2013

AN ECOSYSTEM SERVICE-BASED APPROACH TO TERRESTRIAL VERTEBRATE SPECIES CONSERVATION IN MICHIGAN’S UPPER PENINSULA

Kristin Anne Denryter
Northern Michigan University

Follow this and additional works at: https://commons.nmu.edu/theses

Recommended Citation
Denryter, Kristin Anne, "AN ECOSYSTEM SERVICE-BASED APPROACH TO TERRESTRIAL VERTEBRATE SPECIES CONSERVATION IN MICHIGAN’S UPPER PENINSULA" (2013). All NMU Master's Theses. 381.
https://commons.nmu.edu/theses/381

This Thesis is brought to you for free and open access by the Student Works at NMU Commons. It has been accepted for inclusion in All NMU Master’s Theses by an authorized administrator of NMU Commons. For more information, please contact kmcdonou@nmu.edu,bsarjean@nmu.edu.
AN ECOSYSTEM SERVICE-BASED APPROACH TO TERRESTRIAL VERTEBRATE SPECIES CONSERVATION IN MICHIGAN’S UPPER PENINSULA

By

Kristin Anne Denryter

THESIS

Submitted to
Northern Michigan University
In partial fulfillment of the requirements
For the degree of

MASTER OF SCIENCE

Office of Graduate Education and Research

2013
Title of Thesis: An ecosystem service-based approach to terrestrial vertebrate species conservation in Michigan’s Upper Peninsula

This thesis by Kristin Anne Denryter is recommended for approval by the student’s Thesis Committee and Department Head in the Department of Biology and by the Assistant Provost of Graduate Education and Research.

Committee Chair: Dr. Patrick W. Brown

First Reader: Dr. Jill B.K. Leonard

Second Reader (if required): Dr. Robert J. Legg

Third Reader (if required): Dr. Dean E. Beyer

Department Head: Dr. John E. Rebers

Dr. Brian D. Cherry
Assistant Provost of Graduate Education and Research
ABSTRACT

AN ECOSYSTEM SERVICE-BASED APPROACH TO TERRESTRIAL VERTEBRATE SPECIES CONSERVATION IN MICHIGAN’S UPPER PENINSULA

By

Kristin Anne Denryter

The ever-growing human population has increasing consumptive demands that threaten the natural world through ecosystem destruction, jeopardizing important areas for many species and disrupting ecosystem processes. To minimize problems from future habitat destruction in Michigan’s Upper Peninsula, I used an ecosystem-based conservation approach to identify important areas for ecosystem services and terrestrial vertebrate species. I completed a land cover accuracy assessment as a surrogate of terrestrial vertebrate species accuracy from Gap Analysis Program predicted species occurrences. I then used these data in conjunction with wetland, riparian, and upland ecosystems, which were ecologically important zones (EIZs) in terms of ecosystem services. I quantified the ecosystem service value and area required to implement this approach. I also assessed the ecosystem service value of current protected areas in the U.P. and how they captured predicted species occurrences. The final portion of the project considered how well this approach could capture predicted species occurrences, effectively, if this ecosystem-based approach would protect important areas for terrestrial vertebrate species. I completed all geoprocessing steps and spatial analyses in ArcGIS using a variety of geoprocessing tools and ModelBuilder®. Under the proposed approach, protected EIZs could contribute nearly $25 billion/year in ecosystem services values. Most species occurrences are outside of protected areas (61%) and only approximately 3% of species’ predicted occurrences are in the most highly protected areas. This approach protects
important areas for ecosystem services and terrestrial vertebrate species in the U.P. Applying this or a similar approach could significantly benefit conservation in the U.P. by addressing the shortcomings of the current protected areas.
ACKNOWLEDGEMENTS

First, enormous thanks to the most supportive, encouraging, and helpful advisor, Dr. Pat Brown. I appreciate everything you did to help me grow as a scientist, scholar, and as a person during my time working with you. Thank you for always going above and beyond what was required and for making me feel like an equal. Without your support, I never would have been able to complete this project and I wouldn’t have learned nearly as much as I have in the last three years (especially about *active* voice).

Thank you to all of my committee members for your help both in and out of the classroom and labs. Dr. Jill Leonard you pushed me when I needed it. Dr. Robert Legg you helped me learn and expand my GIS skill set. Dr. Dean Beyer you helped get me out into the field, which has propelled me forward in my career. Thank you all so much for your time, support, and dedication to seeing me and this project through to the end.

A huge thank you to many of the GIS professionals with the U.S. Fish & Wildlife Service for opening up my world to advanced techniques in ArcGIS that made this enormous project more manageable and fun. Thank you Gabriel DeAlessio, Sean Fields, Amy Keister, Eric Kelchlin, Rick Schauffler, and Daryl Van Dyke, as well as Dr. Mike Strager at West Virginia University.

Thank you also to the NMU Biology Department, College of Arts & Sciences, the Graduate College, and the Michigan Waterfowl Association (thank you Dr. Bruggink) for funding and support. Finally, a thank you to my family, my fellow graduate students, and Susie Piziali for helping me more than you know throughout the last three years.

Each chapter is a standalone manuscript in the style of *Conservation Biology.*
PREFACE

The inspiration for this project came from the Environment Canada (2004) publication “How much habitat is enough?” This publication specifically delineated restoration measures for Great Lakes Areas of Concern (AOCs) and described and rationalized the importance of using buffers to protect the critical ecological functions within wetland, riparian, and upland ecosystems. The purpose of buffering the critical zones was to protect important ecosystem cores, maintain ecological processes, and protect biodiversity within target areas.

Michigan’s Upper Peninsula has two AOCs, at Deer Lake and Torch Lake, that would be prime candidates for restoration, but Dr. Brown and I wondered how well the conservation measures outlined above would work across the landscape. Would it be feasible to protect important areas for terrestrial vertebrate species that also maintained ecological processes? We wanted to find out and thus embarked on this journey.

There were some road bumps, like learning ArcGIS from the ground up, and finding out data doesn’t always do what you want it to do. Then we ran into issues of not enough processing power for the vast amounts of data (I mean, this was the entire U.P. we were working with). Eventually, after many late nights, a few GIS workshops, and some blood, sweat, and tears (mostly just the sweat and tears), we derived this approach to conservation planning. It’s been quite a ride, but worth the struggles.
This approach, if implemented, could help Michigan strategically conserve important areas for terrestrial vertebrate species and for ecosystem services, both the goods (e.g. timber and food) and the functions (e.g. water purification and pollination).
# TABLE OF CONTENTS

List of Tables .................................................................................................................. xi

List of Figures ................................................................................................................... xiii

List of Abbreviations ...................................................................................................... xvi

Chapter 1: Land Cover Accuracy Assessment of 2006 National Land Cover Dataset in Michigan’s Upper Peninsula ................................................................. 1

  Chapter overview ........................................................................................................... 1

  Introduction ..................................................................................................................... 1

  Methods .......................................................................................................................... 5

    Study Area .................................................................................................................. 5

    Data Acquisition ......................................................................................................... 5

    Ground Truthing ......................................................................................................... 6

    Sampling Design for Aerial Photo Interpretation ....................................................... 6

    Statistical Analyses ................................................................................................... 7

  Results ............................................................................................................................ 9

    U.P. Ground Truthing from Relevé Sampling ............................................................. 9

    U.P. Land Cover Anderson Level 1 Classifications .................................................. 9

    Kappa Coefficient ..................................................................................................... 10

    User and Producer Accuracy ...................................................................................... 10

    Errors of Commission and Omission ......................................................................... 11

  Discussion ...................................................................................................................... 11

  Accuracy Assessment ................................................................................................. 11
Conclusion .........................................................................................................................................16
Appendix A .........................................................................................................................................17

Chapter 2: An Ecosystem Services Approach to Conservation in the U.P. Using Ecologically Important Zones ..................................................................................................................24

Chapter Overview .................................................................................................................................24

Introduction ...........................................................................................................................................25
    Wetland Ecosystem Services .............................................................................................................25
    Riparian Zone Ecosystem Services ...................................................................................................26
    Upland Forest Ecosystem Services ....................................................................................................27
    Economic Values of Ecosystem Services .........................................................................................28
    Threats to Ecosystem Services ..........................................................................................................29
    How Much Habitat is Enough? ...........................................................................................................32
    An Ecosystem Services Approach to Conservation Planning in the Upper Peninsula ..................33

Methods ................................................................................................................................................35
    Study Area .......................................................................................................................................35
    Data Acquisition & Sources ...............................................................................................................35
    Spatial Analyses ...............................................................................................................................36
    Quantitative Analyses .....................................................................................................................37

Results ..................................................................................................................................................38
    Current Landscape: The U.P., Stewardship, and EIZs .................................................................38
    Potential Stewardship Additions: Land Area and Ecosystem Service Values ................................39

Discussion .............................................................................................................................................41
    Distribution of EIZs: Current .............................................................................................................41
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distribution of Ecosystem Services: EIZs, Values, and Potential Areas</td>
<td>42</td>
</tr>
<tr>
<td>Protecting Ecosystem Services: Assessment and Conclusions</td>
<td>45</td>
</tr>
<tr>
<td>Appendix B</td>
<td>48</td>
</tr>
<tr>
<td>Chapter 3: Does an ecosystem-based approach in conservation planning address terrestrial vertebrate species concerns?</td>
<td>59</td>
</tr>
<tr>
<td>Chapter Overview</td>
<td>59</td>
</tr>
<tr>
<td>Introduction</td>
<td>60</td>
</tr>
<tr>
<td>How Much Habitat is Enough?</td>
<td>60</td>
</tr>
<tr>
<td>Biodiversity and Species Richness</td>
<td>61</td>
</tr>
<tr>
<td>Threats to species persistence</td>
<td>62</td>
</tr>
<tr>
<td>Using an Ecosystem Services Approach to Conserve Native Species</td>
<td>64</td>
</tr>
<tr>
<td>Methods</td>
<td>66</td>
</tr>
<tr>
<td>Study Area</td>
<td>66</td>
</tr>
<tr>
<td>Data Acquisition &amp; Sources</td>
<td>67</td>
</tr>
<tr>
<td>Spatial Analyses</td>
<td>68</td>
</tr>
<tr>
<td>Quantitative Analyses</td>
<td>69</td>
</tr>
<tr>
<td>Results</td>
<td>70</td>
</tr>
<tr>
<td>Species Occurrences on the Landscape and in Ecologically Important Zones</td>
<td>70</td>
</tr>
<tr>
<td>Species Occurrences in Stewardship and Potential Additions</td>
<td>72</td>
</tr>
<tr>
<td>Threatened and Endangered Species</td>
<td>73</td>
</tr>
<tr>
<td>Discussion</td>
<td>74</td>
</tr>
<tr>
<td>Species Representation in Ecologically Important Zones</td>
<td>74</td>
</tr>
<tr>
<td>Stewardship Assessment and Potential Protected Species</td>
<td>76</td>
</tr>
</tbody>
</table>
Table 1.1: National Land Cover Dataset land cover class definitions (Fry et al. 2011)...

Table 1.2: Definitions of vegetation classification levels for the NVCS hierarchy (Grossman et al. 1998)...

Table 1.3: Contingency table analysis for ground-truthed vegetation data. Bolded numbers on diagonals are pixels classified in the same land cover category by the user and producer. Overall accuracy is also on the diagonal (0.90) and represents the number of pixels correctly classified divided by the number sampled. Listed below the overall accuracy is the Kappa statistic (0.77), which is a measure of inter-rater agreement and in this study showed strong agreement.

Table 1.4: Error matrix for 2006 NLCD Anderson Level 1 land cover classification for the U.P. of Michigan. Each of the 7 land cover classes was used to define the sampling strata (1 class = 1 stratum), from which 50 random points were selected for comparison between the 2006 NLCD dataset and satellite imagery from 2010. On-diagonal numbers represent agreement between the NLCD and satellite imagery, while off-diagonal numbers represent misclassifications. Producer accuracy (PA) is the total for a row divided by the number of correct land cover classifications. User accuracy (UA) is the total for a column divided by the number of correct land cover classifications. Omission error is equal to 1-PA, and commission error is equal to 1-UA. Overall accuracy is calculated from the sum of the diagonal numbers, divided by the total sample size (n=350). The Kappa coefficient is calculated using the sum of the on-diagonals (observed agreement) and subtracting the expected agreement, then dividing by 1-expected agreement.

Table 2.1: Definitions of stewardship levels (management Status) in Gap Analysis (after Scott et al. 1993).

Table 2.2: Applied buffer widths (in meters) from Environment Canada (2004) recommendations used in this study.

Table 2.3: Distribution (percentages) of EIZs on the landscape of the entire Upper Peninsula in Michigan compared to distributions in all legally protected stewardship Status lands (1,2,3).

Table 2.4: Distribution of wetlands, riparian zones, and uplands in the U.P. in legally protected stewardship areas (Status 1,2,3) within each EIZ type. Stewardship Status was determined from the Michigan Gap Analysis data and EIZs were delineated from National Wetland Inventory data (wetlands, uplands) or Michigan trout streams data.
Table 2.5: Distribution of ecologically important zones (wetlands, riparian zones, and uplands based on size requirements) in the U.P. in legally protected stewardship areas (Status 1,2,3) within each EIZ type. Stewardship Status was determined from the Michigan Gap Analysis data and EIZs were delineated from National Wetland Inventory data (wetlands, uplands) or Michigan trout streams data. ................................................................. 49

Table 2.6: Percentage of upland, wetland, and riparian zone EIZs (compared to abundance on the U.P. landscape) included in potential stewardship land additions in the U.P. of Michigan............................................................................................................. 49

Table 3.1: Taxonomic group usage of wetland, riparian, and upland ecosystems on the landscape and wetland, riparian, and upland EIZs. Numbers in columns represent percentage of total occurrences (normalized per hectare of ecosystem). ......................... 81

Table 3.2: Species occurrences, by taxonomic group, in Status 1 (permanently protected from conversion to an unnatural state and managed to remain natural), Status 2 (permanent protection from conversion to an unnatural state, but management practices may reduce quality of natural communities), and Status 3 (permanent protection from conversion to an unnatural state, but potentially subject to extractive uses) protected areas, and other unprotected areas in the U.P. of Michigan. ......................................................... 81

Table 3.3: Ecosystem area (totaled from individual species area within taxonomic groups) in millions of hectares within wetlands, riparian zones, and uplands on the landscape and ecosystem area for proposed additions to stewardship through buffers (i.e. 240 m for wetlands, 30 m for riparian zones, and either 100 m or 200 m for uplands) in the U.P. of Michigan. ................................................................. 82

Table 3.4: Percent of all predicted occurrences on the landscape for threatened and endangered species occurring in Status 1, Status 2, or Status 3 lands................................. 83
LIST OF FIGURES

Figure 1.1: National Vegetation Classification Standard hierarchy for terrestrial vegetation (Grossman et al. 1998). ................................................................. 21

Figure 1.2: Hierarchical evolution of land cover accuracy assessments adapted from Congalton (1994). .................................................................................. 21

Figure 1.3: Stratified random sample points for 2006 NLCD land cover accuracy assessment in Michigan's Upper Peninsula. ............................................................. 22

Figure 1.4: Land cover data (2006) NLCD. Lighter areas represent more vegetation while darker areas represent the least vegetation (i.e. developed areas, beaches, open water), and other areas are intermediate. ......................................................... 23

Figure 2.1: Sample iterative model showing geoprocessing steps for determining the amount of riparian zone ecosystems in Status 1, 2, and 3 stewardship in the U.P. Blue ovals are inputs, orange hexagons are iterators (and light blue ovals its value parameter for non-geographic data reference), yellow rectangles are geoprocessing tools and green ovals are outputs, many of which are intermediate. .................................................. 50

Figure 2.2: Wetland EIZs delineated from wetland systems (palustrine, lacustrine, or riverine) of 100 ha or larger in the National Wetlands Inventory dataset. .................... 50

Figure 2.3: Riparian EIZs in the U.P., delineated from Michigan Trout Streams, each with a 10 m bilateral buffer. .................................................................................... 51

Figure 2.4: Upland EIZs in the U.P. delineated from upland systems of 1,000 ha or larger in the National Wetlands Inventory dataset. ..................................................... 52

Figure 2.5: Map of protected areas in the U.P. separated by status, with Status 1 being the most highly protected and Status 3 the lowest level of legal protection. White areas are not legally protected. ................................................................. 53

Figure 2.6: Distribution of protected lands in the U.P. by stewardship Status from the Michigan Gap Analysis dataset. Status 1 (blue; highest protection), Status 2 (red; intermediate protection), and Status 3 (green; lowest protection). ......................... 54

Figure 2.7: Distribution of all EIZs in stewardship by Status (from the Michigan Gap Analysis dataset). Status 1 (blue; highest protection), Status 2 (red; intermediate protection), and Status 3 (green; lowest protection). ........................................ 54
Figure 2.8: Additional land potential for stewardship protection in the U.P. of Michigan. Under Plan A this includes all riparian zones with a 30 m buffer, wetlands greater than 100 ha with a 240 m buffer, and contiguous uplands greater than 1,000 ha with a 100 m buffer. Under Plan B, riparian zone and wetland additions are the same as in Plan A, but contiguous uplands greater than 1,000 ha received a 200 m buffer.

Figure 2.9: Ecosystem service values from ecologically important zones with potential buffer widths in the U.P. of Michigan. I multiplied the potential additional stewardship area for each EIZ by its corresponding 2012 estimated ecosystem services values (i.e. wetlands=$28,086/ha/year, riparian zones=$12,190/ha/year, and uplands=$433/ha/year).

Figure 2.10: Distribution of additional lands according to EIZ category potential under conservation Plan A in the U.P. of Michigan. Under Plan A this includes all riparian zones with a 30 m buffer, wetlands greater than 100 ha with a 240 m buffer, and contiguous uplands greater than 1,000 ha with a 100 m buffer.

Figure 2.11: Distribution of ecosystem service values according to EIZ category potential under conservation Plan A in the U.P. of Michigan. Ecosystem service values from ecologically important zones with potential buffer widths in the U.P. I multiplied the potential additional stewardship area for each EIZ by its corresponding 2012 estimated ecosystem services values (i.e. wetlands=$28,086/ha/year, riparian zones=$12,190/ha/year, and uplands=$433/ha/year).

Figure 2.12: Distribution of additional stewardship lands according to EIZ category potential under conservation Plan B in the U.P. of Michigan. Additional land with potential for stewardship protection. Under Plan B this includes all riparian zones with a 30 m buffer, wetlands greater than 100 ha with a 240 m buffer, and contiguous uplands greater than 1,000 ha with a 200 m buffer.

Figure 2.13: Distribution of ecosystem service values according to EIZ category potential under conservation Plan B in the U.P. of Michigan. Ecosystem service values from ecologically important zones with potential buffer widths in the U.P. I multiplied the potential additional stewardship area for each EIZ by its corresponding 2012 estimated ecosystem services values (i.e. wetlands=$28,086/ha/year, riparian zones=$12,190/ha/year, and uplands=$433/ha/year).

Figure 2.14: Ecosystem service values of riparian zones, wetlands, and uplands currently in stewardship and potential additions under conservation plans A and B in the U.P. of Michigan. Ecosystem service values from ecologically important zones with potential buffer widths in the U.P. I multiplied the potential additional stewardship area for each EIZ by its corresponding 2012 estimated ecosystem services values (i.e. wetlands=$28,086/ha/year, riparian zones=$12,190/ha/year, and uplands=$433/ha/year).
Figure 3.1: Percentages of species occurrences normalized by unit area (number of occurrences/hectare) for all terrestrial vertebrate species on the entire U.P. landscape of Michigan. ................................................................. 84

Figure 3.2: Percentages of species occurrences normalized by unit area (number of occurrences/hectare) for all terrestrial vertebrate species in wetland, riparian, and upland EIZs in the U.P. of Michigan. ................................................................. 84

Figure 3.3: Species occurrences (all TVS) in Status 1 (permanently protected from conversion to an unnatural state and managed to remain natural), Status 2 (permanent protection from conversion to an unnatural state, but management practices may reduce quality of natural communities), and Status 3 (permanent protection from conversion to an unnatural state, but potentially subject to extractive uses) protected areas and on the U.P. of Michigan landscape. ................................................................. 85

Figure 3.4: Distribution of predicted species occurrences for threatened and endangered species in stewardship areas (Status 1, Status 2, and Status 3) and across the U.P. landscape of Michigan. ................................................................. 85
LIST OF SYMBOLS OR ABBREVIATIONS

AOC: Area of Concern
CE: Commission Error
CPI: Consumer Price Index
DNR: Department of Natural Resources
EHD: Epizootic Hemorrhagic Disease
EIZ: Ecologically Important Zone
EPA: Environmental Protection Agency
ESRI: Environmental Systems Research Institute
ETM: Enhanced Thematic Mapper
FEMAT: Forest Ecosystem Management Assessment Team
GAP: Gap Analysis Program
GME: Geospatial Modeling Environment
IUCN: International Union for the Conservation of Nature
MGDL: Michigan Geographic Data Library
MTS: Michigan Trout Streams
NLCD: National Land Cover Dataset
NVCS: National Vegetation Classification System
NWI: National Wetlands Inventory
OE: Omission Error
PA: Producer’s Accuracy
PCB: Polychlorinated Biphenyl
RS: Remote Sensing
TVS: Terrestrial Vertebrate Species

UA: User’s Accuracy

UP: Upper Peninsula

USFWS: United States Fish and Wildlife Service

USGS: United States Geological Survey
CHAPTER OVERVIEW

Land cover data is growing in use as a management tool for many aspects of biodiversity and needs to be verified for accuracy. Understanding the limitations of a land cover dataset can support the decision making process for conservation plans. I assessed the accuracy of the 2006 National Land Cover Dataset for Anderson Level 1 Classification using a stratified random sample of 350 points (50 per land cover class) across Michigan’s Upper Peninsula by completing a photo comparison between the 2006 NLCD and 2010 satellite imagery, with additional ground truthed data. I calculated multiple measures of accuracy including overall accuracy, user and producer accuracy, and the Kappa statistic, to generate a robust accuracy measurement for the dataset. Overall accuracy for the 2006 NLCD in the Upper Peninsula was approximately 75%, with a Kappa coefficient of approximately 70%. User accuracy ranged from 59%-100% for land cover classes, while producer accuracy ranged from 54%-96%. Numerous factors reduced the accuracy of the dataset, potentially including sample size, assumptions, mixed pixels, and georeferencing errors.

INTRODUCTION

Land cover data from remote sensing provides information on the type of vegetation on the landscape, which is a strong indicator of land use. Knowing what type of vegetation and land use are present across the landscape provide planners and managers with a knowledge base that can be used to derive ecosystem maps, locations of ecologically important zones (EIZs), and
predict species occurrences. Determining the thematic accuracy of a map is an important step in deciding if the data are suitable for a particular project.

A thematic land cover accuracy assessment measures the reliability of classified attributes in a map (Campbell 1996). Generally, map errors are the defining measure of thematic accuracy, which users determine from discrepancies and disagreements between the map and the reality (Congalton 1991; Campbell 1996). Remotely sensed (RS) land cover data is useful in conservation planning and wildlife management, when users understand the limitations and errors. Unfortunately, land cover accuracy is frequently undetermined because of the unique challenges presented to analysts who try to define it (Foody 2002).

Land cover classification requires the use spectral data (color bands) from satellite imagery that represent different patterns of reflectance on the landscape. Using satellite data from year to year also allows for the tracking of land cover change over time (Foody 2002), which has important management implications. Differences in the color bands of the land cover data indicate different types of land cover, both spatially and temporally. In the United States, the 2006 National Land Cover Dataset (NLCD) classification uses a modified Anderson Land Classification Scheme from the United States Geological Survey (USGS). Anderson Classification is a hierarchy of physiognomic and floristic vegetation descriptions (Figure 1.1) from the National Vegetation Classification Standard (Grossman et al. 1998). For this study, I used only Level 1 classification, which included seven land cover classes occurring in my study area. These classes are: (1) agricultural vegetation, (2) developed & other human use, (3) forest & woodland, (4) introduced & semi-natural vegetation, (5) open water, (6) recently disturbed or modified, and (7) shrubland & grassland (see Table 1.1 for class descriptions and definitions).
I measured the accuracy of the unsupervised classification 2006 Landsat ETM (Enhanced Thematic Mapper) for Michigan’s Upper Peninsula (U.P.) for the Level 1 Anderson Classification. This is the most recent land cover data available for Michigan. Land cover in this analysis is important for the determination of terrestrial biodiversity supported in EIZs (see chapter two). Because data on individual species are difficult and time-consuming to collect, I used the land cover data as a surrogate (Sarkar et al. 2006) to determine the accuracy of predicted species occurrences for all terrestrial vertebrates in the U.P. Using the most recent land cover data allows me to infer the applicability of these datasets for future conservation action. The land cover data used 30 m x 30 m pixels and was a part of the National Gap Analysis Project (GAP).

Accuracy assessment and accuracy reporting are important in any spatial analysis project, primarily because all spatial datasets have inherent and unavoidable errors (Foody 2002). Reporting errors accurately determines limitations of the dataset by describing the quality of the dataset and strengthens its usefulness. For example, understanding error sources in spatial datasets allows managers to apply spatial data appropriately in the decision making process.

Another crucial component of land cover accuracy assessment is setting an accuracy objective. This objective is a measureable target of accuracy, i.e. 70% or greater accuracy at the Level 1 classification. Accuracy objectives will vary depending on the intended application of the data. I expected a minimum overall accuracy of 70%, but sought an 80% minimum, as determined statistically using a Kappa coefficient, which measures agreement between two raters. In this assessment, one rating was the classification from the remote sensing land cover data and the second from site-specific ground classifications. The 80% target is the minimum measurement for strong agreement (Congalton & Green 1999) and falls between the 70-98%
accuracy estimates for the 2001 National Land cover Database (Homer et al. 2007). Though there is no standard for reporting accuracy statistics, Foody (2002) recommends the Kappa statistic as a primary measure, but suggests the use of multiple accuracy indices.

Land cover accuracy assessment methodology has evolved over time as outlined by Figure 1.2 (adapted from Congalton 1994 as cited in Foody 2002). Initially, accuracy assessments simply considered whether or not a map looked ‘good’ or ‘right’ through a simple visual inspection. The next development in accuracy assessments was the consideration of the areal extent and proportion of features, but this doesn’t consider locational accuracy and was also an ineffective measurement. Ground truthing of specific locations was the third addition to accuracy assessment, which provided an overall measure of accuracy, but became obsolete with the addition of Kappa. Finally, the addition of confusion or error matrices and the Kappa statistic provide robust statistical measures to describe various types of land cover accuracy, as recommended by both Congalton (1991) and Foody (2002).

I compared randomly selected points on the 2006 NLCD U.P. land cover to satellite images to assess accuracy of the 2006 data. I conducted statistical analyses to determine accuracy statistics as a measure of comparison between the spatially referenced data points and the land cover dataset. Statistical analyses provided multiple measures of accuracy including Kappa, user/producer accuracy, commission/omission errors, and overall accuracy. The purpose of completing the statistical accuracy analyses was to decide if the 2006 land cover dataset had high enough accuracy to serve as a surrogate for terrestrial biodiversity (as it was a component of the Gap Analysis Program predicted species occurrence models). I also completed some ground-truthing vegetation surveys to supplement the aerial photo interpretation, but because of limited
accessibility to sites, the ground-truthed do not provide a robust sample size for appropriate statistical analysis.

METHODS

Study Area

Michigan’s Upper Peninsula (U.P.) occupies an area of 4,261,000 ha between 45° N and 48° N latitudes and 83° W and 91° W longitudes. This study focused on the mainland U.P. and excluded small islands. The U.P. is part of the Northern Lakes and Forests ecoregion with typical glacial/nutrient-poor soils, and coniferous and northern hardwood forests (EPA 2007). Much of the vegetation is typical of boreal forest or northern hardwood associations (Henson et al. 2005). Undulating till plains, moraines, broad lacustrine basins, and sandy outwash plains with thicker and less arable soils than in neighboring southern ecoregions define the Northern Lakes and Forests ecoregion (EPA 2007). Lakes in the ecoregion are also less productive and clearer than lakes in neighboring southern ecoregions (EPA 2007).

The Great Lakes markedly influence the climate of the U.P. Heat storage in the lakes occurs during the summer and release occurs in the fall and winter seasons, which moderates near shore climates (Henson et al. 2005). This mechanism is also responsible for lake effect snow and the occurrence of snowbelts on the landscape, east and downwind of the lakes, as well as cool temperatures, coastal fog, and reduced sunlight (Henson et al. 2005). Average snowfall in the region varies from 700-1000mm (Henson et al. 2005).

Data Acquisition

Land cover data for this portion of the project was the 2006 NLCD ETM, available online from the Michigan Geographic Data Library (MGDL) (http://www.mcgi.state.mi.us/mgdl/).
Descriptions of land cover classes based on the National Vegetation Classification System (NVCS) are listed in Table 1.2.

**Ground Truthing**

In the summer and fall of 2011 I sampled 320 sites across Michigan’s U.P. The categories sampled were the categories of interest as wetland, upland, and riparian ecosystems delineated from National Wetlands Inventory and Michigan Trout Stream Data. The land cover classes (Anderson Level 1) of interest were (1) forest & woodland, (2) shrubland & grassland, (3) recently disturbed or modified, and (4) open water. Incidental captures of developed & other human use pixels occurred during the sampling process as well.

**Sampling Design for Aerial Photo Interpretation**

Sample size is an important consideration for any type of statistical analysis, but is particularly important in land cover accuracy assessment because it influences error rates (Henson et al. 2005). For land cover Congalton (2001) recommends a sample size of 50 pixels in each class, which I used. Following Congalton’s (2001) recommendation, I opted for the larger sample size (n=50 per class), totaling 350 sample points for accuracy assessment. Site locations are shown in Figure 1.3, while Figure 1.4 shows land cover for the U.P. with dark green areas representing greater amounts of vegetation and red areas the least amount of vegetation (i.e. developed areas, beaches, open water).

Though simple random samples are ideal for some statistical analyses, the constraints of working with land cover data make this design impractical. To deal with the limitations of land cover data sampling (i.e. cost, accessibility of sites) Congalton (1991) and Foody (2002) suggested using a stratified random sampling scheme. I used the geospatial modeling
environment (GME) ® to generate a systematic random sample for land cover accuracy assessment. I used each of the Level 1 Anderson land cover classes in the study area as the strata and set the sample size to 50 points for each class. I then used aerial photos to interpret each point to classify land cover for comparison with the 2006 RS dataset. Satellite imagery interpretation was the preferred method for accuracy assessment because of its low cost, efficiency, and accessibility to open water points and private lands. I imported satellite imagery from Bing Maps® into ArcMap 10 (ESRI, 2011, Redlands, CA) for accuracy assessment.

**Statistical Analyses**

The accuracy assessment of land cover data is a relatively daunting task and many datasets lack such an assessment. Even when an accuracy assessment is completed, the data may be unclear, especially because the overall accuracy statistic (the number of correctly classified samples divided by the total number of samples) is an incomplete accuracy measure. For example, the overall accuracy statistic identifies the proportion of all sample points correctly classified, but does not provide information about within class accuracy or agreement between raters. The Kappa statistic addresses these shortcomings by providing an overall accuracy statistic of between rater agreement and accounts for chance agreement between raters (Cohen 1960).

Contingency analysis is a common statistical method to assess the accuracy of land cover data because it provides many different accuracy statistics. Contingency analysis compares site specific surveys and remote sensing imagery in a tabular format (Congalton & Green 1999). Overall accuracy, different types of accuracy assessment (user and producer), different types of errors (omission and commission), and agreement between raters (Kappa coefficient) can be determined from contingency tables. The Kappa coefficient is a summary statistic that measures
the agreement between raters (i.e. the user and the producer) and is calculated from the diagonal agreements in a contingency table (Cohen 1960). The equation for Kappa (simplified from Foody 2004) is:

\[
\kappa = \frac{\text{observed} - \text{expected}}{1 - \text{expected}}
\]

Johnson and Ross (2008) provide a succinct summary of the calculations for observed and expected values in contingency analysis for land cover accuracy assessment. The Kappa coefficient is arguably the most important statistic in contingency analysis because it compresses the contingency table into one statistic, which is potentially more user-friendly (Tweddale 2006). Kappa also eliminates agreement due to chance, providing a more robust measure of inter-rater agreement. I calculated Kappa using the crosstabs function in IBM SPSS release 19.0.0.1 (SPSS, Inc., 2010, Chicago, IL).

When determining the quality of land cover data, the types of errors and accuracy are the primary concerns. Like Kappa, contingency analysis provides other error and accuracy statistics. The two main error types of concern are omission and commission errors. Omission errors occur when sampled pixels are not recognized as the target classification, i.e. an agricultural vegetation pixel assigned to a forest and woodland classification. Omission errors are essentially a false negative. Commission errors are the opposite and are basically a false positive. A commission error occurs when a pixel is classified incorrectly belonging to a target classification, i.e. an open water pixel being assigned to a developed and urban classification.

Other measures of accuracy from contingency analysis are the producer’s accuracy and the user’s accuracy. Producer’s accuracy is a measure of the usefulness of the remote sensing imagery to classify site specific samples on the ground. User’s accuracy describes the
probability that a given pixel assigned to a classification actually belongs to that classification.

Inverse relationships exist between producer’s accuracy and omission errors and user’s accuracy and commission errors. Sample size can have an effect on these accuracy measures, hence the use of a minimum sample size of 50 pixels per class (Tweddale 2006).

RESULTS

U.P. Ground Truthing from Relevé Sampling

These data did not meet minimum sample sizes for statistical analysis using contingency tables, except in one category, which was forest & woodland. As the dominant category it represented most of the sample pixels and had a producer accuracy of nearly 99% and user accuracy of 98% (Table 1.3). The sampling design did not target other classes well, which had small sample sizes for the most part, resulting in low producer and user accuracies. With the low user and producer accuracies in all classes except forest and woodland, there was a high error rate for commission and omission errors in the dataset. Overall accuracy for the ground-truthed vegetation data was almost 90% and a Kappa coefficient of 0.77 (p<0.001), meaning the inter-rater agreement was not likely due to chance.

U.P. Land Cover Anderson Level 1 Classifications

The total land area of the U.P. included in this study was approximately 43,998 km² (which included some open water areas not included in other estimates of land area). The Anderson Level 1 land cover class with the greatest area was forest and woodland at nearly 38,499 km², which covered almost 88% of the landscape. The smallest area for any of the land cover classes was the approximately <1 km² of introduced/semi-natural vegetation on Isle Royale. The remaining land cover classes covered the U.P. as follows, from most to least: open
water (~1,689 km$^2$; 4%), recently disturbed or modified (~1,400 km$^2$; 3%), agricultural vegetation (~1,181 km$^2$; 3%), developed and urban (~1,102 km$^2$; 3%) and shrubland and grassland (126 km$^2$; <1%).

The overall accuracy statistic (calculated from the diagonal in the contingency table divided by the total number of sample points) was 75%. The contingency table for these data, included below (Table 1.3), shows three measures of accuracy: Kappa coefficient, user and producer accuracy, and the errors of commission and omission.

**Kappa Coefficient**

The Kappa statistic measured overall agreement between photointerpretation and remotely-sensed 2006 NLCD Landsat TM imagery. Kappa provided an accuracy measure of land cover classification data by summarizing the contingency table (Table 1.3). The Kappa coefficient adjusted for the agreement expected by chance and showed an overall accuracy of 70.3% between raters, which was statistically significant (p<0.001). That is, the observed agreement between raters is not due to chance.

**User and Producer Accuracy**

User and producer accuracy calculations for each of the Level 1 Anderson land cover classes measured categorical accuracy. For each of the seven land cover classes examined, I calculated user and producer accuracy. User accuracy measured the probability of a sample pixel from the RS data accurately represented that pixel on the landscape. Producer accuracy provided a measure of the probability of correctly predicting a ground reference sample from RS data. User accuracy ranged from 59% (forest and woodland) to 100% (introduced/semi-natural
vegetation). Producer accuracy ranged from 54% (developed and urban) to 94% (forest and woodland).

**Errors of Commission and Omission**

Both commission errors (CE) and omission errors (OE) share relationships with the categorical accuracy measures known as user (UA) and producer accuracy (PA). Commission errors were calculated from the user’s accuracy through the relationship \( CE = 1 - UA \). The same relationship exists for omission errors and producers accuracy, which allowed me to calculate omission errors from the equation \( OE = 1 - PA \). Commission errors were greatest for the forest and woodland classification (41%) and lowest for introduced/semi-natural vegetation (0%), which is the inverse of the user accuracy results. Omission errors were greatest for developed and urban (46%) and lowest for forest and woodland (6%), exhibiting an inverse relationship with the producer accuracy results.

**DISCUSSION**

**Accuracy Assessment**

The release of a formal accuracy assessment for the 2006 NLCD will be at the end of 2013 (Homer & Fry 2012). Since these data were unavailable for my work, I calculated multiple accuracy measures for the study area. The use of multiple accuracy measures provided insight into shortcomings in specific parts of the dataset. Since land cover data are a surrogate for GAP species predicted occurrence models, I wanted to use the 2006 NLCD data as an indicator of the accuracy of the species models. The use of land cover as a surrogate for species modeling is important from a management perspective because changes in land cover over the next century are projected to be one of the most significant threats to biodiversity (Chapin et al. 2002).
Overall accuracy of 75% is close to the accuracy of the NLCD 1992 with Anderson Level 1 accuracy of 80.4% and to the NLCD 2001 with 85.3% Anderson Level 1 accuracy (Homer & Fry 2012). The overall accuracy for the entire dataset is probably higher on average than any one area because the NLCD data are most accurate when used at the regional and national levels, as opposed to local use (Homer & Fry 2012). Similar problems with achieving the 80% target accuracy occurred during the National Park Service Vegetation Inventory (Lea & Curtis 2010). The National Park Service determined that the 80% accuracy was not feasible to achieve and subsequently dismissed this standard, addressing limitations in the data and funding to complete adequate sampling toward this target (Lea & Curtis 2010). In a 1995 review of work on land cover accuracy assessment by Trodd (as cited in Foody 2002) most accuracy classifications failed to meet the 85% target set by the USGS for Anderson Level 1 classifications. Other accuracy assessment work rarely met the 85% target either (Shao & Wu 1998) so it is not surprising my work also failed to meet the 80% standard. The actual ground-truthed data also provides support that the aerial images and satellite photos are accurate, but a larger sample size and broader effort would make for more meaningful statistics.

The Kappa statistic was central to the analysis because it represented the inter-rater agreement between the 2006 NLCD Landsat TM derived land cover data and the 2010 satellite imagery. The Kappa statistic showed just above 70% agreement between raters, which was near the minimum value for the 2001 National Land Cover Dataset (Homer et al. 2007). Despite its apparent low agreement, Landis and Koch (1977) classifications identify 70% agreement as substantial, only one class below almost perfect agreement. Other evidence in favoring the strength of a 70% Kappa agreement cites the nature of Kappa as a very conservative statistic that...
tends to underestimate overall accuracy (Muller et al. 1998). Many of the potential reasons for the assessment showing only approximately 70% accuracy are discussed in the context of user/producer accuracy and commission/omission errors.

The secondary measures of accuracy were producer and user accuracy. User accuracy showed the greatest discrepancies in the forest and woodland class, with only 59% accuracy. The user classified 80 points as forest and woodland, which identified flaws in data classification during production. Of the 80 sites the user identified as forest and woodland, the producer identified 47 of those sites accurately, while misclassifying the remaining sites. Quite astonishingly the user identified introduced and semi-natural vegetation 100% accurately, while the producer accuracy was only about 62% for this classification. The main reason for the differences between user and producer in the introduced/semi-natural vegetation was the extremely limited area included in this land cover classification thus, the difficulty in executing focal statistics in these areas.

The greatest cause of rater disagreement appeared to be points on or near the periphery of a land cover type. This frequently occurred along linear features, such as roads and rivers, and likely contributed considerably to the error. Boundaries present a unique example of heterogeneity on the landscape, which illustrates the point that heterogeneity is difficult to map (Herold et al. 2008). Low producer accuracy is a known problem with heterogeneous landscapes and the 54% producer accuracy for the developed and urban classification probably resulted from this situation. The nature of pixelated raster data imposes limits to the peripheries of features because of the shape approximation, which can result in pixel misregistration (Townsend 2000). Mixed pixels, whose features may belong to two different classifications, also
contribute to reduced accuracy along boundaries, so the implementation of fuzzy logic to assign pixels to multiple classes might increase accuracy in the future (Foody 1996). Another method to improve accuracy in boundary areas is to use a degree of tolerance (i.e. within 100 m of a feature) to reduce locational errors (Maling 1989).

In addition to the user and producer accuracy, I was concerned with what the commission and omission errors convey about the data. Commission errors described the user’s accuracy by identifying a rate of occurrence of false positives. The most frequent false positives occurred in the forest and woodland category (41%), which had pixels misclassified in every other class. Most of the misclassified pixels appeared to be either on the periphery of a forest and woodland or in a small forest patch adjacent to larger patches of other land cover types that likely absorbed the forest patch during classification. Two factors probably contributed to errors of this type: generalizations that result in lost information and an insistence on strict positional accuracy that actually works negatively by compounding errors, including those from generalizations (Maling 1989). The recently disturbed or modified classification had the second highest commission error rate (32%), with most of the misclassifications attributed to the developed and urban classification. Many of the recently disturbed or modified sites were visually similar to some types of developed and urban sites and likely had similar reflectance patterns making them difficult to distinguish during classification.

Omission errors described the rate of occurrence of false negative classifications in the data. As previously mentioned, omission errors were greatest for the developed and urban classification (46%) and lowest for forest and woodland (6%). The high omission error for the developed and urban classification was likely the result of the linear features in the developed
and urban classification. Spatial accuracy is an identified problem with linear features (Gustine et al. 2006), including roads, especially when these features are frequently less wide than the 30 m raster pixels. Again, the same constraints of working along boundaries contribute to reduced accuracy in omission errors. The low omission error for forest and woodland classified pixels was probably the result of points occurring in large blocks of forest not impacted by different neighboring pixels.

Other error sources that reduce accuracy during data collection include satellite interference and georeferencing. Problems with spatial accuracy could reduce ground-truthing accuracy because of the misrepresentation of an \((x, y)\) point due to difficulty in geolocation in homogenous terrain (Strahler et al. 2006) or because of misregistration errors (Muller et al. 1998). Similar vegetation structures in homogenous landscapes create problems when trying to distinguish land covers with spectral resemblances, contributing to accuracy errors (Muller et al. 1998). Satellite interference due to atmospheric effects or problems with equipment calibration can reduce thematic accuracy as well, though advances in technology are reducing these errors (Strahler et al. 2006).

Both sample size and assumptions about reference data are potential factors that reduce accuracy. Sample size for this analysis was \(n=50\) per strata as recommended by Congalton (2001). Other work suggests using 100 or more sample points per strata when conducting an accuracy assessment (see Tweddale 2006). Using a larger sample size would potentially provide a better accuracy estimate, but would reduce the time and cost effectiveness associated with a sample size of 50 pixels. In addition to sample size, analysts generally assume that the reference data are more accurate than the thematic map, which may not be true (Congalton 1991).
CONCLUSION

Though the accuracy assessment did not meet the anticipated 80% minimum for the Anderson Level 1 classification, I am confident that the 75% overall accuracy, in conjunction with a 70.3% Kappa, is strong enough to move on to the next part of the analysis. Most problems contributing to reduced accuracy were the result of fixed logic in focal statistics and classification (i.e. no gradient between pixel classifications) at the 30 m resolution. Many of the misclassified pixels occurred very close to the periphery of the land cover classification to which they belonged. Misclassifications resulting from near-periphery occurrences may simply mean that the spatial accuracy for misclassified pixels is due to a lack of horizontal tolerance. This means that the accuracy of a given pixel may only be approximately 70%, but the specific land cover type is generally nearby, within 60-90 m, based on observations made during photointerpretation.

After completing the accuracy assessment using photointerpretation and identifying the shortfalls of the data, it appears the data will not limit the applications of species modeling for conservation. Most vertebrate species use multiple pixels on a landscape. Thus even if the land cover of a given pixel only has a 75% chance of being correctly classified, adjacent pixels likely reflect the correct land cover and in consequence, habitat for that species. Using fuzzy logic when modeling species and land cover would likely reduce errors resulting from limitations of fixed logic models, increasing overall accuracy and the Kappa coefficient. Likewise, using pixel sizes larger than 30 m x 30 m will contribute to increased spatial accuracy, but decrease the amount of detail available for each pixel. The 75% accuracy is strong enough to continue working with the dataset for conservation planning.
APPENDIX A

Table 1.1: National Land Cover Dataset land cover class definitions (Fry et al. 2011).

<table>
<thead>
<tr>
<th>Class</th>
<th>Classification Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open Water</td>
<td>Areas of open water generally with less than 25% cover of vegetation.</td>
</tr>
<tr>
<td>Developed &amp; Other Human Use</td>
<td>Areas characterized by a high percentage (30% or greater) of constructed materials (e.g. asphalt, concrete, buildings, etc.).</td>
</tr>
<tr>
<td>Forest &amp; Woodland</td>
<td>Areas characterized by tree cover (natural or semi-natural woody vegetation, generally greater than 6 meters tall); tree canopy accounts for 25% to 100% of the cover.</td>
</tr>
<tr>
<td>Shrubland &amp; Grassland</td>
<td>Areas characterized by natural or semi-natural woody vegetation with satellite stems, generally less than 6 meters tall, with individuals or clumps not touching to interlocking. Both evergreen and deciduous species of true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions are included.</td>
</tr>
<tr>
<td>Agricultural Vegetation</td>
<td>Areas characterized by herbaceous vegetation that has been planted or is intensively managed for the production of food, feed, or fiber; or is maintained in developed settings for specific purposes. Herbaceous vegetation accounts for 75% to 100% of the cover.</td>
</tr>
<tr>
<td>Herbaceous (Introduced/semi-natural OR Recently Disturbed or Modified)</td>
<td>Areas characterized by natural or semi-natural herbaceous Vegetation; herbaceous vegetation accounts for 75% to 100% of the cover.</td>
</tr>
</tbody>
</table>
Table 1.2: Definitions of vegetation classification levels for the NVCS hierarchy (Grossman et al. 1998).

<table>
<thead>
<tr>
<th>Level</th>
<th>Primary Basis for Classification</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class</td>
<td>Growth form and structure of vegetation</td>
<td>Woodland</td>
</tr>
<tr>
<td></td>
<td>Growth form characteristics, e.g., leaf</td>
<td></td>
</tr>
<tr>
<td>Subclass</td>
<td>phenology</td>
<td>Deciduous woodland</td>
</tr>
<tr>
<td>Group</td>
<td>Leaf types, corresponding to climate</td>
<td>Cold-deciduous woodland</td>
</tr>
<tr>
<td></td>
<td>Relative human impact (Natural/semi-natural or cultural)</td>
<td></td>
</tr>
<tr>
<td>Subgroup</td>
<td>Additional Physiognomic and environmental factors including hydrology</td>
<td>Natural/Semi-natural</td>
</tr>
<tr>
<td>Formation</td>
<td>Dominant/diagnostic species of uppermost or dominant stratum</td>
<td>Temporarily flooded cold-deciduous woodland</td>
</tr>
<tr>
<td>Alliance</td>
<td></td>
<td><em>Populus deltoides</em> temporarily flooded woodland alliance</td>
</tr>
<tr>
<td>Association</td>
<td>Additional dominant/diagnostic species from any strata</td>
<td><em>Populus deltoides-Salix</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Amygdaloides/Salix exigua</em> woodland</td>
</tr>
</tbody>
</table>
Table 1.3: Contingency table analysis for ground-truthed vegetation data. Bolded numbers on diagonals are pixels classified in the same land cover category by the user and producer. Overall accuracy is also on the diagonal (0.90) and represents the number of pixels correctly classified divided by the number sampled. Listed below the overall accuracy is the Kappa statistic (0.77), which is a measure of inter-rater agreement and in this study showed strong agreement.

<table>
<thead>
<tr>
<th></th>
<th>Forest &amp; Woodland</th>
<th>Shrubland &amp; Grassland</th>
<th>Recently Disturbed or Modified</th>
<th>Developed &amp; Other Human Use</th>
<th>Open Water</th>
<th>Total</th>
<th>Producer Accuracy</th>
<th>Omission Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest &amp; Woodland</td>
<td>257</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>260</td>
<td>0.99</td>
<td>0.01</td>
</tr>
<tr>
<td>Shrubland &amp; Grassland</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Recently Disturbed or Modified</td>
<td>2</td>
<td>0</td>
<td>28</td>
<td>5</td>
<td>8</td>
<td>43</td>
<td>0.05</td>
<td>0.95</td>
</tr>
<tr>
<td>Developed &amp; Other Human Use</td>
<td>2</td>
<td>0</td>
<td>13</td>
<td>0</td>
<td>0</td>
<td>15</td>
<td>0.13</td>
<td>0.87</td>
</tr>
<tr>
<td>Open Water</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Total</td>
<td>261</td>
<td>2</td>
<td>42</td>
<td>5</td>
<td>10</td>
<td>320</td>
<td></td>
<td></td>
</tr>
<tr>
<td>User Accuracy</td>
<td>0.99</td>
<td>0.00</td>
<td>0.02</td>
<td>0.00</td>
<td>0.20</td>
<td></td>
<td>0.90</td>
<td></td>
</tr>
<tr>
<td>Commission Error</td>
<td>0.01</td>
<td>1.00</td>
<td>0.98</td>
<td>1.00</td>
<td>0.80</td>
<td></td>
<td></td>
<td>K=0.77</td>
</tr>
</tbody>
</table>
Table 1.4: Error matrix for 2006 NLCD Anderson Level 1 land cover classification for the U.P. of Michigan. Each of the 7 land cover classes was used to define the sampling strata (1 class = 1 stratum), from which 50 random points were selected for comparison between the 2006 NLCD dataset and satellite imagery from 2010. On-diagonal numbers represent agreement between the NLCD and satellite imagery, while off-diagonal numbers represent misclassifications. Producer accuracy (PA) is the total for a row divided by the number of correct land cover classifications. User accuracy (UA) is the total for a column divided by the number of correct land cover classifications. Omission error is equal to 1-PA, and commission error is equal to 1-UA. Overall accuracy is calculated from the sum of the diagonal numbers, divided by the total sample size (n=350). The Kappa coefficient is calculated using the sum of the on-diagonals (observed agreement) and subtracting the expected agreement, then dividing by 1-expected agreement.

<table>
<thead>
<tr>
<th></th>
<th>Shrubland &amp; Grassland</th>
<th>Recently Disturbed or Modified</th>
<th>Open Water</th>
<th>Introduced/Semi-Natural</th>
<th>Forest &amp; Woodland</th>
<th>Developed &amp; Urban</th>
<th>Agricultural</th>
<th>Total</th>
<th>Producer Accuracy</th>
<th>Omission Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shrubland &amp; Grassland</td>
<td>37</td>
<td>0</td>
<td>1</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td>50</td>
<td>0.74</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>Recently Disturbed/Modified</td>
<td>4</td>
<td>36</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>6</td>
<td>50</td>
<td>0.72</td>
<td>0.28</td>
</tr>
<tr>
<td>Open Water</td>
<td>4</td>
<td>0</td>
<td>41</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>50</td>
<td>0.82</td>
<td>0.18</td>
</tr>
<tr>
<td>Introduced/Semi-Natural Veg.</td>
<td>0</td>
<td>4</td>
<td>13</td>
<td>31</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>50</td>
<td>0.62</td>
<td>0.38</td>
</tr>
<tr>
<td>Forest &amp; Woodland</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>47</td>
<td>0</td>
<td>1</td>
<td>50</td>
<td>0.94</td>
<td>0.06</td>
</tr>
<tr>
<td>Developed &amp; Urban</td>
<td>4</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>27</td>
<td>2</td>
<td>50</td>
<td>0.54</td>
<td>0.46</td>
</tr>
<tr>
<td>Agriculture</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>42</td>
<td>50</td>
<td>0.84</td>
<td>0.16</td>
</tr>
<tr>
<td>Total</td>
<td>52</td>
<td>53</td>
<td>55</td>
<td>31</td>
<td>80</td>
<td>28</td>
<td>42</td>
<td>51</td>
<td>0.82</td>
<td>0.18</td>
</tr>
<tr>
<td>User Accuracy</td>
<td>0.71</td>
<td>0.68</td>
<td>0.75</td>
<td>1.00</td>
<td>0.59</td>
<td>0.96</td>
<td>0.82</td>
<td>0.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commission Error</td>
<td>0.29</td>
<td>0.32</td>
<td>0.25</td>
<td>0.00</td>
<td>0.41</td>
<td>0.04</td>
<td>0.18</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Kappa = 0.703
Figure 1.1: National Vegetation Classification Standard hierarchy for terrestrial vegetation (Grossman et al. 1998).

Figure 1.2: Hierarchical evolution of land cover accuracy assessments adapted from Congalton (1994).
Figure 1.3: Stratified random sample points for 2006 NLCD land cover accuracy assessment in Michigan's Upper Peninsula.
Figure 1.4: Land cover data (2006) NLCD. Lighter areas represent more vegetation while darker areas represent the least vegetation (i.e. developed areas, beaches, open water), and other areas are intermediate.
Chapter 2: AN ECOSYSTEM SERVICES APPROACH TO CONSERVATION IN THE U.P. USING ECOLOGICALLY IMPORTANT ZONES

CHAPTER OVERVIEW

The amount of land needed for ecosystem services conservation is a contentious point of debate among authorities in the field of conservation biology. Determinations of how much habitat is enough vary depending on the conservation goals. For Michigan’s Upper Peninsula (U.P.), I used an ecosystem services-based approach to identify ecologically important zones (EIZs) in three ecosystem types (i.e. wetlands, riparian zones, and uplands). I included all riparian zones (the 10 m of land adjacent to streams), wetlands larger than 100 ha, and uplands larger than 1,000 ha as EIZs for this analysis because of their ecological functions and efficiency in terms of size and capturing ecosystem services. I determined the distribution of EIZs on the landscape and in stewardship to protect ecosystem services in each of the EIZs and used this to calculate an estimated value for the ecosystem services provided under this planning approach. Python® scripts, iterators, and multiple process steps models in ArcGIS Modelbuilder® streamlined the geoprocessing of most spatial data. Each of the delineated EIZs had a predetermined buffer width applied, intended to protect critical ecological functions including ecosystem services. The economic value of ecosystem services provided by EIZs in the U.P. is approximately $25 billion annually. Considerable economic benefits from ecosystem services impact local economies and the future of conservation in the U.P. and should be given serious consideration.
INTRODUCTION

Ecosystem services are the beneficial products of functional ecosystems that are valuable to stakeholders. Ecosystem services vary between ecosystems and can include water purification, carbon sequestration, flood mitigation, and ecotourism. Specific ecological zones provide valuable ecosystem services and warrant protection for current and future generations to maintain and benefit from these services. For the purposes of this study, I identified three broad classes of natural areas as ecologically important zones (EIZs) for ecosystem services. EIZs included in this study are wetlands, riparian zones, and upland forests.

Wetland Ecosystem Services

Wetlands have many important ecological functions that provide ecosystem services for humans and wildlife. Ecosystem (or ecological) functions are essentially the natural processes occurring within an ecosystem and if a function benefits humans it is an ecosystem service (Kremen 2005). From an anthropogenic perspective, wetlands contribute to important ecological processes including flood mitigation, aquifer recharge, and improved water quality (Mitsch and Gosselink 2000). Wetlands reduce nutrient concentrations in water, particularly nitrogen and phosphorous, both of which contribute to downstream eutrophication problems (Verhoeven et al. 2006). Reduced nutrient loading is particularly important as agricultural practices expand to meet the demands of a growing human population. Water purification through the removal of heavy metals is another key ecosystem service wetlands provide (Environment Canada 2004). Wetlands are extremely valuable to humans because they renew our water supplies, detoxify effluent, and reduce the severity of damages from rapid changes in water levels.
(Verhoeven et al. 2006). Ecosystem services like these are important, especially as we face potentially dramatic challenges from climate change.

Wetlands are also important sanctuaries and reservoirs for wildlife. Wetlands provide critical habitat for waterfowl and other birds, amphibians, some reptiles, wetland mammals, and fish (Mitsch and Gosselink 2000). In the U.P., wetlands provide habitat for sport species, such as white-tailed deer (*Odocoileus virginanus*) that use conifer swamps for overwintering (Environment Canada 2004), as well as other birds, mammals, and herpetofauna. Wetlands provide many aesthetic and recreational values; benefits extend to furbearer trapping (i.e. beaver [*Castor canadensis*], muskrat [*Ondatra zibethicus*], and otter [*Lontra canadensis*]). In one study that quantified the benefits of draining freshwater marshes in Canada, researchers found that the total economic value of intact wetlands exceeded the conversion value by 60% (Balmford et al. 2002). Public benefits such as hunting, angling, trapping, and birding are lose to private benefits in agricultural conversion of wetlands (Balmford et al. 2002).

**Riparian Zone Ecosystem Services**

Riparian zone ecosystem service values to humans are similar to wetland ecosystem service values and bridge the aquatic and adjacent terrestrial systems. Activities on the terrestrial landscape affect riparian processes and are a clear example of how ecologically important zones and ecosystem services are connected. Rivers and lakes provide recreational and ecotourism opportunities, but the surrounding landscape context (i.e. the riparian zone) greatly impacts their function (Gregory et al. 1991). The ecological impact of riparian zones exceeds their proportional area on the landscape, especially when considering sediment and nutrient reduction capacity and soil
conservation (Baker et al. 2006; Jorgensen et al. 2000). Soil conservation, via erosion prevention, is largely due to natural vegetation in riparian zones, providing structural stability (Beschta & Ripple 2009). Riparian zone ecosystem services benefit humans by improving water quality and maintaining recreational values, as found in wetlands.

In addition to the environmental and social benefits of riparian zones, they also provide habitat and are important corridors for many wildlife species. A 1993 Forest Ecosystem Management Assessment Team (FEMAT) survey in the Pacific Northwest found approximately 73% of species were associated with the riparian reserve networks (Reeves et al. 2006). Natural riparian zone ecosystems contributes to landscape connectivity and wildlife corridors, but the same vegetation regulates water temperature, through shading and cooling, which is important for cold water fish like Michigan’s native brook trout (Salvelinus fontinalis). Rivers, lakes, and riparian zones offer many of the same benefits to wildlife and humans as wetlands, including derived benefits from hunting, angling, and trapping.

**Upland Forest Ecosystem Services**

Forests have some of the most obvious ecosystem values to humans, which range from timber forest products to recreation. Sustainable logging attempts to balance resource extraction with ecological function. Protecting forest integrity through sustainable practices means humans can use forests for our own needs, while protecting watersheds and their associated biota. These indirect use values encompass things like carbon storage, soil conservation, reduced sedimentation, and water flow regulation (Pearce 2001). A decrease in forest cover will increase runoff, potentially diminishing water quality and increasing treatment costs later (Bosch & Hewlett 1982).
Forest-dwelling wildlife species depend on specific forest attributes to provide space and cover. Wildlife-habitat relationships in forests are complex and vary by species, but the amount of forest cover dictates the ability of a forest to support wildlife (Marzluff et al. 2002). Species with large area requirements (e.g. elk \( \textit{Cervus elaphus} \), lynx \( \textit{Lynx canadensis} \), and wolverine \( \textit{Gulo gulo} \)) historically disappeared from landscapes following deforestation (Environment Canada 2004). Forest patch size and edge effects are associated with species’ use of forest ecosystems, with edge intolerant species being lost from patches smaller than 200 ha (Environment Canada 2004). Some edge effects in small forest patches result from nest parasitism and edge predators (Chalfoun et al. 2002). Edge effects increase the possibility of exotic species invasions, which have the potential to reduce ecosystem service values, a problem seen with the emerald ash borer \( \textit{Agrilus planipennis} \) infestation (Poland & McCullough 2006). Intact and connected forest patches mitigate negative edge effects, facilitate interpatch movement of wild species through corridors, keep metapopulations connected, and increase the feasibility of recolonizations (Hames et al. 2001; Spackman et al. 1995; Howe et al. 1991).

**Economic Values of Ecosystem Services**

Worldwide, ecosystem service values are tremendous, nearly $47 trillion/year (adjusted for 2012 U.S. Dollars) (Costanza et al. 1997). Despite the clear economic and conservation importance, ecosystem services are not the typical basis for selecting protected areas. Protected areas, are generally the low-quality lands ("leftovers" from agricultural expansion) presumably with low ecosystem service values (Goldman et al. 2008; Scott et al. 2001). Future conservation acquisitions and stewardship programs on
private lands should focus on ecologically important zones (EIZs) that can provide a cornerstone of conservation plans. An ecosystem service approach to conservation planning mutually benefits human interests, ecosystem functions, and coincides with biodiversity conservation goals (Goldman et al. 2008; Chan et al 2006).

The monetary values of ecosystem services vary with ecosystem type, because of the different functions and resources being provided. One study valued all ecosystem services in Michigan at approximately $44 billion annually, ranking it 4th in ecosystem service value among the coterminous United States (Konarska et al. 2002), further emphasizing the local importance of ecosystem services. Within the $47 trillion per annum estimate, terrestrial ecosystem services represent just over $17 trillion globally each year (estimated converted to 2012 U.S. dollars) (Costanza et al. 1997). The most economically valuable ecosystems (per hectare) in temperate and boreal biomes were wetlands ($19,580/ha/year), lakes and rivers ($8,498/ha/year) and forests ($302/ha/year).

**Threats to Ecosystem Services**

Before a comprehensive and effective conservation plan is developed, planners must understand fundamental threats to targeted ecosystems and services. Primack (2006) identifies seven major threats to biodiversity from human activities, but several potentially impact whole ecosystems. Habitat destruction, habitat degradation, climate change, and the introduction of invasive species impose threats to ecosystem services as they impair function or reduce ecosystem area. Protecting additional ecosystem area serves as a form of insurance against future threats to ecosystem services.

Of the major threats to ecosystem services, habitat destruction is the primary threat and results from human activities and conversion, changing how it functions in an
ecosystem context. In similar boreal habitat of the Great Lakes, logging is one of the main potential threats (Sarakinos et al. 2000). Agriculture, urbanization, and water projects also convert the natural landscape into one that serves a human purpose, reducing the amount of available natural areas (Stein 2001). Urban areas expanded in the U.S. by 120% from 1942-92, with a simultaneous reduction in natural areas (Flather et al. 1999). Extractive industries, such as mining or clear cutting forests, change the landscape when conducted unsustainably (Herzog et al. 2001). What isn’t clear is why ecologically harmful practices persist even without economic return. In the Great Lakes region alone, economic outcomes from mining are negative or neutral in 97% of cases (Freudenburg & Wilson 2002). Despite the negative ecological impacts, these practices carry heavy influence politically because of their short-term economic benefits to some people. Furthermore, landscape changes from unsustainable resource extraction can result in intense wildfires, floods, landslides and other natural disasters normally mitigated in a natural setting (Hansen et al. 2001).

Habitat degradation from human activities typically devalues ecosystem services. Such degradation is apparent in the form of water pollution, which is a serious problem in Great Lakes Areas of Concern (AOCs). There are two AOCs in the Upper Peninsula (Deer Lake and Torch Lake). At these sites, bioaccumulation of toxic chemicals and heavy metals endangers humans and wildlife that consume aquatic species in contaminated areas (Schantz et al. 2001). Polluted air threatens plant communities and increases organismal susceptibility to pathogens (Bearchell et al. 2005). Degradation from pollution physically harms the ecosystem and in severe cases undermines ecosystem services (Dale & Polasky 2007).
Climate change threatens ecosystem services by physically altering weather patterns, melting glaciers, and increasing the occurrence of extreme weather events (Field et al. 2012). Physical alteration of weather patterns changes temperatures and precipitation regimes—conditions that may impact natural disturbance regimes (i.e. wildfires, flooding, and drought). Interfering with a natural disturbance regime could negatively impact the landscape and cause reductions in reduce usable forest and wetland ecosystem areas. Disturbances leading to changes in seed bank composition potentially affect the reestablishment of natural flora, which further impacts wildlife use of affected areas (Mortsch 1998). Warmer temperatures may translate into lower lake levels for the Great Lakes and increases in disease and insect outbreaks. For example, in the Lower Peninsula of Michigan, there was an outbreak of epizootic hemorrhagic disease (EHD) in white-tailed deer during the summer of 2012, following an unusually warm spring. Overall, extreme weather events resulting from climate change may degrade or reduce Great Lakes ecosystem services.

Another major threat to ecosystem services comes from invasive species, especially in the face of climate change and in conjunction with habitat destruction. Costs associated with invasive species removal and control total nearly $137 billion/year in the USA (Primack 2006). Invasive species outcompete and displace native organisms, changing trophic relationships, which changes how an ecosystem functions. In Michigan, reed canary grass (Phalaris arundinacea), garlic mustard (Alliara petiolata), spotted knapweed (Centaurea maculosa) and Phragmites are problematic plants, while the sea lamprey (Petromyzon marinus) and zebra mussels (Dreissena polymorpha) are aquatic invasive animals (Michigan DNR 2012). Habitat destruction and fragmentation create
areas that invasive species easily exploit and in a changing climate where cold winters become milder, invasive species may expand their ranges.

**How Much Habitat is Enough?**

An important question in conservation planning is how much habitat is enough to provide needed ecological, social, and economic benefits? There are numerous threats to ecosystem services provision in natural areas, which makes their conservation crucial, especially as the human population continues to expand. Finding a balance between effective planning for ecosystem services and human development is a delicate process. Though the question may seem straightforward, it is complex and challenging to answer.

The literature is wrought with recommendations and debates, which attempt to define how much is enough area for ecosystem services. Estimates for how much habitat is enough range from conserving 10-50% of an area (Roridgues & Gaston 2001; Solomon et al. 2003; Svancara et al. 2005). The low range estimates of 10-15% may actually be inadequate to sustainably provide specific ecosystem services, particularly in terms of biodiversity provision (Solomon et al. 2003). Minimums such as 10% are not justified by biological science investigations and are inherently arbitrary and political (Sarkar et al. 2006). From a biological perspective, minimum area conservation targets are upwards of 40% of an area, yet conservation plans protect less than 3% of the Earth’s surface (Tear et al. 2005; Bengtsson et al. 2003).

Complicating conservation planning even more is the SLOSS (single large or several small [areas]) debate, which doesn’t set specific percentage goals, but contrasts the idea of single large or several small protected areas in conservation. The scientific community is divided on this debate because there are benefits to both perspectives. For
example, some scientists argue that smaller areas of unique habitat may have a higher value than large areas, especially if such areas are homogenous (Benes et al. 2003). Others argue that large areas, because of their size, they are more likely to encompass diversity of resources and habitat types (Wallis de Vries 2007).

**An Ecosystem Services Approach to Conservation Planning in the Upper Peninsula**

Ecosystem services are valuable to the public on many levels, yet numerous threats erode ecosystem services in unprotected areas. There is no accepted general methodology for planning reserves at a specific size to maintain ecological processes (Leroux et al. 2007). My goal was to provide guidance for local planning authorities by delineating ecologically important zones (EIZs) throughout the Upper Peninsula. I wanted to produce spatially explicit recommendations for candidate stewardship areas because of the spatial nature of planning (Naidoo & Ricketts 2006) and the need for empirical research in ecosystem services provision (Nicholson et al. 2009). My objectives were:

- To identify and delineate wetland, forest, and riparian zone ecosystems across the U.P. and as EIZs
- To assess EIZ distribution in stewardship and compare this to EIZ distributions across the U.P. (for individual EIZs and stewardship classes)
- To quantify how much additional land is needed to protect EIZs using buffer width recommendations from Environment Canada (2004)
- To quantify potential ecosystem service values under this EIZ delineation scheme
- To compare potential differences in EIZs potential for stewardship in terms of area and ecosystem service values
Guidelines for wetlands, forests, and riparian zones restoration in Great Lakes AOCs provided a starting point for EIZ delineation (Environment Canada 2004). I chose EIZs to serve as a surrogate measure of ecosystem services in this project, as direct measures and valuations of services are prohibitively time consuming and expensive to calculate. Likewise, EIZs as surrogates provide measurable areas over which ecosystem services occur, which allow for the estimation of values based on well-accepted calculations in the literature.

In this study, I used habitat guidelines for identifying EIZs from an Environment Canada (2004) publication for restoration of Great Lakes Areas of Concern, as the minimum targets for conservation plans and then minimum buffers for each of the three EIZ types (wetlands, riparian zones, and uplands). Minimum conservation targets presented for EIZs in major watersheds were 10% of wetlands, 75% of riparian zones (naturally vegetated), and 30% forest cover (Environment Canada 2004). Further details and discussion on justifications for these targets are summarized in the Environment Canada (2004) publication.

In this study, I tested three hypotheses under the prescribed EIZ delineation scheme:

(1) EIZs are not uniformly distributed on the landscape and within protected areas. That is, if the U.P. is 50% uplands, then stewardship areas would not be 50% upland;

(2) The U.P. would not meet minimum stewardship targets for each of the EIZs studied;
(3) Monetary values of ecosystem service protected under this scheme would exceed conversion (i.e. urban, agriculture) values minimally by 100%.

**METHODS**

**Study Area**

Michigan’s Upper Peninsula (mainland) lies between 45°-48° N latitudes and between 83°-91° W longitudes, with its north shore bordered by Lake Superior and south shore by Lake Michigan and Lake Huron. It covers an area of approximately 42,610 km². The U.P. is part of the Nature Conservancy’s Superior-Lake of the Woods and Great Lakes ecoregional planning areas. Average annual precipitation for the Upper Peninsula is approximately 90 cm, with average annual snow accumulation of 420 cm (Weather Channel 2012). Depending on latitude and other factors, the average annual temperature ranges from -16° C to 25° C. Much of the land cover is forest, boreal and northern hardwoods, or wetlands typical of northern latitudes (i.e. swamps and bogs).

**Data Acquisition & Sources**

The USGS National Map (http://nationalmap.gov/) and the Michigan Geographic Data Library (http://www.mcgi.state.mi.us/mgdl/) were the two main sources for project data acquisition. The National Map contained the 2006 National Land cover dataset derived from 2006 Landsat TM imagery. After attempting to reclassify these data to meet project needs, I realized the 2006 NLCD dataset was not the best choice for this analysis, based on the EIZ delineation scheme employed. I opted to use the National Wetlands Inventory (NWI) from the United States Fish & Wildlife Service (USFWS), downloaded from the Michigan Geographic Data Library (MGDL) because it provided the data on wetlands and uplands, which I used for non-wetland forested areas. The NWI
data better reflected the descriptions of habitat (ecosystem) types outlined by Environment Canada (2004). I treated riparian wetlands as wetlands and not riparian zones for this project. To delineate riparian zones I used Michigan Trout Stream (MTS) data from the MGDL. To determine the legal status of protected areas I used stewardship data from the Gap Analysis Program (GAP).

**Spatial Analyses**

I identified wetland, riparian, and upland ecosystems on the landscape and then used these areas to derive EIZs. I completed all geoprocessing and spatial analysis operations using ArcMap 10 (ESRI 2011). From NWI data, I created a new feature class of all wetlands (all wetland systems) and a new feature class of all uplands. I included polygons representing 100 ha or larger wetlands and 1,000 ha or larger uplands as EIZs (compared to all wetland and upland ecosystems in the U.P.). Though smaller areas provide important functions, they were not considered in this analysis because of the inefficient nature of protecting small areas with large buffers. From a planning perspective, the concept of efficiency is important because it describes the ability of a plan to capture maximum diversity with minimum area (Rodrigues et al. 1999). Using all wetlands and uplands resulted in identifying the entire U.P. as an EIZ with potential for protection, which is not feasible because of competing human interests. For riparian zones, I used the MTS data, but because streams only have linear units, I buffered each stream by 10 m for both locational accuracy (Gustine et al. 2006) and to create polygons of a simple riparian zone. Since riparian zones were a separate dataset from NWI there was overlap between EIZs from the two datasets. I used the erase function to remove the overlap between the NWI data and MTS data. I used the EIZ feature classes to quantify
the distributions of the three EIZs on the landscape. Figures 2.2-2.4 show wetland, riparian, and upland EIZs respectively.

The next step in the spatial analysis was to examine distributions of EIZs within protected areas. Using the GAP stewardship feature class I clipped each of the EIZ layers (i.e. wetland, upland, riparian) by each stewardship status afforded some legal protection (i.e. Status 1, 2, or 3—see Table 2.1 for definitions). Figure 2.5 provides a map of stewardship areas by status in the U.P. This allowed me to quantify the area of each EIZ in the U.P. that was legally protected at the time GAP was completed. After completing initial delineations, distribution and protected EIZ quantifications on the landscape, I buffered each EIZ using a uniform buffer width, with two separate size buffers for uplands (see Table 2.2).

The predetermined buffer widths were intended to mitigate edge effects and create undisturbed interior habitat patches. I used these data to create spatially explicit maps showing areas recommended as candidates for stewardship because of their ecological importance and ecosystem services values. Combining EIZs in Plan A and Plan B created spatial overlap and duplication of some buffer zones. As a result, I considered the benefits of EIZs individually. All spatial analyses were performed using Python® and Modelbuilder® (see example model Figure 2.1) in ArcGIS®, with multiple process steps and iterators (Fig. 2.1).

**Quantitative Analyses**

My primary goal was to quantify how much additional land we need to protect EIZs in the U.P. using a rudimentary buffering approach based on Environment Canada’s recommendations (2004). I derived starting values from the feature classes I created
from the NWI and Michigan Trout Streams datasets. These numbers showed the proportional distributions of EIZs on the landscape at the completion of the NWI and MTS datasets. I derived proportional distributions of EIZs in stewardship Status 1, 2, and 3 areas from the stewardship EIZs, which allowed me to compare actual distributions on the landscape to distributions in stewardship. Examining these numbers allowed for the identification of distributional discrepancies between the landscape and stewardship level datasets.

In addition to assessing EIZ distributions, I wanted to quantify potential ecosystem service values under this EIZ delineation scheme. I multiplied our derived EIZ areas by the Costanza et al. (1997) values and corrected for inflation to 2012 values in U.S. dollars using the Bureau of Labor Statistics CPI Inflation Calculator (Bureau of Labor Statistics 2013). Further breakdown shows the most economically valuable ecosystems (on a per hectare basis) in temperate and boreal biomes to be wetlands ($28,086/ha/year), lakes and rivers ($12,190/ha/year) and forests ($433/ha/year). I estimated the potential change in economic value due to conversion of EIZs to urban ($0/ha/year) and agricultural lands ($132/ha/year) on a per hectare basis using the 2012 adjusted values from Costanza et al. (1997).

**RESULTS**

**Current Landscape: The U.P., Stewardship, and EIZs**

The total area of the U.P. is approximately 42,610 km$^2$ of which 67% is upland, 31% is wetland, and 2% is riparian zone (Table 2.3). Approximately, 39% of the U.P. land area is conserved in stewardship of Status 1, Status 2, or Status 3 protection. Of the stewardship lands, wetlands account for 50% of total stewardship areas, riparian zones
account for 33%, and uplands account for the remaining 17% (Table 2.3). Within stewardship, Status 1 areas make up 7% of the total, Status 2 lands are 2% and Status 3 lands are 91% (Figure 2.6). Upland areas exhibit the same proportion of stewardship status distributions as the entire U.P. (Table 2.4). Wetlands in the U.P. have the highest proportion of Status 1 stewardship lands, but this is still a very small proportion, about 9%. Status 2 wetlands make up 1% of the protected wetland areas, and Status 3 wetlands account for the additional 90% of wetlands in stewardship throughout the U.P. (Table 2.4). Riparian zones have the lowest proportion of their total area in Status 1 stewardship, at only 5%, 2% in Status 2 stewardship, and 93% in Status 3 stewardship (Table 2.4).

Overall, the total distribution of the delineated EIZs in stewardship did not differ greatly from the proportions on the landscape. Of the EIZs in stewardship, Status 1 EIZs accounted for 8%, Status 2 for 1%, and Status 3 for 91% of these lands (Figure 2.7). Upland EIZs had the same proportions in stewardship Status 1-3, as they did on the landscape (i.e. Status 1= 7%, Status 2=2%, and Status 3=91%) (Table 2.5). Wetland EIZs had the largest proportion of Status 1 lands relative to upland and riparian zone EIZs, with 10% in Status 1 protection, followed by 1% in Status 2, and 89% in Status 3 (Table 2.5). Riparian zone EIZs had the lowest amount of land in Status 1 stewardship at only 5% and a high proportion (93%) in Status 3 protection, followed by only 2% in Status 2 protected areas (Table 2.5).

**Potential Stewardship Additions: Land Area and Ecosystem Service Values**

Under both plans, the buffer schemes for riparian zones and wetlands resulted in an additional 126,330 ha (~1,263 km²) and 784,312 ha (~7,843 km²) to be included
respectively (Figure 2.8). Plan A requires an additional 2,047,652 ha of uplands, while Plan B adds 2,570,564 ha (Figure 2.8). The ecosystem service values for riparian zones and wetlands are the same for both Plan A and Plan B. Total ecosystem service values are nearly $1.5 billion/year for riparian zones and $22 billion/year for wetlands (Figure 2.9). Under Plan A, ecosystem service values for uplands are approximately $0.9 billion/year, and under Plan B total nearly $1.1 billion/year (Figure 2.9).

Under Plan A, 62% of land added to stewardship is uplands, which account for only 4% of the total ecosystem service values of Plan A (Figure 2.10, Figure 2.11). The smallest contribution from an EIZ category in terms of land is from riparian zones at 4% of the additional land, but riparian zones contribute approximately 6% of the ecosystem service values under Plan A (Figure 2.10, Figure 2.11). Wetlands account for 34% of the additional area potential for stewardship protection under Plan A, but would contribute 90% of the value of ecosystem services under Plan A (Figure 2.10, Figure 2.11).

Plan B proposes the same land area for stewardship protection in the riparian zone and wetland EIZs, but includes additional upland lands. The upland land area accounts for 63% of the total land addition to stewardship under Plan B, and contributes 5% of the ecosystem service values (Figure 2.12, Figure 2.13). Riparian zones account for 4% of the area and 6% of the ecosystem service values under Plan B, which is the same as their contribution under Plan A (Figure 2.12, Figure 2.13). Wetlands contribute 33% of the land under Plan B and 89% of the ecosystem service values (Figure 2.12, Figure 2.13). Figure 2.14 provides a summation of the results, showing both the current ecosystem service values provided by each EIZ and what contributions additional area under the potential plan would make to ecosystem service values.
Conservation targets across the U.P. (as a major watershed) were 10% of the U.P. in wetland cover, 75% of riparian zones naturally vegetated, and 30% in forest cover. Under both Plan A (Table 2.6) and Plan B (Table 2.6), the plans exceeded the minimum forest cover target, at 90% and 97% cover respectively. This delineation scheme exceeded the target of 30% wetland cover and included 66% wetland cover across the U.P (Table 2.6). Since all riparian zones were considered to be ecologically important, there was no difference between their occurrence on the landscape as an ecosystem and their distribution as EIZs.

DISCUSSION

Distribution of EIZs: Current

A major goal of this study was to assess the extent to which EIZs currently occur on the U.P. landscape and to evaluate their conservation stewardship status. Uplands were seriously underrepresented in EIZs compared to their distribution on the landscape, but uplands are significant portions of state and federal forest lands. Wetlands and riparian zones were overrepresented in current stewardship areas and accounted for a majority of all stewardship areas. These distributional discrepancies are similar to the state of the global protected area network, which does not evenly represent ecosystem services (Pyke 2007). If wetland, riparian, and upland ecosystems are strong ecosystem service surrogates, then we are observing the same problem of uneven representation locally.

I found weaknesses in the distribution of lands by stewardship status. Status 1 lands, with the highest legal protection, account for only 7% of all stewardship lands in the U.P. Status 2 lands (second most legal protection) account for only 2% of
stewardship lands and Status 3 lands account for a prodigious 91% of all stewardship areas in the U.P., despite providing the least legal protection. Changing the designation of Status 3 lands to Status 1 or Status 2 may prevent alterations to natural areas that would change natural landscape processes. If flexible management strategies are pursued, that monitor and adapt to disturbances and unforeseen perturbations, then these natural areas of any stewardship status should provide conservation benefits (Schröter et al. 2005). Adding additional area to stewardship will likely provide for increased ecosystem diversity and the associated services (Hoekstra et al. 2005). Further research could assess the role of stewardship status in protecting ecosystem services.

**Distribution of Ecosystem Services: EIZs, Values, and Potential Areas**

Ecologically important zones delineated through this approach served as surrogates for all ecosystem services currently protected in stewardship. Potential EIZs delineated in this approach had similar stewardship distributions as their current counterpart ecosystems on the entire landscape (Figure 2.8 & Figure 2.12). Under the current protected area network, ecosystem services are not evenly distributed, but this approach shows using EIZs as ecosystem service surrogates, it is possible to provide a balanced representation of services (Pyke 2007). Uplands and riparian zones had the same distributions on the landscape and within EIZs. There was slightly higher representation of wetland EIZs in Status 1 stewardship than wetland ecosystems across the landscape in Status 1 stewardship. This is likely an artifact of past conservation efforts aimed at conserving contiguous ecosystems. These findings supported the use of these EIZs as representative areas for the three ecosystems being studied.
The ecosystem service values of the EIZs included in this potential conservation approach were tremendous. Wetlands had the highest ecosystem service value per hectare, followed by riparian zones, then uplands as calculated by Costanza et al. (1997). Wetlands had extremely high values, primarily from their roles in regulating disturbances and replenishing water supplies, but also from properties such as waste treatment and cultural values (Costanza et al. 1997). A majority of the riparian zone ecosystem service values calculated by Costanza et al. (1997) come from water regulation and supply values, similar to wetlands. Boreal forest ecosystem service values are not nearly as high as wetlands and riparian zones, likely because they do not have as vital a role in water supply/regulation and waste treatment, which are extremely valuable services. Instead the most valuable boreal forest ecosystem service values are provisioned from climate regulation and wastewater treatment, though this is vastly inferior to the role of wetlands in the same function (Costanza et al. 1997). Locally, there is at least one example of extracting serious ecosystem service values from a natural landscape, which are the tertiary treatment wetlands in Gwinn, Michigan. These wetlands bypass the multi-million dollar (or greater) costs of expanding treatment plants and naturally treat wastewater. A review of similar strategies to employ ecosystem services over traditional, manufactured goods and services, shows many different examples of cost savings associated with these actions (Foley et al. 2005).

Additions to stewardship using this approach would address some of the shortcomings of the current stewardship distributions. Under Plan A there would be an increased area of uplands in stewardship that would make the stewardship distribution more representative of the landscape. Wetlands and riparian zones would be more
representative in new stewardship additions by coming closer to the current distributions of these EIZs on the landscape.

Though Plan A calls for new stewardship additions proportionately similar to current EIZ distributions on the landscape, it does not take into account the economic importance of each of the EIZs. In its current state, Plan A derives its greatest value from wetland ecosystem services, which have a value of almost three times their proportion in the plan. Although by area wetlands are not the highest proportion of land area in the plan, their economic value vastly outweighs the riparian zones and uplands. Because of their significant contributions to ecosystem services and values, wetlands are arguably the most important part of the plan and should be given careful consideration (Costanza et al. 2007). Depending on watershed goals, it may be in the best interest of planners to include as much wetland area as possible.

The distributions of EIZs in Plan B are not very different from those presented in Plan A. In the interest of efficiency, Plan A is probably of more value to planning authorities than Plan B because it exceeds the minimum conservation targets set forth by Environment Canada (2004) for wetlands, riparian zones, and uplands. Unless there are uplands offering specific conservation value or meeting criteria for endangered or threatened species conservation, Plan A should serve as a strong basis for conservation planning for ecosystem services provision. Plan B adds an additional $200 million dollars to ecosystem services annually, so careful evaluations should be made on a site specific basis before entirely discarding this value.

Under both Plan A and Plan B, there is the potential to add valuable land to stewardship that would provide economic benefits through multiple billions of dollars in
ecosystem services annually. Estimates of approximately $24.3-$24.5 billion dollars from ecosystem services for this plan are probably higher than the findings of Konarska et al. (2002) when adjusted for inflation and area. The U.P. is about 17% of the area of the state of Michigan and the value of ecosystem services I estimated for the U.P. is close to 43% (inflation corrected) of what Konarska et al. (2002) calculated for the entire state. Compared to the remainder of the state, the U.P. is in a relatively natural and undeveloped condition, which could contribute to a disproportionate value of ecosystem services being harbored in a more natural landscape than the urbanized southern lower peninsula. Ecosystem service values are estimated $0/ha/year for urban areas and $132/ha/year for agricultural lands (Costanza et al. 1997). Conversion to urban areas, would result in approximately or agricultural landscapes would result in substantial ecosystem service value losses ($23.5-$24 billion annually) that are entirely avoidable.

**Protecting Ecosystem Services: Assessment and Conclusions**

Landscape targets for protecting ecosystem services vary depending on the ecosystem. Across major watersheds (i.e. the U.P.), conservation targets were 10% wetland cover, 75% of stream length (riparian zones) naturally vegetated, and 30% forest cover. Under the basic approach presented, all conservation targets were exceeded. Riparian zones are 100% covered under this scheme, which is probably not feasible in urban areas (i.e. Marquette, Escanaba), but even appropriate conservation strategies in these areas could minimize negative impacts to urban riparian zones. Further refinement of spatial data layers and additional process steps could mitigate shortcomings with ecosystem overrepresentation and buffer overlap issues. Focusing the approach on identification and delineation of EIZs using multiple criteria would likely result in a more
cost-effective, efficient acquisition template that still protects important ecosystem services (Geneletti 2003; Regan et al. 2007; Strager & Rosenberger 2007).

The addition of lands to stewardship protection can reduce external threats to interior areas. Buffering EIZs allows for the maintenance of critical areas that mitigate species invasions and adds additional area for a myriad of species (Cadenasso & Pickett 2001). Climate change has increased the need for protected areas and any additions are a step in the right direction to mitigate threats to ecosystem services associated with climate change (Hannah 2009).

Though this approach provides guidance for a conservation strategy for ecosystem services in the U.P., it is only a first step. There are much more complex models for delineating EIZs, but a lack of data or data unavailability limit the use of more intense models. Watershed and riparian zone delineation through raster analysis would generate a more specific and robust analysis. Likewise, the NWI data was completely missing in a small portion of the western U.P., so I was unable to determine values of land or ecosystem services for this area. Using this approach requires the addition of vast expanses of land, which may not be feasible immediately and may only be possible through piecemeal additions to stewardship. Based on ecosystem service values, additions should be focused primarily on wetland acquisitions. Wetland buffer zones often overlap with upland ecosystems, so buffered wetland additions would contribute to both sets of ecosystem services. Further analysis of riparian zones, especially in developed areas, may be necessary to justify adding 100% of these areas to stewardship. Advanced riparian zone analysis could generate a more targeted approach to identify the most vulnerable and highest priority areas for stewardship candidacy. Future plans
should focus on these issues by addressing efficiency through the use of advanced spatial modeling, suitability analysis, and other methods.

There is not a uniform approach or target for conservation. Providing enough area depends on the goals set for a specific site, ecosystem service, or species, and a one size fits all approach is arbitrary at best (Rodrigues et al. 2004). Weighing the costs and benefits to determine site-specific conservation goals are probably the best method in conservation planning presently. Although this is a basic approach that cannot answer every conservation question, the uncertainty doesn’t mean we should refuse to make progress (Hunter et al. 2010). Developing this approach with additional datasets and spatial analysis work in future iterations will allow for refined EIZ delineations. Refinement of EIZs may provide an even clearer picture of areas that should be priorities for stewardship in the U.P. In the end, this approach is both economically and ecologically sensible, with rewards vastly outweighing the investment for generations to come.
APPENDIX B

Table 2.1: Definitions of stewardship levels (management Status) in Gap Analysis (after Scott et al. 1993).

<table>
<thead>
<tr>
<th>Stewardship Status</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Permanent protection from conversion of a natural state with disturbance regimes to an unnatural state without natural (or managed artificial) disturbance regimes. Management plan aims to maintain natural state.</td>
</tr>
<tr>
<td>2</td>
<td>Permanent protection from conversion to a non-natural state, but management practices or uses may reduce quality of natural communities.</td>
</tr>
<tr>
<td>3</td>
<td>Permanent protection from conversion, but may be subject to extractive uses.</td>
</tr>
<tr>
<td>4</td>
<td>No legal mandate preventing conversion from a natural state OR information to establish inclusion in a higher stewardship level is insufficient or not available.</td>
</tr>
</tbody>
</table>

Table 2.2: Applied buffer widths (in meters) from Environment Canada (2004) recommendations used in this study.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Buffer Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Riparian</td>
<td>30</td>
</tr>
<tr>
<td>Wetland</td>
<td>240</td>
</tr>
<tr>
<td>Upland (Buffer A)</td>
<td>100</td>
</tr>
<tr>
<td>Upland (Buffer B)</td>
<td>200</td>
</tr>
</tbody>
</table>

Table 2.3: Distribution (percentages) of EIZs on the landscape of the entire Upper Peninsula in Michigan compared to distributions in all legally protected stewardship Status lands (1,2,3).

<table>
<thead>
<tr>
<th>Zone Type</th>
<th>U.P.</th>
<th>Stewardship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wetland</td>
<td>31%</td>
<td>50%</td>
</tr>
<tr>
<td>Riparian</td>
<td>2%</td>
<td>33%</td>
</tr>
<tr>
<td>Upland</td>
<td>67%</td>
<td>17%</td>
</tr>
</tbody>
</table>
Table 2.4: Distribution of wetlands, riparian zones, and uplands in the U.P. in legally protected stewardship areas (Status 1,2,3) within each EIZ type. Stewardship Status was determined from the Michigan Gap Analysis data and EIZs were delineated from National Wetland Inventory data (wetlands, uplands) or Michigan trout streams data.

<table>
<thead>
<tr>
<th>Stewardship Status</th>
<th>Wetlands</th>
<th>Riparian Zones</th>
<th>Uplands</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9%</td>
<td>5%</td>
<td>7%</td>
</tr>
<tr>
<td>2</td>
<td>1%</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>3</td>
<td>90%</td>
<td>93%</td>
<td>91%</td>
</tr>
</tbody>
</table>

Table 2.5: Distribution of ecologically important zones (wetlands, riparian zones, and uplands based on size requirements) in the U.P. in legally protected stewardship areas (Status 1,2,3) within each EIZ type. Stewardship Status was determined from the Michigan Gap Analysis data and EIZs were delineated from National Wetland Inventory data (wetlands, uplands) or Michigan trout streams data.

<table>
<thead>
<tr>
<th>Stewardship Status</th>
<th>Wetlands</th>
<th>Riparian Zones</th>
<th>Uplands</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10%</td>
<td>5%</td>
<td>7%</td>
</tr>
<tr>
<td>2</td>
<td>1%</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>3</td>
<td>89%</td>
<td>93%</td>
<td>91%</td>
</tr>
</tbody>
</table>

Table 2.6: Percentage of upland, wetland, and riparian zone EIZs (compared to abundance on the U.P. landscape) included in potential stewardship land additions in the U.P. of Michigan.

<table>
<thead>
<tr>
<th>Plan</th>
<th>Uplands</th>
<th>Wetlands</th>
<th>Riparian</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>90%</td>
<td>66%</td>
<td>100%</td>
</tr>
<tr>
<td>B</td>
<td>97%</td>
<td>66%</td>
<td>100%</td>
</tr>
</tbody>
</table>
Figure 2.1: Sample iterative model showing geoprocessing steps for determining the amount of riparian zone ecosystems in Status 1, 2, and 3 stewardship in the U.P. Blue ovals are inputs, orange hexagons are iterators (and light blue ovals its value parameter for non-geographic data reference), yellow rectangles are geoprocessing tools and green ovals are outputs, many of which are intermediate.

Figure 2.2: Wetland EIZs delineated from wetland systems (palustrine, lacustrine, or riverine) of 100 ha or larger in the National Wetlands Inventory dataset.
Figure 2.3: Riparian EIZs in the U.P., delineated from Michigan Trout Streams, each with a 10 m bilateral buffer.
Figure 2.4: Upland EIZs in the U.P. delineated from upland systems of 1,000 ha or larger in the National Wetlands Inventory dataset.
Figure 2.5: Map of protected areas in the U.P. separated by status, with Status 1 being the most highly protected and Status 3 the lowest level of legal protection. White areas are not legally protected.
Figure 2.6: Distribution of protected lands in the U.P. by stewardship Status from the Michigan Gap Analysis dataset. Status 1 (blue; highest protection), Status 2 (red; intermediate protection), and Status 3 (green; lowest protection).

Figure 2.7: Distribution of all EIZs in stewardship by Status (from the Michigan Gap Analysis dataset). Status 1 (blue; highest protection), Status 2 (red; intermediate protection), and Status 3 (green; lowest protection).
Figure 2.8: Additional land potential for stewardship protection in the U.P. of Michigan. Under Plan A this includes all riparian zones with a 30 m buffer, wetlands greater than 100 ha with a 240 m buffer, and contiguous uplands greater than 1,000 ha with a 100 m buffer. Under Plan B, riparian zone and wetland additions are the same as in Plan A, but contiguous uplands greater than 1,000 ha received a 200 m buffer.

Figure 2.9: Ecosystem service values from ecologically important zones with potential buffer widths in the U.P of Michigan. I multiplied the potential additional stewardship area for each EIZ by its corresponding 2012 estimated ecosystem services values (i.e. wetlands=$28,086/ha/year, riparian zones=$12,190/ha/year, and uplands=$433/ha/year).
Figure 2.10: Distribution of additional lands according to EIZ category potential under conservation Plan A in the U.P. of Michigan. Under Plan A this includes all riparian zones with a 30 m buffer, wetlands greater than 100 ha with a 240 m buffer, and contiguous uplands greater than 1,000 ha with a 100 m buffer.

Figure 2.11: Distribution of ecosystem service values according to EIZ category potential under conservation Plan A in the U.P. of Michigan. Ecosystem service values from ecologically important zones with potential buffer widths in the U.P. I multiplied the potential additional stewardship area for each EIZ by its corresponding 2012 estimated ecosystem services values (i.e. wetlands=$28,086/ha/year, riparian zones=$12,190/ha/year, and uplands=$433/ha/year).
Figure 2.12: Distribution of additional stewardship lands according to EIZ category potential under conservation Plan B in the U.P. of Michigan. Additional land with potential for stewardship protection. Under Plan this includes all riparian zones with a 30 m buffer, wetlands greater than 100 ha with a 240 m buffer, and contiguous uplands greater than 1,000 ha with a 200 m buffer.

Figure 2.13: Distribution of ecosystem service values according to EIZ category potential under conservation Plan B in the U.P. of Michigan. Ecosystem service values from ecologically important zones with potential buffer widths in the U.P. I multiplied the potential additional stewardship area for each EIZ by its corresponding 2012 estimated ecosystem services values (i.e. wetlands=$28,086/ha/year, riparian zones=$12,190/ha/year, and uplands=$433/ha/year).
Figure 2.14: Ecosystem service values of riparian zones, wetlands, and uplands currently in stewardship and potential additions under conservation plans A and B in the U.P. of Michigan. Ecosystem service values from ecologically important zones with potential buffer widths in the U.P. I multiplied the potential additional stewardship area for each EIZ by its corresponding 2012 estimated ecosystem services values (i.e. wetlands=$28,086/ha/year, riparian zones=$12,190/ha/year, and uplands=$433/ha/year).
Chapter 3: DOES AN ECOSYSTEM-BASED APPROACH IN CONSERVATION PLANNING ADDRESS TERRESTRIAL VERTEBRATE SPECIES CONCERNS?

CHAPTER OVERVIEW

The use of ecosystem-based planning approaches for biodiversity conservation have increased in recent years and appear to provide a reasonable method to protect ecosystem services and biodiversity conservation. I used an ecosystem-based approach in Michigan’s Upper Peninsula focusing on three types of ecosystems (wetlands, riparian zones, and uplands) to determine species-ecosystems associations, species occurrence distributions in protected areas (stewardship Status 1-3), and to determine how well represented threatened and endangered species were in protected areas. I used Michigan Gap Analysis Program predicted species occurrence models and stewardship layers, National Wetlands Inventory, and Michigan Trout Stream data to delineate and quantify species occurrences within target zones. Then I determined which taxonomic groups had the strongest association with each ecosystems type and which ecosystem type appeared to be the most important (in terms of area provided for species). I also quantified how much additional land would be conserved through an approach that used ecologically important zones (EIZs), with buffer zones to protect additional area, (100 ha wetlands with a 240 m buffer, 1,000 ha uplands with either a 100 m or 200 m buffer, and all riparian zones with a 30 m buffer). The strongest species-ecosystem associations (number of occurrences per hectare) throughout Michigan’s Upper Peninsula (U.P.) were in uplands, followed by wetlands, and riparian zones. These results contrasted with EIZs in the U.P., where wetlands had the most predicted species occurrences per hectare,
followed by uplands and riparian zones. Stewardship lands included all terrestrial vertebrate species (TVS), but with very low proportions of all TVS in the lands most highly protected from conversion and managed to maintain a natural state (Status 1 and 2), which also occurred with the subset of threatened and endangered species. The study showed a need for an elevation of stewardship Status to higher level of protection for threatened and endangered species and the addition of more EIZs to stewardship protection of any level.

INTRODUCTION

How Much Habitat is Enough?

Ecosystem service-based approaches for biodiversity conservation present opportunities with multiple conservation benefits for both humans and wildlife. Ecologically important zones (EIZs), such as wetlands, riparian zones, and uplands, provide a plethora of ecosystem services and wildlife habitat. Theoretically, the conservation of ecosystem services through EIZs has the potential to maximize benefits to humans and wildlife, but this leads to an important question: How well does an ecosystem services-based approach represent biodiversity concerns? Although this seems to be a straightforward question, it remains a debated issue in the conservation biology community.

Recommendations for reserve size vary depending on the species of interest, location and numerous other factors. Estimates of the amount of area needed to conserve species in a given landscape setting range from 10% to 50% of total land area (Soulé & Sanjayan 1998; Fahrig 2001; IUCN in Rodrigues and Gaston 2001; Solomon et al. 2003;

**Biodiversity and Species Richness**

Biodiversity conservation is inherently related to ecosystem integrity. From a human perspective, biodiversity is essential for providing food, medicine, and genetic information (Pimentel et al. 1997). Many studies have shown that maintaining natural biodiversity can prevent or reduce transmission rates for Lyme disease, malaria, and West Nile Virus (Allan et al. 2003; Yasuoka & Levins 2007; Pongsiri et al. 2009). Maintaining biodiversity from an ecological perspective is important to prevent structural and functional changes of a community. Trophic cascades can have detrimental impacts on ecological functions, which include problems such as stream bank erosion and ungulate over browsing (Beschta & Ripple 2009). These studies suggest that reductions in biodiversity are linked with reductions in ecosystem services and maintaining a baseline level of biodiversity is important to conserving these functions.

Species richness is correlated with ecological productivity (Wright et al. 1993; Tilman et al. 2001; Marquard et al. 2009). Species richness and community biomass are positively correlated, providing more evidence that species richness is a good measure of ecosystem function (Marquard et al. 2009). Adding a species conservation emphasis in conservation planning is important because the threat of extinction exceeds the potential value from current conservation resources (Myers et al. 2000).

Predicted occurrences of vertebrate species from the Gap Analysis Program (GAP) serve as surrogate conservation metric, which addresses the impracticalities of working with other measures of biodiversity (Sowa et al. 2007). But there are
shortcomings to working with species predicted occurrence datasets in spatial and temporal representation (Knight et al. 2007). In fact, a strict focus on a single component of biodiversity is an insufficient surrogate for the remainder of the system (Bonn & Gaston 2005). Using both species occurrence data and environmental features (i.e. Ecologically Important Zones [EIZs]), may be the best way to prioritize conservation areas (Sarakinos et al. 2000). The use of ecosystem diversity as a surrogate for species diversity may be useful, but incomplete. Ecoregions can predict bird and mammal diversity, but are not nearly as useful as using all bird and mammal data (Cabeza & Moilanen 2001). Using both the species occurrence data and EIZs as biodiversity surrogates will address the spatial flaws of using only a species-based approach (Knight et al. 2007).

**Threats to Species Persistence**

The most consistent and significant threat to species persistence is anthropogenic changes to the planet, which have brought the world into a biotic crisis (Myers & Knoll 2001). Seven major categories of threats to biodiversity stem from human activities (Primack 2006): (1) Habitat destruction, (2) habitat fragmentation, (3) habitat degradation (4) overexploitation, (5) introduction of invasive species, (6) disease, and (7) climate change.

Habitat destruction, habitat fragmentation, and habitat degradation are all direct changes to the ecosystem that make it unusable or lower quality habitat. Climate change has the potential to alter weather patterns leading to increased fire frequency and severe weather events, which can have negative effects on mammal communities (Laurance et al. 2007). Some models predict up to 90% reductions in boreal tree species due to a
changing climate regime, which means less area for organisms dependent on these species (Hansen et al. 2001). Direct habitat changes contribute greatly to species declines, but they are not the only threats. The threats invasive species and disease pose to natural species and ecosystems appear to be exacerbated by climate change (Primack 2006; Allan et al. 2003), but conservation planning may be able to address these threats.

Specific to Michigan, there are many examples of how anthropogenic changes within ecosystems can impact our native species. Habitat destruction and fragmentation are some of the greatest threats to species persistence as seen in many forest interior bird species (Robinson et al. 1995). Wood turtle populations declined following increased use of their habitats for human recreation (Garber & Burger 1995), which may be associated with both habitat destruction and ensuing higher mortality rates. Piping plover populations in the Great Lakes region declined following habitat loss from development of their shoreline habitat (Russell 1983). Habitat fragmentation coupled with reduced fire frequency and the invasion of brown-headed cowbirds resulted in the near extinction of Kirtland’s warblers from Michigan in the mid-twentieth century (Mayfield 1993). Habitat fragmentation threatens the future of many large mammals including black bears and wolves (Schoen 1990; Carroll et al. 2004). The loss of large predators can alter habitat and make it nearly impossible to have natural regulation of prey species (Beschta & Ripple 2009). Loss of large predators may be especially important in the face of climate change (Sala 2006).

Habitat degradation from pollution is detrimental to habitat and the organisms living within. Heavy metals, organochlorine pesticides, and excess nutrient loads are detrimental to wildlife, resulting in population declines of bald eagles, peregrine falcons,
amphibians, and fish (Grier 1982; Evans 1987; Steidl et al. 1991; Rouse et al. 1999; Taylor et al. 2005). Polychlorinated biphenyls (PCBs), a type of organochlorine, incidentally consumed via Great Lakes fish are linked to neurocognitive impairments in human adults (Schantz et al. 2001).

Climate change will likely impact many TVS in Michigan. Physiologically sensitive species, such as moose, which are a cold-adapted species, do not tolerate heat well and have specific habitat requirements that aid in thermoregulation (Renecker & Hudson 1986). Climate changes also play a key role in creating conditions for outbreaks of epizootic hemorrhagic disease (EHD) in white-tailed deer (Sleeman et al. 2009), which killed thousands of deer in Michigan during the summer and fall of 2012. Other diseases exacerbated by climate change include bovine tuberculosis, brainworms, white nose syndrome and avian botulism (Schmitt et al. 1997; Szymanski et al. 2009; Beyer et al. 2011; Lafrancois et al. 2011).

Using an Ecosystem Services Approach to Conserve Native Species

Developing an approach for biodiversity conservation is a challenging task because of the complex interactions among species and their habitat. An ideal approach is one that would address native terrestrial vertebrate species in the Upper Peninsula, while protecting ecosystem services using the least amount of land possible (i.e. high efficiency). Using an ecosystem services approach, I created a basic plan to identify ecologically important zones (EIZs). The second part of the study was intended to determine how well this approach worked for terrestrial vertebrate conservation. The ecosystem services approach was important because the services provided are important
to local economies and are vital to protect. They are also an intuitively logical core around which to build a system of conservation stewardship lands (Goldman et al 2008).

Many studies using an ecosystem services based approach have found positive relationships between ecosystem services and biodiversity (Chan et al. 2006; Naidoo & Ricketts 2006; Turner et al. 2007). Biodiversity contributes to ecosystem services such as pest control and primary productivity by regulating temporal stability and resisting external perturbations (Balvanera et al. 2006; Costanza et al. 2007). In one study, researchers modeled numerous planning scenarios and found improved biodiversity circumstances on the landscape had concomitant positive effects on ecosystem services (Nelson et al. 2009). Overall, using an ecosystem services approach as a core in biodiversity conservation offers an efficient, defensible, and practical approach.

A fundamental goal for using an ecosystem services approach to biodiversity conservation was to make progress in answering the question, how much habitat is enough? In the previous chapter, I predicted the extent to which an ecosystem-based approach to conservation planning would protect habitat for terrestrial vertebrate species in Michigan’s Upper Peninsula. To achieve this goal I met the following objectives:

- Determine species distributions and quantify ecosystem area on the landscape and in ecologically important zones (EIZs).
- Determine species distributions and quantify ecosystem area in legally protected areas (stewardship Status 1, 2, or 3).
- Determine if there is a significant difference in the ecosystem area protected under the Plan A methodology and the Plan B methodology.

In this study, I tested the following hypotheses:
(1) All species will use all ecosystems types equally;

(2) All taxonomic groups (i.e. amphibians, birds, mammals, and reptiles) will use all ecosystem types equally;

(3) There is no significant difference in the ecosystem area protected currently compared to the proposed additions to stewardship;

(4) Less than 50% of threatened and endangered species occurrences will be captured by current stewardship areas.

METHODS

Study Area

Michigan’s Upper Peninsula (mainland) lies between 45°-48° N latitudes and between 83°-91° W longitudes, with its north shore bordered by Lake Superior and south shore by Lake Michigan and Lake Huron. It covers an area of approximately 42,610 km². The U.P. is a Northern Lakes and Forests ecoregion with typical glacial, nutrient-poor soils, and coniferous and northern hardwood forests (E.P.A. 2007). Much of the vegetation is typical of boreal forest or northern hardwood associations (Henson et al. 2005). Undulating till plains, moraines, broad lacustrine basins, and sandy outwash plains with thicker and less arable soils than in neighboring southern ecoregions define the ecoregion (E.P.A. 2007). The land cover is typically forest, boreal and northern hardwoods, or wetlands typical of northern latitudes (i.e. swamps and bogs). Its lakes are also less productive, but clearer than lakes in neighboring southern ecoregions (E.P.A. 2007).

The Great Lakes dramatically influence the climate of the U.P. Heat storage in the lakes occurs during the summer and release occurs in the fall and winter seasons,
which moderates near shore climates (Henson et al. 2005). This mechanism is also responsible for lake effect snow and the occurrence of snowbelts on the landscape, east and downwind of the lakes as well as the cool temperatures, coastal fog and reduced sunlight (Henson et al. 2005). Average annual precipitation for the Upper Peninsula is approximately 90 cm, with average annual snow accumulation of 420 cm (Weather Channel 2012). Depending on latitude and other factors, the average annual temperature ranges from -16°C to 25°C (Weather Channel 2012).

**Data Acquisition & Sources**

The USGS National Map (http://nationalmap.gov/) and the Michigan Geographic Data Library (http://www.mcgi.state.mi.us/mgdl/) have all datasets available to download for free. The National Map included the 2006 National Land cover dataset derived from 2006 Landsat ETM imagery. After attempting to reclassify this data for our purposes, I realized that based on our EIZ delineation scheme the 2006 NLCD dataset was not the best choice for this analysis. I decided to use the National Wetlands Inventory (NWI) from the United States Fish & Wildlife Service (USFWS), downloaded from the Michigan Geographic Data Library (MGDL) because it provided us with data on wetlands and uplands, which I used for non-wetland forested areas. The NWI data better reflected the descriptions of ecosystem types outlined by Environment Canada (2004) that were used in this study. I treated riparian wetlands as wetlands and not riparian zones for this project. To delineate riparian zones I used Michigan Trout Stream (MTS) data from the MGDL.

Species and stewardship data came from the Michigan component of the National Gap Analysis Program (Donovan et al. 2004). The species data I analyzed are predicted
occurrence data derived from deductive ecosystem modeling, which used Landsat TM imagery to determine vegetation data, National Wetlands Inventory (NWI), and other data sets to predict species occurrences. Experts used vegetation data as a coarse filter method to model ecosystems and then refined results based on local spatial knowledge. I assessed land cover data for accuracy (see chapter one) following acquisition because of its use as a surrogate in the species modeling process. The stewardship data includes legally protected areas (Status 1, 2, and 3) (Table 1.1), which I used in this analysis.

Spatial Analyses

I determined individual species predicted to be found in EIZs by first locating wetlands, forests, and riparian zones on the landscape. I completed all geoprocessing and spatial analysis operations using ArcMap 10 ® (ESRI 2011). Once I had separate feature classes for each of the EIZs, I built a model using an iterator and the extract by mask tool to run loops inserting species predicted occurrence rasters into the model. This allowed me to determine the area within each EIZ that the species were predicted to occur, which gave both spatial and quantitative data.

To determine how well legally protected (Status 1, 2, and 3) stewardship areas provided habitat for individual species and taxa richness, I created a similar model to the one above. Instead of using the EIZs as the mask for the individual species and taxa richness extractions, I used a stewardship feature class that included all legally protected stewardship areas. This again provided spatial and numerical data on species occurrences, this time being those falling within legally protected areas.

The final portion of the spatial analysis for terrestrial vertebrate conservation followed similar logic and models. I followed recommendations by Environment Canada
(2004) by buffering EIZ feature classes as follows: uplands—100m and 200m buffers, wetlands—240m buffer, and riparian zones—30m buffer. Each of these EIZs served as an extraction mask in another model with iterated species predicted occurrence and taxa richness rasters.

**Quantitative Analyses**

The primary goal was to quantify how much additional species habitat an ecosystem services-based approach modified to include biodiversity conservation would require. I determined how representative Michigan’s current stewardship lands were of actual species distributions across the landscape. I also determined if the use of a rudimentary buffering approach, based on Environment Canada’s recommendations (2004), would call for significantly more habitat area for each species to be added to stewardship protection than what is currently on the landscape. I used the number of predicted species occurrences (i.e. the number of pixels where Gap models predicted a species to occur) for the current protected areas and the EIZs identified as potential additions to stewardship in this approach. Despite several attempts at transforming the number of predicted species occurrence pixels, I could not achieve a normal distribution and analyzed the data using the non-parametric Kruskal-Wallis test in IBM SPSS release 19.0.0.1 (SPSS, Inc., 2010, Chicago, IL).

Another study goal was to determine if there is one particular EIZ category that appeared to be more important to species than others. In terms of importance, I considered the densities of species occurrences, so the more species occurrences per area for a given ecosystem, the more important it would be for conservation. I compared the number of occurrences (for each species) within each of the three EIZs, which I weighted
to correct for differences in area (i.e. found the density of occurrences). These calculations standardized the data because I determined the number of species predicted occurrences per hectare within each EIZ. I automated data extraction with a Python™ script to generate database files for each raster layer for species occurrences in the model. I then quantified how different species and taxa use the landscape and the delineated EIZs.

**RESULTS**

**Species Occurrences on the Landscape and in Ecologically Important Zones**

Across the landscape, a majority of species occurrences (per hectare) were in uplands, accounting for 39% of species occurrences (Figure 3.1). The second largest contributor of species predicted occurrences were riparian zones at 36% (Figure 3.1). Wetlands made the smallest contribution for all species, accounting for only 25% (Figure 3.1) of all species occurrences.

Examination of species occurrences in EIZs revealed differences from pattern across the entire landscape. For the EIZ predicted species occurrences, wetlands provided the highest value per unit area, with 40% of all species occurrences (for all EIZ species occurrences) (Figure 3.2). Uplands accounted for 31% of all predicted species occurrences within EIZs and riparian zones accounted for the remaining 29% of predicted species occurrences in EIZs (Figure 3.2).

In addition to determining how well EIZs represented total species distributions from the total U.P. landscape, I also quantified these distributions within taxonomic groups. Almost one-fourth of the species in each taxonomic group are associated with wetlands in the U.P. Across the entire U.P. 24% of amphibian and bird predicted
occurrences are within wetlands, compared to 40% of amphibian occurrences in all EIZs, and 41% of bird occurrences in all EIZs (Table 3.1). U.P. wetlands accounted for 24% of mammal occurrences, compared to 40% of mammal occurrences among all EIZs (Table 1). Reptiles had the lowest occurrence rate in U.P. wetlands of any taxonomic group at 22%, compared to 37% in wetland EIZs (Table 3.1).

Riparian zones in the U.P. accounted for between 33%–40% of occurrences among taxonomic groups (Table 3.1). Amphibians had the largest proportion of their occurrences on the landscape in riparian zones at 40%, but occurrences in riparian EIZs accounted for only 32% of their occurrences within all EIZs (Table 3.1). Birds had the second highest percentage of species occurrences of any taxonomic group across the U.P. riparian zones (36%), with a decreased occurrence rate within riparian EIZs (29%) (Table 3.1). Riparian zones accounted for 35% of mammal occurrences across the landscape, while only accounting for 29% of their occurrences in EIZs (Table 1). Reptiles had 33% of their species occurrences across the landscape in riparian zones, with only 28% of their EIZ occurrences in riparian zones (Table 3.1).

In uplands, reptiles had the highest percent predicted occurrences in uplands of any taxonomic group at 45%, compared to 37% in EIZ occurrences (Table 3.1). Mammals had the second highest predicted occurrence rate in uplands across the landscape at 41%, but only 32% of their EIZ occurrences were in uplands (Table 3.1). Of birds, 39% of species were predicted in uplands on the landscape, with only 31% occurring in EIZ uplands (Table 3.1). Amphibians had the lowest predicted occurrence rate for landscape-wide uplands at 35%, but only 24% of their occurrences in EIZs were associated with uplands (Table 3.1).
Species Occurrences in Stewardship and Potential Additions

In current protected areas the Status 1 areas (most legally protected) accounted for only 2% of species occurrences, and the second most legally protected areas, Status 2, accounted for just 1% of species occurrences (Figure 3.3). Of protected areas, Status 3 have the least legal protection, but account for 36% of all species occurrences in the U.P. (Figure 3.3). Other areas, which are not afforded legal protection or Status accounted for 61% of species occurrences in the U.P. (Figure 3.3).

Across taxonomic groups, I observed similar patterns of distribution for species occurrences as that of all species. Status 2 lands always accounted for the least species occurrences, 1% for each taxonomic group, followed by Status 1, Status 3, and other Status areas (Table 3.2). Status 1 lands accounted for 2% of all amphibian, mammal, and reptile predicted occurrences, and 3% for birds (Table 3.2). Status 3 areas accounted for a majority of species predicted occurrences within the three highest stewardship levels (Table 3.2). Most of the predicted occurrences for each taxonomic group were in areas that are not legally protected from habitat destruction or unmanaged disturbance, as shown in Table 2.

The additional area proposed for stewardship, from the EIZs and surrounding buffer zones, adds a substantial amount of habitat. For wetland ecosystem, the proposed addition would be approximately 7.2 million hectares of land (Table 3.3). This number represents the sum of area for all predicted species occurrences in wetlands that would be proposed for protection through this approach, with results also listed for riparian and upland ecosystems. EIZs with a 240 m buffer. For riparian zones with a 30 m buffer, the proposed addition results in 10.9 million hectares more in stewardship protection (Table
3.3). Upland EIZs with a 100 m buffer, if included, would add 14 million hectares of area, while upland EIZs with a 200 m buffer would add over 23 million hectares of area (Table 3.3).

I compared the 100 m and 200 m upland EIZ buffer zones and quantified the difference in area proposed for protection under each plan. The number of species occurrences included with a 100 m upland buffer was not statistically different from a 200 m upland buffer ($\chi^2=0.293$, df=1, $p=0.588$). Both methods resulted in a statistically significant increase in the number of species occurrences protected under the proposed buffer plans (100 m buffer: $\chi^2=59.601$, df=1, $p<0.001$; 200 m buffer: $\chi^2=50.023$, df=1, $p<0.001$).

**Threatened and Endangered Species**

Threatened and endangered species are of special concern because of the risk of extirpation and/or extinction. I determined their occurrence rates across the landscape and in stewardship areas to quantify their predicted occurrences in Status 1, Status 2, and Status 3 areas. Less than 5% of predicted occurrences for threatened and endangered species occur in Status 1 and Status 2 lands, while Status 3 lands account for a majority of occurrences in stewardship (Figure 3.4). Most predicted occurrences of threatened and endangered species occur outside protected areas, which account for the remaining 59% of species occurrences in the U.P. (Figure 3.4).

A closer look at the threatened and endangered species reveals the lands where they occur are under-represented and pose a potentially problematic situation. Only 28% of species have greater than 5% of their predicted occurrences in the most highly protected areas (Status 1), with an average of 6% (Table 3.4). A meager 3% of
threatened and endangered species have greater than 5% of their area in Status 2 areas, averaging only 1% (Table 3.4). Almost 97% of threatened and endangered species have greater than 5% of their occurrences in Status 3 protected areas, but the average is only 33% of occurrences (Table 3.4).

DISCUSSION

An ecosystem-based approach to terrestrial vertebrate species conservation results in proposing the addition of vast areas to stewardship. These areas successfully capture many terrestrial vertebrate predicted species occurrences. With any project, the results are only as good as the data and at this time a formal accuracy assessment of the species predicted occurrences models is not yet available for Michigan. Other states report GAP predicted species occurrence model accuracies from 39-95% depending on the accuracy measurement (Dean et al. 1997; Garrison et al. 2000; LaBram et al. 2002; Henebry et al. 2004). An accuracy assessment of species models should be a priority in Michigan.

The three ecosystem types (wetland, riparian, and upland) used in this study provided area for all taxonomic groups. All three ecosystems support a core conservation network for terrestrial vertebrates and ecosystem services. Species-habitat associations are not uniform, dictating the need for diverse areas, and diversity is positively related to area (Connor & McCoy 1979).

Species Representation in Ecologically Important Zones

Defining ecologically important zones is only useful for species conservation if such areas actually provide habitat for species. Uplands of all sizes are extremely important ecosystems for terrestrial vertebrates, based on density of species occurrences, and in other studies have been positively associated with certain taxa (Knutson et al.)
1999). Riparian zones accounted for the second highest density of species occurrences, but accounted for the least area of the landscape. Similar findings support the importance of riparian zones to many species (Reeves et al. 2006). Wetlands were also important, even though they contributed the least as measured by density of predicted species occurrences. Potential explanations for lower predicted species density in wetlands are discussed later. Each of the three ecosystems identified on the landscape accounts for at least ¼ of all species occurrences and are important areas for terrestrial vertebrates.

The delineated EIZs (subset of U.P. ecosystems) were different from their counterparts in terms of species occurrence densities. Wetland EIZs were the most important in this regard, with the highest predicted occurrence densities for each taxonomic group. Wetland ecosystems on the landscape included very small wetlands, compared to wetland EIZs, which were 100 ha and larger. Species richness is positively correlated with wetland area, so smaller area wetlands have lower species richness, and potentially densities of species occurrences like I found (Matthews et al. 2005; Houlahan et al. 2006). Smaller wetland complexes however, can contribute significantly to the conservation of a wetland mosaic on the landscape (Gibbs 2000). Wetland EIZs are extremely important for their strong species concentrations, which make them an important conservation consideration.

Upland EIZs were the second most valuable ecosystem type based on predicted species occurrence densities. Other studies based on species richness, show uplands typically falling behind other ecosystem types, especially riparian zones, and a trend toward decreasing species richness away from riparian areas into uplands (Renöfält et al. 2005; Sabo et al. 2005).
Though riparian zones had the lowest species occurrence rates for all taxa, they accounted for nearly 1/3 of all species occurrences within each taxonomic group. Other work showed the importance of riparian zones for terrestrial vertebrates with up to 73% of endemic species using riparian zones (Reeves et al. 2006). Other studies on plant species richness also showed higher values in riparian zones than in uplands, which differs from the density results shown here (Lott et al. 1987; Sabo et al. 2005). Despite having the lowest density of predicted reptile occurrences, there are reptiles that require riparian habitat, including some snake and turtle species (Semmlitsch and Bodie 2002).

All three ecosystem types studied are important for terrestrial vertebrate species and contribute different conservation values for biodiversity. Conservation area prioritization is crucial to generate meaningful landscape level species benefits (Sarakinos et al. 2000; Knight et al. 2007). Based solely on terrestrial vertebrates in the U.P., wetland EIZ acquisition should be the highest priority of conservation efforts. Upland and riparian EIZs provide unique benefits that are important for non-wetland-associated species. Targeting all three ecosystem types in one conservation approach will maximize biodiversity representation.

**Stewardship Assessment and Potential Protected Species**

The conservation approach presented here would supplement the current reserves, which would provide even more area for terrestrial vertebrates. Less than half of all predicted species occurrences are currently in protected areas. There is at least some representation of every terrestrial vertebrate species protected areas. The very low representation of terrestrial vertebrates in highly protected areas (Status 1 and 2—that are not subject to extractive use) is concerning. Almost 97% of species occurrences under
the current stewardship regime are subject to extractive use or landscape change, which may be insufficient to maintain landscape level species-environmental interactions and processes (Pickett & Thompson 1978). A majority of predicted species occurrences are outside of protected area boundaries. Monitoring populations in protected areas and adjacent boundary areas may provide insight on the role of private lands in species conservation.

For each taxonomic group, distributions within protected areas are representative of the occurrence rates for all areas on the landscape. Birds are the most highly represented taxonomic group in protected areas, followed by mammals, amphibians, and reptiles. These distributions match the order of highest to lowest occurrence rates across the landscape. Distributions within Status 1 and Status 2 lands are dismal for all taxa, though both areas have representative occurrences for each species. Technically, I did not identify any gaps (i.e. species not represented in stewardship), but the very low predicted occurrences accounted for by Status 1 and Status 2 lands are indicative of weaknesses in the reserve system. Status 1 and Status 2 areas make up a very small portion of the landscape, so the low occurrence rates are the result of a small area and do not reflect the conservation value of those areas. The current reserve system does not provide a robust conservation foundation. Upgrading current Status 3 areas to Status 1 or Status 2 would potentially strengthen the species value of the reserve system. If Status 3 areas are promoted, then any new additions to stewardship could be Status 3 areas. The acquisition benefit would be practicing sustainable natural resource extraction, while protecting biodiversity across the landscape.
Under the outlined approach for stewardship additions, Michigan could protect hundreds of millions of hectares of area for TVS. The proposed approach would add significant ecosystem area to stewardship. The use of a 200 m upland EIZ buffer provides the most ecosystem area overall, but does not provide significantly more ecosystem area for species than what a 100 m upland EIZ buffer would provide around 1,000 ha upland EIZs. Based on percent area of predicted species occurrences, the greatest benefit through approach is from riparian EIZs, which would more than triple in size. The average benefit to ecosystem area (i.e. potential habitat) under this approach was approximately 49,000 ha/species (some species overlap) and would protect billions of dollars in ecosystem services production (see chapter two).

**Threatened and Endangered Species**

An important factor to consider is how well the approach protects areas for threatened and endangered species, which are most at risk of extinction. Though all of the threatened and endangered terrestrial vertebrates in the U.P. occur in some level of stewardship, the situation is not very promising. Approximately 41% of threatened and endangered species occurrences occur within legally protected stewardship lands. A majority of the 41% is land subject to extractive use or intense management that alters the natural system. More area for the threatened and endangered species in highly protected areas (Status 1 and Status 2), would benefit these species and increase protection of even more ecological diversity (Olson & Dinerstein 1998; Hoekstra et al. 2005).

I further assessed the distributions of threatened and endangered species occurrences in different stewardship levels. Status 1 and Status 2 weakly represented threatened and endangered species. Of the 40 threatened and endangered species
predicted to occur on the U.P. landscape, only 11 had more than 5% of their predicted occurrences in Status 1 lands, and only 1 had more than 5% of predicted occurrences in Status 2 lands. Five percent is an extremely low measure and probably not sufficient to sustain a population. Current stewardship protection for threatened and endangered species is very low and should be examined through a fine filter approach. At present however, the threatened and endangered species subset may be useful as indicator species for all terrestrial vertebrates in the U.P., which disagrees with other work (Kiester et al. 1996). The occurrence densities by ecosystem may represent the importance of specific ecosystems to species, but additional work with spatial data will likely reveal a more complex picture. Over-representation of the more common species, without protection for at risk species, doesn’t make sense, which is why careful attention to detail is important (Hannah et al. 2007).

**CONCLUSIONS**

The ecosystem-based approach to conservation planning provides a core to sustain terrestrial vertebrate biodiversity and ecological processes across Michigan’s U.P. Though it is a rudimentary approach, there are clear advantages and the potential for conservation success using this methodology. A fine filter approach would alleviate some of the issues with threatened and endangered species conservation and should be employed in future applications. An on the ground accuracy assessment would be beneficial to determine how well the GAP models predict actual species occurrences.

The ecosystem approach provides some level of protection for all species and ecosystem types in the study. The predicted benefits from implementing a conservation approach of this nature provide additional evidence for simultaneous maintenance of
ecosystem services and biodiversity. Biodiversity and ecosystem services will benefit from stewardship status upgrades. Wetland EIZs provide the greatest species benefits (by density), but upland and riparian EIZs provide unique benefits and should be considered accordingly. Prioritizing potential stewardship areas should occur before acquisition. Reassigning stewardship status to higher levels for threatened and endangered species conservation would likely contribute to local recovery efforts by mitigating habitat loss (Hoekstra et al. 2005).

There is no evidence that a one-size-fits-all approach will be successful, which coincides with the findings of many other studies (Soulé & Sanjayan 1998; Fahrig 2001; IUCN in Rodrigues and Gaston 2001; Solomon et al. 2003; Homan et al. 2004; Dietz & Czech 2005; Svancara et al. 2005). Each situation will be different and deserves unique consideration. Goals and targets will vary across individual species and taxa, depending on numerous factors. Species use the landscape in different ways and should have special consideration on an individual basis when appropriate. Adding minimum viable population analyses, minimum dynamic area analyses, or other models has the potential to provide a finer resolution decision making tool and tremendous support for conservation planning.

Biodiversity is important. There are potential values from genetic information and medicinal values that are yet to be discovered (Pimentel et al. 1997). Biodiversity provides humans with food and areas of high biodiversity have higher net primary productivity, which is particularly important as the human population continues to grow (Costanza et al. 2007). An approach like this, that conserves biodiversity and provides ecosystem-services, is a win-win for humanity and warrants serious consideration.
APPENDIX C

Table 3.1: Taxonomic group usage of wetland, riparian, and upland ecosystems on the landscape and wetland, riparian, and upland EIZs. Numbers in columns represent percentage of total occurrences (normalized per hectare of ecosystem).

<table>
<thead>
<tr>
<th>Taxonomic Group</th>
<th>U.P. Wetlands</th>
<th>EIZ Wetlands</th>
<th>U.P. Riparian Zones</th>
<th>EIZ Riparian Zones</th>
<th>U.P. Uplands</th>
<th>EIZ Uplands</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amphibians</td>
<td>25%</td>
<td>40%</td>
<td>40%</td>
<td>32%</td>
<td>35%</td>
<td>24%</td>
</tr>
<tr>
<td>Birds</td>
<td>25%</td>
<td>41%</td>
<td>36%</td>
<td>29%</td>
<td>39%</td>
<td>31%</td>
</tr>
<tr>
<td>Mammals</td>
<td>24%</td>
<td>40%</td>
<td>35%</td>
<td>29%</td>
<td>41%</td>
<td>32%</td>
</tr>
<tr>
<td>Reptiles</td>
<td>22%</td>
<td>37%</td>
<td>33%</td>
<td>28%</td>
<td>45%</td>
<td>37%</td>
</tr>
</tbody>
</table>

Table 3.2: Species occurrences, by taxonomic group, in Status 1 (permanently protected from conversion to an unnatural state and managed to remain natural), Status 2 (permanent protection from conversion to an unnatural state, but management practices may reduce quality of natural communities), and Status 3 (permanent protection from conversion to an unnatural state, but potentially subject to extractive uses) protected areas, and other unprotected areas in the U.P. of Michigan.

<table>
<thead>
<tr>
<th>Taxonomic Group</th>
<th>Status 1</th>
<th>Status 2</th>
<th>Status 3</th>
<th>Other Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amphibians</td>
<td>2%</td>
<td>1%</td>
<td>36%</td>
<td>61%</td>
</tr>
<tr>
<td>Birds</td>
<td>3%</td>
<td>1%</td>
<td>37%</td>
<td>59%</td>
</tr>
<tr>
<td>Mammals</td>
<td>2%</td>
<td>1%</td>
<td>37%</td>
<td>60%</td>
</tr>
<tr>
<td>Reptiles</td>
<td>2%</td>
<td>1%</td>
<td>35%</td>
<td>62%</td>
</tr>
</tbody>
</table>
Table 3.3: Ecosystem area (totaled from individual species area within taxonomic groups) in millions of hectares within wetlands, riparian zones, and uplands on the landscape and ecosystem area for proposed additions to stewardship through buffers (i.e. 240 m for wetlands, 30 m for riparian zones, and either 100 m or 200 m for uplands) in the U.P. of Michigan.

<table>
<thead>
<tr>
<th></th>
<th>Wetland</th>
<th>Wetland 240</th>
<th>Riparian</th>
<th>Riparian 30</th>
<th>Upland</th>
<th>Upland 100</th>
<th>Upland 200</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Species</td>
<td>92.1</td>
<td>99.2</td>
<td>5.4</td>
<td>16.3</td>
<td>250.0</td>
<td>264.0</td>
<td>273.4</td>
</tr>
<tr>
<td>Amphibians</td>
<td>7.8</td>
<td>7.8</td>
<td>0.5</td>
<td>1.3</td>
<td>17.4</td>
<td>18.8</td>
<td>19.6</td>
</tr>
<tr>
<td>Birds</td>
<td>52.3</td>
<td>56.2</td>
<td>3.0</td>
<td>9.1</td>
<td>140.1</td>
<td>148.2</td>
<td>153.5</td>
</tr>
<tr>
<td>Mammals</td>
<td>29.2</td>
<td>31.8</td>
<td>1.7</td>
<td>5.2</td>
<td>82.6</td>
<td>87.0</td>
<td>90.0</td>
</tr>
<tr>
<td>Reptiles</td>
<td>2.8</td>
<td>3.5</td>
<td>0.2</td>
<td>0.6</td>
<td>9.9</td>
<td>10.0</td>
<td>10.2</td>
</tr>
</tbody>
</table>
Table 3.4: Percent of all predicted occurrences on the landscape for threatened and endangered species occurring in Status 1, Status 2, or Status 3 lands.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
<th>Status 1</th>
<th>Status 2</th>
<th>Status 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common loon</td>
<td>Gavia immer</td>
<td>5%</td>
<td>1%</td>
<td>11%</td>
</tr>
<tr>
<td>American bittern</td>
<td>Botaurus lentiginosus</td>
<td>8%</td>
<td>1%</td>
<td>48%</td>
</tr>
<tr>
<td>Least bittern</td>
<td>Ixobrychus exilis</td>
<td>28%</td>
<td>0%</td>
<td>44%</td>
</tr>
<tr>
<td>Black-crowned night-heron</td>
<td>Nycticorax nycticorax</td>
<td>5%</td>
<td>0%</td>
<td>47%</td>
</tr>
<tr>
<td>Trumpeter swan</td>
<td>Cygnus buccinator</td>
<td>10%</td>
<td>1%</td>
<td>15%</td>
</tr>
<tr>
<td>Osprey</td>
<td>Pandion haliaetus</td>
<td>2%</td>
<td>1%</td>
<td>42%</td>
</tr>
<tr>
<td>Bald eagle</td>
<td>Haliaeetus leucocephalus</td>
<td>3%</td>
<td>1%</td>
<td>37%</td>
</tr>
<tr>
<td>Northern harrier</td>
<td>Circus cyaneus</td>
<td>4%</td>
<td>1%</td>
<td>38%</td>
</tr>
<tr>
<td>Northern goshawk</td>
<td>Accipiter gentilis</td>
<td>3%</td>
<td>1%</td>
<td>36%</td>
</tr>
<tr>
<td>Red-shouldered hawk</td>
<td>Buteo lineatus</td>
<td>2%</td>
<td>1%</td>
<td>35%</td>
</tr>
<tr>
<td>Merlin</td>
<td>Falco columbarius</td>
<td>4%</td>
<td>1%</td>
<td>42%</td>
</tr>
<tr>
<td>Peregrine falcon</td>
<td>Falco peregrinus</td>
<td>0%</td>
<td>4%</td>
<td>2%</td>
</tr>
<tr>
<td>Spruce grouse</td>
<td>Falciennis canadensis</td>
<td>2%</td>
<td>1%</td>
<td>47%</td>
</tr>
<tr>
<td>Sharp-tailed grouse</td>
<td>Tymanuchus fasanellis</td>
<td>0%</td>
<td>0%</td>
<td>34%</td>
</tr>
<tr>
<td>Yellow rail</td>
<td>Coturnicops noveboracensis</td>
<td>31%</td>
<td>0%</td>
<td>50%</td>
</tr>
<tr>
<td>King rail</td>
<td>Rallus elegans</td>
<td>42%</td>
<td>0%</td>
<td>45%</td>
</tr>
<tr>
<td>Piping plover</td>
<td>Charadrius melodus</td>
<td>0%</td>
<td>9%</td>
<td>18%</td>
</tr>
<tr>
<td>Caspian tern</td>
<td>Hydroprogne caspia</td>
<td>0%</td>
<td>4%</td>
<td>6%</td>
</tr>
<tr>
<td>Common tern</td>
<td>Sterna hirundo</td>
<td>0%</td>
<td>4%</td>
<td>10%</td>
</tr>
<tr>
<td>Forster's tern</td>
<td>Sterna forsteri</td>
<td>2%</td>
<td>0%</td>
<td>57%</td>
</tr>
<tr>
<td>Black tern</td>
<td>Chlidonias niger</td>
<td>12%</td>
<td>1%</td>
<td>55%</td>
</tr>
<tr>
<td>Long-eared owl</td>
<td>Asio otus</td>
<td>0%</td>
<td>0%</td>
<td>17%</td>
</tr>
<tr>
<td>Short-eared owl</td>
<td>Asio flammeus</td>
<td>2%</td>
<td>1%</td>
<td>38%</td>
</tr>
<tr>
<td>Black-backed woodpecker</td>
<td>Picoides arcticus</td>
<td>3%</td>
<td>1%</td>
<td>48%</td>
</tr>
<tr>
<td>Marsh wren</td>
<td>Cistothorus palustris</td>
<td>14%</td>
<td>0%</td>
<td>53%</td>
</tr>
<tr>
<td>Kirtland's warbler</td>
<td>Dendroica kirtlandii</td>
<td>0%</td>
<td>0%</td>
<td>75%</td>
</tr>
<tr>
<td>Prairie warbler</td>
<td>Dendroica discolor</td>
<td>0%</td>
<td>0%</td>
<td>76%</td>
</tr>
<tr>
<td>Dickcissel</td>
<td>Spiza americana</td>
<td>0%</td>
<td>0%</td>
<td>28%</td>
</tr>
<tr>
<td>Grasshopper sparrow</td>
<td>Ammodramus savannarum</td>
<td>0%</td>
<td>0%</td>
<td>7%</td>
</tr>
<tr>
<td>Hanslow's sparrow</td>
<td>Ammodramus henslowii</td>
<td>0%</td>
<td>0%</td>
<td>5%</td>
</tr>
<tr>
<td>Western meadowlark</td>
<td>Sturnella neglecta</td>
<td>0%</td>
<td>0%</td>
<td>7%</td>
</tr>
<tr>
<td>Yellow-headed blackbird</td>
<td>Xanthocephalus xanthocephalus</td>
<td>24%</td>
<td>0%</td>
<td>35%</td>
</tr>
<tr>
<td>Smoky shrew</td>
<td>Sorex fumeus</td>
<td>0%</td>
<td>0%</td>
<td>5%</td>
</tr>
<tr>
<td>Eastern pipistrelle</td>
<td>Pipistrellus subflavus</td>
<td>1%</td>
<td>0%</td>
<td>33%</td>
</tr>
<tr>
<td>Northern flying squirrel</td>
<td>Glaucomys sabrinus</td>
<td>1%</td>
<td>1%</td>
<td>41%</td>
</tr>
<tr>
<td>Gray wolf</td>
<td>Canis lupus</td>
<td>2%</td>
<td>1%</td>
<td>36%</td>
</tr>
<tr>
<td>Moose</td>
<td>Alces alces</td>
<td>5%</td>
<td>1%</td>
<td>37%</td>
</tr>
<tr>
<td>Wood turtle</td>
<td>Glyptemys insculpta</td>
<td>2%</td>
<td>1%</td>
<td>33%</td>
</tr>
<tr>
<td>Blanding's turtle</td>
<td>Emydoidea blandyngii</td>
<td>4%</td>
<td>2%</td>
<td>10%</td>
</tr>
</tbody>
</table>
Figure 3.1: Percentages of species occurrences normalized by unit area (number of occurrences/hectare) for all terrestrial vertebrate species on the entire U.P. landscape of Michigan.

Figure 3.2: Percentages of species occurrences normalized by unit area (number of occurrences/hectare) for all terrestrial vertebrate species in wetland, riparian, and upland EIZs in the U.P. of Michigan.
Figure 3.3: Species occurrences (all TVS) in Status 1 (permanently protected from conversion to an unnatural state and managed to remain natural), Status 2 (permanent protection from conversion to an unnatural state, but management practices may reduce quality of natural communities), and Status 3 (permanent protection from conversion to an unnatural state, but potentially subject to extractive uses) protected areas and on the U.P. of Michigan landscape.

Figure 3.4: Distribution of predicted species occurrences for threatened and endangered species in stewardship areas (Status 1, Status 2, and Status 3) and across the U.P. landscape of Michigan.
Chapter 4: SUMMARY OF FINDINGS

Land Cover Accuracy Assessment

The overall accuracy of the 2006 NLCD for the U.P. was 75%, which did not meet the 80-85% accuracy targets set for land cover data, but these targets are almost never achieved. Government agencies have encountered similar shortcomings with their accuracy assessments and accuracy less than the target percentages are not uncommon and do not appear to significantly impact work with the datasets. At a larger scale, accuracy is typically greater, and perhaps with a larger sample size, there would be even greater accuracy as well. The ground truthing I conducted supported the use of the 2006 NLCD dataset because of the high accuracy for sample pixels, particularly for forest and woodland pixels. The forest and woodland areas cover most of the U.P. landscape and tend to be nonlinear, which likely contribute to increased accuracy in this classification. Additionally, the Kappa statistic supported the strength of the accuracy assessment by providing evidence of strong inter-rater agreement. Kappa is a conservative measure, so it likely underestimates the agreement value by adjusting for chance agreement, again strengthening the findings in this study.

User and producer accuracies help describe some of the shortcomings of the land cover data. For the ground-truthed data, I had very high user and producer accuracies for the forest and woodland class. All other classes had low user and producer accuracies. Most of these issues are due to sampling near boundaries of linear features (i.e. roads, beaches) or small sample sizes and the low class accuracies are not reflected in the
photointerpretation data. As mentioned in chapter one, boundaries and linear features create problems in mapping because of their heterogeneity in the landscape. Heterogeneous features are known to reduce producer accuracy, which I found to be consistent in this study. Problems leading to reduced user and producer accuracy also contributed to increased commission and omission rates. Generalizations and strict positional accuracy increase commission errors (false positives), which are obvious in the recently disturbed or modified classification. Omission errors (false negatives) were highest for developed and urban pixels, probably because of spatial accuracy and positional issues associated with linear features. Low omission errors in the forest and woodland class are due to the large, homogenous areas covered by this pixel classification and land cover type.

**ECOSYSTEM SERVICES**

Landscape targets for protecting ecosystem services vary depending on the ecosystem. Across major watersheds (i.e. the U.P.), conservation targets were 10% wetland cover, 75% of stream length (riparian zones) naturally vegetated, and 30% forest cover. Under the basic approach presented, all conservation targets were exceeded. Riparian zones are 100% covered under this scheme, which is probably not feasible in urban areas (i.e. Marquette, Escanaba), but even appropriate conservation strategies in these areas could minimize negative impacts to urban riparian zones. Further refinement of spatial data layers and additional process steps could mitigate shortcomings with ecosystem overrepresentation and buffer overlap issues. Focusing the approach on identification and delineation of ELZs using multiple criteria would likely result in a more
cost-effective, efficient acquisition template that still protects important ecosystem services (Geneletti 2003; Regan et al. 2007; Strager & Rosenberger 2007).

The addition of lands to stewardship protection can reduce external threats to interior areas. Buffering EIZs allows for the maintenance of critical areas that mitigate species invasions and adds additional area for a myriad of species (Cadenasso & Pickett 2001). Climate change has increased the need for protected areas and any additions are a step in the right direction to mitigate threats to ecosystem services associated with climate change (Hannah 2009).

Though this approach provides guidance for a conservation strategy for ecosystem services in the U.P., it is only a first step. There are much more complex models for delineating EIZs, but a lack of data or data unavailability limit the use of more intense models. Watershed and riparian zone delineation through raster analysis would generate a more specific and robust analysis. Likewise, the NWI data was completely missing in a small portion of the western U.P., so I was unable to determine values of land or ecosystem services for this area. Using this approach requires the addition of vast expanses of land, which may not be feasible immediately and may only be possible through piecemeal additions to stewardship. Based on ecosystem service values, additions should be focused primarily on wetland acquisitions. Wetland buffer zones often overlap with upland ecosystems, so buffered wetland additions would contribute to both sets of ecosystem services. Further analysis of riparian zones, especially in developed areas, may be necessary to justify adding 100% of these areas to stewardship. Advanced riparian zone analysis could generate a more targeted approach to identify the most vulnerable and highest priority areas for stewardship candidacy. Future plans
should focus on these issues by addressing efficiency through the use of advanced spatial modeling, suitability analysis, and other methods.

There is not a uniform approach or target for conservation. Providing enough area depends on the goals set for a specific site, ecosystem service, or species, and a one size fits all approach is arbitrary at best (Rodrigues et al. 2004). Weighing the costs and benefits to determine site-specific conservation goals are probably the best method in conservation planning presently. Although this is a basic approach that cannot answer every conservation question, the uncertainty doesn’t mean we should refuse to make progress (Hunter et al. 2010). Developing this approach with additional datasets and spatial analysis work in future iterations will allow for refined EIZ delineations. Refinement of EIZs may provide an even clearer picture of areas that should be priorities for stewardship in the U.P. In the end, this approach is both economically and ecologically sensible, with rewards vastly outweighing the investment for generations to come.

TERRESTRIAL VERTEBRATE SPECIES

The ecosystem-based approach to conservation planning provides a core to sustain terrestrial vertebrate biodiversity and ecological processes across Michigan’s U.P. Though it is a rudimentary approach, there are clear advantages and the potential for conservation success using this methodology. A fine filter approach would alleviate some of the issues with threatened and endangered species conservation and should be employed in future applications. An on the ground accuracy assessment would be beneficial to determine how well the GAP models predict actual species occurrences. By itself, it can provide a starting point for conservation initiatives, but with additional
information, can be improved. The approach here is easily reproducible and can be adapted for many ecosystems. Additionally, this approach can be modified with relative ease, which means improvements to the methodology are extremely manageable.

The ecosystem approach provides some level of protection for all species and ecosystem types in the study. The predicted benefits from implementing a conservation approach of this nature provide additional evidence for simultaneous maintenance of ecosystem services and biodiversity. Biodiversity and ecosystem services will benefit from stewardship status upgrades. Wetland EIZs provide the greatest species benefits (by density), but upland and riparian EIZs provide unique benefits and should be considered accordingly. Prioritizing potential stewardship areas should occur before acquisition. Reassigning stewardship status to higher levels for threatened and endangered species conservation would likely contribute to local recovery efforts by mitigating habitat loss (Hoekstra et al. 2005).

**CONCLUSIONS**

After completing the accuracy assessment using photointerpretation and identifying the shortfalls of the data, it appears the data will not limit the applications of species modeling for conservation. Most vertebrate species use multiple pixels on a landscape. Thus even if the land cover of a given pixel only has a 75% chance of being correctly classified, adjacent pixels likely reflect the correct land cover and in consequence, habitat for that species. Using fuzzy logic when modeling species and land cover would likely reduce errors resulting from limitations of fixed logic models, increasing overall accuracy and the Kappa coefficient. Likewise, using pixel sizes larger than 30 m x 30 m will contribute to increased spatial accuracy, but decrease the amount
of detail available for each pixel. Taking these factors into consider for work at the 30 m x 30 m pixel size, 75% accuracy is strong enough to continue working with the dataset for conservation planning.

There is no evidence that a one-size-fits-all approach will be successful, which coincides with the findings of many other studies (Soulé & Sanjayan 1998; Fahrig 2001; IUCN in Rodrigues and Gaston 2001; Solomon et al. 2003; Homan et al. 2004; Dietz & Czech 2005; Svancara et al. 2005). Each situation will be different and deserves unique consideration. Goals and targets will vary across individual species and taxa, depending on numerous factors. Species use the landscape in different ways and should have special consideration on an individual basis when appropriate. Adding minimum viable population analyses, minimum dynamic area analyses, or other models has the potential to provide a finer resolution decision making tool and tremendous support for conservation planning.

Biodiversity is important. There are potential values from genetic information and medicinal values that are yet to be discovered (Pimentel et al. 1997). Biodiversity provides humans with food and areas of high biodiversity have higher net primary productivity, which is particularly important as the human population continues to grow (Costanza et al. 2007). This approach protects billions of dollars in ecosystem service values for humans and contributes immensely to potential terrestrial vertebrate species conservation. The species models are likely accurate enough to use to predict habitat for species, the ecosystem-based approach identifies ecologically important areas (based on ecological functions), and the terrestrial vertebrate species distributions provide a picture
of species-rich areas. An approach like this, that conserves biodiversity and provides ecosystem-services, is a win-win for humanity and warrants serious consideration.
LITERATURE CITED


