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CHANGES IN LAND COVER AND WILDLIFE HABITATS IN TWO WATERSHEDS IN THE LOWER PENINSULA OF MICHIGAN

By

Daniel Thomas Rutledge

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ABSTRACT

CHANGES IN LAND COVER AND WILDLIFE HABITATS IN TWO WATERSHEDS IN THE LOWER PENINSULA OF MICHIGAN

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Daniel Thomas Rutledge

Changes in land cover and changes in wildlife habitats were analyzed in two watersheds in Michigan's Lower Peninsula from the early to mid 1800's to the early 1990's. The Huron River watershed in southeastern Michigan near Detroit underwent extensive conversion from mostly forested (70%) to mostly agricultural (55%) from the early 1800's to the late 1930's. From the 1930's to the 1990's, urban areas expanded from 5% to 29% at the cost of agricultural land. Forest and nonforest areas increased during that time period as well. The Black River watershed in the north central Lower Peninsula underwent extensive clearcutting from the mid 1800's to the early 1900's. Since timber harvesting stopped, the Black returned to a mostly forested condition (73%). However, forest age and composition changed markedly. Conifer forest declined 56%, from 84,000 ha in the 1800's to 37,000 ha by the 1990's. Broadleaf forest increased 14%, as large gains in early successional aspen/white pine (5,000 ha to 40,000 ha) offset losses in northern hardwoods (56,000 ha to 16,000 ha). In both watersheds, mean patch sizes and the number of patches have decreased/increased, respectively, by one to two orders of magnitude.

Habitat changes varied for both watersheds and depended upon the species in question. Losses in the amount of potential habitat occurred primarily from the 1800's to the 1930's. From the 1930's to the 1990's, the amount of potential habitat showed minimal change in the Black River watershed and actually increased for a majority of species in the Huron River watershed. However, in both watersheds, patch sizes of potential habitat typically declined by one to 2 orders of magnitude from the 1800's to the 1930's and remained the same for most species from the 1930's to the 1990's.

The feasibility of modeling future land cover change based on observed patterns of land cover change was investigated. Overall models performed well at predicting anthropogenic changes related to regular features on the landscape such as roads. The models performed poorly at predicting natural changes such as succession. Additional information would be needed to increase the ability of the models to predict future land cover change.

Despite extensive habitat changes, 90% of species still occur in both watersheds. How many and which species will continue to persist in these modified landscapes will require further research. In particular, research should focus on understanding species-habitat relationships at landscape scales (typically 10's to 100's of kilometers) and where land cover data are limited to broad categories. This information, when combined with more detailed studies of wildife-habitat relationships, will provide important insights into species abilities to persist in highly-modified landscapes.

To the Wicked Witch of the West,
With Love

ACKNOWLEDGMENTS

Any dissertation is not possible without tremendous support from a variety of sources. I would like to acknowledge this support and give them my wholehearted appreciation for helping me complete this task.

This project began with initial funding by the Michigan Agricultural Experimental Station and continued under funding from the Michigan Department of Natural Resources Wildlife Division. A College of Agriculture and Natural Resources Dissertation Completion Fellowship provided funds that allowed me to complete this dissertation.

I wish to thank my committee members, Dr. Rique Campa, Dr. Larry Leefers, and Dr. Richard Groop, who provided guidance when requested, good advice when needed, and otherwise did not ask what the heck was taking me so long. I appreciated your patience.

Bob Doepker of the Michigan Department of Natural Resources kindly provided the base data needed to develop the species-land cover matrix.

The Department of Fisheries & Wildlife staff deserves my thanks for their professionalism, support, and keeping the administrative wheels greased. They were always there to answer questions and keep the process moving forward. They included Jane Thompson, Julie Traver, Carla Dombroski, and Sarah Cline. A very special thanks to Jim Brown, Doctor of UNIX Medicine, for keeping our Suns healthy and happy.

I am forever indebted to my platoon of undergraduate interns whose labor and toil and hours of digitizing produced the database that is the foundation of this dissertation. They are JoAnna Lessard, Douglas Longpre, Josh Mohler, Eric Dephouse, Jayson Egeler, Bradley Thompson, Robert Goodwin, Risa Oram, Kathy Damstra, and Vince Videan.

My lab mates deserve recognition for their thoughtful advice, camaraderie, and witty banner that helped keep me from going insane during long hours in front of the UNIX workstations in a windowless lab. They are Kiersten Kress, Jialong Xie, Marc Linderman, and Li An.

I thank my extended family at Michigan State for their encouragement, commiseration, empathy, fun, hockey games, and frequent trips to the Peanut Barrel. They are Annelise Carleton, Sarah Walsh, Joel & Kris Lynch, Kendra & Jubin Cheruvelil, Dr. Angela Mertig, Kathryn Reis, Mike & Kelly Mascarehnas, Michelle & Keith Niedermeier, Darren Benjamin, Mike Rutter, Natalie Waddell-Rutter, Mike Steeves, Gabi Yaunches, Dr. Pat Soranno, Steve Haeseker, Paul Keenlance, Laura Cimo, and Dr. Kelly Millenbah. A very special thanks to Bob Eubanks for his wise and thoughtful counsel. I will miss them all tremendously.

Three friends in particular merit special mention. Dr. Meg Clark served as my own personal barometer and was always there for a moral boost or barefoot walks in the fountain. Chris Lepcyzk was my partner in lifting weights, the cast iron as well as the emotional, intellectual, and spiritual variety. Thanks for helping to "pump me up"! Finally, what about Bob? Dr. Robert Holsman was my sounding board, my confidant, my Jiminy Cricket. He endured it all. He taught me to know

and love Spartan college hockey. And he gets my jokes. What more can one ask of a best friend?

My family and lifelong friends buttressed me throughout the process. This included my sister Amy, my brother Charles, my Uncle Dan and Aunt Gwen, and Greg Bracco and Ed Michalak, who might as well be my brothers. And let me not forget my immediate family: Bugs and Daffy!

Finally, there are two people about whom I cannot say enough. The words are inadequate to describe what they have done for me, but I'll try.

First, there is my advisor, Dr. Jianguo "Jack" Liu. Without his support, patience, and guidance throughout this project, and in particular his faith in me during many difficult times, this document would quite simply not exist. He is a loyal friend, a great scientist, and above all a wonderful person. Thank you, Jack.

And saving the best for last, there is my Mom. I literally owe it all to her. She sacrificed so much for my siblings and me, that I cannot ever thank her enough. Her example has been an inspiration to me and will always be so. She is a great mom and a fantastic person. I love you Mom!

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LIST OF ABBREVIATIONS

GLO .... General Land Office

LP .... Lower Peninsula

MIRIS .... Michigan Resource Information System

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LP .... Lower Peninsula

MIRIS .... Michigan Resource Information System

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INTRODUCTION

The twentieth century has witnessed an unprecedented increase in both the amount and extent of human activity. A primary consequence of this increase has been the modification, and in many cases, wholesale change of ecosystems across the globe (Murphy 1986). The conversion of land to uses geared primarily towards human needs has raised concern about the long-term viability of ecosystem functions and of many wildlife species and the habitats in which they live. For example, Wilson (1986) stated that the rate of extinction due to human causes could be upwards of 10,000 times higher than extinction rates gleaned from the fossil record.

A primary cause of decline for many wildlife species is the reduction of habitat quantity and quality and fragmentation of remaining suitable habitat (Ehrlich 1986). For example, prior to European settlement, Michigan had approximately 14,400,000 ha of forest (95% of total land area) and 4,450,000 ha (30%) of wetlands, including forested wetlands. By 1978, the Michigan Department of Natural Resources estimated that upland forest area had declined to 5,570,000 ha and wetlands, including forested wetlands, to 2,500,00 ha (Warbach and Reed 1995a). Basic ecological theory predicts that the number of species is a function of the total amount of suitable habitat available. Therefore it follows that as the total amount of suitable habitat declines, some species will go extinct (Pimm and Raven 2000). However, which species go extinct, either locally or globally, and the actual process of extinction is not well understood and depends on many factors. Many organisms undoubtedly face a greater challenge to survive

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to survive and to reproduce successfully. For example, species with small ranges typically have a much higher risk of extinction than broadly ranging species for a given amount of habitat loss. Conversely, opportunistic species may actually benefit from such changes. Ultimately differences between species that go extinct and that survive depend on each species' unique habitat needs and its ability to adapt to changing landscape conditions.

Given the extent and rate of habitat changes, conservation efforts have begun to shift towards protecting ecosystems and landscapes and the biodiversity that they contain (Noss 1996, Michigan Department of Natural Resources 1997). Single-species or single-resource management, while still important, must be complemented by broad-scale attempts to conserve entire ecological systems, including small elements within areas dominated by people (Ehrlich 1986, Murphy 1986). To achieve such goals will require understanding how landscape conditions change over time (Turner, M.G. et al. 1995) and how species respond to those changes. Such knowledge will help contribute to developing conservation strategies to cope with the possible consequences of future landscape change.

This dissertation contributes to the understanding of how landscapes change over time and how species have responded to those changes. The research was organized around three main questions that pertain to developing long-term strategies for conserving biodiversity. Those questions are

1) How has land use/land cover changed over time?
2) How have wildlife habitats changed over time?

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3) How might land cover change in the future and what possible implications might those changes have on wildlife habitats?

To answer those questions, this dissertation examines land cover changes in two watersheds in Michigan's Lower Peninsula (LP). The first is the Black River watershed, in the north central LP. Land cover in the Black River watershed was predominantly forest prior to European settlement. Extensive timber harvesting reduced the amount of forest in the late 1800's and early 1900's. Since then, forests have regenerated in the watershed such that the watershed today is predominantly forested but with several agricultural areas. The second is the Huron River watershed in the southeastern LP near Detroit. Land cover in the Huron River watershed was predominantly a mix of forest and oak savanna with scattered wetlands in the early 1800's. Throughout the 1800's and early 1900's, land in the Huron River watershed was converted primarily to agriculture. Since the mid 1900's, extensive urbanization has occurred in the watershed. The Black and Huron river watersheds represent two different patterns and sequences of land cover change in Michigan. Therefore they offer the opportunity to compare changes in wildlife habitats and possible consequences for wildlife populations for two different landscapes.

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CHAPTER 1

SIMILARITIES AND DIFFERENCES IN LAND COVER CHANGE BETWEEN AN URBANIZING AND A RURAL WATERSHED IN MICHIGAN

Introduction

Throughout history, human beings have altered the landscape to suit their needs. Over time, the scope of human changes has expanded, such that approximately 40% of the land surface is now subject to some form of intensive human use (Klopatek et al. 1979, Houghton 1994), and the rate of conversion has generally accelerated over the last several decades (Houghton 1994, Brown 1996). Meyer and Turner (1992) estimated that agricultural areas increased worldwide from approximately 2.8 x 10^6 to 14.9 x 10^6 km^2 (532%) from 1700 to 1980 while forests and woodlands declined from 61.51 to 52.37 x 10^6 km^2 (-14.9%). Esser (1989) estimated that the amount of land in agriculture worldwide grew from 10.3 to 21.0 x 10^6 km^2 between 1860 and 1980. A regional study in southeastern Asia showed agricultural areas increasing by 86% and forested areas decreasing by 29% between 1880 and 1980 (Flint 1994).

The United States has also experienced extensive land cover changes. Approximately half of the U.S. was forested prior to European settlement. By 1987, the amount of forest declined to about 32% of total land area. The amount of cropland was estimated at 22%, pasture at 7%, rangeland (including grasslands) 32%, developed lands at 4% and other lands including surface waters at 3%. Wetlands, considered as subcategories of other land cover types, were esti

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were estimated at 5% (Meyer 1995). A recent draft report (The Heinz Center 1999) provides similar estimates for cropland (20%) and forests (33%). Initially changes were linked to the development of agricultural areas and exploitation of natural resources, e.g. mining and logging (Meyer 1995). Towns and cities grew near sources of naturally limited resources, particularly water, and convenient loci of transportation, especially rivers (Turner and Meyer 1994). However, increasing technological developments, especially the advent of modern transportation networks in the second half of this 20th century, have spurred additional changes on the land (Meyer 1995). First railroads and now highways provided the ability for people to easily travel longer distances. Further, it has decreased the need for home, work, and recreation areas to exist in close proximity to one another (Smyth 1995, LaGro 1998). Coupled with this has been the large shift in the U.S. population from rural to urban areas. Between 1900 and 1990, the percentage of Americans living in urban areas increased from 40% to 75% (U.S. Bureau of the Census 1999).

This combination of demographic, economic, cultural, and infrastructure changes have different consequences for different regions of the United States. The northeastern U.S. has both the highest percentage of forest of any region (Meyer 1995), resulting from regrowth following agricultural abandonment (Foster 1992, Foster et al. 1992, Litvaitis 1993, Orwig and Abrams 1994), and the highest percentage of urban area (Meyer 1995). The southeastern U.S. has approximately 40% forest, 20% cropland, 20% rangeland, and 10% pasture (the remaining 10% was not specified) (Meyer 1995). In a study of nine rural counties in Georgia

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in Georgia, forest in all areas increased while agriculture decreased in the mountains and increased in the plains (Turner and Rusher 1988, Turner 1990). The west has primarily rangeland and forest, with small amounts of cropland (Meyer 1995). However, western states have experienced large population increases from 35 to 56 million from 1970 to 1990 (Haub 1995) resulting in the conversion of croplands or rangeland to urban lands (Kline and Alig 1997).

Studies of land cover change in the Midwest are particularly relevant given that Michigan is a Midwestern state and may have similar patterns of land cover and land cover change. The Midwest is approximately 50% cropland (Meyer 1995). Iverson (1988) studied land cover changes in Illinois from 1820 to 1980. Approximately 80% of native land cover was converted to agriculture during that period. Changes to urban areas only accounted for 5% of the total. Vance (1976) found nearly identical results in a study in Jasper County, Illinois. Between 1939 and 1974, grasslands were reduced by 84%, primarily to cropland. In Ohio, Simpson et al. (1994) found that geology influenced landscape change, with agriculture decreasing on upland moraines and increasing on till plains from 1940 to 1988. Medley et al. (1995) also found intensification of agriculture in Ohio. Sharpe et al. (1987) reported similar trends in a detailed study of land cover change in Cadiz township in Wisconsin, in which native forest and savanna declined from 80-85% to 10% of total area from 1882 to 1978 as a result of conversion to cropland and pasture. Cole et al. (1998) found that forest cover declined 40% in the Great Lakes States (Minnesota, Michigan, Wisconsin) from presettlement to present. All forest types decreased in extent and patch size except as

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except aspen-birch communities, which increased 83% in area and from 700 to 1500 km^2 in size.

Michigan has also undergone significant land cover changes since presettlement times. Originally 95% forested (McCann 1991, Comer et al. 1995, Warbach and Reed 1995a), Michigan now supports a diverse mixture of land cover types. By 1978, the Michigan Department of Natural Resources estimated land cover for the state of Michigan as 29.3% agricultural, 37.2% upland forest, 8.0% nonforest, 6.3% urban, 2.2% water, and 16.8% wetlands and lowland forests (Warbach and Reed 1995a). Much of Michigan's southern Lower Peninsula was converted to agriculture. Most of the forests of Michigan's northern Lower Peninsula and Upper Peninsula were extensively harvested during the mid- to late-1800's but have since returned to predominantly forested conditions by the early 1900's (McCann 1991). During the 1900's industrialization has resulted in the expansion of urban areas in southern Michigan, particularly associated with the development of the auto industry around Detroit (Smyth 1995). Michigan's landscape will continue to change, as trends indicate that suburban and rural residential areas will expand as more people attempt to escape the urban lifestyle and, ironically, return to live in a less congested, more natural setting (Smyth 1995).

This chapter examines the first research question: how has land cover changed over time in Michigan? The chapter has three objectives:

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Study A

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1. Characterize areas with different types and patterns of land cover in two watersheds in Michigan
2. Track the changes in land cover over time for the two watersheds
3. Compare the types and patterns of land cover and land cover change for the two watersheds

The landscapes chosen for this study were the Black and Huron river watersheds located in Michigan's Lower Peninsula (LP) (Figure 1.1). Those two watersheds were chosen because they have different landscape histories and current landscape conditions. Also, they represent two typical landscape complexes in Michigan: urban-agricultural (Huron) and rural-forest (Black) (Table 1.1). The Black River watershed, in the northern LP, has undergone the sequence of forest cutting and regeneration common to the northern Lower Peninsula and Upper Peninsula of Michigan. The Huron River watershed, in the southeastern Lower Peninsula near Detroit, has undergone a sequence of changes common to lower Michigan. First, native forests and prairies were cleared for agriculture. Since the mid-1900's, however, the watershed has experienced extensive urbanization, primarily from the conversion of agricultural land.

Study Areas

Black River Watershed

The Black River watershed is located in the upper LP within Cheboygan, Montmorency, Otsego, and Presque Isle counties (Figure 1.2). The Black River flows from

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flows from south to north and intersects Black Lake in the northern portion of the watershed. The landscape is predominantly forest with concentrations of agriculture north and south of Black Lake. Urban areas are interspersed throughout. Land ownership is divided almost evenly between public (49%) and private (51%) (Table 1.1). The major public lands include portions of the Mackinaw State Forest. The economy of the northern LP comes mainly from natural resources production and tourism (Tyler and LaBelle 1995; Warbach and Reed 1995b). Population density is low relative to the Michigan average (Table 1.1). The largest town in the watershed is Onaway with a population of 1,039 persons in 1990. The watershed has no interstates or limited-access highways, several state highways, and a relatively low density of roads (Table 1.1).

Huron River Watershed

The Huron River watershed is located in the southeastern LP (Figure 1.3), just west of Detroit. The majority of the watershed falls within Livingston, Oakland, and Washtenaw counties, with small lobes extending into Ingham and Jackson counties to the west and a long, narrow lobe extending into Wayne and Monroe counties to the southeast. The Huron River watershed is undergoing rapid urbanization and supports a diverse and highly interspersed mix of land uses. The watershed has diverse physiography. The northeast contains an extensive network of lakes that form the river's headwaters. From there, the river flows southwest through a chain of glacial kettle lakes and wetlands before turning southeast where the watershed becomes narrower and steeper. The Huron finally empties into the northwestern Lake Erie. Total mainstem length is

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219 km. The Huron River has been extensively altered, with 19 dams on the mainstem and 77 dams on tributaries (Hay-Chmielewski *et al.* 1995). The economy of the Huron River watershed is a broad mixture of manufacturing, retail, service, and institutional uses (Tyler and LaBelle 1995). Land ownership is almost exclusively private, with the major public lands being state wildlife management and recreation areas and ten regional parks located along the main stem of the Huron River. In 1990, the population density of the Huron River watershed was almost five times higher than the average Michigan population density (Table 1.1). The Huron River watershed has an extensive system of interstate, federal, and state highways, roads, and streets (Table 1.1).

Methods

Development of land cover database

A digital database of land cover for both watersheds was developed for five time steps from 1938 to the 1990's (Table 1.2). Time between steps varied from approximately 10 to 15 years. Digitized land cover and base maps (e.g. roads, rivers, township boundaries) were obtained from the Michigan Department of Natural Resource's Michigan Resource Information System (MIRIS). The MIRIS land cover maps, which represented Step 4, served as base maps for database development. To prepare Steps 1 – 3 the following procedures were performed on Sun UNIX workstations using ArcInfo Version 7.0.2 (ESRI 1999a).

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1. Digitized black and white aerial photographs on an HP ScanJet 4C at an optical resolution of 150 dpi. Scale varied from 75% to 100%, with most photographs scanned at 75%;
2. Registered the digitized images of aerial photography to the base MIRIS coverages, typically the county roads coverage (State Plane Coordinate System, 1927 North American Datum, Units Feet, Spheroid Clarke 1866, Fipszone 2112 for the Black River watershed and Fipszone 2113 for the Huron River watershed);
3. Rectified the registered digitized images;
4. Clipped the registered and rectified digital images to remove any non-information areas (i.e., white space);
5. Created a mosaic of digitized images for each watershed for each time step using the imagecatalog command in ArcInfo;
6. Overlayed the MIRIS coverage (Step 4) over the image mosaic for Step 3 and then edited the MIRIS coverage to produce a new coverage for Step 3. This was done so that polygon locations would be consistent from one time step to the next and would not change due to errors in registration/rectification;
7. Repeated that process using Step 3 and Step 2 as input to produce Step 2 and Step 1 coverages, respectively.

For the Huron River watershed, the Huron River Watershed Council provided a digitized land cover coverage that served as Step 5. This land cover coverage was a

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was an updated version of the MIRIS land cover that served as Step 4 and used the MIRIS land cover classification system. To produce Step 5 for the Black River watershed, an overlay process identical to that described above for Steps 1 – 3 was used. However, in this case, the photos used were already digitized color aerial photography obtained from the Center for Remote Sensing at Michigan State University (Table 1.2).

All land cover classification followed the MIRIS land cover coding system (Appendix 1). The MIRIS system is a hierarchical system derived from the U.S. Geological Survey Land Use/Land Cover classification system (Anderson et al. 1976). The MIRIS system contains five levels of classification, with each level providing more detailed information on land cover than the higher level (Table 1.3). The first or highest level of the MIRIS system has seven main categories: agriculture, barren, forest, nonforest, urban, water, and wetlands.

Land cover within certain towns in the Huron River watershed was not delineated in MIRIS (i.e., had no land cover codes). For those towns, the land cover delineation provided by the Huron River Watershed Council was inserted into the MIRIS coverage. In addition, the MIRIS cover did not delineate small streams or riparian areas. Therefore, to provide a conservative estimate of riparian areas in the watershed, 3-m buffers were created around a MIRIS stream line coverage, and the resulting polygons were added to the MIRIS land cover coverage.

After editing, the five time steps were combined into one coverage to produce a true spatiotemporal database of land cover change for both watershe

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watersheds (*sensu* Kienast 1993). This database contained polygons that were unique in space and over time. The sequence of change for each unique polygon in the union coverage was systematically examined to identify probable errors resulting from variation in digitization, registration, and/or misclassification in one or more time steps. First, polygons were identified that remained the same throughout the study period and were removed from further editing. Then, polygons were identified with the same classification for four time periods, then three time periods, then two time periods, and finally no time periods until all polygons were examined. Three general types of results were recorded: no obvious errors, obvious errors, and possible errors requiring re-evaluation of the aerial photos for verification. No errors were sequences that exhibited reasonable land cover sequences, e.g. agriculture – agriculture – urban – urban – urban. Obvious errors were those sequences that had one land cover classification that appeared inconsistent with the rest of the sequence. For example, the classification of land cover in the fourth time step in the sequence agriculture – nonforest – urban – forest – urban was assumed to be wrong because the probability of change from urban to other land cover types was nearly zero. Therefore land cover in the fourth time step was reclassified as urban. Possible errors exhibited sequences of change that were less likely given the type of change. For example, the sequence: agricultural – agricultural – wetlands – urban – urban indicated a possible error in the third time step. Based on the overall trends in land cover for both watersheds, wetlands either remained throughout the entire study period or tended to decrease. It was less probable that wetl

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that wetlands appeared and disappeared over the course of 20 to 25 years. In those cases the aerial photos were re-examined to determine whether to keep or change the land cover classification. If the conditions in the aerial photograph did not match the assigned land cover, then the land cover was changed to the appropriate category. In certain cases in which the actual land cover type was not obvious, such as deciding between nonforest and wetlands, the rule was to choose the land cover classification that minimized the amount of change. This approach served two purposes. First, it minimized errors resulting from differences in aerial photo registration, interpretation, and digitization. Second, it tended to underestimate the extent and frequency of land cover change.

After examining all polygons in the spatiotemporal database for consistency, any polygons less than 0.1 hectare (approximately 0.25 acre) were eliminated except for rivers and streams. That value was chosen because it represented the minimal size of an individual residential patch, such as a farmstead, that commonly occurred on both landscapes but still eliminated any small polygons resulting from digitizing or editing error. Removal of larger polygons would have eliminated legitimate land cover polygons, particularly individual residences or farmsteads.

Land cover change analysis

Basic landscape statistics were calculated for MIRIS Level 1 land cover for both watersheds. Statistics were calculated using Patch Analyst Version 2.2 (Rempel et al. 1999) in ArcView 3.2 (ESRI 1999b). Patch Analyst is an adapted vers

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version of FRAGSTATS (McCarigal and Marks 1994), the standard package used to generate landscape statistics.

Landscape transition matrices were calculated for both watersheds for each pair of subsequent time steps from Step 1 to Step 5. The transition matrix listed the amounts and direction of land cover change from one time step to the next. Rows were the "from" land cover type and the columns were the "to" land cover type. Diagonal elements listed how much area remained in the same land cover class from one time step to the next. Off-diagonal elements listed how much area changed between different land cover classes.

Results

Black River watershed

Land cover change

The Black River watershed was 95% forested in the early- to mid-1800's based on vegetation maps prepared from General Land Office (GLO) survey notes (Comer et al. 1995) (Table 1.4). Conifer-dominated communities comprised approximately 58% of the forest, with the amount split fairly evenly between pine and lowland conifers such as cedar and hemlock. Northern hardwoods comprised the remaining 38% of forested areas, made up almost entirely of beech/sugar maple communities. Early successional forest types, e.g. aspen/white birch, accounted for only 3.8% of the overall forested area. Water and wetlands occurred on 3.7% and 0.8% of the landscape, respectively.

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Between the GLO survey and 1938, the first year of this study, almost all forested areas in northern Michigan were clearcut (McCann 1991). Consequently, current forests are predominantly second or perhaps third growth. By 1938, the Black River watershed remained predominantly forested, although below GLO survey levels. Concentrated areas of agriculture developed in the Black River floodplain north and south of Black Lake (Figure 1.4). Other than the town of Onaway, isolated residences and farmsteads were the primary form of urban development.

From 1938 to 1992, land cover in the Black River watershed remained relatively stable (Figure 1.4, Table 1.5). Forest area increased through 1978 but then decreased to below 1938 levels by 1992. Agricultural lands showed a slight decrease over time but appear to have stabilized by 1992. Nonforest remained nearly constant until 1992 and then increased by approximately 50%. Water increased 5.4% during the study period, resulting from the creation of several reservoirs and floodings, such as the Tomohawk Creek flooding in the southwest corner of Presque Isle County. Overall wetland area decreased 18.8%. Although not a large percentage of the watershed, urban land area increased all years and grew a total of 161% during the 55-year study period. Barren land occupied less than 0.01% of the watershed at any time.

The total number of patches and the number of patches of each land cover type increased over time except the number of patches of water, which decreased by 8 over time (Table 1.5). Mean patch size for the land cover types showed little variation from one time step to the next (Table 1.5). Mean forest patch siz

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patch size increased from 1938 to 1978 but then declined by 1992. Mean patch sizes of remaining cover types remained nearly constant. Mean patch sizes fell into three general size categories, with forests about 200 ha, water and agricultural about 50 ha, and urban, nonforest, and wetlands about 10 ha or less.

Forest composition changed over time (Table 1.4, Table 1.6). Presettlement forests were 58% coniferous and 43% broadleaf. By 1938, that ratio had reversed, with 66% broadleaf and 34% coniferous. Over half the broadleaf forests were aspen/white birch. Northern hardwoods decreased from 38% to 15%, while bottomland hardwoods showed a large increase, from 0.3% to 10%. Pine forests showed the largest decrease, from 30% to 16% of total forest area. Bottomland declined from 23% to 15%. The area of all forest types either remained constant or increased slightly from Step 1 to Step 4. From Step 4 to Step 5, total area of most forest types decreased (Table 1.6).

The overall rate of retention among major land cover types was very high (Table 1.7). Areas in forest remained as forest on average 97% and ranged from 91.9 to 99.9%. A total of 1,260 hectares, or 1.1 % of the original 1938 forest area, were converted to urban areas throughout the study period, with over half (706 hectares) converted between 1978 and 1992, including development of two golf courses in the watershed. Otherwise the majority of forest was converted to nonforest. Nonforest land cover showed the greatest variation in total area, as it gained and lost area both to forest and to agriculture. Wetlands had the greatest relative loss of area, with the majority of that transfer going to forested areas as some wetlands developed into bottomland forests.

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Patterns of land cover change

Land cover within the Black River watershed depends strongly on land ownership. The Mackinaw State Forest occupies 49% of the watershed (Figure 1.2). The high amount of state forest contributes to the high amount of forest (70% in 1992) in the watershed. Agricultural areas are concentrated in the north central and central areas of the watershed along the Black River where private land predominates (Figure 1.4). In addition, a large agricultural area also occurs in the southern portion of the watershed south of the Mackinaw State Forest (Figure 1.4).

The pattern of urban development in the watershed reflected several controlling factors at work in the watershed. First, development occurred almost entirely on private lands along the Black River floodplain in the north and central portions of the watershed and in the extreme southern portion of the watershed (Figure 1.5). Second, more extensive development occurred in two principal ways: lakeshore development and home development following the grid of county roads, particularly in the central portion of the county. Third, oil and natural gas wells increased 10-fold during the study period, from 53 in 1938 to 546 in 1992. Mean well size in 1992 was 0.8 hectare (~ 2 acres) with a mean patch fractal dimension of 1.01, indicated that they were essentially square. These wells occurred on both public and private land, scattered primarily throughout the southern portion of the watershed. This mirrors the large increase in oil and natural gas drilling in Michigan, especially Otsego County during the late 1980's and early 1990's (Wycoff and Multane 1995).

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As stated previously, the largest source of landscape change in the Black River watershed is conversion of land cover from forest to nonforest and vice versa (Table 1.7). The largest transfer from forest to nonforest occurred from 1978 to 1992. Prior to that the rate of conversion was lower. Therefore the results presented focus on that period. During the 14-year period from 1978 to 1992, 842 patches of land cover were converted from forest to nonforest, having a mean area of 10.3 ha. During that time, 8,466 hectares of forest were converted to nonforest, yielding a transfer rate of 605 hectares/year. Assuming no additional losses or gains to forest from other land cover types, that rate indicates that the entire forest would undergo conversion to nonforest in approximately 200 years or 0.5% of the total forest area being cut per year. Of the forest converted to nonforest from Step 4 to Step 5, 68.3% was on state forest land (Figure 1.6).

All forest types within the watershed experienced some level of conversion to nonforest (Table 1.8). Aspen/white birch had the highest total area converted, which was over 2.5 times more total area than pine, which had the second highest rate of conversion. Northern hardwoods, lowland hardwoods, lowland conifers, and other upland conifers followed in that order. Aspen/white birch had the highest percentage of total available area converted, followed by northern hardwoods, lowland hardwoods, other upland conifers, and lowland conifers. These results differ from broader regional trends. According to the U.S. Forest Service Forest Inventory Analysis (Leatherberry 1993), total area of timber for the northern LP of Michigan increased by 6%, although jack pine and aspen declined slightly.

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Most forests in Cheboygan, Montmorency, and Otsego counties were classified to dominant tree species and/or stocking level and therefore provided more detail regarding what specific forest types underwent conversion to nonforest (Table 1.9). The largest stocking level and the largest area of forest conversion occurred in category 6, which indicates forests with high percent cover (70-100%) and trees 10-20 m high. This was true for both broadleaf and coniferous forests. Broadleaf forests and conifers did differ in the distribution of the stocking class. Coniferous forest stocking classes were all converted at a 4 to 6% rate from Step 4 to Step 5, which represents a yearly cutting rate of 0.3% to 0.4%. For broad-leafed forests, middle stocking classes (e.g. 5 and 6) had a higher loss of percent of original area.

Huron River watershed

Land cover change

At the time of the GLO surveys in the early 1800's, the Huron River watershed supported a mixture of forests, oak openings, oak barrens, wet meadows, prairies, and wetlands (Table 1.4, Figure 1.7). Approximately 55% of the watershed was forested. The majority of the forests were central hardwoods, particularly oak-hickory and mixed oak communities. Conifers, almost entirely tamarack swamps, occupied only a small part of the watershed. Nonforest, primarily oak barrens and some oak openings, occupied 29% of the watershed. Large patches of these cover types occurred in the northeastern and southw

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southwestern portions of the watershed. Nonforest wetlands occurred on 12% of the landscape, with the majority being prairie meadows (Comer et al. 1995).

By late 1930's, agriculture was the major land cover type, accounting for 54% of the land in the watershed, almost entirely in cropland (Figure 1.7). Forest declined to 15% of the watershed, a reduction of 73% from presettlement estimates. Nonforest was 10.7% of the watershed, a 63% reduction. Wetlands occurred on 9.5% of the watershed, about two-thirds forested and one-third nonforested. Water and urban accounted for 4.5% and 5.3% of the watershed, respectively. Residential development comprised 79% of urban land cover.

From the late 1930's to the 1990's, the major trend in the watershed was the increase of urban land cover (Figure 1.7, Figure 1.8). The amount of urban land cover increased more than five-fold from 12,260 ha in the late 1930's to 68,116 in 1995, when it surpassed agriculture as the major land cover type. In addition, all subcategories of urban land increased during the same period. Conversely, agriculture decreased by more than 50% from 130,059 ha to 61,116 ha. During that period, forest increased through Step 4 and then declined by Step 5. Nonforest nearly doubled until Step 4 and then also declined by Step 5. Wetlands decreased in each successive time period, although the rate of loss fell from 21.7% of remaining area between Step 1 and Step 2 to 1.9% of remaining area from Step 4 to Step 5. Total water land cover increased by 0.7%.

Total number of patches and the number of patches for each land cover type increased over time in the Huron River watershed (Table 1.10). Mean patch size in the Huron River watershed declined from 18.2 to 14.6 ha during the study period.

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period. Mean patch sizes for the land cover types remained mostly constant, except for agriculture, which decreased from 182.7 ha to 45.6 ha (Table 1.10).

Land cover change was highly dynamic in the Huron River watershed (Figure 1.7, Table 1.11). The majority of new urban land cover came from agriculture (30,879 ha). Nonforest contributed the next highest amount (16,380 ha), followed by forest (7,532 ha). About 5% of wetlands were lost directly to development (1,100 ha). The largest gain in urban land cover came between Step 2 and Step 3 (19,226 ha), which corresponded with the highest level of interstate highway construction (1,500 ha). Once developed, urban remained almost exclusively as urban; only 431 ha of urban land, about 0.2% of the total Huron River watershed area, were converted to other land cover types during the study period.

Among other land cover types, several types of change emerged from the land transition matrices (Table 1.11). Nonforest gained mostly from agricultural land (41,573 ha) and from forest (3,765). Forest gained from agriculture (8,015) and nonforest (9,428) and lost area to urban (7,532), agriculture (2,977), and nonforest (3,765). Wetland losses were distributed among agriculture (1,497), nonforest (2,037), and forest (1,914).

Land cover stabilized over time as more of the watershed became urban (Table 1.11). Off-diagonal elements in the land transition matrices typically decreased over time, except for conversions from other land cover types to urban, which increased in area, decreased in area, and then increased in area again.

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Patterns of land cover change

Land cover change in the Huron River watershed occurred at three scales of organization. At the watershed scale, 45% of the land underwent at least one transition between MIRIS Level 1 land cover types during the study period (Figure 1.7). The largest land cover transitions were permanent transfers to urban land cover and exchanges among agriculture, nonforest, and forest (Table 1.11). At subwatershed levels, land cover changes varied according to location. Urban land cover increased most extensively in the northeast, north central, south central, and southeastern lobe of the watershed (Figure 1.7). Exchanges among agriculture, forest, and nonforest occurred in a diffuse pattern within areas of urban development and more extensively in the western half of the watershed. Agricultural areas west and north of Ann Arbor experienced relatively fewer changes. At the section level (i.e., 1-mile square sections of the township and range grid), urban, agriculture, and nonforest tended to occur closer to roads than forest, water, and wetlands.

At the watershed scale, the overall pattern of change is from a rural agricultural landscape to one of mixed urban, suburban, and rural residential development. Urban expansion occurred in a broad general trend from the east to the west and generally followed two patterns: expansion from existing urban areas, particularly around Ann Arbor and Ypsilanti, and diffuse urban development, particularly in the northeast and north central portion of the watershed (Figure 1.8). Urban expansion was particularly extensive from Step 2 to Step 3, which corresponded to the development of the interstate highway syste

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system. Urban land cover gains were typically 2 to 4 hectares in size (Table 1.12).

Patterns of agriculture land cover loss are similar to those of urban gain (Figure 1.9). Large areas of loss occurred in the northeastern area of the watershed and surrounding Ann Arbor and Ypsilanti in the south central and southeastern areas of the watershed. Over time, the loss of agricultural area declined (Table 1.11, Figure 1.9). The pattern of decline of agriculture becomes clearer when examined with a coarser filter (Figure 1.10). Of the 1,058 sections that completely or partially fall within the watershed, 984 had a net loss of agricultural area, with 640 losing 50% or more of their original agricultural area. A total of 15 sections experienced no change (9 with non agriculture at any time and 6 not losing any agricultural area). Finally, 59 sections gained agricultural area, particularly a large cluster in the northwestern corner of the watershed in southeastern Ingham and southwestern Livingston counties.

Forest land cover changes occurred throughout the watershed (Figure 1.11). The average size of gains and losses was small, typically 1.5 to 1.7 hectares (Table 1.12). However, the mean size of forest gains from Step 4 to Step 5 was 5.0 hectares, due to the conversion of a large patch of agriculture to forest in the southwest corner of the watershed (Figure 1.11d).

Nonforest land cover changes also occurred throughout the watershed (Figure 1.12). Losses and gains typically averaged 2.5 to 3.5 hectares (Table 1.12). Changes were particularly extensive throughout the northern half of the watersh

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watershed, corresponding to the same areas where agriculture decreased and urban areas increased.

Water land cover changes were generally small, typically isolated lakes and ponds (Figure 1.13) less than 2 hectares in size (Table 1.12). The exception was the creation of the Kent Lake Reservoir between Step 1 and Step 2 (Figure 1.13a) along the mainstem of the Huron River in the north central portion of the watershed.

Wetland land cover changes were almost entirely losses (Figure 1.14). As discussed earlier, the rate of loss decreased over time. The mean size of wetlands losses also decreased. The number of individual wetland losses also decreased from Step 1 to Step 4 but increased from Step 4 to Step 5 (Table 1.12). Barren land cover changes did occur but were very small in number and extent (Table 1.12).

Land cover change patterns also followed finer levels of organization, principally along the roads that define the township/range grid network and therefore land ownership. In the watershed, 48.8% of the land lies within 250 meters of a county road. Additionally 93.8% lies within 750 meters of county roads, and no land is farther than 2500 meters from a road (Table 1.13). (Those percentages would increase if residential roads were also considered.) Urban, nonforest, and agriculture land covers tended to be located closer to roads than would be expected if land cover was distributed randomly across the landscape (Table 1.13). By 1995, 60% of urban areas fell within the 250-m buffer (Figure 1.19). Urban areas also were located farther from roads than expected because areas

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areas beyond 1250 meters consisted of core urban areas, including two automotive test track facilities that were classified as urban. Conversely, forest, water, and wetlands were distributed farther from roads than expected, typically from 500 to 1500 meters away.

Discussion

The Black and Huron river watersheds represent two different trajectories of land cover change common to Michigan and the Great Lakes region. Both watersheds have undergone extensive changes since the early 1800's, but the type and patterns of change differ based on a combination of physical, biological, and social factors. The factors that affect the patterns of land cover change occur at several different scales. Those factors range from climate and geology at the broadest scales, patterns of land ownership and transportation networks at the watershed scale, and the collective result of many individual land use decisions at local scales.

At the broadest scales, differences in land cover change between the two watersheds depended upon broad physiographic characteristics of both watersheds. The Black River watershed lies north of the tension zone in Michigan, which is a line located approximately from Muskegon to Saginaw (Barnes and Wagner 1981). Above this line, the climate is colder and the growing season is shorter. Also, soils are generally less suited for agriculture except within the Black River floodplain. Finally the Black River watershed does not have or lie near any major transportation sources such as an interstate highway or a po

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or a port. Conversely, the Huron River watershed lies south of the tension zone and therefore has a warmer climate and longer growing season, richer soils based more suitable for agriculture, and is situated along a river with direct access to Great Lakes. Additionally, the Huron River watershed is situated directly west of the Detroit, the largest urban area in the state. These broad factors affect the composition of the vegetation. The Black River watershed supported more coniferous forests than the Huron River watershed, while the underlying soils made the Huron more attractive for farming. Finally, the proximity of the Huron to the largest metropolitan area in Detroit and the extensive network of limited access highways made it attractive for urban expansion.

Black River Watershed

At the watershed level, the Black River watershed showed a pattern of land cover change common to rural areas of northern Michigan and the Great Lakes region. First the watershed experienced extensive deforestation during the second half of the 19th century and the beginning of the 20th century. Once extensive logging stopped, the forest began to regenerate and mature. From 1938 to 1978, forested areas increased in the watershed, although they declined slightly throughout the northern LP (Leatherberry 1993). From 1978 to 1992, forests had matured enough to permit greater levels of harvest. Based on the land cover database, approximately 0.5% of the forest area was cut during that period per year, indicating that the entire forest would be cut once every 200 years.

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At a coarse level of examination, the Black River watershed appears very similar to conditions at the time of the GLO surveys in the mid 1800's given that it remained predominantly forested. However, the land cover database demonstrated that forest composition in the watershed differed from conditions during the GLO surveys in three ways, which agrees with results from other studies in Michigan (Van Deelen et al. 1996, Heitzman 1997). First, forests are younger as most of the forests in the watershed are second or third growth. Based on the trend in the rate of conversion to nonforest, forests in the Black River watershed have only attained sizes and stocking levels suitable for harvesting within the last 10 to 20 years. Therefore timber harvesting has resulted in and will continue to sustain forests with characteristics (e.g. height, diameter breast height, etc.) that are likely different from those of climax forests present before the extensive timber harvesting of the 1800's. Although forests are regenerating, they are being cut when they reach sizes and ages that meet certain market conditions. Second, forest composition has been altered substantially. Prior to extensive timber harvesting in the 1800's, forests were 58% conifer, with 60% in upland and 40% in lowland communities. Northern hardwoods dominated the broad-leafed forests. By 1992, the ratio between broadleaf and coniferous forests reversed, to 57% and 43%, respectively. Early successional communities, in particular aspen-dominated communities, typically re-established on the cut-over areas and now comprise 37% of forested areas. These areas are often maintained as sources of pulp wood for the paper industry and to support game species that depend on early successional communities (e.g. ruffed grouse). Third, timber harvesting creates far more forest gaps than likely existed in climax forests present before extensive European settlement (McCann 1991). The GLO surveys used to develop presettlement vegetation were based on 1 square mile grids and therefore almost certainly missed some small forest gaps. However, it would seem highly unlikely that natural gaps occurred with the same frequency as they did prior to European settlement, especially those generated from the period from 1978 to 1992. Finally, the results from the Black River watershed are consistent with those of other studies that show a strong change in forest composition from conditions at the time of the GLO survey to the present (Heitzman 1997).

The two other significant trends in the watershed regarding land cover change related to increases in urban areas. The number of rural residential and seasonal homes is expected to increase in the northern LP during the next 20-25 years (Smyth 1995), particularly as retired couples move permanently to the area (Tyler and LaBelle 1995). Although each new residence represents a very small change to the watershed in and of itself, the cumulative impact of very low density residential development will increase the presence of people throughout the watershed and create a demand for increased services. This, in turn, will make the area possibly desirable to more people who would otherwise not want to give up access to particular conveniences.

The second large urban trend was the 10-fold increase in the number of gas and oil wells in the watershed. The southern portion of the Black River watershed lies above the Antrim formation, which contains economically viable reserves

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reserves of oil and gas (Wycoff and Moultane 1995). Although the footprint of these facilities is typically small, they do create gaps in what would otherwise be continuous forest. In addition, a network of service roads connects the wells to one another and to the local road system. These roads increase the accessibility of interior forested areas, which could have possible negative effects on wildlife habitat and wildlife.

Huron River Watershed

At the watershed level, the Huron River watershed showed trends of land cover change common to landscapes experiencing a transition from agricultural to urban/suburban and rural residential land cover. The watershed underwent its most extensive conversion from forest/savanna to agriculture early in Michigan's settlement, during the early- to mid-1800's. This was likely followed by a relatively stable period of agricultural activity until the mid 1900's. After World War II, the two biggest changes to the Huron River watershed have been the expansion of urban areas and the development of an extensive system of limited-access highways. The expansion of urban land cover came primarily from conversion of agricultural lands, although the process is not that straightforward. In the northeast and north central portions of the watershed, urban land cover increased the most, due to the presence of many lakes and the Huron river (Walsh 2000).

Nonforest and forest land cover increased at the same time as urban land cover. This suggests that agricultural land sold for development was typically not sold entirely, thereby allowing remnant parcels to revert to early successional states a

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states and eventually to return to forest or that lot sizes are large enough to allow succession to occur on portions of parcels. Over time, some areas undergoing reversion to more natural land covers (e.g. forest, nonforest) underwent conversion to urban areas. This pattern was particularly prominent in the northeastern and north central Huron River watershed, where urban expansion proceeded more as a patchwork of urban land with additional urban development filling in around existing urban areas. Such changes are likely driven primarily by very specific and unique circumstances of individual landowners. However, given the increased appeal of more rural home settings (Smyth 1995), the process of "filling in" is likely to continue for some time unless measures are taken to prevent it.

In the south central and southeastern lobe of the watershed, urban expansion proceeded more rapidly and to a larger extent. The areas around Ann Arbor and Ypsilanti underwent expansion throughout the study period. Detroit International Airport in Wayne County, a portion of which falls within the watershed boundaries, served as a focal point for urban expansion in that area of the watershed.

The development of the federal interstate highway system beginning in the mid-1950's was another principal factor in the urbanization of the watershed. The highway system first appeared in the land cover database in Step 2 (1955 – 1957) and was mostly complete by Step 4 (1978/1985). Interstate highways allowed people to live farther away from major urban centers, such as Detroit and Ann Arbor. Once rural communities like Brighton, in the north central portion of the wat

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the watershed, became accessible as places to live and expanded accordingly. In addition, although not presented in the results, many industrial areas and shopping malls in the watershed occurred adjacent to or near interstates, reflecting the increased importance of locating facilities to provide easy access to transportation.

The increase in forest and nonforest areas was not expected. The typical view of urban expansion is the wholesale conversion of rural, agricultural areas to vast expanses of mixed urban and suburban development. The land cover change trends in the Huron River watershed do not bear such notions out, although future changes may erase the current gains. The increase in more natural land cover types likely reflects individual circumstances, as described above, and also likely reflects the desires of new immigrants to retain a more natural landscape. For example, Leefers and Jones (1996) showed that land values along the segments of the Huron River zoned as a Natural River by the state of Michigan were higher than along similar segments without such zoning. Natural Rivers zoning encourages local governments to enact measures to protect or enhance the natural character of the river. This reflects the general trend for people to value areas that they perceive as more "natural" in character (McGranahan 1991).

Similar trends were found for the Raisin River watershed directly south of the Huron River watershed (Erickson 1995). Over a 20-year period, from 1968 to 1988, forest cover increased in 9 of 10 sampled townships within the watershed. Riparian forest areas increased in area and width (Kleiman and Erickson 1995).

Those increases corresponded to an increase in the number of parcels within the area studied. Those results suggested that natural land covers benefit from the subdivision and conversion of agricultural land. One hypothesis is simply that people only need a small portion of their land for dwellings and other buildings and convert the remaining areas to more natural conditions to increase property values, as discussed above, and to satisfy personal desires. Indeed, other studies have shown that land classified as "urban" may typically only have 30-50% of the area covered by buildings or other man-made structures (Turner and Meyer 1994).

In summary, land cover changes in the Huron River watershed exemplified the process of urbanization of former agricultural areas that has occurred or is occurring in many areas of the United States. The patterns of change demonstrate the result of the interactions between broad-scale factors (physical character of the landscape, locations of towns and highways) and individual factors affecting land cover change. Although individual factors that reflect personal decisions will generally remain difficult to determine, overall land cover change patterns mirror the broad trends of societal wants and needs, particularly the conflicting desire to want to live in a rural setting and yet to retain easy access to work, cultural and recreational opportunities, and public services.

Despite the obvious differences in land cover composition and patterns between the Black and Huron river watersheds, some similarities exist between them. First, human influence has increased the heterogeneity of the landscape, whether that heterogeneity exists as obvious differences in land cover classes or as less

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as less obvious changes to forest composition. People tend to produce patterns that correspond to human scales of influence. Second, the extent of change is much larger and the rate of change is much higher than historically. Although the GLO survey data undoubtedly missed much finer variation in natural communities, it seems unreasonable to expect that natural disturbances occurred so pervasively and with such frequency throughout the landscape, at least on the time scale of several decades examined in this survey. Third, and perhaps most importantly, land cover change in both watersheds highlights the need for more coordinated regional planning among townships or counties that regulate land use and therefore land cover changes. Indeed, the lack of cooperation in regional planning is thought to be one of the principal factors contributing to urban sprawl in Michigan and elsewhere throughout the country (Smyth 1995, Wycoff 1995). A broader spatial and temporal perspective is needed to avoid homogenization of the watershed, particularly in the Huron River watershed which could quickly lose the modest gains in forest and nonforest seen from the 1930's to 1970's as well as much of its remaining farmland.

Factors Affecting Land Cover Database Accuracy

Three factors in particular affected the accuracy of the land cover database and therefore deserve discussion. They were 1) the resolution of the input data, 2) use of multiple photo interpreters, and 3) the lack of independent verification of the land cover classification.

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First, the digitized aerial photographs were of sufficient resolution to classify most land cover types. However, it was difficult to discern between particular land cover types. For example, distinguishing between shrub/scrub nonforested uplands and shrub/scrub wetlands was sometimes difficult. Similar difficulties occurred when classifying forest cover types and when distinguishing between grassland and fallow fields. Higher resolution of the digitized aerial photography would have solved some of those issues. The decision not to use higher resolution data was driven by the cost of data storage capacity when the study began. Scanning a photograph at 150 dots-per-inch resulted in file sizes of 800 kilobytes. In comparison, the same photos scanned at 300 and 600 dots-per-inch were approximately 4 megabytes and 12 megabytes in size respectively. The capacity needed to store that many aerial photos at those resolutions was simply too costly at the time. The same would not be true now.

Second, several different persons performed photo interpretation for this study. Several measures were taken to minimize the probability that different interpreters might classify the same land cover differently. Protocols were developed to resolve ambiguous classification situations. The primary researcher (D. Rutledge) acted as the final judge in all questions of land cover interpretation and reviewed land cover for all time steps for both watersheds as discussed in the methods. Also, experienced photo interpreters trained new photo interpreters to attempt to retain as much continuity as possible and pass on the knowledge gained in the photo interpretation process.

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Third, the land cover database was limited by the inability to independently verify the accuracy of the land cover interpretation. The final review process, in which questionable land cover designations were re-examined as discussed in the methods, possibly reduced classification errors but was by no means an independent verification. True verification could only come through a second interpretation by an independent group, as a second source of land cover data did not exist for all time steps examined. A second, independent interpretation was beyond the monetary and time resources of the study.

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Table 1.1: Comparison of the Black and Huron river watersheds. Public lands were estimates of state lands (state forests) in the Black River watershed and state lands (recreation areas and wildlife management areas) and regional parklands in the Huron River watershed. Average Michigan population density in 1990 was 63.2 persons/km^2 (U.S. Bureau of Census 1999).

	Black	Huron
Area (ha)	155,842	235,917
Land Ownership (private/public)		
Private land (ha)	79,401	212,931
Public land (ha)	76,441	22,986
Population of encompassing townships (1990)		
Number of persons	18,432	739,438
Estimated density (persons/km^2)	11.8	313.4
Roads (total length in km)		
Highways – Interstates, U.S., State	89	750
County Highways/Roads	866	2,920
Residential Roads	60	2,961

Table 1.2: Summary of aerial photos used for land cover database development.

Step 1	Step 2	Step 3	Step 4	Step 5

Table 1.2: Summary of aerial photos used for land cover database development.

Watershed County	Step 1			Step 2			Step 3			Step 4	Step 5		
	Year	Photo Scale	Pixel Size (m)	Year	Photo Scale	Pixel Size (m)	Year	Photo Scale	Pixel Size (m)	Year	Year	Photo Scale	Pixel Size (m)
Huron													
Ingham	1938	1:20,000	4.8	1955	1:20,000	4.8	1970	1:40,000	9.7	1978	1995[a]	-	-
Jackson	1938	1:20,000	4.8	1955	1:20,000	4.8	1972	1:40,000	9.7	1978	1995[a]	-	-
Livingston	1937	1:15,840	3.8	1957	1:20,000	4.8	1970	1:40,000	9.7	1985	1995[a]	-	-
Monroe	1937	1:20,000	4.8	1955	1:20,000	4.8	1973	1:40,000	9.7	1978	1995[a]	-	-
Oakland	1940	1:20,000	4.8	1957	1:20,000	4.8	1972	1:40,000	9.7	1978	1995[a]	-	-
Washtenaw	1938	1:15,840	3.8	1955	1:20,000	4.8	1969	1:40,000	9.7	1985	1995[a]	-	-
Wayne	1937	1:20,000	4.8	1964	1:20,000	4.8	1973	1:40,000	9.7	1985	1995[a]	-	-
Black													
Cheboygan	1938	1:20,000	4.8	1952	1:15,840	3.8	1963	1:20,000	4.8	1978	1992[b]	Varied[c]	2.6
Montmorency	1938	1:20,000	4.8	1952	1:15,840	3.8	1963	1:20,000	4.8	1978	1992[b]	Varied[c]	2.6
Otsego	1938	1:20,000	4.8	1952	1:15,840	3.8	1963	1:20,000	4.8	1978	1992[b]	Varied[c]	2.6
Presque Isle	1938	1:20,000	4.8	1952	1:15,840	3.8	1963	1:20,000	4.8	1978	1992[b]	Varied[c]	2.6
Source	Interpretation of digitized black and white photos			Interpretation of digitized black and white photos			Interpretation of digitized black and white photos			MIRIS			

[a]Huron River Watershed Council; [b]Interpretation of digitized color infrared photos; [c]Scale varied from 1:63,000 to 1:158,000 (mean was 1:98,000)

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Table 1.3: MIRIS Level 1, 2, and 3 land cover codes. Level 4 and 5 codes that provided detailed forest cover classifications are not shown.

Land Cover Type	Code	Land Cover Type	Code
Urban	100	Nonforested	300
Residential	110	Herbaceous	310
Multi-family high-rise	111	Shrub/Scrub	320
Multi-family low-rise	112		
Single family/duplex	113	Forested	400
Mobile home park	115	Broadleaf	410
Commerical	120	Northern hardwood	411
Central business district	121	Central hardwood	412
Shopping mall	122	Aspen/white birch	413
Secondary business district	124	Bottomland hardwood	414
Institutional	126	Coniferous	420
Industrial	130	Pine	421
General	131	Other upland conifer	422
Industrial park	138	Bottomland conifer	423
Transportation/Utilities	140	Christmas tree plantation	429
Air transportation	141		
Rail transportation	142	Water	500
Water transportation	143	Rivers & Streams	510
Highways	144	Lakes	520
Communications	145	Reservoirs	530
Utilities	146	Great Lakes	540
Extractive	170		
Open pit	171	Wetlands	600
Wells	173	Forested	610
Openland	190	Forested	611
Outdoor recreation	193	Shrub/scrub	612
Cemeteries	194	Nonforested	620
		Aquatic bed	621
Agriculture	200	Emergent	622
Cropland	210	Flats	623
Orchards	220		
Confined feeding	230	Barren	700
Pasture	240	Beach	720
Other	290	Sand dune	730
		Bare rock	740

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Table 1.4: Land cover in the Black and Huron river watersheds at the time of the GLO surveys in the early- to mid-1800's.

Land Cover Type Level 1 Level 2	Black River Watershed			Huron River Watershed		
	Area (ha)	% of Total Area	% of Level 1 Area	Area (ha)	% of Total Area	% of Level 1 Area
Nonforested	438	0.3		68,090	28.9	
Herbaceous-Upland Grassland				49	<0.1	0.1
Oak Barrens				57,743	24.5	84.8
Oak Opening				10,298	4.4	15.1
Oak/Pine Barrens	438	0.3	100			
Forested/Forested Wetlands	148,450	95.3		131,011	55.5	
Hardwood/Conifer	79	0.1	0.1	10	< 0.1	< 0.1
Central Hardwood				105,128	44.6	80.2
Northern Hardwood	56,006	35.9	37.7			
Aspen/White Birch	5,559	3.6	3.7			
Lowland Hardwood	475	0.3	0.3	16,213	6.9	12.4
Conifer/Hardwood	1,405	0.9	0.9	92	< 0.1	0.1
Pine/Oak	44,779	28.7	30.2			
Other Upland Conifer	5,960	3.8	4.0			
Lowland Conifer	34,187	21.9	23.0	9,568	4.0	7.3
Water	5,719	3.7	100	7,458	3.2	100
Wetlands	1,218	0.8		29,358	12.4	
Shrub-dominated	642	0.4	52.7	531	0.2	11.8
Emergent Marsh/ Meadow/Prairie	576	0.4	47.3	28,827	12.2	98.2
Barren	7	< 0.1	100			
Cultural Feature	10	< 0.1	100			
Total Area	155,842			235,917		

Table 1.5: Area, number of patches, and mean patch size of MIRIS Level 1 land cover types from the GLO survey to Step 5 in the Black River watershed.

Land Cover	Time					
Type	GLO*	Step 1	Step 2	Step 3	Step 4	Step 5
Agriculture						
Area (ha)	-	13,085	11,482	11,394	10,223	10,480
# of Patches	-	298	291	270	277	283
Mean Patch Size (ha)	-	43.9 ± 124.9	39.5 ± 125.2	42.2 ± 135.6	36.9 ± 96.9	37.0 ± 90.0
Barren						
Area (ha)	7	1	3	3	3	3
# of Patches	1	1	2	2	2	2
Mean Patch Size (ha)	-	0.5 ± 0.0	1.3 ± 0.8	1.3 ± 0.8	1.3 ± 0.8	1.3 ± 0.8
Forest						
Area (ha)	148,450	111,055	116,443	116,542	117,278	108,590
# of Patches	5	659	585	578	574	677
Mean Patch Size (ha)	29,690.0 ± 59,372.5	168.5 ± 2106.6	199.0 ± 2484.2	201.6 ± 2500.0	204.3 ± 2527.8	160.4 ± 2111.8
Nonforest						
Area (ha)	438	17,172	13,716	13,439	14,142	21,197
# of Patches	6	1,758	1,945	1,965	1,967	2,383
Mean Patch Size (ha)	72.9 ± 32.3	9.8 ± 34.0	7.1 ± 21.3	6.8 ± 20.7	7.2 ± 25.4	8.9 ± 26.9
Urban						
Area (ha)	-	1,299	1,769	2,046	2,138	3,387
# of Patches	-	517	631	647	666	1,512
Mean Patch Size (ha)	-	2.5 ± 9.1	2.8 ± 9.2	3.2 ± 11.5	3.2 ± 11.3	2.2 ± 8.4
Water						
Area (ha)	5,719	5,965	6,056	6,055	6,277	6,289
# of Patches	92	107	104	96	90	99
Mean Patch Size (ha)	62.2 ± 443.8	55.8 ± 490.0	58.2 ± 449.7	63.1 ± 467.9	69.7 ± 483.5	63.5 ± 461.5
Wetlands						
Area (ha)	1,218	7,265	6,372	6,361	5,779	5,895
# of Patches	121	1,090	1,099	1,103	1,120	1,149
Mean Patch Size (ha)	10.1 ± 15.0	6.7 ± 25.4	5.8 ± 21.5	5.8 ± 21.3	5.2 ± 12.8	5.1 ± 12.6
Watershed						
# of Patches	224	4,430	4,657	4,661	4,696	6,105
Mean Patch Size (ha)	689.6 ± 9,853.8	35.2 ± 819.1	33.5 ± 886.0	33.4 ± 886.0	33.2 ± 889.2	25.5 ± 707.8

*Does not include one polygon classifed as natural disturbance (beaver pond).

Table 1.6: Area of MIRIS Level 1, 2, and 3 forest land cover types from the GLO survey to Step 5 in the Black River watershed. Areas of Level 2 and Level 3 forest cover types may not sum to the value of the higher Level 1 or Level 2 forest cover types because some areas could only be classified at the higher level.

	Time					
Land Cover Type	GLO	Step 1	Step 2	Step 3	Step 4	Step 5
Forest	148,450	111,055	116,443	116,542	117,279	108,590
Broadleaf	62,040	75,714	77,735	77,845	77,813	70,990
Northern Hardwood	56,006	17,131	17,263	17,384	17,345	16,192
Central Hardwood	-	4,147	4,212	4,212	4,211	4,030
Aspen/White Birch	5,559	43,425	44,984	44,968	45,002	40,310
Lowland Hardwood	475	10,988	11,265	11,271	11,250	10,454
Conifer	84,926	35,337	38,704	38,693	39,463	37,441
Pine	44,779	18,259	21,041	21,406	21,598	20,029
Other Upland Conifer	5,960	318	349	350	351	341
Lowland Conifer	34,187	16,606	17,135	16,761	17,324	16,871
Christmas Tree Plantation	-	152	174	174	190	200

Table 1.7: Land cover transition matrix for the Black River watershed. Area transferred among land cover types between each successive pair of time steps from Step 1 to Step 5. Values in hectares. Blank cells = 0.

Time Step		Agriculture	Barren	Forest	Nonforest	Urban	Water	Wetlands	Total Before
1 to 2	Agriculture	9,240		600	3,089	106		50	13,085
	Barren								
	Forest	1,294		108,058	1,386	260	35	22	111,055
	Nonforest	940	2	6,880	9,216	102	6	26	17,172
	Urban					1,299			1,299
	Water			4		1	5,959	2	5,965
	Wetlands	7		900	25	2	56	6,273	7,265
	Total After	11,482	3	116,443	13,716	1,769	6,056	6,372	
2 to 3	Agriculture	11,147		29	292	7		7	11,482
	Barren		3						3
	Forest	32		115,990	142	268		11	116,443
	Nonforest	208		480	13,001	11		17	13,716
	Urban	7		2	1	1,760			1,769
	Water			2			6,050	4	6,056
	Wetlands			40	3		6	6,323	6,372
	Total After	11,393	3	116,542	13,439	2,046	6,056	6,361	
3 to 4	Agriculture	10,131		114	1,098	38		13	11,393
	Barren		3						3
	Forest	13		116,473	26	26	3	1	116,542
	Nonforest	80		266	13,008	39	3	44	13,439
	Urban			3	8	2,035			2,046
	Water			3			6,052		6,056
	Wetlands			419	2		219	5,721	6,361
	Total After	10,223	3	117,279	14,142	2,138	6,277	5,779	
4 to 5	Agriculture	9,400		48	611	163		1	10,223
	Barren		3						3
	Forest	50		107,760	8,466	706	4	293	117,279
	Nonforest	1,011		641	12,081	396	6	7	14,142
	Urban	6		8	6	2,116		1	2,138
	Water					1	6,276		6,277
	Wetlands	13		132	33	5	2	5,593	5,779
	Total After	10,480	3	108,590	21,197	3,387	6,289	5,895	

Table 1.8: Area of MIRIS Level 3 forest land cover types converted to nonforest from Step 4 to Step 5 in the Black River watershed.

Forest Land Cover Type	MIRIS Code	1978 Area (ha)	1978 to 1992 Area Converted (ha)	% Converted
Broadleaf	410	77,813	6,284	8.1
Northern Hardwood	411	17,345	1,007	5.8
Central Hardwood	412	4,211	128	3.0
Aspen/White Birch	413	45,017	4,432	9.8
Lowland Hardwood	414	11,250	718	6.4
Conifer	420	39,272	2,166	5.5
Pine	421	21,598	1,686	7.8
Other Upland Conifer	422	5,357	397	7.4
Lowland Conifer	423	14,121	337	2.4

Table 1.9: Area of forest land cover types by stocking level converted to nonforest from Step 4 to Step 5 in the Black River watershed. Stocking levels were as follows: (1) 17-39% cover, < 10 m diameter breast height (dbh); (2) 40-69% cover, < 10 m dbh; (3) 70-100% cover, < 10 m dbh; (4) 17- 39% cover, 10 - 20 m dbh; (5) 40-69% cover, 10-20m dbh; (6) 70-100% cover, 10-20m dbh; (7) 17-39% cover, 20+ m dbh; (8) 40-69% cover, 20+ m dbh; (9) 70-100% cover, 20+ m dbh.

	Broadleaf			Conifer		
Stocking Level	1978 Area (ha)	1978 to 1992 Area Converted (ha)	Area Converted (%)	1978 Area (ha)	1978 to 1992 Area Converted (ha)	Area Converted (%)
1	84	5	6.0	1,237	40	3.2
2	555	2	0.4	1,187	72	6.1
3	10,542	427	4.0	2,750	119	4.3
4	2,502	157	6.3	1,908	77	4.0
5	8,834	855	9.7	5,178	276	5.3
6	31,512	2,848	9.0	16,296	1,046	6.4
7	769	45	5.8	224	12	5.4
8	1,649	153	9.3	671	36	5.4
9	1,253	65	5.2	427	24	5.6

Table 1.10: Area, number of patches, and mean patch size of MIRIS Level 1 land cover types from the GLO survey to Step 5 in the Huron River watershed.

Land Cover	Time					
Type	GLO	Step 1	Step 2	Step 3	Step 4	Step 5
Agriculture						
Area (ha)	-	130,060	107,855	79,560	67,803	61,116
# of Patches	-	712	871	1,125	1,188	1,339
Mean Patch Size (ha)	-	182.7 ± 1,156.8	123.8 ± 792.0	70.7 ± 417.0	57.1 ± 379.0	45.6 ± 344.6
Barren						
Area (ha)	-	< 1	20	11	4	4
# of Patches	-	1	7	13	5	3
Mean Patch Size (ha)	-	-	2.9 ± 4.4	0.8 ± 0.9	0.9 ± 1.2	1.3 ± 1.3
Forest						
Area (ha)	131,011	35,587	42,095	43,707	41,557	39,274
# of Patches	190	3,682	3,523	3,371	3,393	3,453
Mean Patch Size (ha)	689.5 ± 4,184.1	23.0 ± 22.8	12.0 ± 28.1	13.0 ± 32.1	12.3 ± 29.4	11.7 ± 33.7
Nonforest						
Area (ha)	68,090	25,187	32,374	40,812	45,753	39,275
# of Patches	90	2,355	2,673	3,171	3,540	3,797
Mean Patch Size (ha)	756.6 ± 2940.7	10.7 ± 24.6	12.1 ± 35.9	12.9 ± 36.2	12.9 ± 35.4	10.3 ± 24.0
Urban						
Area (ha)	-	12,620	25,544	44,750	53,961	68,116
# of Patches	-	2,390	3,506	3,501	3,583	4,237
Mean Patch Size (ha)	-	4.3 ± 33.1	7.3 ± 59.8	12.8 ± 126.0	15.1 ± 143.8	16.1 ± 157.4
Water						
Area (ha)	7,458	9,999	10,646	11,094	11,176	11,624
# of Patches	219	493	485	580	592	639
Mean Patch Size (ha)	34.0 ± 84.3	20.3 ± 251.7	22.0 ± 188.8	19.1 ± 177.6	18.9 ± 176.1	18.2 ± 171.6
Wetlands						
Area (ha)	29,358	22,465	17,383	15,988	15,662	15,367
# of Patches	374	2,813	2,697	2,527	2,626	2,629
Mean Patch Size (ha)	78.5 ± 317.1	7.3 ± 18.0	6.5 ± 13.3	6.1 ± 12.5	6.0 ± 12.1	5.9 ± 11.8
Watershed						
# of Patches	873*	12,986	13,762	14,388	14,927	16,097
Mean Patch Size (ha)	265.0 ± 2,179.0	18.2 ± 278.6	17.1 ± 207.7	16.4 ± 139.8	15.8 ± 135.3	14.7 ± 134.4

*Does not include 17 unclassified polygons totaling 6 ha in area.

Table 1.11: Land cover transition matrix for the Huron River watershed. Area transferred among land cover types between each successive pair of time steps from Step 1 to Step 5. Values in hectares. Blank cells = 0.

Time Step		Agriculture	Barren	Forest	Nonforest	Urban	Water	Wetlands	Total Before
1 to 2	Agriculture	100,385	2	4,445	16,474	8,671	69	13	130,059
	Barren								0
	Forest	1,340		31,654	1,249	1,209	107	27	35,587
	Nonforest	4,841	3	4,523	13,050	2,672	91	7	25,187
	Urban	12		9	1	12,597			12,620
	Water			3		2	9,995		9,999
	Wetlands	1,276	15	1,461	1,599	393	385	17,336	22,465
	Total After	107,855	20	42,096	32,374	25,544	10,646	17,383	
2 to 3	Agriculture	77,261	2	2,241	16,141	12,063	143	4	107,855
	Barren		4			16			20
	Forest	1,120		36,920	1,379	2,613	51	11	42,096
	Nonforest	1,055	1	4,141	22,917	4,193	66	1	32,374
	Urban	2		7	10	25,524	2		25,544
	Water			3	1	3	10,638		10,646
	Wetlands	116	4	394	365	338	194	15,972	17,383
	Total After	79,555	11	43,707	40,813	44,750	11,094	15,987	
3 to 4	Agriculture	66,016		440	8,495	4,563	41	1	79,555
	Barren		4			7			11
	Forest	409		40,618	1,002	1,656	21	0	43,707
	Nonforest	1,266		470	36,114	2,946	16	0	40,813
	Urban	20			78	44,650	1	0	44,750
	Water				4	10	11,080		11,094
	Wetlands	93		28	59	130	17	15,661	15,987
	Total After	67,803	4	41,557	45,753	53,961	11,176	15,662	
4 to 5	Agriculture	60,731		889	563	5,582	39		67,803
	Barren		4						4
	Forest	108		39,201	135	2,054	57	2	41,557
	Nonforest	262		294	38,556	6,569	71	1	45,753
	Urban	3		1	7	53,671	278	1	53,961
	Water					1	11,175		11,176
	Wetlands	12		31	14	239	5	15,363	15,662
	Total After	61,116	4	40,415	39,275	68,116	11,625	15,367	

Table 1.12: Basic patch statistics for lost and gained polygons from Step 1 to Step 5 in the Huron River watershed.

Time Step	Land Cover Type	Lost Count	Lost Mean Area (ha)	Gained Count	Gained Mean Area (ha)
1 to 2	Agriculture	9248	3.2	3435	2.2
	Barren	-	-	7	2.8
	Forest	2643	1.5	6198	1.7
	Nonforest	4489	2.7	5708	3.4
	Urban	18	1.2	3361	3.9
	Water	10	0.5	126	5.2
	Wetlands	2466	2.1	39	1.2
2 to 3	Agriculture	7392	4.1	1430	1.6
	Barren	4	4.1	9	0.8
	Forest	3248	1.6	3587	1.9
	Nonforest	3600	2.6	4815	3.7
	Urban	15	1.4	4932	3.9
	Water	15	0.5	255	1.8
	Wetlands	761	1.9	7	2.3
3 to 4	Agriculture	3091	4.4	665	2.7
	Barren	8	0.8	0	0.0
	Forest	1736	1.8	582	1.6
	Nonforest	1566	3.0	2491	3.9
	Urban	40	2.5	2846	3.3
	Water	14	1.0	56	1.7
	Wetlands	190	1.7	5	0.3
4 to 5	Agriculture	1889	3.7	164	2.3
	Barren	2	0.2	0	0.0
	Forest	1716	1.4	245	5.0
	Nonforest	2861	2.5	303	2.4
	Urban	116	2.5	5918	2.4
	Water	1	0.6	244	1.8
	Wetlands	292	1.0	3	1.5

Table 1.13: Ratio of actual to expected area of each land cover type within road buffers from Step 1 to Step 5 in the Huron River watershed. Values >1 indicate that a land cover type occurs more often in a buffer than would be expected if land cover occurred randomly within the watershed. Values <1 indicate that a land cover type occurs less often in a buffer than would be expected if land cover occurred randomly within the watershed. Expected area was determined by multiplying the buffer area by the percent of the landscape that each land cover type occupied in each time step. Barren values were not included because the expected values were always very close to zero.

Time Step	Land Cover Type	Buffer Distance (m) 250	500	750	1000	1250	1500	1750	2000	2250	2500
	% Watershed	48.8	30.7	14.3	4.2	1.2	0.5	0.2	0.1	0.03	0.01
1	Agriculture	1.12	0.98	0.79	0.60	0.61	0.90	0.98	1.24	1.58	1.46
	Forest	0.63	1.14	1.60	1.94	1.90	1.38	1.84	0.53	0.83	1.28
	Nonforest	1.06	0.92	0.94	1.04	1.05	1.07	1.46	1.81	0.02	0
	Urban	1.39	0.57	0.57	0.83	1.46	1.78	1.20	0.11	0	0
	Water	0.56	1.24	1.66	2.08	1.54	0.63	0.76	0.07	0	0
	Wetlands	0.79	1.14	1.30	1.39	1.30	0.65	0.83	0.36	0	0
2	Agriculture	1.10	1.01	0.83	0.60	0.47	0.50	0.45	0.80	0.60	0
	Forest	0.69	1.13	.149	1.79	1.65	1.38	0.69	0.16	0.14	0
	Nonforest	1.10	0.97	0.83	0.78	0.80	0.38	0.24	0.03	0	0
	Urban	1.29	0.60	0.62	0.92	1.94	3.56	4.91	5.27	6.45	9.23
	Water	0.56	1.25	1.66	2.01	1.45	0.59	0.72	0.07	0	0
	Wetlands	0.77	1.12	1.35	1.51	1.46	0.80	1.02	0.38	0	0
3	Agriculture	1.06	1.03	0.89	0.67	0.56	0.67	0.63	1.11	0.82	0
	Forest	0.69	1.14	1.49	1.79	1.65	1.06	0.53	0.07	0.13	0
	Nonforest	1.12	1.01	0.75	0.59	0.52	0.35	0.22	0.02	0	0
	Urban	1.27	0.70	0.66	0.77	1.32	2.30	2.86	3.04	3.68	5.27
	Water	0.57	1.25	1.64	1.98	1.50	0.56	0.69	0.06	0	0
	Wetlands	0.77	1.12	.136	1.50	1.42	0.84	1.11	0.42	0	0

Table 1.13 (con't)

Time Step	Land Cover Type	Buffer Distance (m) 250	500	750	1000	1250	1500	1750	2000	2250	2500
4	Agriculture	0.90	0.88	0.75	0.54	0.46	0.58	0.63	1.11	0.82	0
	Forest	0.65	1.09	1.44	1.68	1.47	1.00	0.53	0.07	0.13	0
	Nonforest	1.23	1.14	0.89	0.75	0.68	0.54	0.22	0.02	0	0
	Urban	1.51	0.89	0.84	0.96	1.51	2.33	2.87	3.04	3.68	5.27
	Water	0.57	1.26	1.66	1.98	1.50	0.56	0.69	0.06	0	0
	Wetlands	0.75	1.10	1.34	1.49	1.42	0.84	1.11	0.42	0	0
5	Agriculture	1.05	1.04	0.89	0.66	0.60	0.77	0.85	1.45	1.07	0
	Forest	0.68	1.15	1.50	1.79	1.59	1.06	0.53	0.08	0.15	0
	Nonforest	1.08	1.03	0.81	0.73	0.67	0.55	0.22	0.02	0	0
	Urban	1.23	0.79	0.72	0.73	1.03	1.54	1.88	2.00	2.42	3.46
	Water	0.57	1.25	1.64	1.92	1.44	0.54	0.66	0.06	0	0
	Wetlands	0.76	1.13	1.38	1.51	1.42	0.87	1.15	0.43	0	0

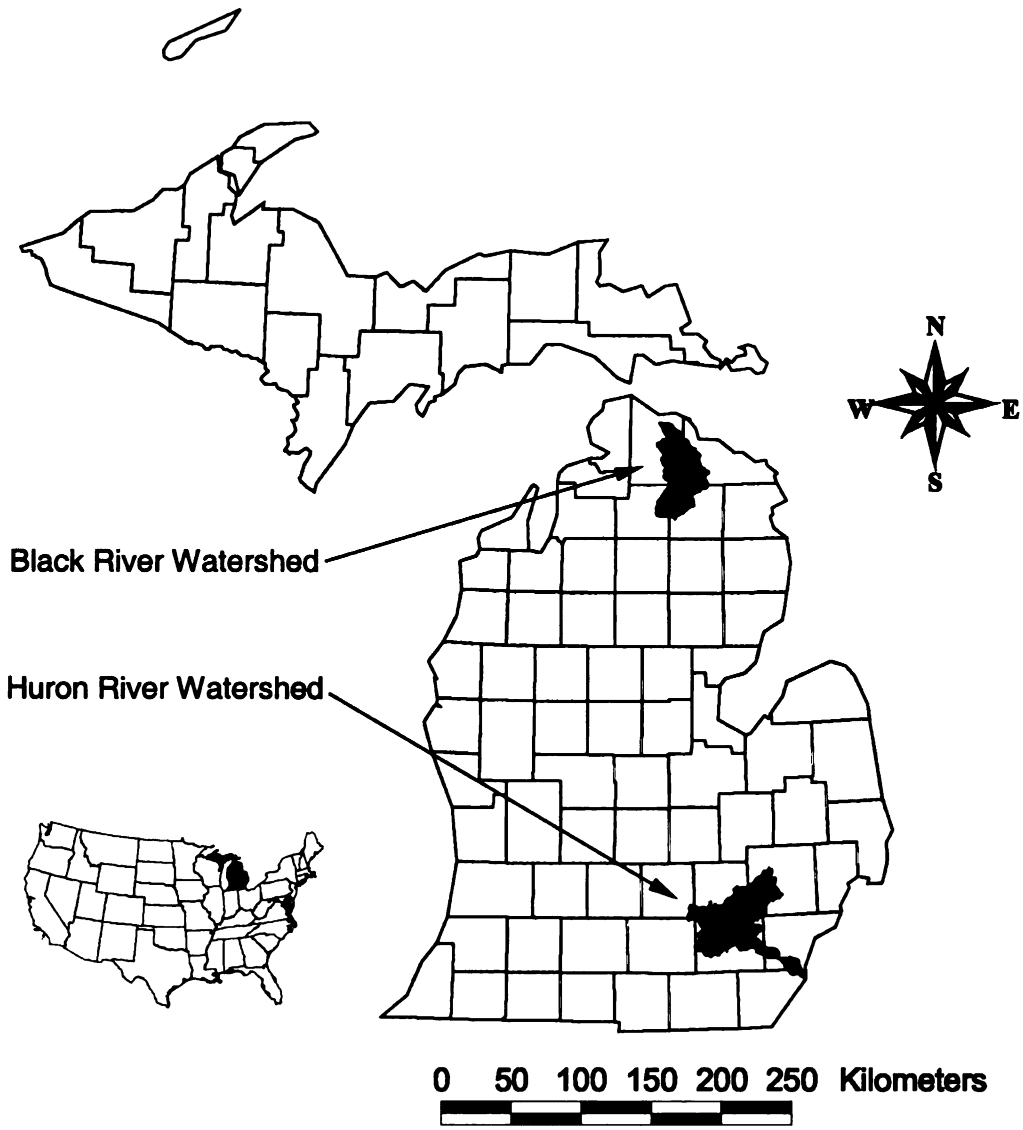


Figure 1.1: Location of Black and Huron river watersheds in Michigan.

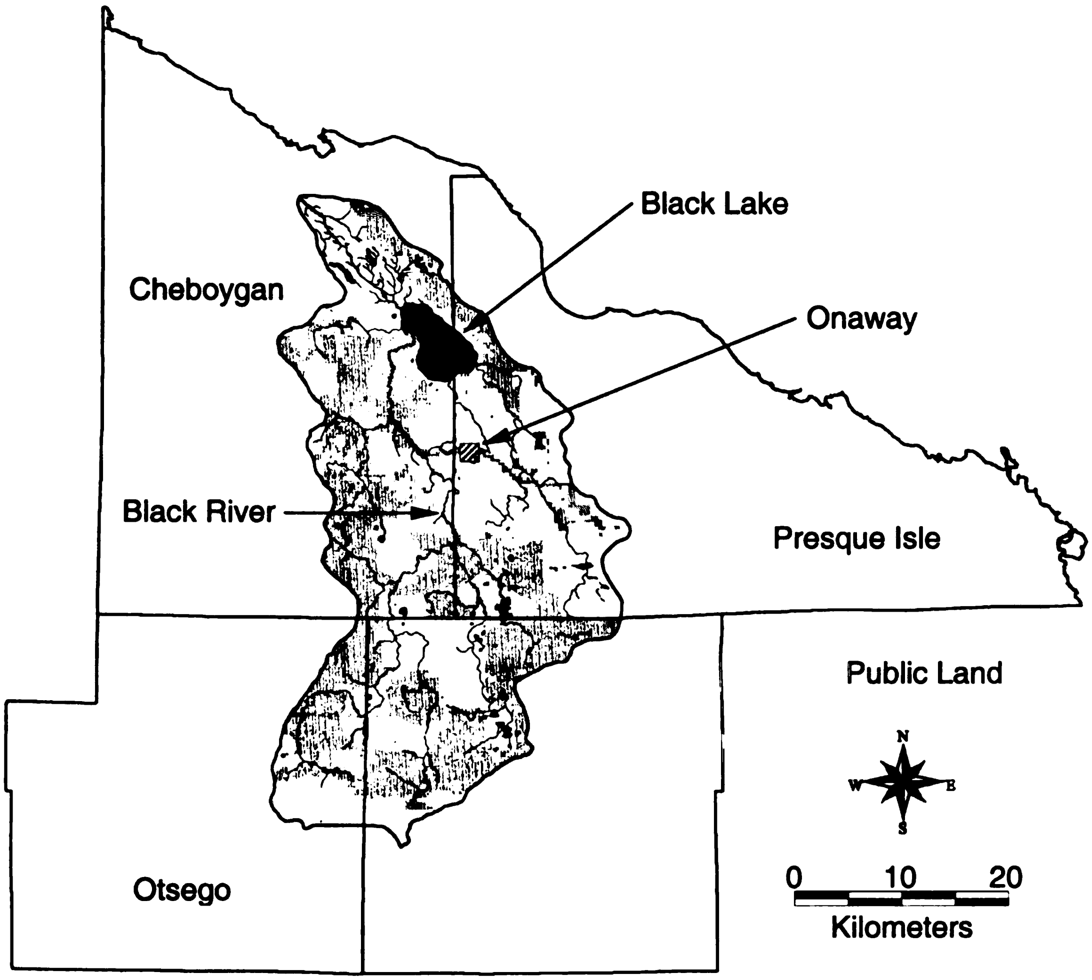


Figure 1.2: Location of Black River watershed in surrounding counties.

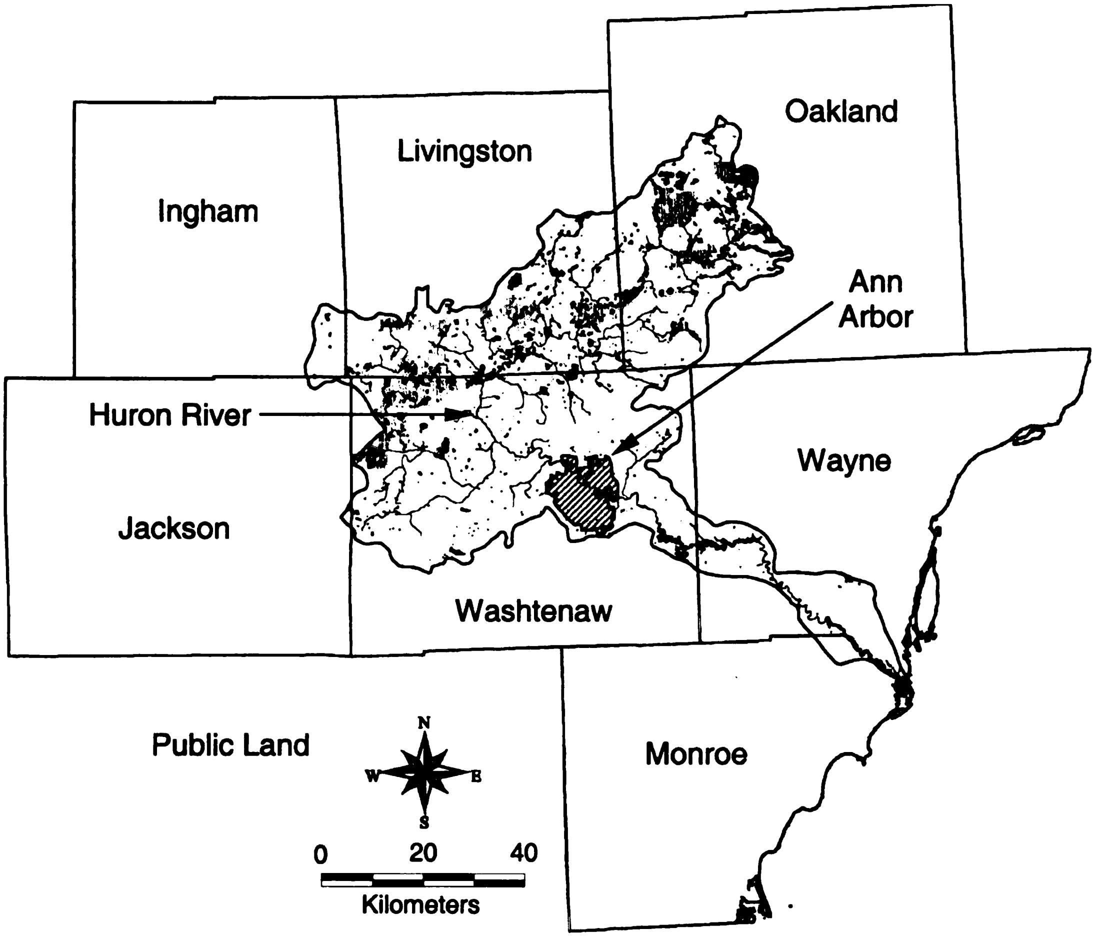


Figure 1.3: Location of Huron River watershed in surrounding counties.

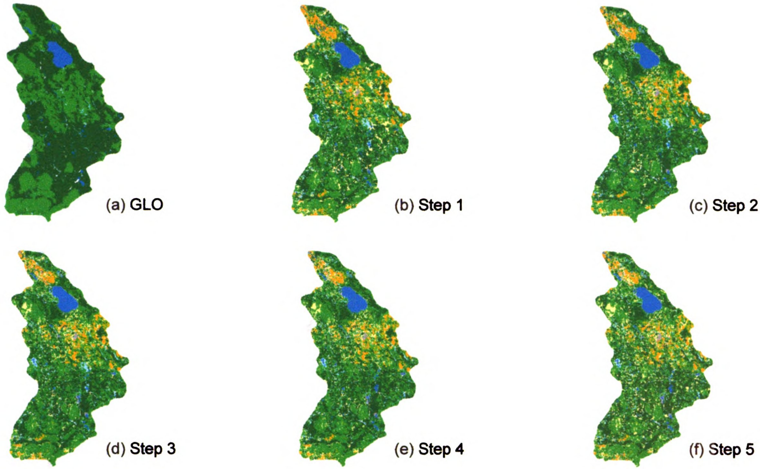
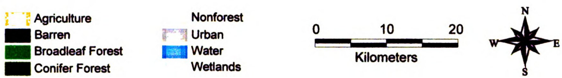


Figure 1.4: MIRIS Level 1 land cover changes from the GLO survey to Step 5 in the Black River watershed.



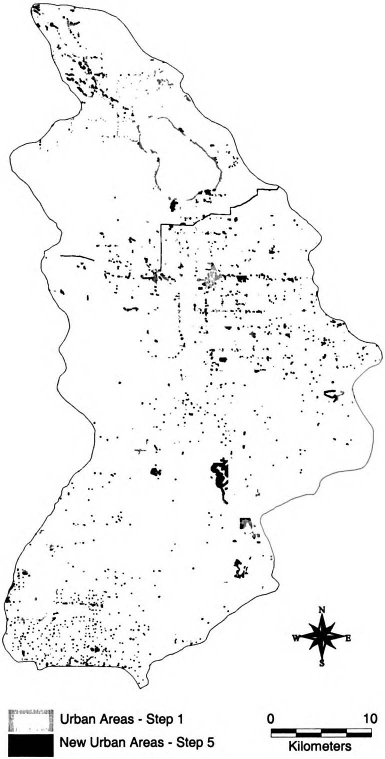


Figure 1.5: Increases in urban land cover from Step 1 to Step 5 in the Black River watershed.

Figure 1.6: Location of areas converted from forest to nonforest from Step 4 to Step 5 in the Black River watershed.

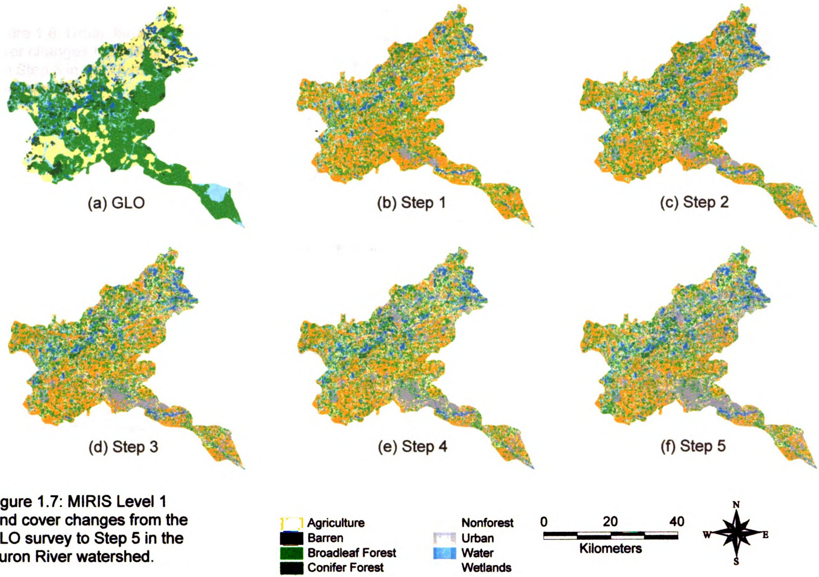


Figure 1.7: MIRIS Level 1 land cover changes from the GLO survey to Step 5 in the Huron River watershed.

Figure 1.8: Urban land cover changes from Step 1 to Step 5 in the Huron River watershed.

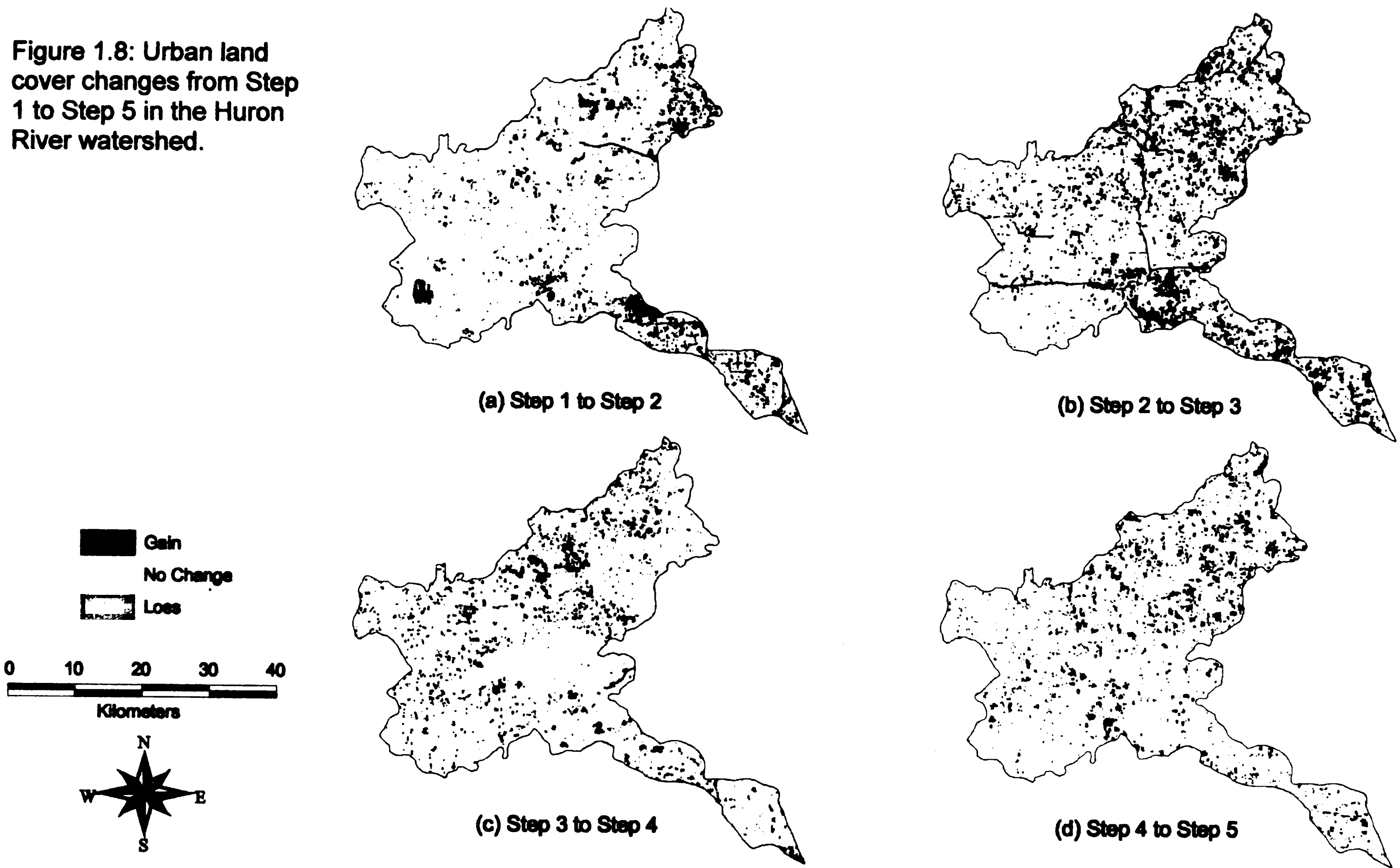
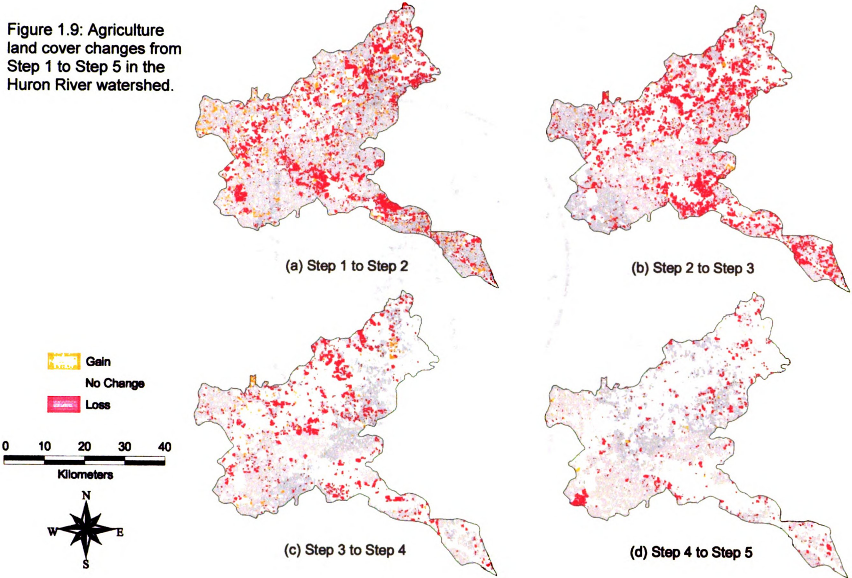


Figure 1.9: Agriculture land cover changes from Step 1 to Step 5 in the Huron River watershed.



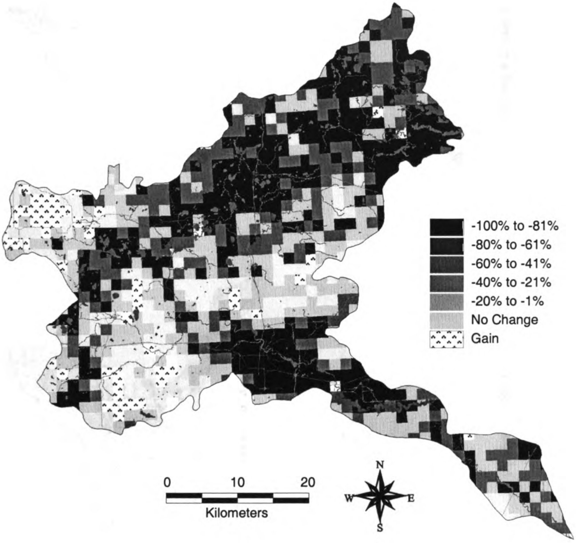
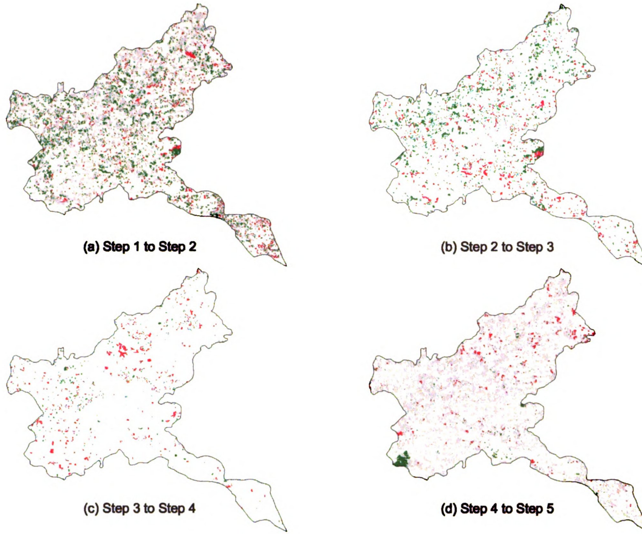


Figure 1.10: Percent gain or loss of agriculture land cover from Step1 to Step 5 in the Huron River watershed.

Figure 1.11: Forest land cover changes from Step 1 to Step 5 in the Huron River watershed.



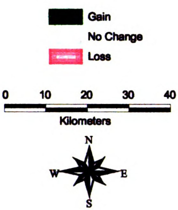


Figure 1.12: Nonforest land cover changes from Step 1 to Step 5 in the Huron River watershed.

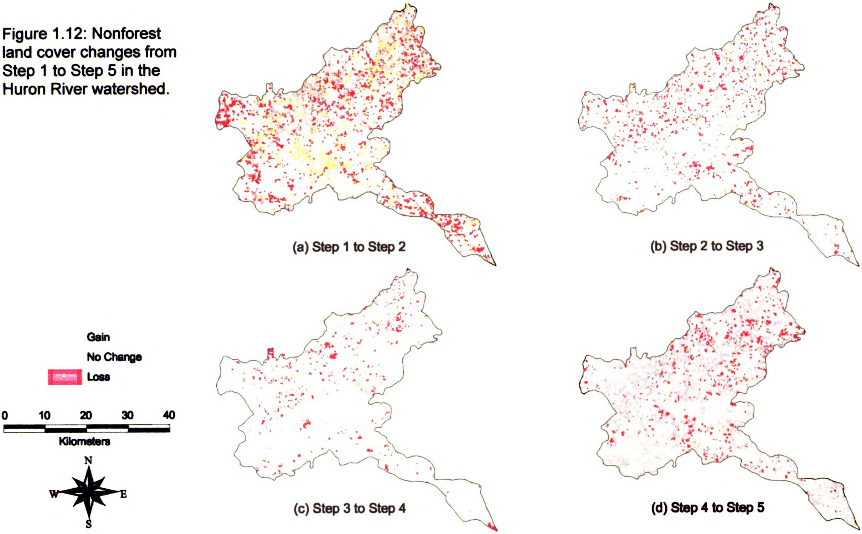


Figure 1.13: Water land cover changes from Step 1 to Step 5 in the Huron River watershed.

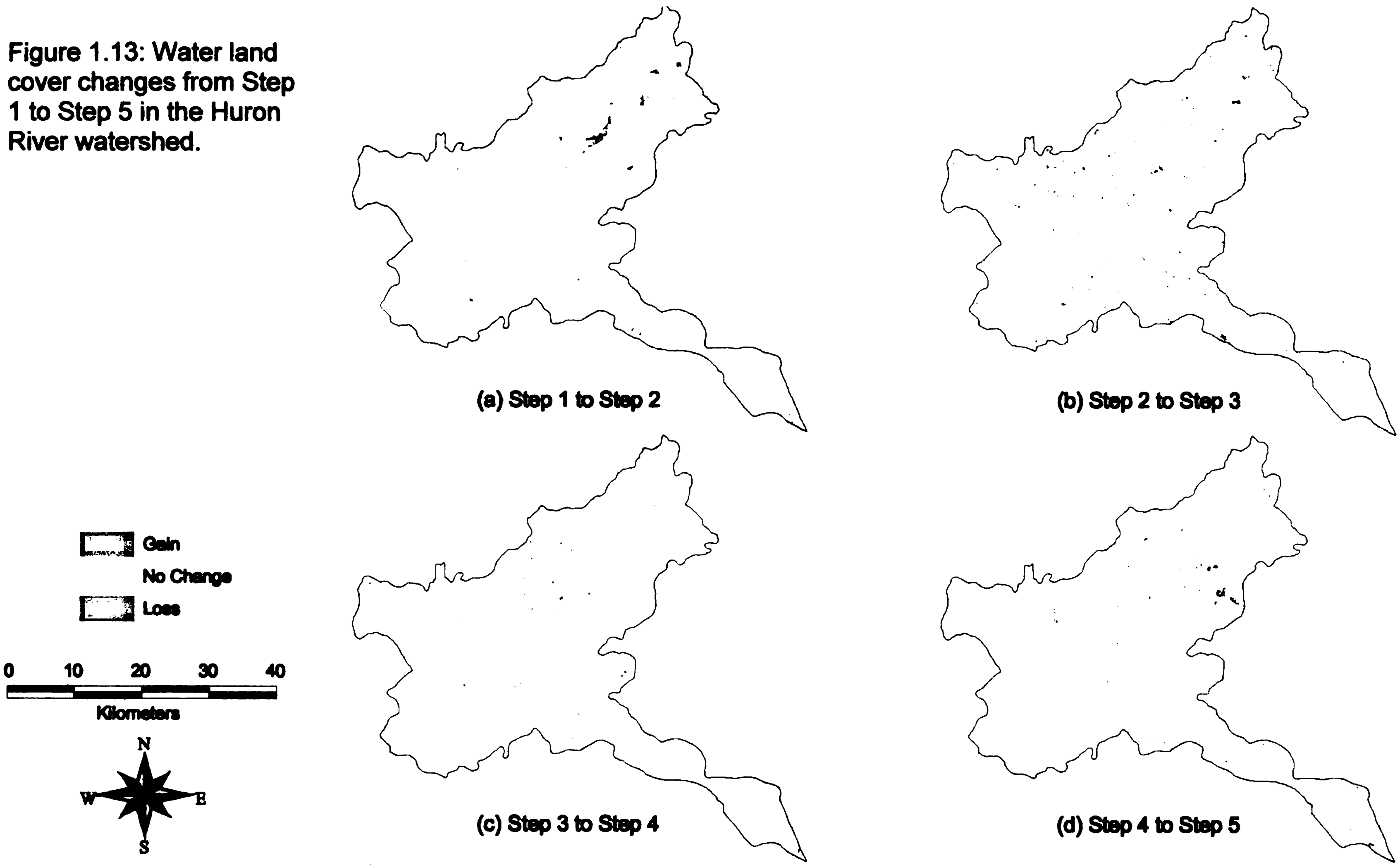
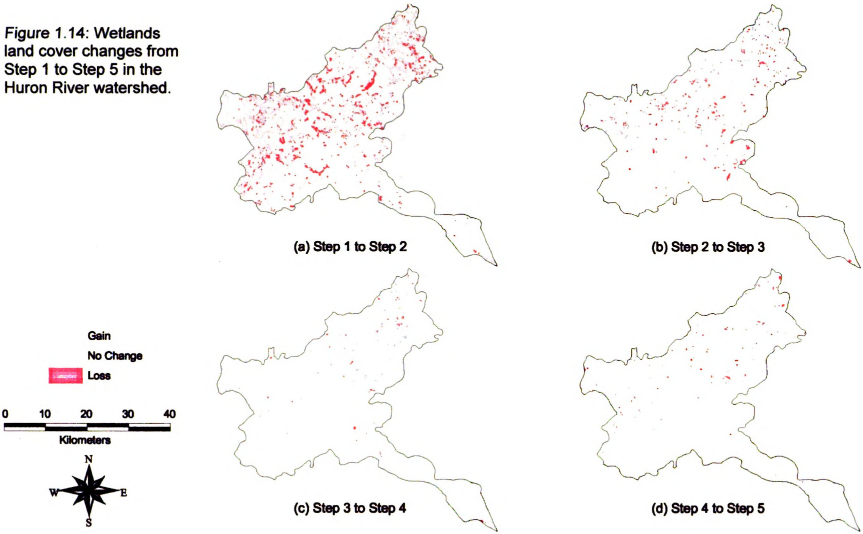


Figure 1.14: Wetlands land cover changes from Step 1 to Step 5 in the Huron River watershed.



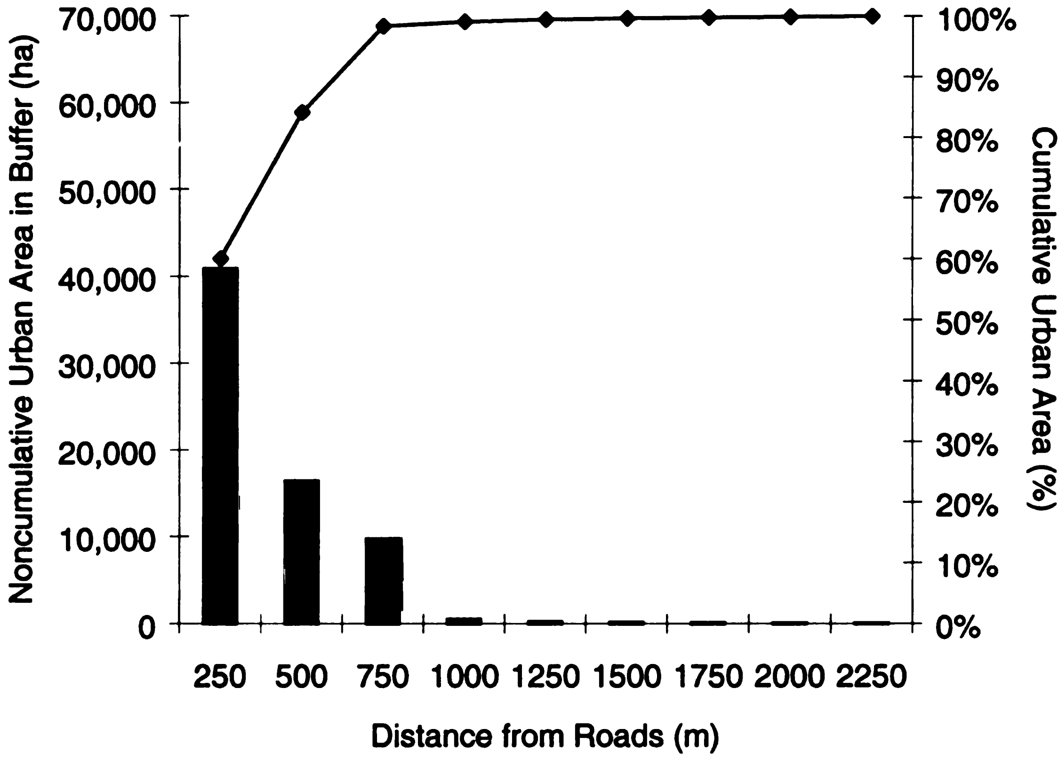


Figure 1.15: Amount of urban land cover as a function of distance to roads in Step 5 in the Huron River watershed.

CHAPTER 2

CHANGES IN WILDLIFE HABITATS OVER TIME IN THE BLACK AND HURON RIVER WATERSHEDS

Introduction

Changes in land cover can affect the composition, structure, or function of ecological systems (Saunders et al. 1991). Such changes may alter the habitat or the set of ecological conditions needed by a species to survive and reproduce successfully (Morrison et al. 1992, Best et al. 1997). From a landscape perspective, these conditions include the quantity, quality, context, and configuration of suitable habitat (Toth et al. 1986, Forman 1995, Wiens 1996). Because each species has different habitat requirements, they will view land cover conditions in a unique way (Figure 2.1). Furthermore, each species will respond to a given change in land cover differently depending upon their life history and habitat requirements (Pearson et al. 1996).

Modeling wildlife-habitat relationships

Determining the consequences of land cover change to wildlife requires understanding the relationships between wildlife and their habitats. Models are the primary tool for characterizing those relationships. They can range from simple descriptive case studies to quantitative models based on field observation to purely mathematical models based solely on ecological theory (Morrison et al.

1992). The type of model used will depend upon the scale of study and the amount and type of available information (Turner et al. 1995).

At the landscape level, modeling wildlife-habitat relationships typically involves understanding the quantity, quality, context, and configuration of suitable habitat and how that habitat changes over time (Pulliam et al. 1992, Turner et al. 1993, Liu et al. 1995). Quantity is simply the total amount of suitable habitat available. Quantity depends on landscape composition, e.g. the amount of different land cover types available, and on the suitability of different land cover types for use by a given species. Quality reflects the degree to which a patch of suitable habitat provides needed resources. This will depend on the functional and structural components of the patch as well as inputs and outputs from surrounding areas. Configuration describes the spatial and temporal patterns among habitat patches. Context is an extension of configuration and considers spatial and temporal patterns among habitat patches and the surrounding landscape.

The ability to model wildlife-habitat relationships properly is also a function of the amount and type of available information. For most species, information is lacking (Franklin 1994, Lidicker and Koenig 1996). As Marcot and Murphy (1996, p. 62) pointed out:

> "Unfortunately for most species, reliable empirical data on historic population dynamic trends, the role of environmental conditions in regulating populations, and other crucial information simply do not exist."

Exceptions to this are generally in-depth studies of endangered species that required extensive field work and sampling to construct and parameterize habitat models (Gutierrez and Harrison 1996, Liu et al. 1999). Standard habitat models, such as habitat suitability indices (Hays et al. 1981, U.S. Fish and Wildlife Service 1981), habitat evaluation procedures (U.S. Fish and Wildlife Service 1980), or population viability analyses (Soulé 1987, Shafer 1990, Gilpin 1991), are therefore not easily applied to landscapes. A further complication is the number of species under consideration. Considering habitat changes to many species simultaneously introduces a new layer of complexity.

To address these limitations, studies of multiple species at landscape scales have taken several approaches. One of the most common approaches is the development of species-habitat matrices that link species requirements to vegetation types (Toth et al. 1986, Haufler 1994). Vegetation types are listed as suitable or unsuitable for each species. Using this matrix, maps of potentially suitable habitat can be derived for each species and used for conservation planning. The matrix can also be used in a number of ways for conservation planning. The matrices can be used in a top-down, or coarse-filter, approach in which major areas of potential habitat are protected (Haufler et al. 1996). Alternatively, a bottom-up, or fine-filter, approach can be taken in which each vegetation type is represented to create the opportunity to conserve as many species as possible. Perhaps the most well-known use of such matrices is the United States GAP analysis process (Scott et al. 1993). This process predicts potential species habitat to determine if there are "gaps" in the protection of particular habitats.

Objectives

This chapter attempts to answer the second research question posed in the introduction: how have wildlife habitats changed over time? To answer that question, three specific objectives have been identified. Those three objectives are to:

1. identify vertebrate wildlife species that historically occurred in both watersheds and their status;
2. characterize habitat requirements of those species from objective #1;
3. evaluate how wildlife habitats have changed over time.

The wildlife-habitat matrix approach can be used to assess availability of and changes to wildlife habitat in the Black and Huron river watersheds. The land cover database for the watersheds does not provide detailed information about habitat quality, e.g. composition, structure, or function. However, it does provide a coarse means to identify areas that could provide habitat for a species. Such areas will be referred to hereafter as "potential habitat" because they may provide the appropriate abiotic and biotic resources needed by a species to survive and reproduce (Morrison et al. 1992, Hall et al. 1997).

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Methods

A list of vertebrate wildlife species (amphibians, birds, mammals, reptiles) whose historic ranges overlapped entirely or partially with each watershed was compiled from range maps published in primary data sources for Michigan fauna (Baker 1983, Brewer et al. 1991, Harding and Holman 1990, Harding and Holman 1999, Holman et al. 1999). Such data sources included information on ranges based on observations and specimen locations. In addition, the Michigan Breeding Bird Atlas provided information on bird species presence/absence based on field observations (Brewer et al. 1991). The status of each species within each watershed was determined: either present or extirpated. Also it was determined whether each species was listed as federally endangered, federally threatened, state endangered, state listed, or state special concern (Michigan Natural Features Inventory 1999).

To delineate potential wildlife habitat in each watershed, a species-land cover matrix was developed. The matrix identified those land cover types that were potential habitat for each species. More specifically, those land cover types could contain the biotic and abiotic resources needed by a species to survive and reproduce (Hall et al. 1997). Some MIRIS land cover types described vegetation associations that were potential habitat, such as broadleaf forest, while other types more correctly describe land use that was potential habitat, such as residential areas. Whether an area actually was habitat for a particular species could not be determined given the level of information in the land cover database.

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Basic information on species-land cover relationships came from a matrix developed for the Michigan GAP analysis project (B. Doepker, personal communication). The matrix included vegetation associations (Hall et al. 1997), e.g. forest, nonforest, water, and wetlands, found in Michigan and provided a binary (yes/no) assessment of whether the vegetation association was potential habitat for each vertebrate wildlife species found in Michigan. That matrix was modified for use with the MIRIS land cover database as follows. First, vegetation associations were assigned corresponding MIRIS Level 3 land cover codes (Table 1.3). The assignment of codes was straightforward in most cases, i.e., grassland = 310, rivers and streams = 510. For forests, certain limitations occurred, which are discussed below.

The Michigan GAP matrix classified forests based on type (coniferous, deciduous, mixed), moisture gradient (upland vs. lowland), and age (re-generating, young, mature, old). MIRIS Level 3 land cover types provided more specific forest cover classifications based on dominant canopy tree species, e.g., central hardwoods, northern hardwoods, pine (Table 1.3). Upland conifer was considered to include pine or other upland conifers. Lowland conifer was considered to include bottomland conifer. Upland deciduous was considered to include aspen/white birch, central hardwood, or northern hardwood. Lowland deciduous was considered to include bottomland hardwood. The MIRIS land cover system did not include a designation for mixed forests; therefore those entries were not used. Lowland deciduous or lowland conifer forest were also considered to include forested wetlands, as the MIRIS system does not distinguis

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distinguish between coniferous forested wetlands and deciduous forested wetlands. The age of forest patches could not be accurately determined from the land cover database and therefore was not used in the species-land cover matrix.

Second, entries for urban and agricultural land cover types were added to the species-land cover matrix. Using descriptions of habitat preferences (Baker 1983, Brewer et al. 1991, Harding and Holman 1990, Harding and Holman 1999, Holman et al. 1999), determinations were made regarding whether urban or agricultural land cover types could be potential habitat for each species. For birds, the Michigan Breeding Bird Atlas (Brewer et al. 1991) proved particularly useful because it provided quantitative data on frequency of observation of breeding birds in specific land cover types, such as agricultural fields or residential areas.

Habitat analysis

The species-land cover matrix was joined to the land cover coverages for each watershed. Species sharing the same set of land cover types that were potential habitat were combined into species groups for the habitat analyses. Based on that information, new coverages of potential habitat were created for each species group for each time step. Statistics were calculated for each coverage of potential habitat, including total amount of potential habitat, number of patches of potential habitat, and mean patch size of potential habitat.

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Results

Status of wildlife species

Based on the best current knowledge, 382 vertebrate wildlife species currently inhabit Michigan (Table 2.1). The Black River watershed currently has 262 species. The Huron River watershed currently has 289 species. Since presettlement times, ten species have been extirpated from Michigan, including one (passenger pigeon, <u>Ectopistes</u> <u>migratorius</u>), which has gone extinct (Table 2.2). Current estimates indicate that 19 species have been extirpated from the Black River watershed. The wild turkey was extirpated but has been reintroduced. The eastern elk (<u>Cervus</u> <u>elaphus</u> <u>canadensis</u>) was also extirpated, but Rocky Mountain elk (<u>Cervus</u> <u>elaphus</u> <u>nelsonii</u>) has been introduced into the northern LP as a replacement. Estimates for the Huron are 22 extirpations and at least one extirpation/reintroduction (wild turkey). Both watersheds have a higher percentage of extinct mammals, 16% for the Black and 27% for the Huron, than the state (6%).

A total of 66 species, or 17% of the total number of current species, are listed by the state of Michigan as endangered, threatened, or of special concern (Michigan Natural Features Inventory 1999), including 33% of reptiles, 17% of amphibians, 16% of mammals, and 16% of birds (Table 2.2). In the Black River watershed, 13% of species are state-listed, accounted for primarily by bird species (70%). In the Huron River watershed, 14% of species are state-listed, 59% of which are bird species.

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Based on the species-land cover matrix, forest land cover types were potential habitat for larger numbers of species (i.e., species richness), followed by nonforest, wetlands, and water (Table 2.3). Forested wetlands were potential habitat for the largest number of species (164). Certain urban and agricultural land cover types, such as residential areas or urban-openlands (e.g. parks) were potential habitat for intermediate numbers of species. Land covers with intensive levels of human use, such as urban transportation and agricultural croplands, were potential habitat for smaller number of species. The four urban-extractive land cover types provided potential habitat for no species. Appropriate habitat may occur in those land cover types for certain species. However, given the limited information on use of such areas by different species, they were not considered as potential habitat.

The number of land cover types that were potential habitat for a species ranged from 1 to 22 (Figure 2.2), out of a total of 46 possible land cover types. The mean number of land cover types that were potential habitat was 6.6 ± 4.3 across all species groups. Ten species had only one land cover type (nonforest-grasslands) as potential habitat, including 7 bird species. The alder flycatcher (Empidonax alnorum) was the only other species with one land cover type (wetlands-shrub/scrub) as potential habitat. The eastern tiger salamander (Ambystoma tigrinum tigrinum) and chimney swift (Chaetura pelagica) both had the highest number of land cover types (22) that were potential habitat.

Placing species with the same set of land cover types that were potential habitat into groups produced 214 species groups (Figure 2.2). Species groups occurred

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occurred primarily for species that had 6 or fewer land cover types as potential habitat. When 7 or more land cover types were potential habitat, the likelihood that any two species shared the same set of land cover types decreased rapidly. Combinations of 11 or more land cover types were almost always unique, resulting in species groups with only one member. The largest species group included 18 member species for which three land cover types (rivers, lakes, and reservoirs) were potential habitat. The second (17 species) and third (14 species) largest species groups had all four coniferous and all five deciduous land cover types, respectively, as potential habitat. Species groups with larger numbers of species tended to follow natural breaks in land cover, such as only deciduous upland or all water and wetland land cover types.

The same analysis was performed on a species-land cover matrix that only included natural land cover types, defined as forest, nonforest, water, and wetlands. Human-dominated land cover types were excluded, including all urban, all agriculture, and reservoirs. This was done to examine to what extent species have or have not adapted to human-dominated land cover types. The use of the term "natural" was only used to signify land cover types that may occur in the absence of human influence. "Natural" was not meant to imply the actual condition (e.g. pristine, undisturbed, etc.) of any land cover type.

The number of natural land cover types that were potential habitat for a species ranged from 1 to 14. The northern spring peeper (Pseudacris crucifer crucifer) had all 14 natural land cover types, except grasslands, as potential habitat. The mean number of natural land cover types that were potential habitat was

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was 5.05 ± 0.14. The number of member species in the largest species group increased from 18 to 20. This species group included species where both upland and lowland coniferous forest land cover types were potential habitat, such as the blackburnian warbler (Dendroica fuscia), American marten (Martes americana), lynx (Felis lynx), and wolverine (Gulo gulo).

The number of member species per species group declined exponentially (Figure 2.3). A total of 163 species groups had only one member species when all land cover types were considered. This declined to 21 groups with 2 species, 10 groups with 3 species, and fewer than 10 groups with 4 or more species. An exponential decrease was also observed if only natural land cover types were considered, although the rate of decrease was lower.

Comparison of the species-land cover matrix with all land cover types to the species-land cover matrix with only natural land cover types showed that 199 species have potential habitat in human-dominated land cover types, i.e., urban, agriculture, and reservoir land cover types. Increases typically ranged from 1 to 10 land cover types, and the mean increase was 3 land cover types (Figure 2.4). One species, the chimney swift (Chaetura pelagica) showed an unusually large gain, increasing from 2 land cover types in the species-natural land cover matrix to 22 in the species-all land cover matrix. As discussed above, the largest gains came in urban-openlands (e.g. cemeteries and parks) and urban-single family residential areas. The number of natural land cover types and the number of additional land cover types by species showed a statistically significant but small correlation ($r = 0.20$, $p < 0.001$, $n = 214$).

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Black River watershed

Vegetation changes

The Black River watershed was almost exclusively forested (95%) at the time of the GLO survey. It remained mostly forested from Step 1 (71% in 1938) through Step 5 (70% in 1992) (Table 1.5). As a result of timber harvesting and subsequent burning of cleared areas, forest composition shifted from a 58%/42% mixture of conifers/broadleaf to a 66%/34% mixture of broadleaf/conifers. All original dominant forest types decreased in extent including pine, northern hardwood, other upland conifers, and bottomland conifers (Table 2.4). Central hardwoods, bottomland broadleaf and aspen/white birch increased substantially. The combined total area of those three forest cover types increased from 6,054 ha in the GLO coverage to 54,795 ha in Step 5, with 40,311 ha (74%) being aspen/white birch. Although appropriate data are lacking, overall forest age likely decreased greatly as well. Presettlement forests were more likely mature or older climax communities, whereas forests in 1992 were generally much younger than 150 years of age due to timber harvesting.

Of the other land cover types, nonforest showed the largest increase, from essentially nil during the GLO survey to over 21,000 hectares by 1995 (Table 2.4). Wetland area increased from 1,218 ha to 5,246 ha. Lake area remained constant, while rivers and streams doubled in area, most likely due to resolution differences between the GLO and modern land cover database.

In addition to compositional changes, the number of forest patches increased while forest patch size decreased (Table 2.4). The number of patches v

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increased by at least one order of magnitude for each forest cover type. Consequently, mean forest patch size decreased. Mean forest patch sizes from the GLO land cover database ranged from 111 to 1,037 ha while modern forest patch sizes ranged from 4.1 to 35.1 ha. Considered from a higher level of aggregation, mean patch size of broadleaf forests decreased from 955 ha to 54 ha and coniferous forests from 477 ha to 26 ha. Northern hardwoods showed the largest decrease, from a mean patch size of 1,037 ha to 23.8 ha. Largest forest patch sizes mirrored changes in forest area, decreasing when total area decreased and increasing when total area increased (Table 2.4). The decrease in patch sizes likely had consequences for many species, particularly birds. For example, some interior forest birds become very uncommon if forest patch size drops below 100 ha (Robbins et al. 1989).

For other land cover types, mean patch sizes remained more stable than forest (Table 2.4). Water, which had the largest mean patch sizes from Step 1 to Step 5, showed the smallest variation as a percent of size. Nonforest and wetlands land cover types had mean patch sizes less than 10 hectares that varied by as much as 50%. Largest patch sizes remained constant for rivers and lakes from Step 1 to Step 5, decreased for grasslands, and decreased and then increased for nonforest shrub/scrub. Nonforest wetland largest patch sizes remained nearly constant, while forested wetlands largest patch size showed the largest percentage decrease of any land cover type from 419 to 35 ha.

Mean nearest neighbor values decreased from the GLO survey to Step 1 for all land cover types except rivers and then remained fairly constant from Step

1 to Step 5. The only exception was nonforest shrub/scrub, which decreased by 30% (Table 2.4). Mean nearest neighbor distance was negatively correlated with the number of patches (Figure 2.5, $r = -0.45$, $p < 0.0001$, $n = 75$). The outliers in the lower left hand corner represented values from rivers and streams.

Changes in potential wildlife habitat

Of the 214 species groups, 168 have at least one member whose range included the Black River watershed. Of those groups, 96 species groups had a net gain of potential habitat from Step 1 to Step 5, while 72 had a net loss of potential habitat over time. The mean change in potential habitat area for species groups from the GLO survey to Step 5 was +850 ha. From the GLO survey to Step 1, 59% of the groups gained potential habitat, and 41% lost potential habitat. From Step 1 to Step 5, 50% gained and 50% lost potential habitat (Table 2.5). The pattern of gains and loss was not consistent over time, as 100 species groups either gained then lost or lost then gained potential habitat. Fourteen species groups had no potential habitat at the time of the GLO survey. The largest net gain was 37,266 hectares, a group with only one member (American kestrel, Falco sparverius). This also represented the largest percent gain in habitat of any group (5,807%). The largest net loss was –47,096 ha for a group of 18 species restricted to coniferous forests. Example members of that group included the American marten (Martes americana), Blackburnian warbler (Dendroica fuscia), lynx (Felis lynx), pine grosbeak (Pinicola enucleator), and Swainson's thrush (Catharus ustulatus). The largest percent loss of habitat was 60% for a group of two bird species, the blackpoll warbler (Dendroica striata) and *a*

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evening grosbeak (Coccotraustes vespertinus) that only occurred in upland coniferous forest.

Potential habitat area correlated significantly over time from the GLO survey to Step 5 (Figure 2.6, $r = 0.95$, $p < 0.0001$, $n = 168$), the GLO survey to Step 1 (Figure 2.7, $r = 0.95$, $p < 0.0001$, $n = 168$) and Step 1 to Step 5 (Figure 2.8, $r = 1.00$, $p < 0.0001$, $n = 168$). The majority of change took place from the GLO survey to Step 1 (Figure 2.7). In that period, species groups clustered into 8 distinct groups, 4 of which gained potential habitat area over time (A,C,E,G) and 4 of which lost potential habitat area over time (B,D,E,G). Whether a species group gained or lost potential habitat area over time depended primarily on the set of natural land cover types that could provide habitat for that group (Table 2.6). In particular, the combination of forest cover types that could provide habitat often determined whether a group gained or lost potential habitat over time. For example, Cluster C (Figure 2.6) included species for which all broadleaf forest land cover types could provide habitat while Cluster F included species for which only coniferous forests could provide habitat. Within clusters, differences depended upon the number and types of non-forest land cover types that could provide habitat.

Change in potential habitat area did not correlate with the number of land cover types that could provide habitat (Figure 2.9, $r = 0.18$, $p = 0.69$, $n = 168$). A significant but small negative correlation existed between the number of additional human-dominated land cover types that were potential habitat and change of potential habitat area (Figure 2.10, $r = 0.18$, $p = 0.02$, $n = 168$).

The number of patches of potential habitat increased for all species from the GLO survey to Step 5 (Figure 2.11). Patch number increased most from the GLO survey to Step 1 (Figure 2.12) and again from Step 1 to Step 5 (Figure 2.13), but at a much lower rate. No discernible pattern was evident that tended to delineate groups by potential habitat.

Mean size of potential habitat patches declined from the GLO survey to Step 5 for all but 15 of the 168 groups within the Black River watershed (Figure 2.14). Overall mean patch size was 6,782 ha for the GLO survey but declined to 112 ha by Step 1. Overall mean patch size then increased from Step 1 to Step 4 (133 ha) but declined again in Step 5 (121 ha). Mean patch size was correlated over time between the GLO survey and Step 1 (Figure 2.14, $r = 0.63$, $p < 0.0001$, $n = 168$) and between Step 1 and Step 5 (Figure 2.15, $r = 1.00$, $p < 0.0001$, $n = 168$). Similar to potential habitat area, the majority of change in mean patch size occurred from the GLO survey to Step 1 (Figure 2.15). Mean patch sizes showed 5 distinct clusters when comparing the GLO survey to Step 5. The five clusters had distinct land cover types that were potential habitat (Table 2.7).

Huron River watershed

Vegetation changes

The amount of natural vegetation in the Huron River watershed decreased substantially from the GLO survey to Step 1 (Table 2.8). By Step 1, the total area of natural land cover types (forest, nonforest, water, and wetlands) was 91,469 ha, a 60% reduction. Forests declined by 73%, nonforest by 63%, and wetlands by 23%. Only water increased in total area (12%). However, from Step 1 to Step

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5, forest, nonforest, and water increased in total area, by 14%, 56%, and 16%, respectively. Wetlands continued to decline. By Step 5, they totaled 53% of the amount at the time of the GLO survey.

The composition of natural land covers changed from conditions present at the time of the GLO survey but not as substantially as within the Black River watershed. Central hardwoods remained the dominant forest cover type, although it decreased substantially in extent, from 44.6% to 10.6% of watershed area (Table 2.8). Although it decreased in area, bottomland broadleaf increased as the total percentage of forest area, as did pine forest. Bottomland conifer forests showed the largest decrease in total area, from 9,568 ha during the GLO survey to 399 ha by Step 5 (Table 2.8)

Grasslands increased, from only 49 ha to 20,833 ha by Step 5. Nonforest shrub/scrub declined to 27% of its original area. In addition, the shrub/scrub identified during the GLO survey times was a combination of oak barrens and oak openings and structurally and floristically different from nonforest shrub/scrub occurring in the 20th century.

Rivers and streams increased in area (Table 2.8), likely due to a better ability to detect them in Step 1 to Step 5 than an actual increase. Lakes also increased in total area due to the creation of several reservoirs due to damming of the Huron River and isolated lakes and ponds throughout Step 1 to Step 5.

Number of patches increased for nonforest and water. Number of patches decreased from Step 1 to Step 5 for central hardwood, bottomland broadleaf, and wetlands, while increasing for aspen/white pine, pine, and bottomland conifer

(Table 2.8). As in the Black River watershed, the numbers of patches during Step 1 to Step 5 were one or more orders of magnitude higher than those found during the GLO survey. The only exception was bottomland conifer forests, which decreased by 50%. Mean patch sizes were at least an order of magnitude smaller. Except for wetlands, mean patch size for most land cover types increased from Step 1 to Step 4, before decreasing again in Step 5. Wetlands mean patch sizes decreased, except for forested wetlands, which increased from 4.4 to 6.4 ha. Similarly largest patch sizes from Step 1 to Step 5 were one to two orders of magnitude smaller than at the time of the GLO survey (Table 2.8).

Similar to the Black River watershed, mean nearest neighbor distances decreased from the GLO survey to Steps 1 to 5 and then remained mostly constant. The exception was bottomland conifers, in which the distance increased. Mean nearest neighbor distances correlated negatively with the number of patches (Figure 2.17, $r = -0.62$, $p < 0.0001$, $n = 69$).

Changes in potential wildlife habitat

Of the 214 unique species groups, 181 groups have at least one member whose range included the Huron River watershed. From the GLO survey to Step 5, 131 species groups lost potential habitat area while 50 groups gained potential habitat area (Table 2.9). Of the 131 species groups with a net loss from the GLO survey to Step 5, 102 gained potential habitat area from Step 1 to Step 5. Twenty-five species groups, which included many species with wetlands and forests as potential habitat, lost potential habitat area from the GLO survey to Step 1 and from Step 1 to Step 5,. The largest net loss in potential habitat area

was 144,675 hectares for Group 206, consisting only of the northern spring peeper (Pseudacris crucifer crucifer). The largest percentage loss of potential habitat was 76% for Group 83 that included only the ruffed grouse (Bonasa umbellus). The biggest habitat gains was 152, 818 ha for the barn swallow (Hirundo rustica), which was also the largest percentage gain (258,811%).

Unlike the Black River watershed, species groups in the Huron River watershed did not form tight clusters based on gains and losses of potential habitat area from the GLO survey to Step 5 (Figure 2.18). The overall trend is a decline in potential habitat area during the study period. Species that gained potential habitat from the GLO survey to Step 5 were species occurring in grasslands, water, and/or wetland habitats that adapted to similar human-dominated land cover types such as pastures or recreational areas. As in the Black River watershed, most changes occurred from the GLO survey to Step 5 (Figure 2.19). The mean change in potential habitat area from the GLO survey to Step 5 was -38,115 ha. This resulted from a mean loss of 51,687 ha from the GLO survey to Step 1 and mean gain of 13,574 ha from Step 1 to Step 5. In fact, from Step 1 to Step 5, 135 species gained potential habitat area (Table 2.9, Figure 2.20). Of the 66 species groups that lost potential habitat area from Step 1 to Step 5, those that had agricultural land cover types, especially cropland, as potential habitat had the largest losses.

Change in potential habitat area correlated negatively with the number of land cover types serving as potential habitat (Figure 2.21, $r = -0.22$, $p < 0.003$, $n = 181$). Conversely, the number of additional, human-dominated land cover types that were potential habitat correlated positively with change in potential habitat area for species groups (Figure 2.22, $r = 0.29$, $p < 0.001$, $n = 181$).

The number of patches of potential habitat increased for all species groups from the GLO survey to Step 5 (Figure 2.23). The majority of increases occurred from the GLO survey to Step 1 (Figure 2.24). From Step 1 to Step 5, changes in the number of patches of potential habitat fell into three broad categories: increases, constant, and decreases (Figure 2.25). Species groups with increasing patch numbers included those with grasslands, water, and wetlands as potential habitat. Groups with decreasing patch numbers included species groups with nonforest and forest as potential habitat that also had residential and openland land cover types as potential habitat.

Mean patch size of potential habitat declined from the GLO survey to Step 5 for all but 5 of the 181 species groups within the Huron River watershed (Figure 2.26). Overall mean patch size was 2,460 ha at the time of the GLO survey but declined to 56 ha by Step 1. From Step 1 to Step 5, overall mean patch size declined again to 39 ha. Mean patch size correlated over time between the GLO survey and Step 1 (Figure 2.27, $r = 0.63$, $p < 0.0001$, $n = 181$) and between Step 1 and Step 5 (Figure 2.28, $r = 1.00$, $p < 0.0001$, $n = 181$). Similar to potential habitat area, most changes in mean patch sizes of potential habitat occurred from the GLO survey to Step 1. During that period, species groups sorted into 4 broad categories (Figure 2.27). Group A consisted of grassland species for which urban and agriculture land cover types were potential habitat. Mean patch size for Group A increased over time. Group B included species restricted primarily to wetland complexes consisting of water, wetlands, and associated bottomland forests. Mean patch sizes declined for this group from 10's to 100's of hectares to typically less than 10 ha. Group C showed declines in mean patch sizes but not as severe as most other species. These were species for which forest land cover types were potential habitat but then adapted such that urban and agriculture land cover types were also potential habitat. Group D included most other species, for which mean patch size of potential habitat declined by several orders of magnitude.

Mean patch sizes of potential habitat showed 3 broad clusters when comparing Step 1 to Step 5 (Figure 2.28). The majority of species groups (Group A) had small changes in mean patch size. Mean patch size increased for species groups with nonforest and forest as potential habitat (Group B),while mean patch size decreased for species groups with agriculture as potential habitat (Group C).

Discussion

Wildlife habitat trends

Wildlife habitats in the Huron and Black river watersheds have undergone extensive changes since European settlement. Both watersheds have experienced substantial changes in the composition and spatial arrangement of land cover types that translated into changes of potential wildlife habitats. Because what constitutes habitat varies among species, analysis of habitat changes are complex and do not fit easily explainable patterns. Nonetheless, some broad trends did emerge.

For forests and wetlands, total area and mean patch size decreased and the number of patches increased from the GLO survey to Step 5 in both watersheds due to urban and agricultural development. The extent of change varied among land cover types. Area of MIRIS Level 3 forest cover types decreased 20% or more, and corresponding mean patch sizes decreased by 1 or 2 orders of magnitude. In the Black River watershed, aspen/white pine was an exception to that trend, increasing in both total area and mean patch size as a result of timber harvesting. Wetlands showed a similar decrease, although the rate of loss declined substantially from Step 1 to Step 5.

Despite their overall decrease, forests in both watersheds increased in area from Step 1 to Step 5, although mean forest patch sizes remained very small compared to those at the time of the GLO survey. The mechanisms of increase differed between watersheds. In the Black River watershed, forested areas appeared to be regenerating from the extensive harvesting that ended in the early 1900's. From Step 1 to Step 4, little timber harvesting took place. However, from Step 4 to Step 5, the rate of timber harvesting increased. In the Huron River watershed, forests increased in total area in conjunction with urban development as farms were converted to urban uses. But, as in the Black River watershed, forests again declined from Step 4 to Step 5. Both trends suggest the forest gains may be temporary. Timber harvesting (Black) and the need for land for development (Huron) may continue the trend in forest losses begun from Step 4 to Step 5 in both watersheds.

In contrast to forest and wetlands, grasslands showed substantial gains in total area, number of patches, and mean patch sizes in both watersheds. Such trends are not surprising given the predominantly forested conditions of both watersheds prior to the GLO survey. In the Black, increases in nonforest resulted from timber harvesting and to a lesser extent agriculture. In the Huron River watershed, increases in nonforest resulted from conversion of land from agriculture either permanently as farms were sold for development and temporarily as farmland went fallow. Increased areas of nonforest offer increased opportunities for many wildlife species. For example, grasslands may provide habitat components for certain bird species that are of conservation concern (Best et al. 1997). However, the increased availability of nonforest areas came side-by-side with increased human activity, particularly in the Huron River watershed where nonforest increased in conjunction with urban and suburban development. The implications of the large increase in grasslands will vary depending upon the species in question and likely relate to its tolerance to people.

Wildlife Species Trends

Despite the extensive changes in land cover, almost all species that historically ranged in one or both watersheds continue to occur in those watersheds today. Less than 10% of vertebrate wildlife species have been extirpated from both watersheds. Large mammals fared proportionately the worst. Given their large area requirements, such results were not surprising. In addition, economic value (e.g. hunting and trapping of furbearers) as well as deliberate removal based on perceived danger (e.g. mountain lion, gray wolf) also contributed to their decline (Baker 1983, Winterstein et al. 1995).

The trend among bird species was less clear. Extirpated or listed species occurred throughout the range of natural habitats, including coniferous forests (black-backed woodpecker, northern parula, long-eared owl), wetlands (king rail), broadleaf forests (spruce grouse), and nonforest (greater prairie chicken). Therefore the reasons for decline or loss appear to be more species-specific and less amenable to generalizations than mammals. For bird species, many factors can influence their viability, such as patch size (e.g. prothonatary warbler), lack of undisturbed habitat (e.g. common tern, possibly the least bittern), changes in habitat structure, or nest parasitism (many songbirds).

Reptiles and amphibians seemed to have fared the best among vertebrate wildlife species, as no extirpations have likely occurred to date. However, this assessment is based principally on knowledge of broad-scale trends in such species. Given the apparent overall decline in those species (Moulahan et al. 2000), their status in the watersheds could currently be very poor and may actually worsen during the next 10 to 20 years. To that end, the state of Michigan has initiated a yearly survey of breeding frogs and toads as a potential indicator of broad-scale trends among anuran (frog and toad) species.

As demonstrated by the species-land cover matrix, human-dominated land cover types (e.g. urban, agricultural, reservoirs) could be potential habitat for more than half of the vertebrate wildlife species found in Michigan. In many cases, the potential use of human-dominated land cover types offset the loss of ca

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potential habitat area that would have occurred if only natural land cover types had been considered. The use of human-dominated land cover types, as well as increases in natural land cover types, explained why potential habitat area increased for approximately 80% of the vertebrate wildlife species in the Huron River from the 1930's to 1990's – a time of extensive urban expansion. In this case, the expansion of urban areas potentially benefits some wildlife species because not all farmland became urban area. Much of it returned to nonforest (grasslands, shrub/scrub) and forest. On the other hand, mean patch sizes did not increase substantially. Further, the gains in potential habitat area came in concert with increased human presence and activity. Whether an increase in potential habitat actually enhanced conditions for a particular species requires further study, as a number of factors must be considered. Those factors are considered below in the discussion of recommended research.

Limitations of habitat analysis and recommendations for further research

The habitat analysis was limited in that it offered only a first approximation of habitat quantity and, to a lesser degree, habitat configuration. The other components of habitat – quality and context were not measured due to limitations in the data. In the case of habitat quality, the land cover database did not provide such information. In the case of habitat context, such measures would vary depending upon species and would require additional information to provide a non-arbitrary assessment of its importance to a particular species. In most cases, that data are not available.

MIRIS land cover types, used at the third level of classification, provided a means to approximate changes to the quantity of potential wildlife habitat. Obviously with more detailed information, a better assessment of habitat quality could be made, which would in turn affect estimates of habitat quantity. In developing the species-land cover matrix, a yes/no (binary) decision was required regarding the suitability of a land cover type as potential habitat for each species. The decision process required re-evaluating land cover in ecological terms based on qualitative habitat descriptions. For natural land cover types, the species-habitat matrix provided by Bob Doepker of the MDNR was mapped to the MIRIS system fairly readily with the assumptions outlined in the methods above. Assessment of urban and agriculture land cover types as potential habitat was less straightforward and more subjective and required re-interpreting land cover types from an ecological perspective. For example, if a species inhabited grasslands, then an urban or agricultural land cover type that contained similar features might potentially serve as habitat, e.g. pasture, recreational lands, cemeteries. In most cases, the decision was made not to include such habitats unless habitat descriptions explicitly stated such areas were potentially utilized. In many cases, the decision reflected the tolerance of a species for humans or human activities. Bird species were the exception, as the Michigan Breeding Bird Atlas (Brewer et al. 1991) included data on bird occurrence in land cover types that matched MIRIS land cover types.

Changes to habitat configuration were reflected in changes in patch number and mean patch sizes. The number of patches increased and mean

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patch size decreased for most land cover types, and the number of patches and mean patch size of potential habitat increased and decreased, respectively, as a result of those changes. However, those trends did not apply to all species. Further a species home range need not fall entirely within a patch of suitable habitat (Wilson et al. 1998). These difficulties highlight the problem of interpreting habitat configuration for a single species and comparing changes in configuration among different species, especially the large number included in this study. The analysis of mean nearest neighbor values for natural land cover types indicated those values correlated strongly with number of patches and therefore provided little additional information. Landscape metrics used to measure spatial configuration, such as contagion or interspersion/juxtaposition, by themselves do not provide useful information. They would need to be coupled with data on species presence/absence and, even better, data on dispersal, to provide a more useful measure of the consequences of habitat configuration.

As discussed above, an assessment of habitat quality cannot be made from the land cover database. The land cover data simply do not provide the more detailed types of information needed to assess habitat quality. In the future, advances in the resolution of remote sensed data, both increases in resolution and information context, may enhance the ability to assess habitat conditions in more detail at broader spatial scales.

Similar to habitat quality, changes in habitat context were not determined given a lack of information on how to measure it. Habitat context can be important (Pearson 1995). However, the extent or actual size of the surrounding c

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area to study for habitat context is not known for most species. In addition, the idea of context relates to how to define a patch of habitat for a particular species. As indicated above, species home ranges may include areas of unsuitable habitat. In that case, would an analysis of context include such areas or not? That answer, like most, will likely vary according to species.

Benefits of habitat analysis

Despite the limitations of the habitat assessment, its importance should not be dismissed or discounted. Although the species-land cover matrix will require additional refinement, it nonetheless now exists. In conjunction with information on species ranges within the state, the matrix can be linked to any MIRIS land cover map in Michigan to generate a map of potential habitat for any vertebrate wildlife species of interest. As updates to the MIRIS land cover maps are currently in progress (R. Groop, personal communication), changes to potential habitat could be assessed for the entire state of Michigan for all vertebrate wildlife species. Further the habitat analysis demonstrated that land cover changes in the Black and Huron river watersheds did not negatively impact all species. In fact, many species may have benefited from the land cover changes, particularly those found in early successional habitats that are more extensive today than historically. Finally, the habitat analysis can serve as a guide to develop conservation goals given how species utilize land cover. The matrix indicates more explicitly which species potentially benefit or suffer from increases or decreases in particular land cover types. It also helps distinguish habitat specialists from habitat generalists and helps identify those species that may be vulnerable to land cover changes in the future, especially those species that have not adapted to non-natural land cover types.

Table 2.1: Status of wildlife species in Michigan and the Black and Huron river watersheds. Number of species presently occurring followed by number of extirpated species in parentheses. Listed species is the total number of species listed by Michigan followed by the number listed as endangered-threatened-special concern in parentheses.

	Michigan		Black		Huron	
	No.	Listed	No.	Listed	No.	Listed
Amphibians	23	4	17	-	19	2
	-	(1-1-2)	-	-	-	(1-0-1)
Birds	268	42	184	25	201	26
	(6)	(8-13-21)	(10)	(3-12-10)	(10)	(5-8-13)
Mammals	62	10	45	7	43	8
	(4)	(5-1-4)	(9)	(3-0-3)	(12)	(4-1-3)
Reptiles	30	10	16	3	26	8
	-	(2-2-6)	-	(0-0-3)	-	(1-1-6)
Total	382	66	262	36	289	43
	(10)	(16-17-33)	(19)	(7-13-15)	(22)	(12-11-19)

Table 2.2: Federally-listed, state-listed, and extirpated species of the Black and Huron river watersheds. E = endangered, T = threatened, SC = special concern, C = candidate, P = present today, X = present historically but now extirpated, ? = status uncertain, blank = not present historically.

Species	Listed Status		Watershed Status	
	Federal	State	Black	Huron
AMPHIBIANS				
Blanchard's Cricket Frog		SC		P
Smallmouth Salamander		E		P
BIRDS				
American Bittern		SC	P	P
American Coot			X	P
Bald Eagle	T	T	P	X
Black-backed woodpecker		SC	X?	
Black-crowned Night Heron		T		P
Cerulean Warbler		SC		P
Caspian Tern		T	?	
Common Loon		T	P	
Common Merganser			X?	
Common Moorhen		SC		P
Common Tern		T		P
Cooper's Hawk		SC	P	P
Dickcissel		SC		P
Forster's Tern		SC		?
Grasshopper Sparrow		SC	P	P
Greater Prairie-Chicken		X	X	X
Henslow's Sparrow		SC		P
Hooded Warbler		SC		P
King Rail	E			X?
Kirtland's Warbler	E	E	P	
Lark Sparrow		X		X
Least Bittern		T	P	P
Loggerhead Shrike		E	X	X
Long-eared Owl		T		X
Louisiana Waterthrush		SC		P
Marsh Wren		SC	?	P
Northern Goshawk		SC	P	
Northern Harrier		SC	P	P
Northern Parula			P	X
Northern Saw-Whet Owl			X?	
Osprey		T	P	X
Passenger Pigeon	X	X	X	X

Table 2.2 (con't)

Species	Listed Status Federal	Listed Status State	Watershed Status Black	Watershed Status Huron
BIRDS (con't)				
Prairie Warbler		E		P
Prothonotary Warbler		SC		X?
Red-shouldered Hawk		T	P	P
Sharp-tailed Grouse		SC	?	
Spruce Grouse		SC	X?	
Swainson's Thrush			X?	
Virginia Rail			X?	P
Western Meadowlark		SC	P	P
Yellow Rail	T		?	
Yellow-headed Blackbird		SC		P
Yellow-Throated Warbler		T		P?
MAMMALS				
Black Bear			P	X
Bison		X		X
Bobcat			P	?
Caribou		X	X	X
Elk			P	X
Ermine			?	?
Fisher			X	X
Gray Wolf	E	E	X	X
Indiana Bat	E	E	X	?
Lynx	T	E	X	X
Marten		T	X	X
Moose		SC	X	X
Mountain Lion	T	E-X	X	X
Porcupine			P	X
Wolverine		X	X	X
Woodland Vole		SC	P	P
REPTILES				
Black Rat Snake		SC		P
Blanding's Turtle		SC	P	P
Eastern Box Turtle		SC		P
Eastern Fox Snake		T		P
Eastern Massasauga Rattlesnake	C	SC	P	P
Kirtland's Snake		E		P
Spotted Turtle		SC		P
Wood Turtle		SC	P	P

Table 2.3: Number of species with potential habitat in MIRIS Level 3 land cover.

Land Cover Type	Amphibians	Birds	Mammals	Reptiles	Total
Agriculture-Confined Feeding	-	-	4	-	4
Agriculture-Cropland	3	10	2	3	18
Agriculture-Orchards	8	3	28	9	48
Agriculture-Other	7	3	12	7	29
Agriculture-Pasture	8	25	22	9	64
Forest-Coniferous-Bottomland	6	58	39	3	106
Forest-Coniferous-Christmas Tree	-	14	9	-	23
Forest-Coniferous-Other Upland Confier	7	67	38	5	117
Forest-Coniferous-Pine	7	67	38	5	117
Forest-Deciduous-Aspen/White Pine	13	86	48	10	157
Forest-Deciduous-Bottomland	7	74	29	7	117
Forest-Deciduous-Central Hardwood	13	86	48	10	157
Forest-Deciduous-Northern Hardwood	13	86	48	10	157
Nonforest-Grassland	8	99	34	12	153
Nonforest-Shrub/Scrub	10	83	36	12	141
Urban-Commercial-Instiutional	3	30	11	-	44
Urban-Commercial-Primary Business	-	1	-	-	1
Urban-Commercial-Secondary Business	-	1	-	-	1
Urban-Commercial-Shopping Mall	-	1	-	-	1
Urban-Communications	-	1	-	-	1
Urban-Extractive-Open Pit	-	-	-	-	-
Urban-Extractive-Other	-	-	-	-	-
Urban-Extractive-Underground	-	-	-	-	-
Urban-Extractive-Wells	-	-	-	-	-
Urban-Industrial-General	-	1	-	-	1
Urban-Industrial-Industrial Park	-	1	-	-	1
Urban-Industrial-Unknown	-	1	-	-	1
Urban-Openland-Cemetery	7	31	24	9	71
Urban-Openland-Outdoor Recreation	7	31	23	9	70
Urban-Residential-High Rise Apt.	-	1	-	3	4
Urban-Residential-Low Rise Apt.	-	35	5	4	44
Urban-Residential-Mobile Home	4	30	11	5	50
Urban-Residential-Single Family	6	35	12	5	58
Urban-Transportation-Air	-	1	-	-	1
Urban-Transportation-Highway	-	1	1	-	2
Urban-Transportation-Rail	-	1	-	-	1
Urban-Transportation-Unknown	-	1	-	-	1
Urban-Transportation-Water	-	1	1	-	2
Urban-Utilities	-	1	-	-	1
Water-Lakes	18	83	14	13	128
Water-Reservoir	6	71	10	9	96
Water-River/Stream	11	65	13	13	102
Wetlands-Forested-Shrub/Scrub	11	84	28	12	135
Wetlands-Forested-Wooded	10	107	40	7	164
Wetlands-Nonforested-Aquatic Bed	16	53	9	13	91
Wetlands-Nonforested-Emergent	16	56	6	14	92

Table 2.4: Statistics for natural land cover (MIRIS Level 3) types from the GLO survey to Step 5 for the Black River watershed. MNN = Mean Nearest Neighbor.

Land Cover Type	GLO	Step 1	Step 2	Step 3	Step 4	Step 5
Forest						
Central Hardwood						
Area (ha)	-	4,147	4,213	4,212	4,211	4,030
Number of Patches	-	206	208	207	206	209
Mean Patch Size (ha)	-	20.1	20.3	20.3	20.4	19.3
Largest Patch (ha)	-	194	194	194	202	200
MNN (m)	-	366	386	402	404	403
Northern Hardwood						
Area (ha)	56,006	17,131	17,263	17,385	17,345	16,192
Number of Patches	54	624	631	625	636	681
Mean Patch Size (ha)	1,037	27.5	27.4	27.8	27.3	23.8
Largest Patch (ha)	15,193	4,386	5,216	5,260	5,195	4,950
MNN (m)	502	235	231	231	228	216
Bottomland Broadleaf						
Area (ha)	475	10,988	11,265	11,271	11,251	10,454
Number of Patches	30	895	894	892	892	970
Mean Patch Size (ha)	16	12.3	12.6	12.6	12.6	10.8
Largest Patch (ha)	91	506	506	506	506	421
MNN (m)	2,040	236	230	232	232	214
Aspen/White Pine						
Area (ha)	5,559	43,425	44,984	44,968	45,002	40,311
Number of Patches	19	1,290	1,283	1,290	1,292	1,531
Mean Patch Size (ha)	293	33.7	35.1	34.9	34.8	26.3
Largest Patch (ha)	1,179	2,655	2,628	2,628	2,629	2,109
MNN (m)	900	116	115	115	115	107
Pine						
Area (ha)	44,779	12,481	10,721	10,644	9,621	9,821
Number of Patches	59	747	809	804	837	899
Mean Patch Size (ha)	759	24.4	26.0	26.6	25.8	22.3
Largest Patch (ha)	28,252	2,171	2,885	2,885	2,885	2,559
MNN (m)	246	231	216	219	218	205
Other Upland Conifers						
Area (ha)	5,960	318	349	349	351	341
Number of Patches	27	74	84	83	83	83
Mean Patch Size (ha)	215	4.3	4.2	4.2	4.2	4.1
Largest Patch (ha)	1,503	25	25	26	26	25
MNN (m)	1,416	904	830	897	896	876

Table 2.4 (con't)

Land Cover Type	GLO	Step 1	Step 2	Step 3	Step 4	Step 5
Bottomland Conifer						
Area (ha)	34,187	16,606	17,135	16,761	17,324	16,871
Number of Patches	307	896	876	875	867	902
Mean Patch Size (ha)	111	18.5	19.6	19.2	20.0	18.7
Largest Patch (ha)	4,667	1,124	1,136	1,137	1,137	1,124
MNN (m)	256	224	231	236	233	232
Nonforest						
Grasslands						
Area (ha)	-	10,983	9,278	9,281	9,972	10,633
Number of Patches	-	1225	1324	1330	1339	1616
Mean Patch Size (ha)	-	8.97	7.01	6.98	7.45	6.58
Largest Patch (ha)	-	486	388	388	388	223
MNN (m)	-	241	216	217	213	204
Shrub/Scrub						
Area (ha)	-	6,189	4,438	4,159	4,170	10,565
Number of Patches	-	803	981	974	980	1318
Mean Patch Size (ha)	-	7.7	4.5	4.3	4.3	8.0
Largest Patch (ha)	-	204	185	185	189	356
MNN (m)	-	335	316	322	313	234
Water						
Rivers and Streams						
Area (ha)	323	637	621	621	622	621
Number of Patches	9	59	60	60	61	61
Mean Patch Size (ha)	28	10.8	10.4	10.4	10.2	10.2
Largest Patch (ha)	181	219	219	219	219	219
MNN (m)	31	50	50	50	50	50
Lakes						
Area (ha)	5,291	5,218	5,223	5,217	5,211	5,224
Number of Patches	80	98	94	87	80	93
Mean Patch Size (ha)	65	53.2	55.6	60.0	65.1	56.2
Largest Patch (ha)	4,106	4,100	4,100	4,100	4,100	4,100
MNN (m)	1,109	921	961	945	954	942

Table 2.4 (con't)

Land Cover Type	GLO	Step 1	Step 2	Step 3	Step 4	Step 5
Wetlands						
Forested Wetlands						
Area (ha)	-	1,042	965	969	587	588
Number of Patches	-	204	194	195	199	199
Mean Patch Size (ha)	-	5.1	5.0	5.0	3.0	3.0
Largest Patch (ha)	-	419	419	419	35	35
MNN (m)	-	593	584	562	532	533
Shrub/Scrub						
Area (ha)	642	5,122	4,339	4,328	4,207	4,246
Number of Patches	43	906	897	900	906	929
Mean Patch Size (ha)	15	5.7	4.8	4.8	4.6	4.6
Largest Patch (ha)	77	371	205	205	205	205
MNN (m)	2,075	327	339	337	337	326
Aquatic bed						
Area (ha)	-	238	209	209	199	201
Number of Patches	-	52	54	54	54	54
Mean Patch Size (ha)	-	4.6	3.9	3.9	3.7	3.7
Largest Patch (ha)	-	71	71	70	70	70
MNN (m)	-	2,029	1,883	1,883	1,842	1,993
Emergent						
Area (ha)	576	852	847	843	774	851
Number of Patches	79	212	219	218	217	230
Mean Patch Size (ha)	7	4.0	3.9	3.9	3.6	3.7
Largest Patch (ha)	60	119	119	119	119	119
MNN (m)	1,603	728	708	708	704	870

Table 2.5: Number of species groups gaining and losing potential habitat area from the GLO survey to Step 5 in the Black River watershed. Total number of species groups for the Black River watershed was 168.

	Time					
	GLO to Step 1		Step 1 to Step 5		GLO to Step 5	
	Gain	Loss	Gain	Loss	Gain	Loss
Number of Species Groups	42		42		42	
	52			52	52	
		2	2		2	
	5			5		5
		41	41			41
			26		26	26
Total	99	69	85	83	96	72

Table 2.6: Land cover types that were potential habiat for species groups clustered by change in potential habitat area from the GLO survey to Step 5 in the Black River watershed. Group refers to species group clusters in Figure 2.6. "X" = required. "O" = occasional. Blank = not used.

	Forest						
	Broadleaf		Conifer				
Group	Upland	Bottomland	Upland	Bottomland	Nonforest	Water	Wetlands
A					X	X	X
B				X		O	O
C	X	X			O	O	O
D			X	X			
E	X	X		X	O		
F	X	O	X		O		O
G	X	X	X		X		
H	X	X	X	X	O		O

Table 2.7: Land cover types that were potential habitat for species groups clustered by change in mean patch size of potential habitat from the GLO survey to Step 5 in the Black River watershed. Groups refer to species group clusters in Figure 2.14 and Figure 2.15. "X" = required. "O" = occasional. Blank = not used.

	Forest						
	Broadleaf		Conifer				
Group	Upland	Bottomland	Upland	Bottomland	Nonforest	Water	Wetlands
A					X		
B				O			O
C					O	O	O
D	O	O	O	O			O
E	X	O	X	X	O		O

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Table 2.8 Statistics for natural land cover (MIRIS Level 3) types from the GLO survey to Step 5 for the Huron River watershed. MNN = Mean Nearest Neighbor.

Land Cover Type	GLO	Step 1	Step 2	Step 3	Step 4	Step 5
Forest						
Central Hardwood						
Area (ha)	105,128	22,215	26,177	27,338	25,582	25,000
Number of Patches	126	2,994	2,877	2,660	2,642	2,653
Mean Patch Size (ha)	834	7.4	9.1	10.3	9.7	9.4
Largest Patch (ha)	12,022	326	331	331	274	912
MNN (m)	133	162	153	166	171	174
Northern Hardwood						
Area (ha)	-	2	2	2	2	2
Number of Patches	-	1	1	1	1	1
Mean Patch Size (ha)	-	1.5	1.5	1.5	1.5	1.5
Largest Patch (ha)	-	1.5	1.5	1.5	1.5	1.5
MNN (m)						
Bottomland Broadleaf						
Area (ha)	16,213	12,553	14,364	13,814	13,248	12,871
Number of Patches	145	1,851	1,906	1,795	1,748	1,740
Mean Patch Size (ha)	111	6.8	7.5	7.7	7.6	7.4
Largest Patch (ha)	4,721	350	362	363	364	370
MNN (m)	833	228	225	249	260	259
Aspen/White Pine						
Area (ha)	-	138	213	261	249	235
Number of Patches	-	49	55	65	63	65
Mean Patch Size (ha)	-	2.8	3.9	4.0	4.0	3.6
Largest Patch (ha)	-	25	34	37	37	28
MNN (m)	-	1,107	1,057	934	1,018	931
Pine						
Area (ha)	-	419	980	1,841	1,985	1,820
Number of Patches	-	114	212	344	357	356
Mean Patch Size (ha)	-	3.7	4.6	5.4	5.6	5.1
Largest Patch (ha)	-	71	71	71	71	71
MNN (m)	-	1,110	908	714	696	690
Other Upland Conifers						
Area (ha)	-	1	5	36	50	50
Number of Patches	-	1	3	11	15	15
Mean Patch Size (ha)	-	0.8	1.7	3.3	3.3	3.3
Largest Patch (ha)	-	1	3	16	16	16
MNN (m)	-	0	24,526	2,115	3,298	3,298

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Table 2.8 (con't)

Land Cover Type	GLO	Step 1	Step 2	Step 3	Step 4	Step 5
Bottomland Conifer						
Area (ha)	9,568	261	355	397	402	399
Number of Patches	206	59	76	89	93	93
Mean Patch Size (ha)	46	4.4	4.7	4.5	4.3	4.3
Largest Patch (ha)	1,309	33	34	34	34	34
MNN (m)	813	1,236	1,291	1,135	1,178	1,178
Nonforest						
Grasslands						
Area (ha)	49	11,148	13,478	19,976	25,015	20,833
Number of Patches	4	1,262	1,583	2,041	2,456	2,574
Mean Patch Size (ha)	12	8.8	8.5	9.8	10.2	8.1
Largest Patch (ha)	28	191	191	294	185	167
MNN (m)	5,375	281	263	206	180	181
Shrub/Scrub						
Area (ha)	68,041*	14,039	18,896	20,837	20,739	18,442
Number of Patches	90	1,514	1,986	2,392	2,677	2,631
Mean Patch Size (ha)	756	9.3	9.5	8.7	7.7	7.0
Largest Patch (ha)	27,211	308	724	437	309	300
MNN (m)	359	272	232	208	193	195
Water						
Rivers and Streams						
Area (ha)	725	1,427	1,403	1,409	1,413	1,443
Number of Patches	7	184	179	180	179	181
Mean Patch Size (ha)	104	7.8	7.8	7.8	7.9	8.0
Largest Patch (ha)	602	227	223	243	243	243
MNN (m)	757	40	40	41	40	41
Lakes						
Area (ha)	6,622	6,815	6,966	7,317	7,409	7,824
Number of Patches	220	576	581	679	691	758
Mean Patch Size (ha)	30.1	11.8	12.0	10.8	10.7	10.3
Largest Patch (ha)	334	254	254	255	255	255
MNN (m)	723	510	566	495	484	451

*Represents a combination of oak barrens and oak openings

Table 2.8 (con't)

Land Cover Type	GLO	Step 1	Step 2	Step 3	Step 4	Step 5
Wetlands						
Forested Wetlands						
Area (ha)	-	859	781	696	667	653
Number of Patches	-	197	154	112	102	102
Mean Patch Size (ha)	-	4.4	5.1	6.2	6.5	6.4
Largest Patch (ha)	-	54	40	40	40	40
MNN (m)	-	1,023	972	1,063	1,193	1,129
Shrub/Scrub						
Area (ha)	496	14,987	11,482	10,414	10,206	10,064
Number of Patches	26	2,268	2,077	2,002	2,002	1,991
Mean Patch Size (ha)	19	6.6	5.5	5.2	5.1	5.1
Largest Patch (ha)	59	155	79	91	77	77
MNN (m)	3,989	211	241	248	249	250
Aquatic bed						
Area (ha)	34	483	477	442	431	400
Number of Patches	1	120	120	108	105	104
Mean Patch Size (ha)	34	4.0	4.0	4.1	4.1	3.9
Largest Patch (ha)	34	33	33	33	33	24
MNN (m)	-	1,147	1,037	1,031	1,103	1,098
Emergent						
Area (ha)	28,827	6,122	4,628	4,420	4,344	4,234
Number of Patches	356	1,022	900	872	870	872
Mean Patch Size (ha)	81	6.0	5.1	5.1	5.0	4.9
Largest Patch (ha)	4,200	160	127	113	113	110
MNN (m)	386	306	336	327	331	334

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Table 2.9: Number of species groups gaining and losing potential habitat area from the GLO survey to Step 5 in the Huron River watershed. Total number of species groups for the Huron River watershed was 181.

	Time					
	GLO to Step 1		Step 1 to Step 5		GLO to Step 5	
	Gain	Loss	Gain	Loss	Gain	Loss
Number of Species Groups	22		22		22	
	17			17	17	
		11	11		11	
	4			4		4
		102	102			102
		25		25		25
Total	43	138	135	66	50	131

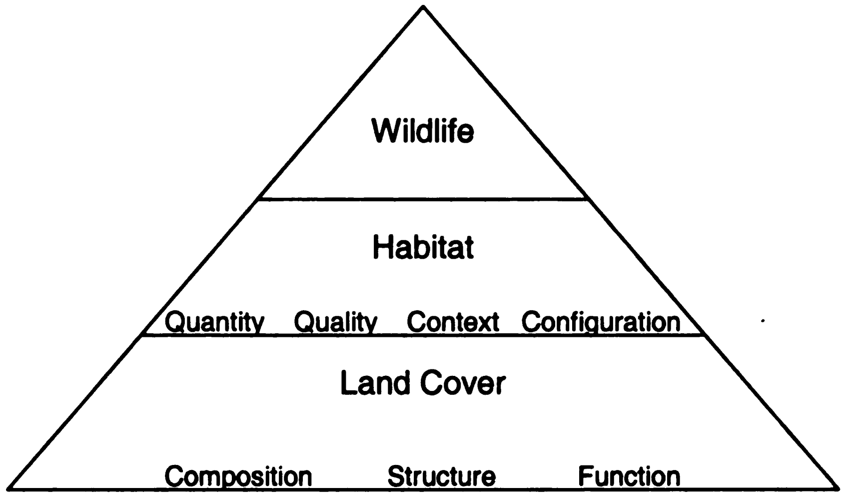

Figure 2.1: Conceptual relationship between land cover, habitat, and wildlife.

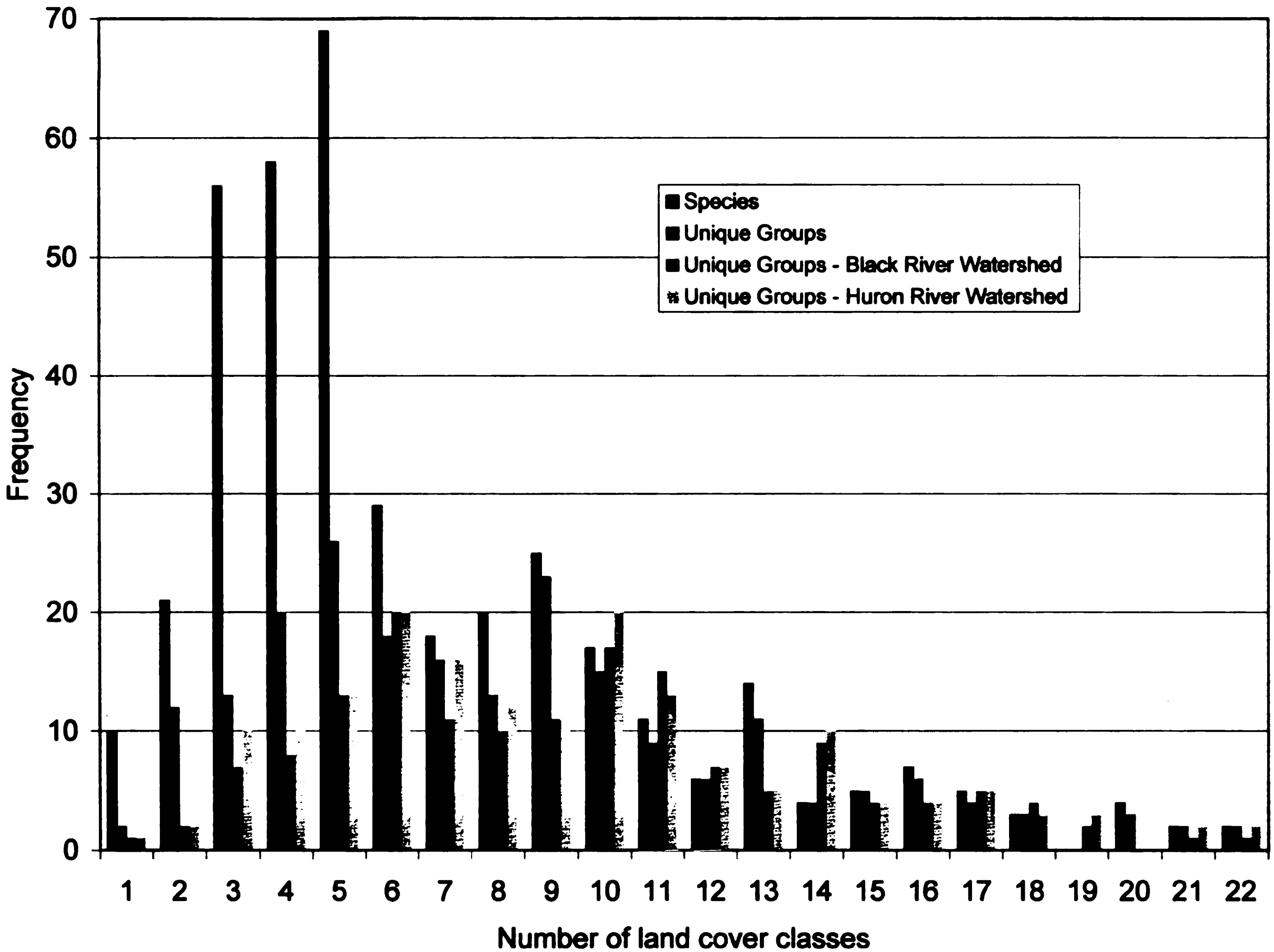

Figure 2.2: Frequency of species and unique species groups by number of land cover types.


Frequency

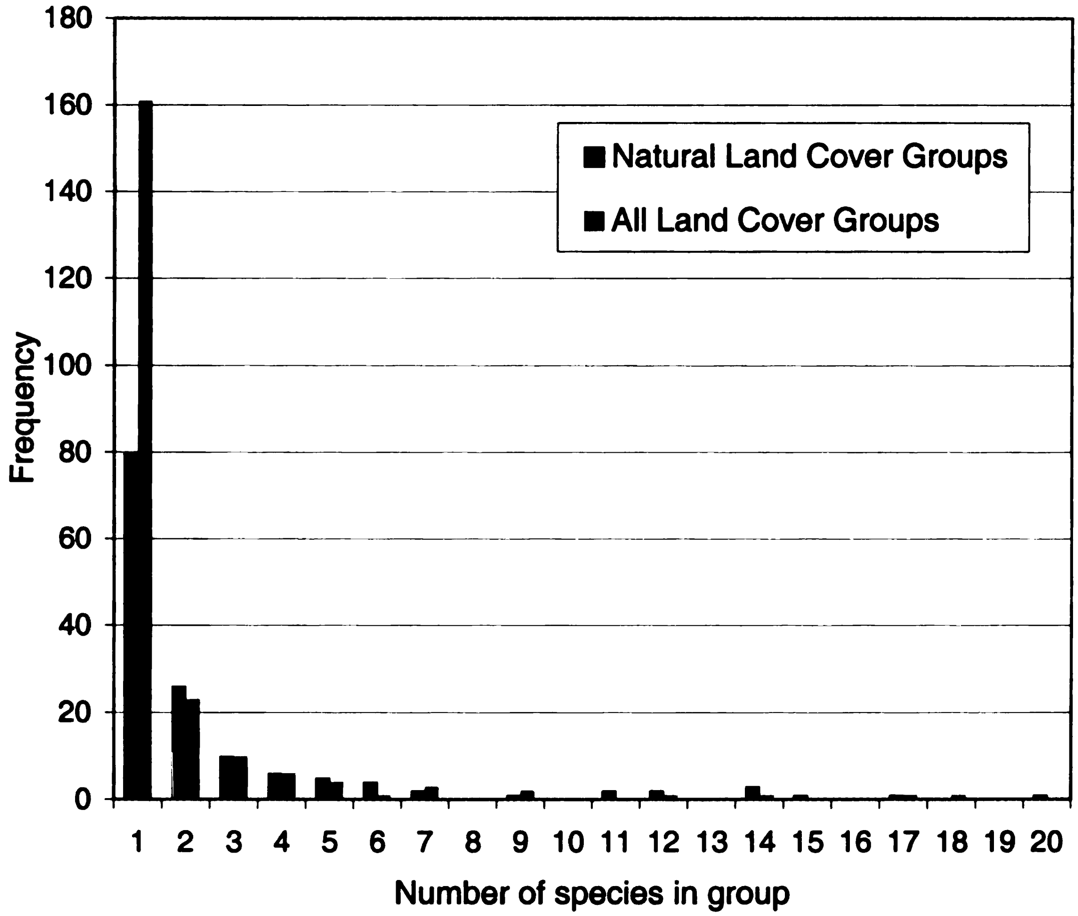

Figure 2.3: Frequency of the number of species in species groups based on natural and all land cover types.

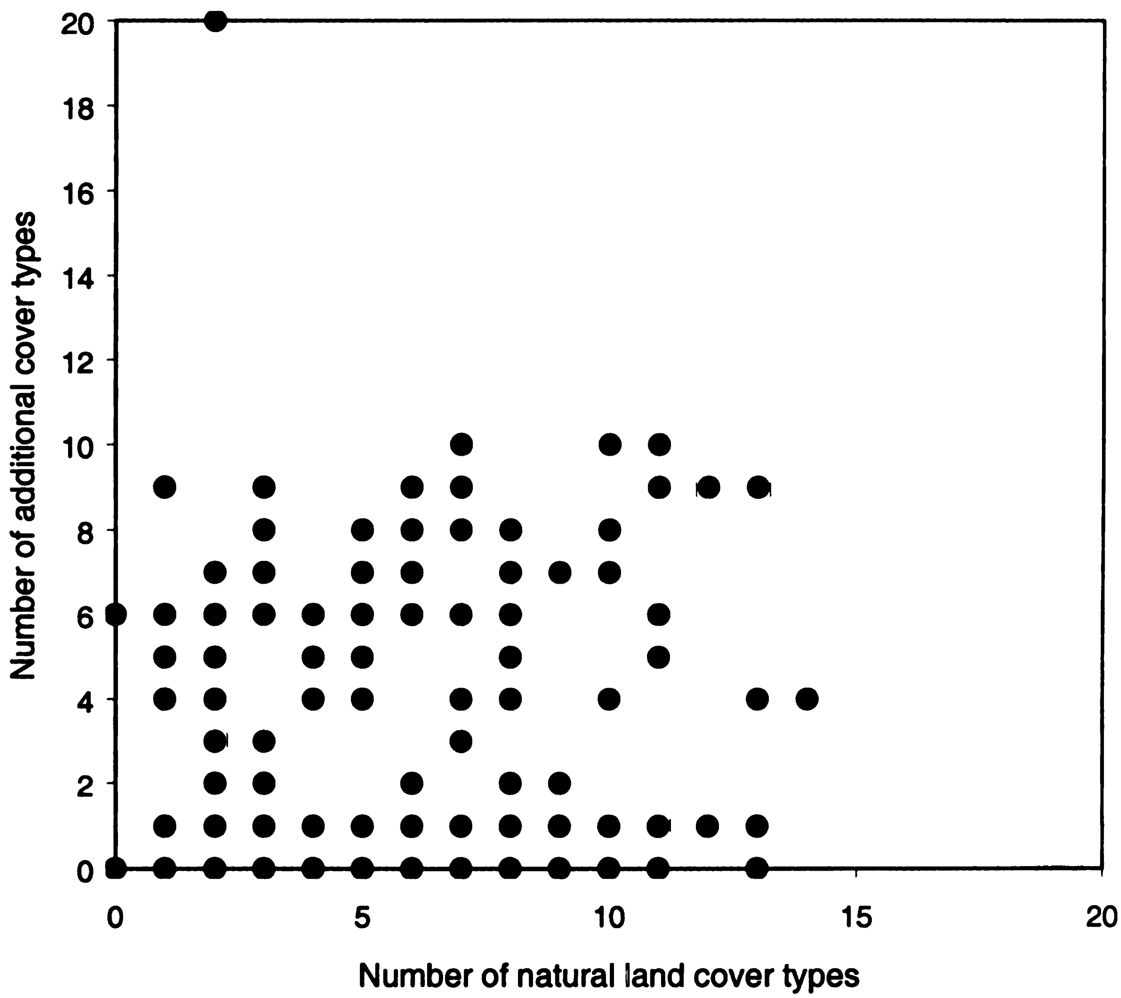

Figure 2.4: Number of natural land cover types that were potential habitat versus the number of additional (agriculture, urban, reservoirs) land cover types that were potential habitat for each species group.

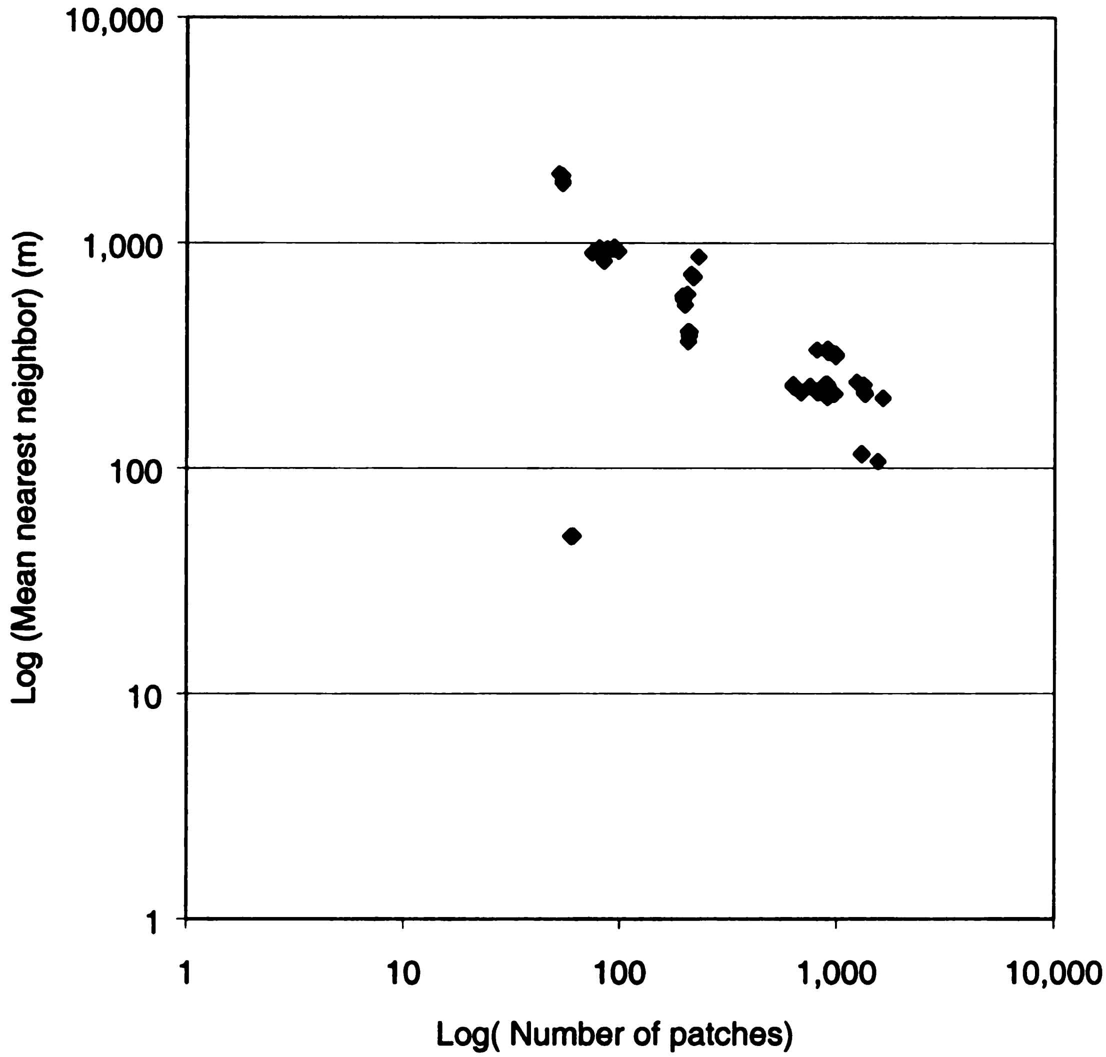

Figure 2.5: Correlation between number of patches and mean nearest neighbor distance for natural land cover types in the Black River watershed.

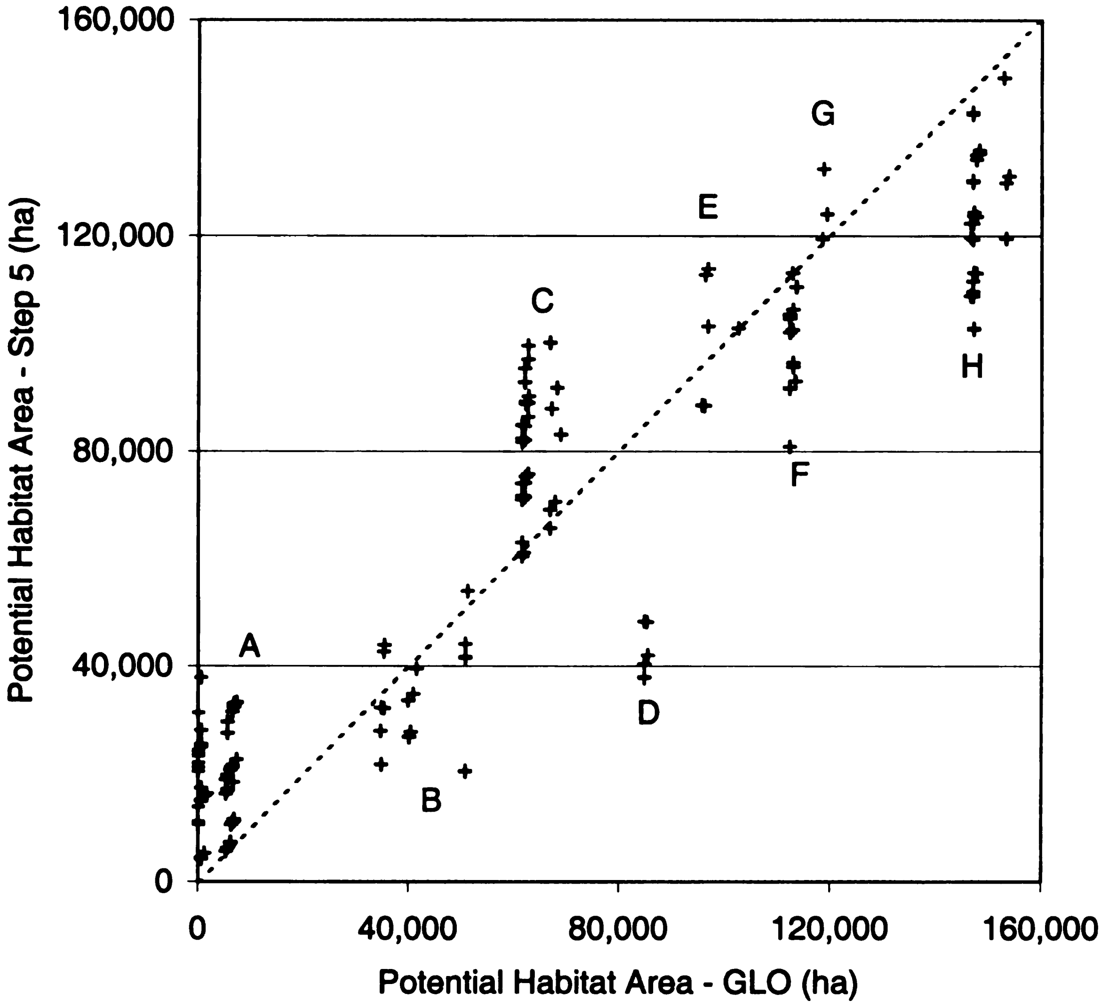

Figure 2.6: Change in area of potential habitat for species groups from the GLO survey to Step 5 in the Black River watershed.

Potential Habitat Area - Step 1 (ha)

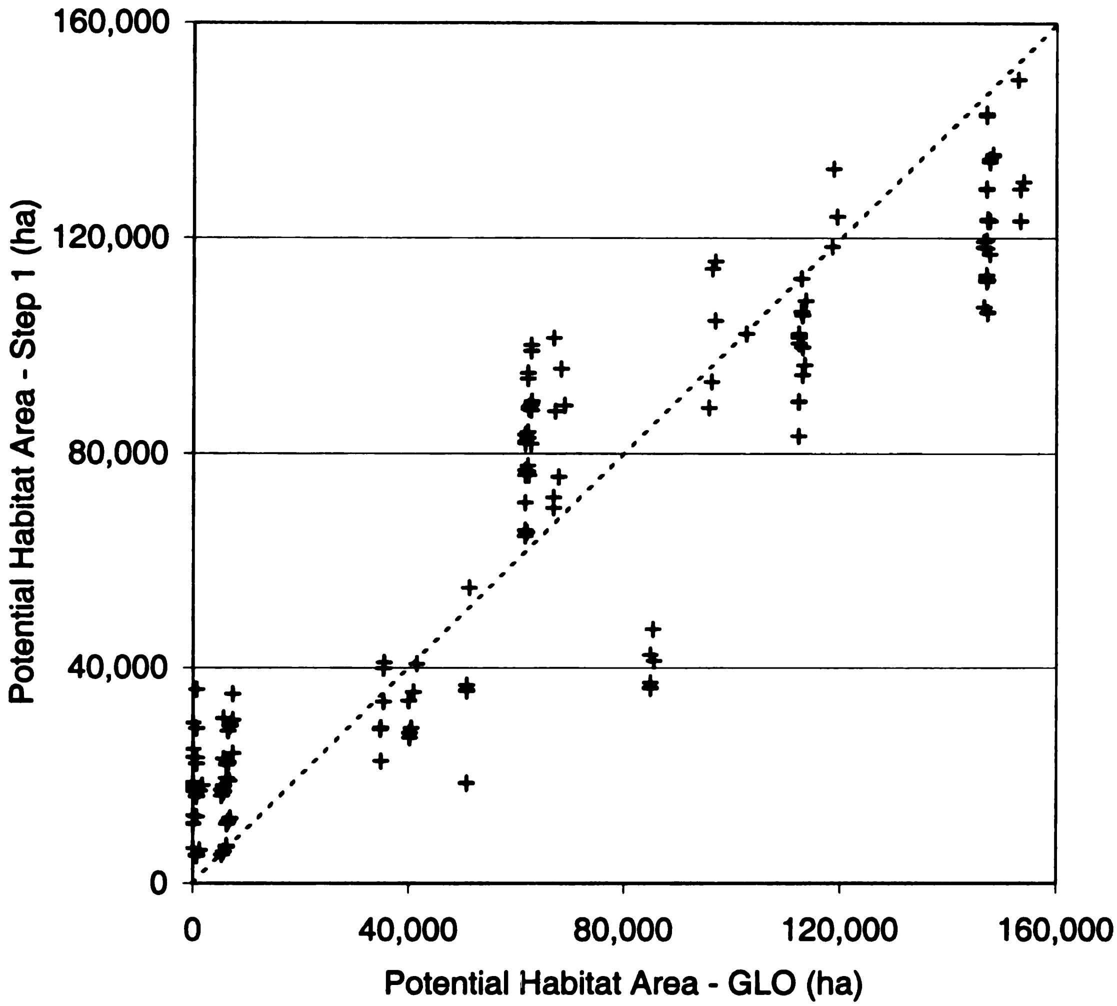

Figure 2.7: Change in area of potential habitat for species groups from the GLO survey to Step 1 in the Black River watershed.

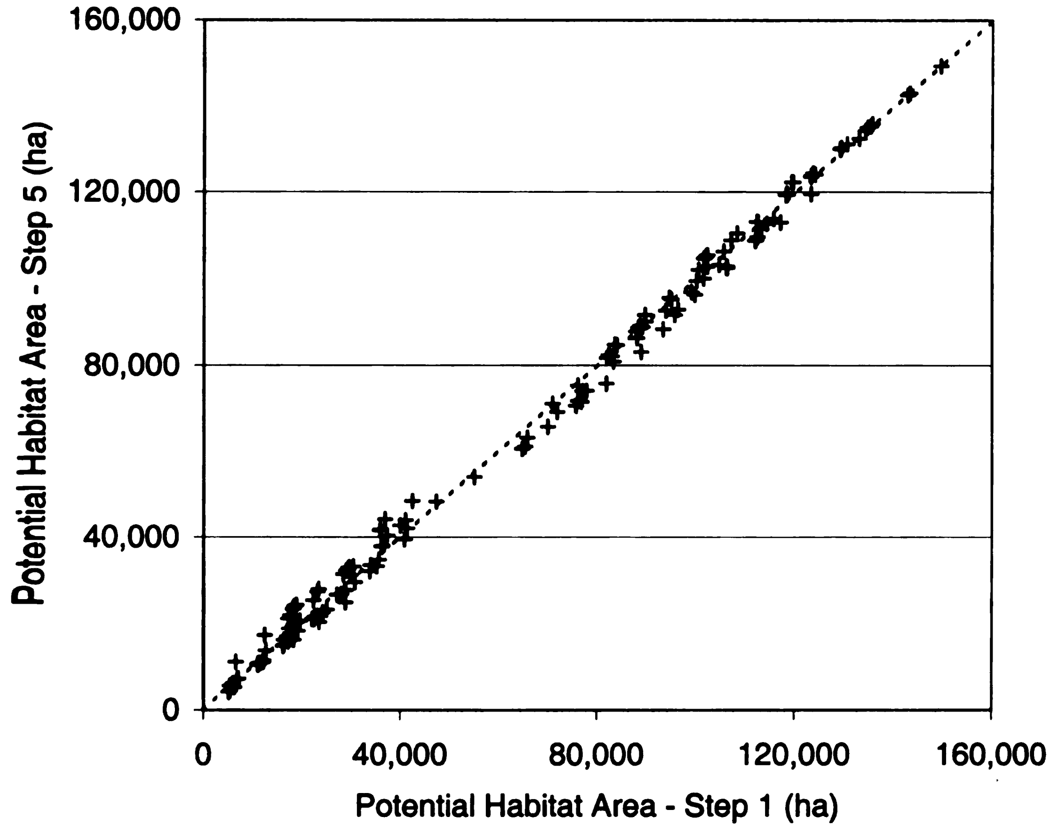

Figure 2.8: Change in area of potential habitat for species groups from Step 1 to Step 5 in the Black River watershed.

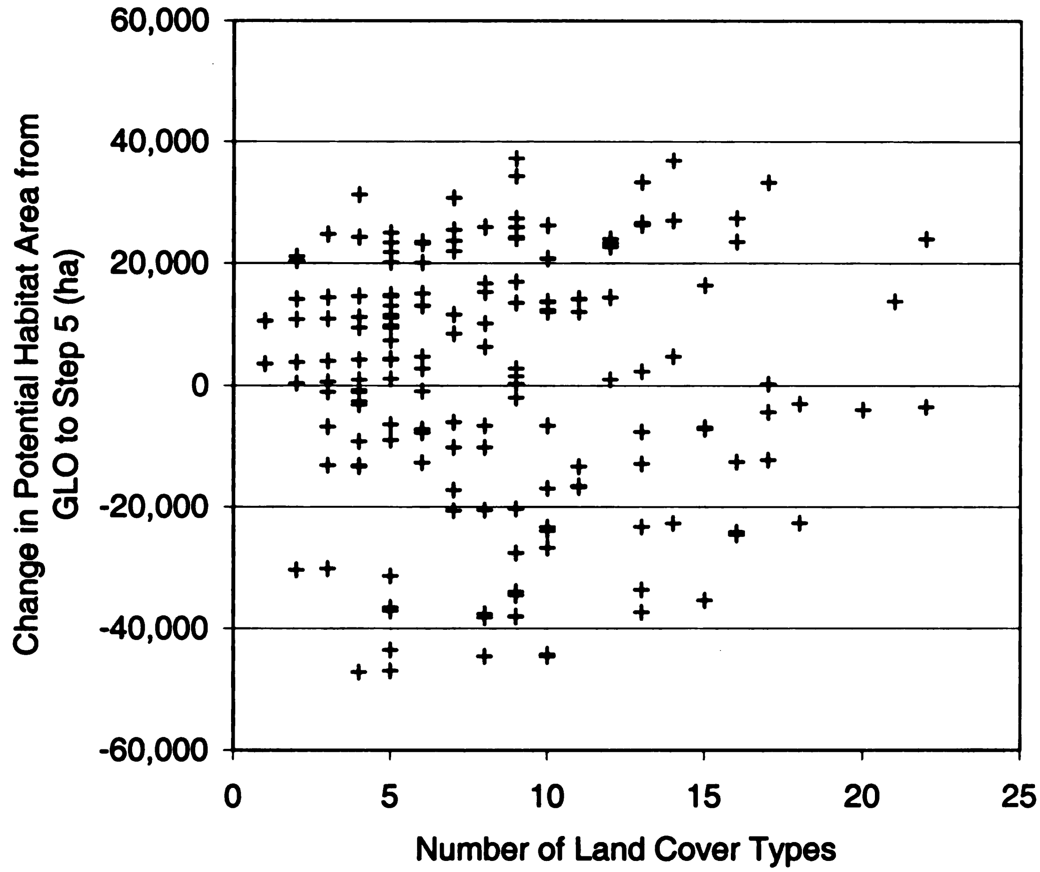

Figure 2.9: Correlation between the number of all land cover types that were potential habitat and change in potential habitat area for species groups from the GLO survey to Step 5 in the Black River watershed.

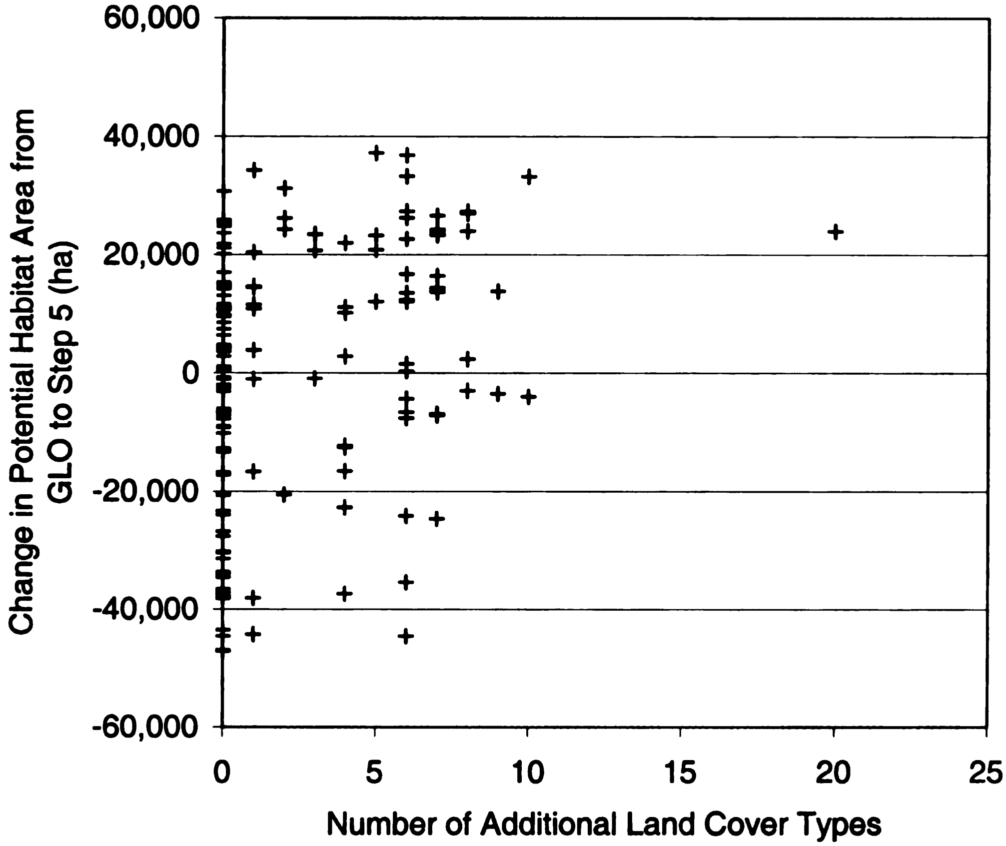

Figure 2.10: Correlation between the number of additional land cover types (agriculture, reservoirs, urban) that were potential habitat and change in potential habitat area for species groups from the GLO survey to Step 5 in the Black River watershed. # of additional land cover types = # of all land cover types - # of natural land cover types (see text).

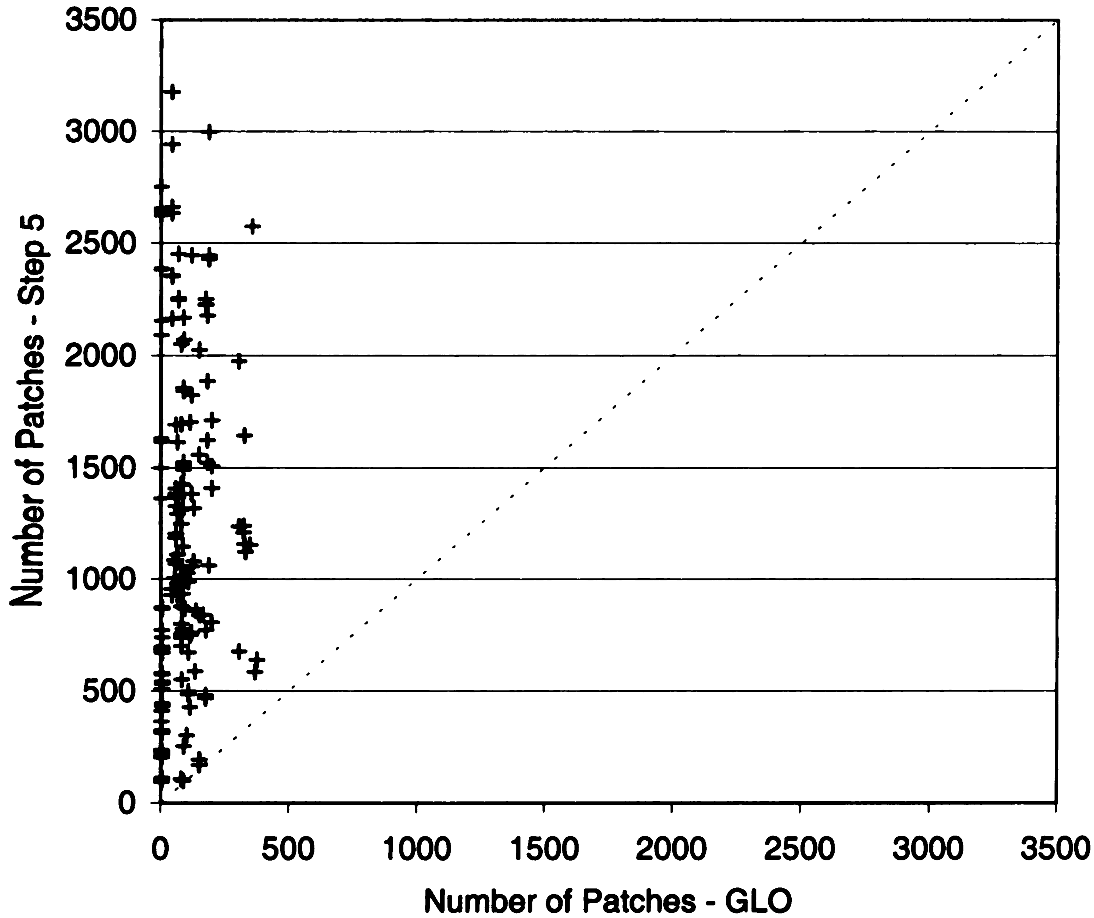

Figure 2.11: Change in the number of patches of potential habitat for species groups from the GLO survey to Step 5 in the Black River watershed.

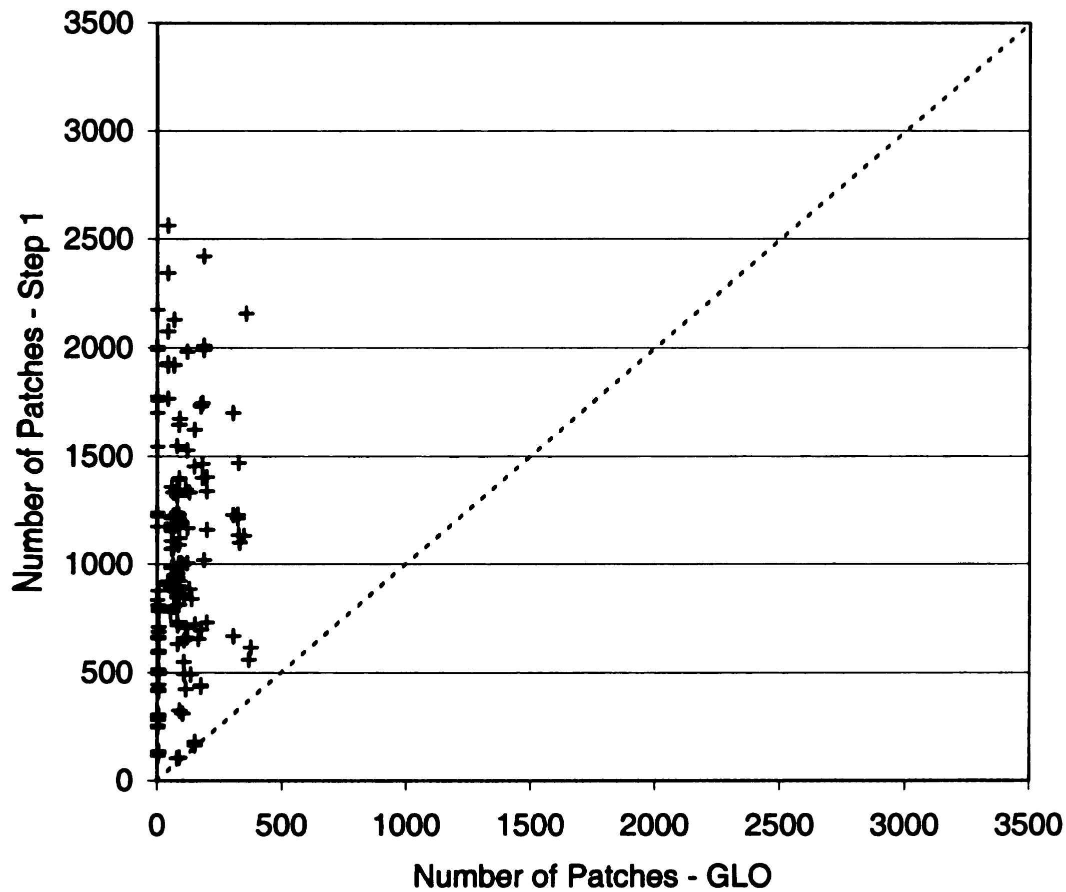

Figure 2.12: Change in the number of patches of potential habitat for species groups from the GLO survey to Step 1 in the Black River watershed.

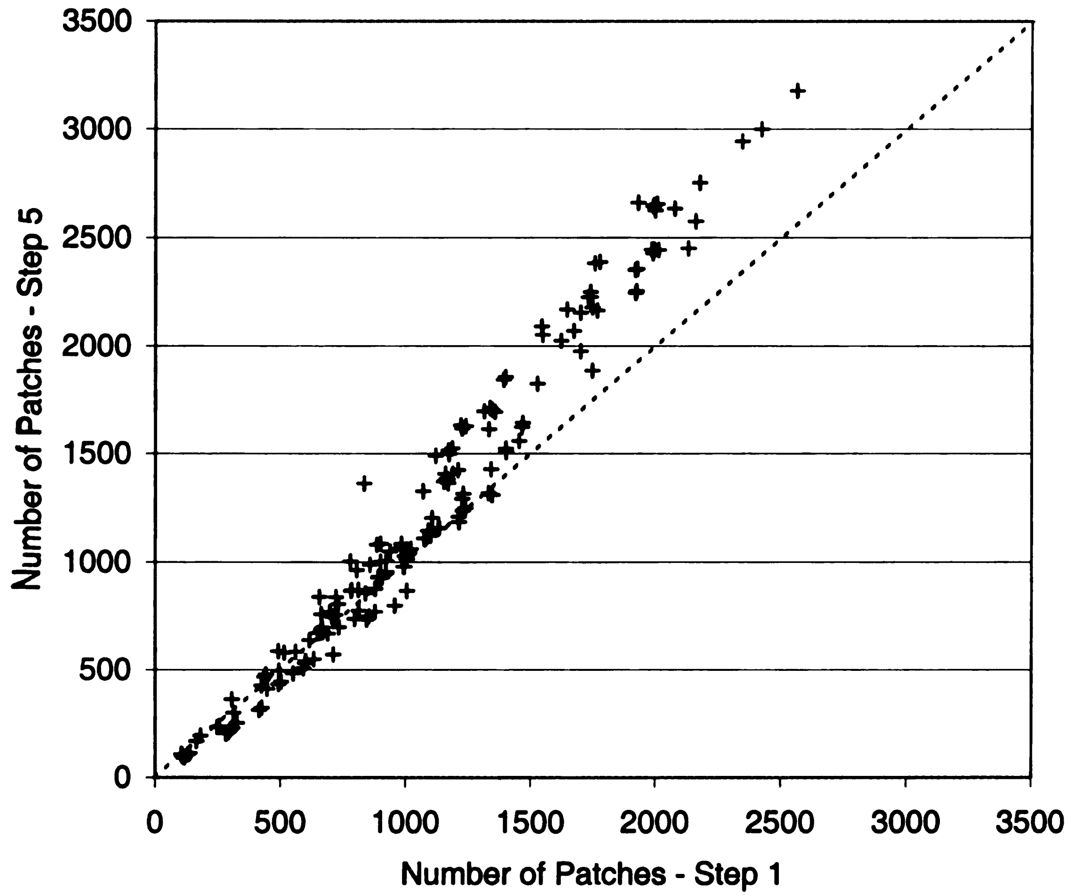

Figure 2.13: Change in the number of patches of potential habitat for species groups from Step 1 to Step 5 in the Black River watershed.

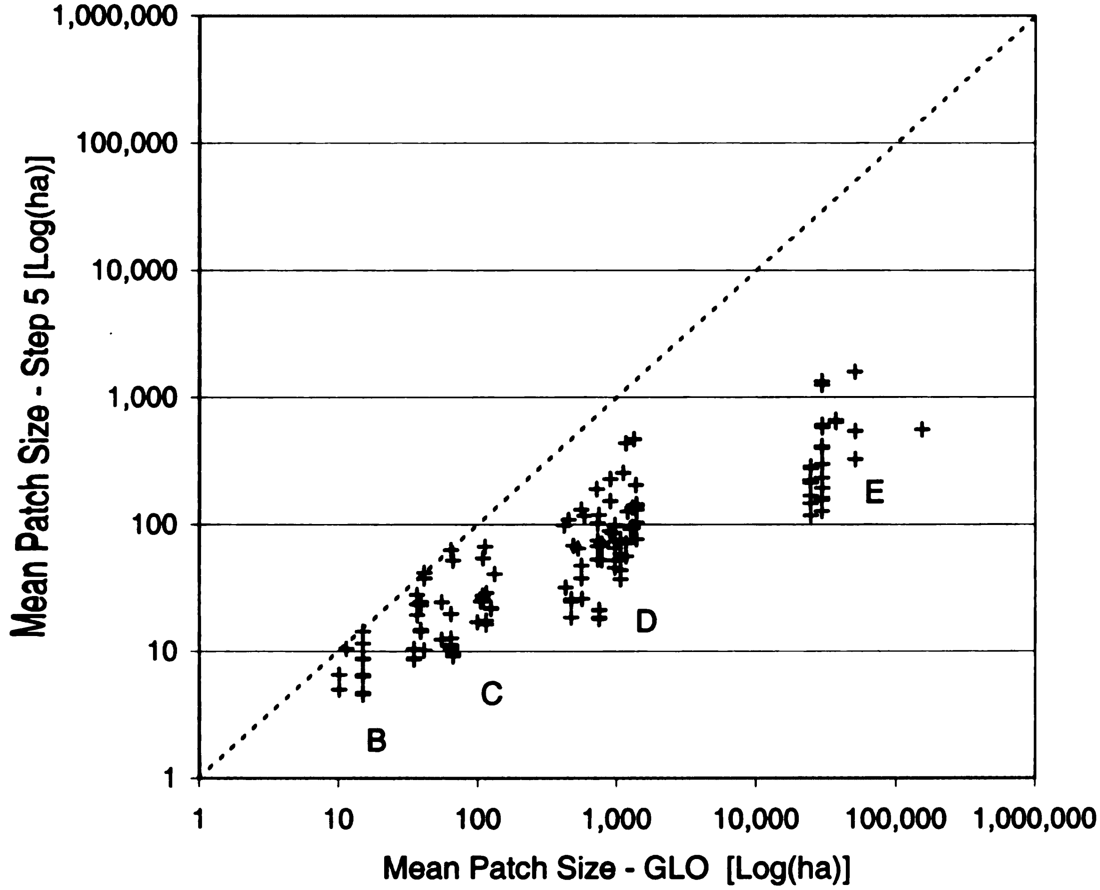

Figure 2.14: Change in the mean patch size of potential habitat for species groups from the GLO survey to Step 5 in the Black River watershed. Group A had no potential habiatat at the time of the GLO survey and therefore does not appear.

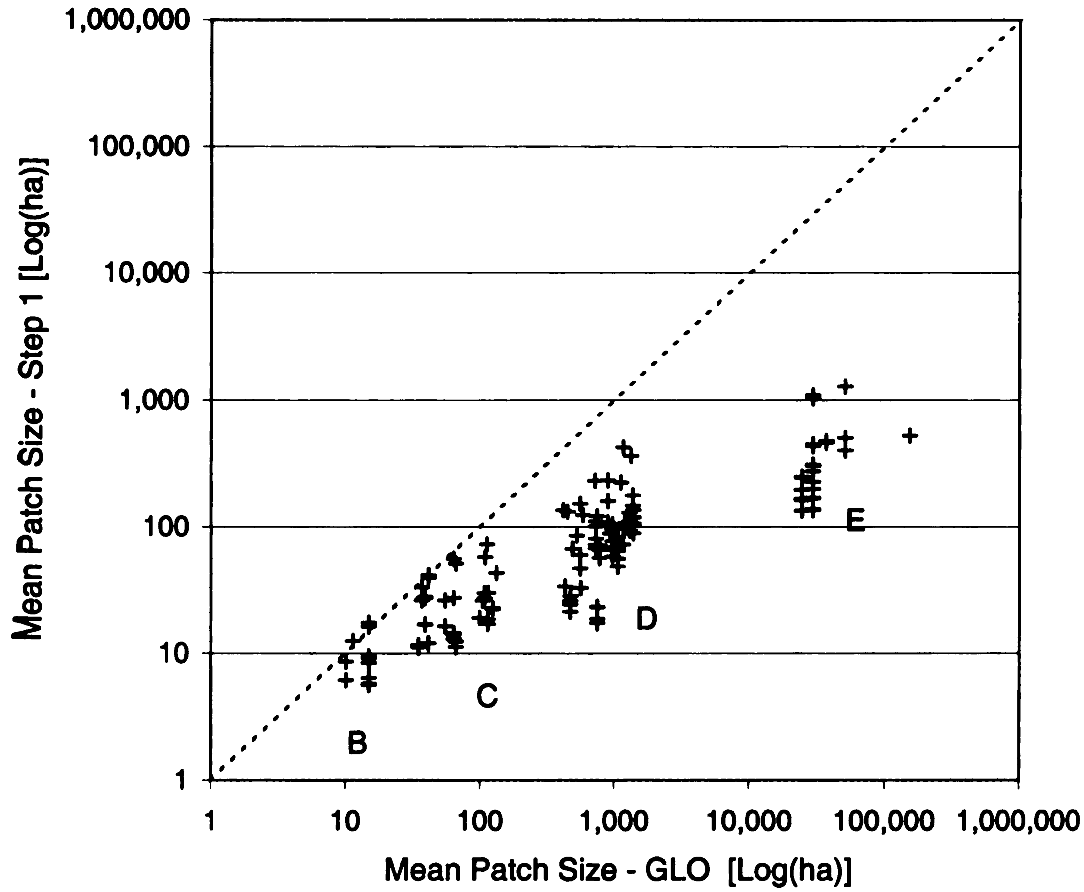

Figure 2.15: Change in the mean patch size of potential habitat for species groups from the GLO survey to Step 1 in the Black River watershed. Group A had no potential habitat at the time of the GLO survey and therfore does not appear.

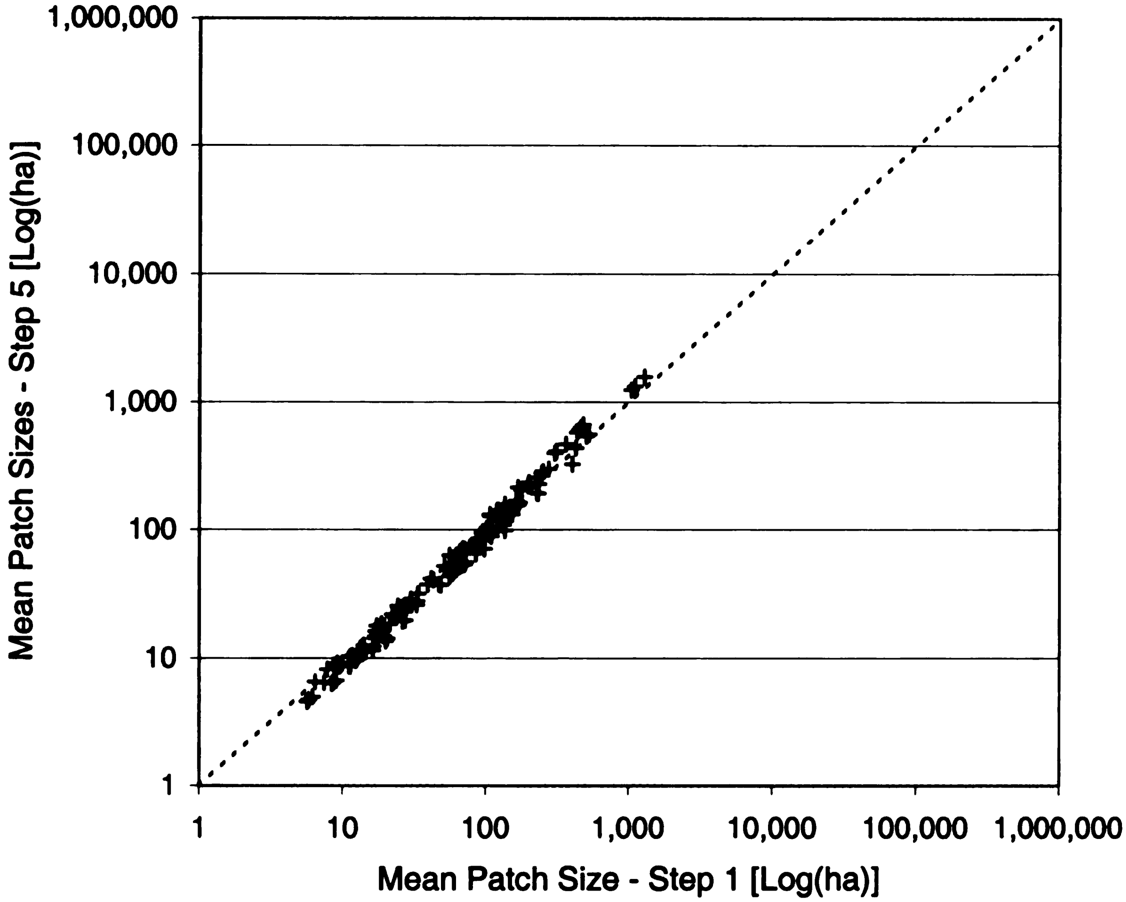

Figure 2.16: Change in the mean patch size of potential habitat for species groups from Step 1 to Step 5 in the Black River watershed.

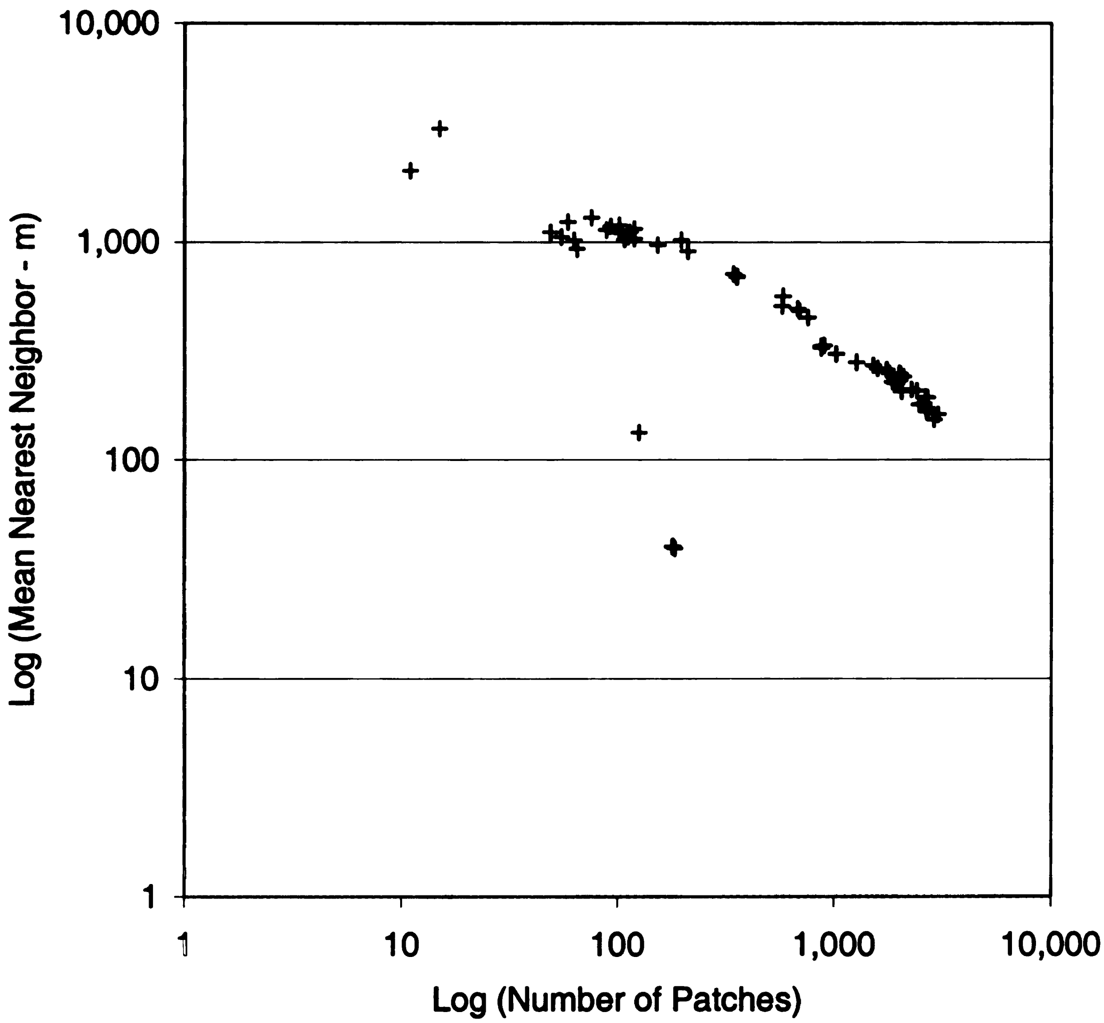

Figure 2.17: Correlation between number of patches and mean nearest neighbor distance for natural land cover types in the Huron River watershed.

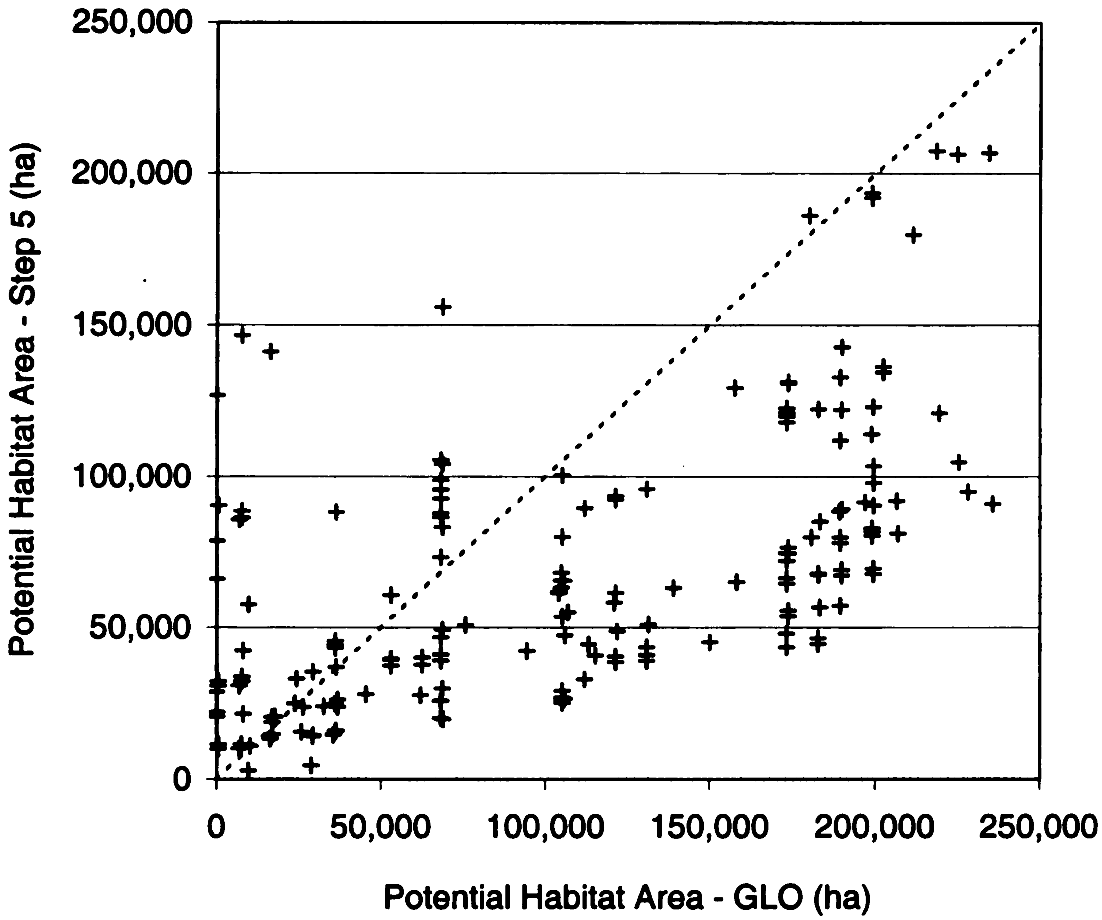

Figure 2.18: Change in area of potential habitat for species groups from the GLO survey to Step 5 in the Huron River watershed.

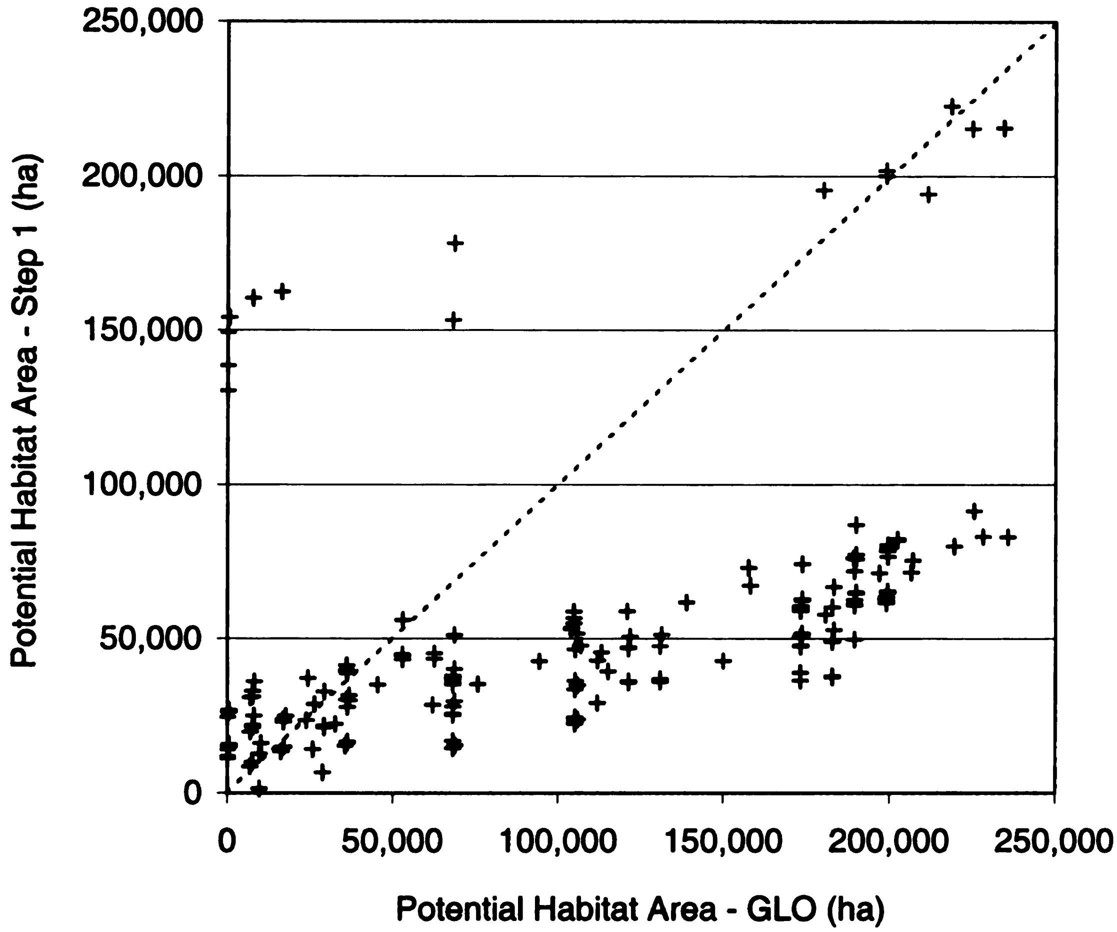

Figure 2.19: Change in area of potential habitat for species groups from the GLO survey to Step 1 in the Huron River watershed.

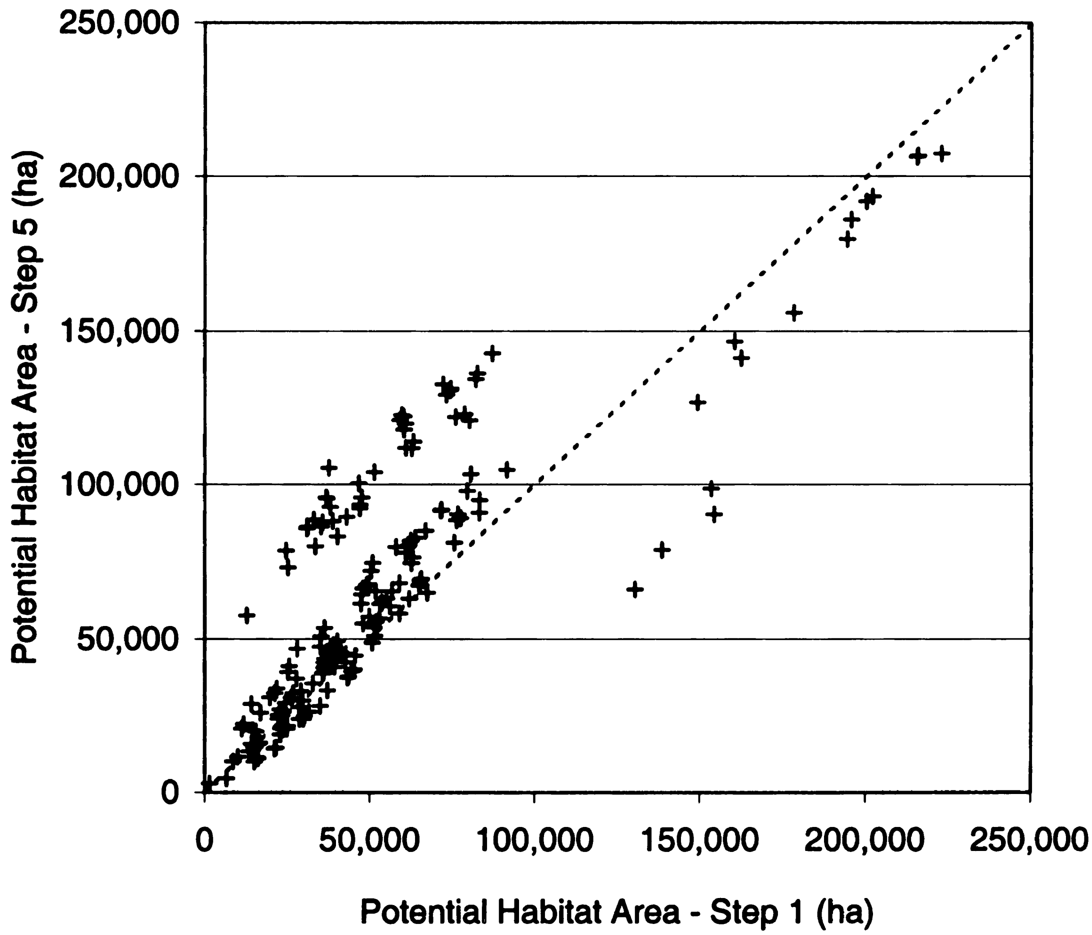

Figure 2.20: Change in area of potential habitat for species groups from Step 1 to Step 5 in the Huron River watershed.

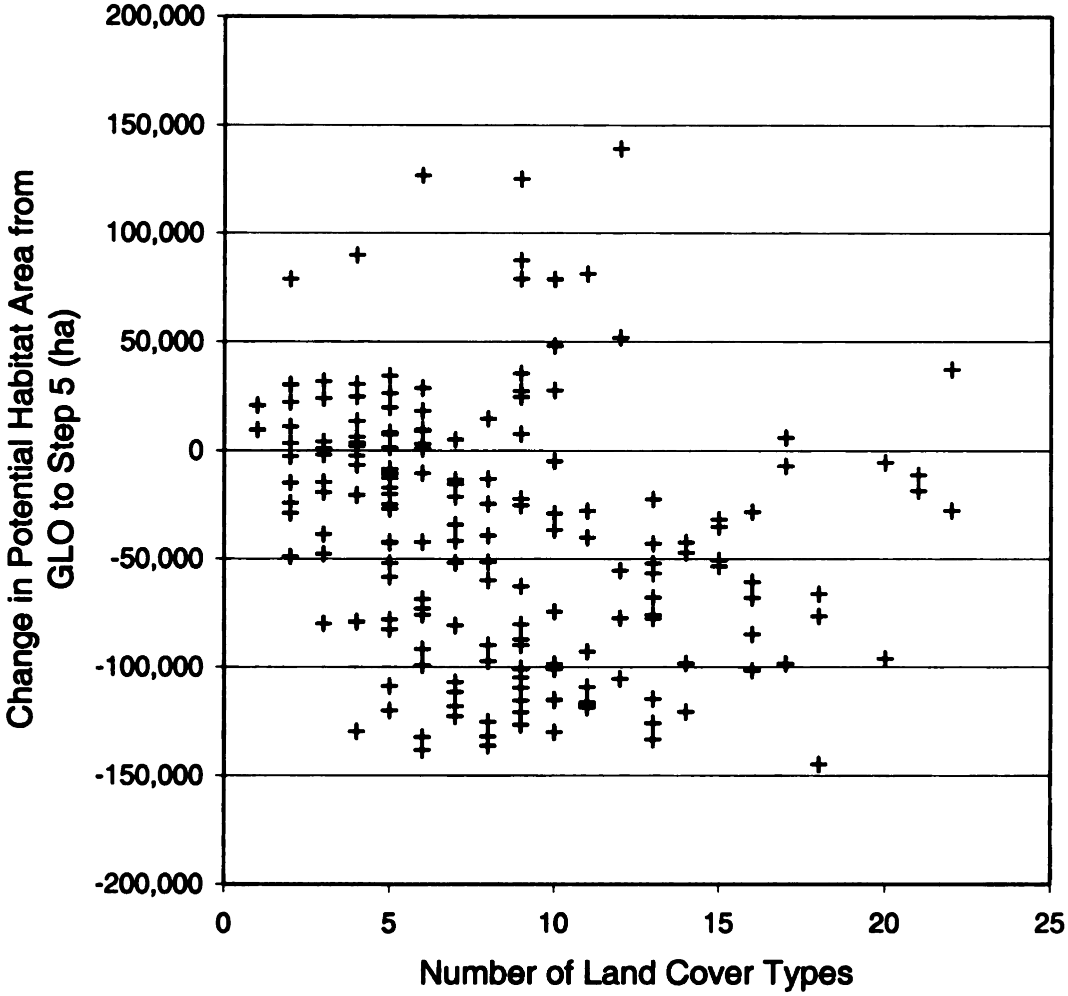

Figure 2.21: Correlation between the number of all land cover types that were potential habitat and change in potential habitat area for species groups from the GLO survey to Step 5 in the Huron River watershed.

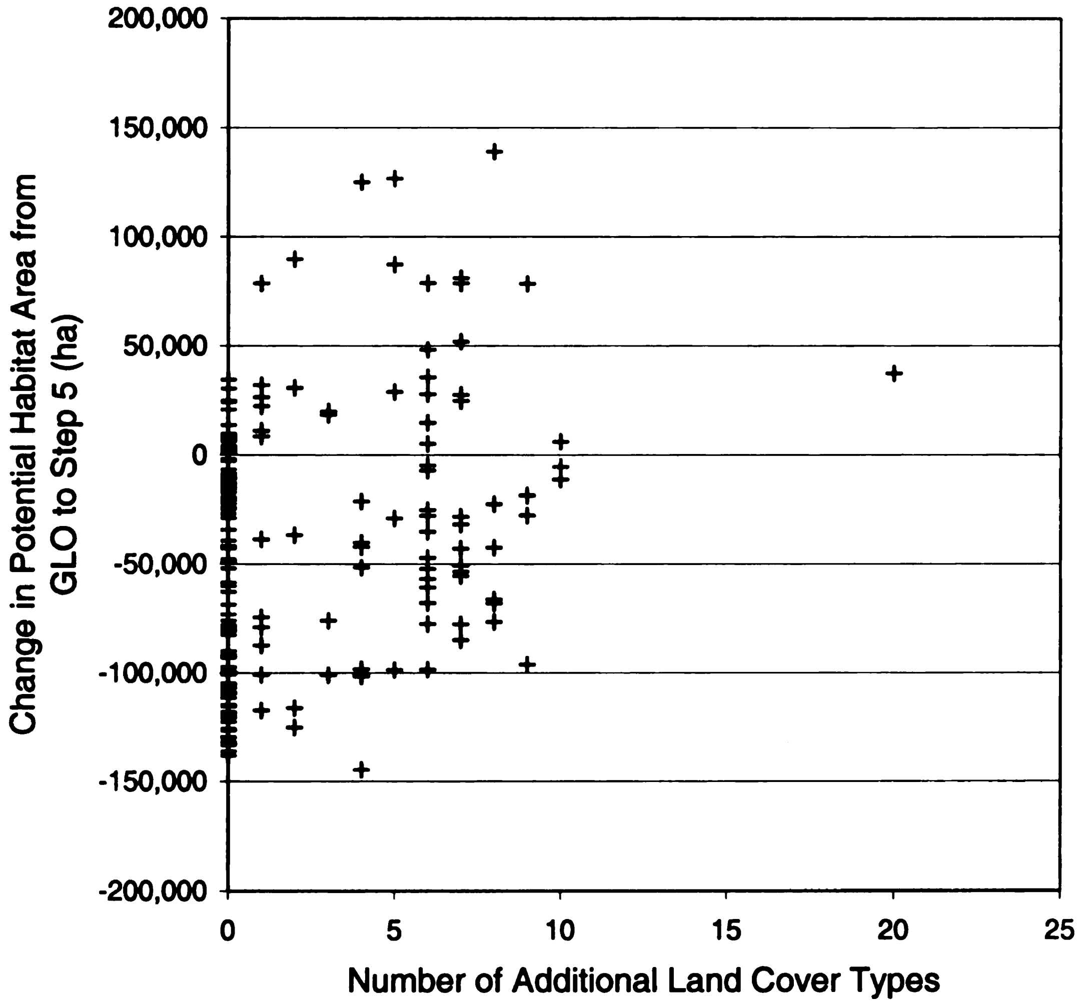

Figure 2.22: Correlation between the number of additional land cover types (agriculture, reservoirs, urban) that were potential habitat and change in potential habitat area for species groups from the GLO survey to Step 5 in the Huron River watershed. # of additional land cover types = # of all land cover types - # of natural land cover types (see text).

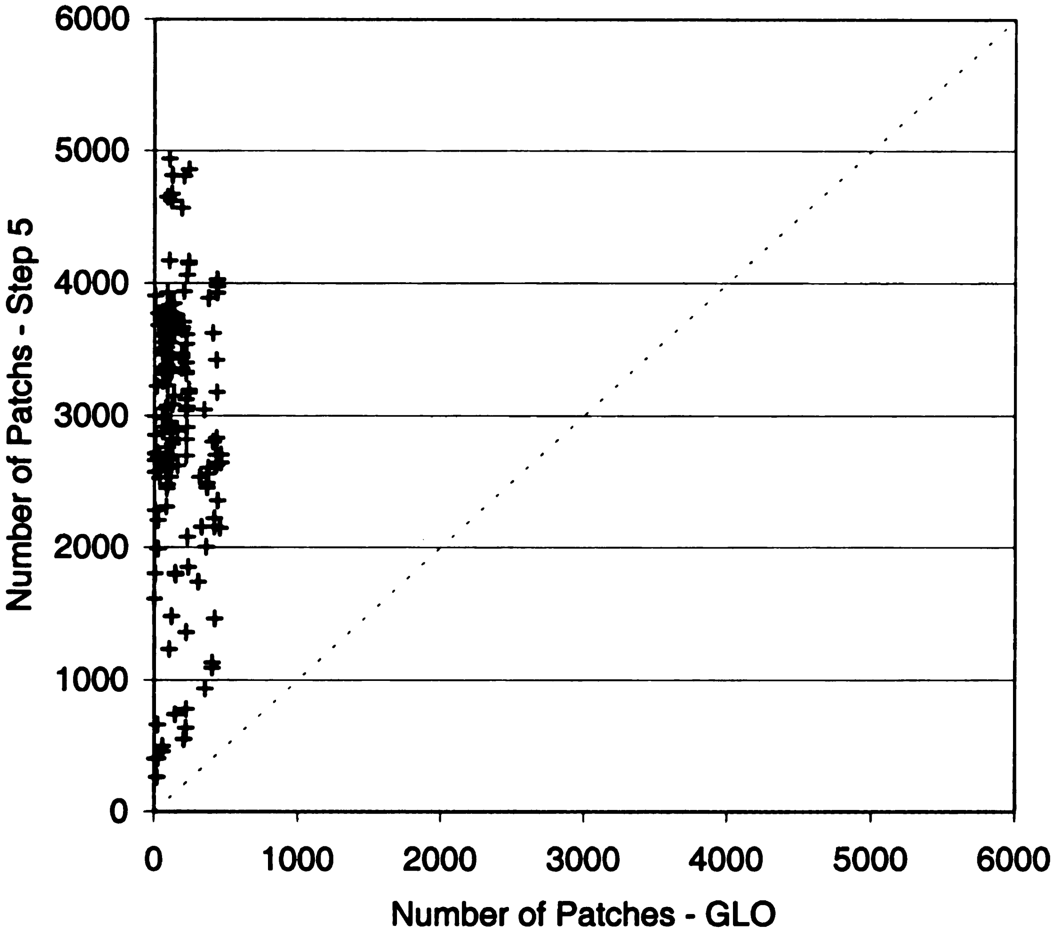

Figure 2.23: Change in the number of patches of potential habitat for species groups from the GLO survey to Step 5 in the Huron River watershed.

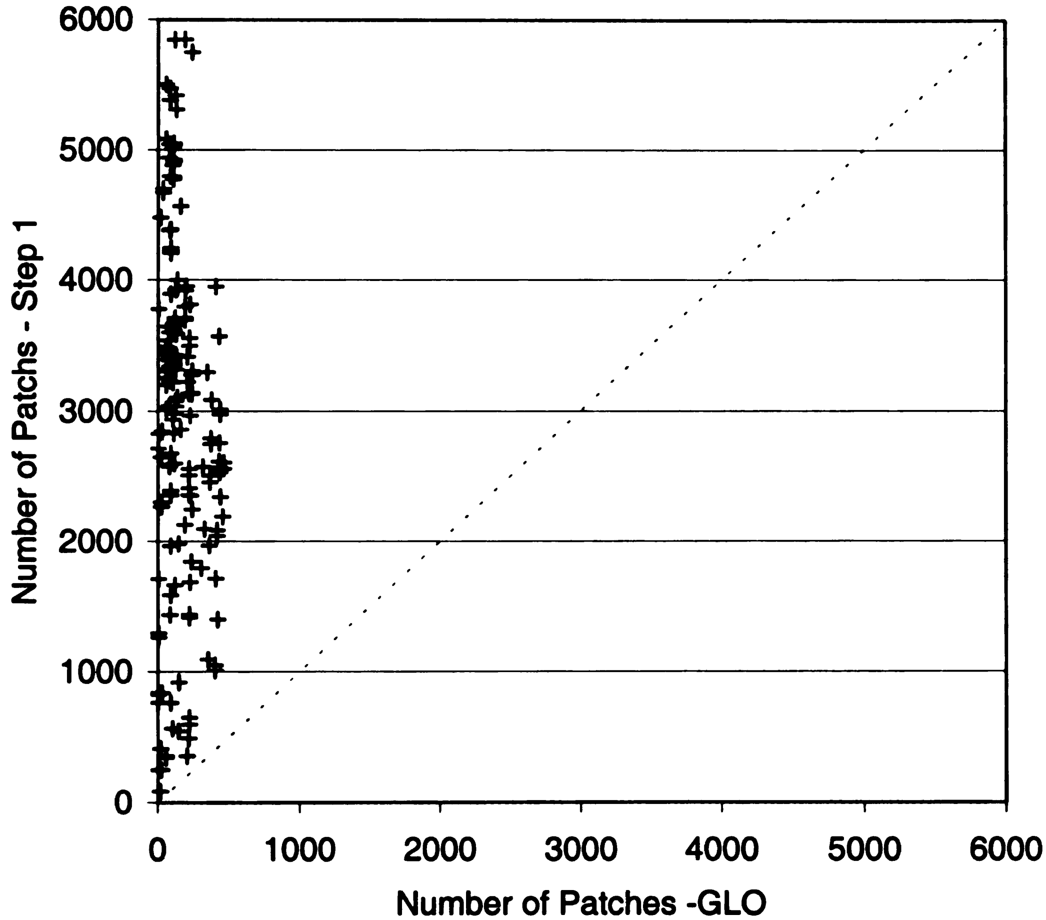

Figure 2.24: Change in the number of patches of potential habitat for species groups from the GLO survey to Step 1 in the Huron River watershed.

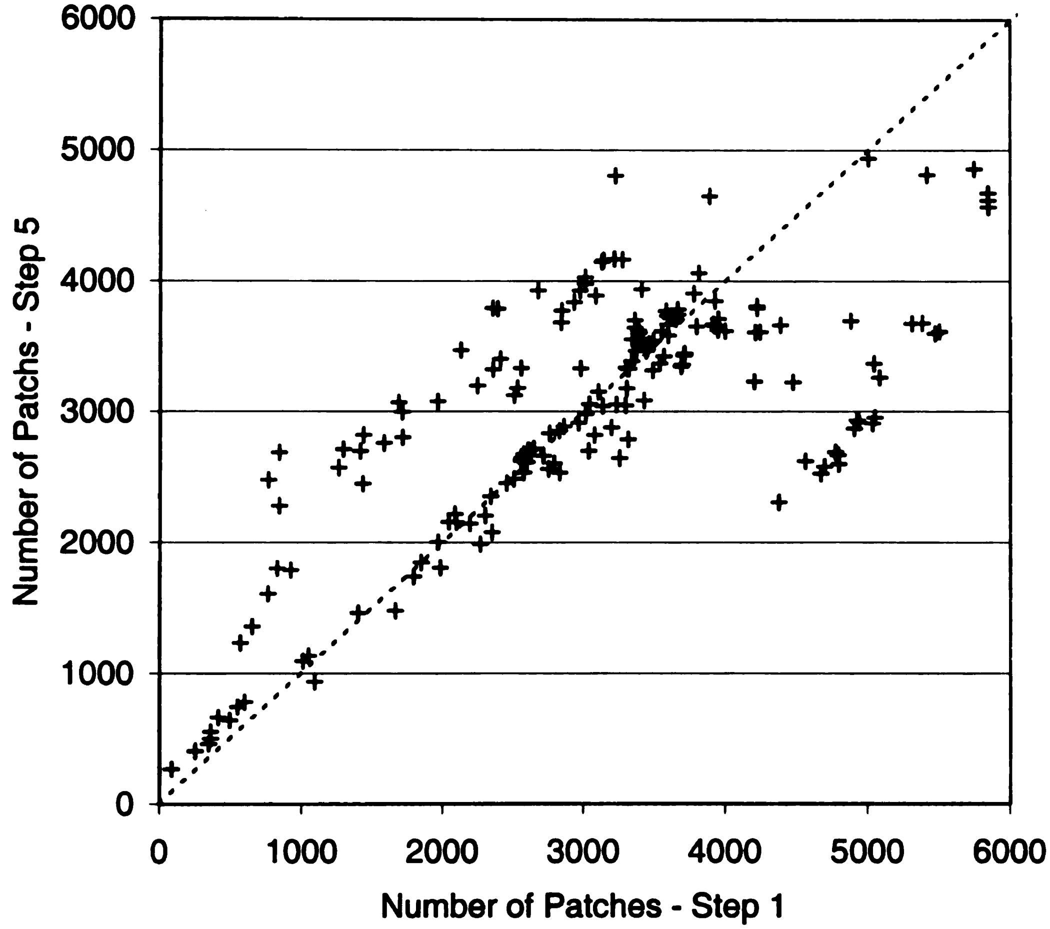

Figure 2.25: Change in the number of patches of potential habitat for species groups from Step 1 to Step 5 in the Huron River watershed.

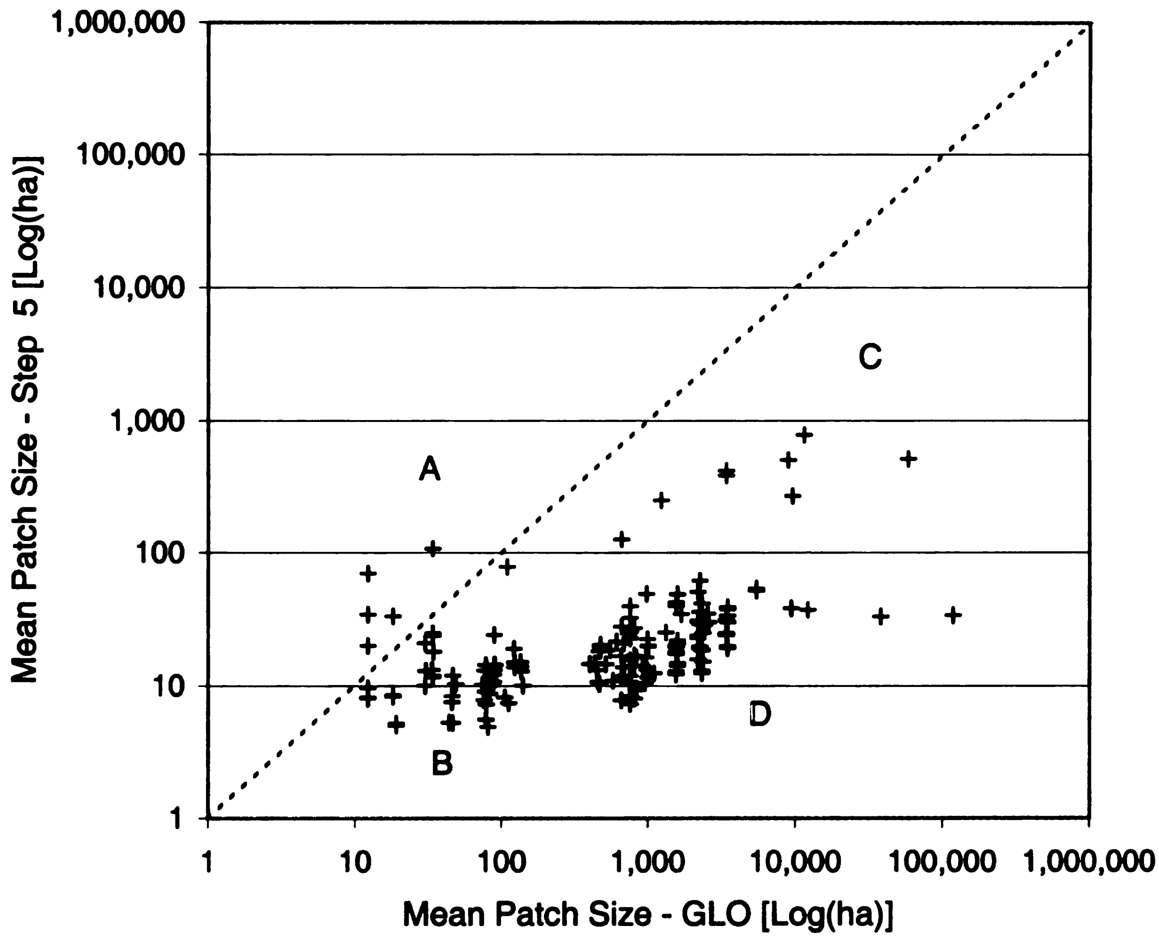

Figure 2.26: Change in the mean patch size of potential habitat for species groups from the GLO survey to Step 5 in the Huron River watershed.

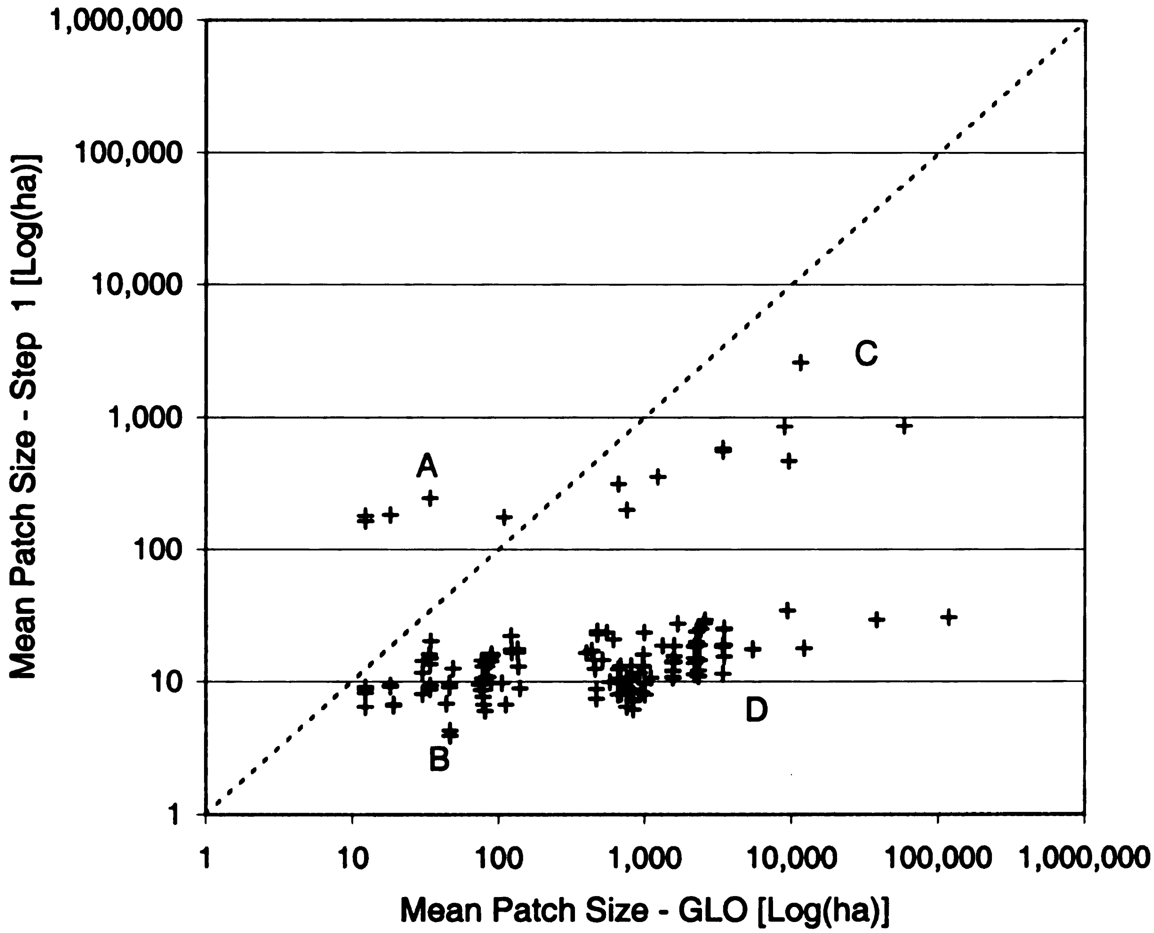

Figure 2.27: Change in the mean patch size of potential habitat for species groups from the GLO survey to Step 1 in the Huron River watershed.

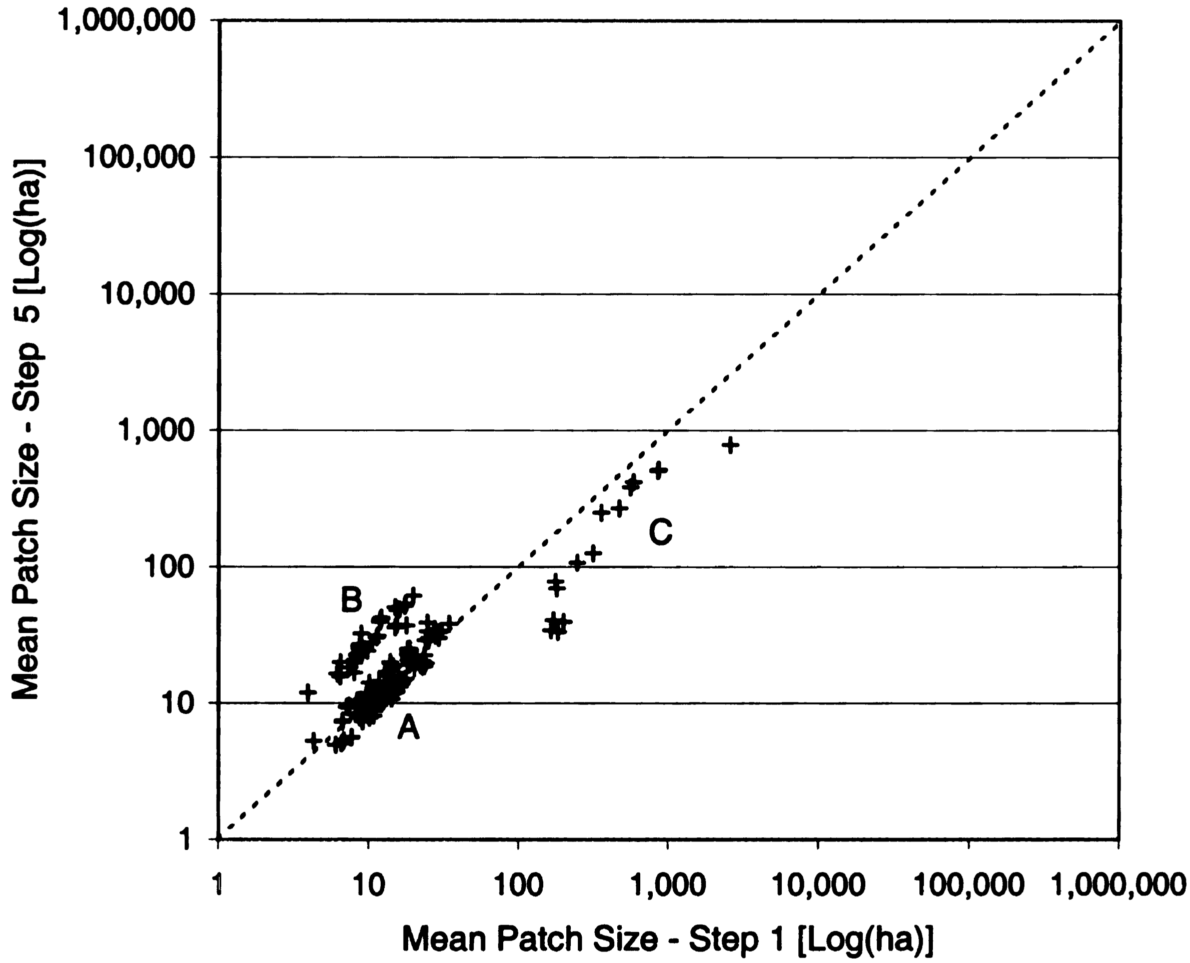

Figure 2.28: Change in the mean patch size of potential habitat for species groups from Step 1 to Step 5 in the Huron River watershed.

CHAPTER 3

FUTURE TRENDS IN LAND COVER CHANGE

Introduction

The increasing extent and rate of human activity has spurred the need to understand the patterns, causes, and potential consequences of land cover change that results from those activities (Turner, B.L. et al. 1995, Lambin et al. 1999). Understanding possible implications of present land cover conditions and future land cover change for wildlife species is particularly important. Most species today range completely or partially in landscapes extensively altered by and lived in by people (McCullough 1996). Suitable habitat in those landscapes is typically much smaller in total area, often is more highly fragmented, and usually has much different conditions than larger areas of intact habitat (Saunders et al. 1991). These habitat remnants can be very important to species survival on the landscape. Therefore, to gauge the future viability of wildlife populations, an understanding of possible future land cover changes is critical.

Land cover change occurs as the result of the interaction between spatial and aspatial factors, both biophysical and human (Meyer and Turner 1994). Examples of spatial factors would include the location of roads, towns, natural features, drainage patterns, etc. Examples of aspatial factors would include household income, profession, family status, and ethnic group. The combination of spatial and aspatial factors together influence individual human decisions, thereby affecting the types and patterns of land cover found in any area and the types, rates, and patterns of land cover change.

Because land cover patterns and land cover change reflect the response of many individuals to a similar set of biophysical, economic, and social factors, past land cover change can potentially be used to model future land cover change (Wear and Flamm 1993). For example, from the late 1930's to the mid 1990's, the Huron River watershed in southeastern Michigan experienced a large increase in urban land cover, from 5% to 29% of total area, largely from the conversion of agricultural land. Urban growth was particularly high in the northwest and north central portion of the watershed where lake density was much higher than in the rest of the watershed. The patterns of urban change reflected the decisions of many individuals, including farmers who sell their property, developers that buy the farmers' property and build on it, and residents or businesses that purchase the newly-developed properties. While predicting individual instances of future urban development would be very difficult without more detailed information, predicting broader patterns of future urban development could be possible under a given set of the biophysical, economic, and social conditions.

Land use/land cover change models

Predicting future land cover change, either urban development or other processes such as vegetation succession, requires the use of models (Baker 1983, Briassoulis 2000). The development and the use of models help refine the understanding of the systems involved, identify gaps in knowledge, and provide the means to analyze a range of conditions that would be impossible to manipulate in the real world. In particular, models can be used to forecast potential future conditions and therefore help guide policy and management to achieve desirable outcomes or avoid undesirable ones (Liu et al. 1994).

A variety of modeling approaches have been applied to the study of land cover change. The models vary substantially depending on the goals of the research questions and the scale of analysis (Briassoulis 2000). One class of models that is frequently used to study land cover change are Markov-chain models (Horn 1975, Usher 1981, Muller and Middleton 1994). Markov-chain models use transition probabilities to forecast land cover change. In the simplest case, a Markov-chain model uses the percent of change among land cover types from Time n to Time n+1 as the probability that a given land cover type will change from Time n+1 to Time n+2. Most cases assume a first-order Markov chain in which the state of the land at Time n+1 only depends on the state of the land at Time n and not on any previous states (e.g, Time n-1,Time n-2, Time n-3, etc.).

The advantage of a Markov model is that it only requires knowledge of land cover at two time steps to predict land cover at a time in the future. No further information is necessary to project future land cover change. However, a Markov-chain model has three potential drawbacks (Briassoulis 2000). First, it assumes that transition probabilities are homogeneous across time. Second, it assumes that transition probabilities are homogeneous across space. Third, as stated above, history may or may not matter, implying that a simple first-order

Markov-chain model may not be appropriate. Land cover change in the Huron and Black River watersheds did not meet the first two assumptions and may or may not meet the third assumption. First, land cover transition probabilities varied over time in both watersheds (Table 3.1, Table 3.2). Second, land cover transition probabilities are not uniform over space. For example, loss of agriculture and growth of urban areas in the Huron River watershed varied across the watershed (Figure 1.8, Figure 1.9). Also, in the Black River watershed, the presence of large tracts of state forest land, on which certain land cover transitions such as change to residential areas could not occur, would violate the assumption of spatial uniformity of land cover transitions. Third, land cover transitions may or may not depend on past land cover conditions. Successional changes will likely have a historical component. For example, forest condition will be a function of the time since the last disturbance. Other changes, such as agriculture to urban, may only depend on the state of the land at one point in time.

An alternative model to investigate land cover changes is logistic regression (Ludeke et al. 1990, Wear and Flamm 1993, Agresti 1996). Logistic regression links the probability of an event happening or not happening to a vector of predictor variables using one of several functions. The most common function, and the one used for this analysis, is the logit:

$$\text{logit}[\pi(x)] = \log\left(\frac{\pi(x)}{1-\pi(x)}\right) = \alpha + \beta x$$

where $\pi(x)$ denotes the probability of "success" or an event occurring (Agresti 1996). Once the model has been fit, parameter values can be input to back calculate the probability of an event occurring.

There are several benefits to using logistic regression to model land cover change. First, logistic regression can use both continuous and categorical variables as independent variables in the model. Second, logistic regression models are relatively straightforward to construct using standard statistics packages and therefore do not require the development of customized modeling software. However, the input-output become cumbersome when dealing with large datasets such as land cover data. Third, logistic regression models probabilities for an event to occur. When applied to a landscape, the result is a response surface that indicates the likelihood of land cover change taking place within a specified unit of time. Therefore this analysis generates maps that show where land cover change is more or less likely to occur. Such maps could then be used in conjunction with maps of species distributions to identify habitat with a higher probability or risk of changing to nonhabitat. This, in turn, would help focus conservation efforts on vulnerable areas that may be critical to the future viability of a species or the continued functioning of a critical ecological process.

Objective

The objective of this chapter is to model land cover change using logistic regression with independent variables derived only from the land cover database. In essence, this approach seeks to determine how much of the variability of land cover change can be explained by variables derived solely from the land cover database. Although such variables may not actually be drivers of land cover change, they may reflect true drivers of land cover change, especially when considering the aggregation of all cases where land cover did or did not change. This approach is similar to Markov models in that it requires only the land cover database. It differs from the Markov model in that it makes no assumptions about homogeneity across time or space and whether or not history matters. If successful, then logistic regression models could be used to generate maps of probable types of future land cover change. Such maps could then be used to determine possible future changes in wildlife habitats.

Methods

Vector-based maps of land cover, roads, highways, and other features for both watersheds were converted to raster maps with a cell size of 30 x 30 meters. The 30-m cell size was chosen because it best approximated the 0.1 hectare minimum mapping size used to create the land cover database, which were vector coverages. In addition, 30-m cell sizes produced raster maps with a reasonable number of cells. For example, in the Huron River watershed, a 30-m cell size yielded approximately 2,400,000 cells. A 10-m cell size yielded approximately 9,000,000 cells, and a 5-m cell size yielded approximately 24 million cells. Typically the geometric increase in the number of cells also translated into a geometric increase in computer processing time to conduct various map manipulations and analyses. The resulting 30-m cell size maps were used to generate independent variables to serve as predictors of land cover change in the logistic regression models.

Two types of variables were used in the logistic regression models: distance variables and neighborhood variables. Distance variables were chosen because the location of individual cells relative to features of interest such as rivers, lakes, towns, or section lines may be important for determining whether land cover does or does not change. For example, areas near roads appeared more likely to undergo conversion from agriculture to urban land cover. All distance values were integer Euclidean distances from a grid cell to a major land cover. Distances from section lines were determined to account for the pattern of land ownership in both watersheds. Distances were calculated using the "find distance" routine in ArcView 3.2 (ESRI 1999b).

Neighborhood variables were chosen because the context of the surrounding area may be important for determining whether land cover does or does not change. For example, a forest cell within a large forested area may be less likely to be converted to another land cover type, such as urban via development or nonforest via windthrow than a forest cell at the edge of a large forested area. Furthermore, the scale of the context could vary such that areas directly adjacent to a cell are not important but areas farther away are important. Therefore, neighborhood context was calculated as counts of the number of cells of each land cover type within a series of 4 square boxes of successively larger areas (Figure 3.1). Neighborhood sizes ranged from only the eight cells adjacent to the focal cell to all cells within 1,695 m (~ 1 mile) of the focal cell.

Neighborbood variables were calculated using the "Neighborhood analysis" routine in ArcView 3.2 (ESRI 1999b).

For each cell, values from each distance and neighborhood map of interest and X and Y coordinates were output to a comma-delimited text file, as follows:

Record #1, Row 1, Column 1, Grid1 Value, Grid2 Value, etc.
Record #2, Row 1, Column 2, Grid1 Value, Grid2 Value, etc.
...

for importation to SAS statistical software (SAS Institute 1999). Each line therefore contained the values for the distance and neighborhood variables for each cell within the grid. Any cell with a "No Data" value for any distance or neighborhood variable was omitted from the analysis.

Potential land cover change was modeled as a probability surface using logistic regression (Agresti 1996). Because land cover is a nominal/categorical variable, individual logistic regressions were fitted as pair-wise binary models, with the "event" being change from land cover A to land cover B. When modeling nominal categories, the choice of the baseline category (e.g. the "nonevent") is arbitrary. Parameter estimates will be the same regardless of which category is chosen (Agresti 1996, p. 206). However, the logical choice was to model land cover change versus no change. In other words, each land cover category served as the baseline for the set of logistic equations that modeled the event as P(land cover changed from A to B | land cover A). In other words, $\pi(x)$ is the probability for land cover to change from A to B.

Only land cover changes from Step 4 to Step 5 were modeled. Because land cover transition probabilities changed over time (Table 3.1, Table 3.2), it was assumed that probabilities generated by equations modeling change from Step 4 to Step 5 would provide the best estimate of transition probabilities from Step 5 to a future time step. Similar to a Markov model, land cover history of a given cell was not considered in this current analysis.

Because the potential and actual number of land cover changes was very large (Table 3.3), only changes between MIRIS Level 1 land cover types were modeled except in the Black River watershed (Table 3.4, Table 3.5). In that case, MIRIS Level 2 forest cover types (broadleaf and conifer) were modeled separately to reduce the number of non-event cells from approximately 1.2 million forest cells to 782,000 broadleaf cells and 410,000 coniferous cells (Table 3.4). Therefore 12 and 11 land cover transitions were modeled in the Black and Huron river watersheds, respectively. Further, only land cover transitions were modeled that had 1,000 cells or more change from land cover A to land cover B. In other words, at least 90 hectares of land had to undergo change to be included in the modeling process. This number was chosen because most land cover changes had either many more or much less than 1,000 cells change (Table 3.4, Table 3.5).

Results

Black River Watershed

For all logistic regression models of land cover change, the overall slope of the model differed from 0 (e.g. reject H_0: $\beta = 0$, $p < 0.0001$). Model goodness-of-fit varied with different measures (Table 3.6). In all cases, deviance measures were not significant. Pearson's measure varied considerably, however, ranging from a minimum of 0.771 to a maximum of 23.472, with associated probabilities ranging from 1.000 to < 0.0001. The Pearson's statistics showed very high sensitivity to the data set, as a value of 0.985 yielded a probability of 1.00 while a value of 1.025 yielded a probability of < 0.0001. Large discrepancies between Pearson's goodness of fit and deviance imply an overdispersion of the data due to unaccounted heterogeneity of the subjects (Agresti 1996).

Concordance measures ranged from a minimum of 63.8 for broadleaf to urban transitions to a high of 83.9 for nonforest to coniferous. Concordance/ discordance values did not show any relationship to the probability of land cover change. For example, the second lowest concordance value was for changes from broadleaf forest to nonforest, which had the highest percentage change of any land cover transition.

The fitted logistic regression equations showed substantial variation in the number and set of significant explanatory variables (Table 3.7, Table 3.8, Table 3.9, Table 3.10). The least number of significant variables was 10 for changes from broadleaf forest to wetlands (Table 3.8), while the highest number was 25 for changes from broadleaf forest to nonforest (Table 3.8). No strong trends were observed in which variables were significant for which types of land cover transitions. Also, most coefficients tended to be low, typically 0.01 or less.

Distance variables were significant in 7 to 9 of the 12 possible transitions. None were significant in the transitions from nonforest to broadleaf and coniferous forest (Table 3.10) and from broadleaf forest to wetlands (Table 3.8). The magnitude of distance coefficients approximately ranged from 1×10^{-4} to $1x10^{-5}$, both positive and negative. The highest absolute value was -0.00151 for distance from rivers in changes of coniferous forest to wetlands (Table 3.9). The lowest absolute value was 8.28×10^{-6} for distance from highways in changes of broadleaf forests to nonforest (Table 3.8). The signs of the coefficients also showed no discernable pattern within land cover transitions. Also, no strong trends were apparent for a particular variable across all land cover transitions. The exception was roads, the coefficients of which were positive for changes to nonforest, negative for changes to urban and agriculture, and not significant for changes to wetlands and forests. This implies that changes to nonforest were more likely farther from roads, changes to agriculture and urban were less likely farther away from roads, and changes to wetlands and forests did not depend on the distance from roads.

With respect to neighborhood variables, the strongest trend was the decreasing absolute value of the magnitudes of the coefficients with increasing neighborhood size (Table 3.7, Table 3.8, Table 3.9, Table 3.10). Neighborhood variables typically were significant in 7 to 9 of the 12 possible land cover transitions. Variables for the largest water and wetlands neighborhoods had the highes

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highest frequency of significance (11 of 12), while the variable for the smallest forest neighborhood had the smallest frequency (1 of 12). Similar to distance coefficients, the neighborhood coefficients showed no strong trends within land cover transitions or across land cover transitions for a single variable.

The varied results of the logistic regression modelling are also evident when comparing the predicted probability maps generated by the equations with the actual maps of land cover change from Step 4 to Step 5 in the Black River watershed (Figures 3.2 to 3.13). Overall the ability of the maps to forecast potential land cover change depended on the type of change and the pattern of change across the watershed.

The types of change could be divided broadly into anthropogenic changes resulting directly from human action and natural changes. Anthropogenic changes included changes from forest to nonforest via timber harvesting or development (Figure 3.4, Figure 3.7), agriculture to nonforest (Figure 3.2), agriculture to urban (Figure 3.3), nonforest to agriculture (Figure 3.10), and nonforest to urban (Figure 3.13). These changes tended to follow regular patterns that conform primarily to the network of roads on the landscape. This regularity made such types of land cover change easier to predict. The primary exception to this was the conversion of forest, either broadleaf or conifer, to urban. This was due to the large number of oil and gas wells developed from Step 4 to Step 5. Well locations were typically random compared to the network of roads within the watershed.

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Conversely, land cover changes such as forests to wetlands (Figure 3.6, Figure 3.9) or nonforest to forest (Figure 3.11, Figure 3.12) tended to follow more natural patterns on the landscape related to underlying physical variables not directly measured in the regression models. These types of changes also were less frequent on the landscape.

Related to the type of change was the pattern of change. Anthropogenic changes tended to follow regular patterns such as roads or rivers and were clustered due to such factors as proximity to towns or other features. More natural changes, on the other hand were more scattered or distributed across the landscape. For example, the change from broadleaf forest to wetlands (Figure 3.6) were widely scattered throughout the landscape, and the resulting probability map showed a low but fairly uniform chance of such changes throughout the entire watershed. A similar low but fairly uniform probability of change was evident for other natural transitions such as succession from nonforest to forest (Figure 3.11, Figure 3.12). The opposite of this was the change from nonforest to agriculture (Figure 3.10), which clustered in the northern, central, and extreme southern parts of the landscape. These changes reflected the pattern of public and private land ownership throughout the watershed.

Huron River Watershed

For all logistic regression models of land cover change, the overall slope of the model differed from 0 (e.g. reject H_0: $\beta = 0$, $p < 0.0001$). Similar to the Black River watershed, the results of the Pearson's and deviance model fitting tests did not completely agree (Table 3.11). All deviance values were non-significant ($p = 1.000$). Results for the Pearson's model fitting varied considerably. The values for forest to agriculture and the reverse were very high (3245 and 813, respectively). The Pearson's values were again very sensitive, as a change from 0.996 (forest to urban) to 1.007 (nonforest to urban) completely reversed the outcome of the test (0.996 to 0.0002).

Concordance/discordance values were slightly higher on average in the Huron than the Black (Table 3.11). Interestingly, the transition from forest to agriculture, which had the second worst outcome for Pearson's goodness-of-fit test, also had the best concordance value (94.5%). The lowest concordance value was the transition from nonforest to urban (67.2%).

Distance variables were significant in all land cover transition models (Table 3.12, Table 3.13, Table 3.14, Table 3.15). Rivers, roads, and section lines were significant in all transitions. Highways, towns, and lakes were significant in 10, 9, and 8 transitions. Overall, distance to features appeared to play a stronger role in the Huron than the Black River watershed. Again the probability of land cover changing to urban from another land cover type decreased with increasing distance from roads. Otherwise, distance relationships from different features to land cover transitions varied. For example, the transition from forest to agriculture was negative for distance to highways, roads, and section lines, indicating that it had a higher probability of occurrence closer to those features. Conversely, it was positively related to distance from rivers, indicating that probability increased as distance from rivers increased. Changes from nonforest to urban had a higher probability closer to rivers, roads, and section lines (negative relationship) and farther from highways, lakes, and towns (positive relationship).

Neighborhood variables also showed no strong trends other than the decrease in absolute value of variable coefficients with increasing neighborhood size (Table 3.12, Table 3.13, Table 3.14, Table 3.15). The largest neighborhood sizes for forests, urban,and water were significant in all 11 land cover transitions. The smallest neighborhood size for nonforest, urban, and water were significant to the least number of land cover transitions (5). The set of significant variable and the sign of their coefficients differed among different land cover transitions.

The maps of predicted probabilities for the Huron River watershed reflected the trends in land cover change that have been occurring in the watershed for the past 20 or 30 years (Figures 3.14 – 3.24). As discussed in Chapter 1, the major land cover changes in the watershed were changes to urban from other land covers and changes among agriculture, forest, and nonforest. The predicted probability maps demonstrated these changes. For example, the maps for changes from agriculture (Figure 3.16), forest (Figure 3.19), and nonforest (Figure 3.22) to urban have relatively higher magnitudes and broader distributions than other changes, reflecting the diffuse and broad scale urban growth pattern seen throughout much of the watershed. Interchanges among agriculture, forest, and nonforest (Figure 4.14, Figure 4.15, Figure 4.17, Figure 4.18, and Figure 4.20) were as diffuse but tended to have lower probabilities. The exception to this was transitions from nonforest to forest

(Figure 3.21), which showed higher probabilities more like transitions to urban land covers.

Transitions from urban to water and wetlands to urban showed more distinct and individual trends. The urban to water probability map (Figure 3.23) appeared to greatly overestimate conversion probabilities. The reason for this apparent overshoot was unclear. The logistic regression equation predicted higher levels of probability for conversion from urban to wetlands nearer to the mainstem of the Huron River, but actual changes tended to occur farther away from the river itself (Figure 3.24).

Discussion

Overall the use of logistic regression equations using landscape-derived variables showed potential for modeling future land cover change. This is especially true regarding the use of such equations to predict anthropogenic changes that follow regular patterns throughout the landscape. The fact that the logistic regression equations appeared to predict human activities was not surprising given that the inputs to the models were variables that would tend to reflect the choices that people make in using the landscape. Distances from roads, towns, sections lines, etc. are for the most part anthropocentric. If left undisturbed, some type of succession would likely take place on a given parcel of ground without regard to distance from roads, highways, towns, etc.

Better prediction of naturally land cover transitions such as succession would require including biophysical variables in the land cover transition models.

These could include elevations, slopes, and soil characteristics. The choice would depend on the system of interest.

The disagreement between Pearson and deviance goodness-of-fit statistics most likely stems from two problems. First, the land cover data used to model land cover transitions likely suffered from overdispersion. This happens when the data exhibits variability larger than expected by the model (Agresti 1996). As mentioned at the beginning of the chapter, one large source of variability is the choice made by individuals regarding the use of parcel of land. A regression model cannot directly account for such variability. However, additional factors could be incorporated that might decrease the overdisperson by increasing the amount explained by a given model. For example, the distance to town measurement could be divided to include distances from specific towns. In the Huron River watershed, urban growth patterns were different around Ann Arbor than in the rest of the watershed. By modeling that distance separately, some additional variation might be explained and the model fit enhanced.

Second, similar to residuals in normal regression analysis, Pearson and deviance residual statistics measure the difference between estimated and actual probabilities to help examine the fit of a model (Agresti 1996). In the case of binary response models, actual probabilities are either 0 or 1 to reflect no change (non event) or a change (event). Also, the residuals are more robust when responses can be grouped into sets of trials with the same values for the independent predictor variables. Obviously such groupings are not possible with land cover transitions because each cell has a unique set of values for the independent variables associated with it. For deviance values in particular, the large number of nonevents can lead to a false impression that the model fits extremely well (low values, high probabilities). Very low probabilities would be compared to a nonevent probability of zero and could mask a poor fit where event cells had generally lower predicted probabilities than nonevent cells.

One possible way to increase predictability would be to use more detailed MIRIS classifications. For example, in the Black River watershed, no distinction was made among the different types of urban growth. Houses were treated the same as gas wells which were treated the same as golf courses. Therefore more specific levels of classification could increase the predictive power. However, increased specificity reduces sample size of specific land cover transitions. Therefore a balance would be needed between more detailed models of land cover change versus the decrease in sample size, particularly nonevents.

A final consideration for enhancing model performance could involve the use of specific location information. The variables used in the land cover change model did not account for the relative locations and directions of different features in the landscape. For example, the Huron River watershed shows a strong level of retention of agriculture in the southwest portion of the watershed. Effects at that level may be important for predicting what types of land cover change might occur.

In summary, building logistic regression models that only use variables derived only from a land cover database offers the possibility of predicting land cover change without needing a large amount of exogenous data. The models are simple, straightforward to run, and require little if no customized development. They are more realistic than simple first-order Markov models because they can capture spatial and temporal variation. In addition, logistic regression models probabilities and not static outcomes and avoid the need to conduct large numbers of repetitions typically needed in other types of land cover change analysis.

Table 3.1: Annual probability (%) of land cover change from Step 1 to Step 5 in the Black River watershed. Values were determined by dividing the percent change from successive steps by the number of years between those steps. "-" means the no transition took place between those two land cover types.

Time		Agriculture	Barren	Forest	Nonforest	Urban	Water	Wetlands
1 to 2	Agriculture	97.901	-	0.327	1.686	0.058	-	0.027
	Barren	-	100.000	-	-	-	-	-
	Forest	0.083		99.807	0.089	0.017	0.002	0.001
	Nonforest	0.391	0.001	2.862	96.691	0.042	0.002	0.011
	Urban	-	-	0.002	-	99.998	-	-
	Water	-	-	0.005	-	0.001	99.993	0.002
	Wetlands	0.007	-	0.885	0.025	0.002	0.056	99.025
2 to 3	Agriculture	99.735	-	0.023	0.231	0.006	-	0.005
	Barren	-	100.000	-	-	-	-	-
	Forest	0.003	-	99.965	0.011	0.021	-	0.001
	Nonforest	0.138	-	0.318	99.526	0.007	-	0.011
	Urban	0.033	-	0.008	0.006	99.952	-	-
	Water	-	-	0.004	0.001	-	99.990	0.006
	Wetlands	-	-	0.057	0.005	-	0.009	99.930
3 to 4	Agriculture	99.261	-	0.067	0.643	0.022	-	0.007
	Barren	-	100.000	-	-	-	-	-
	Forest	0.001	-	99.996	0.002	0.002	-	-
	Nonforest	0.040	-	0.132	99.786	0.019	0.001	0.022
	Urban	-	-	0.011	0.025	99.963	-	-
	Water	-	-	0.004	-	-	99.996	-
	Wetlands	-	-	0.439	0.002	-	0.230	99.329
4 to 5	Agriculture	99.425	-	0.033	0.427	0.114	-	0.001
	Barren	-	100.000	-	-	-	-	-
	Forest	0.003	-	99.421	0.516	0.043	-	0.018
	Nonforest	0.510	-	0.324	98.959	0.200	0.003	0.004
	Urban	0.022	-	0.028	0.022	99.925	-	0.004
	Water	0.000	-	-	-	0.001	99.999	-
	Wetlands	0.016	-	0.164	0.041	0.006	0.002	99.771

Table 3.2: Annual probability (%) of land cover change from Step 1 to Step 5 in the Huron River watershed. Values were determined by dividing the percent change from successive steps by the number of years between those steps. "-" means the no transition took place between those two land cover types.

Time		Agriculture	Barren	Forest	Nonforest	Urban	Water	Wetlands
1 to 2	Agriculture	98.736		0.190	0.704	0.370		
	Barren		100.000					
	Forest	0.209		99.386	0.195	0.189	0.017	0.004
	Nonforest	1.068		0.998	97.325	0.589	0.020	
	Urban			0.004		99.996		
	Water						100.000	
	Wetlands	0.316		0.361	0.396	0.097	0.095	98.735
2 to 3	Agriculture	97.984		0.148	1.069	0.799		
	Barren		94.199			5.801		
	Forest	0.190		99.132	0.234	0.443		
	Nonforest	0.233		0.914	97.928	0.925		
	Urban					100.000		
	Water						100.000	
	Wetlands			0.162	0.150		0.080	99.608
3 to 4	Agriculture	98.586		0.046	0.890	0.478		
	Barren		100.000					
	Forest	0.078		99.415	0.191	0.316		
	Nonforest	0.258		0.096	99.044	0.601		
	Urban				0.015	99.985		
	Water						100.000	
	Wetlands			0.014	0.031			99.955
4 to 5	Agriculture	99.202		0.101	0.064	0.633		
	Barren		100.000					
	Forest	0.020		99.575	0.025	0.380		
	Nonforest	0.044		0.049	98.790	1.104	0.012	
	Urban					100.000		
	Water						100.000	
	Wetlands	0.006		0.015	0.007	0.117	0.002	99.853

Table 3.3: Possible and actual number of land cover transitions for MIRIS Level 3 land cover types from Step 1 to Step 5 in the Black and Huron river watersheds. Values included cases where land cover did not change (e.g. forest to forest). The number of possible land cover transitions changed over time because the number of land cover types changed over time in both watersheds.

	Number of Land Cover Changes			
	Black		Huron	
Transition	Possible	Actual	Possible	Actual
Step 1 to Step 2	2,070	240	1,804	375
Step 2 to Step 3	2,070	285	1,980	360
Step 3 to Step 4	1,932	231	2,070	285
Step 4 to Step 5	1,848	265	2,162	318

Table 3.4: Number of 30-meter cells changing between MIRIS Level 1 land cover types from Step 4 to Step 5 in the Black River watershed. "-" indicates no cell underwent that transition.

		Step 5							
				Forest					
		Agriculture	Barren	Broadleaf	Conifer	Nonforest	Urban	Water	Wetlands
	Agriculture	104,349	-	224	307	6,765	1,796	-	9
	Barren	-	28	-	-	-	-	-	-
	Forest								
	Broadleaf	355	-	782,348	3,330	70,010	6,462	44	2,059
Step 4	Conifer	197	-	792	410,521	24,245	1,367	-	1,190
	Nonforest	11,224	-	4,751	2,343	134,331	4,339	68	81
	Urban	67	-	32	62	70	23,608	-	15
	Water	11	-	-	-	-	-	69,759	-
	Wetlands	143	-	625	841	369	52	22	62,166

Table 3.5: Number of 30-meter cells changing between MIRIS Level 1 land cover types from Step 4 to Step 5 in the Huron River watershed. "-" indicates no cell underwent that transition.

		Step 5						
		Agriculture	Barren	Forest	Nonforest	Urban	Water	Wetlands
	Agriculture	675,037	-	9,843	6,275	62,084	428	-
	Barren	-	44	-	-	4	-	-
	Forest	1,169	-	435,576	1,452	22,914	635	27
Step 4	Nonforest	2,904	-	3,241	428,169	72,987	794	13
	Urban	36	4	11	82	596,290	3,077	11
	Water	-	-	-	-	7	124,218	-
	Wetlands	122	-	335	155	2,697	49	170,607

Table 3.6: Summary information for logistic regression equations fitted to MIRIS Level 1 land cover transitions from Step 4 to Step 5 in the Black River watershed.

Land Cover		Number of Cells		Goodness of Fit						
From	To	Unchanged	Changed	Pearson's	Pr > χ^2	Deviance	Pr > χ^2	% Concordant	% Discordant	% Tied
Agriculture	Nonforest	104,349	6,765	2.179	<0.0001	0.390	1.000	79.8	19.5	0.8
	Urban		1,796	1.044	<0.0001	0.156	1.000	73.3	23.4	3.2
Broadleaf Forest	Nonforest	782,344	70,010	1.0252	<0.0001	0.545	1.000	64.4	34.2	1.3
	Urban		6,462	0.985	1.000	0.091	1.000	63.8	25.8	10.4
	Wetlands		2,059	23.472	<0.0001	0.031	1.000	80.2	8.5	11.3
Conifer Forest	Nonforest	410,520	24,245	1.048	<0.0001	0.415	1.000	63.9	34.1	2.1
	Urban		1,367	1.233	<0.0001	0.040	1.000	67.3	15.7	17.0
	Wetlands		1,190	0.900	1.000	0.032	1.000	79.2	8.0	12.8
Nonforest	Agriculture	134,330	11,224	0.771	1.000	0.436	1.000	83.3	16.3	0.4
	Broadleaf Forest		4,751	1.128	<0.0001	0.265	1.000	75.3	23.2	1.6
	Conifer Forest		2,343	5.719	<0.0001	0.138	1.000	83.9	13.6	2.6
	Wetlands		4,399	1.756	<0.0001	0.246	1.000	78.3	20.3	1.4

Table 3.7: Parameter estimates for logistic regression equations of changes from agriculture to other land cover types in the Black River watershed. Only values for parameters with P (> χ^2) < 0.01 are shown. Neighborhood refers to amount of each land cover type in the areas depicted in Figure 3.1.

		Land Cover Change From Agriculture	
Variable		To Nonforest	To Urban
Intercept		-11.66	-6.05
Distance			
Highways		0.000053	
Lakes			0.000140
Roads		0.00125	-0.00369
Towns		0.000015	0.000031
Rivers		0.000397	
Section Line		0.000774	
Neighborhood	Amount of		
A	Agriculture		
B		0.00991	
C			-0.00182
D		0.000524	0.000327
A	Forest		
B		0.0110	
C		0.00249	
D			0.000137
A	Nonforest	0.0139	
B		-0.00009	
C			-0.00166
D			0.000175
A	Urban		
B		0.0181	
C		0.000196	-0.00131
D			0.000616
A	Water	0.3134	-0.0376
B		0.0170	
C		0.00847	
D		-0.00183	-0.00278
A	Wetlands		
B		-0.0093	0.0127
C		0.00309	-0.00233
D		0.000382	-0.00050

Table 3.8: Parameter estimates for logistic regression equations of changes from broadleaf forest to other land cover types in the Black River watershed. Only values for parameters with P (> χ^2) < 0.01 are shown. Neighborhood refers to amount of each land cover type in the areas depicted in Figure 3.1.

		Land Cover Change From Broadleaf Forest		
Variable		To Nonforest	To Urban	To Wetlands
Intercept		-2.67	-7.7295	-4.4446
Distance				
Highways		8.28×10^{-6}	-	-
Lakes		0.000098	0.000096	-
Roads		0.000053	-0.00052	-
Towns		-0.00004	0.000015	-
Rivers		0.000038	0.000115	-
Section Line		0.000476	-	-
Neighborhood	Amount of			
A	Agriculture	-0.0986	-	-0.042
B		-0.00481	0.0114	-
C		0.000476	-0.00197	-
D		-0.00024	0.000313	-
A	Forest	-		-
B			0.00689	
C		-0.00348	-	-0.00519
D		0.000015	-	0.000043
A	Nonforest	-	-	-
B		-0.00424	0.0110	-
C		0.000674	-0.0021	-
D		-0.00019	-	-0.00027
A	Urban	-	0.2125	-
B		-0.00673	0.0147	-
C		-	-0.00189	-
D		-0.00087	-0.00038	-0.00229
A	Water	-0.8909	-	-
B		-0.00955	0.0132	0.0498
C		-0.00065	-0.00265	-0.0154
D		0.000369	0.000179	-0.00391
A	Wetlands	-0.0958	-	-
B		-0.00634	0.00758	-
C		0.00115	-0.00121	0.000654
D		-0.00013	-0.00020	0.000317

Table 3.9: Parameter estimates for logistic regression equations of changes from conifer forest to other land cover types in the Black River watershed. Only values for parameters with P (> χ^2) < 0.01 are shown. Neighborhood refers to amount of each land cover type in the areas depicted in Figure 3.1.

		Land Cover Change From Conifer Forest		
Variable		To Nonforest	To Urban	To Wetlands
Intercept		-5.8866	-5.4115	-7.8483
Distance				
Highways		-0.00002	-0.00016	-0.00007
Lakes		-0.00011	-0.00009	-0.00029
Roads		0.000201	-0.00048	-
Towns		0.000019	0.000051	-0.00002
Rivers		-0.00007	-0.00029	-0.00151
Section Line		0.000510	0.000680	0.000480
Neighborhood	Amount of			
A	Agriculture	-	-	0.6146
B		-	-	0.0148
C		0.000893	-	-0.00428
D		-0.00058	-	0.000565
A	Forest	0.1034	-	-
B		-	0.00535	0.0108
C		0.000549	-0.00272	-
D		0.000023	0.000048	0.000057
A	Nonforest	0.1809	-	-0.3967
B		-	0.00439	0.0208
C		-0.00095	-	-0.00300
D		0.000410	-0.00035	-
A	Urban	-	-	-
B		-0.00335	0.0179	-
C		0.000277	-0.00146	-0.00088
D		0.000327	-	
A	Water	-0.6458	-	0.8941
B		-0.00763	0.0124	--
C		-	-0.00135	-0.0023
D		-0.00011	0.000294	-0.00213
A	Wetlands	-	-0.7739	-
B		-0.00845	-	0.0392
C		0.00125	0.00296	-0.0061
D		-0.00028	-0.00117	-

Table 3.10: Parameter estimates for logistic regression equations of changes from nonforest to other land cover types in the Black River watershed. Only values for parameters with P (> χ^2) < 0.01 are shown. Neighborhood refers to amount of each land cover type in the areas depicted in Figure 3.1.

		Land Cover Change From Nonforest			
Variable		To Agriculture	To Broadleaf Forest	To Conifer Forest	To Urban
Intercept		-5.3467	-1.1101	-2.1794	-2.3811
Distance					
Highways		0.000100			0.000068
Lakes		0.000210			0.00009
Roads		-0.00120			-0.00224
Towns		-0.00009			-0.00004
Rivers		0.000220			0.000203
Section Line		0.000275			-0.00158
Neighborhood	Amount of				
A	Agriculture	0.0904		0.0241	
B		0.00792	0.00276	0.00186	0.00355
C		-0.00093	-0.00122		-0.00252
D			0.000475	-0.00096	0.000337
A	Forest				
B					0.00544
C		-0.00099		-0.0111	
D		0.000106	-0.00004		0.000104
A	Nonforest				
B		0.00858	0.00463	0.00521	0.00221
C		-0.00089	0.00174	0.00239	-0.00117
D			-0.00111	-0.00172	
A	Urban				
B		0.00391	-0.0285	-0.0106	0.00559
C		-0.00119		0.00186	-0.00245
D		-0.00122	-0.00055		-0.00104
A	Water				
B		-0.00465	0.0168	-0.00753	0.0209
C			-0.00159		-0.00387
D		-0.00038	0.00060	0.00045	
A	Wetlands				
B		0.00616	0.000633	-0.00478	
C		-0.00404		0.00181	-0.000068
D		0.000828	-0.00027	-0.00119	

Table 3.11: Summary information for logistic regression equations fitted to MIRIS Level 1 land cover transitions from Step 4 to Step 5 in the Huron River watershed.

Land Cover		Number of Cells		Goodness of Fit						
From	To	Unchanged	Changed	Pearson's	Pr > χ^2	Deviance	Pr > χ^2	% Concordant	% Discordant	% Tied
Agriculture	Forest	674,801	9,843	3245.596	<0.0001	0.103	1.000	86.1	9.2	4.6
	Nonforest		6,275	0.819	1.0000	0.084	1.000	84.7	11.7	3.5
	Urban		62,071	0.527	1.0000	0.923	1.000	73.2	25.9	0.8
Forest	Agriculture	435,445	1,169	813.106	<0.0001	0.016	1.000	94.5	1.0	4.5
	Nonforest		1,492	0.909	1.0000	0.040	1.000	74.2	13.3	12.5
	Urban		22,906	0.996	0.9696	0.366	1.000	70.5	28.0	1.5
Nonforest	Agriculture	428,004	2,904	1.668	<0.0001	0.070	1.000	72.0	19.6	8.4
	Forest		3,241	3.523	<0.0001	0.069	1.000	85.0	9.7	5.3
	Urban		72,965	1.007	0.0002	0.780	1.000	67.2	32.1	0.7
Urban	Water	596,045	3,077	1.589	<0.0001	0.049	1.000	88.2	6.9	4.9
Wetland	Urban	170,551	2,695	0.901	1.0000	0.146	1.000	74.7	21.6	3.6

Table 3.12: Parameter estimates for logistic regression equations of changes from agriculture to other land cover types in the Huron River watershed. Only values for parameters with P (> χ^2) < 0.01 are shown. Neighborhood refers to amount of each land cover type in the areas depicted in Figure 3.1.

Variable		To Forest	Land Cover Change From Agriculture To Nonforest	To Urban
Intercept		-3.5121	-6.7349	-1.8072
Distance				
Highways		0.000376	-0.00006	-0.000009
Lakes		-0.00081	0.000219	0.000022
Rivers		-0.00088	0.000143	-0.00008
Roads		-0.00019	0.000749	-0.00055
Section Line		0.0002	-0.00016	0.0000055
Towns		-0.00061	0.000015	0.000318
Neighborhood	Amount of			
A	Agriculture		-0.0719	-0.0624
B			0.00879	0.00285
C		0.00115	--0.00148	-0.00027
D		-0.00031		-0.00018
A	Forest	0.1569	-0.1006	-0.0728
B		-0.00397	0.0112	
C			-0.00203	
D		-0.00066	0.000569	-0.00009
A	Nonforest			-0.0770
B			0.0138	0.00130
C		0.00185	-0.00169	-0.00027
D		0.000065	0.000236	0.000180
A	Urban		-0.0952	
B			0.0154	0.00192
C		-0.00065	-0.00075	0.000446
D		-0.00098	0.000355	0.000092
A	Water		-0.4916	-0.1435
B		-0.1797	0.1654	
C		0.000842	-0.00307	0.000439
D		-0.00110	0.000462	-0.00004
A	Wetlands			-0.1208
B		0.00546	0.0229	0.00110
C		-0.00118	-0.00515	-0.00039
D		-0.00013	0..000851	

Table 3.13: Parameter estimates for logistic regression equations of changes from forest to other land cover types in the Huron River watershed. Only values for parameters with P (> χ^2) < 0.01 are shown. Neighborhood refers to amount of each land cover type in the areas depicted in Figure 3.1.

Variable		Land Cover Change From Forest To Agriculture	To Nonforest	To Wetlands
Intercept		2.9683	-3.7820	-2.3489
Distance				
Highways		-0.00117	0.000028	0.000112
Lakes				-0.00006
Rivers		0.000456	0.000273	-0.00006
Roads		-0.00180	-0.00170	-0.00069
Section Line		-0.00018	-0.00021	-0.00005
Towns			-0.00099	0.000531
Neighborhood	Amount of			
A	Agriculture	0.6175		
B		-0.0103		0.00300
C		-0.00093		-0.00048
D			-0.0004	-0.00010
A	Forest	0.3354		
B		-0.0116		0.00376
C		0.00459		-0.00064
D		-0.00137	-0.00003	-0.00031
A	Nonforest	0.3148		
B		-0.0125		0.00383
C		-0.00309		-0.00034
D			-0.00010	0.000181
A	Urban	0.5727		
B		0.0131	-0.00328	0.00311
C				-0.00081
D		-0.00292	0.000110	0.000161
A	Water			-0.3024
B		-1.2205	-0.1570	0.0337
C		-0.00837	0.00133	-0.00052
D		0.00315	-0.00055	0.000202
A	Wetlands	0.2949		-0.1457
B		-0.00701	-0.0124	
C			-0.00212	-0.00056
D			0.00149	0.00030

Table 3.14: Parameter estimates for logistic regression equations of changes from nonforest to other land cover types in the Huron River watershed. Only values for parameters with P (> χ^2) < 0.01 are shown. Neighborhood refers to amount of each land cover type in the areas depicted in Figure 3.1.

			Land Cover Change From Nonforest	
Variable		To Agriculture	To Forest	To Urban
Intercept		-3.3371	-5.9543	-1.0095
Distance				
Highways			0.000087	0.000071
Lakes			0.000477	0.000061
Rivers		0.000285	0.000282	-0.00010
Roads		0.000939	-0.00039	-0.00061
Section Line		-0.00019	-0.00015	-0.00007
Towns			-0.00030	0.000223
Neighborhood	Amount of			
A	Agriculture	0.0823		-0.1150
B			0.00827	
C		-0.00092	-0.00444	0.000523
D		0.000189	0.000832	-0.00021
A	Forest			-0.1400
B		-0.00386	0.0134	-0.00120
C		-0.00129	-0.00149	0.000584
D		0.000699	0.00028	-0.00024
A	Nonforest	0.0356		-0.0935
B			0.0119	0.00357
C			-0.00256	0.000097
D		-0.00066	-0.00015	
A	Urban	0.0749		-0.0974
B		-0.00220	0.0141	0.00163
C			-0.00406	0.000390
D		-0.00021	0.000878	-0.00007
A	Water			-0.3904
B		-0.0992		-0.0258
C		-0.00229	-0.00268	0.000520
D		0.000418	-0.00323	-0.00015
A	Wetlands	0.1161		-0.1983
B		-0.0113		-0.00079
C				-0.00050
D		0.000230	-0.00038	0.000048

Table 3.15: Parameter estimates for logistic regression equations of changes from urban to water and from wetlands to urban in the Huron River watershed. Only values for parameters with P (> χ^2) < 0.01 are shown. Neighborhood refers to amount of each land cover type in the areas depicted in Figure 3.1.

		Land Cover Change	
		From Urban	From Wetlands
Variable		To Water	To Urban
Intercept		-1.9376	-4.2734
Distance			
Highways		-0.00033	0.000058
Lakes		-0.00078	0.000134
Rivers		-0.00059	-0.00007
Roads		0.000757	-0.00066
Section Line		0.000118	0.000027
Towns		0.00293	
Neighborhood	Amount of		
A	Agriculture	-1.1210	
B		0.0126	0.00651
C		-0.00384	-0.00039
D		0.00112	
A	Forest	-1.0417	
B		0.00580	
C		-0.00431	0.000366
D		0.000745	
A	Nonforest	-1.0195	
B		0.0126	0.00472
C		-0.00481	
D		0.00125	-0.00020
A	Urban	-0.7557	
B		0.0157	
C		-0.00268	0.00142
D		0.000259	-0.00014
A	Water	-0.5813	-0.2183
B		0.0834	
C		-0.00380	
D		0.000542	-0.00003
A	Wetlands	-0.8616	
B			
C			0.00135
D			-0.00062

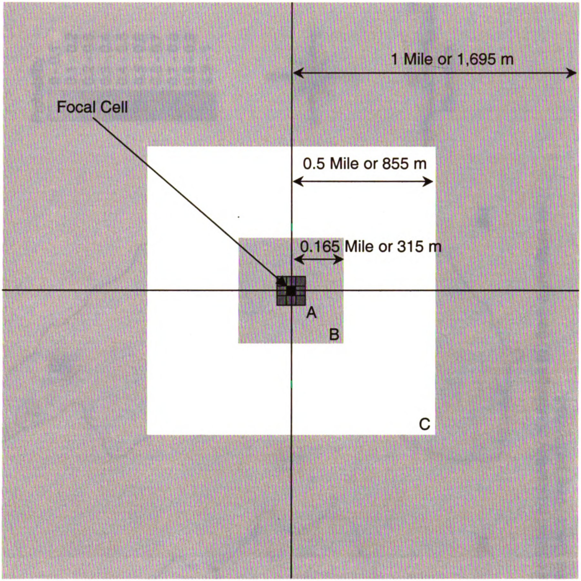


Figure 3.1: Neighborhood areas used in logistic regression of land cover change. "A" refers to the cells directly adjacent to the focal cell.

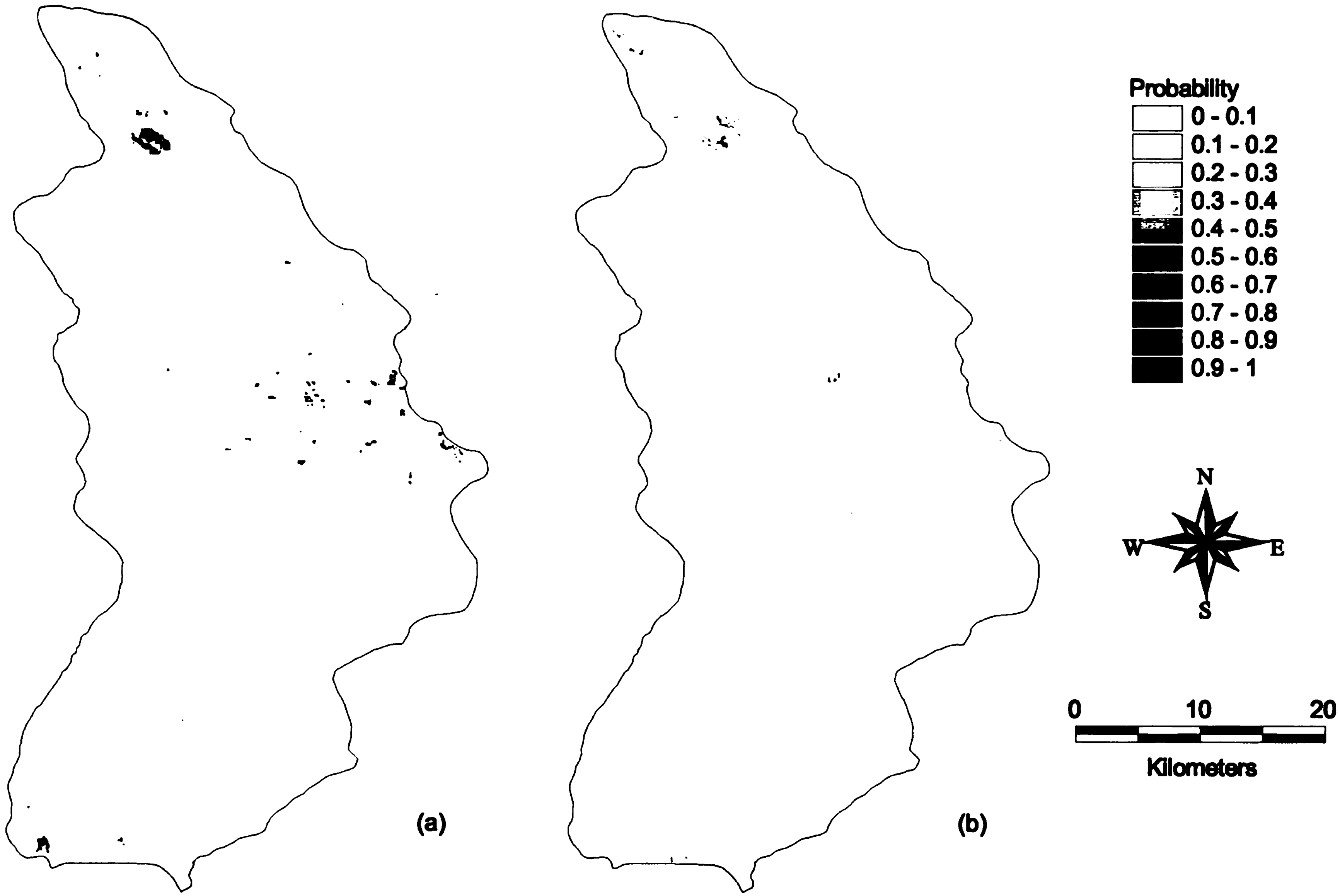


Figure 3.2: Actual change (a) and predicted probability of change (b) from agriculture to nonforest from Step 4 to Step 5 in the Black River watershed.

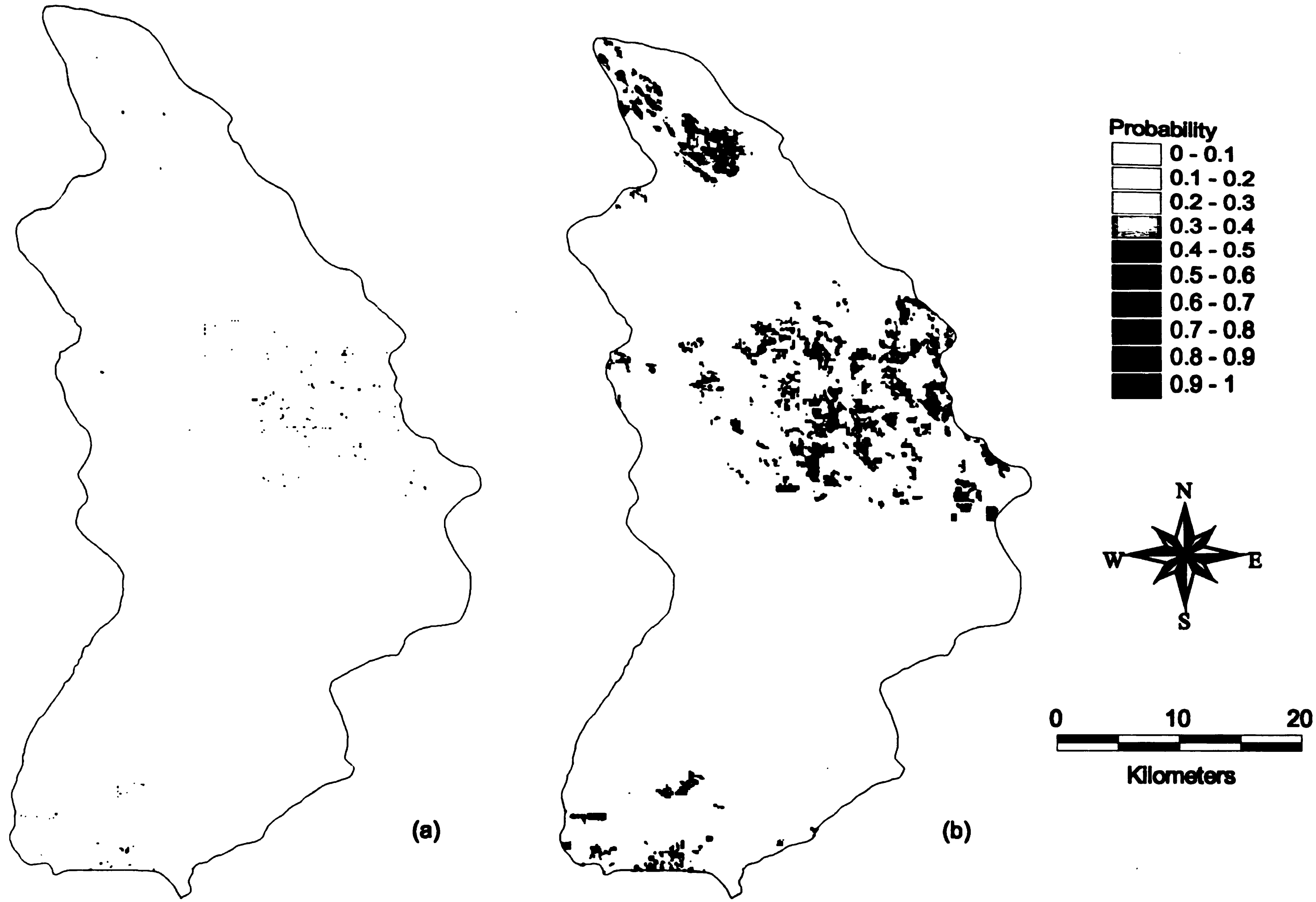


Figure 3.3: Actual change (a) and predicted probability of change (b) from agriculture to urban from Step 4 to Step 5 in the Black River watershed.

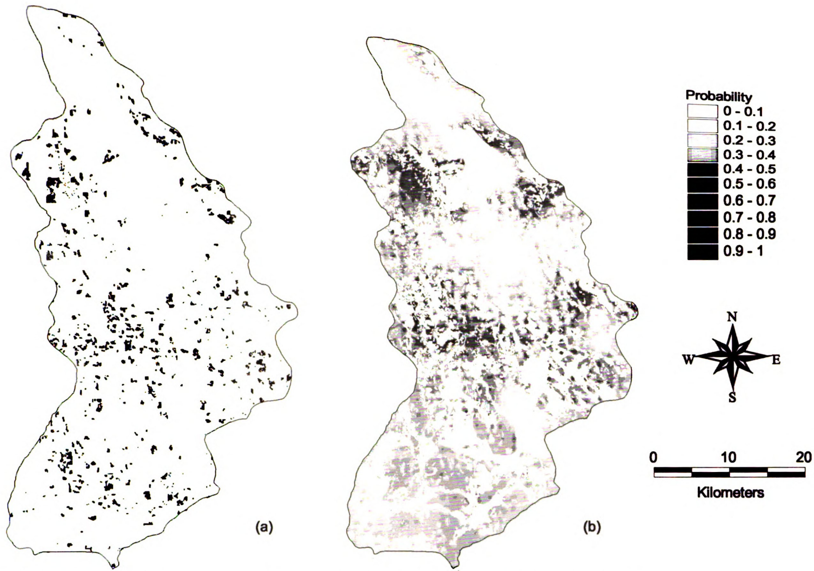


Figure 3.4: Actual change (a) and predicted probability of change (b) from broadleaf forest to nonforest from Step 4 to Step 5 in the Black River watershed.

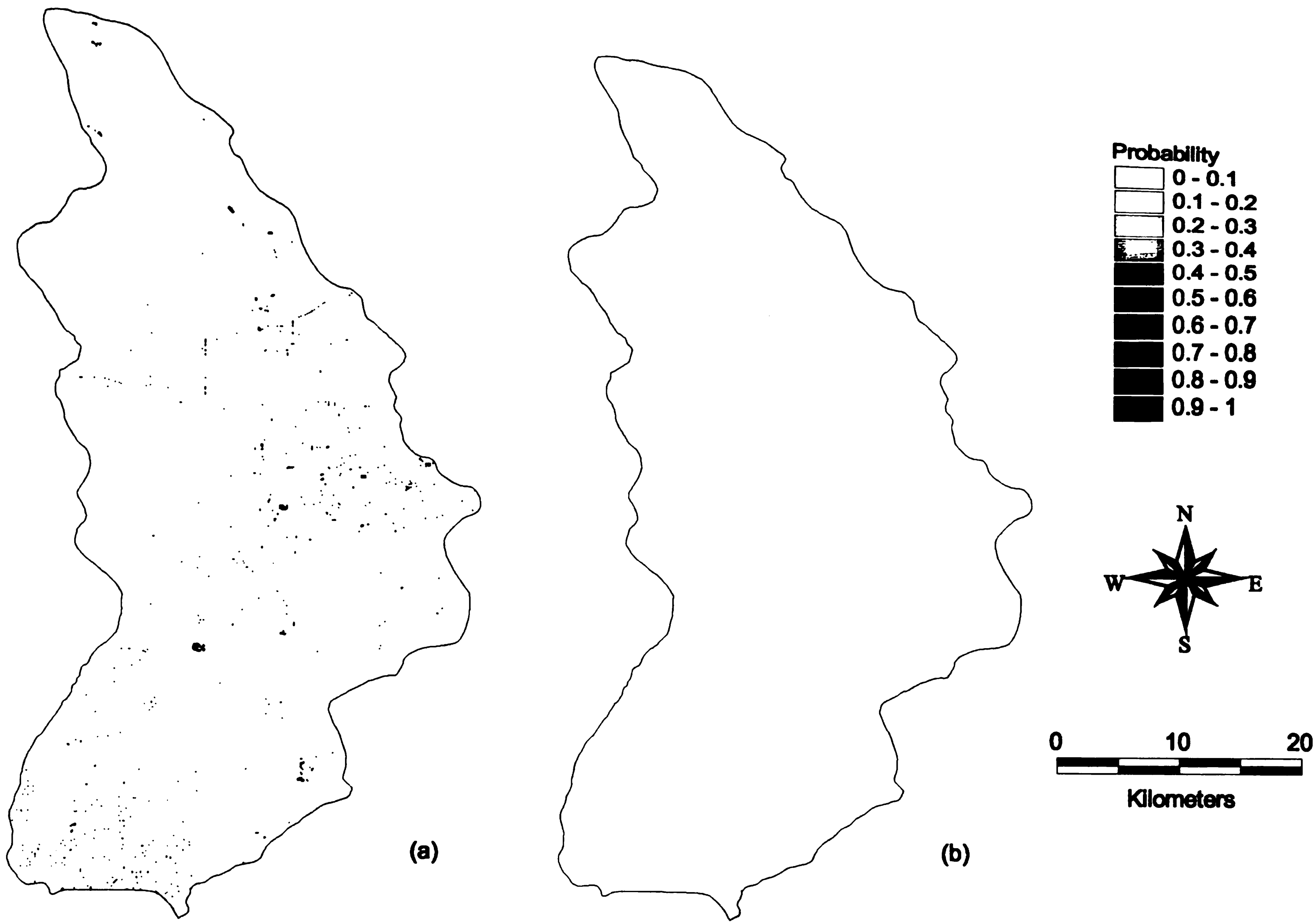


Figure 3.5: Actual change (a) and predicted probability of change (b) from broadleaf forest to urban from Step 4 to Step 5 in the Black River watershed.

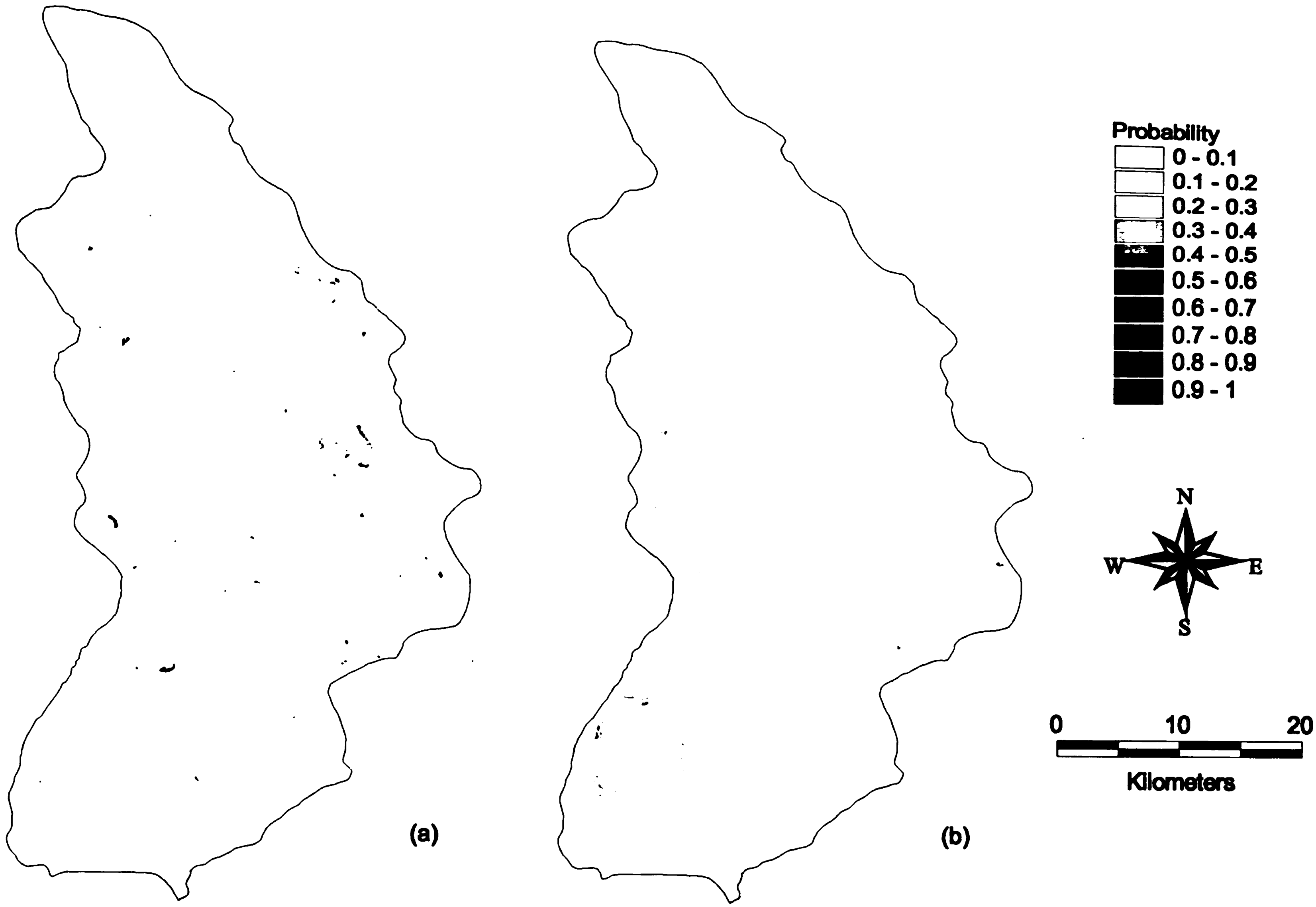


Figure 3.6: Actual change (a) and predicted probability of change (b) from broadleaf forest to wetlands from Step 4 to Step 5 in the Black River watershed.

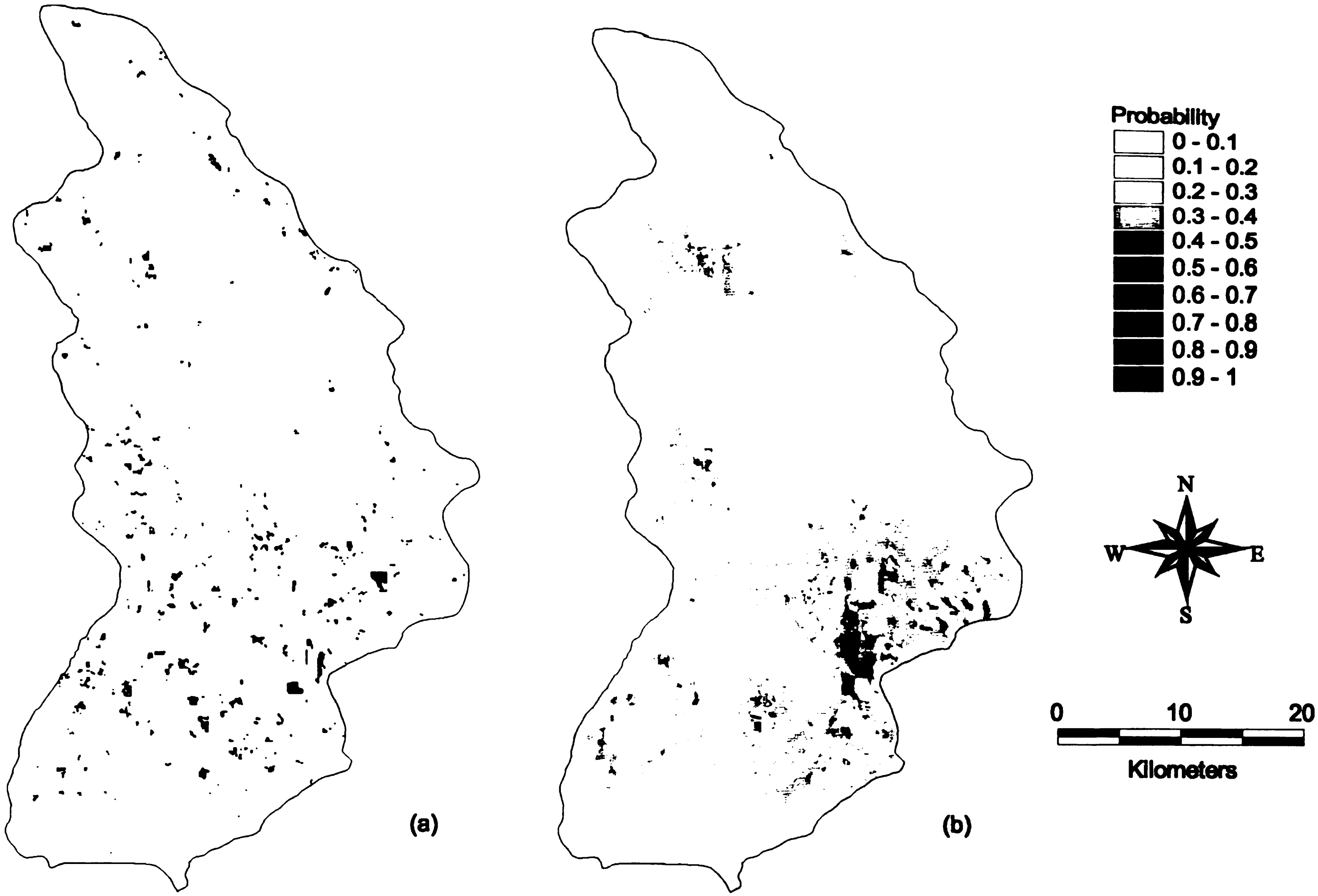


Figure 3.7: Actual change (a) and predicted probability of change (b) from conifer forest to nonforest from Step 4 to Step 5 in the Black River watershed.

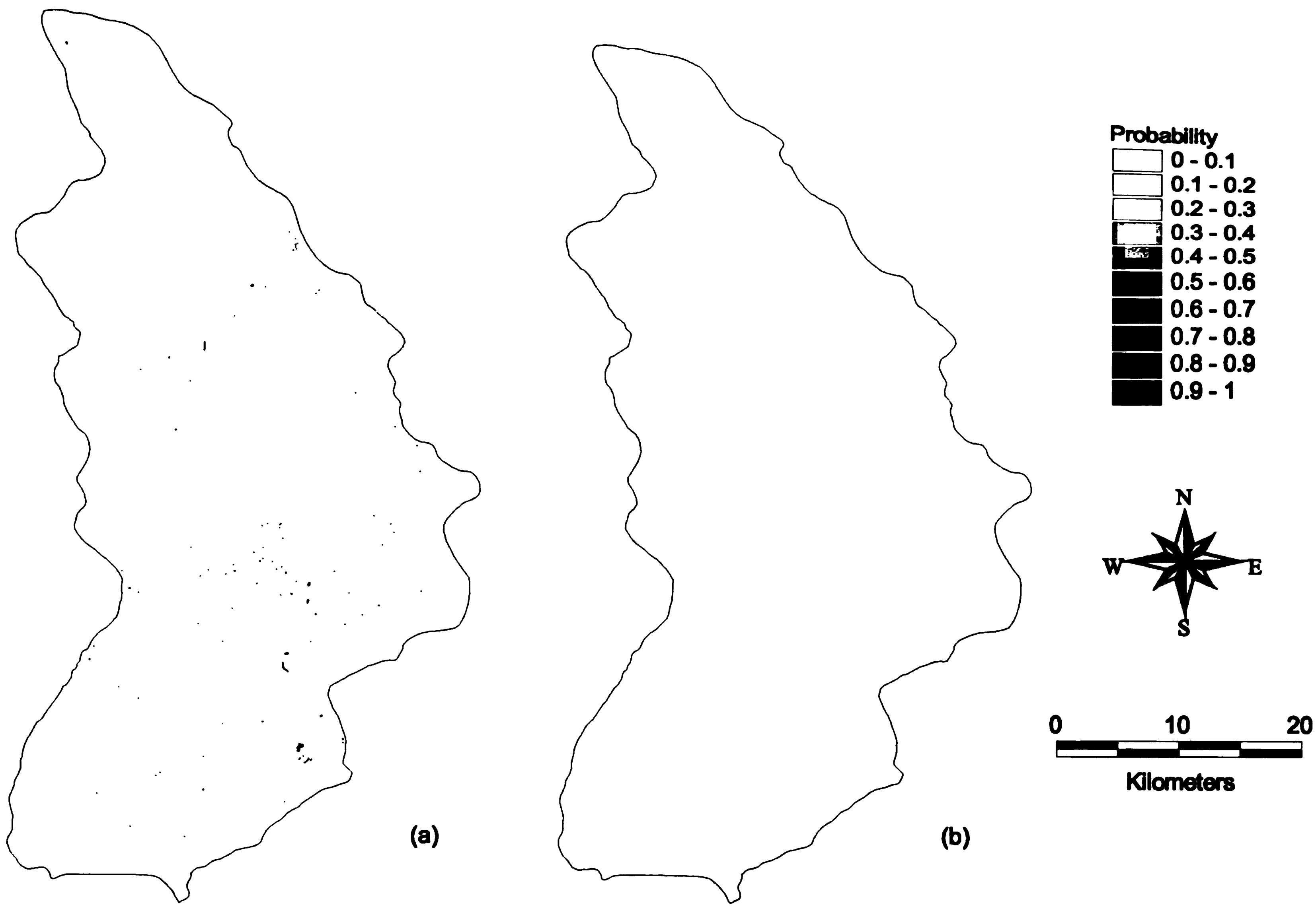


Figure 3.8: Actual change (a) and predicted probability of change (b) from conifer forest to urban from Step 4 to Step 5 in the Black River watershed.

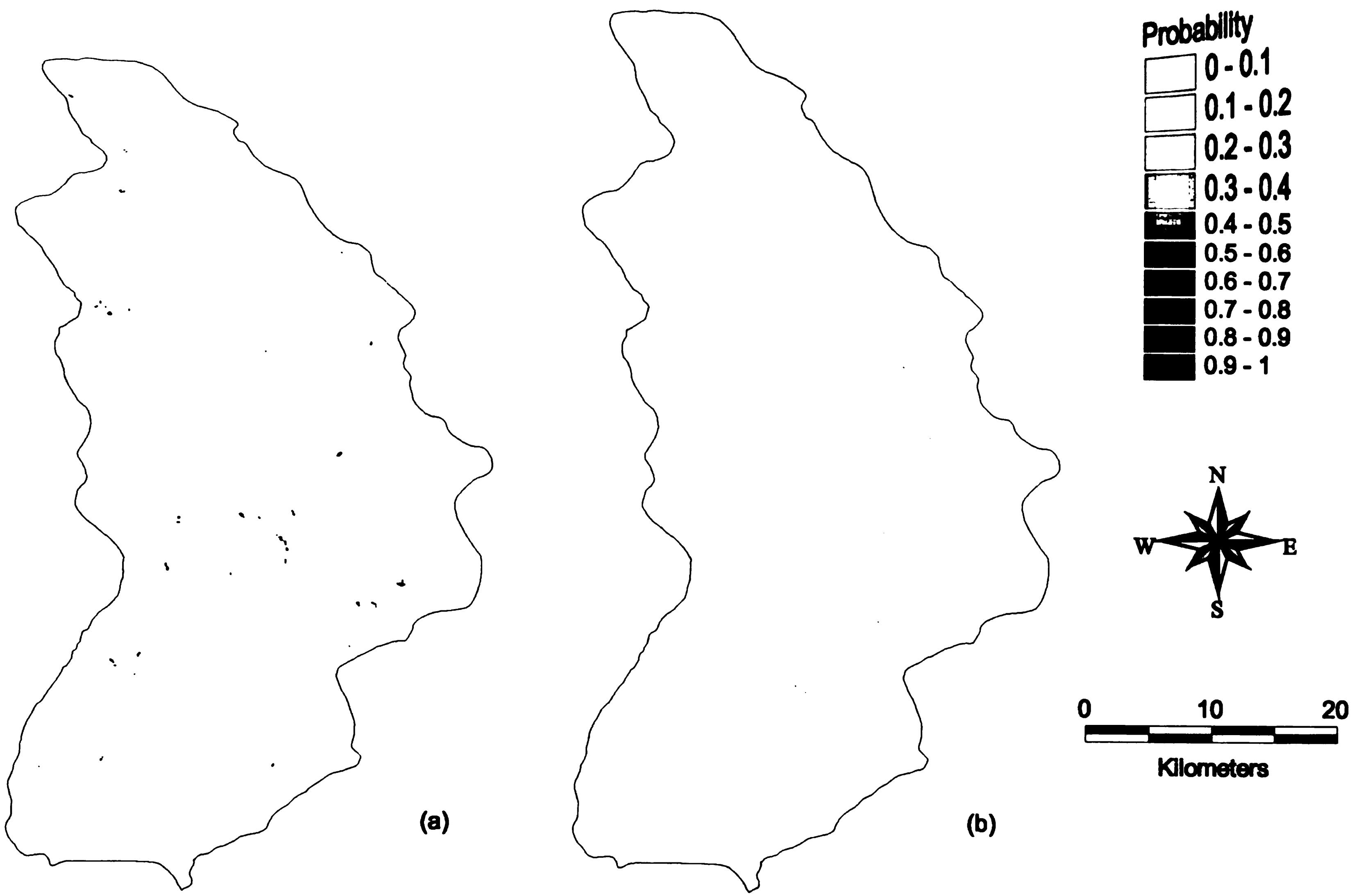


Figure 3.9: Actual change (a) and predicted probability of change (b) from conifer forest to wetlands from Step 4 to Step 5 in the Black River watershed.

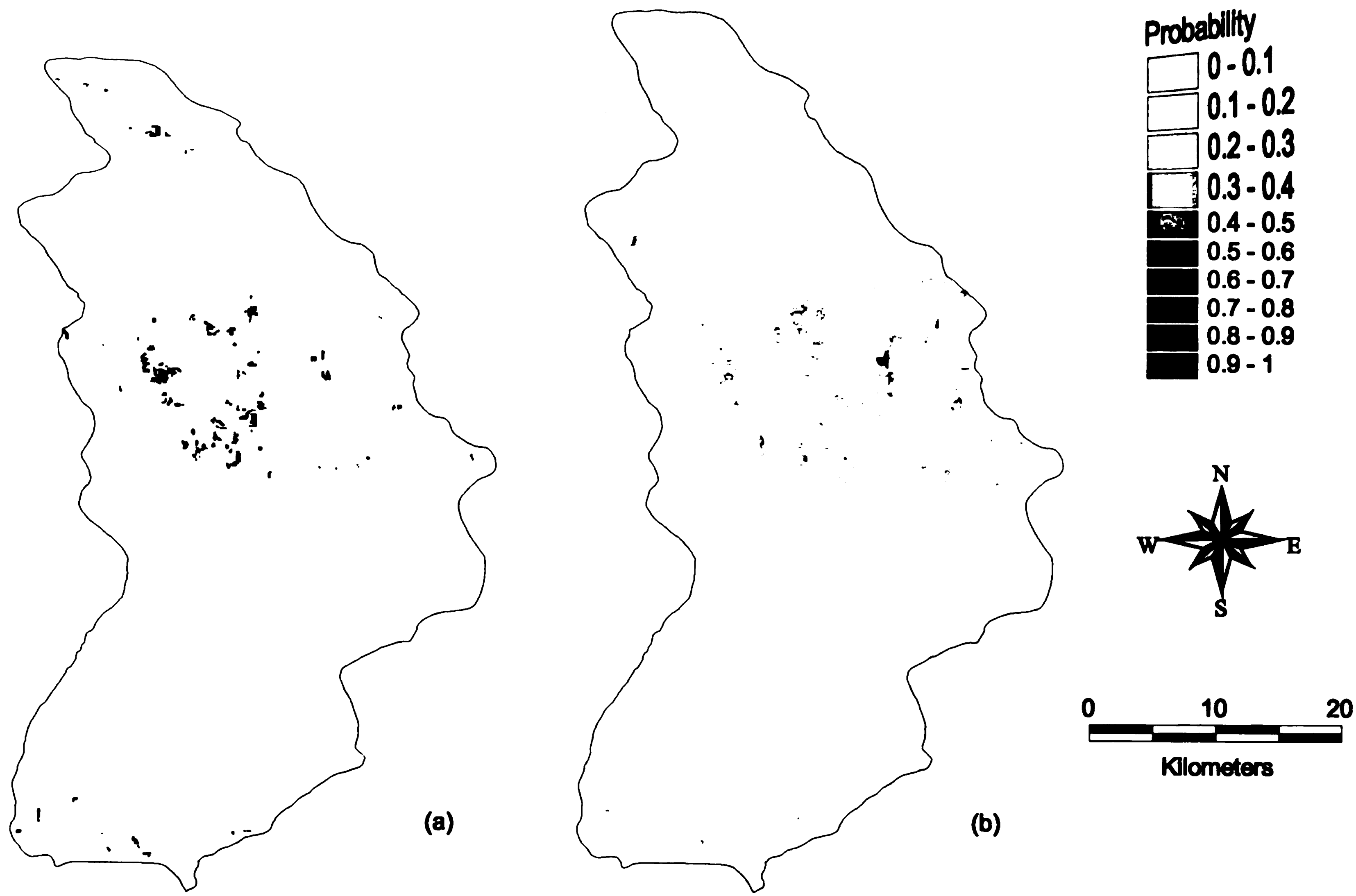


Figure 3.10: Actual change (a) and predicted probability of change (b) from nonforest to agriculture from Step 4 to Step 5 in the Black River watershed.

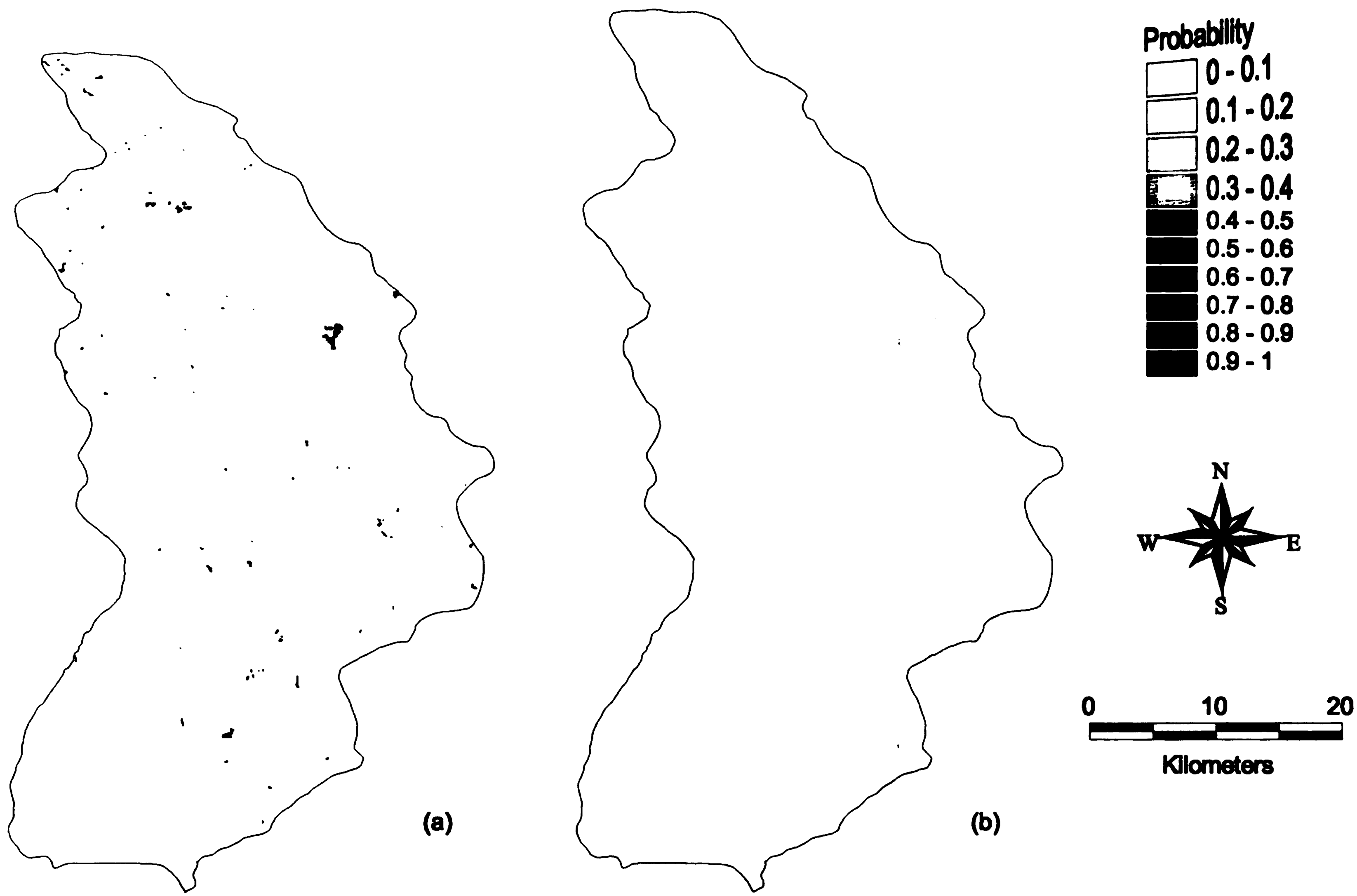


Figure 3.11: Actual change (a) and predicted probability of change (b) from nonforest to broadleaf forest from Step 4 to Step 5 in the Black River watershed.

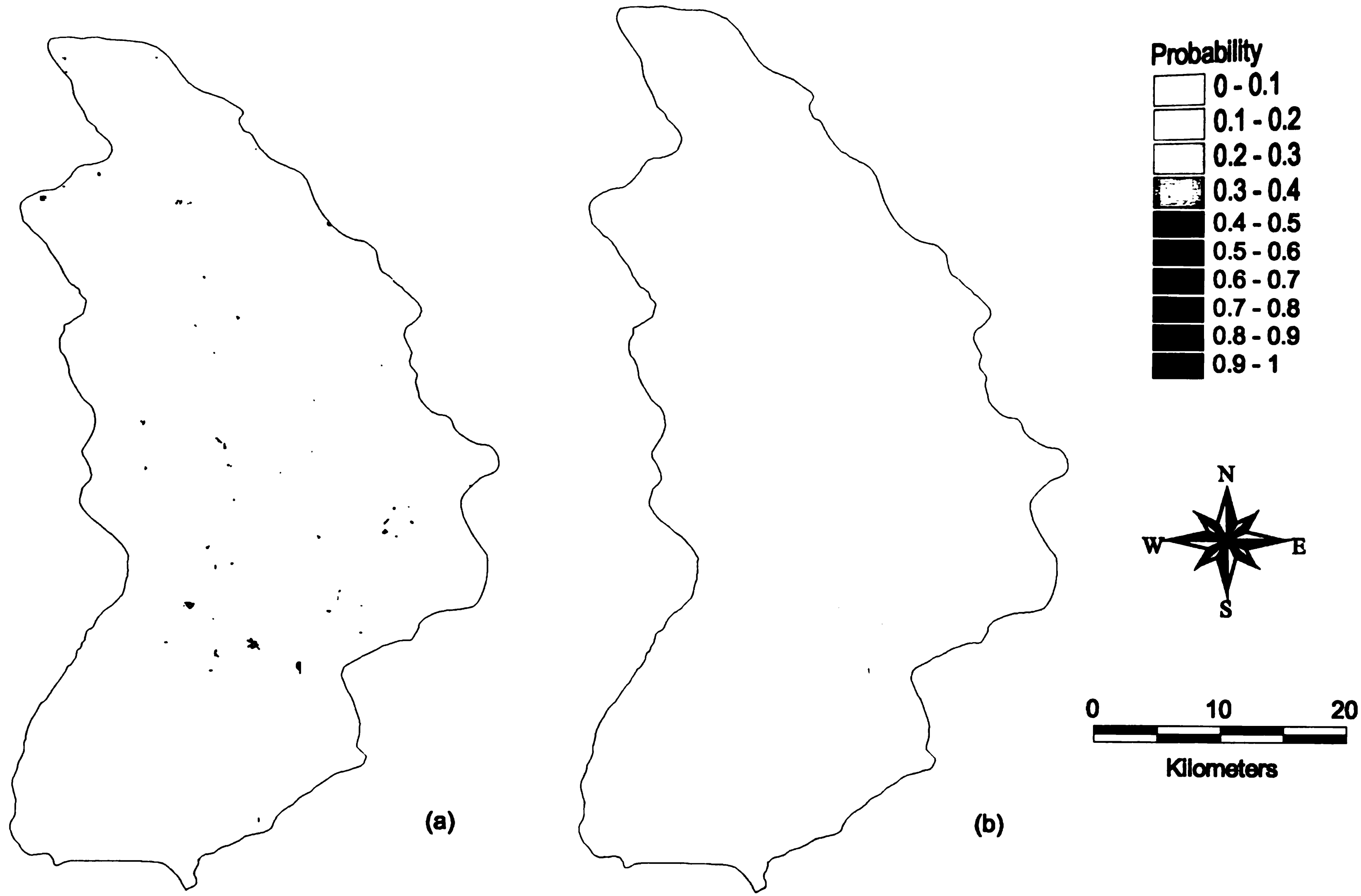


Figure 3.12: Actual change (a) and predicted probability of change (b) from nonforest to conifer forest from Step 4 to Step 5 in the Black River watershed.

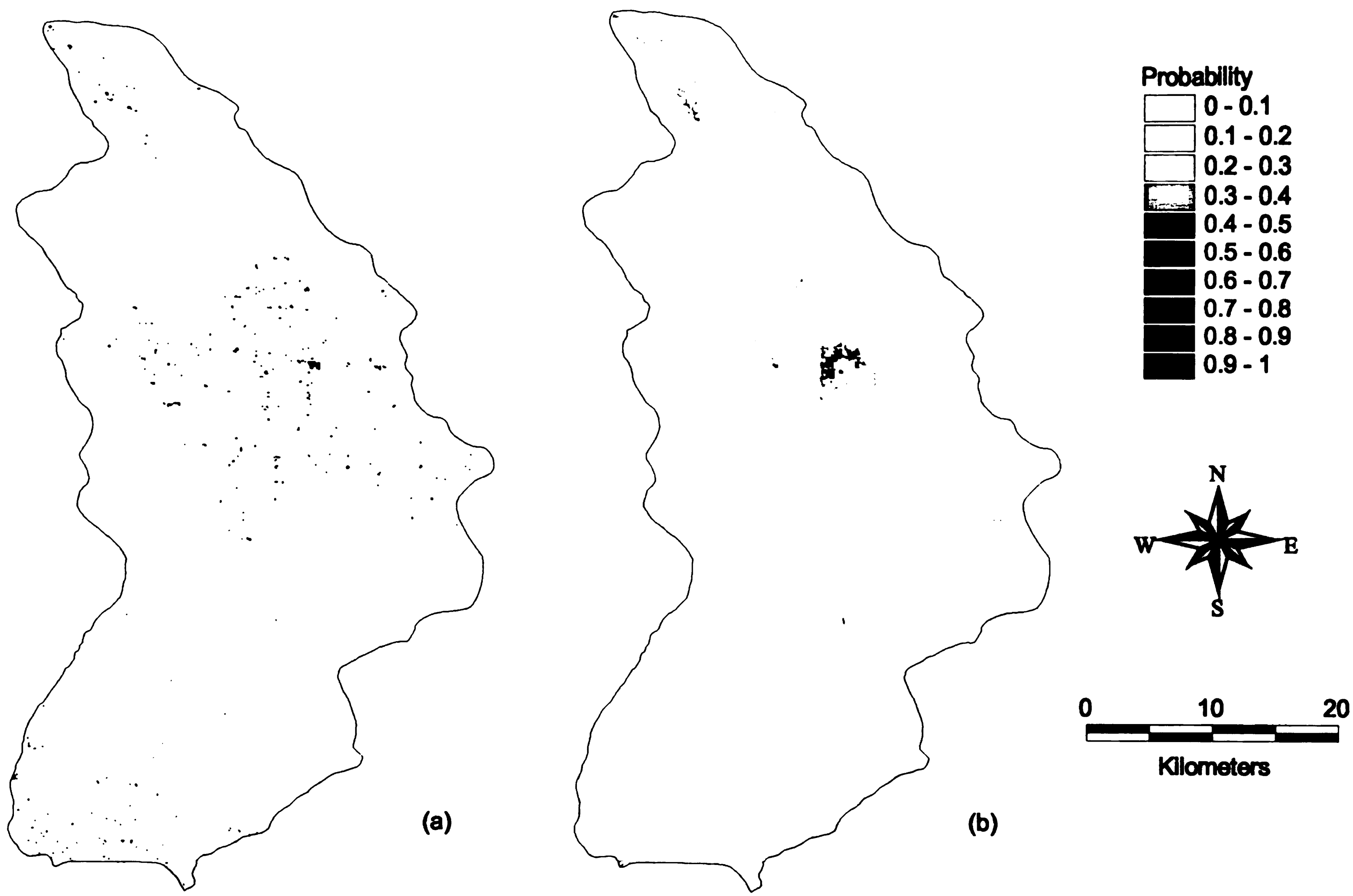


Figure 3.13: Actual change (a) and predicted probability of change (b) from nonforest to urban from Step 4 to Step 5 in the Black River watershed.

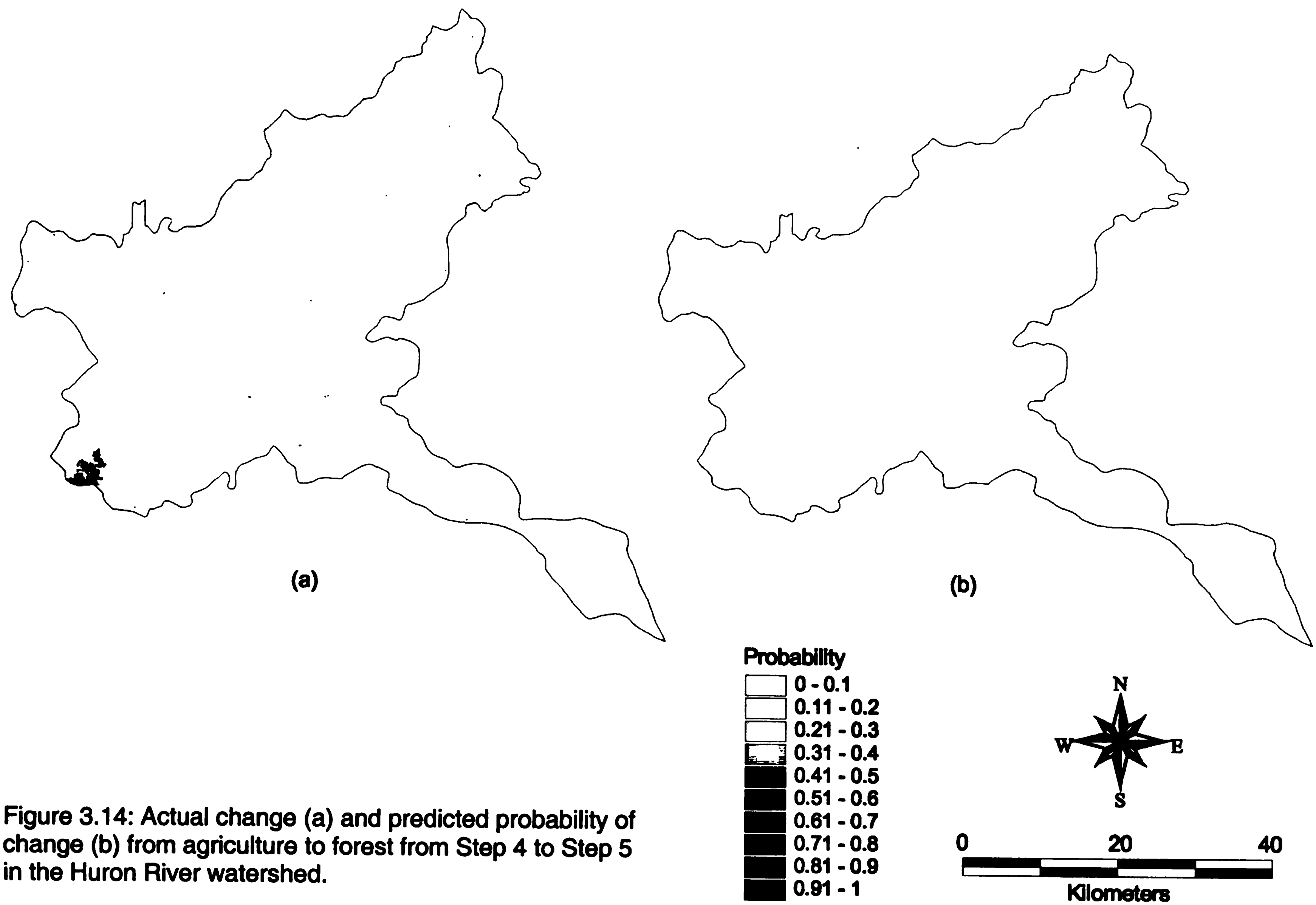


Figure 3.14: Actual change (a) and predicted probability of change (b) from agriculture to forest from Step 4 to Step 5 in the Huron River watershed.

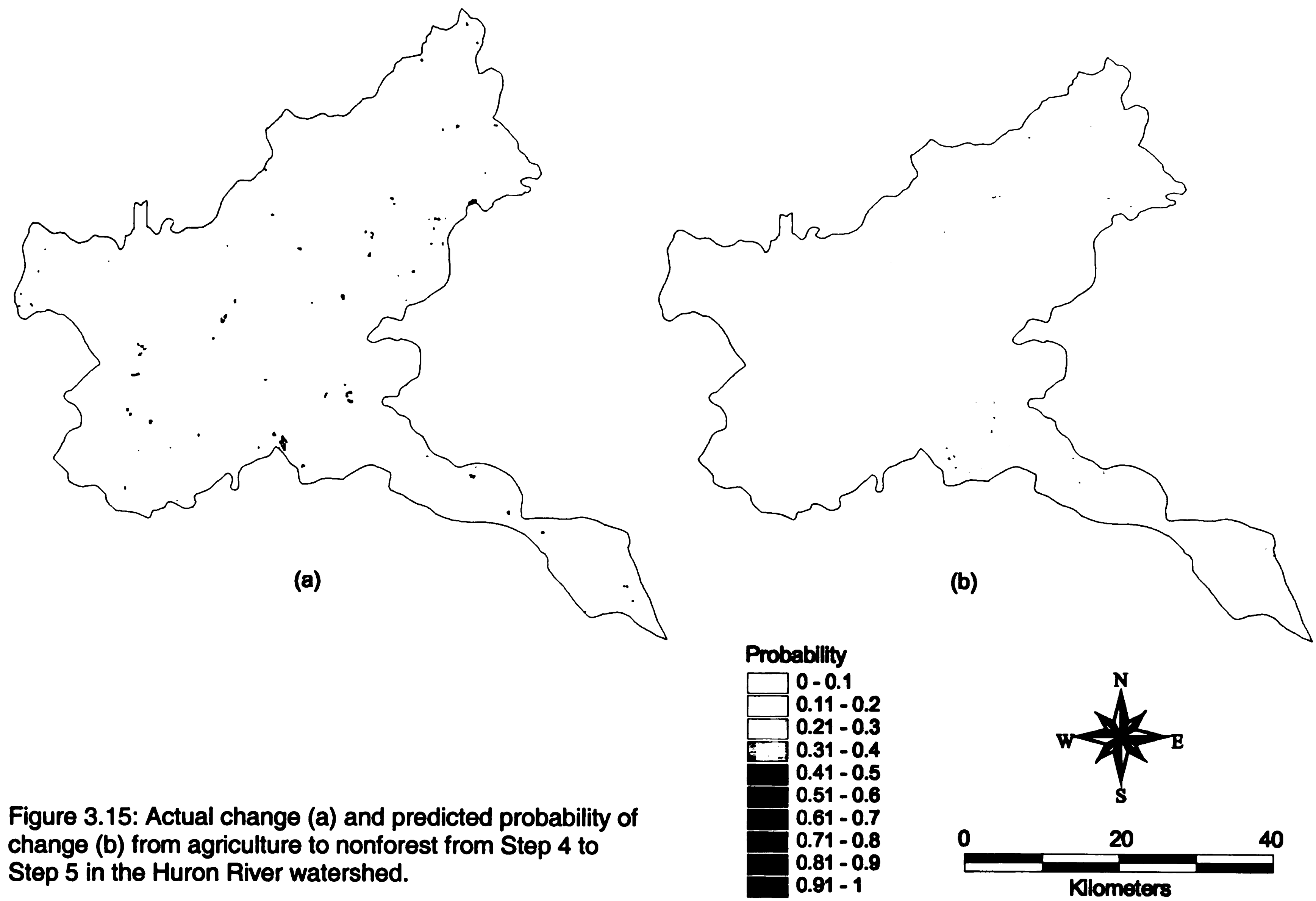


Figure 3.15: Actual change (a) and predicted probability of change (b) from agriculture to nonforest from Step 4 to Step 5 in the Huron River watershed.

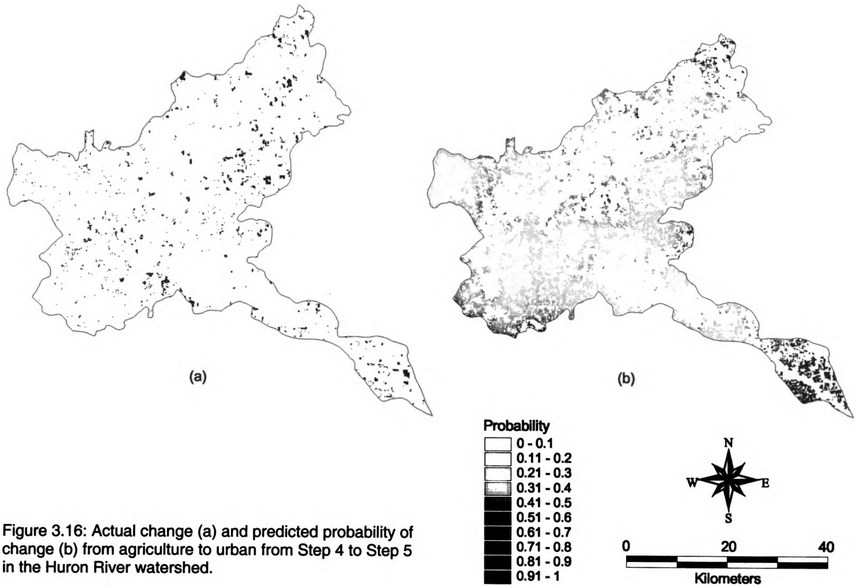


Figure 3.16: Actual change (a) and predicted probability of change (b) from agriculture to urban from Step 4 to Step 5 in the Huron River watershed.

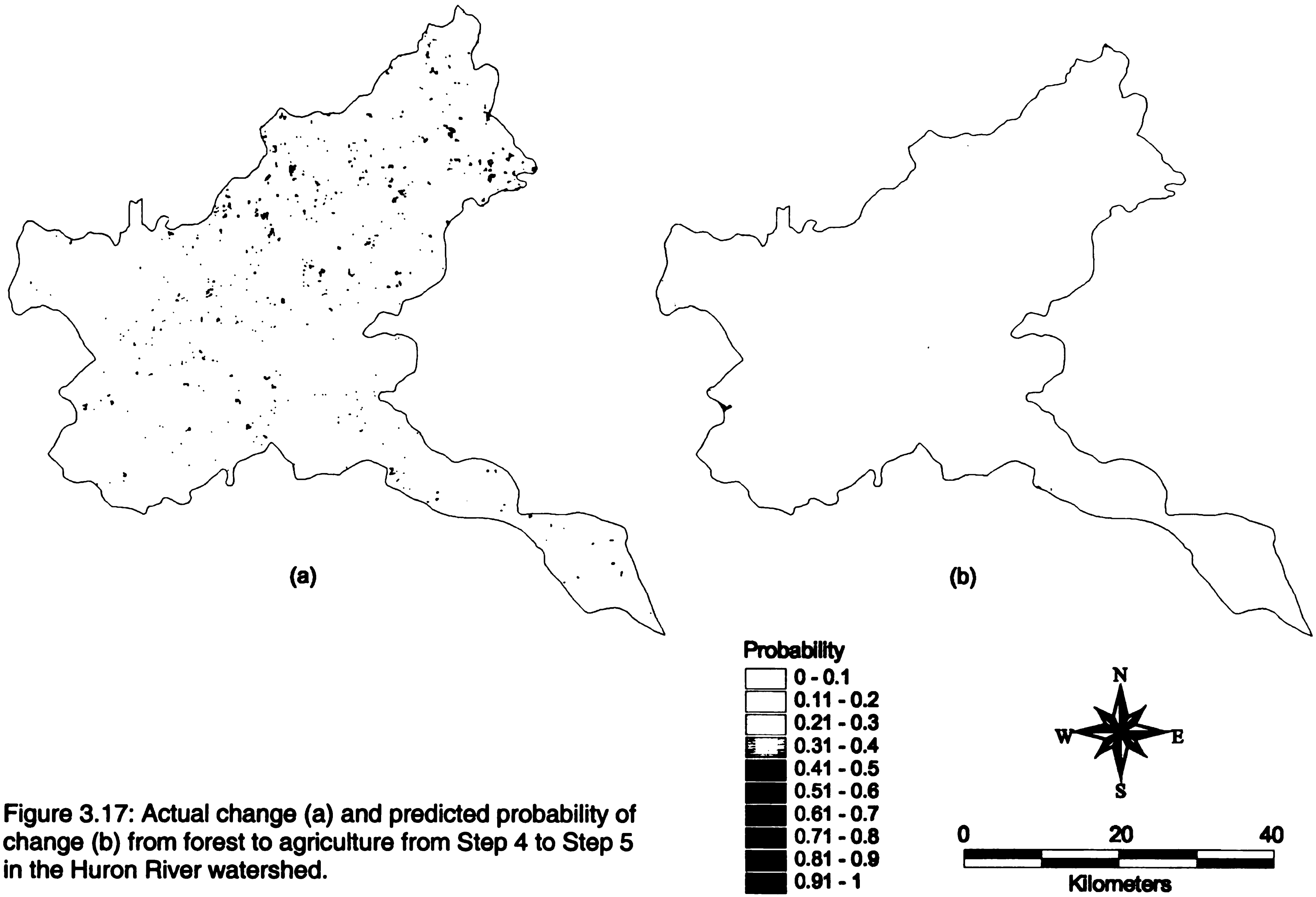


Figure 3.17: Actual change (a) and predicted probability of change (b) from forest to agriculture from Step 4 to Step 5 in the Huron River watershed.

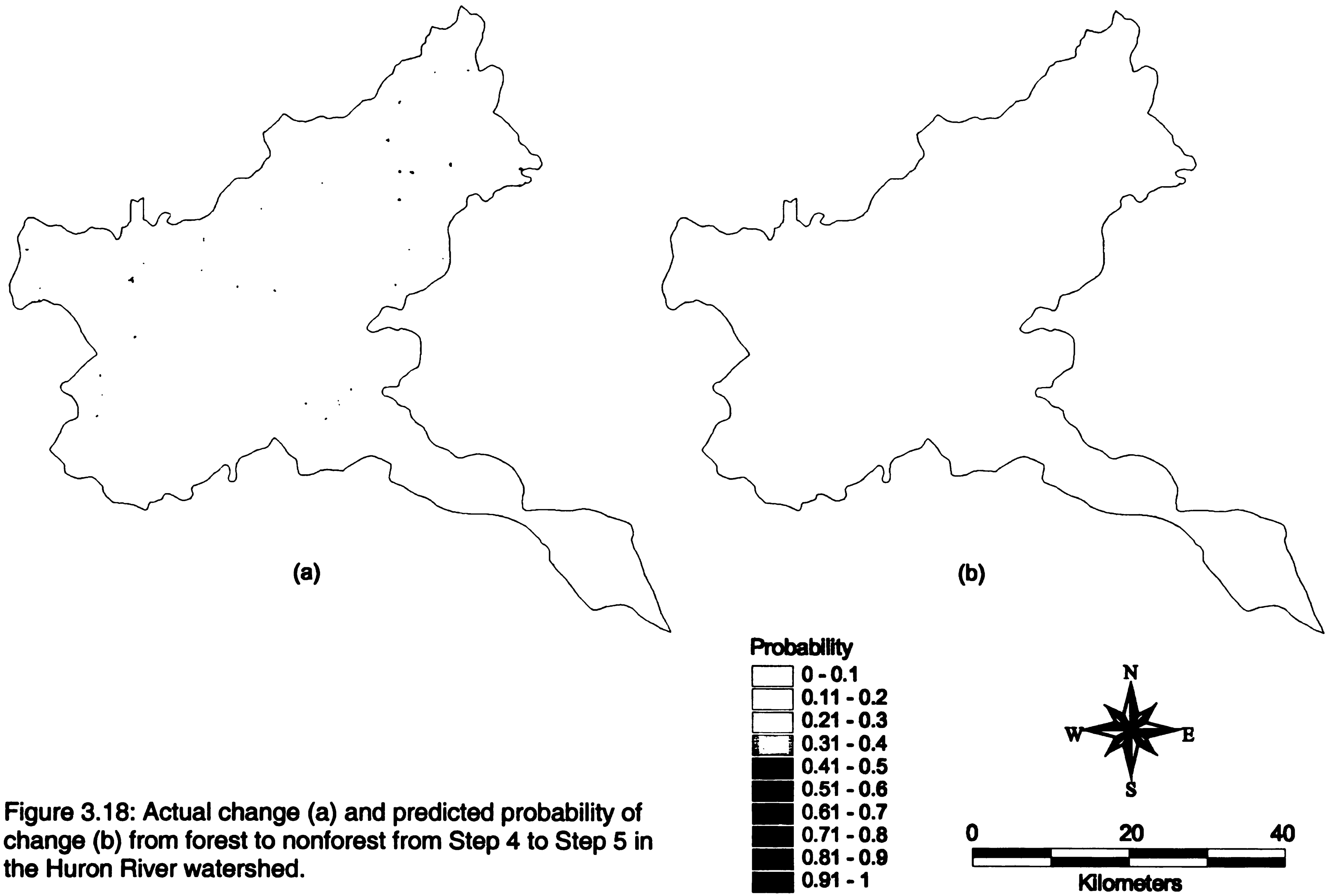


Figure 3.18: Actual change (a) and predicted probability of change (b) from forest to nonforest from Step 4 to Step 5 in the Huron River watershed.

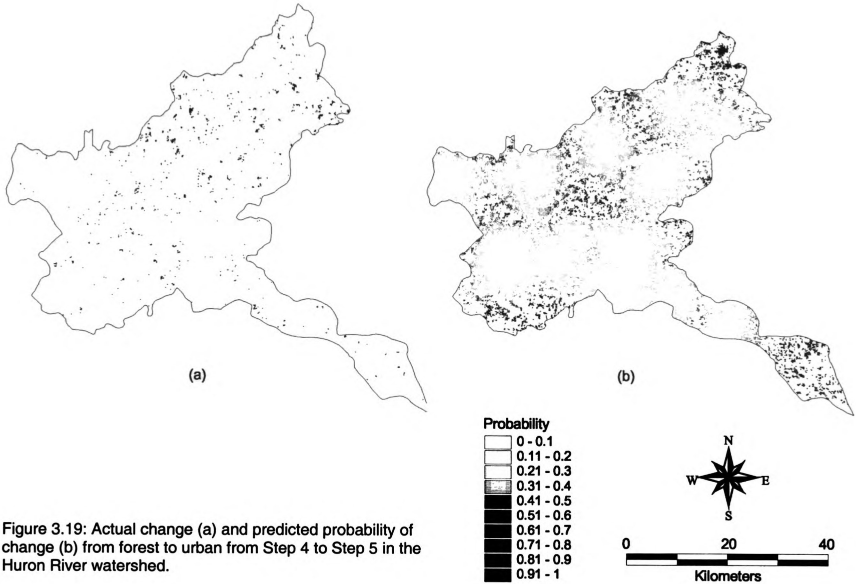


Figure 3.19: Actual change (a) and predicted probability of change (b) from forest to urban from Step 4 to Step 5 in the Huron River watershed.

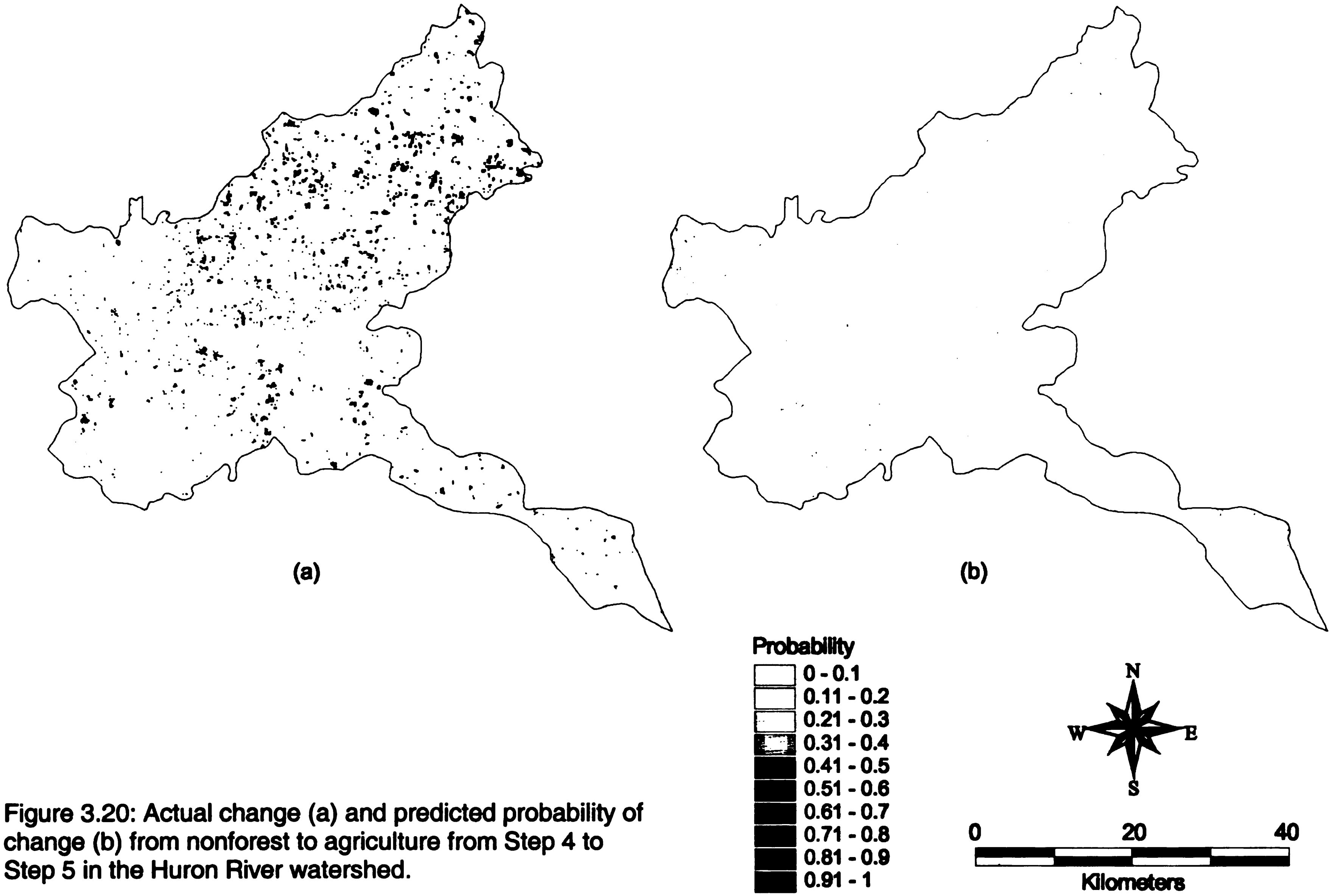


Figure 3.20: Actual change (a) and predicted probability of change (b) from nonforest to agriculture from Step 4 to Step 5 in the Huron River watershed.

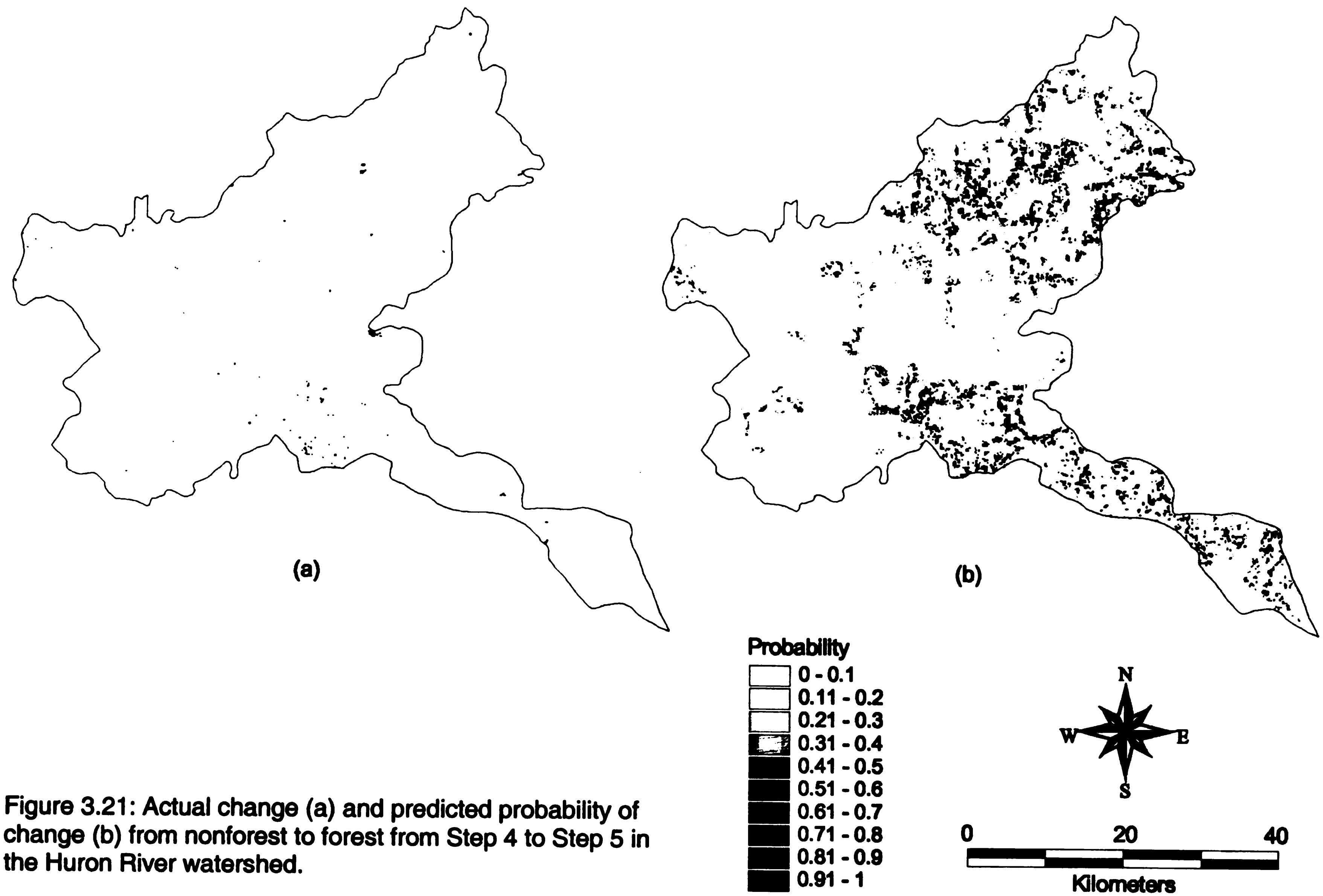


Figure 3.21: Actual change (a) and predicted probability of change (b) from nonforest to forest from Step 4 to Step 5 in the Huron River watershed.

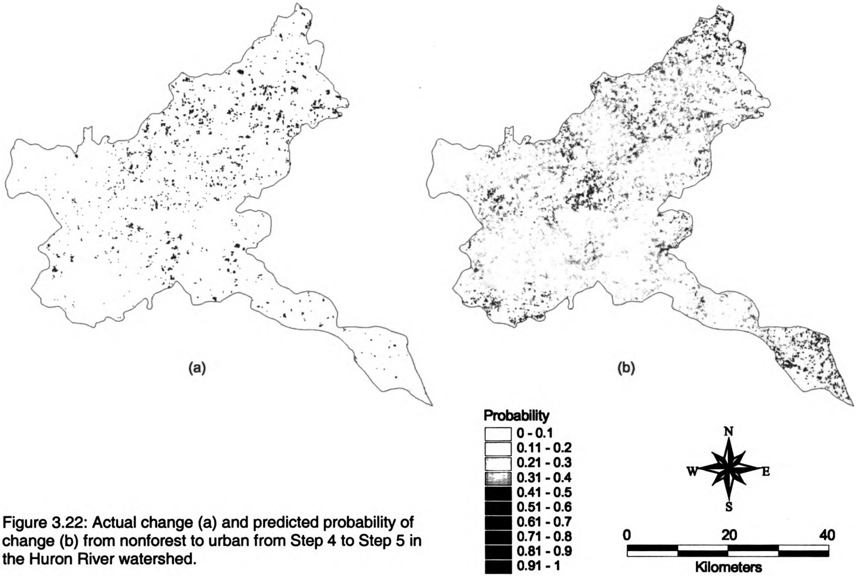


Figure 3.22: Actual change (a) and predicted probability of change (b) from nonforest to urban from Step 4 to Step 5 in the Huron River watershed.

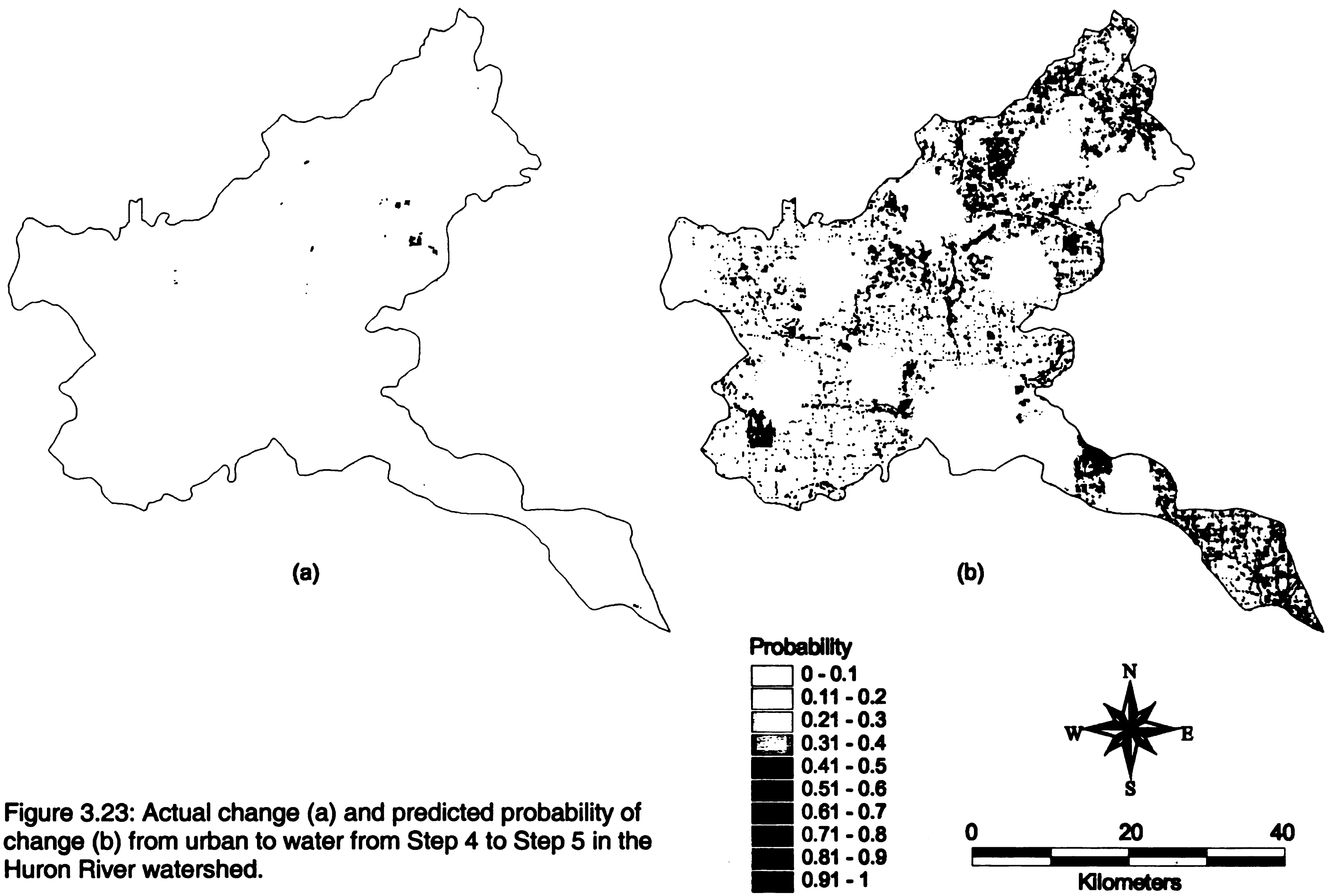
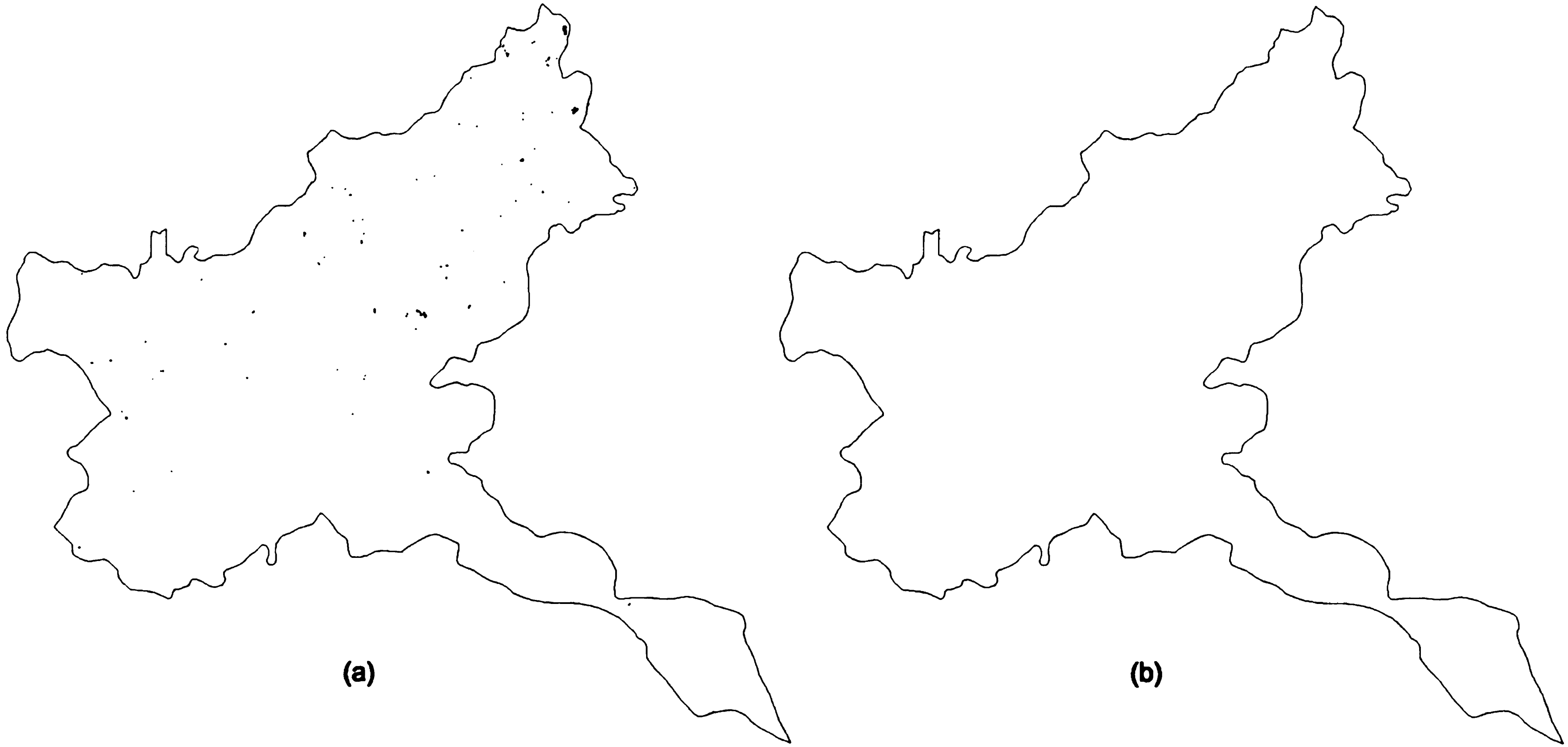


Figure 3.23: Actual change (a) and predicted probability of change (b) from urban to water from Step 4 to Step 5 in the Huron River watershed.



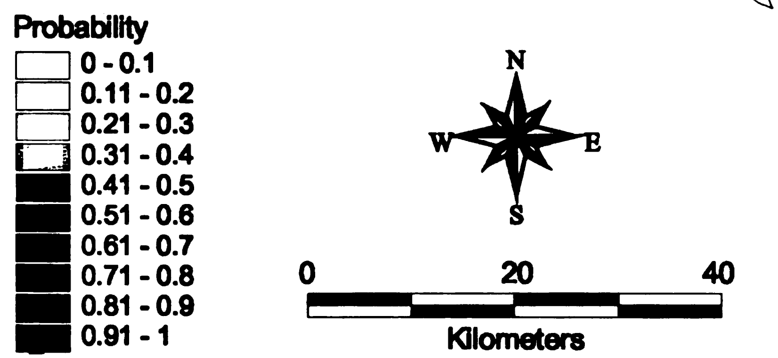


Figure 3.24: Actual change (a) and predicted probability of change (b) from wetlands to urban from Step 4 to Step 5 in the Huron River watershed.

CONCLUSIONS AND SYNTHESIS

The goal of this dissertation was to understand how land cover has changed over time and how those changes translate into changes in wildlife habitat. Overall, the results of this study both confirmed the extensive changes in land cover and wildlife habitats since presettlement and yet demonstrated that the outcomes of those changes with respect to wildlife and wildlife habitat were mixed and perhaps not as bleak as might be expected. Currently approximately 90% of the species with ranges that included either the Black and Huron river watershed are still found in each today to some degree. However, the status of most species beyond presence/absence, how they have adapted to those altered landscapes, and their ability to persist in those landscapes in the future are not known. To gather appropriate data will require coupling studies of fine-scale species-habitat relationships with studies of broad-scale species-landscape relationships. Together such studies should provide a more complete picture for the successful conservation of wildlife species.

Without question, the landscapes of the Black and Huron river watersheds have been extensively altered since European settlement. Although the driving forces and mechanisms were different, both watersheds have experienced a dramatic change in land cover composition and spatial pattern. For the Black River watershed, the changes reflected the historical dominance of the timber industry and the present mixture of forestry and natural-resource related activities dominant today. Forest composition is markedly different from conditions at the time of General Land Office surveys. In particular, the contributions of conifer and broadleaf forests have reversed since the GLO surveys. Conifer forests were once the dominant, but broadleaf forests now occupy 45% of the landscape. In addition, 57% of broadleaf forests are early successional aspen-dominated communities compared with only 10% at the GLO survey. Urban development in the Black River watershed consisted primarily of lakeshore developments and isolated residences and farmsteads. Some farming did occur, but mostly within the floodplain of the Black River, where soil conditions were likely more suitable for such activities.

In the Huron River watershed, land cover changes were more obvious. Fifty-five percent of the watershed had been converted to agriculture by the late 1930's. Since that time, nearly half of the agricultural area has been lost to urban development. Much of that development has been rural residential development in the northeastern and north central portions of the landscape. As in the Black River watershed, people apparently were drawn to the area by the appeal of its rural and somewhat natural character. Despite differences in the manner of change, however, land cover patterns in both watersheds exhibited similar trends. In effect both watersheds have undergone extensive human development. The dominant effect was the decrease in patch sizes, with a corresponding increase in patch numbers by several orders of magnitude, and the development of extensive road networks, such that no areas are very far from human influence. While the large differences in patch statistics from the GLO survey to modern times undoubtedly reflected the coarse nature of the GLO database, it is not unreasonable to assume that the forests of the Black and Huron river watersheds were fairly contiguous prior to settlement. The observed decreases may therefore be larger than in actuality. Despite these cautions, the general trend is to reduce landscape components to human scales (Cole et al. 1998). Thus it is not surprising that mean patch sizes in the Huron were converging to roughly 20 hectares, or about 40 acres - the size of a quarter-quarter section of land. Similar patch sizes were evident in the Black except for forest. The large amount of publicly-owned state forest likely served as a buffer to help maintain higher forest patch sizes.

The increase in both forest and nonforest areas from Step 1 to Step 4 was not expected. The results in the Black were more understandable given the history of timber harvesting in the region. By the late 1930's, much of the forested area had only just returned to conditions possibly suitable for harvesting. Regular planting patterns, such as resulted from Depression-era work programs, were clearly visible in several of the 1938 black-and-white aerial photographs of the Black River watershed. Therefore the increase in forest from Step 1 to Step 4 was not entirely unexpected and was consistent with broader forest trends (Leatherberry 1993).

The increase in forests and nonforest area in the Huron River watershed ran contrary to conventional wisdom. Urban expansion is typically viewed as a primary cause of destruction of more natural land cover. However, in the case of the Huron River watershed, the pattern of low density suburban and rural residential development actually resulted in an increase in forest and nonforest land cover, almost always at the expense of agricultural land. Those increases likely resulted from several possible pathways. Large lot sizes, as encouraged by the Michigan Subdivision Control Act, could allow people to leave or return large portions of their property to forest or more natural conditions. What remains to be seen is whether those gains are permanent or temporary. Real estate prices could make larger plots more susceptible to subdivision in the future, thereby negating the gains made from Step 1 to Step 5. Indeed the losses may already be starting to occur as shown by the decline of both forest and nonforest from Step 4 to Step 5.

Wildlife habitat changes: results, definitions, and implications for landscape ecology

As land cover changed, so changed wildlife habitat. However, the implications of those changes varied between watersheds and among species. In the Black River watershed, the general trend was a small gain (mean increase of 850 ha per species group) in potential habitat from the GLO survey to 1992. However, the small increase masks a wide variation in potential habitat changes, as the standard deviation of those changes was ±20,998. Species clustered into groups that either gained or lost habitat depending upon their relationship with major (i.e., broadleaf or conifer) forest cover types. In the Huron, the general trend was a loss in habitat from the GLO survey to 1995 (mean loss of 38,115 ha). Again variation was high, as the standard deviation of potential habitat area changes was ±59,739. Not all species experienced a decline in habitat. Forty-two species in the Black River watershed and 33 species in the Huron River watershed gained potential habitat area from the GLO survey to Step 5 (Table 2.5, Table 2.9). More surprisingly, 85 species (50%) and 135 (74%) of species gained potential habitat in the Black and Huron river watershed, respectively, from Step 1 to Step 5. However, it should be noted that mean patch sizes of potential habitat declined by at least one order of magnitude from the GLO survey to Step 5, although they remained fairly constant from Step 1 to Step 5.

The complex results of the habitat analysis stem from the interaction of three factors operating in each landscape: the decline of forest and wetlands that comprised the majority of the vegetation in both watersheds at the time of the GLO survey, the increase in nonforest, and the ability of species to use human-dominated land cover types (e.g., urban and agriculture). The larger negative trend in the Huron River watershed was a direct result of the extensive forest and wetland losses that have occurred there. Forest declines in the Black were not as large, although the compositional changes in forest had their effects, especially for species dependent on conifers (e.g., blackburnian warbler, Dendroica fuscia; boreal chickadee, Parus hudsonicus; lynx, Felis lynx; pine grosbeak, Pinicola enucleator; wolverine, Gulo gulo). Counteracting the losses of forest and wetlands were the increases in nonforest land cover, which potentially benefited a wide range of species such as the prairie vole (Microtus ochrogaster), northern bobwhite (Colinus virginianus), and the six-lined racerunner (Cnemidophorus sexlineatus). Finally many human-dominated land cover types (e.g., urban and agricultural areas) may provide habitat to a wide variety of species.

The negative relationship between the numbers of land cover types as potential habitat and change in potential habitat area was unexpected but understandable. The number of species occurring in natural land cover types was usually 1.5 to 2 times higher than the number occurring in human land cover types (Table 2.3). Therefore, although some species made up for lost "natural" habitat by using "human" habitat, most species lost some amount of potential habitat. In the Black River watershed the primary type of land cover change was a shift from conifer to broadleaf forest. The losses incurred by conifer forest species (117, Table 2.3) would be offset by gains of broadleaf forest species (157, Table 2.3). Species occurring in both forest types would gain or lose even small amounts of habitat. In addition, gains in nonforest and wetlands would tend to offset the forest losses, as would expansion into urban and agricultural areas. The negative relationship in the Huron reflected the extensive losses in forest and wetlands. Broad-ranging species would tend to experience higher losses in potential habitat area because they had more to lose. In addition, species with smaller ranges, which often included nonforest areas, typically experienced an increase in potential habitat area given the large increase in nonforest areas, particularly grasslands.

The wildlife habitat analysis and preceding discussion was based entirely on a species-land cover association matrix. Deciding whether to list a land cover type as suitable or unsuitable was typically made from qualitative descriptions of species accounts. Birds were the primary exception, as the Michigan Breeding Bird Atlas provided quantitative information on observations of breeding birds in different land cover types, which was assumed to indicate that the land cover in question provided habitat for the species of interest. This raises the issue of how useful the MIRIS land cover system is for habitat analysis. In particular, with respect to urban and agricultural habitats, the MIRIS land cover types are really more a hybrid of land use and land cover. The process of deciding whether a particular land cover type could be potential habitat was actually very interesting because it required re-evaluating the land cover from a species perspective. Consider a shrub-nesting bird, for example. In this case, many urban areas (e.g., residential, recreational) may contain shrubs of a suitable type, size, and density that would serve as a habitat for the bird species in question. Therefore those land cover types were viewed as potential habitat unless accounts of the species habitat preferences indicated that the species in question did not tolerate humans or perhaps only required native shrubs not likely to be found in those areas.

The MIRIS system is also a hierarchical classification, meaning that urban takes precedence over agriculture, which takes precedence over forest, etc. If an area contained scattered houses with mixed forest, it was classified as residential unless the forest patches were large enough to warrant separate delineation. However, lands that are classified as urban often have as little as 10-30% of actual surface area taken up by impervious surfaces such as buildings or parking lots (Meyer and Turner 1995). The remaining areas typically contain vegetation or other features that could be potential habitat for many species. For example, Michigan State University, which would be classified as institutional (Code 126) in the MIRIS system, contains large areas of green space and several forest reserves that support many wildlife species. While the campus may not harbor threatened or endangered species or unique natural communities, it does have some value as wildlife habitat that should not be discounted.

In the case of habitat quality, much detailed information exists for many species. In particular, Habitat Suitability Indices (U.S. Fish and Wildlife Service 1981) have been prepared for several hundred species. Such studies provide essential information on species habitat requirements. The species-land cover matrix used in this study would not exist without this type of research. However, the difficulty lies in applying such models to broader landscape and regional analyses. The MIRIS land cover database, which can be fairly detailed for a land cover classification system, still represents a very coarse picture of potential habitat conditions. Additional research is needed that links the fine-scale species-habitat relationships to the broad – and often crude – land use/land cover databases available for landscape and regional analyses. Of particular interest would be better assessments of the extent to which different species use human-dominated land cover types, such as various urban or semi-urban areas, although such studies are becoming more common (e.g., Boal and Mannen 1998, Boal and Mannen 1999). Linking fine and broad-scale information, most likely with the aid of improvements in remote sensing techniques, will be needed to assess the population status of different wildlife species across a range of landscape conditions.

Regarding spatial configuration and spatial context, the data are scarce. Both relate to two aspects of species viability on the landscape. First, how do they influence the selection of habitat, either for breeding or other activities such as migration? Second, how do they influence dispersal, especially in highly fragmented habitat such as the Huron River watershed? Species need a variety of resources to satisfy their life history requirements. For example, species home ranges can be highly variable in space and over time as resource needs or availability change (Baker 1983). Also, species - such as broad-ranging carnivores - may have home ranges that include non-essential areas. Migratory species often have different, non-contiguous habitat needs while travelling, such as feeding and loafing areas. Therefore simply identifying the size of a potentially suitable habitat patch and then comparing that patch to a published or estimated home range size may be inappropriate, although it will provide a conservative estimate of habitat availability. More information is needed on the amount of different habitats needed relative to the scale of species movements and how those relationships might change over different time scales, e.g., daily, seasonally, or over the lifetime of the individual. The situation is similar for dispersal information, although recent work on developing general relationships between body size and dispersal distances provides a starting point (Sutherland et al. 2000) for estimating species ability to move across the landscape.

If data as described above became available, how might such data affect the results of the habitat analysis? The answer to that question would be species-specific. First, potential habitat could change qualitatively (suitable/unsuitable) and spatially (within distance "d" of a wetland, in the case of some amphibians or reptiles). Second, more detailed information on home range analysis could decrease (species X must have only land cover Y) or increase (species X needs 60% of land cover Y scattered throughout its home range) potentially suitable habitat. The same could hold true for spatial configuration (isolated patches beyond maximum dispersal distance may be unsuitable) and spatial context (the patch is OK but it is too close to a nearby shopping area).

The limitations discussed above clearly point out the need for several directions for future landscape ecology research. First, more fine-scale studies need to be repeated at broad spatial scales and across different landscape conditions, similar to the Michigan Breeding Bird Atlas project. By repeating such studies at multiple locations, information on habitat characteristics and species presence/absence or where possible, abundance, could be related to landscape features that can be readily observed from broad-scale data, such as are available within a GIS. Detailed habitat assessments at specific locations are necessary for species conservation, but they must somehow be linked to information available for broad-scale analyses. Also such studies must be repeated over time, such as is done for the Breeding Bird Survey and is now being done with the Michigan Frog and Toad survey, to understand the long-term viability of species relative to fine-scale and broad-scale changes.

Second, with respect to land cover types and habitat associations, more work is needed to quantify how different species use - or avoid – human-dominated land cover types. This also relates to understanding how much area classified as urban is actually urban, or agricultural, or whatever land cover type we happen to assign to a particular parcel of land. Conservation of species must include human-dominated landscapes; therefore more research is needed regarding what factors influence species to use or not use human-dominated landscapes.

Third, more information on species dispersal is needed to better understand the viability of species in fragmented landscapes. Individual-based studies of dispersal, which are often very complex and intensive and often prohibitive on broad-scales, should be performed in concert with simpler studies that estimate dispersal indirectly, such as via presence-absence metapopulation models (Hanski and Gilpin 1991). In these models, species presence and absence is monitored in patches across the landscape to develop a longitudinal data set of patch occupancy/extinction. Using this data, relationships can be developed between patch sizes and probability of extinction and patch locations and probability of recolonization. Although a simple model, it is perhaps the most realistic means to assess dispersal over broad scales. Together, individual-based dispersal studies and broad-scale metapopulation studies may offer reasonable estimates of species viability in fragmented landscapes (Crone et al. 2000).

Finally, additional modelling effort is needed to forecast potential land cover change. Currently such models seem to exist at simple and complex extremes. Simple Markov models are often put forward to explain more complicated land cover processes. At the other extreme are complex socio-economic models that require large amounts of additional data to parameterize and test and apply to one particular case. Instead model development should focus on developing generalized tools and methodologies for describing and characterizing land cover change with an acceptable level of accuracy but without requiring large amounts of additional information or costly work. As demonstrated in Chapter 3, model development could focus on methods to use information inherent in the data itself, i.e. patterns of land cover change, to help predict possible future land cover configurations. Such an approach might reduce the additional amount of data needed and could in some circumstances get around the lack of data that exist in many cases.

Management implications

The state of Michigan has, in theory, adopted a policy that advocates ecosystem management (Michigan Department of Natural Resources 1997). While the definition of ecosystem management remains elusive (Grumbine 1994), it broadly implies the conservation of the physical and biological components of the environment for some specified period of time. Conservation of wildlife species would then follow as a subset of ecosystem management, with maintaining viable populations of wildlife species into the "foreseeable" future as one objective or set of objectives. While the results of this research do not delineate an exact set of management prescriptions, they do offer insights that can help wildlife managers and policymakers increase the effectiveness of current conservation measures.

First, it is very encouraging that approximately 90% of the vertebrate wildlife species that historically ranged in the Huron or Black river watersheds (or both) can still be found in those watersheds. However, beyond presence/absence, the status and trend of many species, especially non-game species, within each watershed is poorly known. Therefore a primary objective of wildlife management should include an inventory of species at regular intervals and at scales appropriate to the species range. Existing surveys, such as the Breeding Bird Survey and the Michigan Frog and Toad Survey, should be complimented by additional survey work for mammals and other herpetofauna. As stated above, the primary goal at first would include establishment of species presence or absence at broad-scales, be it watersheds, counties, regions, or even the entire state of Michigan. Based on that information, more detailed assessments could follow for species of concern once adequate baselines have been established.

Second, a primary goal of conservation on a landscape perspective should be the increase of patch sizes wherever possible. Many studies have documented the physical and biological consequences of smaller patch sizes (see Saunders et al. 1991 for a good review). In the Huron and the Black river watersheds, the amount of potential habitat, although crudely measured, increased from the late 1930's to the early 1990's for many species. However, patch sizes did not increase appreciably. For many species this could be a limiting factor. Therefore increasing patch sizes - especially in areas such as the Black and Huron river watersheds where they have been severely reduced - and not just total amount of habitat should be a primary goal of management efforts.

Third, the state of Michigan should strive as much as possible to involve private landowners in conservation efforts. This should include an expansion of the Purchase of Development Rights program, land swaps where appropriate, or offering incentives for landowners to manage portions of their property for wildlife. Especially in the Huron River watershed, the increases in nonforest and forest cover types from Step 1 to Step 4 likely represent an opportunity to set aside areas primarily for conservation. From Step 4 to Step 5, however, those gains began to erode. If expected lifestyle trends continue in the Huron River watershed, especially people seeking housing on large lots in more rural and – ironically – natural settings, losses of those recently reverted areas will likely continue.

APPENDICES

APPENDIX A

MIRIS LAND COVER CODE CLASSIFICATION

(Note: The following information describes the MIRIS land classification system used to delineate land cover as described in Chapter 1. The information was copied from a Michigan Department of Natural Resources pamphlet. Any mistakes or typographical errors in the pamphlet were not corrected.)

CURRENT USE INVENTORY CLASSIFICATION SYSTEM DEFINITIONS

Division of Land Resource Program

Department of Natural Resources

The land cover and structures upon Michigan's landscape are going to be identified, classified and mapped by many different groups every five years through the PA 204 current use inventory process. To insure that these current use inventories are of maximum value for determining the extent and location of Michigan's land resources, and for tracking changes in those land resources, it is very critical that consistency be maintained in the classification system.

The classification system which the Inventory Advisory Committee (IAC) has established is based on upon explicit organizing critieria to maintain consistency among groups preparing current use inventories and between the first current use inventories and those which will follow:

1. It is comprehensive enough to alllow for an appropriate category for identifying the existing use of every 2.5 to 5.0 acres of land in Michigan.

2. Every category has a unique description or set of characteristics to resolve questions of double or multiple category classifications.

3. The classification system can be applied using aerial photography as the primary source of data for the inventory. Since aerial photography has certain limitations, the classification system recognizes those limitations and is designed to allow different interpretors using aerials to obtain the same results. Further a minimum level of accuracy in the interpretations of different categories is obtainable using the system.

4. The current use classification system is part of a larger one which allows for the interpretation and mapping of subcategories when larger scale photography is available or where on-the-ground checking can occur.

The following list of land cover/use categories make up the current use classification system adopted by the IAC. The cagegory names and the corresponding number should be placed on the map legend. The definitions provided should be used by the interpretor to distinguids henbtween the categories. (NOTE: A the interpretor becomes familiar with the definitions, pay particular attention to the categories lised as potential interpretation problem areas. Tips for delineating potential problem categories using aerials are provided. When in doubt, either field check the area or identify the cover/use at the more general level, i.e., use the two digit classification code versus the three digit code.)

URBAN AND BUILT UP LANDS

Urban or Built Up Land is comprised of areas of intensive use with much of the land covered by structures. Included in this category are cities, villages, strip-developments along highways, transporation, power, and communications facilities, and areas such as those occupied by mines and quarrries, shopping centers, industrial and commercial complexes, and institutions that may, in some instances, be isolated from urban areas.

As development progresses, land having less intensive use may be located in the midst of Urban or Built-up areas and will generally be included in this category. Agricultural land, forest, wetland, or water areas on the fringe of Urban or Built-up areas will not generally be included. The Urban or Built-up category takes precedence over others when the criteria for more than one category are met. For example, residential areas that have sufficient tree cover to meet Forest Land criteria will be placed in a Residential category.

The following categories of Urban and Built Up Lands should be delineated by current use inventory participants for their communicity. Within those delineations, lable each with the corresponding two, three or four digit code.

111 Multi-family residential – medium to high rise

This category includes all mutli-family and apartment structures of four or more stories and generally containing an average gross density 20 or more dwelling untis per acre (50 or more per hectare). Included are apartments, condominiums, and the like whether in complexes or as single structures. When mapping ths category, include lawns, parking areas, and small recreational facilities such as basketball or tennis courts built on site.

112 Multi-family residential – low rise

This is similar to 111 except that is for structures of 3 or less stories and contain an average gross density of up to 19 dwellings units per acre. Duplexes are not included in this category, but townhouses are.

113 Single family/duplexes

This category includes areas having dtached single and two-family structures generally containing an average gross density of no more than 6 dwelling units per acre (15 units per hectare). Lawns, drive ways, and associated structures such as garages, tool sheds, garden sheds, etc., should be included in the 113 category.

115 Mobile home park

Groupings of three or more mobile homes and related service structures and recreational spaces belong in this category.

12 Commerical, services, and Institutional

This 12 category should be used to identify those areas used predominantly for the sale of products and services that are not encompassed in 121, 122, 124 and 126 categories or to identify those commercial uses which cannot be accurately separated into one of the four categories.

121 Primary/central business district

The 121 category should be used to identify the main commercial service center in the community. The uses included in this class are retain establishments and the business, financial, professional and repair services of the area. The 121 category often contains institutional uses such as governmental offices, churches and schools. These should not be separated out unless they exceed approximately one-third of the area.

122 Shopping center/malls

This is usually a structure or closely packed group of structures that contain a large amount of floor space and a variety of commercial and service establishments. Shopping centers/malls have large common parking lots, usually larger in area that the structure grouping itself.

124 Secondary/neighborhood business district

These areas are composed of relatively compact groups of stores, institutional structures and service providers outside of the 121 category. The 124 classes are usually located on major streets and are surrounded by non-commercial uses. Parking is scattered throughout the area.

126 Institutional

Education, government, religious, health, correctional and military facilities are found in this category. All buildings, grounds, and parking lots that compose the facility are included wihtin the institutional class. Small institutional units in developed areas that do not meet the one to two hectare minimim size standard should be placed within the adjacent categories which are usually residential or commercial.

13 Industrial

Industrial areas include a wide array of uses from light manufacturing and industrial parks to heavy manufacturing plants. Identification of light industries – those focused on design, assembly, finishing, and packaging of products – can often be based on the type of building, parking, and shipping arrangments. Light industrial areas may be, but are not necessarily, directly in contact with urban areas; many are now found at airports or in relatively open country. Heavy industries use raw materials such as iron ore, lumber, or coal. Included are steel mills, pulp or lumber mills, oil refineries and tank farms, chemcial plants and brick making plants. Stockpiles of raw materials, large power sources, and waste product disposal areas are usually visible, along with transportation facilities capable of handling heavy materials.

138 Industrial parks

The 138 category should be used to map those areas set aside within the community and specifically provided with the necessary community facilities such as roads, water and sewer lines, power, to support industrial growth and development.

141 Air transportation

This category includes all facilties directly connected with air transport, whether it be commercial, municiple, militiary, or private. The area delineated by 141 on the inventory should contain the runways, terminals, service buildings, hangers, navigation aids, fuel storage areas, parking lots and a limited buffer area.

143 Water transportation

This category includes those areas related to water transportation, excluding the water. The major components of this category are port areas, docks, shipyards and locks. Recreationally oriented marinas and yacht basins should be mapped under the 19 category.

145 Communications

Those areas associated with radio, radar, television, telegraph, telephone, etc., are included in this category. Smaller facilities or those associated with industrial, commerical or other uses should be included within the category which they are associated with.

146 Utilities

Those areas associated with the transport and storage of gas,oil, water, electricity, and waste products are included in this category. Small facilities or those associated with an industrial, commercial or extractive use should be included with those categories.

1467 Waste Injection Wells

17 Extractive

Extractive mineral land encompasses both surface and subsurface mining operations, such as sand and gravel pits, stone quarries, oil and gas wells, and metallic and nonmetallic mines. In size, these mineral activities range from the large open pit mines covering thousands of acres to the often unidentified oil and gas wells less than a foot square. Surface structure and equipment operations utlilizing large power shovels and production trucks, installed primary crushers, concentrating or processing plants, stockpiles, maintenance buildings waste dumps, tailings basins and parking lots. The waste dumps and tailing basins are located generally within relatively short distances from the mining and processing facilities. Uniform identification of all the diverse mineral extraction facilities may be difficult from remote sensor data alone.

Generally the concentrating, agglomeration or smelting and refining facilities are located near the source of the minerals and are included as part of the primary facilities for classfication and for taxation. In some instances there may be further processing that may be classified as an industrial facility. Areas of future reserves are included in the appropriate present use category; i.e., as agricultural or forest lands, regardless of the anticipated future use. Unused pits or quarries that are flooded are placed in the water category if the water body is larger than 2.5 to 5.0 acres (1 to 2 hectares). Areas of tailing, waste dumps and abandoned or unused pits and quarries, that are not flooded, generally are subject to reclamation as provided for in Michigan's Act 92, P.A. 1970, as amended, and are vegetated and otherwise reclaimed.

171 Open pit

Extractive activities which are primarily carried out upon the surface of the earth through the creation of a large pit.

1711 Metallic Mineral Quarry
1712 Nonmetallic Mineral Quarry
1713 Coal
1714 Sand and Gravel
1719 Other

172 Underground

Extractive activities primarily carried out underground; portions of this activity covered the barren category include bare disturbed land and development waste rock.

1721 Metallic
1722 Nonmetallic
1723 Coal
1729 Other

173 Wells

This category includes the areas used for the extraction of oil and natural gas and other minerals from the sub-strata. In the case of one individual well, the area immediate surrounding the well is all that is placed, with the code number, into this category. Care must be taken not to confuse these wells with water wells.

1731 Oil
1732 Gas
1733 Brine Production
1734 Waste Disposal
1739 Other

179 Other extractive

Extractive uses not covered in the above categories.

19 Open land and other

Open land consists of land and structures used for outdoor cultural, public assembly and recreational purposes. Examples would be zoos, botanical gardens, fairgrounds, golf courses, athletic fields, and amusement parks.

193 Outdoor recreation

This category includes recreation facilities an areas which are on open land. This category may contain on these park lands incidental buildings such as shelters, toilets, beach change areas, etc. Do not, however, map forest, water, wetland an barren lands within these areas as 193. map them in their respective 4, 5, 6, or 7 classification.

194 Cemeteries

Include chaples, masoleums, and maintenance buildings.

AGRICULTURAL LANDS

Agricultural lands can be defined broadly as land use for production of food and fiber. The agricultural land class is divided into five categories for the purposes of the current use inventory. If problems arise during interpretation and it is difficult to distinguish between the categories, it is acceptable for the sake of accuracy to numerically label agricultural lands simply as "2".

21 Cropland

Land used to produce crops such as grains, hay, or row crops including vegetables.

22 Orchards, bush fruits, vineyards, and ornamental horticulture areas

This category is to be used to map areas which product fruit and berry crops. Horticulture areas including nurseries, floricultural areas and seed and sod areas used perennially for that purpose should be classed 22.

23 Confined feeding operations

Feeding operations are large, specialized, livestock-production enterprises, chiefly beef cattle feedlots and large poultry farms, but also including large hog, dairy, and fur-bearing animal farms. Excluded from this classification are shipping corrals and other temporary holding facilitiies. Game farms and zoos do not meet the animal-population densities to be placed in this subcategory.

24 Permanent pasture

This category produces grasses and certain types of legumes which are grazed by animals. The land is continuously use for pasture with tillage only to reestablish the grasses and legumes. This category will be at times difficult to distinguish with some of the nonforested categories. The interpretor should try to spot evidence of tillage or animal activity in order to affirm a 24 category identification.

29 Other agricultural lands

Farmsteads, greenhouses, and noncommercial training areas primarily for race horses should be placed in this category.

NONFORESTED LANDS

Nonforested land (open land, rangeland) is defined as areas supporting early stages of plant succession consisting of plant communities characterized by grasses or shrubs. In cases where there is obvious evidence of seeding, fertilizing or other cultural practices, these areas should be mapped as cropland or permanent pasture (Agricultural Land 21 and 24 respectively).

31 Herbaceous openland

Herbacenous openlands (prairies, grassland, rangeland) are dominated by grasses and forbs. Such areas are often subjected to continuous disturbance such as mowing, grazing or burning to maintain the herbaceous character. Typical plant species are quackgrass, Kentucky bluegrass, upland and lowland sedges, reed canary grass and clovers.

32 Shrubland

Shrublands are dominated by native shrubs and low woody plants. If left undisturbed, such areas are soon dominated by young tree growth. Typical shrub species include blackberry and raspberry briars, dogwood, willow, sumac, and alder.

33 Pine or oak opening (savannah)

This category should be used to classify those openings in oak or pine forestland where grass cover is so thick that seeds cannot germinate. Oak savannahs primarily occur in the sandy plains through Muskegon, Oceana, Newaygo and Mecosta counties, although some may still exist in some of the more southern counties. The pine savannahs can be found in the jack pine forestland between Gaylord and Grayling.

FOREST LAND

Forest lands are lands that are at least 10 percent stocked by forest trees of any size, or formerly having such tree cover, and not currently developed for nonforest use.

Forest land can generally be identified rather easily from high altitiude imagery. On some lands there may be large areas that have little or no visible forest growth. Lands such as these on which there is forest rotation (involving clear cutting and regeneration) should be classified under the Forest Land Category. Lands that meet the criteria for Forest Land and also are being used for a higher category should be placed in the higher category (Urban and Built Up, Agricultural or Nonforested).

41 Broadleaved forest (generally deciduous)

In Michigan, typical broadleaved species include oak, maple, beech, birch, ash, hickory, aspen, cottonwood and yellow poplar. The 41 classification should be subdivided to the maximum extent feasible into the following groupings:

411 Northern hardwood

Areas throughout Michigan where the following species predominate or are intermixed – sugar and red maple, elm, beech, yellow birch, cherry, basswood and white ash.

412 Central hardwood

This category of beech/maple and oak/hickory forest lands are found primarily south of the tesion zone (the line between Bay City-Muskegon where soil types and plant species are different). Species found in the 412 category also include sugar and red maple, beech, basswood, cherry and ash. For these species located north of the tension zone, place them in the 411 category.

413 Apen, white birch, and associated species

The 413 category should be used to map the trembling aspen, bigtooth aspen, white birth and related species.

414 Lowland hardwoods

Ash, elm, and soft maple along with cottonwood, balm-of-Gilead and other lowland hardwoods will be mapped through this category.

42 Coniferous forest

Coniferous forests include forested land in which the trees are predominantly those with needle foliage. In Michigan these would include species such as pine, spruce, balsam, larch, hemlock, and cedar. The 42 classification should be subdivided to the maximum extent feasible into the following groupings:

421 Pine

Those forests where white, red, jack and scotch pine predominates.

422 Other upland conifers

The 422 category should be used to map white or black spruce, balsam or douglas fir along with areas covered by larch and hemlock.

423 Lowland conifers

The lowland species category includes areas of predominantly cedar, tamarack, black and white spruce and balsam fir stands.

429 Managed christmas tree plantation

The 429 category should be used to map those lands specifically managed for the short term growth and harvesting of scotch pine, douglas fir and black or white spruce.

WATER BODIES

The water category includes all areas which are predominantly or persistently water covered. Water bodes that are vegetated are placed in the Wetlands category. Sewage treatment or water supply facilities are a basic part of the urban pattern and should be included in the Urban and Built Up category even where the unit is large enough to be separately identified.

51 Streams and waterways

This category includes rivers, streams, creeks, canals, drains, and other linear bodies of water. Intermittent streams which flow in wet seasons but are dry during dry seasons should be classified as streams if they are water covered the majority of the time. Ephermeral streams which carry surface runoff during and immeadiately after periods of precipitation or snow melt should not be classified as streams. These areas generally have no permanent or well-defined channels but follow slight depressions in the natural contour of the ground surface. Where the water course is interrupted by a control structure which creates an impoundment, the impounded area should be classified as a reservoir. The boundary between streams and lakes, or reservoirs, is the straight line across the mouth of the stream. The St. Mary's, St. Clair, and Detroit Rivers, are classified as Great Lakes connecting waterways.

52 Lakes

Lakes are nonlinear water bodies, excluding reservoirs. A water body should be classified as a lake if a structure has been installed primarily to regulate or stabilize lake levels without significantly increasing the water area. The delineation of a lake will be based on the areal extent of water at the time the data is collected. Islands within lakes which are too small to delineate will be included in the water area.

53 Reservoirs

Reservoirs are artificial impoundments of water, whether for irrigaion, flood control, municple and/or industrial water supply, hydroelectric power, or recreation. The reservoir category should not include lakes which have had control structures built to stabliize lake levels without significantly increasing the water area. Reservoirs can usually be identified by the presence of dams, levels, or other water control structures.

54 Great Lakes

The Great Lakes are the waters of Lake Superior, Lake Michigan, Lake Huron, Lake St. Clair amd Lake Erie. Connecting waterways are the St. Clair, St. Marys and Detroit rivers. Bays and estuaries of these lakes and waterways should be included under this heading.

WETLANDS

Wetlands are those areas between terrestrial and aquatic systems where the water table is at, near, or above the land surface for a signifcant part of most years. The hydrologic regime is such that it permits the formation of hydric soils or it supports the growth of hydrophytic vegetation. Hydrophytes are usually established on wetlands, although some alluvial deposits and mud flats may be nonvegetated. Examples of wetlands include marshes, mudflats, wooded swamps, and floating vegetation situation on the shallow margins of bays, lakes, rivers, ponds, streams and manmade impoundments such as reservoirs. They include wet meadows or perched bogs and seasonally wet or flooded basins or potholes with no surface water outflow. Open water areas deeper than two meters (6.7 feet) and permanently or semi-permanently flooded shallower water areas with less than 30 percent vegetative cover are classifed as water.

Wetland areas drained for any purpose, and which no longer support hydrophytes, belong to other land use categories, whether it be Agriculture Land, Nonforested Land, Forest Land, or Urban and Built Up Land. When the drainage is discontinued and such use ceases, classification reverts to Wetland after characteristic vegetation is reestablished. Areas that have been dredged, dammed, or otherwise altered by man to create wetland conditions with its resultant, hydrophytic vegetation, are classified as wetlands.

The Wetland category is one of the more difficult ones to map strictly from aerials. It is best that the interpretor check soils surveys for the community, especially when delineating wetland boundaries in forested areas.

The Wetland classification is divded into two main categories – Forested and Nonforested. Those two main ones are further divided into five categories. If the interpretor has difficulty in distinguishing between the five refined areas, classify the wetlands into one of the two main categories to maintain accuracy.

61 Forested (wooded) wetlands

Forested wetland includes seasonally flooded bottomland hardwoods, shrub swamps, and wooded swamps including those around bogs. Because forested wetlands can be detected and mapped using seasonal (winter/summer imagery, and because delineation of forested wetlands is needed for many environmental planning activities, *they are separated from other forest land* (i.e., 414 Lowland hardwoods and 423 Lowland conifers). Wooded swamps and flood plains contain primarily oaks, red maple, elm, ash, alder, and willow. Bogs typically contain larch, black spruce, and heath shrubs. Shrub swamp vegetation includes alder, willow, and buttonbush. If possible, the 61 category should be divided into 611 Wooded and 612 Shrub/scrub categories.

611 Wooded wetland

This class applies to wetlands dominated by trees more than 20 feet tall. The soil surface is seasonally flooded with up to 12 inches of water. Several levels of vegetation are usually present, including trees, shrubs, and herbaceous plants. Some of the predominate tree species include: ash, elm, red maple, cedar, black spruce, tamarack, and balsam fir.

612 Shrub/scrub wetland

This class applies to wetlands dominated by woody vegetation less than six meters tall. Vegetation includes shrub and small or stunted trees. This class includes both stable shrub wetlands and areas in a successional stage leading to wooded wetlands. Some of the predominate species include alder, dogwood, sweetgale, leatherleaf, willow-buttonbush associations, and water willow. Any standing dead trees, shrubs and stumps should be placed in the 612 category.

62 Nonforested wetlands

Nonforested wetlands are dominated by wetland herbaceous vegetation or are nonvegetated. These wetlands include inland nontidal fresh marshes, fresh-waer meadows, wet prairies, and open bogs. The following are examples of vegetation associated with nonforersted wetland. Narrow-leaved emergents such as cordgrass and rush are dominated in coastal marshes. Both narrow-leaved emergents such as cattail, bullrush, sedges, and other grasses and broad-leaved emergents such as water lily, pickerelweed, arrow arum, and arrowhead, are typical of fresh water locations. Mosses and sedges grow in wet meadows and bogs. The 62 category should be divided into 621 Aquatic beds, 622 Emergent and 623 Flats to the maximum extent possible.

621 Aquatic bed wetland

The 621 category is to be used to map an area that generally has 30 percent or more vegetation cover of submerged; floating leaved or floating plants and is less than two meters (6.2 feet) deep. Typical plants species are yellow water lily, duck weed and pond weed.

622 Emergent wetland

These are wetland areas dominated (30 percent or more cover) by erect, rooted herbaceous hydrophytic plants, which are present for most of the growing season in most years. Usually dominated by perennial plants, although annuals are often present too. Typical species include cattail, bulrush, sedges, reeds, wild rice, pickerel weed, arrowhead, etc.

623 Flats

These are level or nearly level deposits of unconsolidated (sand, mud, organic sediments with less than 75 percent aerial coverage of stones, boulders, or bedrock; and less than 30 percent aerial coverage of vegetation other than pioneeering plants.

BARREN LAND

Barren land is land of limited ability to support life and little or no vegetation. Land temporarily barren owing to man's activities and where it may be reasonably inferred that the land will be returned to its former use, it is included in one of the other categories. Agricultural land temporarily without vegetation because of tillage practices is still classified as agricultural land. Sites for urban development stripped of cover before construction begins should be classified as urban and built up. Areas of extractive and industrial land having waste and tailings dumps should be placed in the respective extractive and industrial category. Three main categories will be used to represent barren land.

72 Beaches and riverbanks

The 72 category should be used to map sloping accumulations of exposed sand and gravel along shorelines.

73 Sand dunes

The 73 category should be placed on the delineations of hills, mounds or ridges of wind blown sand in a primarily unvegetated condition.

74 Bare exposed rock

The Bare exposed rocks category includes areas of bedrock exposure, scarps, talus, slides and other accumulations of rock without vegetative cover.

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APPENDIX B

LIST OF VERTEBRATE WILDLIFE SPECIES IN MICHIGAN

The following tables list the vertebrate wildlife species of Michigan, their occurrence or lack thereof in the Black and Huron river watersheds, and the species group to which they belong. The list is organized by classes: Amphibia, Aves, Mammalia, and Reptilia. A "P" under the Black or Huron river watershed column indicates the species either historically or currently ranges within the watershed in question.

CLASS AMPHIBIA

SCIENTIFIC NAME	COMMON NAME	MICHIGAN DISTRIBUTION	BLACK	HURON	SPECIES GROUP
Acris crepitans blanchardi	Blanchard's Cricket Frog	Southeast LP	-	P	72
Ambystoma laterale	Blue-spotted Salamander	Entire	P	P	185
Ambystoma maculatum	Spotted Salamander	Entire	P	P	38
Ambystoma opacum	Marbled Salamander	Extreme Southeast LP	-	P	22
Ambystoma texanum	Small-mouthed Salamander	Southeast LP	-	P	170
Ambystoma tigrinum tigrinum	Eastern Tiger Salamander	LP, central UP	P	P	213
Bufo americanus americanus	Eastern American Toad	Entire	P	P	211
Bufo woodhousii fowleri	Fowler's Toad	Western and Southern LP	-	-	32
Hemidactylium scutatum	Four-toed Salamander	UP; LP except W & E shore	P	P	43
Hyla chrysoscelis	Cope's Gray Treefrog	Entire	P	P	204
Hyla versicolor	Eastern Gray Treefrog	Entire	P	P	204
Necturus maculosus maculosus	Mudpuppy	Entire	P	P	27
Notophthalmus viridescens louisianensis	Eastern (Central) Newt	Northwest LP and UP	P	-	140
Notophthalmus viridescens viridenscens	Eastern (Red Spotted) Newt	Southeast LP	-	P	140
Plethodon cinerus	Red-backed Salamander	Entire	P	P	65
Pseudacris crucifer crucifer	Northern Spring Peeper	Entire	P	P	206
Pseudacris triseriata maculata	Boreal Chorus Frog	Isle Royale	-	-	54
Pseudacris triseriata triseriata	Western Chorus Frog	LP	P	P	54
Rana catesbeiana	Bull Frog	Entire	P	P	72
Rana clamitans melanota	Green Frog	Entire	P	P	91
Rana palustrus	Pickerel Frog	Entire	P	P	91
Rana pipiens	Northern Leopard Frog	Entire	P	P	173
Rana septentrionalis	Mink Frog	UP	-	-	73
Rana sylvatica	Wood Frog	Entire	P	P	176
Siren intermedia mettingi	Western lesser siren	Allegan & Van Buren counties	-	-	28

CLASS AVES

SCIENTIFIC NAME	COMMON NAME	MICHIGAN DISTRIBUTION	BLACK	HURON	SPECIES GROUP
Accipiter cooperii	Cooper's Hawk	Entire	P	P	93
Accipiter gentilis	Northern Goshawk	UP and N LP	P	-	65
Accipiter striatus	Sharp-shinned Hawk	Entire	P	P	94
Actitus macularia	Spotted Sandpiper	Entire	P	P	33
Aegolius acadicus	Northern Saw-whet Owl	Entire	P	P	145
Agelaius phoeniceus	Red-winged Blackbird	Entire	P	P	60
Aix sponsa	Wood Duck	Entire	P	P	167
Ammodramus henslowii	Henslow's Sparrow	S UP and LP	P	P	7
Ammodramus leconteii	Leconte's Sparrow	UP	-	-	8
Ammodramus savannarum	Grasshopper Sparrow	S UP and LP	P	P	2
Anas acuta	Northern Pintail	Scattered shorelines	P	P	11
Anas americana	American Wigeon	Scattered shorelines	-	P	91
Anas clypeata	Northern Shoveler	Scattered shorelines	-	P	58
Anas crecca	Green-winged Teal	Entire	-	P	76
Anas discors	Blue-winged Teal	Entire	P	P	58
Anas platyrhynchos	Mallard	Entire	P	P	97
Anas rubripes	American Black Duck	Entire	P	P	132
Anas strepera	Gadwell	Scattered shorelines	-	P	58
Aquila chrysaetos	Golden Eagle	Entire	P	P	2
Archilochus colubris	Ruby-throated Hummingbird	Entire	P	P	49

CLASS AVES (con't)

SCIENTIFIC NAME	COMMON NAME	MICHIGAN DISTRIBUTION	BLACK	HURON	SPECIES GROUP
Ardea herodias	Great Blue Heron	Entire	P	P	139
Arenaria interpres	Ruddy Turnstone	Entire	P	P	27
Asio flanneus	Short-eared Owl	Entire	-	-	34
Asio otus	Long-eared Owl	Entire	P	-	125
Aythya affinis	Lesser Scaup	Entire	P	P	47
Aythya americana	Redhead	Scattered shorelines	-	P	72
Aythya collaris	Ring-necked Ducks	UP and N LP	P	-	91
Aythya marila	Greater Scaup	Entire	P	P	47
Aythya valisineria	Canvasback	Manistee Co. and SE LP	-	P	48
Barrtamia longicauda	Upland Sandpiper	Entire	P	P	18
Bombycilla cedrorum	Ceder Waxwing	Entire	P	P	177
Bonasa umbellus	Ruffed Grouse	Entire	P	P	83
Botaurus lentiginosus	American Bittern	Entire	P	P	28
Branta canadensis	Canada Goose	Entire	P	P	75
Bubo virginianus	Great Horned Owl	Entire	P	P	122
Bubulcus ibis	Cattle Egret	Saginaw Bay, Erie Shore	-	P	120
Bucephala albeola	Bufflehead	Entire	P	P	27
Bucephala clangula	Common Goldeneye	UP and N LP	P	-	89
Buteo jamaicensis	Red-tailed Hawk	Entire	P	P	109
Buteo lagopus	Rough-legged Hawk	Entire	P	P	5

CLASS AVES (con't)

SCIENTIFIC NAME	COMMON NAME	MICHIGAN DISTRIBUTION	BLACK	HURON	SPECIES GROUP
Buteo lineatus	Red-shouldered Hawk	Entire	P	P	64
Buteo platypterus	Broad-winged Hawk	Entire	P	P	82
Butorides striatus	Green-backed Heron	Entire	P	P	121
Calidris alpina	Dunlin	Entire	P	P	45
Calidris bairdii	Baird's Sandpiper	Entire	P	P	27
Calidris fuscicollis	White-rumped Sandpiper	Entire	P	P	74
Calidris mauri	Western Sandpiper	Entire	P	P	28
Calidris melanotus	Pectoral Sandpiper	Entire	P	P	27
Calidris minutilla	Least Sandpiper	Entire	P	P	47
Calidris pusilla	Semi-palmated Sandpiper	Entire	P	P	45
Caprimulgus carolinensis	Chuck-will's-widow	S LP	-	P	164
Caprinulgus vociferus	Whip-poor-will	Entire	P	P	4
Cardinalis cardinalis	Northern Cardinal	LP	P	P	181
Carduelis flammea	Common Redpoll	Entire	P	P	4
Carduelis pinus	Pine Siskin	Entire	P	P	147
Carduelis tristis	American Goldfinch	Entire	P	P	179
Carpodacus mexicanus	House Finch	LP	P	P	103
Carpodacus purpureus	Purple Finch	UP and N LP	P	P	159
Casmerodius albus	Great Egret	SLP	-	P	120
Cathartes aura	Turkey Vulture	Entire	P	P	4

CLASS AVES (con't)

SCIENTIFIC NAME	COMMON NAME	MICHIGAN DISTRIBUTION	BLACK	HURON	SPECIES GROUP
Catharus fuscescens	Veery	Entire	P	P	85
Catharus guttatus	Hermit Thrush	UP and N LP	P	-	101
Catharus ustulatus	Swainson's Thrush	UP and N LP	P	-	42
Certhia americana	Brown Creeper	Entire	P	P	118
Ceryle alcyon	Belted Kingfisher	Entire	P	P	27
Chaetura pelagica	Chimney Swift	Entire	P	P	214
Charadrius melodus	Piping Plover	Western LP and eastern UP			27
Charadrius semipalmatus	Semi-palmated Plover	Entire	P	P	27
Charadrius vociferus	Killdeer	Entire	P	P	79
Chen caerulescens	Lesser Snow Goose	Entire	P	P	17
Chilidonias niger	Black Tern	Entire	P	P	72
Chondestes grammacus	Lark Sparrow	Entire	P	P	162
Chordeiles minor	Common Nighthawk	Entire	P	P	77
Circus cyaneus	Northern Harrier	Entire	P	P	30
Cistothorus palustris	Marsh Wren	Entire	P	P	14
Cistothorus platensis	Sedge Wren	Entire	P	P	13
Clangula hymealis	Oldsquaw	Entire	P	P	10
Coccotrraustes vespertinus	Evening Grosbeak	UP and N LP	P	-	15
Coccyzus americanus	Yellow-billed Cuckoo	Entire	P	P	100
Coccyzus erthropthalmus	Black-billed Cuckoo	Entire	P	P	59

CLASS AVES (con't)

SCIENTIFIC NAME	COMMON NAME	MICHIGAN DISTRIBUTION	BLACK	HURON	SPECIES GROUP
Colaptes auratus	Northern Flicker	Entire	P	P	178
Colinus virginianus	Northern Bobwhite	S UP and LP	-	P	16
Contopus borealis	Olive-sided Flycatcher	UP and N LP	P	-	70
Contopus virens	Eastern Wood-pewee	Entire	P	P	22
Corvus brachyrhynochos	American Crow	Entire	P	P	201
Corvus corax	Common Raven	UP and N LP	P	-	145
Coturnicops noveboracensis	Yellow Rail	Entire	P	P	28
Cyanocitta cristata	Blue Jay	Entire	P	P	194
Cygnus buccinator	Trumpeter Swan	Entire	P	P	75
Cygnus olor	Mute Swan	LP	P	P	74
Dendragapus canadensis	Spruce Grouse	UP and northern LP	P	-	42
Dendroica caerulescens	Black-throated Blue Warbler	UP and N LP	P	-	22
Dendroica castanea	Bay-brested Warbler	UP	-	-	42
Dendroica ceurlea	Cerulean Warbler	S LP and Marquette Co.	-	P	104
Dendroica coronata	Yellow-rumped Warbler	UP and N LP	P	-	71
Dendroica discolor	Prairie Warbler	LP	P	P	20
Dendroica dominica	Yellow-throated Warbler	S LP	-	P	23
Dendroica fuscia	Blackburnian Warbler	Entire	P	-	42
Dendroica kirtlandii	Kirtland's Warbler	Middle LP	P	-	25
Dendroica magnolia	Magnolia Warbler	UP ad N LP	P	-	62

CLASS AVES (con't)

SCIENTIFIC NAME	COMMON NAME	MICHIGAN DISTRIBUTION	BLACK	HURON	SPECIES GROUP
Dendroica palmarum	Palm Warbler	UP	-	-	42
Dendroica pensylvanica	Chestnut-sided Warbler	Entire	P	P	114
Dendroica petechia	Yellow Warbler	Entire	P	P	61
Dendroica pinus	Pine Warbler	UP and N LP	P	P	25
Dendroica striata	Blackpoll Warbler	All shore but Superior	P	-	15
Dendroica tigrina	Cape May Warbler	UP and N LP	P	-	42
Dendroica virens	Black-throated Green Warbler	Entire	P	P	66
Dolichonyx oryzovorus	Bobolink	Entire	P	P	18
Dryocopus pileatus	Pileated Woodpecker	Entire	P	P	118
Dumetella carolinensis	Gray Catbird	Entire	P	P	187
Egretta caerulea	Little Blue Heron	Southern 1/3 LP	-	P	72
Egretta thula	Snowy Egret	Entire	P	P	72
Egretta tricolor	Tricolored Heron	Western Great Lakes	-	P	72
Empidonax alnorum	Alder Flycatcher	Entire	P	P	3
Empidonax flaviventris	Yellow-bellied Flycather	UP	-	-	26
Empidonax minimus	Least Flycatcher	Entire	P	P	144
Empidonax traillii	Willow Flycatcher	Entire	P	P	16
Empidonax virescens	Acadian Flycatcher	Southern LP	-	P	12
Eremophila alpertris	Horned Lark	Entire	P	P	6
Euphagus carolinus	Rusty Blackbird	UP	-	-	26

CLASS AVES (con't)

CLASS AVES (con't)

SCIENTIFIC NAME	COMMON NAME	MICHIGAN DISTRIBUTION	BLACK	HURON	SPECIES GROUP
Euphagus cyanocepahlus	Brewer's Blackbird	Entire	P	P	4
Falco columbarius	Merlin	UP and northern LP	P	-	113
Falco peregrinus	Peregrine Falcon	Entire	P	P	33
Falco Sparverius	American Kestrel	Entire	P	P	127
Fulica americana	American Coot	Entire	P	P	72
Gallinago gallinago	Common Snipe	Entire	P	P	16
Gallinula chloropus	Common Moorhen	LP	-	P	72
Gavia immer	Common Loon	UP and northern LP	P	-	10
Geothlypis trichas	Common Yellowthroat	Entire	P	P	138
Grus canadensis	Sandhill Crane	Entire	P	P	34
Haliaeetus leucocephalus	Bald Eagle	UP and northern LP	P	P	169
Helmitheros vermivorus	Worm-eating Warbler	Southwest LP	-	-	22
Hirundo pyrrhonota	Cliff Swallow	Entire	P	P	166
Hirundo rustica	Barn Swallow	Entire	P	P	172
Hylocichla mustelina	Wood Thrush	Entire	P	P	64
Icterai virens	Yellow-breasted Chat	Southern LP	-	P	59
Icterus galbula	Northern Oriole	Entire	P	P	168
Icterus spurius	Orchard Oriole	Southern LP	-	P	35
Ixobrychus exilis	Least Bittern	Entire	P	P	27
Junco hyemalis	Dark-eyed Junco	UP and northern LP	P	-	31

CLASS AVES (con't)

SCIENTIFIC NAME	COMMON NAME	MICHIGAN DISTRIBUTION	BLACK	HURON	SPECIES GROUP
Lanius excubitor	Northern Shrike	UP and northern LP	-	-	50
Lanius ludovicainus	Loggerhead Shrike	LP	-	P	50
Larus argentatus	Herring Gull	Scattered shorelines	P	P	33
Larus delavarensis	Ring-billed Gull	Scattered shorelines	P	P	33
Larus philadelphia	Bonaparte's Gull	Scattered shorelines	P	P	56
Laterallus jamaicensis	Black Rail	Southern LP	-	P	27
Lophodytes cucullatus	Hooded Merganser	Entire	P	P	105
Loxia curvirostra	Red Crossbill	UP and northern LP	-	-	42
Loxia leucoptera	White-winged Crossbill	UP and southeastern LP	-	P	42
Melanerpes carolinus	Red-bellied Woodpecker	LP	P	P	64
Melanerpes erthrocephalus	Red-headed Woodpecker	Entire	P	P	157
Meleagris gallopavo	Wild Turkey	LP and southern UP	P	P	94
Melospiza georgiana	Swamp Sparrow	Entire	P	P	28
Melospiza lincolnii	Lincoln's Sparrow	UP and northern LP	P	-	36
Melospiza melodia	Song Sparrow	Entire	P	P	129
Mergus merganser	Common Merganser	UP and northern LP	P	-	107
Mergus serrator	Red-breasted Merganser	UP and northern LP	P	-	45
Mimus polyglottos	Northern Mockingbird	LP and eastern UP	P	P	4
Mniotitla varia	Black-and-white Warbler	Entire	P	P	64
Molothrus ater	Brown-headed Cowbird	Entire	P	P	190

CLASS AVES (con't)

SCIENTIFIC NAME	COMMON NAME	MICHIGAN DISTRIBUTION	BLACK	HURON	SPECIES GROUP
Myiarchus crinitus	Great Crested Flycatcher	Entire	P	P	22
Myiopsitta monachus	Monk Parakeet	Southern LP	-	P	92
Nyctanassa violacea	Yellow-crowned Night-heron	Southeastern LP	-	P	106
Nyctea scandiaca	Snowy Owl	UP and northern LP	-	-	19
Nycticorax nycticorax	Black-Crowned Night Heron	All shore but Superior	P	P	88
Oporornis agilis	Connceticut Warbler	UP and northern LP	P	-	24
Oporornis formosus	Kentucky Warbler	Southern LP	-	P	64
Oporornis philadelphia	Mourning Warbler	Entire	P	P	82
Otus asio	Eastern Screech-owl	LP	P	P	55
Oxyura jamaicensis	Ruddy Duck	Middle LP	-	P	48
Pandion haliaetus	Osprey	UP and northern LP	P	-	68
Parula americana	Northern Parula	UP and northern LP	P	-	42
Parus atricapillus	Black-capped Chickadee	Entire	P	P	118
Parus bicolor	Tufted Titmouse	LP	P	P	64
Parus hudsonicus	Boreal Chickadee	UP	-	-	42
Passerculus sandwichensis	Savannah Sparrow	Entire	P	P	30
Passerella iliaca	Fox Sparrow	Entire	P	P	115
Passerina cyanea	Indigo Bunting	Entire	P	P	93
Pelecanus erythrorhynchos	American White Pelican	Entire	P	P	27
Perisoreus canadensis	Gray Jay	UP	P	P	66

CLASS AVES (con't)

SCIENTIFIC NAME	COMMON NAME	MICHIGAN DISTRIBUTION	BLACK	HURON	SPECIES GROUP
Phalacrocorax auritus	Double-crested Cormorant	Scattered shorelines	-	P	67
Phalaropus tricolor	Wilson's Phalarope	Eastern LP	-	-	72
Phasianus colchicus	Ring-necked Pheasant	LP and southern UP	P	P	16
Pheucticus ludovicianus	Rose-breasted Grosbeak	Entire	P	P	64
Picoides arcticus	Black-backed Woodpecker	UP and northern LP	P	-	42
Picoides pubescens	Downy Woodpecker	Entire	P	P	157
Picoides tridactylus	Three-toed Woodpecker	UP and northern LP	P	-	42
Picoides villosus	Hairy Woodpecker	Entire	P	P	65
Pinicola enucleator	Pine Grosbeak	UP	-	-	42
Pipilo erythrophthalmus	Rufous-sided Towhee	Entire	P	P	35
Piranga olivacea	Scarlet Tanger	Entire	P	P	64
Piranga rubra	Summer Tanager	Southwest LP	-	-	64
Plectrophenax nivalis	Snow Bunting	Entire	P	P	2
Pluvialis squatarola	Black-bellied Plover	Entire	P	P	27
Pluvialus dominica	Golden Plover	Entire	P	P	33
Podiceps auritus	Horned Grebe	St. Clair Flats	-	-	48
Podiceps grisegena	Red-necked Grebe	UP	-	-	72
Podiceps nigricollis	Eared Grebe	Western 1/2 of state	-	-	48
Podilymbus podiceps	Pied-billed Grebe	Entire	P	P	72
Polioptila caerulea	Blue-grey Gnatcatcher	LP	-	P	135

CLASS AVES (con't)

SCIENTIFIC NAME	COMMON NAME	MICHIGAN DISTRIBUTION	BLACK	HURON	SPECIES GROUP
Pooecetes gramineus	Vesper Sparrow	Entire	P	P	29
Porzana carolina	Sora	Entire	P	P	74
Pronge subis	Purple Martin	Entire	P	P	133
Protonoratia citera	Prothonotary Warbler	Southern LP	-	P	23
Quiscalus quiscalus	Common Grackle	Entire	P	P	151
Rallus elegans	King Rail	Southern LP	-	P	99
Rallus limicola	Virginia Rail	Entire	P	P	91
Regulus calendula	Ruby-crowned Kinglet	UP and northern LP	P	-	42
Regulus satrapa	Golden-crowned Kinglet	Entire	P	-	42
Riparia riparia	Bank Swallow	Entire	P	P	57
Salpinctes obsoletus	Rock Wren	Entire	P	P	1
Sayornis phoebe	Eastern Phoebe	Entire	P	P	178
Scolopax minor	American Woodcock	Entire	P	P	123
Seiurus aurocapillus	Ovenbird	Entire	P	P	22
Seiurus motacilla	Louisiana Waterthrush	Southern LP	-	P	23
Seiurus moveboracensis	Northern Waterthrush	Entire	P	P	41
Setophaga ruticilla	American Redstart	Entire	P	P	102
Sialia sialis	Eastern Bluebird	Entire	P	P	128
Sitta canadensis	Red-breasted Nuthatch	Entire	P	P	66
Sitta carolinensis	White-breasted Nuthatch	Entire	P	P	22

CLASS AVES (con't)

SCIENTIFIC NAME	COMMON NAME	MICHIGAN DISTRIBUTION	BLACK	HURON	SPECIES GROUP
Sphyrapicus varius	Yellow-bellied Sapsucker	UP and northern LP	P	P	65
Spiza americana	Dickcissel	LP and southern UP	P	P	2
Spizella arborea	American Tree Sparrrow	Entire	P	P	96
Spizella pallida	Clay-colored Sparrow	UP and northern LP	P	-	51
Spizella passerina	Chipping Sparrow	Entire	P	P	196
Spizella pusilla	Field Sparrow	LP and southern UP	P	P	51
Stelgidopteryx serripennis	Northern Rough-winged Swallow	Entire	P	P	153
Sterna caspia	Caspian Tern	Scattered shorelines	P	-	10
Sterna forsteri	Forster's Tern	Scattered shorelines	P	P	72
Sterna hirundo	Common Tern	Scattered shorelines	P	P	27
Strix nebulosa	Great-grey Owl	Northern UP	-	-	95
Strix varia	Barred Owl	Entire	P	P	111
Sturnella magna	Eastern Meadowlark	Entire	P	P	18
Sturnella neglecta	Western Meadowlark	Entire	P	P	2
Tachycineta bicolor	Tree Swallow	Entire	P	P	199
Thryomanes bewickii	Bewick's Wren	Southern LP	-	P	182
Thryothorus ludovicianus	Carolina Wren	LP	-	P	82
Toxostoma rufum	Brown Thrasher	Entire	P	P	35
Tringa flavipes	Lesser Yellowlegs	Entire	P	P	45
Tringa melanoleuca	Greater Yellowlegs	Entire	P	P	45

CLASS AVES (con't)

SCIENTIFIC NAME	COMMON NAME	MICHIGAN DISTRIBUTION	BLACK	HURON	SPECIES GROUP
Tringa solitaria	Solitary Sandpiper	Entire	P	P	27
Troglodytes aedon	House Wren	Entire	P	P	117
Troglodytes troglodytes	Winter Wren	Entire	P	P	66
Turdus migratorius	American Robin	Entire	P	P	177
Tympanuchus phasianellus	Sharp-tailed Grouse	UP and northern LP	-	-	4
Tyrannus tyrannus	Eastern Kingbird	Entire	P	P	189
Tyrannus verticalis	Western Kingbird	Middle LP	-	-	2
Tyto alba	Barn Owl	Southern LP	-	P	34
Vermivora chrysoptera	Golden-winged Warbler	Entire	P	P	85
Vermivora peregrina	Tennessee Warbler	UP	-	-	52
Vermivora pinus	Blue-winged Warbler	Southern LP	P	P	59
vermivora ruficapilla	Nashville Warbler	UP and northern LP	P	-	119
Vireo bellii	Bell's Vireo	Southeastern LP	-	P	21
Vireo flavifrons	Yellow-throated Vireo	Entire	P	P	22
Vireo gilvus	Warbling Vireo	Entire	P	P	174
Vireo griseus	White-eyed Vireo	Southern LP	-	P	78
Vireo olivaceus	Red-eyed Vireo	Entire	P	P	64
Vireo philadelphicus	Philadelphia Vireo	UP and northern LP	P	-	82
Vireo solitarius	Solitary Vireo	Entire	P	P	25
Wilsonia canadensis	Canada Warbler	Entire	P	P	84

CLASS AVES (con't)

SCIENTIFIC NAME	COMMON NAME	MICHIGAN DISTRIBUTION	BLACK	HURON	SPECIES GROUP
Wilsonia citrina	Hooded Warbler	Southern LP	-	P	64
Wilsonia pusilla	Wilson's Warbler	Eastern UP	-	-	26
Xanthocephalus xanthocephalus	Yellow-headed Blackbird	Entire	-	P	48
Zenaida macroura	Mourning Dove	Entire	P	P	131
Zonotrichia albicollis	White-Throated Sparrow	UP and northern LP	P	-	134
Zonotrichia leuocophrys	White-crowned Sparrow	Entire	P	P	50

CLASS MAMMALIA

SCIENTIFIC NAME	COMMON NAME	MICHIGAN DISTRIBUTION	BLACK	HURON	SPECIES GROUP
Alces alces	Moose	LP (all but SW 1/4)	P	P	184
Bison bison	Bison	Lower quarter of LP	-	P	16
Blarina brevicauda	Northern Short-Tailed Shrew	Entire	-	P	209
Canis latrans	Coyote	Entire	P	P	195
Canis lupus	Gray Wolf	Entire	P	P	161
Castor canadensis	American Beaver	Entire	P	P	87
Cervus elaphus	Wapiti (elk)	Entire	P	P	148
Clethrionomys gapperi	Southern Red-backed Vole	UP, northern LP	P	-	143
Condylura cristata	Star-nosed Mole	Entire	P	P	41
Cryptotis parva	Least Shrew	Southern LP	-	P	130
Didelphis virginiana	Virginia Opossum	SW UP	-	P	197
Eptesicus fuscus	Big Brown Bat	Entire	P	P	203
Erethizon dorsatum	Porcupine	Entire	P	P	141
Eutamias minimus	Least Chipmunk	UP	-	-	142
Felis concolor	Cougar	Entire	P	P	161
Felis lynx	Lynx	Entire	P	P	42
Felis rufus	Bobcat	Entire	P	P	156
Glaucomys sabrinus	Northern Flying Squirrel	UP, northern LP	P	-	118
Glaucomys volans	Southern Flying Squirrel	LP	P	P	86
Gulo gulo	Wolverine	Entire	P	P	42
Lasionycteris noctavgans	Silver-Haired Bat	Entire	P	P	163
Lasiurus borealis	Red Bat	Entire	P	P	149
Lasiurus cinereus	Hoary Bat	Entire	P	P	175

CLASS MAMMALIA (con't)

SCIENTIFIC NAME	COMMON NAME	MICHIGAN DISTRIBUTION	BLACK	HURON	SPECIES GROUP
Lepus americanus	Snowshoe Hare	UP, northern 1/2 LP	P	-	158
Lurta canadensis	Northern River Otter	Entire	P	P	72
Marmota monax	Woodchuck	Entire	P	P	150
Martes americana	American Marten	Entire	P	P	42
Martes pennanti	Fisher	Entire	P	P	143
Mephitis mephitis	Striped Skunk	Entire	P	P	191
Microtus ochrogaster	Prairie Vole	SW LP	-	-	2
Microtus pennsylvanicus	Meadow Vole	Entire	P	P	188
Microtus pinetorum	Woodland Vole	LP	P	P	40
Mustela erminea	Ermine	UP, northern LP	P	P	136
Mustela frenata	Long-tailed Weasel	Entire	P	P	207
Mustela nivalis	Least Weasel	LP (all by NE tip)	-	P	165
Mustela vision	Mink	Entire	P	P	152
Myotis lucifugus	Little Brown Bat	Entire	P	P	175
Myotis septentrionalis	Northern Long-eared Bat	UP	-	-	180
Myotis sodalis	Indiana Bat	Southern LP	-	P	39
Napaeozopus insignis	Woodland Jumping Mouse	UP, northern LP	P	-	118
Nycticeius humeralis	Evening Bat	Southern LP	P	-	64
Odocoileus virginicanus	White-tailed Deer	Entire	P	P	192
Ondatra zibethicus	Muskrat	Entire	P	P	91
Peromyscus leucopus	White-footed Mouse	LP, UP (Alger)	P	P	116
Peromyscus maniculatus	Deer Mouse	Entire	P	P	160

CLASS MAMMALIA (con't)

SCIENTIFIC NAME	COMMON NAME	MICHIGAN DISTRIBUTION	BLACK	HURON	SPECIES GROUP
Pipistrell subflavus	Eastern Pipistrelle	UP and southwest LP	-	-	53
Procyon lotor	Raccoon	Entire	P	P	205
Rangifer tarandus	Caribou	LP (all but SW 1/4)	P	P	118
Scalopus aquaticus	Eastern Mole	LP	P	P	4
Sciurus carolinensis	Eastern Gray Squirrel	Entire	P	P	155
Sciurus niger	Eastern Fox Squirrel	LP, eastern UP	P	P	112
Sorex arcticus	Arctic Shrew	UP	-	-	44
Sorex cinereus	Masked Shrew	Entire	P	P	208
Sorex fumeus	Smoky Shrew	Sugar Island, Chippewa Co.	P	P	24
Sorex hoyi	Pygmy Shrew	UP and Northern LP	P	-	146
Sorex palustris	Water Shrew	UP and Norhtern LP	P	-	90
Spermophilus tridecemlineatus	13-lined Ground Squirrel	Entire	P	P	154
Sylvilagus floridanus	Eastern Cottontail	LP, western UP	P	P	200
Synaptomys cooperi Baird	Southern Bog Lemming	Entire	P	P	26
Tamias striatus	Eastern Chipmunk	Entire	P	P	193
Tamiasciurus hudsonicus	Red Squirrel	Entire	P	P	183
Taxidea taxus	American Badger	Entire	P	P	98
Urocyon cinereoargenteus	Gray Fox	Entire	P	P	124
Ursus americanus	Black Bear	Entire	P	P	160
Vulpes vulpes	Red Fox	Entire	P	P	195
Zapus hudsonius	Meadow Jumping Mouse	Entire	P	P	202

CLASS REPTILIA

SCIENTIFIC NAME	COMMON NAME	MICHIGAN DISTRIBUTION	BLACK	HURON	SPECIES GROUP
Apalone [= Trionyx] spinfera	Spiny Softshell Turtle	Southern 3/4 LP	-	P	28
Chelydra serpentina	Snapping Turtle	Entire	P	P	80
Chrysemys picta	Painted Turtle	Entire	P	P	91
Clemmys guttata	Spotted Turtle	Western and southern LP	-	P	73
Clemmys insculpta	Wood Turtle	Northern LP and UP	P	-	73
Clonophis kirtlandii	Kirtland's Snake	Southern 1/3 LP	-	P	69
Cnemidophorus sexlineatus	Six-lined Racerunner	Tuscola County	-	-	2
Coluber constrictor foxii	Blue Racer	Southern 2/3 LP	-	P	81
Diadophis punctatus edwardsi	Northern Ring-necked Snake	Entire	P	P	22
Elaphe gloydi	Eastern Fox Snake	Shore of south 1/2 LP	P	P	27
Elaphe obsoleta obsoleta	Black Rat Snake	Southern 1/3 LP	-	P	137
Elaphe vulpina	Western Fox Snake	Western 1/2 UP	-	-	2
Emydoidea blandingii	Blanding's Turtle	LP and central UP	P	P	73
Eumeces fasciatus	Five-lined Skink	LP and central UP	P	P	118
Graptemys geographica	Common Map Turtle	Southern 2/3 LP	-	P	27
Heterodon platirhinos	Eastern Hog-nosed Snake	LP	P	P	171
Lampropeltis triangulum triangulum	Eastern Milk Snake	LP	P	P	198
Liochlorphis vernalis	Smooth Green Snake	Entire	P	P	126
Nerodia erythrogaster neglecta	Copper-bellied Water Snake	Southwest LP	-	-	108
Nerodia sipedon sipedon	Northern Water Snake	LP and eastern UP	P	P	46

CLASS REPTILIA (con't)

SCIENTIFIC NAME	COMMON NAME	MICHIGAN DISTRIBUTION	BLACK	HURON	SPECIES GROUP
Regina septemvittata	Queen Snake	Southern 1/2 LP	-	P	9
Sistrurus catenatus catenatus	Eastern Massasauga Rattlesnake	LP	P	P	37
Sternotherus odoratus	Common Musk Turtle	Southern LP	-	P	27
Storeria dekayi	Brown Snake	LP and southern tip UP	P	P	210
Storeria occipitomaculata occipitomaculata	Northern Red-bellied Snake	Entire except extreme south LP	P	P	210
Terrapene carolina carolina	Eastern Box Turtle	Western and southern LP	-	P	63
Thamnophis butleri	Butler's Garter Snake	Eastern 1/2 LP	-	P	186
Thamnophis sauritus septentrionalis	Northern Ribbon Snake	LP	P	P	110
Thamnophis sirtalis sirtalis	Eastern Garter Snake	Entire	P	P	212
Trachemys scripta elegans	Red-eared Slider	Southern LP (exotic)	-	P	47

APPENDIX C

SPECIES GROUP – LAND COVER MATRIX

The following tables show which land cover types were potential habitat for each of the 214 species groups discussed in Chapter 2. The first column of each table is the species group. The column labeled "#LC" indicates the number of land cover types that were potential habitat for that species group. The columns labeled "BL" and "HR" indicate whether that group has at least one member in the Black or Huron river watersheds, respectively. The MIRIS land cover codes correspond to the code values shown in Table 1.3. Note that tables showing land cover types from 310 to 622 comprise the set of "natural" land cover types discussed in Chapter 2.

SPECIES				MIRIS LEVEL 3 LAND COVER CODE												
GROUP	#LC	BL	HR	111	112	113	115	121	122	124	126	130	131	138	141	142
Grp001	0	1	1													
Grp002	1	1	1													
Grp003	1	1	1													
Grp004	2	1	1													
Grp005	2	1	1													
Grp006	2	1	1													
Grp007	2	1	1													
Grp008	2															
Grp009	2		1													
Grp010	2	1														
Grp011	2		1													
Grp012	2		1													
Grp013	2	1	1													
Grp014	2		1													
Grp015	2	1														
Grp016	3	1	1													
Grp017	3	1	1													
Grp018	3	1	1													
Grp019	3															
Grp020	3		1													
Grp021	3		1													
Grp022	3	1														
Grp023	3		1													
Grp024	3	1														
Grp025	3	1														
Grp026	3	1	1													
Grp027	3	1	1													
Grp028	3	1	1													
Grp029	4	1	1													
Grp030	4	1	1													
Grp031	4	1														
Grp032	4															
Grp033	4	1	1													
Grp034	4	1	1													
Grp035	4	1	1													
Grp036	4	1														
Grp037	4															
Grp038	4	1	1													
Grp039	4	1	1													
Grp040	4	1	1													
Grp041	4	1	1													
Grp042	4	1	1													
Grp043	4	1	1													
Grp044	4	1	1													
Grp045	4	1	1													
Grp046	4															
Grp047	4	1	1													
Grp048	4		1													
Grp049	5	1	1		1	1					1					
Grp050	5	1	1													

SPECIES	MIRIS LEVEL 3 LAND COVER CODE															
GROUP	143	144	145	146	147	171	172	173	179	193	194	210	220	230	240	290
Grp001																
Grp002																
Grp003																
Grp004																
Grp005																
Grp006												1				
Grp007															1	
Grp008																
Grp009																
Grp010																
Grp011																
Grp012																
Grp013															1	
Grp014																
Grp015																
Grp016																
Grp017																
Grp018															1	
Grp019																
Grp020																
Grp021															1	
Grp022																
Grp023																
Grp024																
Grp025																
Grp026																
Grp027																
Grp028																
Grp029												1			1	
Grp030												1			1	
Grp031																
Grp032																
Grp033																
Grp034																
Grp035																
Grp036																
Grp037																
Grp038																
Grp039																
Grp040													1			
Grp041																
Grp042																
Grp043																
Grp044																
Grp045																
Grp046																
Grp047																
Grp048																
Grp049																
Grp050																

SPECIES	MIRIS LEVEL 3 LAND COVER CODE																
GROUP	310	320	411	412	413	414	421	422	423	429	510	520	530	611	612	621	622
Grp001																	
Grp002	1																
Grp003															1		
Grp004	1	1															
Grp005	1														1		
Grp006	1																
Grp007	1																
Grp008																	
Grp009		1									1						
Grp010												1	1				
Grp011																1	1
Grp012						1								1			
Grp013															1		
Grp014															1		1
Grp015							1	1									
Grp016	1	1													1		
Grp017	1											1	1				
Grp018	1														1		
Grp019																	
Grp020		1					1	1									
Grp021		1													1		
Grp022			1	1	1												
Grp023						1					1			1			
Grp024						1			1					1			
Grp025							1	1		1							
Grp026									1					1	1		
Grp027											1	1	1				
Grp028															1	1	1
Grp029	1	1															
Grp030	1														1		
Grp031	1	1					1	1									
Grp032																	
Grp033	1										1	1	1				
Grp034	1														1	1	1
Grp035		1	1	1	1												
Grp036		1							1					1	1		
Grp037																	
Grp038			1	1	1							1					
Grp039			1	1	1						1						
Grp040			1	1	1												
Grp041						1			1					1	1		
Grp042							1	1	1					1			
Grp043									1			1		1	1		
Grp044									1			1	1		1		
Grp045											1	1	1		1		
Grp046																	
Grp047											1	1	1				1
Grp048												1	1			1	1
Grp049	1	1															
Grp050	1	1	1	1	1												

SPECIES GROUP	#LC	BL	HR	MIRIS LEVEL 3 LAND COVER CODE 111	112	113	115	121	122	124	126	130	131	138	141	142
Grp051	5	1														
Grp052	5															
Grp053	5	1	1													
Grp054	5	1	1													
Grp055	5	1	1													
Grp056	5	1	1													
Grp057	5	1	1													
Grp058	5	1	1													
Grp059	5	1	1													
Grp060	5	1	1													
Grp061	5	1	1													
Grp062	5	1														
Grp063	5	1	1													
Grp064	5	1	1													
Grp065	5	1	1													
Grp066	5	1	1													
Grp067	5		1													
Grp068	5	1	1													
Grp069	5	1	1													
Grp070	5	1														
Grp071	5	1														
Grp072	5	1	1													
Grp073	5	1														
Grp074	5	1	1													
Grp075	6	1	1													
Grp076	6		1													
Grp077	6	1	1		1	1	1									
Grp078	6		1													
Grp079	6	1	1		1	1										
Grp080	6		1													
Grp081	6		1													
Grp082	6	1	1													
Grp083	6	1	1													
Grp084	6	1	1													
Grp085	6	1	1													
Grp086	6	1	1								1					
Grp087	6	1	1													
Grp088	6		1													
Grp089	6															
Grp090	6	1	1													
Grp091	6	1	1													
Grp092	6		1													
Grp093	7	1	1													
Grp094	7	1	1													
Grp095	7															
Grp096	7	1	1													
Grp097	7	1	1													
Grp098	7	1	1													
Grp099	7															
Grp100	7	1	1													

SPECIES	MIRIS LEVEL 3 LAND COVER CODE															
GROUP	143	144	145	146	147	171	172	173	179	193	194	210	220	230	240	290
Grp051																
Grp052																
Grp053																
Grp054																
Grp055																
Grp056																
Grp057															1	
Grp058																
Grp059																
Grp060															1	
Grp061																
Grp062																
Grp063										1	1		1		1	
Grp064																
Grp065																
Grp066																
Grp067																
Grp068																
Grp069																
Grp070																
Grp071																
Grp072																
Grp073																
Grp074																
Grp075																
Grp076																
Grp077																
Grp078																
Grp079												1			1	1
Grp080																
Grp081										1	1		1		1	1
Grp082																
Grp083																
Grp084																
Grp085																
Grp086											1		1			
Grp087																
Grp088																
Grp089																
Grp090																
Grp091																
Grp092										1	1	1	1		1	1
Grp093																
Grp094																
Grp095																
Grp096																
Grp097																
Grp098										1	1		1		1	
Grp099																
Grp100																

SPECIES	MIRIS LEVEL 3 LAND COVER CODE																
GROUP	310	320	411	412	413	414	421	422	423	429	510	520	530	611	612	621	622
Grp051	1	1					1	1		1							
Grp052																	
Grp053	1	1									1	1	1				
Grp054	1	1										1			1		1
Grp055	1		1	1	1						1						
Grp056	1										1	1	1		1		
Grp057	1										1	1	1				
Grp058	1											1			1	1	1
Grp059		1	1	1	1										1		
Grp060	1											1			1		1
Grp061		1				1			1					1	1		
Grp062		1					1	1	1					1			
Grp063		1															
Grp064			1	1	1	1								1			
Grp065			1	1	1		1	1									
Grp066						1	1	1	1					1			
Grp067						1					1	1	1	1			
Grp068						1			1			1	1	1			
Grp069						1								1	1	1	1
Grp070							1	1	1					1	1		
Grp071							1	1	1	1				1			
Grp072											1	1	1			1	1
Grp073											1	1			1	1	1
Grp074												1	1		1	1	1
Grp075	1											1	1		1	1	1
Grp076	1	1										1			1	1	1
Grp077	1	1								1							
Grp078	1	1	1	1	1										1		
Grp079	1																
Grp080	1										1	1	1			1	1
Grp081	1																
Grp082		1	1	1	1	1								1			
Grp083		1	1	1	1				1					1			
Grp084			1	1	1	1			1					1			
Grp085			1	1	1	1								1	1		
Grp086			1	1	1												
Grp087			1	1	1						1	1			1		
Grp088						1					1	1		1	1	1	
Grp089																	
Grp090									1		1	1		1	1	1	
Grp091											1	1	1		1	1	1
Grp092																	
Grp093	1	1	1	1	1	1								1			
Grp094	1	1	1	1	1		1	1									
Grp095																	
Grp096	1	1							1					1	1	1	1
Grp097	1	1									1	1			1	1	1
Grp098	1	1								1							
Grp099																	
Grp100		1	1	1	1		1	1							1		

SPECIES				MIRIS LEVEL 3 LAND COVER CODE												
GROUP	#LC	BL	HR	111	112	113	115	121	122	124	126	130	131	138	141	142
Grp101	7	1														
Grp102	7	1	1													
Grp103	7		1		1	1	1				1					
Grp104	7		1													
Grp105	7	1	1													
Grp106	7		1													
Grp107	7	1														
Grp108	7		1													
Grp109	8	1	1													
Grp110	8	1	1													
Grp111	8	1	1													
Grp112	8	1	1													
Grp113	8															
Grp114	8	1	1													
Grp115	8	1	1													
Grp116	8	1	1													
Grp117	8	1	1		1	1	1				1					
Grp118	8	1	1													
Grp119	8	1														
Grp120	8		1													
Grp121	8	1	1													
Grp122	9	1	1													
Grp123	9	1	1													
Grp124	9	1	1													
Grp125	9		1													
Grp126	9		1													
Grp127	9	1	1		1	1	1									
Grp128	9	1	1		1	1	1				1					
Grp129	9	1	1		1	1	1				1					
Grp130	9	1	1			1	1									
Grp131	9	1	1		1	1	1									
Grp132	9	1	1													
Grp133	9	1	1		1	1	1				1					
Grp134	9	1														
Grp135	9		1													
Grp136	9	1	1													
Grp137	9															
Grp138	9	1	1													
Grp139	9	1	1													
Grp140	9	1														
Grp141	9	1	1													
Grp142	9	1	1								1					
Grp143	9	1	1													
Grp144	9	1	1		1	1	1				1					
Grp145	10	1														
Grp146	10	1														
Grp147	10	1	1													
Grp148	10	1	1													
Grp149	10	1	1													
Grp150	10	1	1								1					

SPECIES GROUP	143	144	145	146	147	171	172	173	179	193	194	210	220	230	240	290
	MIRIS LEVEL 3 LAND COVER CODE															
Grp101																
Grp102																
Grp103										1	1					
Grp104																
Grp105																
Grp106																
Grp107																
Grp108																
Grp109																
Grp110																
Grp111																
Grp112										1	1		1		1	
Grp113																
Grp114																
Grp115																
Grp116													1		1	
Grp117										1	1					
Grp118																
Grp119																
Grp120																
Grp121																
Grp122																
Grp123																
Grp124													1			
Grp125																
Grp126										1	1		1		1	
Grp127												1			1	
Grp128										1	1				1	
Grp129										1	1					
Grp130										1	1		1		1	1
Grp131												1				
Grp132																
Grp133										1	1					
Grp134																
Grp135																
Grp136																
Grp137																
Grp138																
Grp139																
Grp140																
Grp141																
Grp142																
Grp143																
Grp144										1	1					
Grp145																
Grp146																
Grp147																
Grp148																
Grp149										1	1		1			
Grp150										1	1		1		1	

SPECIES GROUP	MIRIS LEVEL 3 LAND COVER CODE 310	320	411	412	413	414	421	422	423	429	510	520	530	611	612	621	622
Grp101		1	1	1	1		1	1		1							
Grp102		1	1	1	1	1								1	1		
Grp103		1															
Grp104			1	1	1	1	1	1						1			
Grp105						1			1		1	1		1		1	1
Grp106						1					1	1	1	1	1		1
Grp107						1					1	1	1	1		1	1
Grp108						1					1	1		1	1	1	1
Grp109	1	1	1	1	1		1	1							1		
Grp110	1	1									1	1	1		1	1	1
Grp111	1		1	1	1	1	1	1						1			
Grp112	1		1	1	1												
Grp113																	
Grp114		1	1	1	1	1			1					1	1		
Grp115		1	1	1	1		1	1	1					1			
Grp116		1	1	1	1		1	1									
Grp117		1													1		
Grp118			1	1	1	1	1	1	1					1			
Grp119			1	1	1		1	1	1					1	1		
Grp120						1			1		1	1		1	1	1	1
Grp121						1					1	1	1	1	1	1	1
Grp122	1	1	1	1	1	1	1	1						1			
Grp123	1	1	1	1	1	1			1					1	1		
Grp124	1	1	1	1	1	1								1	1		
Grp125	1	1	1	1	1		1	1	1					1			
Grp126	1	1	1	1	1												
Grp127	1	1								1					1		
Grp128	1	1															
Grp129	1	1													1		
Grp130	1	1															
Grp131	1					1	1	1						1			
Grp132	1					1					1	1	1	1	1	1	1
Grp133	1											1	1				
Grp134		1	1	1	1	1	1	1	1					1			
Grp135		1	1	1	1	1	1	1						1	1		
Grp136		1	1	1	1		1	1	1					1	1		
Grp137																	
Grp138		1				1					1	1	1	1	1	1	1
Grp139						1			1		1	1	1	1	1	1	1
Grp140			1	1	1	1	1	1						1		1	1
Grp141			1	1	1	1	1	1	1	1				1			
Grp142			1	1	1	1	1	1	1					1			
Grp143			1	1	1	1	1	1	1					1	1		
Grp144			1	1	1												
Grp145	1	1	1	1	1	1	1	1	1					1			
Grp146	1	1	1	1	1		1	1	1					1	1		
Grp147	1	1	1	1	1		1	1	1	1				1			
Grp148	1	1	1	1	1		1	1	1					1		1	
Grp149	1	1	1	1	1						1	1					
Grp150	1	1	1	1	1												

SPECIES				MIRIS LEVEL 3 LAND COVER CODE												
GROUP	#LC	BL	HR	111	112	113	115	121	122	124	126	130	131	138	141	142
Grp151	10	1	1		1	1	1				1					
Grp152	10	1	1													
Grp153	10	1	1		1	1	1				1					
Grp154	10	1	1		1	1	1				1					
Grp155	10	1	1			1					1					
Grp156	10	1	1													
Grp157	10	1	1		1	1					1					
Grp158	10	1	1								1					
Grp159	10	1	1		1	1	1				1					
Grp160	11	1	1													
Grp161	11	1	1													
Grp162	11	1	1													
Grp163	11															
Grp164	11		1													
Grp165	11	1	1													
Grp166	11	1	1		1	1	1				1					
Grp167	11	1	1													
Grp168	11	1	1		1	1	1				1					
Grp169	12	1	1													
Grp170	12															
Grp171	12	1	1			1	1									
Grp172	12	1	1		1	1	1				1					
Grp173	12	1	1			1	1									
Grp174	12	1	1		1	1	1				1					
Grp175	13		1													
Grp176	13	1	1													
Grp177	13	1	1		1	1	1				1					
Grp178	13	1	1		1	1	1				1					
Grp179	13	1	1		1	1	1				1					
Grp180	13	1	1													
Grp181	13	1	1		1	1	1				1					
Grp182	13		1		1	1	1									
Grp183	13	1														
Grp184	13	1	1													
Grp185	13	1	1			1	1				1					
Grp186	14	1	1													
Grp187	14	1	1		1	1	1				1					
Grp188	14	1	1													
Grp189	14	1	1		1	1	1				1					
Grp190	15	1	1		1	1	1				1					
Grp191	15	1	1			1	1									
Grp192	15	1	1			1	1									
Grp193	15															
Grp194	15	1	1		1	1	1				1					
Grp195	16	1	1													
Grp196	16	1	1		1	1	1				1					
Grp197	16	1	1		1	1	1									
Grp198	16	1	1		1	1	1									
Grp199	16	1	1		1	1	1				1					
Grp200	16	1	1			1	1				1					

SPECIES	MIRIS LEVEL 3 LAND COVER CODE															
GROUP	143	144	145	146	147	171	172	173	179	193	194	210	220	230	240	290
Grp151										1	1					
Grp152													1		1	
Grp153										1	1				1	
Grp154										1	1		1		1	1
Grp155										1	1		1		1	
Grp156																
Grp157										1	1					
Grp158																
Grp159										1	1					
Grp160																
Grp161																
Grp162															1	
Grp163																
Grp164													1		1	
Grp165										1	1		1		1	
Grp166										1	1				1	
Grp167																
Grp168										1	1					
Grp169																
Grp170																
Grp171										1	1		1		1	1
Grp172										1	1	1			1	
Grp173										1	1		1		1	1
Grp174										1	1					
Grp175																
Grp176																
Grp177										1	1					
Grp178										1	1					
Grp179										1	1				1	
Grp180																
Grp181										1	1					
Grp182										1	1		1		1	
Grp183										1	1		1		1	
Grp184																
Grp185										1	1		1		1	1
Grp186																
Grp187										1	1					
Grp188										1	1		1		1	
Grp189										1	1				1	1
Grp190										1	1				1	
Grp191										1	1		1		1	1
Grp192										1	1	1	1			1
Grp193																
Grp194										1	1					
Grp195										1	1		1		1	
Grp196										1	1					
Grp197										1	1		1		1	1
Grp198										1	1		1		1	1
Grp199										1	1				1	
Grp200										1	1		1			1

SPECIES	MIRIS LEVEL 3 LAND COVER CODE																
GROUP	310	320	411	412	413	414	421	422	423	429	510	520	530	611	612	621	622
Grp151	1	1					1	1									
Grp152	1	1									1	1	1		1	1	1
Grp153	1										1	1					
Grp154	1																
Grp155	1		1	1	1												
Grp156		1	1	1	1	1	1	1	1					1	1		
Grp157			1	1	1	1								1			
Grp158			1	1	1		1	1	1	1				1	1		
Grp159							1	1	1					1			
Grp160	1	1	1	1	1	1	1	1	1	1				1			
Grp161	1	1	1	1	1	1	1	1	1					1	1		
Grp162	1	1	1	1	1	1	1	1	1					1			
Grp163																	
Grp164	1	1		1	1	1	1	1	1					1			
Grp165	1		1	1	1		1	1							1		
Grp166	1										1	1	1				
Grp167			1	1	1	1					1	1	1	1	1	1	1
Grp168			1	1	1	1								1			
Grp169	1	1	1	1	1	1	1	1			1	1	1	1			
Grp170																	
Grp171	1	1	1	1	1												
Grp172	1										1	1	1				
Grp173	1										1	1				1	1
Grp174		1	1	1	1	1								1			
Grp175	1	1	1	1	1	1	1	1	1		1	1	1	1			
Grp176	1	1	1	1	1	1	1	1	1					1	1	1	1
Grp177	1	1	1	1	1	1								1			
Grp178	1	1	1	1	1		1	1									
Grp179	1	1	1	1	1										1		
Grp180		1	1	1	1	1	1	1	1		1	1	1	1	1		
Grp181		1	1	1	1	1								1	1		
Grp182		1	1	1	1	1								1			
Grp183			1	1	1	1	1	1	1	1				1			
Grp184			1	1	1	1	1	1	1		1	1	1	1	1	1	
Grp185			1	1	1							1				1	
Grp186	1	1	1	1	1	1	1	1				1	1	1	1	1	1
Grp187	1	1	1	1	1	1								1	1		
Grp188	1	1	1	1	1		1	1	1					1	1		
Grp189	1	1	1	1	1										1		
Grp190	1	1	1	1	1		1	1		1							
Grp191	1	1	1	1	1		1	1		1							
Grp192	1	1	1	1	1				1					1			1
Grp193																	
Grp194			1	1	1	1	1	1	1	1				1			
Grp195	1	1	1	1	1	1	1	1	1	1				1	1		
Grp196	1	1	1	1	1		1	1	1	1				1			
Grp197	1	1	1	1	1										1	1	1
Grp198	1	1	1	1	1										1	1	1
Grp199	1		1	1	1	1					1	1		1			1
Grp200		1	1	1	1	1	1	1	1					1			

SPECIES GROUP	#LC	BL	HR	111	112	113	115	121	122	124	126	130	131	138	141	142
	MIRIS LEVEL 3 LAND COVER CODE															
Grp201	17	1	1		1	1					1					
Grp202	17	1														
Grp203	17	1	1		1	1	1									
Grp204	17	1	1			1										
Grp205	18	1	1		1	1	1									
Grp206	**18**	1	1													
Grp207	**18**		1			1	1									
Grp208	**19**															
Grp209	**20**		1								1					1
Grp210	**20**	1	1	1	1	1	1									
Grp211	21	1	1			1	1				1					
Grp212	21		1	1	1	1	1									
Grp213	22	1	1			1	1				1					
Grp214	22	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

SPECIES GROUP	143	144	145	146	147	171	172	173	179	193	194	210	220	230	240	290
	MIRIS LEVEL 3 LAND COVER CODE															
Grp201										1	1	1				
Grp202										1	1		1		1	
Grp203										1	1	1	1	1	1	1
Grp204										1	1		1		1	1
Grp205										1	1		1		1	1
Grp206										1	1		1		1	
Grp207										1	1		1	1	1	1
Grp208																
Grp209		1								1	1		1	1	1	1
Grp210										1	1	1	1		1	1
Grp211										1	1	1	1		1	1
Grp212										1	1	1	1		1	1
Grp213										1	1	1	1		1	1
Grp214	1	1	1	1	1					1	1					

SPECIES GROUP	310	320	411	412	413	414	421	422	423	429	510	520	530	611	612	621	622
	MIRIS LEVEL 3 LAND COVER CODE																
Grp201	1	1	1	1	1	1	1	1	1	1				1			
Grp202	1	1	1	1	1	1	1	1	1					1	1	1	1
Grp203	1	1	1	1	1							1				1	
Grp204		1	1	1	1				1		1	1		1	1	1	1
Grp205	1	1	1	1	1		1	1							1	1	1
Grp206		1	1	1	1	1	1	1	1		1	1		1	1	1	1
Grp207		1	1	1	1	1	1	1	1					1	1		
Grp208																	
Grp209	1	1	1	1	1	1	1	1	1					1	1		
Grp210	1	1	1	1	1	1	1	1	1					1			
Grp211	1	1	1	1	1	1	1	1				1		1		1	1
Grp212	1	1	1	1	1	1	1	1						1	1		1
Grp213	1	1	1	1	1	1	1	1	1			1		1		1	1
Grp214	1	1															

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