive (*Elaeagnus angustifolia* L.) is a tree native to southern Europe and western Asia (Little 1961). It is deciduous, growing up to 12 m (39 ft) in height, and is characterized by silver-gray leaves and a dense rounded crown (Hamilton et al. 2006). It was introduced into North America during colonial times for ornamental purposes, for windbreaks in agricultural settings, and for wildlife enhancement purposes (Elias 1980; Stannaer et al. 2002). In the 1900s, scientists described extensive naturalization of Russian-olive throughout the western United States in riparian areas and pastures, along fences and ditch banks, and in wetland sites (Christiansen 1963; Lesica and Miles 2001). This is not a surprise, because Russian-olive has adapted to a variety of habitats. For example, it has flexible germination patterns including long seed viability and the ability to germinate in shadier and drier environments (Reynolds and Cooper 2010; Shafroth et al. 1995). It tolerates varied moisture, soil, and temperature conditions, and it has the ability to fix nitrogen through actinorhizal symbiosis (Bertrand and Lalonde 1985).

Russian-olive has a broader environmental tolerance such as survival in dense shade and lower moisture conditions than does saltcedar (*Tamarix* spp.) and cottonwood (*Populus* spp.) (Jarnevich and Reynolds 2011; Reynolds and Cooper 2010). Friedman et al. (2005) reported that it was the fourth most abundant woody species in Western riparian zones. The abundance of Russian-olive in riparian habitats leads to replacement of native cottonwood and willow (*Salix* spp.) trees (Lesica and Miles 1999). Replacement is also influenced by beaver damage due to their high preference for cottonwood and willow over Russian-olive (Lesica and Miles 2001). A decline of such dominant native riparian woody plants negatively impacts habitats for cavity-nesting and insectivorous birds (Olson and Knopf 1986).

Biologists carried out ecological surveys of Russian-olive along riparian habitats in the United States that focused on distribution, restoration, regeneration, and nutrient dynamics (Gaddis and Sher 2012; Harner et al. 2009). For example, Gaddis and Sher (2012) studied how restoration efforts, that is, removing Russian-olive from riparian habitats, affects native vegetation. Their results showed that moisture and temperature are the main factors contributing to restoration success of abundance of native vegetation. Harner et al. (2009) surveyed on the rate of decomposition of Russian-olive and cottonwood trees in riparian habitats. The results showed that the Russian-olive leaf litter decayed significantly faster than cottonwood. Russian-olive is widely distributed through the western and central United States (Nagler et al. 2011; Reynolds and Cooper 2010). According to the Atlas of the Flora of the Great Plains, the distribution of Russian-olive in the North Dakota is common (McGregor et al. 1977). North Dakota Forest Service personnel have observed Russian-olive in riparian habitats and have also noted that it has disrupted regeneration and succession of native cottonwood forest (Kangas 2003). Madurapperuma et al. (2011) also reported that 3.15% of riparian forests were occupied by Russian-olive in the lower Missouri River basin of North

Dakota. Furthermore, they showed that the species was well established in open habitats such as roadsides, agricultural lands, and pasturelands (Madurapperuma et al. 2012a).

The purpose of our study was to document how changes in land-use and land-cover influenced the naturalization of Russian-olive in the riparian and upland grasslands in the BMWUI. Bismarck is the second largest metropolitan city in North Dakota and BMWUI is vulnerable to urbanization pressures and frequent flooding. Therefore, our study is important because it locates likely habitats for invasion by Russian-olive within the region, which is useful for city planners and wildlife managers seeking to implement a surveillance and restoration program. We address the following research questions: (1) What is the areal cover and rate of expansion of Russian-olive in the study area? (2) Over which land-use types (defined by the National Land Cover Datasets) has Russian-olive distributed the most? (3) Are there any differences in distribution of Russian-olive in riparian and upland terrestrial ecosystems? (4) Is there a relationship between coverage of Russian-olive and soil types? We selected both terrestrial and riparian habitats to investigate the spatial distribution of Russian-olive in BMWUI.

2.3. Materials and Methods

2.3.1. Study Site

North Dakota harbors 214 wildland–urban interfaces, which were derived using block-level housing units and wildland vegetation using National Land Cover Datasets (Hermansen-Baez et al. 2009). According to the U.S. Department of Agriculture and U.S. Department of the Interior (2001) definition, “the Wildland Urban Interface is the area where houses meet or intermingle with undeveloped wildland vegetation.” Bismarck–Mandan is one of the main wildland–urban interfaces in North Dakota, having an extent of 52,786 ha (130,437 acres) (FRMA 2008). Bismarck is the state capital and second largest city in North Dakota, where economic, cultural, and political centers are located. It is a metropolitan area,

and the center of the BMWUI, which lies along the Missouri River and has over 128 housing units km^{-2} (49 mi^{-2}) (Hammer and Radeloff 2003). From 2010 census results, Bismarck's population grew by 10.3% over the previous decade, to 61,272 citizens (U.S. Census Bureau 2010). In 2010, Mandan's population was 18,331 (U.S. Census Bureau 2010). The BMWUI is divided in half by the Missouri River, which is the longest river in North Dakota. Riparian forests are one of the main forest types in North Dakota, with seventeen percent of forest lands located within 200 feet of a stream or lake of the Missouri River (Haugen et al. 1999). The total forest cover within BMWUI was 2655 ha (Madurapperuma et al. 2012b). The upland area of the BMWUI is mainly occupied by grasslands. The elevation ranges from 503 to 630m.

2.3.2. Feature Extraction

We used high-resolution aerial photography, Landsat 4-5 TM geo-referenced images, and *in-situ* reference data to map the distribution of Russian-olive in BMWUI. Russian-olive has a unique spectral signature with a distinctive silver-gray color, which can be captured easily using natural color imagery (Hamilton et al. 2006). Three data sources, namely Landsat TM image, National Agricultural Imagery Program (NAIP), and National Land Cover Database (NLCD), were used to map Russian-olive within the urban interface and among randomly selected sampling locations. The inundation extents were digitized in ArcGIS 9.3[®] (ESRI) using base satellite imagery immediately after the flooding event (from georeferenced Landsat 4-5 TM geo-referenced image for May 25, 2011, corresponding to path 32 and row 28, and GeoEye-1 downloaded from the USGS (2011)). Forests and Russian-olive within the inundated boundary were digitized using NAIP 2005 and NAIP 2010 base maps. Similarly, Russian-olive within the urban interface was digitized using 2005 and 2010 NAIP images downloaded from the NRCS data gateway (NRCS 2010). Russian-olive trees become reproductively mature at about 10 years (Lesica and Miles 1999), and due to the limitation of

high-resolution images for a decade we choose five-year time intervals from 2005 to 2010 to detect the changes of coverage of this species. The forest cover and the extents of land-use types in the urban interface was estimated using the 2001 NLCD (USGS, 2006).

2.3.3. Vegetation Sampling

We performed random sampling across the BMWUI to illustrate the ecological significance of Russian-olive in relation to the land-use and land-cover changes. Based on a prior rationale, we sampled 30% of the area, to gauge the distribution of Russian-olive in the BMWUI. We treated individual sections in the U.S. Public Land Survey System as sampling plots. From a total of 170 plots (average section extent = 2.6 km²), we selected 65 random plots using random number generator (Fig. 2.1). We used an NLCD 2001 image (<http://www.mrlc.gov/nlcd2001.php>) as a base reference image to generate forest cover and other land-use extents.

We exported the NLCD 2001 image into ArcGIS ArcInfo[®] 9.3 to obtain grid datasets with 30-m spatial resolution. Then raster reclassification was performed where minor NLCD classes were collapsed into the major categories. For example, class 41 (deciduous forest), class 42 (evergreen forest), and class 43 (mixed forest) were reclassified as forest. The total number of classes was eight and three of these represented land-use classes, namely, urban, cropland, and pasture, whereas the remaining represented land-cover classes such as grassland, forest, wetland, native shrubland, and water. Soil data were obtained from the Soil Survey Geographic Database (<http://websoilsurvey.nrcs.usda.gov/app/>) of the Natural Resources Conservation Service. Soil data were spatially clipped to the specific sampling sites boundaries spatial extents using a basic minimum bounding rectangle. The soil characteristics in each sampling site was then integrated with the land-use and land-cover data to perform multivariate analysis.

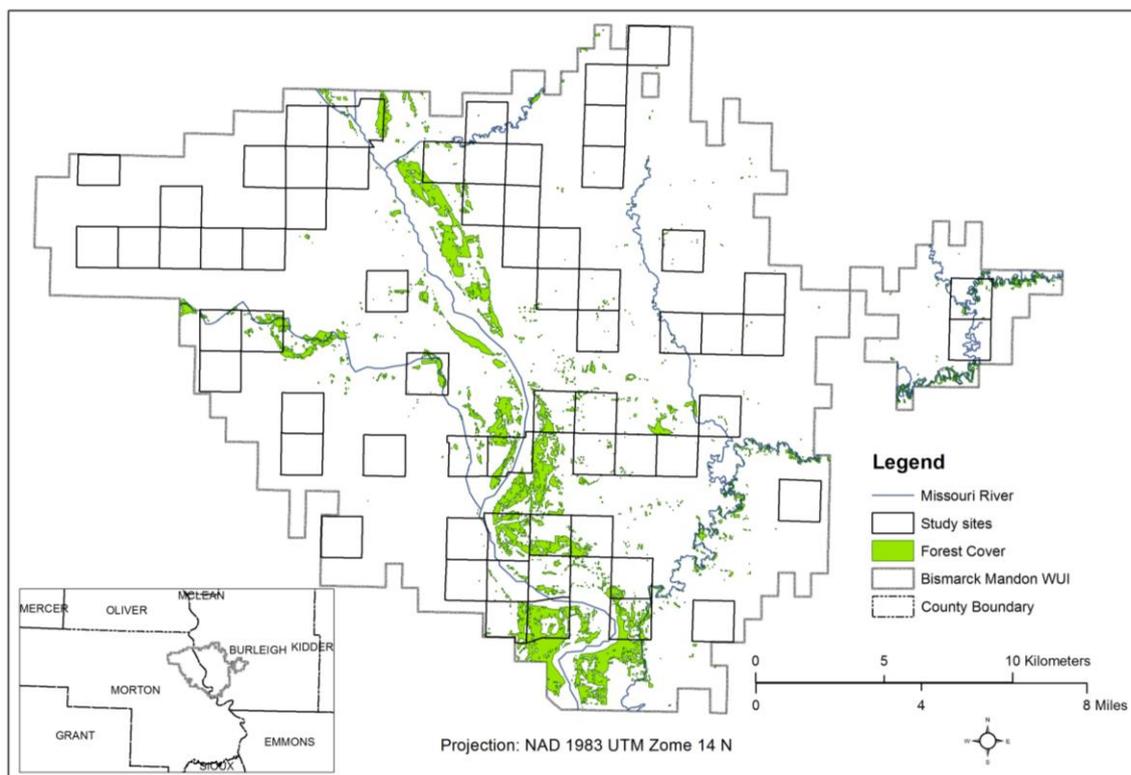


Figure 2.1. Map of study area depicting sampling locations (black outlined boxes represent the sampling sites and plots that are assigned according to the random numbers) and forest cover, which were generated from the 2001 NLCD image. Data for the boundaries of Bismarck-Mandan WUI, counties and river were downloaded from the North Dakota GIS Hub Data Portal (<http://www.nd.gov/gis/>). Accessed: June 02, 2011. Forest cover data was derived from NLCD data obtained from <http://www.mrlc.gov/nlcd2001.php> web portal. Accessed: May 18, 2011.

2.3.4. Multivariate Analysis

We produced two data matrices, where land-use and land-cover data and Russian-olive extent within each sampling site were treated as a primary data matrix. Soil data were treated as a secondary data matrix. These data matrices were used as primary inputs of multivariate analysis. Canonical correspondence analysis (CCA) was performed by overlaying the two data matrices using PCORD₄ software (MJM Software, Gleneden Beach, OR). Less Russian-olive coverage within sampling units was not down-weighted when performing the CCA. The joint plot for the ordination was created using soil data, and the threshold was set to 0.10. Joint plot shows as radiating lines of the ordination diagram, which

gives relationship between soil variables and land-use and land-cover data.

2.3.5. Classification and Regression Tree (CART)

Classification and Regression Tree (CART) is a rule based decision tree, which explains variation of a single response (for example, Russian-olive coverage) variable by splitting the data into more heterogeneous groups using combinations of categorical and/or numerical data to predict pattern and process of ecological data (Ath et al. 2000). We modeled Russian-olive coverage with numerical data such as land-use and land-cover using CART[®] software (Salford Systems, San Diego, California) to estimate habitat suitability for Russian-olive. An unsupervised classification algorithm was employed using the Gini index to determine the best split of records. The Gini index, used to reduce the impurity of the records, is given by:

$$\text{Gini}(t) = 1 - \sum_{i=0}^{c-1} [p(i|t)]^2 \quad (2.1)$$

where p denotes the fraction of records belonging to class i at a given node t . Classification tree models infer their accuracy by partitioning the available data into a training subset and a testing subset. Each terminal node of the classification tree identifies the percentage of original and copy data segments. The classification tree was devised using nine continuous variables: Russian-olive coverage in 2005 and 2010 and binary distributions for cropland, pastureland, urban, forest, grassland, wetland, and water. Unsupervised learning of CART was performed using the entire 65 sampling sites. This method detects structure in data by contrasting original data with randomized variants, which results in original and copy classes in each cluster division.

2.3.6. Linear Regression Models

Russian-olive coverage within the sampling plots, i.e. extent of Russian-olive between 2005 and 2010, was compared using linear regression models (Minitab[®] 14 statistical

software package, Minitab Inc., State College, PA). This model explains the linear functional relationship between coverage of Russian-olive in 2005 and 2010 at the floodplain and the upland region. Twenty-five training samples in each region were used as input sets for the linear regression models.

2.4. Results

Figure 2.2 shows the ordination between land-use and land-cover classes and soil types. The ordination diagram separated five groups of land-use and land-cover types with eight different soil types. The group that represents Russian-olive coverage in 2005 and 2010 is associated closely with silt loams and silty clay soil type. The coverage of Russian-olive in 2005 and 2010 is not significantly different ($P > 0.5$). The forest and shrub group distinguished at the leftmost side of axis 2 and is associated with loam and silty clay loam, loam and silty loam, and loam soil types (Fig. 2.2).

In addition, the grassland and pasture group showed great association with the loam and silty clay loam, loam and silty loam, and loam soil types. The urban and cropland group separated at the rightmost side of axis 2 and had greater statistical distance from loamy over sand and gravel, loamy fine sand, and fine sandy loam soil types (Fig. 2.2). The last group, the wetland and water class, occurred at the rightmost side of axis 1 (Fig. 2.2). The linear functional relationship of Russian-olive coverage between 2005 and 2010 showed a higher correlation for the upland region than for the floodplain (Fig. 2.3). The slope of the linear regression model for the upland region was nearly 1 and for the floodplain it was 0.9. The regression line for the upland region overlaps the reference line (1:1 Russian-olive coverage in 2005 and 2010 at the floodplain), whereas for the floodplain it shows a slight deviation from the reference line.

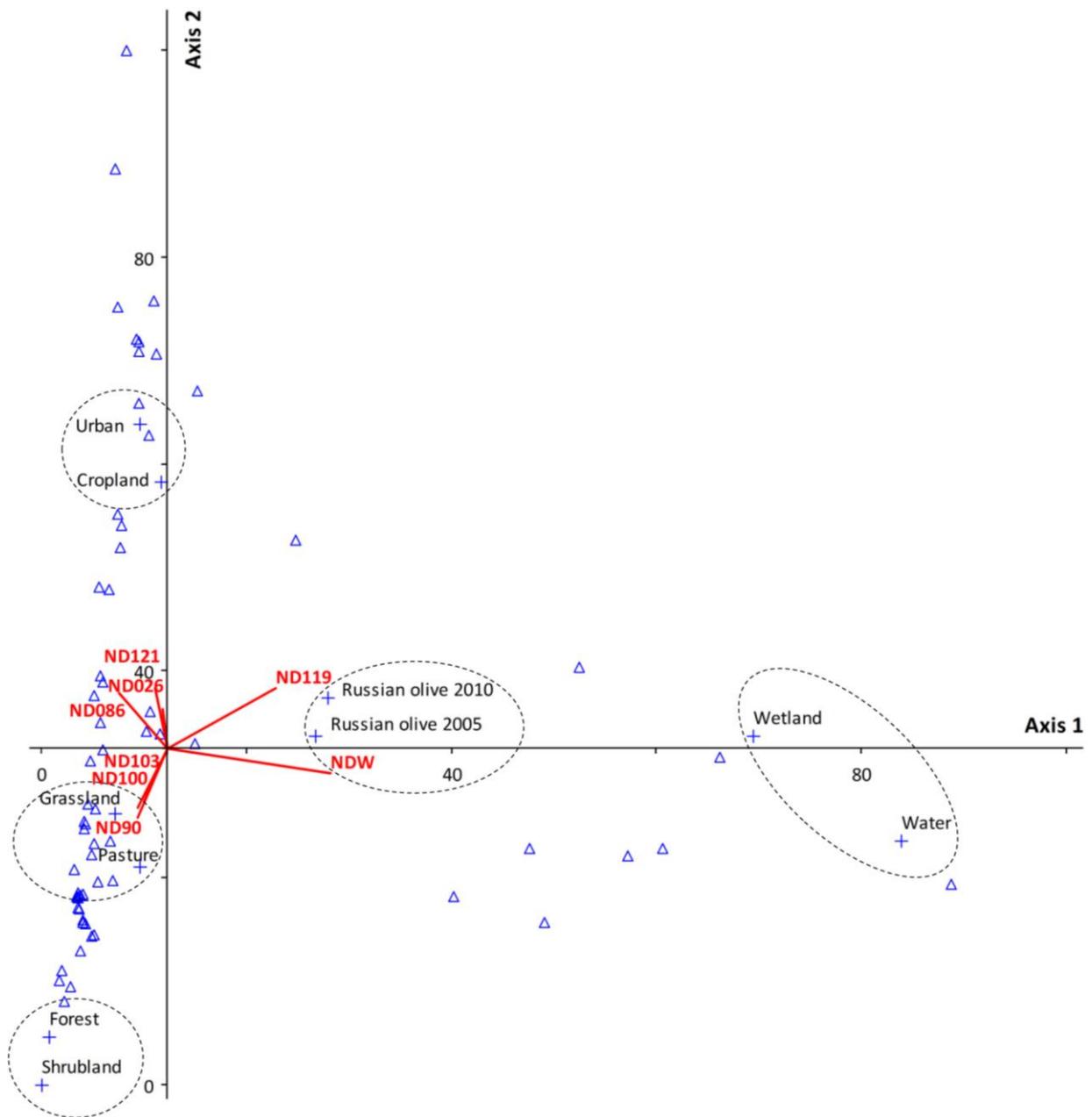


Figure 2.2. Canonical correlation analysis (CCA) ordination of land-use and land-cover classes according to soil types. Each closed triangle (Δ) represents a sampling plot (see also Fig. 2.1). Each cross (+) represents a land-use and land-cover class. Each joint-plot line indicates the soil type. ND026 - loamy over sand and gravel; ND086 - silt loam; ND090 - loam and silty clay loam; ND100 - loam and silt loam; ND103 - loam; ND119 - silt loam and silty clay; ND121 - loamy fine sand and fine sandy loam; NDW - water.

I mapped the groups, which were identified by the ordination diagram using soil types (Fig. 2.4). The result shows that the Russian-olive distribution is prominent along the floodplain of the Missouri River.

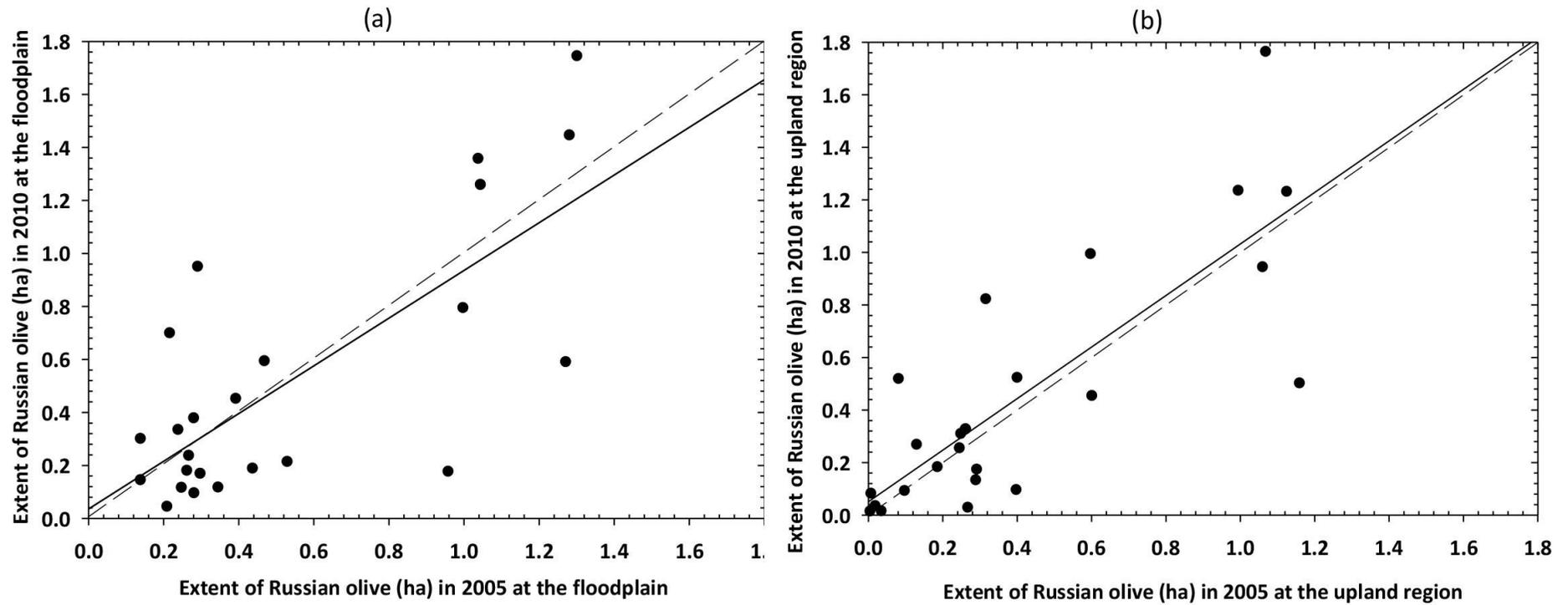


Figure 2.3. Linear regression models for Russian-olive coverage in 2005 and 2010 at (a) the floodplain and (b) upland regions. The solid line represents the linear regression model and the dashed line represents the reference line. The linear regression equation for the coverage of Russian-olive at the floodplain is $Y = 0.8993X + 0.0369$ with an R^2 value of 0.55. The linear regression equation for the coverage of Russian-olive in the upland is $Y = 0.981X + 0.0513$ with a slightly higher R^2 value of 0.65.

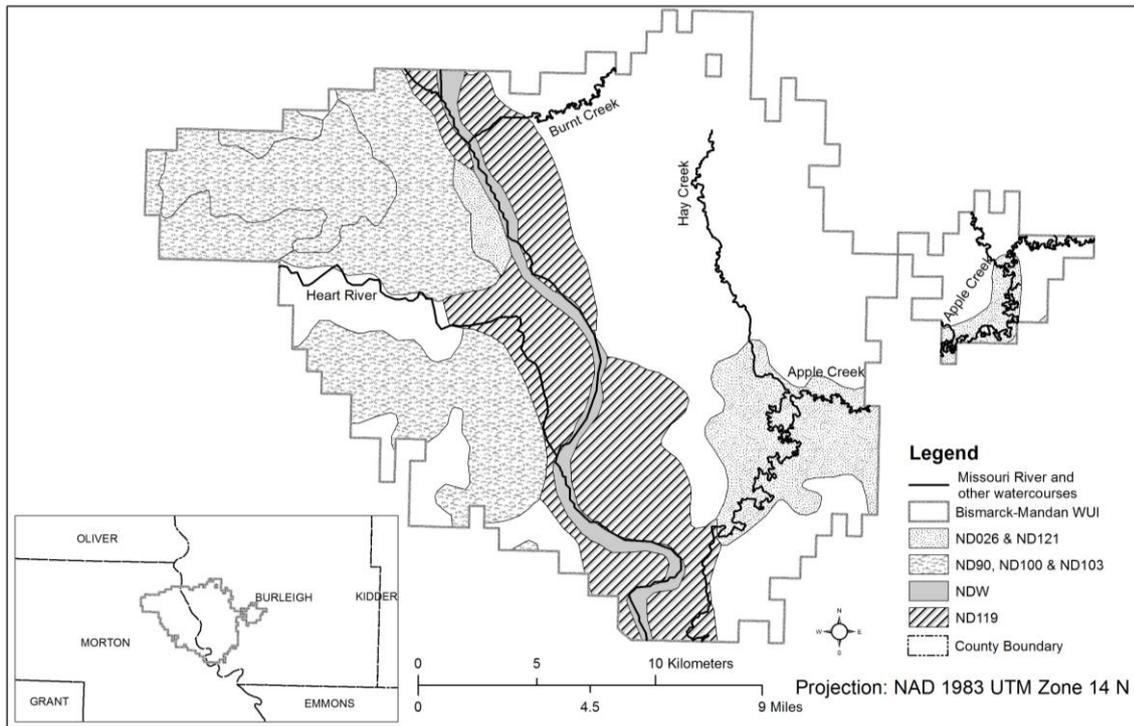


Figure 2.4. Distribution map of land-use and land-cover according to soil type. Four groups separated by the ordination diagram are illustrated here: urban-crop group association with loamy over sand, gravel and loamy fine sand, fine sandy loam (ND026 & ND121); grass-pasture group association with loam and silty clay loam, loam and silt loam, and loam (ND90, ND100 & ND103); wetland-water group association with water (NDW); and the Russian-olive group 2005 and 2010 association with silt loam and silty clay (ND119). Data Sources: Data for the boundaries of Bismarck-Mandan WUI, counties and river were downloaded from the North Dakota GIS Hub Data Portal (<http://www.nd.gov/gis/>). Accessed: June 02, 2011. Land-cover data was derived from NLCD data obtained from <http://www.mrlc.gov/nlcd2001.php> web portal. Accessed: May 18, 2011.

The urban and cropland group occurred upstream of the Missouri River and along the right tributary of the Missouri River at the eastern part of the BMWUI. The grassland and pasture group was localized at the western region of the BMWUI.

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The trends of the numeric data illustrated by the CCA were analyzed further to model the Russian-olive coverage using CART. The accuracy of the CART model based on the learning algorithm was 72.31%. The classification tree in Figure 2.5 comprised 10 splits with 21 nodes. The first split in the tree differentiated high grassland sites and low grassland sites (three times greater than low grassland sites); Russian-olive 2005 was twice more abundant at low grassland sites depicted on the left side of the tree. The classification tree segregated into two major clusters, with cropland on the left side and wetland on the right side, and with a threshold of ≤ 112 ha with eight nodes (nodes 2 to 9) and a threshold of > 112 ha with seven nodes (nodes 10 to 16) (Fig. 2.5).

The first subcluster separated into two groups with 24 records of urban space (≤ 7.15 ha) and 40 records of forest (≤ 1.15 ha). The urban group ends up with ≤ 0.62 ha of Russian-olive 2005 with 50% of both original and copy classes. The forest group is distinguished into areas with open water at ≤ 2.82 ha and Russian-olive 2005 at ≤ 0.5 ha. Wetland was separated at ≤ 0.15 ha from the water class and Russian-olive 2005 terminates at ≤ 0.28 ha with 64% of original class. The first division of the second sub-cluster (i.e., wetland) separated into Russian-olive mapped in 2005 (0.50 ha) and urban (≤ 0.42 ha). From the urban class (≤ 0.42 ha) Russian-olive mapped in 2010 separated at ≤ 0.35 ha, whereas the Russian-olive mapped in 2005 (≤ 0.05 ha) separated at > 0.68 ha of the urban class.

Figure 2.6 shows the distribution of Russian-olive in the BMWUI in 2005 and 2010. Table 2.1 shows the coverage of Russian-olive in relation to land-use and land-cover coverage within BMWUI. The total forests within the inundated boundary (See also Fig. 2.6) in the BMWUI derived from the NAIP images for 2005 and 2010 comprised 498 ha and 482 ha, respectively. The total extent of Russian-olive in BMWUI in 2005 was 110 ha, and, of that, 13 ha were in the inundated habitats, while in 2010 Russian-olive covered 125 ha within the BMWUI, and, of that, 25 ha (20%) were in the inundated habitats (Table 2.1).

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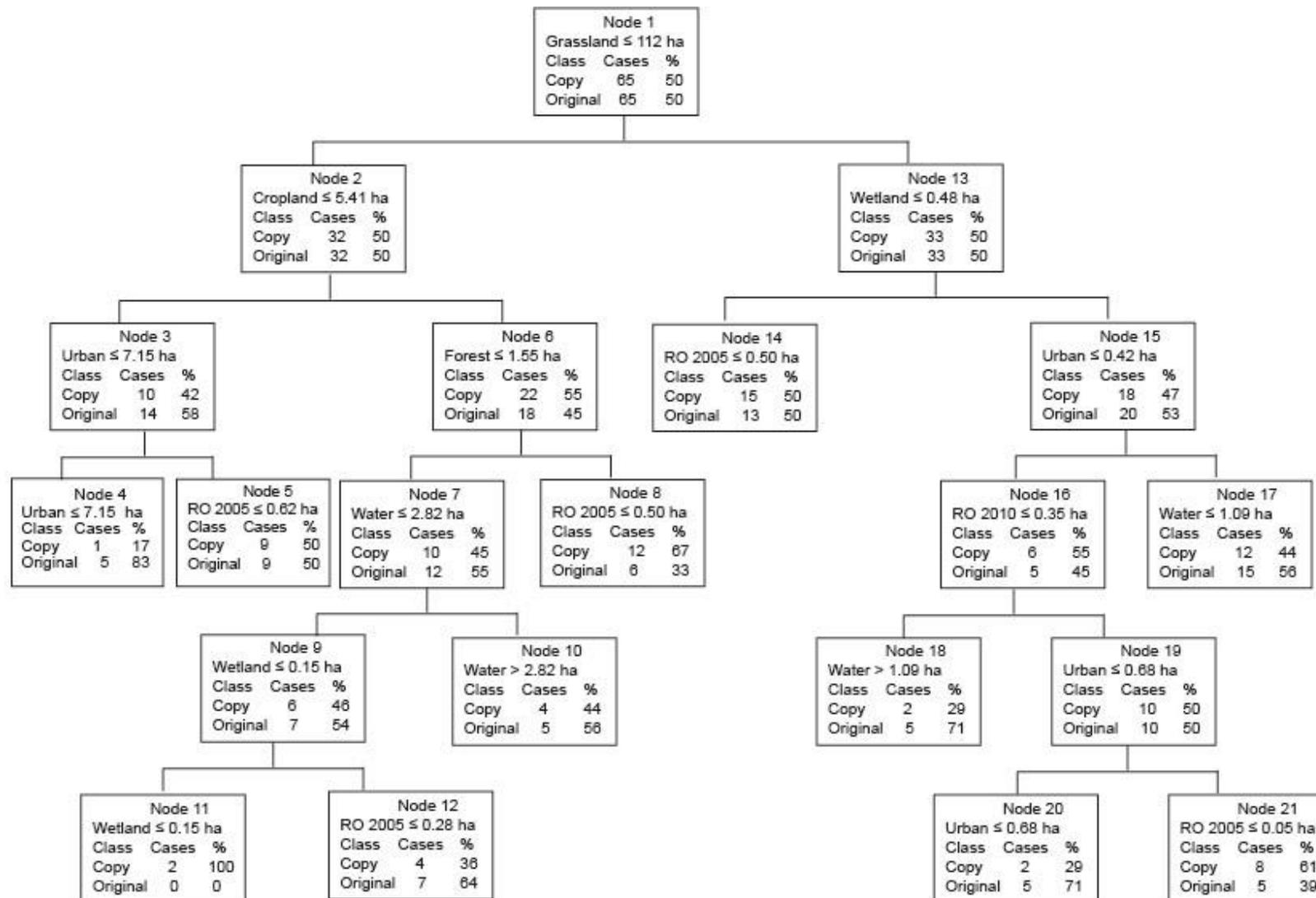


Figure 2.5. Classification tree analysis of the coverage of the Russian-olive in 2005 and 2010 according to land-use and land-cover classes within the sampling sites. Each of the splits (non-terminal nodes) is labelled with the variable and its value that determine the split. Each node is labelled with node number and percentage of original and copy data segments.

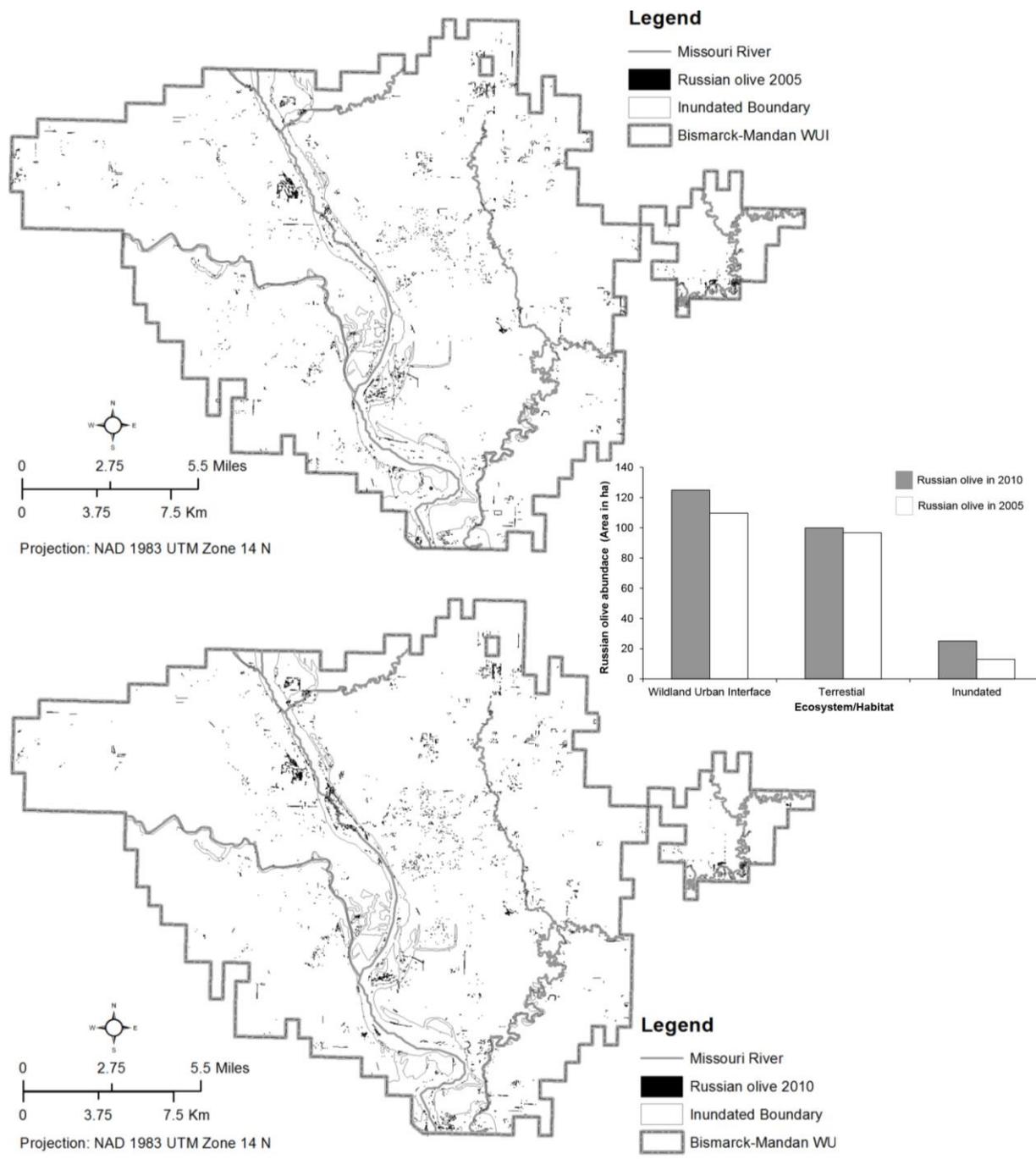


Figure 2.6. Map of Russian-olive created from NAIP image through digitizing polygons for 2005 and 2010. Data sources: Data for the boundaries of Bismarck-Mandan WUI and river were downloaded from the North Dakota GIS Hub Data Portal (<http://www.nd.gov/gis/>). Accessed: June 02, 2011. NAIP images were obtained from <http://datagateway.nrcs.usda.gov/> web portal. Accessed: August 08, 2011.

Table 2.1. Russian-olive coverage and land-use and land-cover extent of Bismarck-Mandan Wildland Urban Interface derived from NAIP 2005 and 2010 images and NLCD 2001 image.

Land-use/ land-cover category	Extent (ha) derived from the images		
	NAIP 2010	NAIP 2005	NLCD 2001
<i>Russian-olive</i>			
Wildland Urban Interface	124.90	109.62	-
Terrestrial	99.88	96.67	-
Inundated	25.03	12.95	-
<i>Land-cover</i>			
Inundated forest	482.39*	498.15	-
Inundated forest (NLCD)	-	-	693.27
Total forest cover within WUI	-	-	2655.20
<i>Land-use</i>			
Grassland	-	-	24256.27
Cultivated crops	-	-	6684.34
Pasture/Hay	-	-	2653.10
Urban	-	-	2616.76
Shrubland	-	-	114.88

(* Source: Rozario et al. 2011)

2.5. Discussion

Mapping vulnerable habitats that Russian-olive may colonize is important for understanding its local-scale potential distribution in terms of land-use and land-cover conversion. Although Russian-olive has been distributed widely across the United States, the extent of land infested with Russian-olive in North Dakota is still unknown. Therefore, our findings provide valuable baseline information especially for riparian forests and upland grasslands in the BMWUI. Because Bismarck is the capital city of North Dakota, this information is especially valuable for city planners, forest managers, wildlife managers, and policy makers for management implications both in and outside the city and entities that deal with forest resource management along the Missouri River. For example, the city of Bismarck manages street tree resources and public parks (Peper et al. 2004) and these findings may be important to city foresters, enabling them to visualize whether Russian-olive invades the landscape they manage.

From 2005 to 2010, the Russian-olive extent within the inundated boundary is almost doubled (Table 2.1). This may be an indication of degradation of riparian forest due to natural and anthropogenic disturbances. Russian-olive can tolerate flooding for the periodic inundation scenarios, which prevails for 40 consecutive days (Tiborcz et al. 2011), and it apparently invades silt loam and silty clay soils with low to moderate concentrations of soluble salt, that is, 100-3500 ppm (Carman and Brotherson 1982; Stannard 2003). Finally, the lack of intense pressure from herbivores and tolerance of the competitive effects of established vegetation make Russian-olive a successful invader in riparian habitats (Katz and Shafroth 2003).

In the ordination diagram, five assemblages of land-use and land-cover classes have been clearly separated. Water and wetland land-cover types are aligned to the right of axis 1, whereas terrestrial land-use and land-cover types such as forest and shrubland are aligned to the left of axis 1 (Fig. 2.2). Russian-olive distributions in 2005 and 2010 are aligned to the middle of axis 1 and also have positive relationships with the silt loams and silty clay soil type. This reveals that Russian-olive occurrence is ample in between the terrestrial and aquatic habitats, when silt loams and silty clay soil types are available. In our study, we are unable to provide broader perspectives such as the relationship between Russian-olive coverage and soil nutrient content which need to be addressed in future.

Although the ordination diagram depicts the trends and relationships among the land-use and land-cover classes, the technique is unable to quantify at which level each category contributes more to establishment of Russian-olive in either time period. We address this issue using a classification tree, and also compare the results with both multivariate techniques. In the ordination diagram, grassland has the least statistical distance to Russian-olive, which depicts the higher association between these two classes. From the classification tree, variables such as the quantity of land area distributed between cropland, urban area, forest, and wetland influenced variation in the distribution of Russian-olive in 2005. The combination of factors most likely to support Russian-olive proliferation in 2005 included the presence of large urban

(> 7.15 ha), forest (> 1.55 ha), and wetland (> 0.15 ha) areas. In contrast, the Russian-olive 2010 distribution was facilitated by more wetland areas (> 0.48 ha) and smaller urban interface areas (\leq 0.48 ha). Russian-olive abundance in the riparian habitats doubled from 2005 to 2010, which may be an indication that invasion into wetlands is increasing.

This study provides key information about Russian-olive distribution at the BMWUI that can be utilized to enhance forest stewardship program objectives. We found that the upland grassland habitats in the western part of Mandan within BMWUI was least impacted, although it would also be prudent to monitor these areas periodically. These results can be incorporated with *in-situ* data to ascertain any association between Russian-olive and other vegetation. In the future we hope to analyze soil samples for the specific sites in order to determine possible relationships between Russian-olive occurrence and edaphic soil conditions.

2.6. Conclusions

Understanding vulnerable habitats for rapid invasions by exotic species is crucial for land managers to identify and implement successful management strategies. Habitat suitability modelling is useful for identifying critical arboreal ecosystems that can be targeted with surveillance, prevention and eradication measures to avoid wide-scale infestations. This study provides valuable baseline information of preferred habitats for current and potential future distribution of Russian-olive within the Bismarck-Mandan Wildland Urban Interface (BMWUI) on the banks of Missouri River. Specifically, we found that riparian habitats are more suitable for establishment of Russian-olive than are upland terrestrial habitats. Forest managers can use our distribution data to monitor how Russian-olive colonization of an area may impact growth and survival of native trees such as cottonwood and willow at similar sites. The North Dakota Natural Heritage Inventory (NDNHI) has carried out botanical surveys, for example, creating an inventory of rare plants, and our results may complement theirs as to whether Russian-olive has also been threatening rare plants in this region. Weed managers in other regions of the Missouri River can compare our results with their data to create strategies

to manage Russian-olive regionally through prescribed restoration programs. This study also provides valuable information from which city and wildlife managers can make better management plans to conserve native plants, protecting them from the invasive species in the riparian and upland regions.

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CHAPTER 3. PHYTOSOCIOLOGY OF NATIVE AND EXOTIC PLANTS IN A RIPARIAN FOREST ALONG THE BANKS OF MISSOURI RIVER, NORTH DAKOTA*

3.1. Abstract

Riparian forests provide important ecosystem functions, including flood protection, run-off filtering, and habitat for wildlife. Anthropogenic activities and weather conditions can create riparian forests that are susceptible to invasion by exotic species. Therefore, understanding the factors that correlate or contribute to distribution of a particular invasive species is essential for early management decisions. We attempt to understand how Russian-olive (*Elaeagnus angustifolia* L.) associates with native plants and address potential habitats for distribution of Russian-olive along sections of the Missouri River in North Dakota. A phytosociological study was carried out along the elevation gradient of the Missouri River. Edaphic parameters were pooled with vegetation characteristics to establish a relationship between plant associations and soil type. Classification and ordination techniques were used to identify vegetation groups in relation to soil characteristics. Three plant communities were identified—Russian-olive-cottonwood, green ash-chokecherry-bur oak, and boxelder-elm—using multivariate analysis. Russian-olive-cottonwood association correlates with lower elevation, low pH, and high Fe. In addition, the green ash-chokecherry-bur oak plant community correlated with high K, and the boxelder-elm plant correlated with high organic matter. We also predicted potential habitats for distribution of Russian-olive, which may be useful in preventing future introduction of Russian-olive to non-infested areas.

*This material in this chapter was Co-authored by Buddhika D. Madurapperuma, Peter G. Oduor, Anthony W. Wamono, and Larry A. Kotchman.

3.2. Introduction

Riparian forests are important in the functioning of river ecosystems and for the protection of biodiversity (Olson et al. 2007). Healthy riparian forests act as a buffer zone, which filter sediments running off from agricultural lands (Liu et al. 2008). Also, riparian forests provide a variety of habitats for fish and wildlife.

But riparian forests are not static ecosystems. The phytosociology of riparian forests is influenced by natural phenomena, such as river channel migration and flooding, and anthropogenic activities (Suzuki et al. 2002; Brummer et al. 2006). Bank erosion cuts off the river channel and thus changes the river morphology. Pointbar edges form at bank cutoffs where river water moves slowly, which creates a dynamic landscape that influences both structure and composition of riparian forests. Therefore, pointbar formations provide additional soil habitats for plant communities to establish (Meitzen, 2009). However, exotic plants may colonize in those habitats as pioneers since they have plastic biological attributes, which are common to many weed species. For example, Russian-olive and saltcedar (*Tamarix ramosissima* Ledeb.) are two common exotic species, which are widely distributed at the riparian habitats in the US (Friedman et al. 2005; Katz and Shafroth 2003; Mineau et al. 2012; Nagler et al. 2011).

Flooding is an important natural phenomenon in the establishment of riparian vegetation (Brown and Peet 2003). Many riparian plants' growth and reproduction rely upon periodic inundation. For example, cottonwood (*Populus* spp.) and willow (*Salix* spp.) plants regenerate at the floodplain with deposition of alluvial soil mainly by periodic flooding (Lesica and Miles 1999).

Human-induced land-use and land-cover change, including agricultural land conversion, and climatic variability, such as flooding, have caused substantial ecological changes to riparian ecosystems (Madurapperuma et al. 2012). To prevent flooding, the US

Army Corps of Engineers established river catchment areas in the US and built dams across rivers. For example, seven dams were constructed along the Missouri River during the twentieth century (NRC 2002). However, the dams caused ecological changes to riparian habitats, including large catchment areas of the upper Missouri River were inundated due to reservoirs. The native vegetation at the downstream areas of the Missouri River was converted to farmland (NRC 2002).

The Missouri River is the second largest river in the US and includes a large, relatively intact, floodplain. The broad floodplains in the Missouri River are recognized for their diverse and abundant off-channel habitats and rich floristic communities (Keammerer et al. 1975). For example, 220 species of vascular plants were reported between the Garrison Dam and Oahe Reservoir in North Dakota (Keammerer et al. 1975). However, the Missouri River ecosystems experienced an ecological transformation from forest to farmlands during the twentieth century, which led to a reduction in natural habitats (NRC 2002). The aim of this study is to investigate the spatial distribution of native and non-native plants from the Garrison Dam to the lower Missouri River at the Bismarck-Mandan Wildland Urban Interface. The primary goal of our field sampling was to assess Russian-olive density compared to native plants along the Missouri River in North Dakota.

3.3. Materials and Methods

3.3.1. Vegetation Sampling

We selected sampling sites along the elevation gradient from Lake Sakakawea to the Oahe Reservoir (Fig. 3.1, Table 3.1). Individual sections in the US Public Land Survey System covering the Missouri River area were used to generate random areas from riparian habitat. Twenty plots were selected from the randomly generated individual sections, and each 10 m × 10 m plot was established along the Missouri River representing an elevation

gradient from 574 m to 498 m. One of the randomly generated sampling sites was inaccessible, so I chose to sample an accessible site along a tributary of the Missouri River.



Figure 3.1. A map of the study area showing sampling locations ranging from Lake Sakakawea to the Oahe Reservoir in North Dakota. Data Sources: Data for the administrative and river boundaries were downloaded from the North Dakota GIS Hub Data Portal (<http://www.nd.gov/gis/>). Accessed: June 02, 2011.

Vegetation sampling was carried out using three different size classes, namely: (i) individuals ≥ 10 cm gbh (girth at breast height) and above 1 m height (ii) individuals below 10 cm gbh and above 1 m height and (iii) individuals less than 1 m in height.

Table 3.1. GIS coordinates and elevation data for sampling sites. Sampling sites S1 - S7 represented Lake Sakakawea area; sampling sites S8 - S12 represented an intermediate region; and sampling sites S13 - S20 represented the Bismarck-Mandan area.

Sampling sites	Latitude	Longitude	Elevation (m)
S1	47.5313	-101.4520	572
S2	47.5164	-101.4490	572
S3	47.5067	-101.4397	574
S4	47.4932	-101.4214	520
S5	47.4918	-101.4251	519
S6	47.4665	-101.4375	523
S7	47.4763	-101.4045	509
S8	47.2871	-101.3375	526
S9	47.2898	-101.0406	512
S10	47.2073	-101.9694	511
S11	47.1301	-100.9390	509
S12	47.1292	-100.9386	507
S13	46.9407	-100.9031	504
S14	46.8906	-100.8935	500
S15	46.8480	-100.8630	503
S16	46.8467	-100.8598	538
S17	46.8284	-100.8332	504
S18	46.7446	-100.7966	504
S19	46.7387	-100.7973	505
S20	46.6722	-100.7333	498

The species, girth and height of individual plants were recorded for the first vegetation size class, whereas the number of individuals was enumerated for the second vegetation size class within the main plot. Percent ground cover of vegetation less than 1 m in height was measured using visual estimates. The density of species within 100 m² plots was calculated by counting all individuals. The basal area for each individual was calculated using

the girth measurement formula, πr^2 , where r equals $\frac{1}{2}$ diameter at breast height (dbh) and π equals $22 / 7$.

3.3.2. Soil Sampling and Analysis

Four soil samples within 0-25 cm depth at the corner of the main plot were collected from each plot using a soil corer. Then these soil samples were aggregated together to yield a representative composite sample. Each sample was oven dried at 105 °C to a constant weight and then air-dried and sieved (< 2 mm). Dry samples were ground and stored for further chemical analyses. Soil chemical tests were done by the NDSU Soil Testing Lab. Soil chemical analysis was done using the following methods: soil pH using a pH meter using a soil to water ratio of 1:5; electrical conductivity measurements using a soil to water ratio of 1:2 (for example Dahnke and Whitney 1988); NO_3^- - N using the water extraction method (for example Keeney and Nelson 1982); organic matter content by the ignition method (for example Walkley and Black 1934); phosphorus by the Olson method (Olsen et al. 1954); potassium, calcium, magnesium, sodium by the ammonium acetate method (for example Schollenberger and Simon 1945); and zinc, iron, manganese using the Diethylene Triamine Pentaacetic Acid (DTPA) method (for example Lindsay and Norvell 1978).

3.3.3. Multivariate Analysis

We performed a cluster analysis to find how species associate in the riparian habitats using BioDiversity Pro[®] 2.0 software package. The species grouping was created according to Bray-Curtis distance matrix. Bray-Curtis is a similarity metric that can be computed using presence/ absence data or density data of species. Bray-Curtis values range from 0 to 1 with one indicating two species are similar in composition (Bray and Curtis 1957). In order to obtain trends and relationships between vegetation and soil factors we employed ordination techniques using the PC-ORD₄ software package. The densities of species within 20 sampling plots were used to derive a primary data matrix, while soil chemical data was used

to generate a secondary data matrix. Twelve tree species (out of 15 species of trees and shrubs) from the 20 sampling plots, were employed to make the primary data matrix. In contrast, 13 soil chemical parameters such as NO_3^- -N, P, K, organic matter, pH, electrical conductivity, Ca, Mg, Na, S, Zn, Fe, and Mn were used to generate the secondary data matrix. Then the two data matrices were overlain using canonical correspondence analysis (CCA) to determine the correlation between species and soil characteristics. The variables in the secondary data matrix are represented as biplots in the CCA diagram with arrows that point to a direction of maximum variation. In addition, the length of the arrow is proportional to the rate of change (for example ter Braak 1986).

3.3.4. Habitat Suitability Modelling

We used species occurrence data along the Missouri River to predict current and future distribution of the species under study using maximum entropy distribution modelling or MaxEnt (see also Elith et al. 2011; Kumara and Stohlgren 2009). A total of 138 records for Russian-olive from Lake Sakakawea to Oahe Reservoir and 15 environmental variables were used to predict the species distribution within eco-regions in North Dakota. The bio-climatic environment variables were obtained from CliMond datasets (<https://www.climond.org/Download.aspx>). We used radiation and soil moisture variables (Bio20-Bio35) as environmental variables to elucidate potential or viable habitats that would favour Russian-olive within North Dakota. I selected radiation and soil moisture variables, which are of interest to plant ecologists and are used in habitat suitability modeling. Bio-climatic environmental variables used for this model are as follows: ‘bio 20’ is annual mean radiation, ‘bio 21’ is highest weekly radiation, ‘bio 22’ is lowest weekly radiation, ‘bio 23’ is radiation seasonality, ‘bio 24’ is radiation of wettest quarter, ‘bio 25’ is radiation of driest quarter, ‘bio 26’ is radiation of warmest quarter, ‘bio 27’ is radiation of coldest quarter, ‘bio 28’ is annual mean moisture index, ‘bio 29’ is highest weekly moisture index, ‘bio 30’ is

lowest weekly moisture index, ‘bio 31’ is moisture index seasonality, ‘bio 32’ is mean moisture index of wettest quarter, ‘bio 33’ is mean moisture index of driest quarter, ‘bio 34’ is mean moisture index of warmest quarter, ‘bio 35’ is Mean moisture index of coldest quarter. We used the freely available MaxEnt software, version 3.3 (<http://www.cs.princeton.edu/~schapire/maxent/>), to generate probability of species occurrence in North Dakota.

3.4. Results

3.4.1. Vegetation Structure

In general, vegetation structure can be described by density, basal area, and girth class distribution. Figure 3.2 represents density and basal area of Russian-olive and native species ≥ 10 cm gbh in each of the twenty sampling sites, which represent the elevation gradient along the Missouri River from upstream (574 m) to downstream (498 m). Sampling sites 1 to 7 (S1 - S7) were selected from the Lake Sakakawea area (509 m – 574 m \pm 30), sampling sites 8 to 12 (S8 – S12) represented an intermediate region (509 m – 526 m \pm 7), and sampling sites 13 to 20 (S13 – S20) were selected from the Bismarck-Mandan area (498 m – 538 m \pm 13). Russian-olive density at the lower Missouri River area (S13- S20) seems to be higher compared to the upstream area (S1 - S7). This correlates to an elevation gradient, where lower elevation sites had more Russian-olive than areas at higher elevations. Russian-olive stands occurred at only three sample sites (S4, S9, and S20) at an elevation range of 498 m – 520 m \pm 11. The average density of native plants was higher (21 individuals /100 m² \pm 22) in the intermediate region compared to the upstream region (2 individuals /100 m² \pm 3). Overall, Russian-olive showed a high basal area for the upstream and downstream areas (0.1406 m²) (Table 3.2).

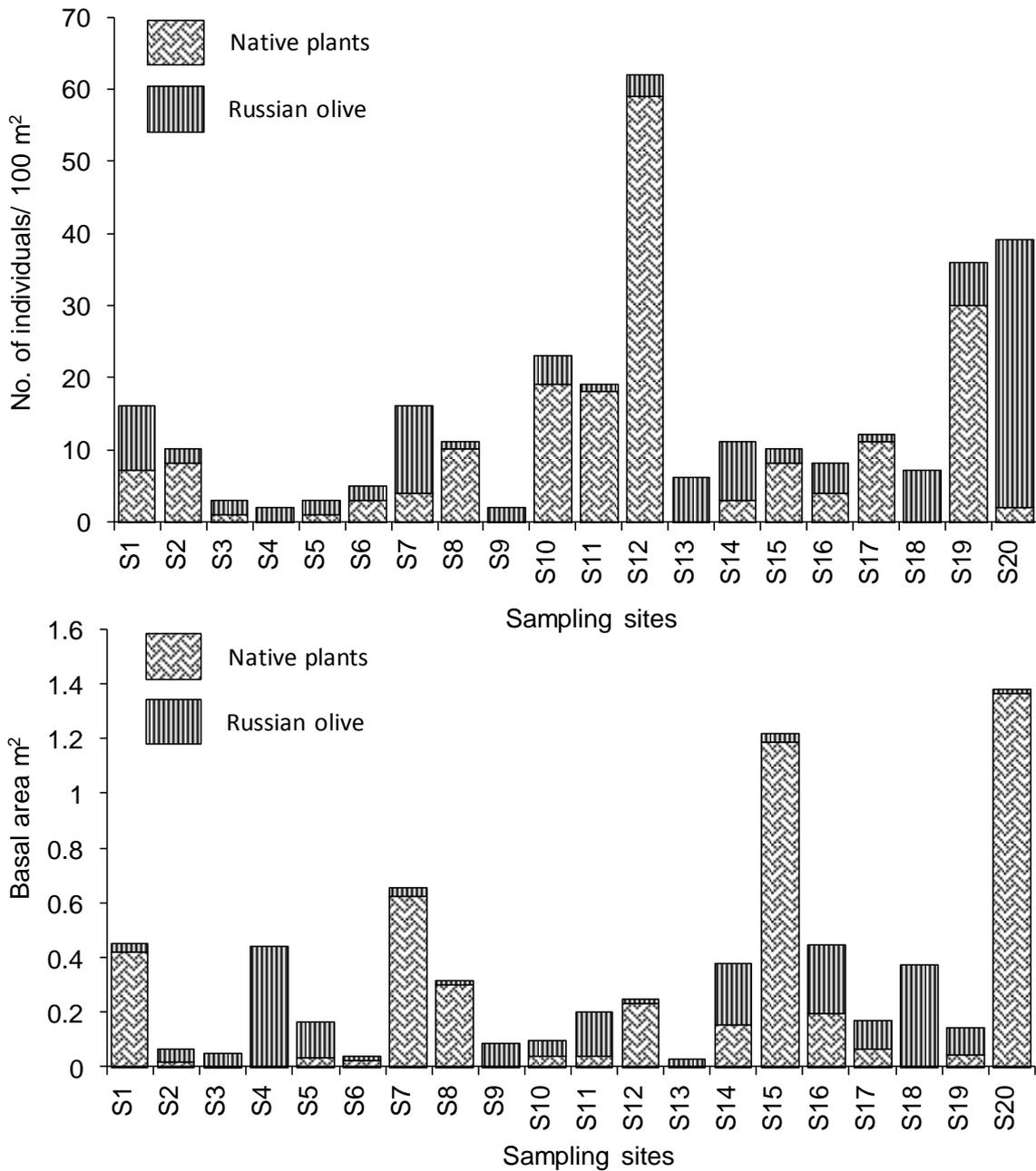


Figure 3.2. Density (upper) and the basal area (lower) of woody individuals (≥ 10 cm girth) in 20 sampling sites along the Missouri River in North Dakota. Sampling sites S1 - S7 represent the upstream, S8 – S12 intermediate, and S13 – S20 downstream regions of the Missouri River.

In contrast, native plants showed much higher basal area for the downstream area (0.3745 ± 0.56). Although Russian-olive density was highest at S20, its basal area was very low, which indicated that the plants were young. Compared to S20 (2 individuals /100 m²),

S15 had higher densities (8 individuals /100 m²) for native plants with high basal area (1.19 m²).

Table 3.2. Comparison of density and basal area of Russian-olive and native plants for the sampling sites from upstream to downstream along the Missouri River in North Dakota.

Sampling sites	Elevation (m)	Region	Density (Individuals / 100 m ²)		Basal area (m ²)	
			Russian olive	Native density	Russian olive	Native plants
S1-S7	509-574	Upstream	4 ± 4	2 ± 3	0.1052 ± 0.15	0.1594 ± 0.26
S8-S12	509-526	Intermediate	2 ± 1	21 ± 22	0.0666 ± 0.06	0.1199 ± 0.13
S13-S20	498-538	Downstream	9 ± 9	8 ± 10	0.1406 ± 0.13	0.3745 ± 0.56

Figure 3.3 compares the diameter class distribution of Russian-olive and native species based on their density. The girth class distribution showed a reverse J-shaped curve. Both Russian-olive and native plants showed higher densities for the lower DBH (diameter at breast height) size class. Russian-olive density for 10 cm - 20 cm DBH size class was higher compared to the density of native plants. The highest DBH size class for Russian-olive was 30 cm - 40 cm, whereas it was over 50 cm for the native plants.

3.4.2. Floristic Composition

A total of 15 species belonging to 12 genera and 9 families were identified (Appendix A). This is only a fraction of the total floristic composition, because the herbaceous species were not identified up to species. The most common species was Russian-olive (*Elaeagnus angustifolia* L.) with 113 individuals across all sampling sites. Green Ash (*Fraxinus pennsylvanica* Marsh.) and cottonwood (*Populus deltoides* Bartr. ex Marsh) were the second most common species with 39 and 38 individuals, respectively. Salicaceae is the leading family with five species, namely *Populus deltoides* Bartr. ex Marsh., *Salix amygdaloides* Anderss., *Salix fragilis* L., *Salix interior* Rowlee, and *Salix rigida* Muhl. The most common families were Elaeagnaceae and Rosaceae with two species in each.

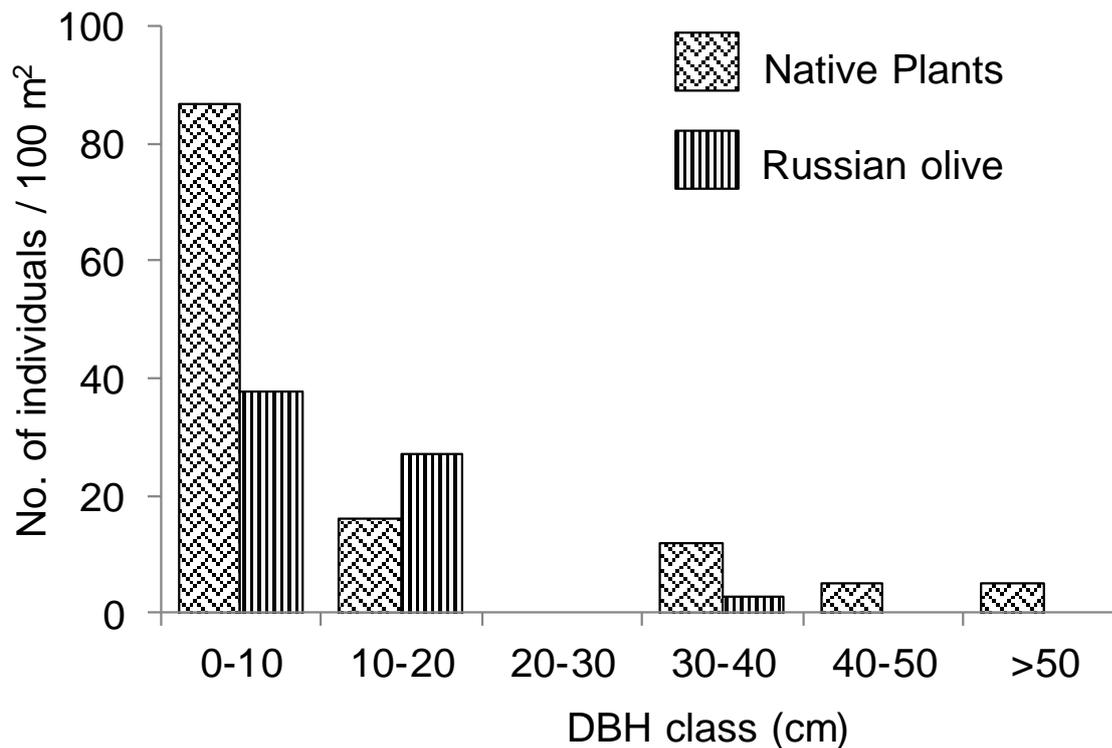


Figure 3.3. Diameter at breast height (DBH) class distribution of native and exotic Russian-olive at the Missouri River in North Dakota.

3.4.3. Cluster Analysis

Figure 3.4 is a classification tree, which shows the species assemblage in the riparian ecosystem along the Missouri River. Species are clustered based on their similarity index, which measures the variability among species using Bray-Curtis similarity matrix. Three major groups of species were separated from the cluster analysis. These groups were treated as plant communities and identified using the common names of the plants. The first group, comprised of three species, separated at 24% similarity level and was identified as the Russian-olive-cottonwood- buffaloberry plant community. The second group, comprised of three species, separated at 55% similarity level and was identified as the green ash-chokecherry-bur oak plant community. The third group, comprised of two species, separated at 67% similarity level was identified as the boxelder- elm plant community. Four species of willows (*Salix* spp.) were separated as individual clusters from the main cluster.

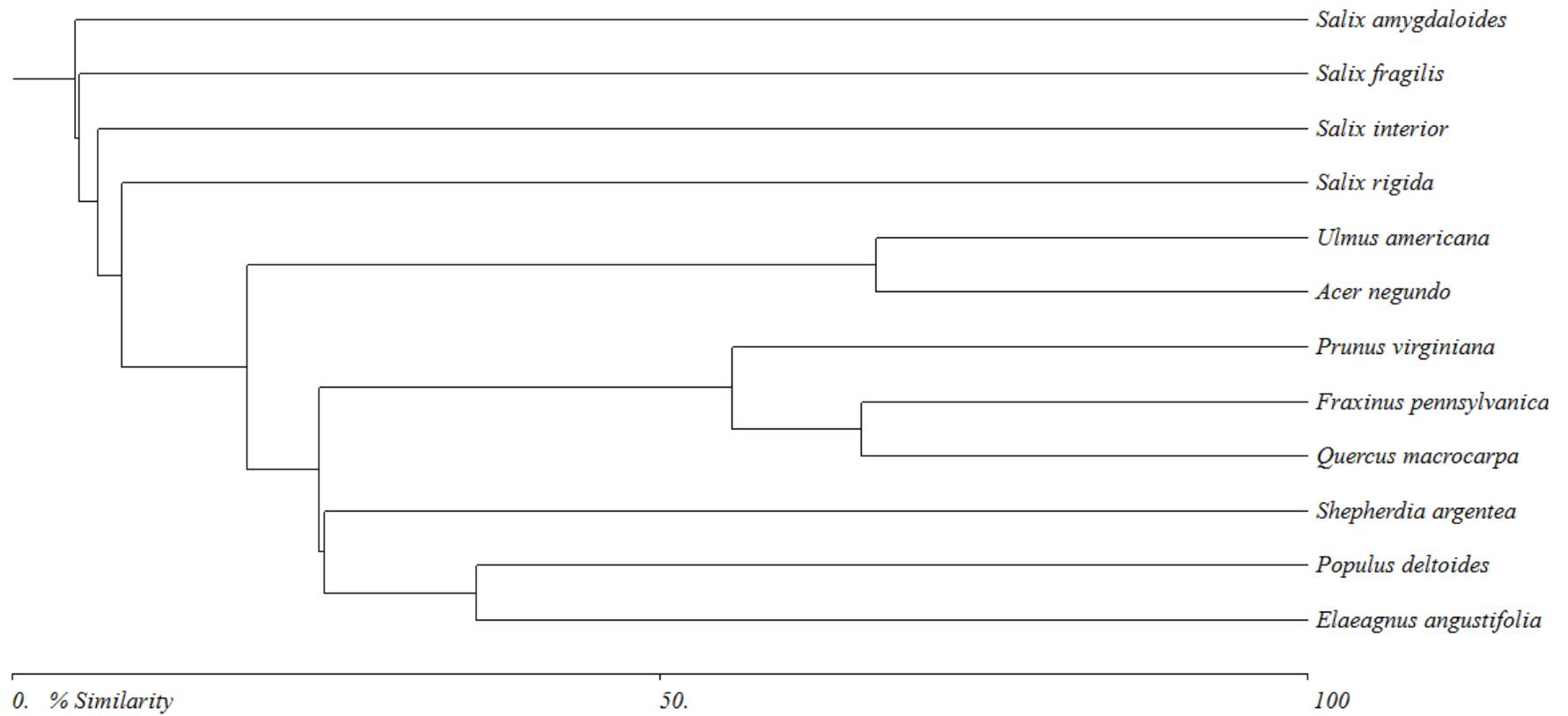


Figure 3.4. Cluster analysis of species association. Bray-Curtis similarity values based on density for the vegetation ≥ 10 cm gbh were used for individuals in the Missouri River floodplain in North Dakota.

The Bray-Curtis index was used to compare the similarity of species among sites (Table 3.3). The derived index yielded 67% similarity for the boxelder-elm plants, 66% for green ash-bur oak, 56% of bur oak-chokecherry. Medium similarity was observed for the green ash-chokecherry (43%) and the Russian-olive-cottonwood (36%) plant communities.

3.4.4. CCA Ordination

Figure 3.5 shows the ordination results of the CCA for species density and soil chemical parameters. The twenty sampling sites along with twelve species and thirteen soil chemical parameters are plotted along axes 1 and 2 of the ordination diagram. The Pearson correlation between species and soil variables for axis 1 and 2 is 0.99 and 0.96 respectively. Three plant communities identified by the cluster analysis were clearly distinguishable from the CCA diagram with associated soil parameters. These plant communities comprised of Russian-olive-cottonwood, green ash-chokecherry-bur oak, and boxelder-elm.

Table 3.3. Comparison of species using Bray-Curtis similarity index (Sorensen's index), which measures the similarity between two different sites. A Bray-Curtis similarity index was made using density data from species documented during the survey of 20 plots sampled in the Missouri River floodplain in North Dakota. Four letter codes represent scientific names of species, coded as the first two letters in the generic name coined with the first two letters of the species name.

Species ↓	Codes →	Elan	Pode	Quma	Frpe	Prvi	Acne	Ulam	Shar	Saam	Safr	Sain	Sari
<i>Elaeagnus angustifolia</i>		1											
<i>Populus deltoides</i>		35.76	1										
<i>Quercus macrocarpa</i>		6.06	14.04	1									
<i>Fraxinus pennsylvanica</i>		7.89	12.99	65.52	1								
<i>Prunus virginiana</i>		12.16	8.22	55.56	43.24	1							
<i>Acer negundo</i>		1.75	5.13	10	5	0	1						
<i>Ulmus americana</i>		1.74	10	9.52	9.76	0	66.67	1					
<i>Shepherdia argentea</i>		7.52	24.14	10.26	23.73	10.91	9.52	18.18	1				
<i>Salix amygdaloides</i>		3.48	0	0	4.88	0	0	0	0	1			
<i>Salix fragilis</i>		5.17	0	0	0	0	0	0	0	0	1		
<i>Salix interior</i>		1.75	0	0	0	0	0	0	0	0	0	1	
<i>Salix rigida</i>		8.45	0	0	0	0	0	0	0	0	0	6.67	1

The Russian-olive-cottonwood association showed a positive correlation for Fe, but all other elements are negatively correlated with this group. Green ash-chokecherry-bur oak association showed a positive correlation with K concentration. Boxelder-elm association showed a higher correlation for organic matter content. Two willow plant species, namely American McKay (Sari) and sandbar willow (Sain) were separated from other species at the top right corner of the diagram. American McKay and sandbar willow were found at a sandbar on the Missouri River (S19).

Table 3.4 shows the correlations and biplot scores of soil variables for axis 1 and 2 of the ordination diagram. Axis 1 and axis 2 showed a high variability for certain soil chemical parameters. Of the soil chemical parameters, K and organic matter content indicate the high variability of axis 1 (0.85 and 0.72, respectively). Nitrogen (N) is parallel to axis 1, which means axis 1 can be described by the soil N gradient. On the other hand, Fe and pH show high correlation with axis 2 (0.62 and 0.52, respectively), which explains the high variability of this axis.

3.4.5. Habitat Suitability Modelling

The MaxEnt model was used to predict suitable habitat for Russian-olive based on environmental variables and Russian-olive present-absent data (Fig. 3.6). The predicted potential habitats for Russian-olive can be assessed from the probability classes, that is, 0.01-0.25 (low probability), 0.25-0.57 (medium probability), and 0.57-0.87 (high probability). According to the model, the most suitable area for Russian-olive is the North-western Glaciated Plains eco-region, which mainly represents the Missouri River floodplain (Fig. 3.6). The North-western Great Plains eco-region is the next highest predicted area for Russian-olive occurrence. The least potential habitat for Russian-olive occurrence is observed at the Northern Glaciated Plains eco-region. The MaxEnt model's internal jackknife test of

variable importance showed that “radiation of the wettest quarter” is the most highly correlated predictor (23%) of Russian-olive’s habitat distribution (Fig. 3.6).

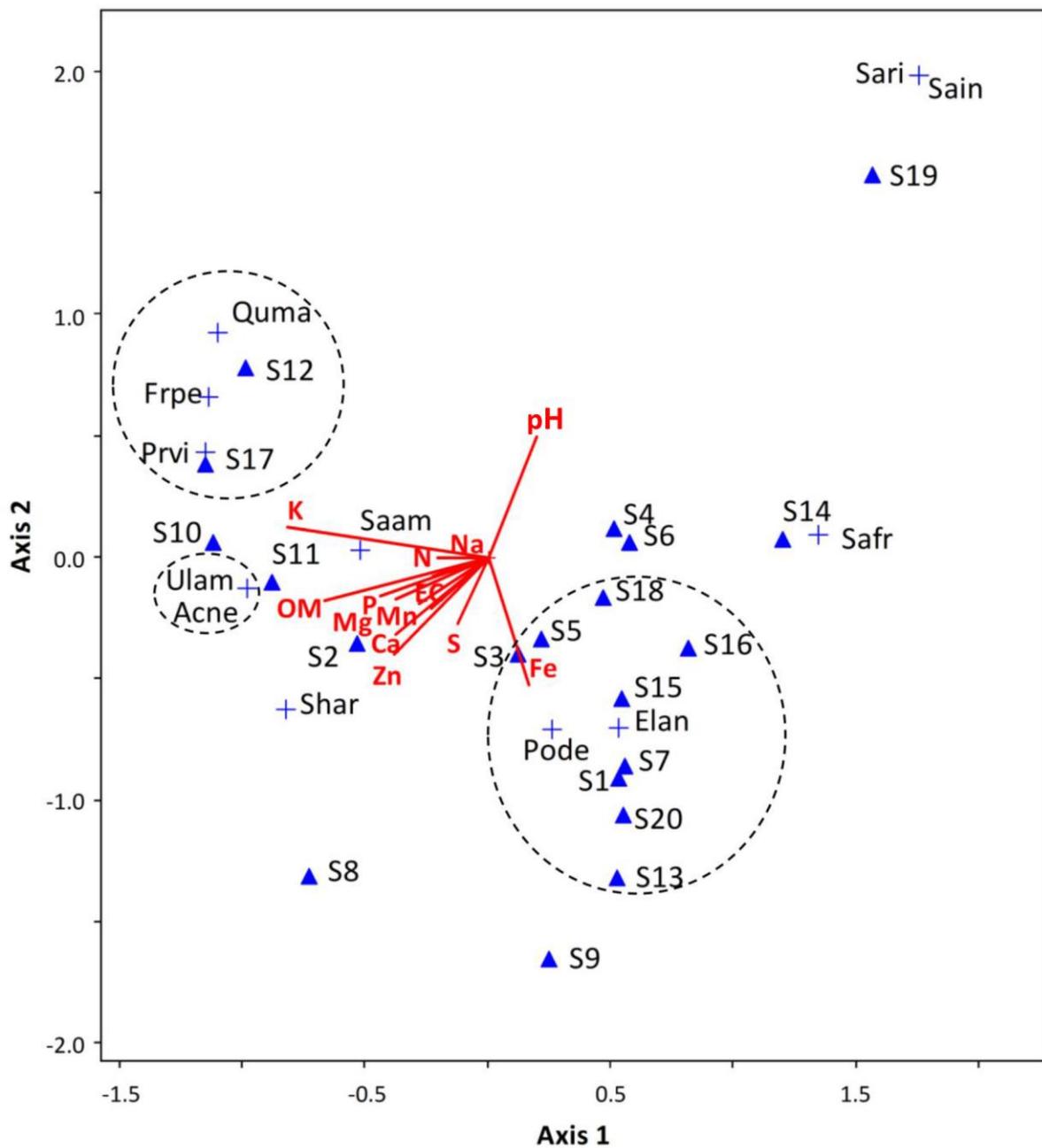


Figure 3.5. Canonical correspondence analysis (CCA) ordination of species and sampling plots of the first two axes with groups identified by cluster analysis. Each closed triangle (▲) represents a sampling site and a cross (+) represents plant species. The first two letters from genera and first two letters from species were used as a code to indicate corresponding plant species (see Appendix A). Each joint-plot line indicates soil chemical parameters. The dotted-line circles represent the plant communities and are similar to the clusters identified using the Bray-Curtis similarity index.

Table 3.4. Correlations and biplot scores for 13 soil chemical parameters.

Variable	Correlations		Biplot Scores	
	Axis 1	Axis 2	Axis 1	Axis 2
N	-0.266	0.126	-0.251	0.114
P	-0.409	-0.129	-0.386	-0.116
K	-0.854	0.054	-0.806	0.049
p ^H	0.206	0.532	0.194	0.48
EC	-0.198	-0.368	-0.187	-0.332
OM	-0.717	-0.139	-0.677	-0.126
S	-0.093	-0.428	-0.088	-0.386
Zn	-0.433	-0.334	-0.408	-0.301
Fe	0.19	-0.642	0.18	-0.579
Mn	-0.311	-0.154	-0.294	-0.139
Ca	-0.341	-0.498	-0.322	-0.449
Mg	-0.448	-0.245	-0.423	-0.221
Na	-0.234	-0.113	-0.221	-0.102

3.5. Discussion

Ecological assessment of a riparian forest is useful to evaluate how plant groups including keystone species change over time according to anthropogenic and natural disturbances. Therefore, we compared our results with Keammerer et al. (1975) floristic data, which was conducted at the Missouri River bottomland forest from the Garrison Dam to the Oahe Reservoir (Fig. 3.1). Although the Keammerer et al. (1975) survey reported 220 species, 152 genera and 54 families, we only recorded 15 species, representing 12 genera and 9 families. The reason for this difference is in the sampling method and sampling unit. For example, we did quantitative sampling in 20 sampling plots but Keammerer et al. (1975) conducted a qualitative survey in 34 forest stands. In addition, I sampled bank vegetation, while Keammerer et al. (1975) sampled bottomland forests.

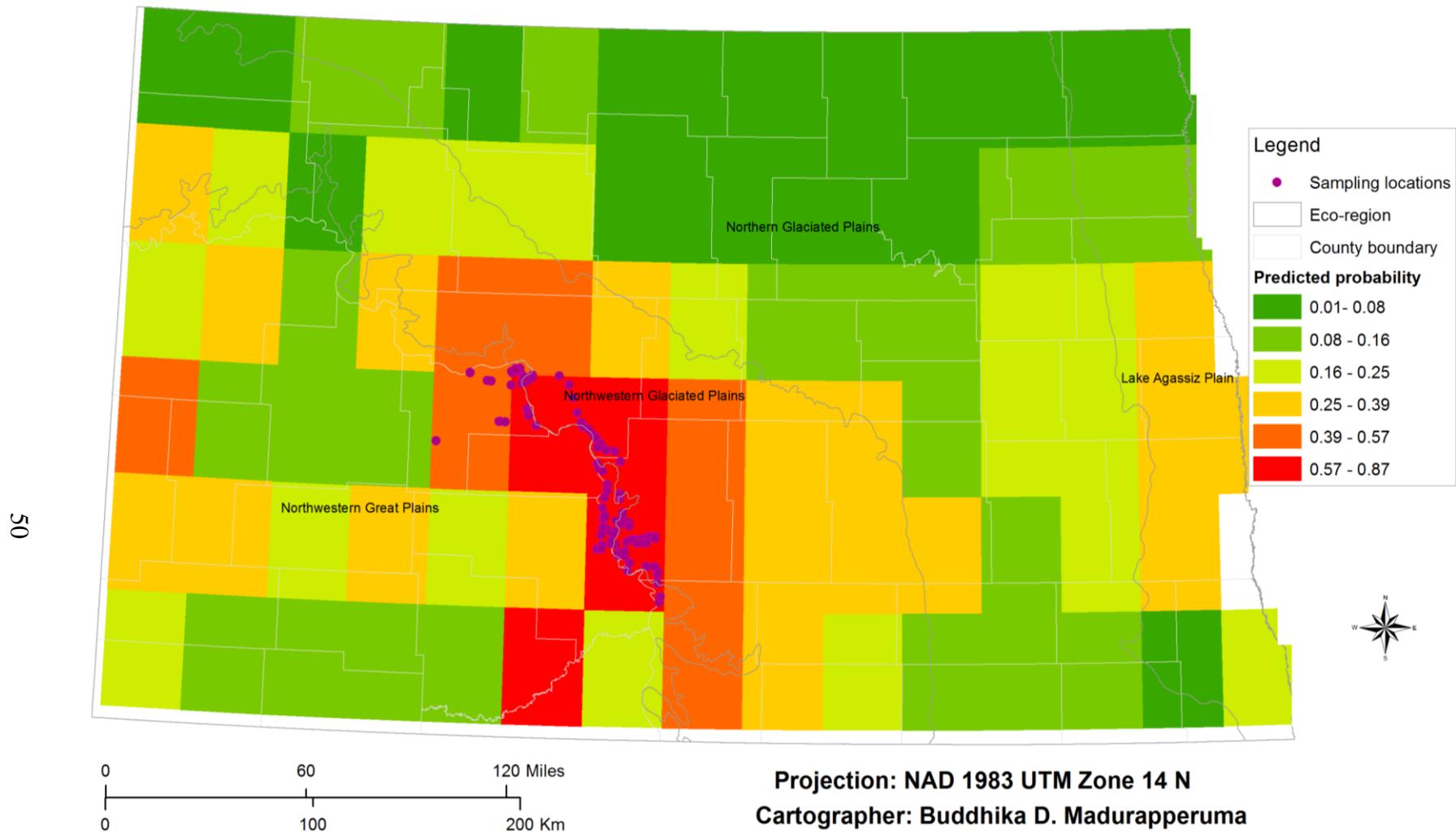


Figure 3.6. The habitat suitability model for Russian-olive in North Dakota using maximum entropy (MaxEnt) modelling software. Data Sources: Data for the administrative boundaries were downloaded from the North Dakota GIS Hub Data Portal (<http://www.nd.gov/gis/>). Accessed: June 02, 2011.

However, both studies are comparable in terms of plant associations. Keammerer et al. (1975) identified two vegetation classes of remnant riparian forest: (1) cottonwood - dominated forest, and (2) green ash, boxelder, American elm and bur oak - dominated forest. In our study, we classified plants into three communities (Fig. 3.4). The dominant species in the three communities we identified are similar to the dominant plants identified by Keammerer et al. (1975).

However, we observed different species associations compared to Keammerer et al. (1975). For instance, our study showed that Russian-olive is more common in the cottonwood forest, but Keammerer et al. (1975) showed that Russian-olive is scattered in cottonwood forest. Similarly, we observed rare occurrence of buffaloberry in cottonwood forest, but Keammerer et al. (1975) found that buffaloberry is common in cottonwood forest. This result suggests that Russian-olive is actively advancing to the cottonwood forests while replacing native plants like buffaloberry. Through our in-situ survey at the Missouri River, we found that Russian-olive is more common at the lower elevation areas (Table 3.2) with newly formed soils, that is, alluvial soil deposits on the floodplain.

According to Hoffman et al. (2008), along the North Platte River in Nebraska, elevation and distance from the river are the two important variables to predict the potential suitable habitats for Russian-olive. We also found that most of the native plants establish in the old growth soil, but Russian-olive colonizes in the alluvial soil deposits perhaps because of less competition. For example, the highest Russian-olive density site, S20, is characterized by a large floodplain area with alluvial soil. In addition, the basal area of Russian-olive at S20 is small, which suggests that the Russian-olive is young.

The ordination diagram clustered Russian-olive and cottonwood together as a distinguishable plant community. Likewise, we observed that Russian-olive occurred at the edge of the cottonwood forest as an understory plant at the lower elevation sites in the

riparian habitats (Fig. 3.7). Similarly, Lesica and Miles (2001) found that Russian-olive recruitment on upper terraces was facilitated only if the overstory was occupied by cottonwood. The co-occurrence of these species might be due to adaptation in poor soil conditions. For example, Russian-olive can fix nitrogen using symbiotic association with bacteria, which improves soil nutrition (Shah et al. 2010; DeCant 2008).

MaxEnt modelling showed that there is a high predicted habitat of Russian-olive along the Missouri River floodplain. This may be because the Missouri River has the largest floodplain compared to other riverine areas such as the Red River, Souris River, and James River of North Dakota, and this floodplain may facilitate the regeneration of Russian-olive. The Red River valley area, which is a part of the Lake Agassiz plain, showed a medium potential predicted habitat for Russian-olive distribution. The model showed that western and eastern parts of North Dakota have a medium predicted probability for Russian-olive occurrence. The environment variables selected for the MaxEnt model, for example, radiation and moisture gradient, were the most important ecological parameters. Model validation and sensitivity analyses were not performed due to absence of comparable datasets.

The green ash-bur oak-chokecherry association is separated as a group in the ordination diagram. This group correlated with high potassium (K) and high elevation (520 m). This might indicate soil accumulated K faster than K was leached. The high K accumulation association with the green ash-bur oak-chokecherry community could be due to either decomposition of broad leaf litter or the release of K from mineral weathering from the soil.



Figure 3.7. Species association: (a) cottonwood (overstory) and Russian-olive (understory), and (b) Russian-olive and buffaloberry as understory vegetation in the Missouri River floodplain.

Even though the habitat suitability model adopted does not address species abundance it is important to know about potential suitable areas, where future spread is more or less likely (see also Nagler et al. 2011). So the information may be useful for forest managers in informing landowners about the potential encroachment of Russian-olive. The Red River valley region seems a potential suitable habitat for distribution of Russian-olive (Fig. 3.6), and therefore landowners in this region may be advised not to use Russian-olive for windbreaks or shelter-belts.

3.6. Conclusions

My results indicated that Russian-olive associated with native plant communities such as cottonwood and buffaloberry along the Missouri River. Russian-olive coverage was positively correlated with poor soil conditions, such as, low pH, low nitrogen and high Fe contents. For example, Russian-olive occurred with buffaloberry, which establishes in soil that is highly saline and highly eroded. Moreover, young Russian-olive growth was observed in the lower elevations of the lower Missouri River, which is characterized by a large floodplain and poor soil conditions. Therefore, monitoring Russian-olive distribution at the lower Missouri River region is critically important and consequently native plants restoration in those areas should be implemented.

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CHAPTER 4. ANALYSIS OF SPATIO-TEMPORAL LAND-USE/COVER CHANGE OF THE DEVILS LAKE WATERSHED USING NDVI AND NDWI DATA*

4.1. Abstract

Devils Lake is the largest natural lake (9,800 km²) in North Dakota, United States. It is a closed basin saline, hyper-eutrophic lake, which is characterized by flooding. In this study, we attempt to determine mappable water-related indices vis-à-vis to land-cover data within the Devils Lake sub-watershed region using Landsat 5 Thematic Mapper (TM) images from 1991 to 2005. Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI) vector datasets were derived from Landsat 5 TM satellite imagery using ENVI EX[®] to evaluate the multi-year changes of vegetation and water resources. In addition, land-use and land-cover change were assessed using National Land Cover Database (NLCD). ArcGIS Explorer online platform was used to map Federal Emergency Management Agency (FEMA) 100 year flood zones and associated land-cover change. Results show that the NDVI is negatively correlated with NDWI. For example, in the periods of 1991-1994 and 2000-2005 NDVI values greatly increased in this region, while NDWI values considerably decreased in those time steps. The dramatic decline of greenness was observed in the 1994-2000 period. Devils Lake experienced a historically unprecedented rise in water levels, especially from 2000 onwards, causing catastrophic flooding in the area. This study also provides a summary of how land-use and land-cover have changed due to human activities, that is, growing agricultural pressures and the current flood-prone condition of Devils Lake.

*This material in this chapter was Co-authored by Buddhika D. Madurapperuma, Peter G. Oduor, Janaka. M. Kurupparachchi, Jayamina U. Munasinghe and Larry A. Kotchman (Published in GIT4 NDM Proceedings). The paper was adjudged as Best Paper and Best Poster award at 4th International Conference on Geo-information Technology for Natural Disaster Management.

4.2. Introduction

Devils Lake is a closed basin lake in North Dakota, characterized by large fluctuations in water levels in response to climatic variability (Swenson and Colby 1955). It is the largest natural water body in North Dakota, and is situated in the Devils Lake Basin and adjacent to Red River Basin at the north-eastern region of North Dakota (Fig. 4.1). The dissolved solids concentration in Devils Lake was ranged from 3580 to 20100 $\mu\text{S}/\text{cm}$ and fluctuates with water level (Sando and Lent 1995). Considering the spatial characteristic of land-use at watershed scales, the development of an integrated approach that can simulate land-use changes and their effects on water resources at the watershed is critical (USGS 2011).

It is also important to understand how land-use and land-cover changes affect water balance and river hydrology. For example, if there is significant forest cover along the stream channel, the immediate implication would be an increase in water retention capacity in the particular geographic area. Devils Lake has continued to rise and consequently has overflowed to Stump Lake. Since the Sheyenne River is a tributary of the Red River, flooding poses potential environmental risks downstream. The North Dakota State Water Commission (2011) proposed three strategies to mitigate the catastrophic flooding in Devils Lake, consisting of: (1) upper basin water management using wetland restoration to reduce the amount of water inflow into the Devils Lake (2) protection of properties such as roads levees, and relocation (3) make emergency outlets to carry excess water from the Devils Lake to reduce the flooding impacts at the downstream area. For the third strategy, land managers are interested in finding which lands may be available for emergency outlets or for temporary water storage downstream of Devils Lake.

This study takes into purview historic land-use and land-cover change, climatic variability, and water balance in the Devils Lake watershed, critical information which can be used as baseline data for management of Devils Lake watershed. Even though the

surrounding Devils Lake hills are delineated as one of the top five high-priority areas of North Dakota upland forests, land-use and land-cover change has severely altered the hydrology of this closed basin. This project aimed to understand the dynamics of anthropogenic-induced land-use and land-cover changes of riparian arboreal ecosystems within Devils Lake watershed.

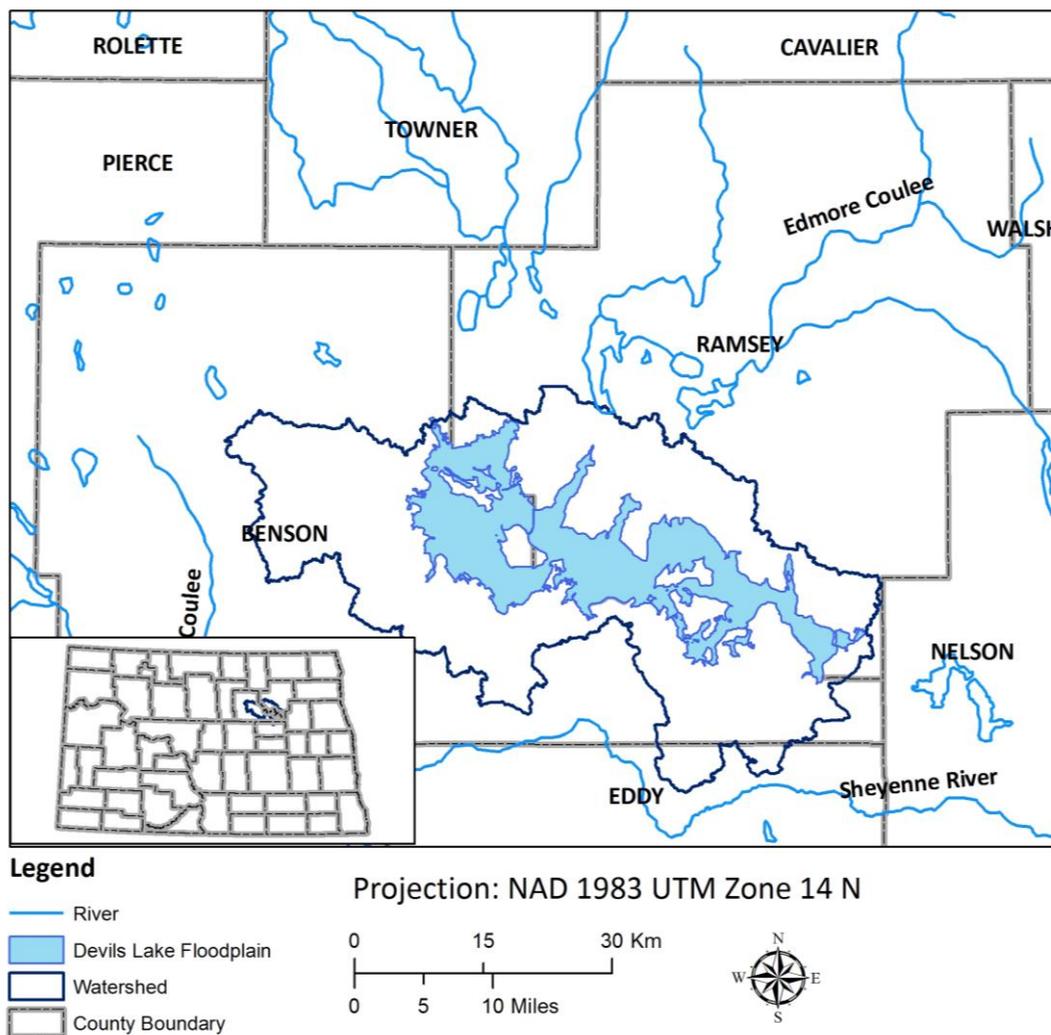


Figure 4.1. Location map of the Devils Lake basin in North Dakota. FEMA 100 year floodplain is used to derive the extent of Devils Lake. Data sources: Data for the boundaries of administrative, watershed and river were downloaded from the North Dakota GIS Hub Data Portal (<http://www.nd.gov/gis/>). Accessed: June 02, 2011. The FEMA 100 year floodplain data was acquired from ArcGIS Explorer Online web portal <http://www.arcgis.com/home/item.html?id=f11e5220347942659327122bd1a699eb>. Accessed: April 27, 2012.

4.3. Materials and Methods

Landsat images of the study area were acquired from the Global Land Cover Facility (<http://glcf.umiacs.umd.edu/>). These images were acquired over the span of four different years *viz.*, 1991, 1994, 2000 and 2005. Table 4.1 shows the details of the acquired images including the Worldwide Reference System (WRS), path and row information. The images are on a scale of 30 m spatial resolution.

Table 4.1. Landsat time series scenes used in the study.

Satellite	Sensor	Date	Resol ⁿ	WRS	Path	Row
Landsat 5	TM	31/08/1991	30 m	2	31	27
Landsat 5	TM	22/07/1994	30 m	2	31	27
Landsat 7	ETM+	30/07/2000	30 m	2	31	27
Landsat 5	TM	18/06/2005	30 m	2	31	27

These freely available data were obtained in the form of individual bands ranging from B1 to B7 (Table 4.2). These individual bands were then stacked to represent satellite imagery using ENVI[®] 4.5. Layer stacking creates a new multiband file from the input bands which are resampled and re-projected. Upon layer stacking of the Landsat scenes, they were also georeferenced to UTM Zone 14 North from WGS-84 Datum, then converted to calibrated radiance using ENVI[®] 4.5 software. Thereafter each data set was exported to ENVI[®] EX environment to detect the changes between the 1991 to 2005 time steps based on Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI) using an image difference tool. NDVI measures seasonal and inter-annual changes in vegetation growth and activity. NDVI is functionally equivalent to simple band ratios of TM image and can be described by the following equation (4.1).

$$NDVI = (\rho_{nir} - \rho_{red}) / (\rho_{nir} + \rho_{red}) \quad (4.1)$$

ρ_{nir} spectral reflectance for band 4

ρ_{red} spectral reflectance for band 3

NDWI measures canopy water content and is sensitive to changes in liquid water content of vegetation canopies (Jensen 2005) . NDWI is functionally equivalent to simple band ratios of TM image and can be described by the following equation (4.2).

$$NDWI = (\rho_{\text{band4}} - \rho_{\text{band5}}) / (\rho_{\text{band4}} + \rho_{\text{band5}}) \quad (4.2)$$

ρ_{band4} spectral reflectance for band 4

ρ_{band5} spectral reflectance for band 5

Table 4.2. Thematic Mapper (TM) spectral bands wavelengths.

Band	Wavelength (µm)	Resolution (m)	Description
1	0.45-0.52	30	Blue
2	0.52-0.61	30	Green
3	0.63-0.69	30	Red
4	0.76-0.90	30	Near Infrared
5	1.55-1.75	30	Short-wave Infrared
6	10.4-12.5	120	Thermal Infrared
7	2.08-2.35	30	Short-wave Infrared

Source: <http://landsat.gsfc.nasa.gov/about/tm.html>

Each NDVI and NDWI value was imported to ArcGIS 9.3[®] to create change detection maps of the study area. Although for the NDVI/NDWI analysis we used Landsat TM images for years 1991, 1994, 2000, and 2005, we had to utilize classified land-cover images of 1992, 2001, and 2006 since those were the only available images that covered the time line.

4.3.1. Data Processing

National Land Cover Database (NLCD) datasets for 1992, 2001, and 2006 originally derived from classified LandSat TM satellite imagery were imported into ArcMap-ArcInfo[®] 9.3. A set coordinate system and projection, namely, Universal Transverse Mercator (UTM) North American Datum (NAD) 1983, was chosen since the generic linear measurements are

in meters and work well with NLCD datasets. NLCD data are raster datasets with 30 m spatial resolution. Each imported NLCD dataset was spatially clipped to Devils Lake watershed boundary spatial extents using a basic Minimum Bounding Rectangle (MBR). In the GIS environment, the resulting image was exported using the clipped extents and the pixel size set to 0.00027777 decimal degrees (30 m) for the associated latitude.

The total area of the clipped raster was determined by multiplying the number of pixels by each set pixel area. Raster reclassification was performed where minor NLCD classes were collapsed into defined major categories; for example, class 41 (deciduous forest), class 42 (evergreen forest), and class 43 (mixed forest) were reclassified as forest. The total number of classes was 7, namely, (i) Forest (ii) Urban Developed (iii) Grassland (iv) Pasture/Hay (v) Cultivated Crops (vi) Wetland (vii) Water.

4.3.2. Accuracy Assessment

Classification accuracy refers to the extent of correspondence between the remote sensed data and reference information from ground truthing data (Congalton 1991). In this study, accuracy assessment for the NLCD land-cover classifications was performed by generating error matrices. The total number of cell counts in each land-cover type was set out in a square array of rows and columns. The columns in the matrix represent the reference data (ground truthing land-cover data) and the rows represent assigned (mapped) land-cover types (Congalton 2007). Error matrices have been used to correlate between two data sets with a high coefficient of agreement, Khat, \hat{K} , (Kappa) value indicating how two datasets are similar or dissimilar (Oduor et al. 2012). The set years for the land-cover data were aggregated using *Combine* function in Raster Calculator of Spatial Analyst extension of ArcMap-ArcInfo® 9.3, for example, *Combine* (['landcover_92'], ['landcover_01']). The attribute table of the resulting calculation was exported as a .dbf file (for example Oduor et al.

2012). A crosstab query table for the .dbf file was done using Microsoft® Access. The crosstab result was exported to Excel® and Kappa derived from (see also, Jensen, 2005):

$$\hat{K} = \frac{N \sum_{i=1}^k x_{ii} - \sum_{i=1}^k (x_{i+} \times x_{+i})}{N^2 - \sum_{i=1}^k (x_{i+} \times x_{+i})} \quad (4.3)$$

Khat is coefficient of agreement, N is the total number of sites in the matrix, k is the number of rows in the matrix, x_{ii} is the number in row i and column i , x_{i+} is the total for row i and x_{+i} is the total for column i .

4.4. Results

4.4.1. NDVI and NDWI Relationship

Figure 4.2 shows the land-cover change based on the NDVI and the NDWI indices for the periods of 1991-1994, 1994-2000, and 2000-2005. The positive and the negative changes in land-cover correspond to the *big increase* and *big decrease* of the particular area respectively.

Results show great increase of NDVI between 1991-1994 with a great declining of NDWI. In contrast, in the 1994-2000 period there was a big decrease of NDVI. Between 2000-2005 NDVI showed both an increase and a decrease; on the other hand NDWI showed only a decrease.

4.4.2. Climatic Variability

Figure 4.3 shows the rainfall and temperature in the Devils Lake basin for the years 1991, 1994, 2000, and 2005. Rainfall increased from April to June with a major peak in June. The rainfall exceeded 100 mm threshold for 1994, 2000, and 2005.

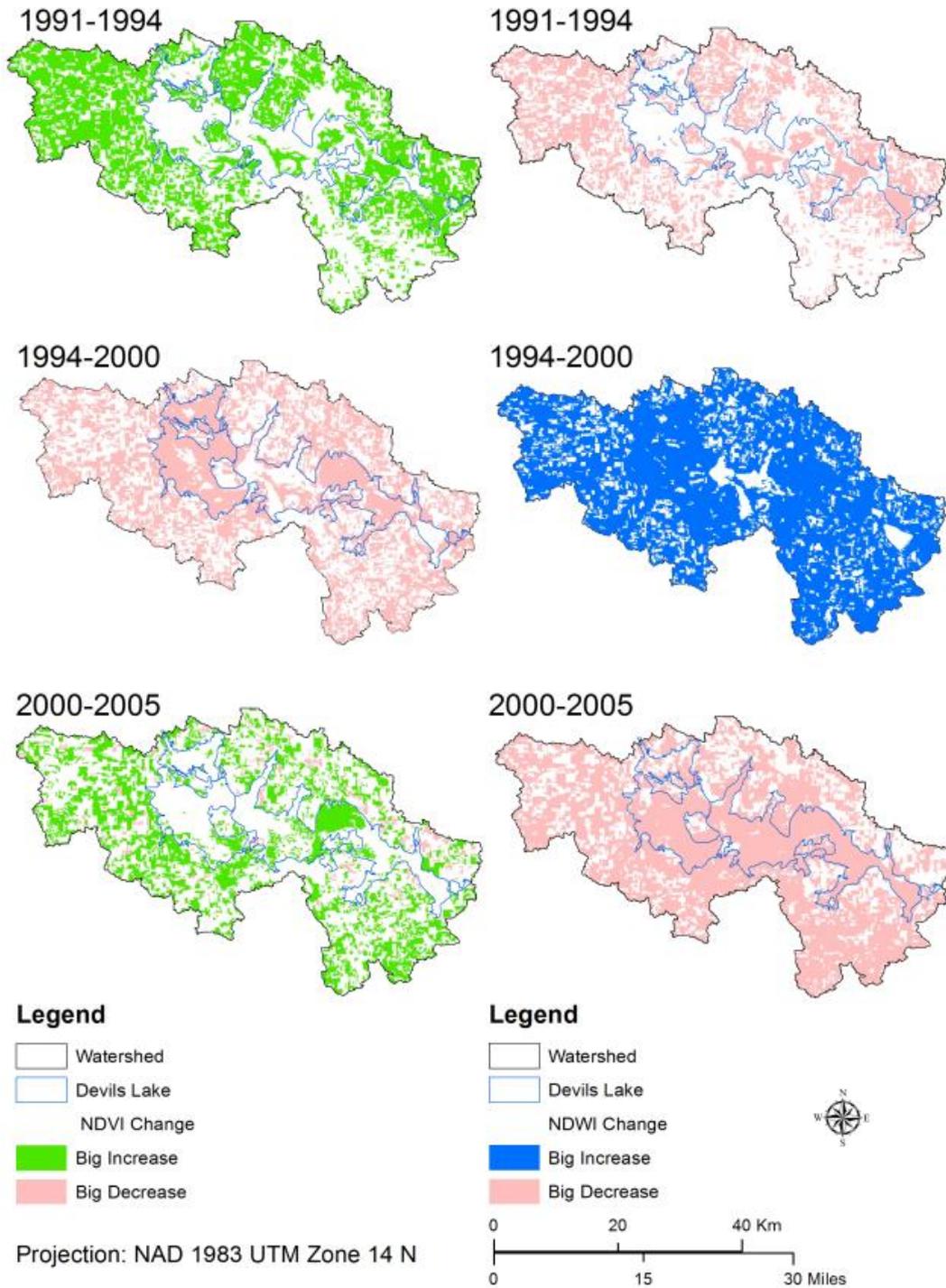


Figure 4.2. Land-cover change in the Devils Lake basin for 1991-1994, 1994-2000, and 2000-2005. Image difference was performed using NDVI and NDWI using ENVI EX® software. Data sources: Data for the watershed and the Devils Lake boundaries were downloaded from the North Dakota GIS Hub Data Portal (<http://www.nd.gov/gis/>). Accessed: June 02, 2011. Landsat TM images were acquired from the Global Land Cover Facility (<http://glcf.umiacs.umd.edu/>). Accessed: June 15, 2012.

A minor peak of rainfall was observed for September to November months. The temperature was below zero from November to March, and then it increased to a maximum of 21°C for the months of March to August for all years except 1994. The temperature then declined to zero from August to November for all years except 1994.

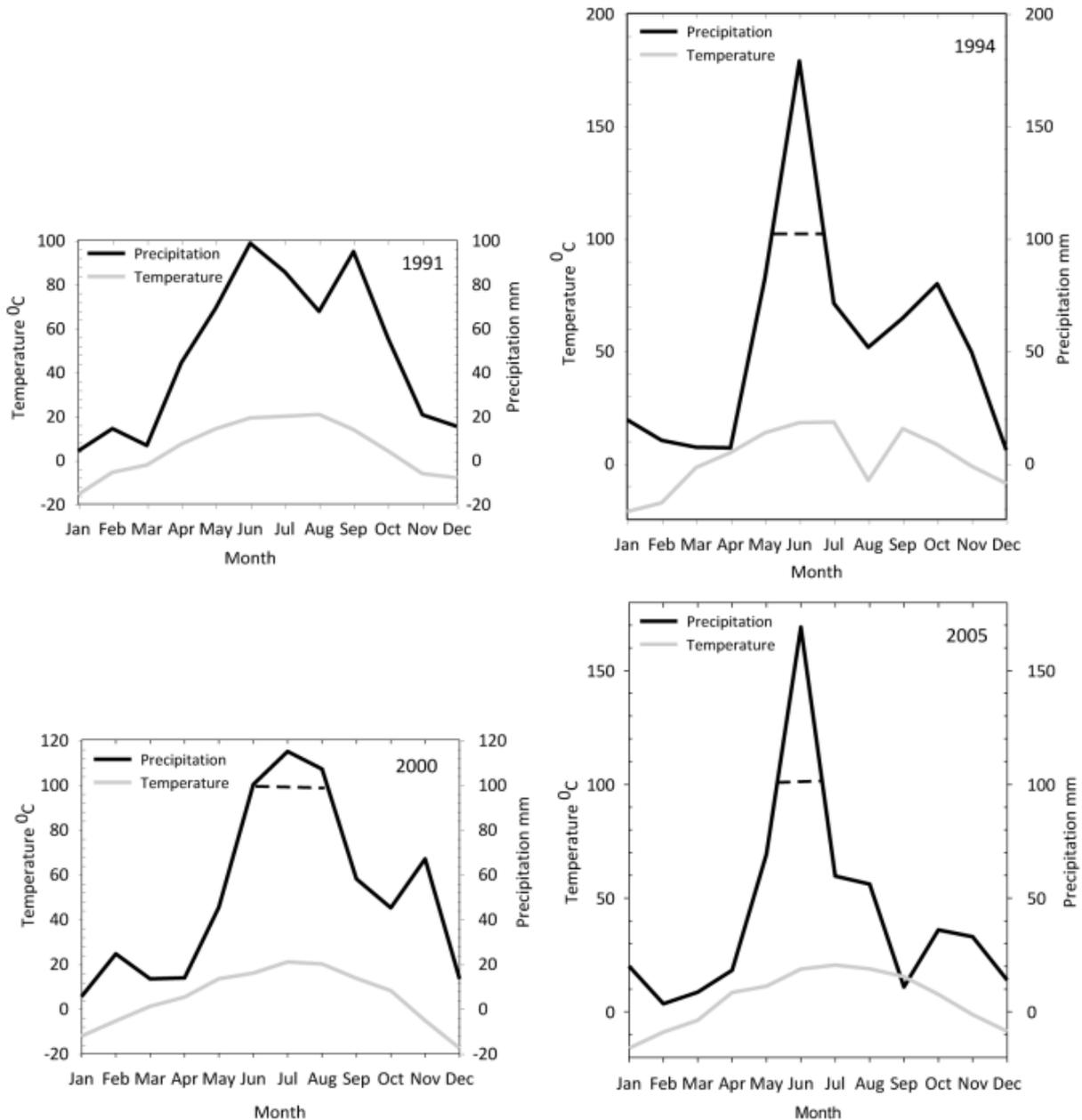


Figure 4.3. Climate diagrams for the Devils Lake basin for the years 1991, 1994, 2000, and 2005. The area above the dotted line represents rainfall values greater than 100 mm. The annual rainfall for 1991, 1994, 2000, and 2005 was 576 mm, 627 mm, 601 mm, and 499 mm respectively. The climatic data was acquired from <http://www.prism.oregonstate.edu/>.

4.4.3. Land-use and Land-cover Change

Figure 4.4 depicts how land-use and land-cover changed from 1992 to 2006. We assumed that 1991-2005 (Fig. 4.2) and 1992-2006 periods (Fig. 4.4), which span 15 years, are compatible for detecting land-cover change in the Devils Lake basin. Figure 4.4 clearly shows that the extent of the Devils Lake increased especially in 2001 and 2006 compared to 1994.

However, in 1992 the Devils Lake shrank compared to 2001 and 2006 mainly in those areas that occupied wetlands and the forests in the western and central parts respectively. The grassland extent in 1992 is 15,708 acres. The pastureland, which is anthropogenic land-use, is mainly confined to the lower basin of the Devils Lake (Fig. 4.4).

Figure 4.5 shows the land-use and land-cover dynamics for the years 1992 to 2006. In 1992 the land-cover acreages of grassland, wetland, and forest were comparatively higher than in 2001 and 2006. By contrast, urban, water, and crops in 1992 were comparatively lower than 2001 and 2006. The pasture land extent for the entire period is more or less similar. Of all the classes, crops exceed 30% of coverage for the entire period.

4.4.4. Cellular Automata (CA) Model

The constrained CA-based simulation models were developed using numbered land-use and land-cover types and 3D models were generated from commission error (Fig. 4.6a, b and c). In the 3D graphs diagonals showed a significant correlation as indicated by relatively high values. For example, in 1992-2001 forest and cultivated crops showed 0.77 (error = 0.23) and 0.75 values respectively. In 2001-2006 all diagonals showed a high correlation, where water category showed a value of 0.96. Similarly in 1992-2006, 1.0 (no error) value was observed for water, and a 0.85 value for the developed category. Figures 4.6d, e, and f show omission errors and conditional Kappa results. In 2001-2006 land-use and land-cover categories showed high Khat values with low omission errors. We calculated the overall

coefficient of agreement (Khat) and the results showed that it was 0.39 in 1992-2001, 0.84 in 2001-2006, and 0.38 in 1992-2006.

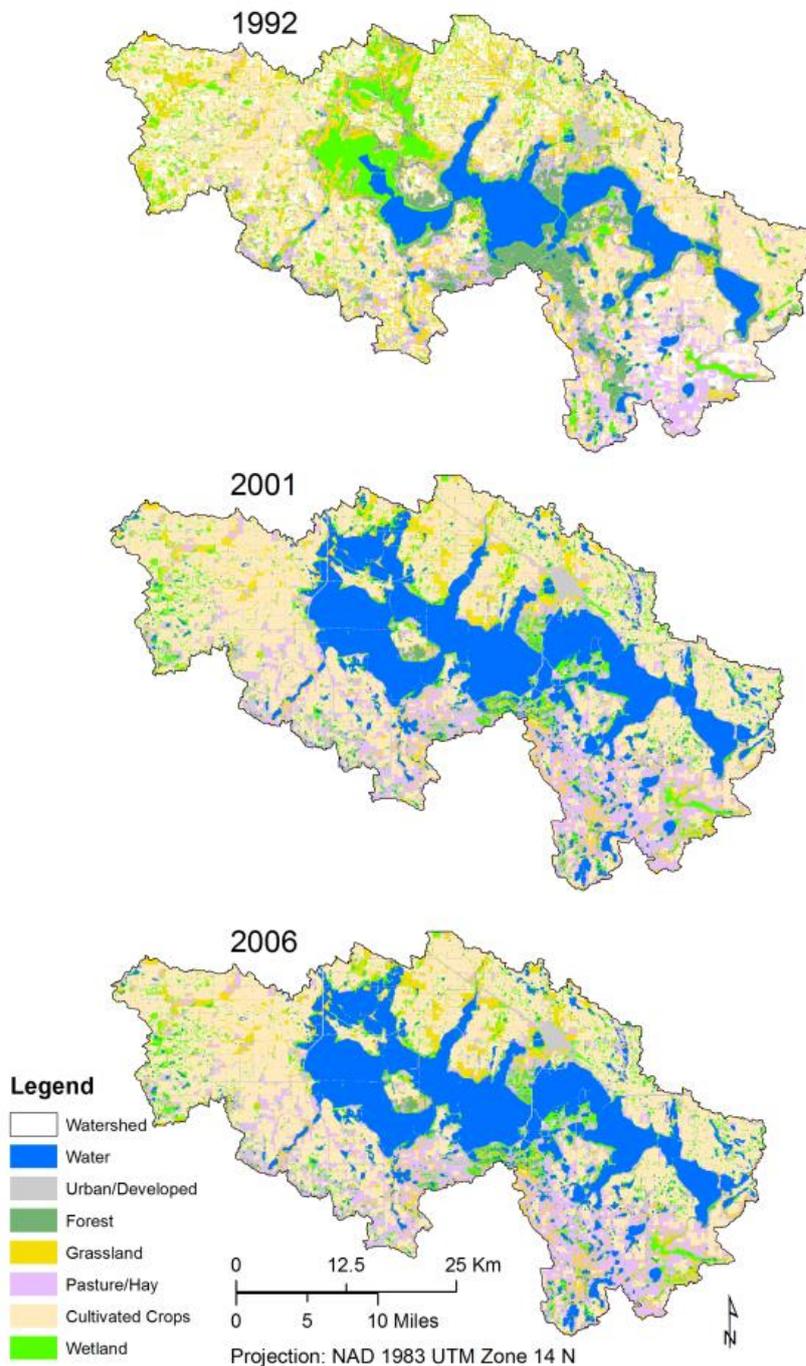


Figure 4.4. Land-use and land-cover in the Devils Lake basin using National Land Cover Database (NLCD) for the years 1992, 2001, and 2006. Data Sources: NLCD Land-cover data was obtained from the multi-resolution land characteristic consortium (MRLC web portal (http://www.mrlc.gov/nlcd92_data.php). Accessed: May 18, 2011. Watershed boundary was downloaded from the North Dakota GIS Hub Data Portal (<http://www.nd.gov/gis/>). Accessed: June 02, 2011.

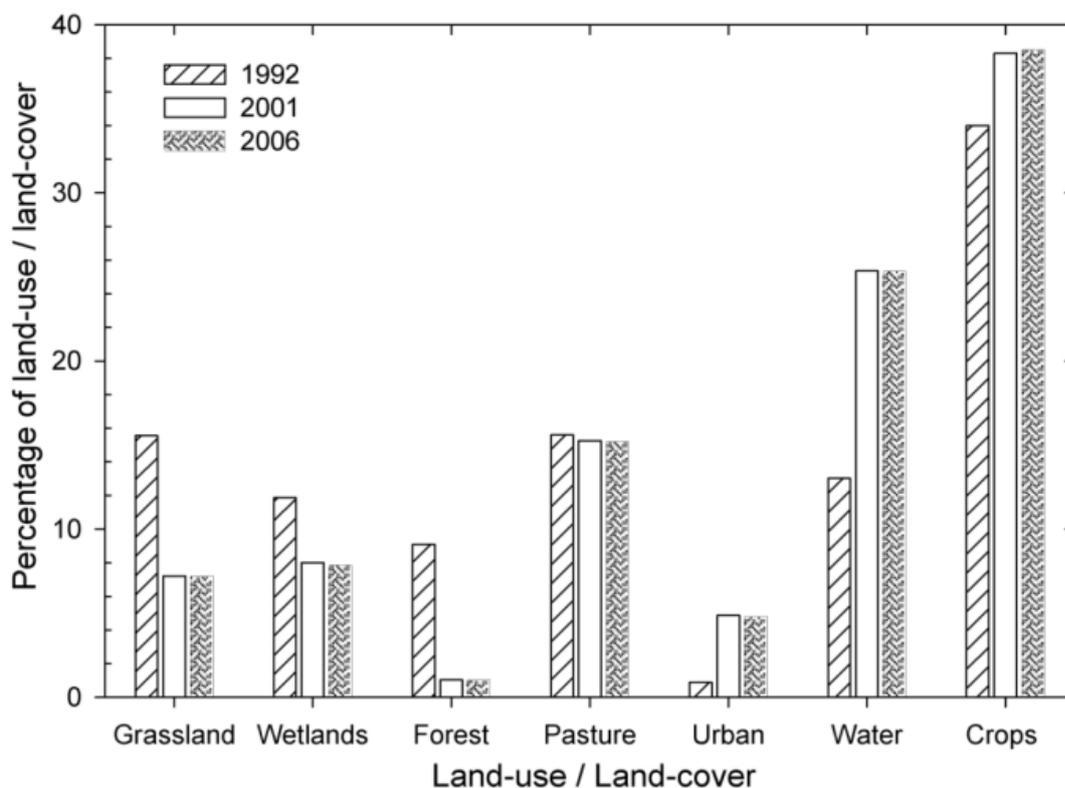


Figure 4.5. Land-use and land-cover change for years 1992, 2001, and 2006 in the Devils Lake basin.

4.5. Discussion

This study provides information on how land-use and land-cover changes influence the water resource when an area is exposed to a historic flooding scenario. We used remote sensing techniques to address the impact of land-use on the primary loss of riparian arboreal ecosystems.

NDVI and NDWI are useful parameters to reveal temporal vegetation changes. In the 1991 to 1994 period NDVI showed an increase due to high occupancy of forest and cropland. According to land-use and land-cover data from 1992 (Figs. 4.4, 4.5) 43% of land was occupied by vegetation. The NDVI increment for the 2000-2005 periods is mainly due to increased extent of cultivated crops (Fig. 4.5). The forest acreage declined from 9% to 1% while water areal extents increased from 13% to 25% between 1992 and 2006.

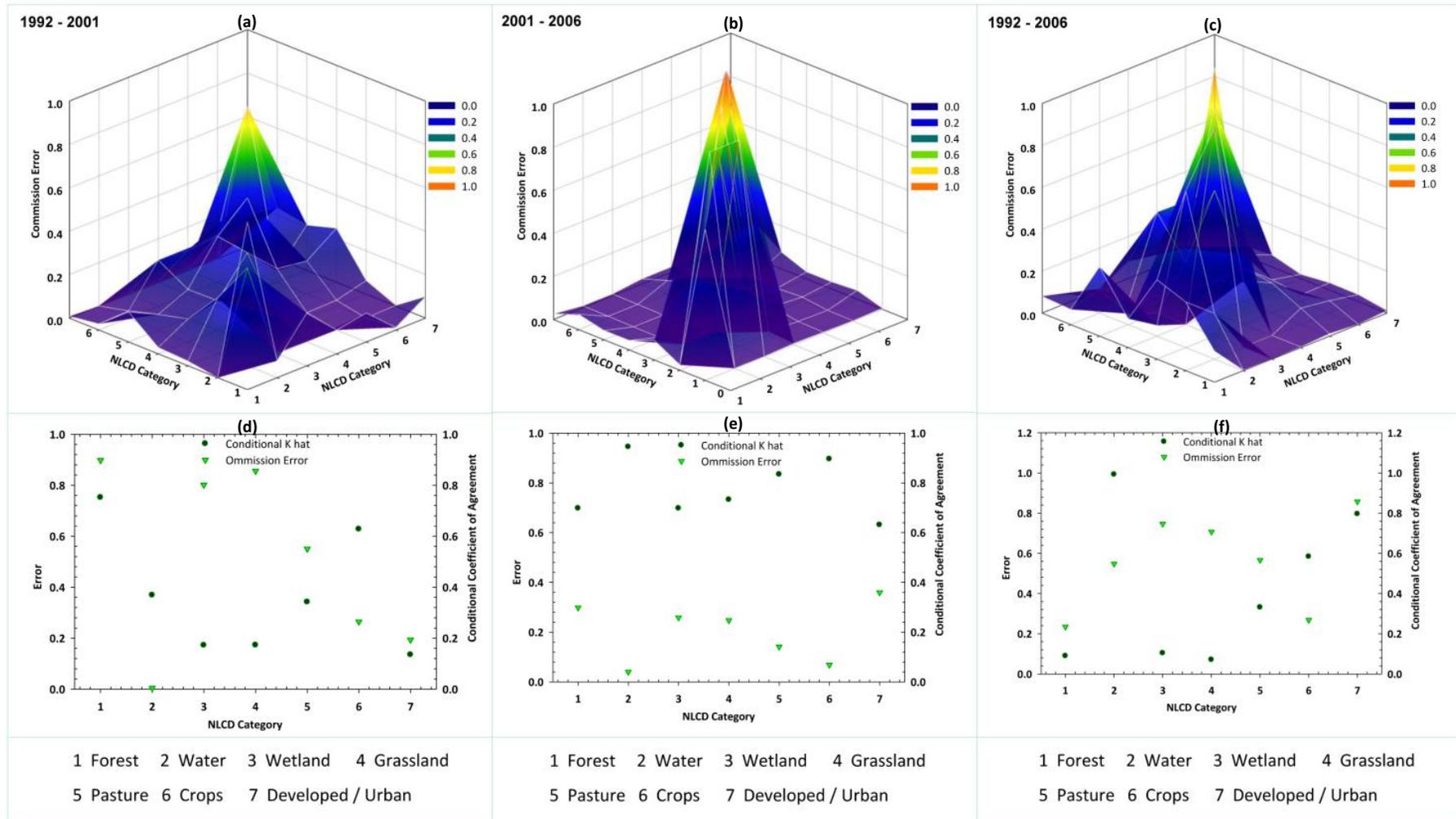


Figure 4.6. Error analysis of NLCD data for the Devils Lake basin.

The Devils Lake water level has risen rapidly since 1993 and 50,000 acres of land around the lake were flooded in 1993 (Wiche 1998). In the 1994-2000 period the Devils Lake water level changed from 433 m to 441 m, which overflowed to Stump Lake at about 433 m (http://nd.water.usgs.gov/devilslake/images/DLPOR_Mar2010.pdf). This is primary reason for a significant change of NDWI between 1994 and 2000. The other reason would be high annual rainfall, which also contributed to a marked increment of the NDWI value (Fig. 4.3). According to Parameter-elevation Regressions on Independent Slope Model (PRISM), precipitation data for Devils Lake watershed annual average precipitation ranged from 475 mm – 521 mm from 1998 to 2010.

From Fig. 4.4 the prominent land-use type at the lower Devils Lake basin is pastureland, which can be utilized to extend the drainage area of the watershed. This may reduce the impact of catastrophic flooding at the downstream areas such as Stump Lake and the Sheyenne River. Prior to implementing a flood mitigation project, it is worthwhile to do a feasibility study using cost and benefit analysis.

The Devils Lake hills are delineated as one of the five priority areas of North Dakota upland forests (Kotchman 2010). The adjacent riparian forest may control flooding minimally through water uptake and majorly by forming a natural flood-wall. The Forest Stewardship Program between North Dakota Forest Service and private forest landowners is beneficial in mitigating effects of flooding in North Dakota.

4.6. Conclusions

This study shows that NDWI negatively correlated with NDVI, which implies that increasing water cover results in decreasing forest cover. Similarly, NLCD land-cover data showed that the forest acreage declined from 9% to 1% and water areal extents increased from 13% to 25% between 1992 and 2006. In addition, loss of forest cover associated with the increase of cropland in 2001 and 2006. Our results may be useful for land managers to

grasp the impact of land-use practices and land-cover change over a 15 year period.

Furthermore, the State Water Commission may use this information when they implement the Devils Lake emergency outlet project.

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CHAPTER 5. DETECTING LAND-COVER CHANGE USING STOCHASTIC SIMULATION MODELS AND MULTIVARIATE ANALYSIS OF MULTI- TEMPORAL LANDSAT DATA FOR CASS COUNTY, NORTH DAKOTA*

5.1. Abstract

Understanding forest transitioning at wildland-urban interfaces offers a glimpse into the effect of anthropogenic activities that may threaten biota. We examined forest conversion from 2006 to 2011 at urban-wildland fringes in Cass County, North Dakota. Grid data from the National Agricultural Statistic Service, published by USDA, were used as preliminary inputs to ascertain land-use and land-cover dynamics. Markovian transition probabilities were derived for each pair of years from 2006 to 2011. These transition probabilities were further subjected to multivariate analysis to detect forest change in one year time steps. From this study, pairwise combinations of years yielded two distinct statistical groups. The first group comprised of seven pairs of year combinations displaying high transition probability of unchanged forest ($0.54 \leq P_{ff} \leq 0.68$), while the second group comprised of eight pairs of year combinations and showed a low transition probability of unchanged forest ($0.26 \leq P_{ff} \leq 0.37$). A third group displayed comparatively high transition probabilities of forest transitioning to non-forest ($0.26 \leq P_{fnf} \leq 0.36$), such as forest to row crops, with an increasing probability over time. We also generated the forest cover in relation to soil characteristics. Forest cover on poorly drained soils showed a higher acreage compared to somewhat poorly drained soil, which could be due to the unsuitability of this soil for crop cultivation. The results of this study on how land-cover has changed in Cass County for the last six years could be used by policy makers and forest managers in applying BMPs (Best Management Practices).

*This material in this chapter was Co-authored by Buddhika D. Madurapperuma, Peter G. Oduor and Larry A. Kotchman.

5.2. Introduction

Land-use and land-cover change (LULCC) is a dynamic, widespread and accelerating process. LULCC is mainly driven by natural phenomena and anthropogenic activities, which have driven changes that impact natural ecosystems (Ruiz-Luna and Berlanga-Robles 2003; Turner and Ruscher 2004). Anthropogenic-induced conversion of semi-natural managed forest into non-forested agricultural land is currently driven by global demand for cash crops. Agricultural land usage for high-yielding crop varieties, e.g. corn, have been identified as one of the most common forms of land-cover modification (Matson et al. 1997). For example, 20 eastern United States ecoregions have seen a decrease in forest cover by more than 4% (3.7 million ha) from 1973 to 2000 due to agricultural expansion (Drummond and Loveland 2010).

To design appropriate policies for sustainable development, it is important to understand how technical innovations such as irrigation development and adoption of high-yielding varieties in forest frontiers influence deforestation of upland forests (Maertens et al. 2006). Accurate and up-to-date land-cover change information is necessary to understand these influences. The land-cover information is essential for developing long-term strategies for managing priority landscapes, delineating and prioritizing forest resources, assessing risks, conditions and trends in forests. Secondly, this information can be used to assess how forest cover changes result in environmental consequences, such as climate change and biodiversity (Giri et al. 2005).

Ad hoc forest resource mapping can be applied as a powerful tool to identify forest resource threat patterns and also to manage natural forest resources sustainably. Remote sensing has the capability of capturing land-use and land-cover data, extracting the LULCC information from satellite data requires effective and automated change detection techniques (Roy et al. 2002). LULCC mapping and detection of change are of paramount importance to

planners, geographers, environmentalists and policy makers for the sustainable development of natural resources (Abbas et al. 2010). The basic premise for using remote sensing data to detect change is that the process can identify change between two or more dates that is uncharacteristic of normal variation (Kasereka 2010). Modelling land-use and land-cover change has become popular since it addresses when, where and why land-use and land-cover change occurs (Baker 1989; Lambin 1997; Theobald and Hobbs 1998).

Markov Chain Monte Carlo simulation models of LULCC can offer a glimpse in understanding the changes of landscape (Oduor et al. 2012) over a time scale and can then extend those patterns into the future allowing for prediction (Brown et al. 2000; Clarke and Gaydos 1998). Markovian models are one of the most widely used approaches for predicting forest cover change with discrete parameter space (Acevedo et al. 1996; Hall et al. 1991; Logofet and Lesnaya 2000; Wu et al. 2006). A Markov chain consists of a system with a series of changes from one state to another over time, which is measured in discrete intervals (Kemeny and Snell 1976). The Markov chain models are employed by ecologists to study the vegetation dynamics and succession process, to evaluate conservation intervention and to simulate forest dynamic transformation patterns (Mondal and Southworth 2010; Yuliang et al. 2008; Leps 1988).

This study is primarily based on the application of stochastic methods to address year-to-year stratified changes in land-cover with a special emphasis on forestry in Cass County, North Dakota, which contains a major metropolitan area. Our main goal was to estimate transition probabilities for forest to non-forest conversion using random-walk stochastic processes and Markovian models. This pixel-wise transition model approach can be used to simulate forest-cover changes and ongoing factors associated with changing forest management at landscape scales in Cass County.

The research questions addressed in this paper were:

- (i) How has forest cover changed in Cass County from 2006 to 2011?
- (ii) What are the primary drivers of land-use and land-cover change in Cass County?
- (iii) Is there a relationship between soil characteristics and forest cover change?

5.3. Materials and Methods

5.3.1. Study Area

Cass County is located in south-eastern North Dakota in the Red River valley bounded by 46° N and 47° N latitude and 96° W and 97° W longitude. The Red River of the North establishes Cass County's eastern border, separating it from Minnesota. The county experienced 19.7% population growth from 1990 to 2000, and it increased to 21.6% in the 2000-2010 period with a 149,778 population count in 2010 (US Census Bureau 2011). Cass County contains over 457, 699 ha of total land area, including over 52,000 parcels, which are units of land delineated according to land ownership, covering a nearly square area roughly 71 km west to east by 68 km north to south (www.casscountynd.gov/county/depts/planning/.../Chp2.pdf). The extent of forest cover in Cass County is estimated to be about 6, 691 ha (http://ndfsdss.ndsu.nodak.edu/maps/map_data/County/Cass.pdf). The average annual temperature for Fargo is 41.5° F with an average yearly precipitation of 53.82 cm (Godon and Godon 2002). Four general land-use classes (agricultural, rural non-farm, small city and metropolitan area) can be identified within areal extents of Cass County.

5.3.2. Land-cover Maps

We generated a GIS database based on the analysis of a sequence of satellite images dating from 2006 to 2011. These images are 30 m in spatial resolution. National Agricultural Statistics Service (NASS) datasets originally derived from classified Landsat ETM⁺ satellite imagery for Cass County were imported into ArcMap-ArcInfo[®] 9.3. Then each dataset was

exported into ArcMap-ArcInfo® 9.3 to obtain grid datasets with 30 m spatial resolution. Raster reclassification was performed where minor NASS classes were collapsed into the major categories, for example, class 22 (durum wheat) and class 21 (barley) were reclassified as grains hay seeds (USDA National Agricultural Statistics Service 2009). The total number of classes was 8, namely, (i) Row Crops (ii) Grains, Hay, Seeds (iii) Other Crops (iv) Idle Cropland/Fallow (v) Grass, Pasture, non-agriculture (vi) Forest (vii) Urban/Developed and (viii) Water. Some of these original Landsat ETM+ images were classified using both NASS classes and NLCD classes (National Land Cover Database), we collapsed those classes also into eight major classes. For instance, class 141 (deciduous forest), class 142 (evergreen forest) and class 143 (mixed forest) were reclassified as forest.

5.3.3. Markov Model

A finite time step first-order Markov process was generated as a probability matrix $P(t)$ representing the mutual pixel wise transition from one category defined or redefined as aforementioned. The basic equation used was, $P_{X_{(ij)}}(X_n, t_n | X_{n-1}, t_{n-1})$ with time homogeneity transition probability expressed as, $p_{ij}(t) = P\{X_t = j | X_{t-1} = i\}$, solved as a set of transition matrices where p_{ij} are the elements in the matrix of transition probabilities $P(t)$. Transition probabilities were derived using SemGrid (a freely available program). This was done by first converting each derived raster grid to ASCII files, which are the generic input file format for SemGrid. Forest transition probabilities for each selected pair of years, for example, 2006-2007, 2007-2008 and 2008-2009 were then derived by running stochastic analyses on each pairing. The transition probabilities are calculated using a Markovian random process algorithm, which factors in corresponding pixel centroids and pairwise relationships. Brown et al. (2000) subsidiary two state variation of transition probabilities was also adopted for this study to determine probabilities of lumped areas converting from forest to non-forest cover.

5.3.4. Multivariate Analysis

In order to trend results generated from Markov chain analyses, we introduced a new method to illustrate the *in-situ* variation between each pair of transition states using ordination and classification techniques. The pixels that changed for each land-use and land-cover category for each pair of years were subjected to multivariate analysis using PCORD₄ software (MJM software, Gleneden Beach, Oregon, USA). Cluster Analysis and Canonical Correspondence Analysis (CCA) were performed to identify the trends and relationships between pixel change in each land-use and land-cover class and time steps. The dendrogram was constructed using the distance between objects index measured by Bray-Curtis and groups were linked by the nearest neighbor method. The Bray-Curtis method was adopted due to its retention of sensitivity in more heterogeneous data sets and because it weights fewer outliers compared to Euclidean distance (for example Roberts 1986).

An ordination technique was used to reveal subtle intrinsic patterns that may not be readily evident in the data especially on a multidimensional scale. The primary data matrix for the CCA was assembled using pixel change in LULC of forest to non-forest (P_{fnf}) and non-forest to forest (P_{nff}) for each time step. The secondary data matrix was generated using the forests' extent in relation to underlying soil characteristics, population and housing density data of the area of interest obtained from the United States Census Bureau (<http://www.census.gov/>).

Although the time steps (rows) of the two matrices are equal, the variables (columns) of the two matrices differ. The eight variables for the primary data matrix were: row crops; grains, hay, seeds; other crops; idle cropland; grass, pasture, non-agriculture; forest; urban/developed, and water. The six variables for the secondary data matrix were forest acreage, moderately well drained to somewhat poorly drained soil, moderately well drained

soil, poorly drained soil and somewhat poorly drained soil, population density and housing density.

The two data matrices were overlaid (the joint plot scale was set to 0.10) through canonical corresponding analysis and the results given by the ordination diagram. The results of the joint plots in the ordination diagram show the relationship between soil characteristics and LULC types through a diagram of radiating lines. The angle and length of each line indicates the direction and strength of the relationship (McCune and Grace 2002). In the ordination diagrams, the grouping was done using cluster analyses.

5.3.5. Forest Soil Associations

We investigated the spatial distribution of forests with respect to soil types. Forest acreage in each time period was derived from the classified Landsat ETM+ image using a raster to vector conversion algorithm. Soil data was obtained from the Soil Survey Geographic (SSURGO) Database (<http://soils.usda.gov/survey/geography/ssurgo/>) of the Natural Resources Conservation Service. Soil types grouped by soil characteristics, for example well drained soils, were overlain with the forests layer to tease out any relationships between soil types and forest. The forest acreage in each of the soil types (for example moderately well drained, moderately well drained to somewhat poorly drained soil, somewhat poorly drained soil and poorly drained) was generated.

5.4. Results

5.4.1. Land-use/Cover Change

Figure 5.1 shows the changes of land-use and land-cover types in Cass County from 2006 to 2011. According to the landsat-based analysis, row crops showed an increasing trend of cultivation with high correlation ($R^2 = 0.80$) over the time period (Table 5.1, Fig. 5.1). According to my results, soybean was the main row crop cultivated in Cass County with

208,698 ha planted in 2006, increasing to 242,378 ha in 2011. In contrast, grains, hay, seeds showed a decreasing trend from 2006 to 2011 ($R^2 = 0.80$).

Spring wheat was the leading crop of grains, hay, seeds cultivated at 74,069 ha in 2006 and decreased to 43,561 ha in 2011. The other crops also showed a decreasing trend ($R^2 = 0.72$), but the acreage of other crops was much lower than the acreage of grains, hay, seeds from 2006 to 2011. For example, sugarbeet was the main crop for the other crop class, with 20,510 acres cultivated in 2006 decreasing to 10,803 acres in 2011. Forest cover increased in 2007 (6,059 ha), but overall was stable from 2006 to 2011. The forest acreage in 2006 was 3,904 ha and in 2011 it was 3,938 acres.

Table 5.1. Land-use and land-cover change from 2006 to 2011 in Cass County.

Year	Land-use and land-cover extents in ha			
	Row crops	Grains, hay, seeds	Other crops	Forests
2006	269,438	80,442	10,920	3,904
2007	282,378	76,349	8,772	6,059
2008	289,002	67,510	9,731	4,968
2009	318,587	42,911	8,035	4,999
2010	320,898	50,714	8,570	4,135
2011	325,779	47,528	4,649	3,938

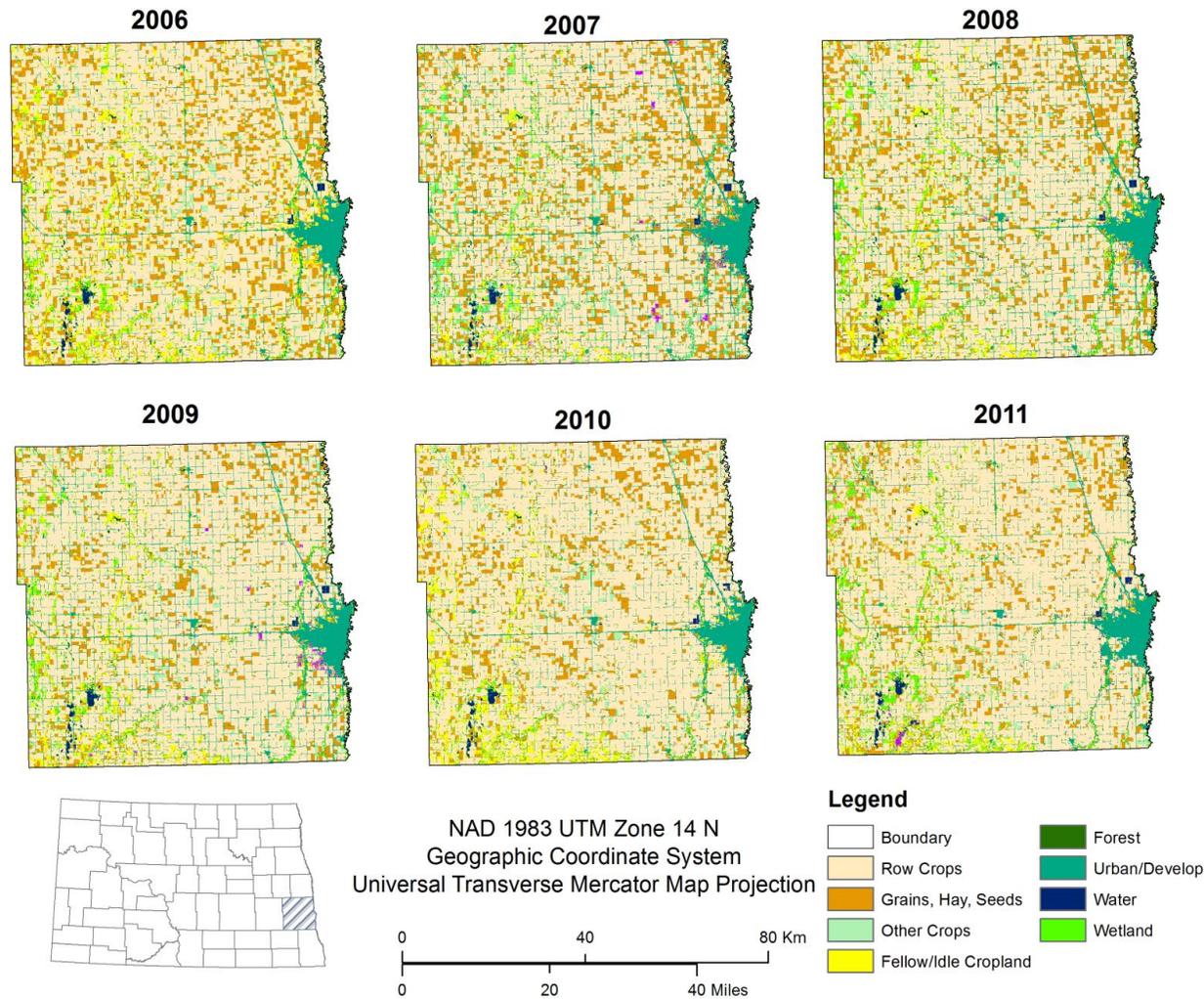


Figure 5.1. Land-use and land-cover change in Cass County from 2006 to 2011 in North Dakota. Data sources: Cropland data was obtained from National Agricultural Statistic Service (NASS) web portal (<http://nassgeodata.gmu.edu/CropScape/>). Accessed: September 10, 2012. North Dakota administrative boundaries were obtained from the North Dakota GIS Hub Data Portal (<http://www.nd.gov/gis/>). Accessed: June 02, 2011.

5.4.2. Multivariate Analysis

Cluster analysis was used to identify the forest transition relationship between pairs of years from 2006 to 2011. Based on this analysis, two major groups were separated for the forest to non-forest (FNF) transition (Fig. 5.2). The first group separates seven pairs of years at 92% similarity, which comprised of pairwise comparisons between images analyzed for 2006 compared to those analyzed for the years 2007-2009, images derived from 2007 compared to those from 2008-2009, image 2008 compared to image 2009, and image 2010 compared to image 2011. The second group distinguishable at 90% similarity includes eight pairwise comparisons: the 2006 image compared to images from 2010 to 2011, images derived from 2007 compared to those from 2010 to 2011, images derived from 2008 compared to those from 2010 to 2011, and images derived from 2009 compared to those from 2010 to 2011.

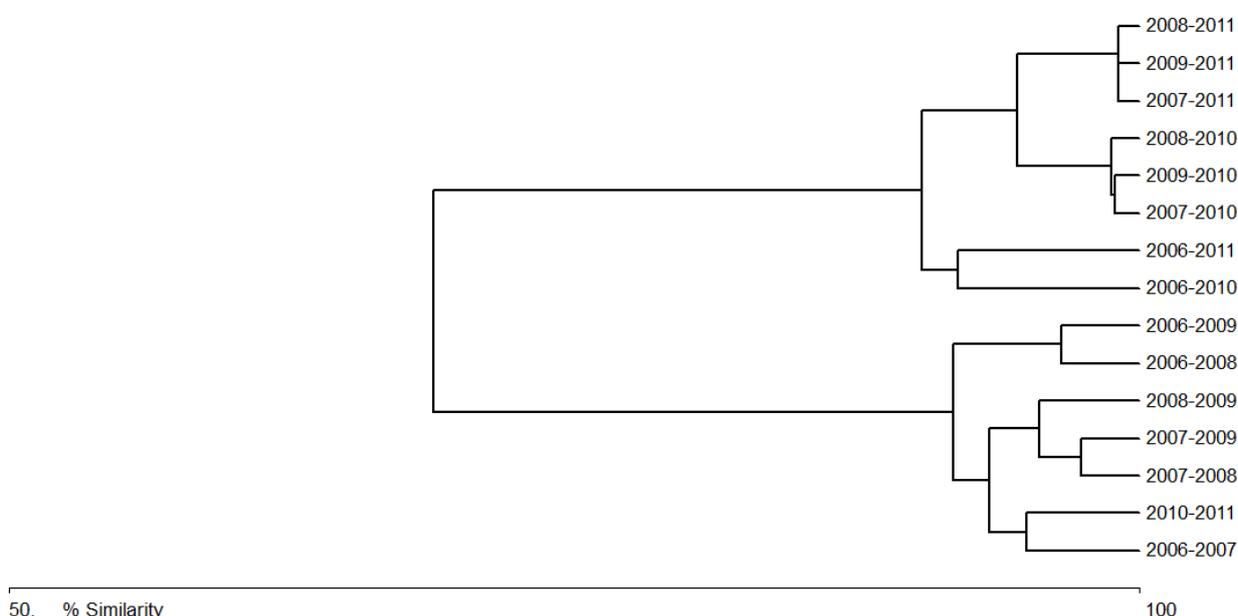


Figure 5.2. Dendrogram for the probabilities of forest to non-forest transition using Bray Curtis similarity values for Cass County for the 2006 to 2011 period. Transition probabilities for 15 pairs of year combinations were used to produce the cluster analysis.

The data gathered in this study were further analyzed using a Canonical Correspondence Analysis (Fig. 5.3). We examined the ordination diagram from this analysis in relation to the groups identified in the cluster analysis (Fig. 5.2). As the diagram showing axis 1 and 2 (Pearson correlation 0.98 & 0.96 respectively) gave the best separation of land-use and land-cover data (Fig. 5.3), we therefore adopted it to gauge interrelationships among variables.

The first group forms a unique cluster at the left-most side of Axis 1 and is closely associated with the forest category. In addition, this group clearly separates from moderately well drained and somewhat poorly drained soil types (Fig. 5.3). This group included image 2007 compared to images 2008 to 2009, image 2008 compared to image 2009, and image 2010 compared to image 2011. The second group separated at the lower bottom side of Axis 2 and associated with row crops and water. This group included pairwise comparisons between images from 2007 compared to images from 2010 to 2011, image 2008 compared to images from 2010 to 2011, and image 2009 compared to images from 2010 to 2011. The third group separated at the upper eastern-most side of Axis 1 and can be associated with grains, hay, seeds and other crops. This group included image 2006 compared to images from 2007 to 2011. Table 1 shows the forest to non-forest transition (P_{fnf}) probabilities for pairwise comparisons of images according to the groups separated from the cluster analysis (Fig. 5.2) during the period 2006 to 2011 for Cass County. Results showed that P_{fnf} was high for unchanged forest ($P_{ff} = 0.5400-0.6806$) for the first cluster group (Table 5.2).

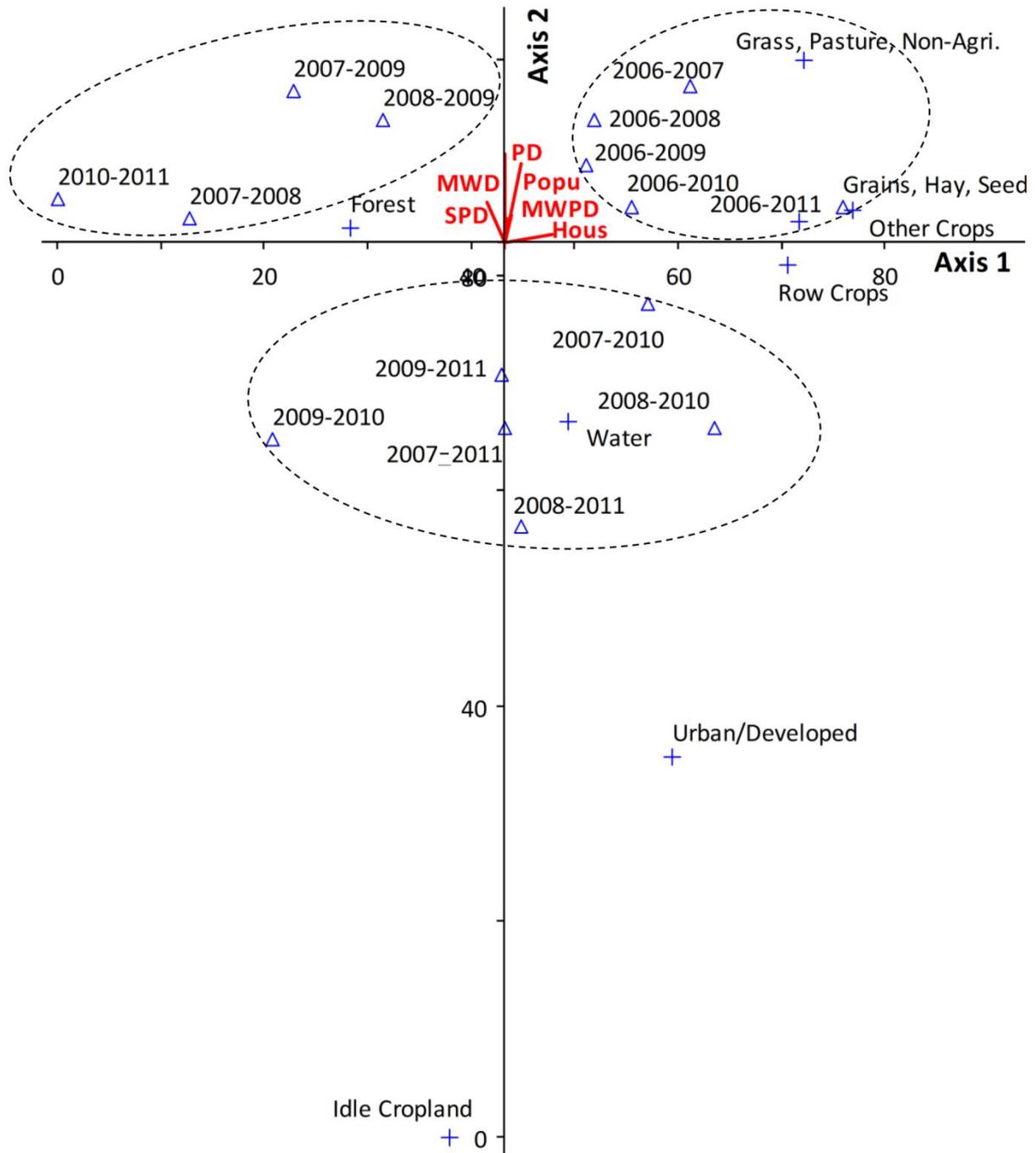


Figure 5.3. Canonical corresponding analysis ordination for the probabilities of forest to non-forest transition using pairs of year combinations, land-use classes and secondary data such as population density, housing number and forest acreages in each soil types. Joint plot was performed at the 0.01 cut off levels. Two to four letter codes represent the variables such as population (Popu), housing number (Hous), somewhat poorly drained soil (SPD), moderately well drained (MWD), poorly drained (PD) and moderately well drained to somewhat poorly drained soil (MWP).

Table 5.2. Land-use transitional probabilities (P_{nf}) of each sub-period for Cass County, North Dakota.

Time Steps	1	2	3	4	5	6	7	8
First Group								
2006 - 2007	0.0210	0.0073	0.0001	0.0000	0.0236	0.6806	0.0422	0.0062
2006 - 2008	0.0344	0.0095	0.0003	0.0000	0.0861	0.5478	0.0456	0.0126
2006 - 2009	0.0485	0.0046	0.0002	0.0000	0.0668	0.5400	0.0488	0.0059
2007 - 2008	0.0255	0.0114	0.0001	0.0000	0.0726	0.6153	0.0140	0.0102
2007 - 2009	0.0348	0.0032	0.0000	0.0001	0.0626	0.6082	0.0171	0.0054
2008 - 2009	0.0249	0.0024	0.0001	0.0000	0.0386	0.6351	0.0127	0.0088
2010 - 2011	0.0101	0.0037	0.0001	0.0009	0.0024	0.6797	0.0057	0.0094
Second Group								
2006 - 2010	0.3579	0.0362	0.0025	0.0004	0.1080	0.2634	0.0563	0.0135
2006 - 2011	0.3022	0.0600	0.0015	0.0018	0.0806	0.2832	0.0567	0.0215
2007 - 2010	0.3190	0.0305	0.0021	0.0003	0.0845	0.3572	0.0284	0.0100
2007 - 2011	0.2685	0.0466	0.0012	0.0028	0.0652	0.3624	0.0298	0.0180
2008 - 2010	0.3224	0.0276	0.0023	0.0003	0.0744	0.3627	0.0294	0.0101
2008 - 2011	0.2698	0.0457	0.0012	0.0022	0.0577	0.3647	0.0317	0.0193
2009 - 2010	0.3171	0.0300	0.0020	0.0004	0.0799	0.3659	0.0258	0.0088
2009 - 2011	0.2630	0.0482	0.0011	0.0019	0.0644	0.3599	0.0269	0.0149

Key to transition states: 1 row crops 2 grains, hay, seeds, 3 other crops 4 idle cropland 5 grass, pasture, non-agriculture 6 forest 7 urban/developed 8 water.

In contrast, the transition probabilities for other crops and idle cropland were low. The second group consisted of eight pairs of years. Of those pairs, image 2007 compared to images 2010 to 2011, image 2008 compared to images 2010 to 2011, and image 2009 compared to images 2010-2011 showed comparatively high transition probabilities (0.3572-0.3659) for unchanged forest compared to the transition probabilities for image 2006 compared to images 2010 to 2011 (0.2634-0.2832). In contrast, the transition probabilities for row crops for image 2006 compared to images from 2010 to 2011 were higher than other land-use and land-cover categories (0.3579 and 0.3022).

Figure 5.4 shows the results of the cluster analysis for the non-forest to forest transition (P_{nff}) from 2006 to 2011. Two distinguishable groups were identified, which was

similar to the previous cluster analysis. The first group clearly separated at 92% similarity and included image 2006 compared to images analyzed for years 2007 to 2009, image 2007 compared to images analyzed for years 2008 to 2009, image 2008 compared to image 2009, and image 2010 compared to image 2011. The subgroup of the first cluster, which separated at 98% similarity, included image 2006 compared to images 2008 to 2009. The second group separated at 88% similarity and included the 2006 image compared to images analyzed for years 2010 to 2011, image 2007 compared to images 2010 to 2011, image 2008 compared to images 2010 to 2011, and image 2009 compared to images 2010 to 2011. The sub group of the second main cluster separated at 96% similarity and included image 2006 compared to images 2010 to 2011.

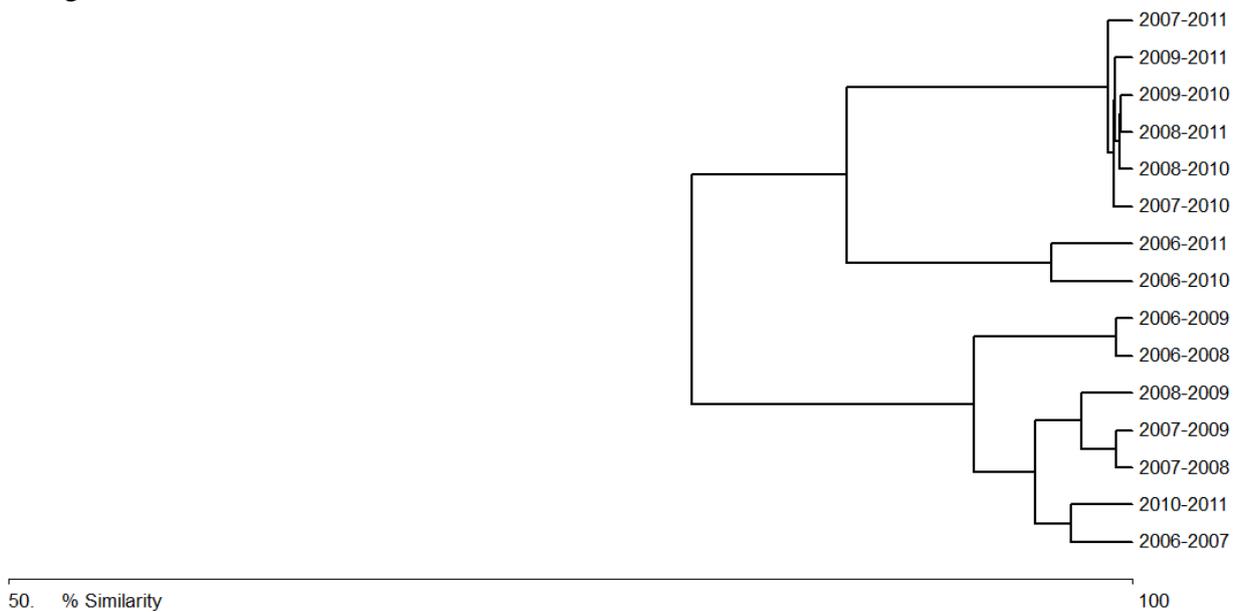


Figure 5.4. Dendrogram for the probabilities of non-forest to forest transition using Bray Curtis similarity values for Cass County for the 2006 to 2011 period. Transition probabilities for 15 pairs of year combinations were used to make the cluster analysis.

Of the three main axes in the ordination diagram (Fig. 5.5), Axes 1 and 2 were selected to describe the inherent variation among variables due to the high Pearson correlation (0.99 & 0.95 respectively). The first group, which is similar to the cluster analysis, is separated at the right-most side of Axis 1.

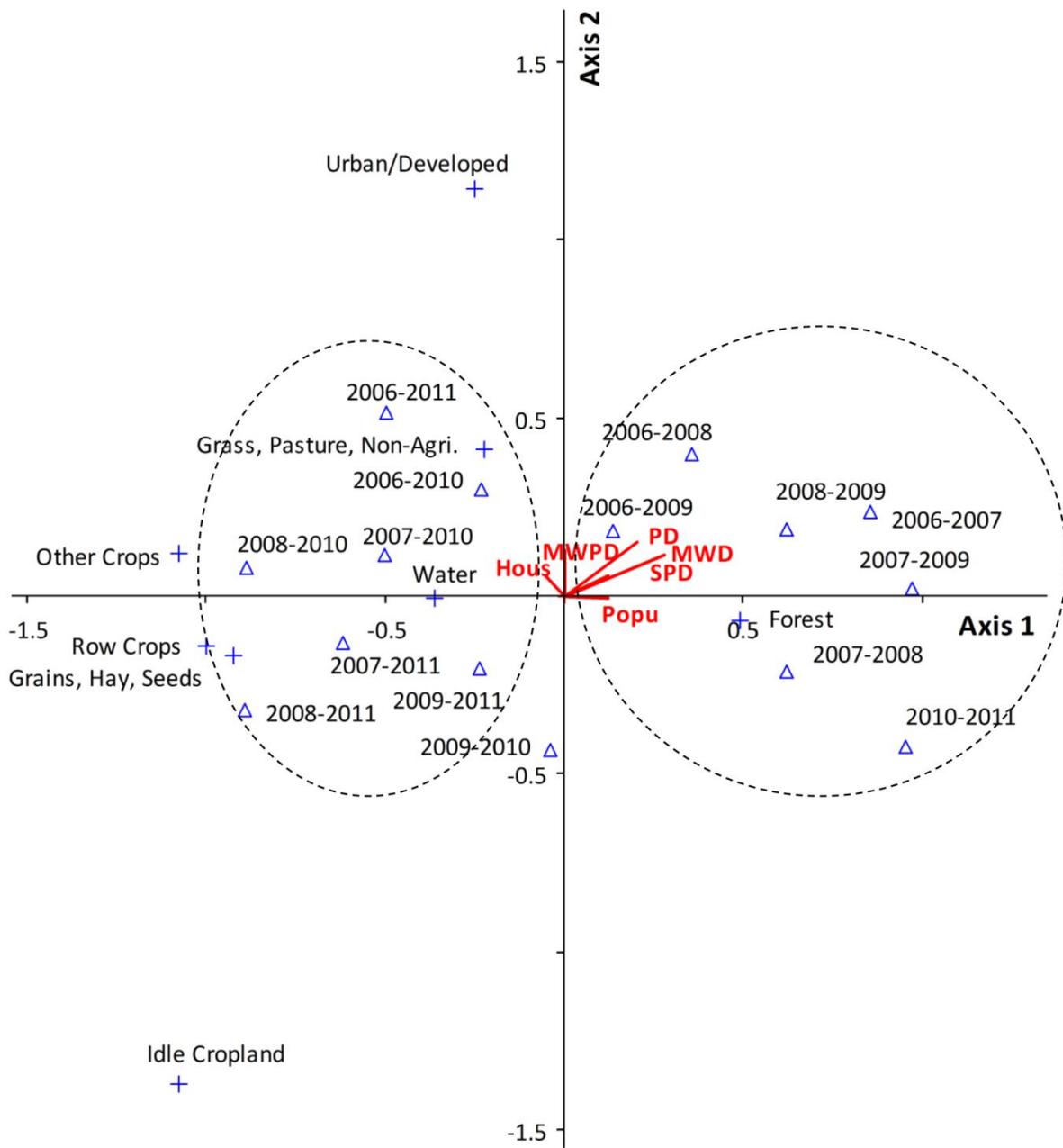


Figure 5.5. Canonical corresponding analysis ordination for the probabilities of non-forest to forest transition using pairs of year combinations, land-use classes and secondary data such as population density, housing number and forest acreages in each soil types. Joint plot was performed at the 0.01 cut off levels. Two to four letter codes represent the variables such as population (Popu), housing number (Hous), somewhat poorly drained soil (SPD), moderately well drained (MWD), poorly drained (PD) and moderately well drained to somewhat poorly drained soil (MWPD).

The first group is closely associated with forest, moderately well drained and somewhat poorly drained soil and human population. The second group separates at the left-most side of Axis 1 and is associated with water and grass, pasture, non-agriculture land-use.

Non-forest to forest transition probabilities of each land-use class for 2006 to 2011 are listed in Table 5.3. The first and the second group showed very low transition probability values for all land-use classes except forest. The transition probabilities for unchanged forest were much greater in the first group ($0.5400 \leq P_{ff} \leq 0.6806$) than the second group ($0.2634 \leq P_{ff} \leq 0.3659$).

Table 5.3. Land-use transitional probabilities (P_{nff}) of each sub-period for Cass County, North Dakota.

Time Steps	1	2	3	4	5	6	7	8
First Group								
2006 - 2007	0.0042	0.0027	0.0015	0.0000	0.0256	0.6806	0.0043	0.0115
2006 - 2008	0.0034	0.0019	0.0012	0.0000	0.0210	0.5478	0.0033	0.0114
2006 - 2009	0.0034	0.0019	0.0012	0.0000	0.0207	0.5400	0.0029	0.0084
2007 - 2009	0.0348	0.0032	0.0000	0.0001	0.0626	0.6082	0.0171	0.0054
2007 - 2008	0.0001	0.0002	0.0000	0.0000	0.0042	0.6153	0.0011	0.0090
2008 - 2009	0.0004	0.0006	0.0000	0.0000	0.0125	0.6351	0.0007	0.0112
2010 - 2011	0.0001	0.0001	0.0000	0.0000	0.0006	0.6797	0.0001	0.0038
Second Group								
2006 - 2010	0.0036	0.0024	0.0014	0.0000	0.0221	0.2634	0.0083	0.0155
2006 - 2011	0.0036	0.0023	0.0016	0.0000	0.0202	0.2832	0.0079	0.0090
2007 - 2010	0.0015	0.0011	0.0007	0.0013	0.0106	0.3572	0.0068	0.0112
2007 - 2011	0.0014	0.0010	0.0008	0.0011	0.0085	0.3624	0.0064	0.0074
2008 - 2010	0.0016	0.0014	0.0005	0.0016	0.0157	0.3627	0.0072	0.0165
2008 - 2011	0.0015	0.0013	0.0007	0.0016	0.0134	0.3647	0.0068	0.0134
2009 - 2010	0.0016	0.0015	0.0004	0.0014	0.0151	0.3659	0.0075	0.0145
2009 - 2011	0.0016	0.0013	0.0006	0.0009	0.0133	0.3599	0.0071	0.0084

Key to transition states: 1 row crops, 2 grains, hay, seeds 3 other crops 4 idle cropland 5 grass, pasture, non-agriculture 6 forest 7 urban/developed 8 water.

5.4.3. Forest Soil Associations

The relationship between soil drainage and forest cover in each year is shown in Figure 5.6. Forest cover occurrence in moderately well drained soil (MWD) and poorly drained soil (PD) was greater than forest cover in moderately well drained to somewhat poorly drained soil (MWPD) and somewhat poorly drained soil (SPD). PD had the highest forest cover (58%), followed by MWD (25%), SPD (15%), and MWPD (2%).

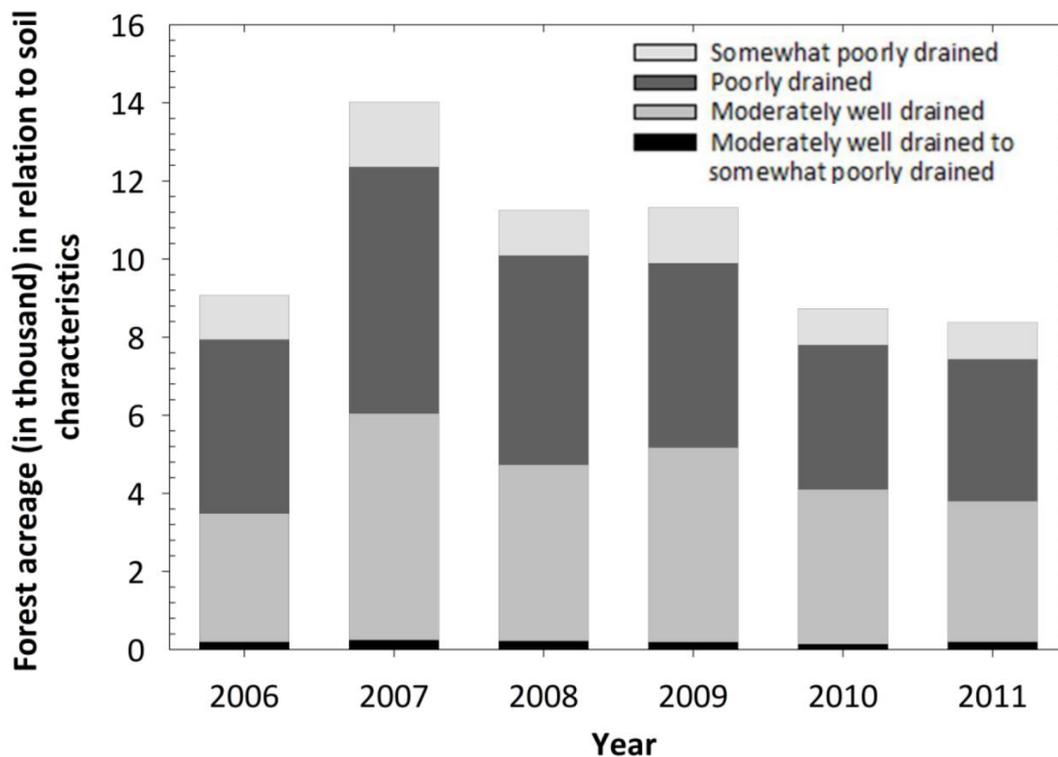


Figure 5.6. Forest acreage in relation to soil characteristics for Cass County, North Dakota.

5.5. Discussion

5.5.1. Land-use/Cover Change

The multi-temporal satellite image analysis of land-use and land-cover change in Cass County showed that more land was used for cultivation of row crops from 2006 to 2011. Conversely, less land was used for cultivation of grains, hay, seeds and other crops from 2006 to 2011. Forest cover increased by 55% in 2007, but overall remained consistent from 2006 to 2011. The big increase of forest coverage in 2007 may be either due to classification error

or that when the image was acquired, the trees were not defoliated and thus were classified as forest lands. Neau et al. (2011) reported that the major changes occurring across the U.S. landscape were the conversion of lands from traditional small grain production to corn and soybean production. North Dakota is an agricultural state and soybeans are a major row crop cultivated in this region (VanWechel et al. 2003). According to an economic census in North Dakota, the Red River Valley area, which includes Cass County and Richland County, was the major region that cultivated soybean (Bangsund and Leistritz 1999). The demand for soybean oil for production of biodiesel could explain the increase in acreage of soybeans in Cass County (VanWechel et al. 2003).

The Red River Valley of North Dakota and Minnesota is one of the main regions, which cultivate sugarbeets in the US, but from 2003 to 2010, the industry decreased planted acreage. The decrease was greater in North Dakota (18%) than in Minnesota (11%). The decline in sugarbeet production can be associated with high expenditure for processing and marketing activities (Bangsung et al. 2012).

5.5.2. Multivariate Analysis

We derived first-order Markov chain models, which can serve as an indicator of the direction and magnitude of land-cover change in the future as well as a quantitative description of change in the past (see also Weng 2002). An important aspect of change detection is to determine which land-use class is changing and how it is changing (Shiferaw 2011). This information reveals both the desirable and undesirable changes and classes that are relatively stable over time, which is useful for management decisions.

Cass County is a metropolitan area with a 21.6% population increase recorded from 2000 to 2010 (US Census Bureau 2011). Even though the population increased for the study period, forest cover did not change considerably except in 2007. The reasons could be attributed to an increased interest by landowners including farmers in conservation forestry

programs and also change in the main economic base of the city from farming to white collar jobs. For instance, the agricultural community together with the forest service in North Dakota established windbreaks and shelterbelts (Kotchman 2010). The group worked to change tree cover in those time periods slightly. In addition, Cass County contains a Soil Conservation District, which implements natural forest, urban and community forestry conservation practices.

Also, according to the Lake Agassiz resource surveys (Lake Agassiz resource conservation and development area plan council 2008), in Cass County, changing land-use patterns to the production of small grains and row crops caused severe erosion problems. Wind erosion continues to be the most serious conservation problem occurring in cropland areas. Windbreaks are therefore established in agricultural settings in order to protect crops.

5.5.3. Forest Soil Associations

Understanding the relationship between LULC practices and soil characteristics is important for controlling factors associated with deforestation or reforestation. Therefore, many plant geographers are interested in the relationship between vegetation and soil characteristics. For example, Iverson (1988) used GIS techniques in assessing relationships between vegetation types and the soil characteristics to compare the soil and landscape attributes of Illinois with its historic vegetation, current land-use, and patterns of land-use change.

In our study, forest change in terms of soil characteristics was analyzed. Forest occurrence in poorly drained soils (58%) showed a higher distribution compared to moderately well drained to somewhat poorly drained soil (2%). This soil type was unsuitable for cropland because of its texture, that is, silty clay, silty clay loam, and sandy loam, which may hold excess water. As Hopkins et al. (2012) suggested, saturated soil contributed to higher soil salinity, which prevented planting in the Dakotas. Moreover, Hopkins et al. (2012)

reported that the Cass County soil contains high exchangeable sodium percentage at shallower depths, which apparently is undesirable for crop cultivation.

The forest occurrence at the moderately well drained soil is also noticeable. The main soil textures associated with this class were silt loam, loam, sandy loam, and silty clay loam. Ideally, these soils are suitable for agricultural crops and therefore the forest lands confined to shelterbelts and/or windbreaks.

5.6. Conclusions

This research adopts concepts of random-walk stochastic processes and multivariate analysis to investigate forest cover change from a spatial evolution perspective in Cass County, North Dakota. In general, row crops showed an increasing trend, while grains, hay, seeds and other crops showed a declining trend from 2006 to 2011. Of the cultivated crops, soybean showed a tremendous increase, while spring wheat and sugarbeet showed a declining trend. Interestingly, forest cover showed a stable trend. Although Cass County is one of the major metropolitan areas in North Dakota with an increasing population, our results show that this increasing population is not resulting in a depletion of forest lands.

Multivariate analysis resulted in two distinct groups: one group with unchanged forest transition probabilities that were comparatively high ($0.54 \leq P_{ff} \leq 0.68$), and the second group with low transition probabilities of unchanged forest ($0.26 \leq P_{ff} \leq 0.37$). Our results show that the forests in Cass County are established in poorly drained soil, which is apparently unsuitable for growing crops due to high water retention capacities.

5.7. Literature Cited

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CHAPTER 6. CONCLUSIONS AND FUTURE DIRECTION

6.1. Conclusions

The first two sections of this dissertation discussed the factors that correlate or contribute to the distribution and abundance of Russian-olive within the Bismarck-Mandan Wild Urban Interface (BMWUI) and the adjacent banks of the Missouri River. Russian-olive proliferation doubled from 2005 to 2010 along the banks of the Missouri River floodplain within the BMWUI. This result correlates with soil characteristics, for example, silt loams and silty clay soil types typically associated with the floodplain of Missouri River. In addition, less grassland areas in the terrestrial habitats were also favorable for the establishment of Russian-olive.

Remote Sensing data were compared with *in-situ* data to analyze further relationships between Russian-olive and native plants in terms of soil data. Russian-olive showed a close association with cottonwood trees (*Populus deltoides*) and buffaloberry (*Shepherdia argentea*) plants at lower elevations. Russian-olive-cottonwood association correlates with low nitrogen, low pH, and high Fe. In comparison, the green ash-chokecherry-bur oak plant community correlated with high K, and the boxelder-elm plant community correlated with organic matter. MaxEnt modeling was used to predict potential suitable habitats for distribution of Russian-olive based on soil moisture content and Russian-olive presence data. The most suitable area for Russian-olive occurrence is in the Northwestern Glaciated Plains eco-region in North Dakota. Long-term monitoring and restoration of arboreal ecosystems will be essential to reducing vulnerabilities of such ecosystems from the exotic Russian-olive invasions.

The third section of this dissertation focused on how land-use/cover changes and climatic parameters influence vulnerabilities of an arboreal ecosystem. Two widely used indices, Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water

Index (NDWI) were adapted to estimate fractional vegetation cover change at the Devils Lake sub-watershed region using multi-temporal satellite data. Results show that the NDVI is negatively correlated with NDWI. For example, a big increase of NDVI or vegetation growth was observed for the periods of 1991-1994 and 2000-2005, while NDWI was considerably decreased in those time frames. Land-cover change using satellite imagery showed that the forest acreage declined from 9% to 1% and water areal extents increased from 13% to 25% between 1992 and 2006.

The fourth section of this dissertation synthesized stochastic models on how land-use/cover types changed with respect to both forest resources in the past and potential trends of forest cover change in the future within Cass County. The multi-temporal satellite image analysis of land-use/cover change in Cass County showed an increasing trend for row crops and a declining trend for grains, hay, seeds and other crops from 2006 to 2011. Interestingly, forest cover increased slightly in 2007, but overall remained consistent from 2006 to 2011. These results are useful for forest managers to make better forest stewardship programs with landowners in applying BMPs (Best Management Practices).

6.2. Future Direction

In this study, high spatial resolution data was used to map Russian-olive distribution along the Missouri River. Initially manual digitizing technique was adapted to extract the Russian-olive features from the NAIP images (National Agriculture Imagery Program), which was an arduous task. Later Russian-olive features were extracted using object oriented feature extraction techniques, which is an automated technique on ENVI[®] EX. Even though this method is accurate and less time consuming compared to manual digitizing, it only works well for small areas on the county level. Mapping Russian-olive distribution on a large scale will need further sophisticated methods, which should be accurate and comparable to the previous techniques.

Developing a spectral library using a spectroradiometer like FieldSpec[®] 4, can be used to discern subtle spectral characteristics especially when comparing Russian-olive (*Elaeagnus angustifolia*) and its associated plant communities such as cottonwood (*Populus deltoides*) and silver buffaloberry (*Shepherdia argentea*). Although feature extraction using ENVI EX[®] software can be used to distinguish Russian-olive and buffaloberry from high resolution NAIP images, both plants have silvery grey green leaves, and the feature extraction tool is not sensitive enough to capture the different spectral signatures of these plants. Therefore, the spectral library technique is useful to distinguish morphologically similar species not only from high resolution images, but also from satellite imagery.

**APPENDIX A. SPECIES LIST OF IDENTIFIED VEGETATION IN TWENTY
SAMPLING PLOTS ALONG THE MISSOURI RIVER FLOODPLAIN**

Family / Botanical Name	Common Name	Life form
Aceraceae		
<i>Acer negundo</i> L.	Boxelder	Tree
Asteraceae		
<i>Helianthus annuus</i> L.	Sunflower	Herb
Elaeagnaceae		
<i>Elaeagnus angustifolia</i> L.	Russian-olive	Tree
<i>Shepherdia argentea</i> (Pursh) Nutt.	Buffaloberry	Shrub
Equisetaceae		
<i>Equisetum laevigatum</i> A. Braun	Smooth horsetail	Herb
Fagaceae		
<i>Quercus macrocarpa</i> Michx.	Bur oak	Tree
Oleaceae		
<i>Fraxinus pennsylvanica</i> Marshall	Green ash	Tree
Rosaceae		
<i>Prunus virginiana</i> L.	Chokecherry	Shrub
<i>Rosa woodsii</i> Lindl.	Woods' rose	Shrub
Salicaceae		
<i>Populus deltoides</i> W. Bartram ex Marshall	Cottonwood	Tree
<i>Salix amygdaloides</i> Andersson	Peachleaf willow	Tree
<i>Salix fragilis</i> L.	Crack willow	Tree
<i>Salix interior</i> Rowlee	Sandbar willow	Shrub
<i>Salix rigida</i> Muhl.	American McKay	Shrub
Ulmaceae		
<i>Ulmus americana</i> L.	American elm	Tree

APPENDIX B. PUBLICATIONS ARISING FROM THIS RESEARCH

- Madurapperuma B.D., Oduor, P.G., Anar, M.J. and Kotchman, L.A. 2012. Understanding Factors that correlate or contribute to exotic Russian-olive invasion at a wildland-urban interface ecosystem. *Invasive Plant Science and Management* 6: 130-139.
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