# A LANDSCAPE INTEGRITY METHOD FOR DETERMINING TRADEABLE CREDITS AS THE BASIS FOR CONSERVATION BANKING

By

MARGARET ELEANOR CONROY

A dissertation submitted to the

Graduate School – New Brunswick

Rutgers, The State University of New Jersey

In partial fulfillment of the requirements

For the degree of

Doctor of Philosophy

Graduate Program in Ecology and Evolution

Written under the direction of

Richard Lathrop

And approved by

New Brunswick, New Jersey

May 2017

ABSTRACT OF THE DISSERTATION

# A landscape integrity method for determining tradeable credits as the basis for conservation banking

By MARGARET ELEANOR CONROY

Dissertation Director:

Richard Lathrop

Habitat destruction and degradation are the most pervasive threats to biodiversity and contribute to the endangerment of many threatened or endangered species. The Endangered Species Act protects the ecosystems on which the endangered species depend through the mitigation hierarchy: avoid, reduce or compensate for negative impact to habitat. A piecemeal approach to mitigation, whereupon each project is compensated for separately often results in small non-sustainable parcels of habitat scattered throughout the landscape, is discouraged while consolidated market-based mitigation approaches are encouraged. Proactive planning and pooling of habitat mitigation areas can result in more cohesive, larger areas being conserved. Conservation banking, a key method of off-site consolidated mitigation, has been shown to be beneficial. However, there are barriers to implementing conservation banking; a major difficulty being a ready means of determining habitat mitigation debits and credits. It is especially difficult to determine debits and credits without having population presence data or detailed ground-level surveys. I developed a method of valuing habitat based on a characterization of landscape integrity from an individual species perspective. The methodology relies  primarily land use/land cover Geographic Information Systems (GIS) mapping, along with life history and home range/habitat use information for each species. An assessment using independent sightings data, multiple metrics, and 15 species of a variety of taxa confirms the reliability of the wildlife habitat values calculated. From the wildlife habitat values I developed a system that establishes both debits, the value of the habitat lost if land is developed, and credits, the increase in the value of the land if it is preserved and managed in perpetuity for the good of the species in question. All values are based on place-based decision-making. Debit and credit values can be used together to attempt no net loss of habitat value.

# Table of Contents

## List of Tables:

CHAPTER 1



CHAPTER 2



CHAPTER 3



CHAPTER 4

## List of Figures:

# A landscape integrity method for determining tradeable credits as the basis for conservation banking

## INTRODUCTION

### Overview

Human-driven changes in the terrestrial component of the earth have significant impact to the structure and function of ecosystems (Steffen et al. 2004). Over 50% of the earth's ice-free land surface has been transformed by direct human modification with around 40% of the terrestrial ice-free land now in agriculture (Turner et al. 2007). Most of the world's biomes have been between 20% and 50% converted to human use; the rates of conversion exceed 50% within half of the world's biomes (Collinge, 2009). Urbanization, in particular has transformed the world's landscapes, resulting in a suite of ecological and environmental impacts. In 2010, excluding Antarctica and Greenland, urban land globally was close to 3%, the global built-up area was 0.65%, and the global impervious surface area was 0.45% (Liu et al. 2014). My study area of New Jersey has a long history as having the highest population density, as well as the highest percentage of land area in urban land uses of any state in the United States. By 2012, over 31% of New Jersey's five million acre territory had become urbanized, surpassing any other land use type in total number of acres. (Lathrop et al. 2016). As the percentage of land in agriculture and urbanized land area increases, wildlife habitat area decreases and what is left is often fragmented. Both the habitat loss and fragmentation create downward pressure on some native wildlife populations often working synergistically with invasive species, disease, overexploitation and climate change increasing the negative impacts on native species populations (Collinge

2009). Though there is no remedy for much of the land use change and habitat destruction, protection of endangered species and their habitats affords some protection or at least mitigation of endangered species habitat. In the United States, the Endangered Species Act provides protection for the ecosystems upon which endangered and threatened species depend (ESA 1973). In order to assure that large tracts of habitat are preserved, regional planning should be implemented so that development and preservation of habitat are directed at a landscape scale. This is true on a national scale; the recent U.S. Fish and Wildlife Service Endangered Species Act Compensatory Mitigation Policy (USFWS 2016) states that one of its primary intents is to encourage strategic planning at the landscape level. Further the policy encourages collaboration to develop and implement compensatory mitigation measures and programs through a landscape-scale approach to achieve the best possible conservation outcomes for activities subject to ESA compliance. The plan discourages a piecemeal approach to conservation that often results in small, non-sustainable parcels of habitat scattered through the landscape and encourages the use of market-based mitigation approaches, especially those that have the advantages of flexibility, advance planning, and economies of scale. (USFWS 2016)

Since few of the effects of urbanization are reversible in the short term, it is imperative, if parcels of land are to be conserved, that they be identified prior to development. There are several difficulties of large-scale planning: data, policy, and planning limitations. I am setting up a framework and protocols to make proactive protection feasible, but will need the political will to make it happen. The data limitation of large-scale planning is being overcome by the ability to use remote sensing systems to indirectly create estimates of potential species ranges just as Turner et al. anticipated years ago (Turner et al. 2003).

Using geographic information systems (GIS) data, I have developed a powerful mapping tool for regional planning that identifies potential threatened and endangered species habitat and determines a measure of the relative value to the species of the habitat. I lay out in the following document a model to establish threatened and endangered species wildlife habitat values over a wide area, and from these wildlife habitat values, to assign tradeable debit and credit values for use in a conservation banking approach to habitat mitigation. The model creates useful place-based information that can inform land use and development planning early in the decision process, thereby reducing the conflict by allowing developers to acknowledge the areas with potential wildlife conflicts and promoting a conservation banking system that increases habitat integrity, connectivity, and contiguity.

## Advantages of place-based decision-making

### Background: Wildlife Habitat and the Impact of Fragmentation

Large contiguous tracts of forest, wetland and grasslands (i.e., natural habitat) that are not fragmented by human development are especially valuable as wildlife habitat. Human development has the direct impact of removing existing natural habitat as well as fragmenting the habitat that remains into smaller remnants. Fahrig's review of empirical studies came to the conclusion that habitat loss has large and consistently negative effects on biodiversity, while habitat fragmentation has much weaker effects that are often highly species specific (Fahrig 2003). When considered from a landscape perspective, the spatial pattern of forest remnants may play an important role in maintaining connectivity across a watershed and thereby facilitating such important ecological processes as dispersal for forest-dependent wildlife species (Gardner et al. 1987; With and Crist 1995). In highly fragmented landscapes, the habitat quality of the intervening matrix (i.e., developed or agricultural lands) can also be important in determining how well species can disperse across a landscape as they try to traverse between forest remnants or other habitat patches (Franklin 1993; Malanson 2003). Connectivity to other habitat is crucial to ensure long-lasting populations (Bunn et al. 2013). In assessing landscape integrity in the New Jersey Pinelands, Zampella et al. (2008) were guided by the principle that the conservation of characteristic Pinelands animal species, including wide-ranging species, requires the protection of relatively large tracts of Pinelands habitat, including upland forests, wetlands and water bodies.

Paved roads, residential and commercial development often serve as a hazard or barrier to wildlife movement and native plant dispersal, as well as altering “natural” disturbance regimes. Roads of all kinds are associated with negative effects on the biotic integrity of both terrestrial and aquatic habitats (Forman et al. 2003, Trombulak and Frissell 2000). Human development also has "indirect" impact by creating different kinds of intrusions with varying depths of impact into adjacent natural habitat and recreational open spaces. These intrusions include increased air, water, noise and light pollution; changes in microclimatic conditions due to higher sunlight and wind levels; increased populations of invasive “weed” species; and increased frequency of disturbance due to direct contact with humans, human pets, and associated “rural/suburban pest” species. The border area affected by these disturbances is labeled edge, as compared to the undisturbed core or interior forest habitat (Zipperer 1993). While many generalist species prefer edge habitat other species require core habitat (Foreman et al. 2003).

One reason for the decline of New Jersey’s threatened and endangered species is the loss of habitat through forest fragmentation and development pressure (Niles et al. 1999). There are a number of so-called area-sensitive species that depend on large tracts of undisturbed interior habitat to maintain viable populations. Large raptors such as red-shouldered hawks (*Buteo lineatus*) and barred owls (*Strix varia*) are area-sensitive species that require large blocks of mature forested wetlands and adjacent upland forest (Niles et al. 1999). In addition, there are a number of wide-ranging, area-sensitive mammal species such as bobcats (a state threatened species in New Jersey) that rely on large areas of relatively intact forest (Niles et al. 1999). Many characteristic Highlands amphibians and reptiles are sensitive to habitat fragmentation and human disturbances. Slow moving amphibians and reptiles are especially susceptible to road-kill and are therefore impacted by increasing densities of roads and traffic volumes (Mitchell 1992). Timber rattlesnakes (*Crotalus horridus*), a New Jersey endangered species of particular concern in the Highlands, are especially susceptible to roads and other human disturbance (Brown 1993; Clark et al. 2010). Many of the other reptiles are also affected heavily by roads (Foreman et al. 2003). The federally threatened bog turtle (*Glyptemys muhlenbergii*) and state threatened wood turtle (*Glyptemys insculpta*) need contiguous blocks of wetland buffered by upland forest (Niles et al. 1999).

### "Landscape integrity" aspect of the wildlife habitat value model

Based on the overriding importance of habitat area and the degree of fragmentation in controlling threatened and endangered species distributions and long term sustainability, I based my model of habitat value on overall habitat area, core habitat area and habitat contiguity. Using place-based decision-making through geographic information systems allow contemplation of external qualities of the habitat such as proximity to other habitat, size of patch, and contiguity to other habitat as well as internal qualities such as land cover. The measure of habitat is spatial; the value of a pixel is the percentage of the surrounding circular area the size of the average home range of the species that is composed of the land covers consistent with habitat for that species. The core habitat metric is determined by measuring how much of the circular area (the size of the average home range) centered at the pixel is core habitat. The third measure is one of contiguity measuring this size of habitat area the species can easily access using habitat and neutral areas that are not cut by major roads for travel.

## Conservation Banking

Habitat destruction and degradation are the most pervasive threat to biodiversity and contribute to the endangerment of the vast majority of species listed as threatened and endangered (Wilcove et al. 1998). One of the purposes of the Endangered Species Act of 1973 (ESA) was "to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved" (Endangered Species Act of 1973). To this end, a hierarchy of approaches designed to mitigate for the loss of habitat was set out in regulations. The hierarchy developed was first avoid negative impacts to threatened and endangered (T&E) species or their habitat; if avoidance is impossible, reduce the negative impact on-site; and then restore, offset, and compensate in order to create a positive impact elsewhere (i.e. off-site) that offsets the negative impact (ESA 1973).. The compensatory options include permittee-responsible mitigation, payment of an in-lieu fee, or conservation banking. Restoration and offsets were often completed on either part of the same tract or on a neighboring tract of land to the destroyed or degraded land leading to small, fragmented habitat areas being restored or conserved. However, it is the large contiguous tracts of forest, wetland, and grasslands (i.e. natural habitat) that are not fragmented by human development that are especially valuable as wildlife habitat. (Fahrig 2003, USFWS 2016) While empirical studies suggest that habitat loss has large and consistently negative effects on biodiversity, habitat fragmentation also has negative effects, though often much weaker and highly species specific (Fahrig 2003). Conservation banking was developed as an off-site mitigation option with the goal of preserving larger tracts of existing habitats (USFWS 2012). It is one of the mechanisms that consolidates compensatory mitigation on larger landscapes which, when serving project proponents with small to moderate impact actions, are ecologically more effective and provide more economical options to achieve compensation than permittee-responsible mitigation (USFWS 2016).

Conservation banks are lands containing natural resource values that are permanently protected and managed for conservation of species of concern (USFWS 2012). Conservation banking is the process where developers purchase habitat or species credits from a conservation bank, which offsets unavoidable adverse impacts of their projects (Bunn et al. 2014, USFWS 2012). These credits are also called offsets. Conservation banking facilitates pooling of mitigation resources from multiple developers or development projects, allowing larger tracts of contiguous land to be preserved and managed than would have occurred with permittee-responsible mitigation (Bunn et al. 2014). Species credits are primarily created through preservation and management of habitat, the idea being that by conserving large areas of high quality habitat with connectivity to other preserved sites and managing the land to support species recovery, the species will persevere and thrive despite a net loss of habitat (Madsen et al. 2010) As the USFWS describes it, the mitigation goal is not necessarily based on habitat area, but on numbers of individuals; size and distribution of populations; the quality and carrying capacity of habitat, which I am defining as wildlife habitat value; or the capacity of the landscape to support stable or increasing populations of the affected species (USFWS 2016). The idea is not no net loss of habitat area, but rather the goal is species recovery and "no net loss of habitat value" (USFWS refers to this simply as "no net loss" (USFWS 2016)).

One objective of Conservation Banking is to create an economic incentive to conserve or restore endangered species habitat. Previously owning endangered species habitat could be an economic detriment which led some people to prevent endangered species from occupying their property by proactively destroying unoccupied habitats – an approach dubbed the "scorched earth" technique by the National Association of Homebuilders (Wilcove and Lee 2004). With the ability to sell habitat credits under certain circumstances, endangered species habitat now becomes an economic asset (USFWS 2016).

A great difficulty in implementing Conservation Banking is determining the debits (quantitative measure of the adverse impacts of intended use) incurred by developers and determining the credits generated by conservation bank owners by permanently protecting, perpetually managing and perhaps restoring the habitat areas of the bank. Ten Kate et al. note in their monumental 2004 report "Biodiversity offsets: Views, experience, and the business case" that "Perhaps the fundamental challenge of biodiversity offsets is establishing the basis for determining "no net loss" when no two hectares are ecologically identical" (ten Kate et al. 2004). Thirteen years on setting debits and credits is still a fundamental challenge. Goncalves et al., in their literature review of scientific literature on biodiversity offsets published between 1999 and 2014, note that the two conceptual challenges of offsets that are of paramount importance are choice of metric and location (Goncalves et al. 2015). Other areas ripe for improvement in Conservation Banking are regional planning for the sites and monitoring and assessing the success or failure of Conservation Banking systems (Bunn et al. 2014). My project addresses these concerns.

## Current State of the Art – Estimation of Conservation Banking Credits

Conservation banking is a fairly recent phenomenon and the estimate of conservation banking credits is still in its infancy. California established the first conservation banking program in the United States in 1995 (CDFW 2012). In 2003, the US Fish & Wildlife Service released its guidance for the establishment, use, and operation of conservation banks (USFWS 2003). The main conservation banking areas in the United States remain in California with lesser activity in the US Northwest and Southeast (Madsen et al. 2010). Neither the US Fish and Wildlife Service guidelines nor the California Department of Fish and Wildlife guidelines provide individualized guidance on setting credit values for endangered species (Madsen et al. 2010, USFWS 2003, USFWS 2013, CADFW 2012). The US Fish and Wildlife Service states simply that "acres of habitat occupied by the species and the number of individual or breeding pairs generally provide the metrics used to quantify the credits" (USFWS 2013). The most recent U.S. Fish and Wildlife Service policy, the first comprehensive treatment of compensatory mitigation under the authority of the ESA to be issued, also does not lay out guidelines for the determination of credits. In fact, it states that "a discussion of tools used to calculate mitigation is not within the scope of this policy" (USFWS 2016), but does note that credits are often expressed as a measure of surfaces area, linear distance of constant width, or number of individuals or mating pairs. Though the U.S. Fish and Wildlife Service agrees that transparent formulas to calculate "mitigation ratios" reduce subjectivity and increase transparency and the Service agrees that equivalent metrics for determining losses due to impacts and gains due to mitigation would aid in the assessment of “no net loss” or “net gain,” they leave specifics to the implementer.

The current state of the art in debit/credit criteria for conservation banking is simplistic: acres of habitat or ad hoc evaluations. The lack of a good metric for credits is a major obstacle inhibiting the spread of conservation banking as a conservation tool. (Bunn et al. 2013, Madsen et al. 2010) According to Madsen et al. in species conservation banking in the United States, the unit of credit is most often an acre of habitat. Occasionally the unit may be a breeding pair or combination of habitat and the actual species (Madsen et al. 2010). In order to determine the number of breeding pairs, a biologist generally is sent in to survey a particular tract of land (Bunn et al. 2013). For those banks whose unit is not an acre, one of the two toughest issues to resolve, as identified by wildlife agency respondents, was reaching agreement on the number of credits warranted by the value of the wildlife at the site. (Bunn et al. 2013)

Worldwide, there is little agreement on what should be the basis of a credit and a lack of sophistication in the definition of credit. One of the problems in Brazil with Forest Code offsets is a lack of clear guidelines as to what determines an “ecological equivalence” in selecting appropriate candidate offsets (Madsen et al. 2010). Therefore, Brazil’s developer’s offsets suffer from a lack of a direct link between impacts and compensation (Madsen et al. 2010).

Germany has a well-established system for offsetting and mitigating impacts called the Impact Mitigation Regulations (IMR) which aims to compensate for impacts in entire ecosystems and landscapes. However, there are no legal provisions in the IMR specifying how to assess the initial state of the area to be affected, the probable impacts of the intervention, or the method to determine compensation (Goncalves et al. 2015).

Since 2008, France has implemented a scheme to increase a supply of biodiversity credits for habitats, species, and ecosystem functions. The credits needed are determined by an impact study but it appears from the definition of the units as hectare units that the units sold as credits may be based on the area of land in the offset bank. (Froger et al. 2015).

Some of the other measures used for offsets in other parts of the world are: Mexico, hectares; Colombia, number of trees affected by development; Paraguay, land area (little enforcement); Argentina, inconsistent, but typically number of trees. Africa has little in the way of biodiversity offsets except for South Africa that does have offsets and these are apparently done using conservation targets for different biotopes using vegetation types as surrogates and using a 'basic offset ratio' of hectares to offset developed hectares. Australia uses native vegetation area X score (Quetier and Lavorel 2011).

In summary, it appears the most commonly employed approaches to measure credits are either simple area measures or measures relying on an examination of the particular tract of land creating the debit or credit. Problems with straight area measures are the obvious issue that the value or condition of the lands are not taken into account; excellent habitat and lesser habitat are valued the same amount, potentially allowing excellent habitat to be destroyed and mitigated by lesser habitat. The problems with ad hoc biological surveys of properties to determine debits/credits are: expense, lack of foresight, and inconsistency.

A review of the literature provides underlying criteria that should be fulfilled to move the concept of conservation banking forward:

- Using standardized criteria for site size, connectivity, and habitat diversity in initial assessments would improve site selection (Bunn et al. 2014)
- Fundamental challenge of biodiversity offsets is establishing the basis for determining "no net loss" when no two hectares are ecologically identical. (ten Kate et al. 2004)
- "mitigation banking programs are reluctant to stray far from strict, in-kind policies and that this problem will be endemic to habitat trading programmes in general, until ecologists can deliver cheaply calculated, refined currency for habitat values." (ten Kate et al. 2004)
- "Our analysis suggests that two of the most pressing conceptual issues associated with implementation of biodiversity offsets are the choice of metric and location. Their choice, and especially the choice of metric will cascade down affecting all other offset challenges. Therefore, it is essential that the research community contribute to establish a sound theoretical framework on how to measure biodiversity offsets…" (Goncalves et al. 2015)
- "Metrics that measure ecological functions and/or services at compensatory mitigation sites and impact sites must be science-based, quantifiable, consistent, repeatable, and related to the conservation goals for the species." (USFWS 2016)

Though some of the suggestions refer to biodiversity offsets (which include multiple species) rather than single-species habitat offsets, it seems clear that for any conservation banking strategy or other tradeable unit strategy of mitigation, that the determination and measurement of the units is still a challenge to implementation. One major gap is an objective, reproducible, ecologically credible means of estimating debits and credits.

Therefore, I strove to fill a void in the current knowledge base. The current systems of measurement that are not strictly acre for acre swaps base their measurement from surveys of a particular property (Froger et al. 2015; Goncalves et al, 2015; Bunn et al. 2014; Quetier and Lavorel 2011;ten Kate et al. 2004). My approach estimates debits and credits for threatened and endangered species habitat mitigation in a consistent, repeatable, quantifiable way based on sound science.

My objective was to create a reasonable measure of tradeable debits and credits over an entire region or landscape area using widely available data which would take into account habitat integrity such as Geographic Information Systems (GIS) land use, land cover data in conjunction with generally known species specific life history and habitat use data. Moreover, I wanted to develop the model without relying on species population survey data since these data are notoriously difficult and expensive to obtain over wide areas, on privately owned property, and in many of the regions where one might want to implement conservation banking. The high expense of ground-level biological surveys along with the lack of manpower to complete the surveys makes ground-level biological survey data inefficient to work with. While it would be wonderful to base the species distribution models on spatially extensive and intensive ground surveys, that takes time and money. We can't wait until all these studies are undertaken to do anything. We need to be proactive and precautionary before all the at-risk habitat is converted to non-compatible uses. The costs of remote sensing data, necessary software, and hardware to handle the imagery are high but are declining and the number of individuals with the expertise handle the imagery is increasing (Turner et al. 2003, Drummond and French 2008) all of which point to using remotely sense-derived characterizations of habitat structure along with geospatial analyses of habitat integrity, when ground survey data are not available. Comprehensive field data isn't available for many species. What limited data was available was used to establish the validity of the models.

## Tradeable Habitat Value Credits

In order to better implement Conservation Banking, it is imperative that an efficient, effective method of setting tradeable credits be developed. The newest policy on Compensatory Mitigation under the ESA calls for a metric that is science-based, quantifiable, consistent, repeatable, and related to the conservation goals for the species. Furthermore, the new policy seeks to encourage strategic planning at the landscape level (USFWS 2016). The challenge is to improve the way different landscape areas or habitats for threatened and endangered species are characterized and how their value is quantified. My goal was to provide a tool that identifies areas of high habitat values to preserve and restore while identifying lower value habitat areas that, if development will or must take place, can be the target of development with the minimum impacts to the species of concern.

One basic improvement to threatened and endangered habitat mitigation trades or conservation banking is to clearly define both the value of the habitat lost and value of the habitat preserved or gained since these are two distinct measures. For this project, I've termed debit as the value of the parcel of land as habitat that would be lost were the land to be developed or the land use or land cover to change so that it is no longer habitat for the species in question. Credit is termed the increase in value of a parcel of land as habitat due to the conversion of the land from its current/prior state to the conservation bank or managed mitigation status. Currently, debit and credit values are often conflated.

Until recently there was often only a credit value determined and a multiplier was used as a crude measure and a hedge against uncertainty. For every acre lost some multiple of acres must be preserved, restored, or created. I contend that it is better to have two distinct measures: a measure of what is lost (debit) and a measure of what is gained (credit), instead of using a simple multiplier.

An ideal method of estimating debits and credits should be consistent, proactive, efficient and above all, effective. It is important that the estimation be consistent because this allows market forces to direct the costs and allows true offsetting of habitat areas such that the species in question would not lose habitat value and would presumably not show a change in population size due to the offset. It is important that the estimation and mapping be proactive so that development can be nudged into the inferior habitat while conserving the core habitat areas and other habitat areas of the highest value to the threatened and endangered species. If the estimation of debits and credits is done after the areas or potential areas for development and/or conservation have already been selected, the possibility of directing development and increasing the efficacy of planning will not be available. An ideal method of estimating debits and credits must be efficient so that the estimates can be done in a timely manner with reasonable transaction costs so that conservation banking can be widely instituted in third-world and developing countries as well. One way to increase efficiency is to use landscape versus site level characteristics. There must be a way to monitor the effectiveness of any conservation banking debit and credit measures in order to assure that habitat value is not lost and that threatened and endangered species are not stressed further by loss or degradation (including fragmentation) of habitat.

## Summary

This dissertation develops a new methodology for estimating Conservation Banking debits and credits (Figure 1). The methodology is based on the quantification of wildlife habitat value based on measures of landscape level habitat integrity, of translating the habitat values into debits (i.e., values lost on development and conversion), and of determining credits (i.e. values gained from preservation, restoration and management in perpetuity). The validity of the measure of wildlife habitat value based on landscape integrity has been assessed using an independent data set of species sightings. The overall methodology is proactive, internally consistent for each species, and efficient.

The approach was developed and tested using fifteen wide-ranging New Jersey state-listed threatened and endangered species from a variety of taxa: Barred owl (*Strix varia*), Black-crowned night heron (*Nycticorax nycticorax*), Bobcat (*Lynx rufus*), Bobolink (*Dolichonyx oryzivorus*), Bog turtle (*Glyptemys muhlenbergii*), Grasshopper Sparrow (*Ammodramus savannarum*), Indiana Bat (*Myotis sodalis*), Long-eared Owl (*Asio otus*), Long-tailed Salamander (*Eurycea longicauda*), Northern Goshawk (*Accipiter gentilis*), Red-headed Woodpecker (*Melanerpes erythrocephalus*), Red-shouldered Hawk (*Buteo lineatus*), Timber Rattlesnake (*Crotalus horridus*), Vesper Sparrow (*Pooecetes gramineus*), and Wood Turtle (*Glyptemys insculpta).*

Chapter 1 lays out quantitative methods of determining relative value of habitat which is the first step in meeting the challenge posed by ten Kate et al. and shows results for the 15 test species statewide. Chapter 1 includes an assessment of the method for the test species. Chapter 2 uses the wildlife habitat value (WHV) created/calculated in Chapter 1 as a proxy for relative species abundance/population numbers which is then normalized into a

biologically reasonable range of abundance. The range of abundance is used to assign debit values for properties that might be developed. Chapter 3 investigates the "additionality" - conservation benefit or gain produced as a result of delivering an offset that would have not arisen in the absence of the compensation action (Goncalves et al. 2015; USFWS 2016) - of the intended credits and assigns credits accordingly breaking the increase in value due to the credit into the increase in value due to preservation and the increase in value due to management.

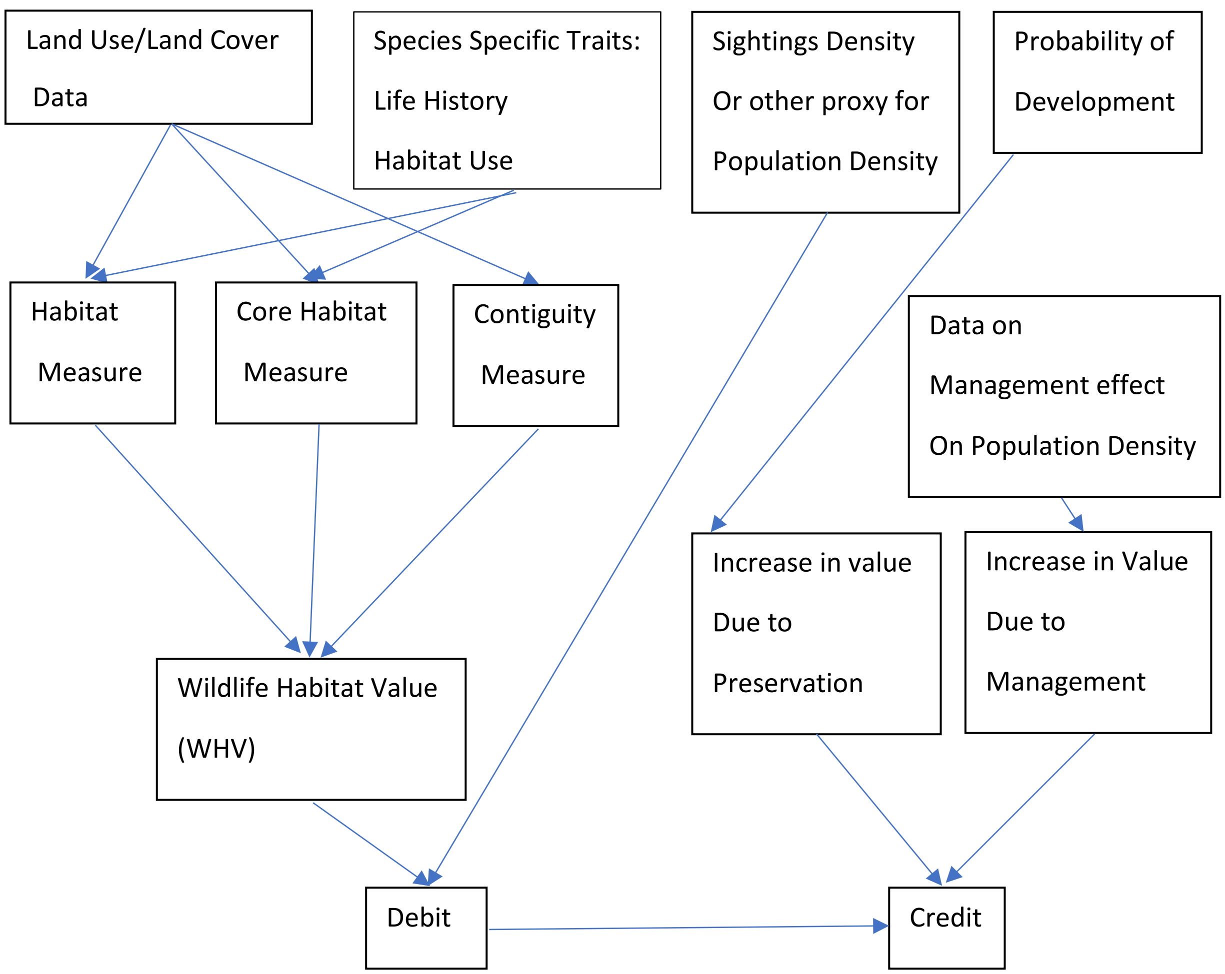



Figure 1: Overview of entire debit/credit estimation model.

The main inputs to the model are land use/land cover satellite data which has been coded into Anderson codes, species specific information from the NJDEP Landscape project, some proxy for population density, an estimate of the probability of development, and general information on the average effect that management has on population density. All spatial information is NJ state plane with 50ft pixel resolution.

## Unique Contribution to the Field

Conservation banking has matured since its inception over twenty years ago. It is a market-based mitigation strategy with many advantages such as the ability to consolidate the mitigation of many smaller projects which creates mitigation that is ecologically more effective and can create economies of scale. However, conservation banking is hampered by the difficulty of setting the debits and credits to be traded. My model, which values wildlife habitat and sets tradeable debits and credits, provides a reliable and consistent metric as called for in the U.S. Fish and Wildlife Endangered and Threatened Wildlife and Plants: Endangered Species Act Compensatory Mitigation Policy (USFWS 2016). The metrics from my model comply with the requests in the USFWS policy; they are science-based, quantifiable, consistent, repeatable, and related to the conservation goals for the species. They are habitat-based. They account for duration of the impact and temporal loss to the species. They use additionality judiciously. The debits and credits assigned by my model also meet the fundamental challenge of biodiversity offsets mentioned by ten Kate et al. in 2004. ("The fundamental challenge of biodiversity offsets is establishing the basis for determining "no net loss" when no two hectares are ecologically identical. (ten Kate et al. 2004)). The fact that "mitigation banking programs are reluctant to stray far from strict, in-kind policies and that this problem will be endemic to habitat trading programmes in general, until ecologists can deliver cheaply calculated, refined currency for habitat values." (ten Kate et al. 2004) is holding back the adoption of mitigation banking. My model is one type of cheaply calculated refined currency. My method not being dependent on site level data (and hence cheaper to use), capturing important information on habitat area, integrity, and contiguity (making it refined) and having been validated by independent data is just what is being called for and the introduction and use of such a method would overcome a major roadblock in conservation banking. Because my model is spatially-based and run at a regional level, entire landscapes are mapped allowing and encouraging strategic planning which is another purpose of the new USFWS policy. My model is a unique contribution to the field of conservation biology.

## Cited Sources

Barry, S and J. Elith. 2006. Error and uncertainty in habitat models. Journal of Applied Ecology. 43, 413-423

Bayon, R. 2008. Banking on Biodiversity. Chapter 9 in 2008 State of the World. Worldwatch Institute, Washington, D.C. pp. 123-137.

Beans, B. and L. Niles. 2003. Endangered and threatened Wildlife of New Jersey. Rutgers University Press. New Brunswick, NJ

Brown, W. S. 1993. Biology, status and management of the timber rattlesnake (Crotalus horridus): a guide for conservation. Society for the Study of Amphibians and Reptiles. Herpetology Circular No. 22. 78 p.

Bonneuil, C. 2015. Tell me where you come from, I will tell you who you are: a genealogy of biodiversity offsetting mechanisms in historical context. Biological Conservation 192:485-491

Bull, J.,Milner-Gulland, E., suttle, K., Singh, H. 2014. Comparing biodiversity offset calculation methods with a case study in Uzbekistan. Biological Conservation. 178 (2014)2-10.

Bunn, D. Lubell, M., and Johnson, C. K. 2013. Reforms could boost conservation banking by landowners. *California Agriculture* 67(2):86-95.

Bunn, D., Moyle, P.B., Johnson, C.K. 2014. Maximizing the ecological contribution of conservation banks. Wildlife Society Bulletin. DOI: 10.1002/wsb.398

California Department of Fish and Wildlife. Conservation Banking. 2012.

Clark, R. W., Brown, W. S., Stechert, R., and Zamudio, K. R. 2010. Roads, interrupteddispersal, and genetic diversity in Timber Rattlesnakes. Conservation Biology 24(4):1059-1069.

Collinge, S. 2009. Ecology of Fragmented Landscapes. The Johns Hopkins University Press.

DOI Office of Policy Analysis. 2013. A Preliminary Analysis of the Conservation Banking Program and Results from a Survey of USFWS Staff. 66 p. http://www.fws.gov/endangered/landowners/pdf/CB%20Report%20DOI_Final_Sept2013.pdf

DOI Office of Policy Analysis. 2013. Conservation Banking Overview and Suggested Areas for Future Analysis. 16 p. http://www.fws.gov/endangered/landowners/pdf/Conservation%20Banking%20Overview%20DOI-Sept2013.pdf

Drummond, W., French, S., 2008. The future of GIS in Planning: Converging technologies and diverging interests. Journal of the American Planning Association, 74:2, 161-174

Endangered Species Act of 1973. Public Law 93-205 as amended through public law 107-136. 2002

Fahrig, L. 2003. Effects of Habitat fragmentation on Biodiversity. Annual Review Ecology Evolution and Systematics 34:487–515

Forman, R.T., Sperling, D., Bissonette, J., Clevenger, A., Cutshall, C., Dale, V., Fahrig, L., France, R., Goldman, C., Heanue, K., Jones, J., Swanson, F., Turrntine, T., Winter, T. 2003. Road Ecology: Science and Solutions. Island Press.

Franklin, J.F. 1993. Preserving Biodiversity: Species, Ecosystems, or Landscapes? Ecological Applications 3:202-205.

Froger, G., Menard, S., Meral, P. 2015. Towards a comparative and critical analysis of biodiversity banks. Ecosystem Services 15:152-161

Gardner, R.H., Milne, B.T., M.G. Turner, M.G., and O'Neill, R.V. 1987. Neutral models for analysis of broad-scale landscape pattern. *Landscape Ecology,* 1(1):19-28.

Gardner, T.A., Von Hase, A., Brownlie, S.,M., Ekstrom, J.M.M., Pilgrim, J.D., Savy, C.E., Stephens, R.T.T., Treweek, J., Ussher, G.T., Ward, G., and Ten Kate, K. 2013. Biodiversity Offsets and the Challenge of No Net Loss. Conservation Biology 27(6):1254-1264.

Goncalves, B., Marques, A., Soares, A., Pereira, H. 2015. Biodiversity offsets: from current challenges to harmonized metrics. Current Opinion in Environmental Sustainability 14:61-67

Hasse, J. and R. Lathrop. 2010. Changing Landscapes in the Garden State: Urban Growth and Open Space Loss 1986 through 2007. New Brunswick, NJ: Center for Remote Sensing and Spatial Analysis, Rutgers University. http://www.crssa.rutgers.edu/projects/lc/NJ_Urb_Growth_III_executive_summary_0801_2010.pdf

Lathrop, R., Niles, L., Conroy, M., Smith, J., Danihel, M. 2014. Creating a more effective protection of endangered and threatened species habitat through conservation banking

Lathrop, R., Bognar, J., Hasse, J., 2016. Changing Landscapes in the Garden State: Land use change in NJ 1986 thru 2012.

Liu, Z., He, C., Zhou, Y., Wu, J. 2014. How much of the world's land has been urbanized, really? A hierarchical framework for avoiding confusion. Landscape Ecology, 29:763-771

Madsen, B., Caroll, N., Moore Brands, K. 2010. State of Biodiversity markets report: Offset and Compensation Programs Worldwide. Washington, DC: Forest Trends. http://www.ecosystemmarketplace.com/documents/acrobat/sbdmr.pdf

Madsen, B., Caroll, N., Kandy, D., and Bennett, G. 2011. 2011 Update State of Biodiversity markets: Offsets and Compensation Programs Worldwide. Washington, DC: Forest Trends. http://www.ecosystemmarketplace.com/reports.2011_update_sdbm

Malanson, G.P. 2003. Habitats, hierarchical scales, and nonlinearities: An ecological perspective on linking household and remotely sensed data on land-cover/land use change. In: *People and the Environment: Approaches for Linking Household and Community Surveys to Remote Sensing and GIS* (Edited by J. Fox, R.R. Rindfuss, S.J. Walsh, and V. Mishra). Kluwer Academic Publishers. Boston. Pp.265-283.

Mitchell, A. 1992. The New Jersey Highlands: Treasures at Risk. New Jersey Conservation Foundation, Morristown, NJ. 152 pp.

Nash, J.R. 2008. Trading Species: A new direction for habitat trading programs. Environmental Law Reporter 38:10539-10552.

New Jersey Department of Environmental Protection. 2013. New Jersey's Endangered and Threatened Wildlife. http://www.state.nj.us/dep/fgw/tandespp.htm

Niles, L.J., J. Myers, and M. Valent. 1999. The Landscape Project. NJ Endangered and Nongame Species Program, NJ Department of Environmental Protection, Trenton, New Jersey. 26 p.

NJDEP Bureau of Freshwater & Biological Monitoring: http://www.state.nj.us/dep/watershedmgt/bfbm/sgwqt.html

Quetier, F. and S. Lavorel. 2011. Assessing ecological equivalence in biodiversity offset schemes: Key issues and solutions. Biological Conservation 144 (2011) 2991-2999

Ten Kate, K., Bishop, J., and Bayon, R. 2004. Biodiversity offsets: views, experience, and the business case. International Union for the Conservation of Nature.

http://www.insightinvestment.com/Documents/responsibility/Executive_Summary_Biodiversity_Offsets_Report.pdf

Trombulak, S.C. and Frissell, C.A. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14(1):18-30.

Turner, B., Lambin, E., Reenberg, A. 2007. The emergence of land change science for global environmental change and sustainability. Proceedings of the National Academy of Sciences of the United States of America, 104:52:20666-20671

Turner, W., Spector, S., Gardiner, N., Fladeland, M., Sterling, E., Steininger, M. 2003. Remote sensing for biodiversity science and conservation. Trends in Ecology and Evolution 18:6:306-314

U.S. Fish and Wildlife Service. 2003. Guidance for the Establishment, Use, and Operation of Conservation Banks. Memorandum, May 2. 18 p.

U.S. Fish and Wildlife Service. 2012. Conservation Banking: Incentives for Stewardship. Factsheet. http://www.fws.gov/endangered/esa-library/pdf/conservation_banking.pdf

U.S. Fish and Wildlife Service. 2016. Endangered and Threatened Wildlife and Plants: Endangered Species Act Compensatory Mitigation Policy. Federal Register Vol. 81, No. 248, pp. 95316 - 95349

Wilcove DS, Rothstein D, Dubow J, Phillips A, Losos E. 1998. Quantifying threats to imperiled species in the United States. BioScience **48**:8:607-615

Wilcove, D.S. and Lee, J. 2004. Using Economic and Regulatory Incentives to Restore Endangered Species, Conservation Biology 18:639.

With, K.A., and Crist, T.O. 1995. Critical thresholds in species' responses to landscape structure. *Ecology*, 76(8):2446-2459.

Zampella, R.A., Procopio, N.A., DuBrul, M.U., and Bunnell, J.F. 2008. An Ecological-Integrity Assessment of the New Jersey Pinelands: A Comprehensive Assessment of the Landscape and Aquatic and Wetland Systems of the Region. The New Jersey Pinelands Commission, New Lixcccsbon, NJ. 168 p. http://www.state.nj.us/pinelands/images/pdf%20files/EIA_Final_Report.pdf

Zipperer, W.C. 1993. Deforestation Patterns and their Effects on Forest Patches. Landscape Ecology 8:177-184.

# CHAPTER 1 - Wildlife Habitat Value

## A method of habitat valuation for threatened and endangered species for use in planning, mitigation, or conservation banking

## Abstract

Off-site mitigation is an increasingly integral part of conservation and rehabilitation of threatened and endangered (T&E) species. Proactive planning of mitigation areas can result in more cohesive, larger areas than ad hoc case-by-case approaches. Conservation banking can be a mechanism to support a strategic approach to habitat conservation. A major difficulty inhibiting the wide use of conservation banking is that of determining debits and credits. It is especially difficult to determine debits and credits without having population presence data. We developed a method of valuing habitat from the species perspective without having presence data using widely available data: primarily land use, land cover Geographic Information Systems (GIS) maps, along with life history and home range/habitat use information for each species. The values calculated can be used to set conservation banking debits and credits. Our assessment using independent sightings data, multiple metrics, and 15 species of a variety of taxa confirms the reliability of the habitat values calculated.

# Introduction

Habitat destruction and degradation are the most pervasive threats to biodiversity and contribute to the endangerment of the vast majority of species listed as threatened and endangered (Wilcove et al. 1998). The purposes of the Endangered Species Act of 1973 (ESA) include “to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved” (Endangered Species Act of 1973). To this end, the mitigation hierarchy has been set out in Federal regulations. The hierarchy is to avoid negative impacts to threatened and endangered species or their habitat; if avoidance is impossible, then reduce the negative impact followed by the options of restore, offset, and compensate in order to create a positive impact elsewhere to offset the negative one. Conservation Banking has developed as an option for the last steps in the hierarchy: restoring, offsetting, and compensating for negative impacts to species habitat.

Conservation banks are lands containing natural resource values that are permanently protected and managed for conservation of species of concern (USFWS 2012), and conservation banking is the process of developers purchasing habitat or species credits from a conservation bank to offset unavoidable adverse impacts of their projects (USFWS 2012; Bunn et al. 2014). These credits are also called offsets. Conservation banking facilitates pooling of mitigation resources from multiple developers or development projects, allowing larger tracts of contiguous land to be preserved and managed than would occur with permittee-responsible mitigation (Bunn et al. 2014). Species credits are primarily created through preservation and management of habitat, the idea being that by conserving large areas of high quality habitat with connectivity to other preserved sites and managing the land to support species recovery the species will persevere and thrive despite a net loss of habitat (Madsen et al. 2010). Preservation creates value because though preserved land carries no current extra value to the species, the future value is enhanced; Thus if the present value of the future use of the land is taken into account, preservation raises the value. Through conservation banking, the objective is not "no net loss of habitat *area"*, but rather no net loss of habitat *value* while still meeting the broader goal of species recovery.

In our study area of New Jersey, USA, where T&E species conservation banking has yet to be implemented, many of the existing mitigation projects which have been mandated for T&E species are ad-hoc, one-off projects which may not have sufficient concern for long-term viability. Many are small, fragmented, habitat areas that are being restored or conserved. However, it is the large contiguous tracts of forest, wetland, and grasslands (i.e. natural habitat) that are not fragmented by human development that are especially valuable as wildlife habitat.

Conservation Banking creates an economic incentive to conserve or restore endangered species habitat.  Previously, owning endangered species habitat could be an economic detriment which led some people to prevent endangered species from occupying their property by proactively destroying unoccupied habitats – an approach dubbed the "scorched earth" technique by the National Association of Homebuilders (Wilcove and Lee 2004). Conservation banking creates a positive economic value and potential market for land supporting T&E species. Land-owners can sell property to conservation banks or create conservation banks.

A great difficulty with Conservation Banking is determining the debits (quantitative measure of the adverse impacts of intended use) incurred by developers and determining the credits generated by conservation bank owners by permanently protecting, perpetually managing and perhaps restoring the habitat areas of the bank. The lack of methods for setting tradable credits is a major problem inhibiting the spread of conservation banking as a conservation tool (Madsen et al. 2010, 2011; Bunn et al. 2013). Currently many conservation banking areas use an acre-for- acre swap which leads to the task of finding an area of similar quality to preserve. Others perform an ad hoc biological survey on land to be developed and a few sites that have been identified as areas for potential mitigation (Madsen et al. 2010). It is expensive and time consuming to do biological surveys. Some surveys can only be done seasonally. Thus, if surveys are needed to determine debits and credits of conservation banking, the time lag can be long, which is expensive for developers. In addition, very few areas are usually surveyed so the choice of locations of development and mitigation under this method are constricted. Many widely-used species distribution models, which can be used for prediction and extrapolation of species presence, are for the most part models based on observations of species occurrence or abundance (Elith and Leathwick, 2009).

We sought to fill the knowledge and methodology gap that exists for setting wildlife conservation banking debits and credits, because the lack of reasonable and affordable methods of setting debits and credits hinders the spread of conservation banking. We proposed to set tradable credits based on assessments of wildlife habitat value defined as the relative value of the habitat to the species, using affordable, easily accessible information. We developed a consistent, proactive, efficient, and effective method to determine credits that vary according to the quality of the habitat and are calculable over wide landscapes (such as statewide) which can be monitored long-term. We have completed the modelling in geographic space as opposed to the environmental space often used as a first step in species distribution modelling due to the fact that we have worked with several species in which many of the members are wide-ranging and thus habitat integrity and cohesion are key components of habitat value in these cases. We tested the method on fifteen species in a variety of taxa over a wide geographic area.

Our objective was to develop a method that is internally consistent for each species so that true offsetting of habitat areas over large landscapes can be achieved such that there is no net loss of habitat value. Our method is proactive so that development can be nudged into inferior habitat or non-habitat while conserving core and other high quality habitat. Our method is efficient so that estimates can be done in a timely manner with reasonable transaction costs such that conservation banking can be widely instituted.

# Methods

### Study Region, Species Modelled, and Parameters

We studied the entire state of New Jersey. As we sought to determine whether it was possible to design a model using extant, widely available data such as landscape characteristics over a wide area, we tested the model on a wide area: an entire state. The model is on a base layer of 50 foot grid cells based on 2007 land use/land cover maps and NJ Land Use/Land Cover codes (Modified Anderson LU/LC code). This was a fine enough scale for site-based planning and decision-making (i.e., at the scale of a typical ownership parcel). The model also relies upon the species-specific information documented in the NJ

Endangered & Nongame Species Program (ENSP) Landscape Project Version 3 (LP3) (New Jersey Department of Environmental Protection, 2012). This information includes the land use/land cover types that constitute each species' known habitat, what constitutes core area vs. edge area, and the species' home range or siting diameter size.

We conjectured that, because we were using landscape level data, wide-ranging species whose habitat requirements were general enough to be captured by Anderson Land Use/ Land Cover codes would be the best candidates for our model. Our test species are New Jersey listed T&E species from a variety of taxa: Barred owl (*Strix varia*), Black-crowned night heron (*Nycticorax nycticorax*), Bobcat (*Lynx rufus*), Bobolink (*Dolichonyx oryzivorus*), Bog turtle (*Glyptemys muhlenbergii*), Grasshopper Sparrow (*Ammodramus savannarum*), Indiana Bat (*Myotis sodalis*), Long-eared Owl (*Asio otus*), Long-tailed Salamander (*Eurycea longicauda*), Northern Goshawk (*Accipiter gentilis*), Red-headed Woodpecker (*Melanerpes erythrocephalus*), Red-shouldered Hawk (*Buteo lineatus*), Timber Rattlesnake (*Crotalus horridus*), Vesper Sparrow (*Pooecetes gramineus*), and Wood Turtle (*Glyptemys insculpta).*

We mapped all habitat suitable for each species without limiting it to habitat that has been proven to be occupied by the species. In fact, during the modelling process we had no species presence nor absence data. Suitable habitat without confirmed sightings may be used or inhabited by the species. Suitable but currently unoccupied habitat may be needed for recovery such as increase in population size or improvement in status to achieve long-term persistence (Camanclang et al. 2015).

Our metric of habitat value is grounded in sound conservation biological principles as measured by species habitat area, intactness, and contiguity. The three components of

WHV are a measure of habitat, a measure of core habitat, and a measure of contiguity. These were chosen as the most appropriate measures for several reasons. Clearly whether a property has the land cover needed by a species is crucial as to whether it is habitat at all for the species and has a direct bearing on whether it is good habitat or not; thus the index for whether an area is habitat. Many studies have indicated that edge habitat for many species is inferior to core habitat including most of the T&E species (Forman et al. 2003); thus the index of core habitat. Connectivity to other habitat is crucial to ensure mating opportunities and gene flow between populations to avoid inbreeding depression which can especially be a problem with rare species (Bunn et al. 2013) and thus an index of contiguity was developed.

## Model Specifics

We employed a grid-based modeling approach repeating the same model steps for each species. We begin with land use/land cover maps and analyze to get wildlife habitat values (WHV). (Figure 1) We used both ArcMap and Imagine for the analysis.

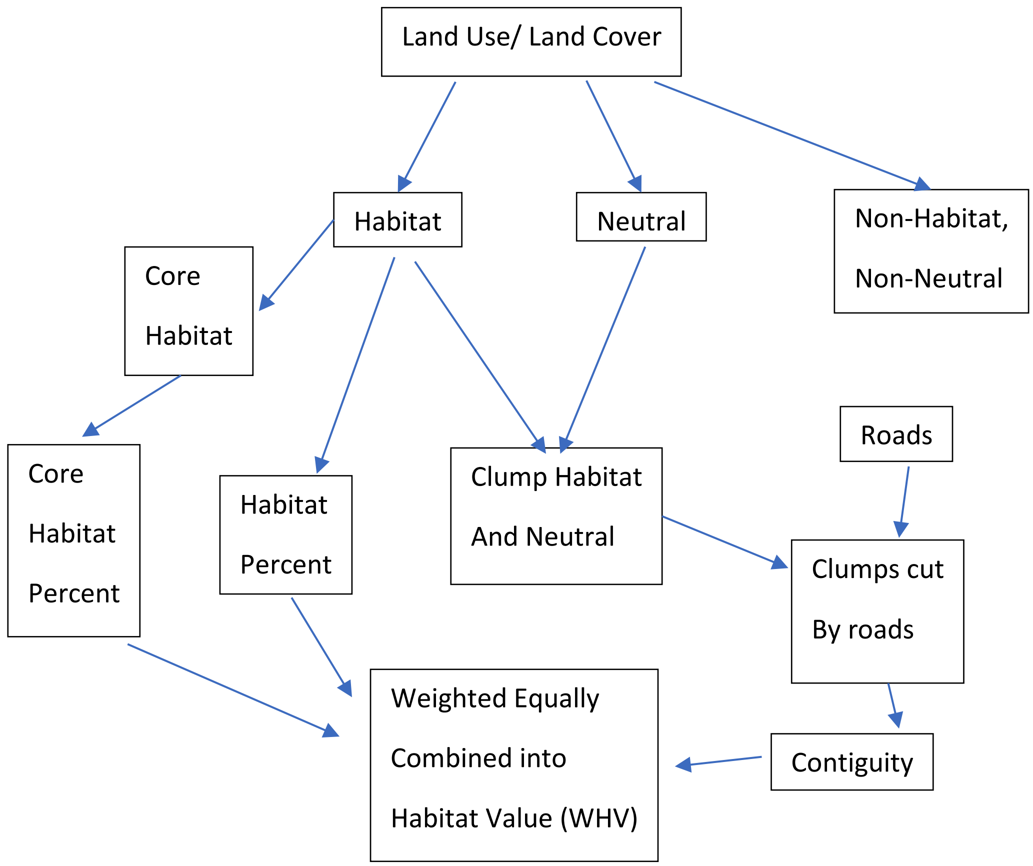



Figure 1. Detailed flowchart for Wildlife Habitat Value model.

We rasterized the NJ Land Use Land cover map into 50 foot pixels using NJ State Plane projection. This grid cell resolution was chosen to provide a reasonable degree of spatial detail but also allow for efficient statewide GIS processing. We added a 10 km buffer around the state using the national land use land cover data in order to get more correct habitat values near the borders of NJ where habitat patches might extend into neighboring states. We re-projected the original national data which was 30 meter pixels to state plane coordinates and recoded into as close to the NJ LU/LC categories as possible then changed to 50 foot pixel size. We merged NJ and buffer in a union with maximum value. Definitions of what land use/land cover types constitute habitat for each species and home range size came from NJ Department of Environmental Protection Endangered and Non-game Species Program Landscape Project data. (NJDEP 2012). The NJ Landscape Project definitions of habitat were chosen because they have been developed by wildlife biologists familiar not only with the species, but with their habitats and ranges within New Jersey and because these habitat definitions and home range sizes have been accepted by many of the stakeholders of this habitat value model.

We categorized land into three categories: potential habitat, neutral non-habitat, and altered non-habitat with a thematic output. (Figure 2) We buffered 300 feet inward from altered non-habitat. We defined core habitat area as habitat less the buffer.

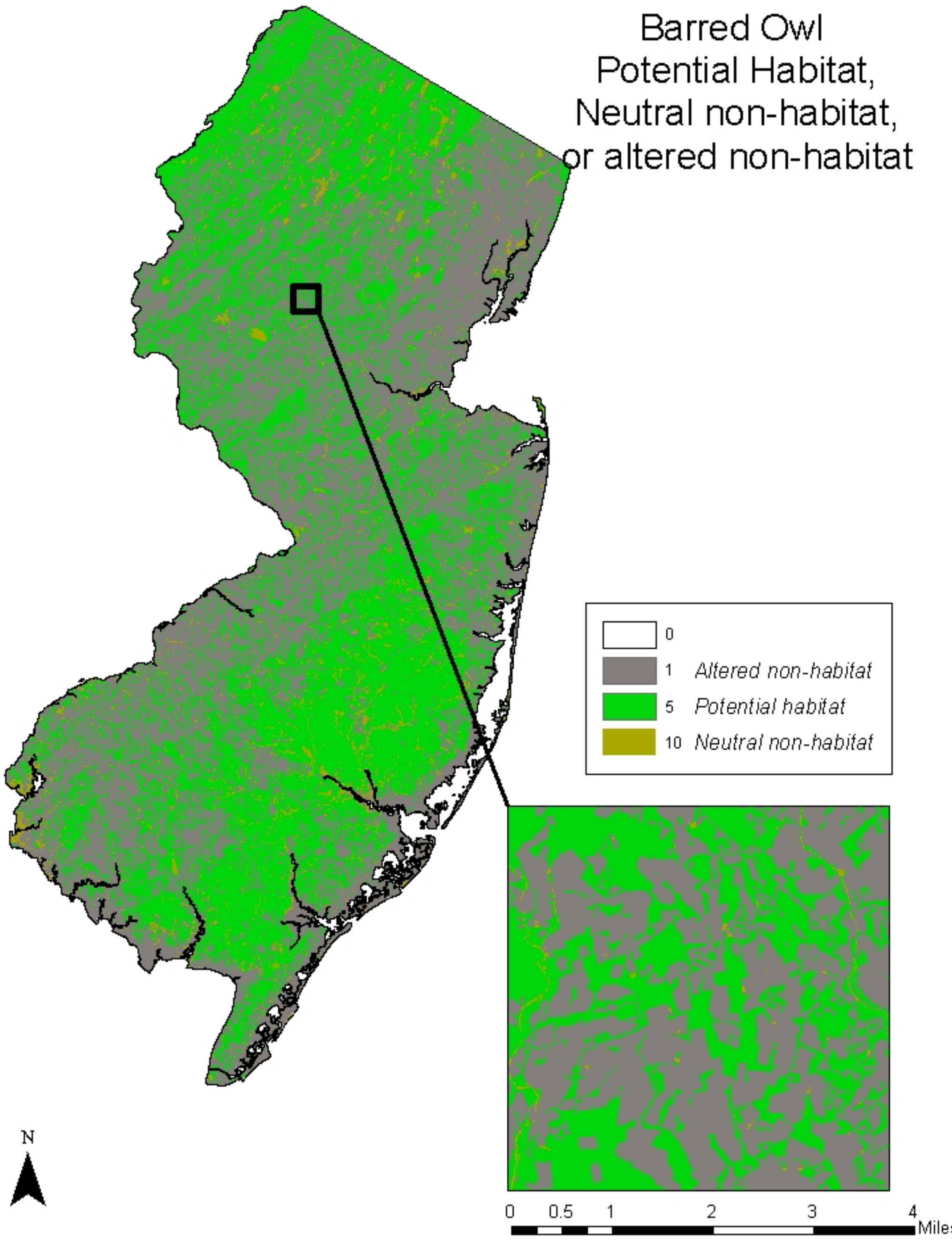



Figure 2: Barred owl potential habitat, neutral non-habitat, and altered non-habitat shown statewide.

## Habitat and Core Habitat

We calculated the percentage of potential suitable habitat using a GIS moving window approach which determines the value of a pixel using a circular window equal in size to the average home range area centered at the pixel. This approach is similar to that employed to characterize landscape integrity in the New Jersey Pinelands (Zampella et al. 2008). The percentage of the pixels within the circular area that are designated habitat multiplied by 100 is the value of the central pixel. This represents the amount of the home range centered at the pixel that is habitat. After applying the moving window we masked to include only previously defined habitat areas. (Figure 3) We calculated the percentage of core habitat analogously. (Figure 4)

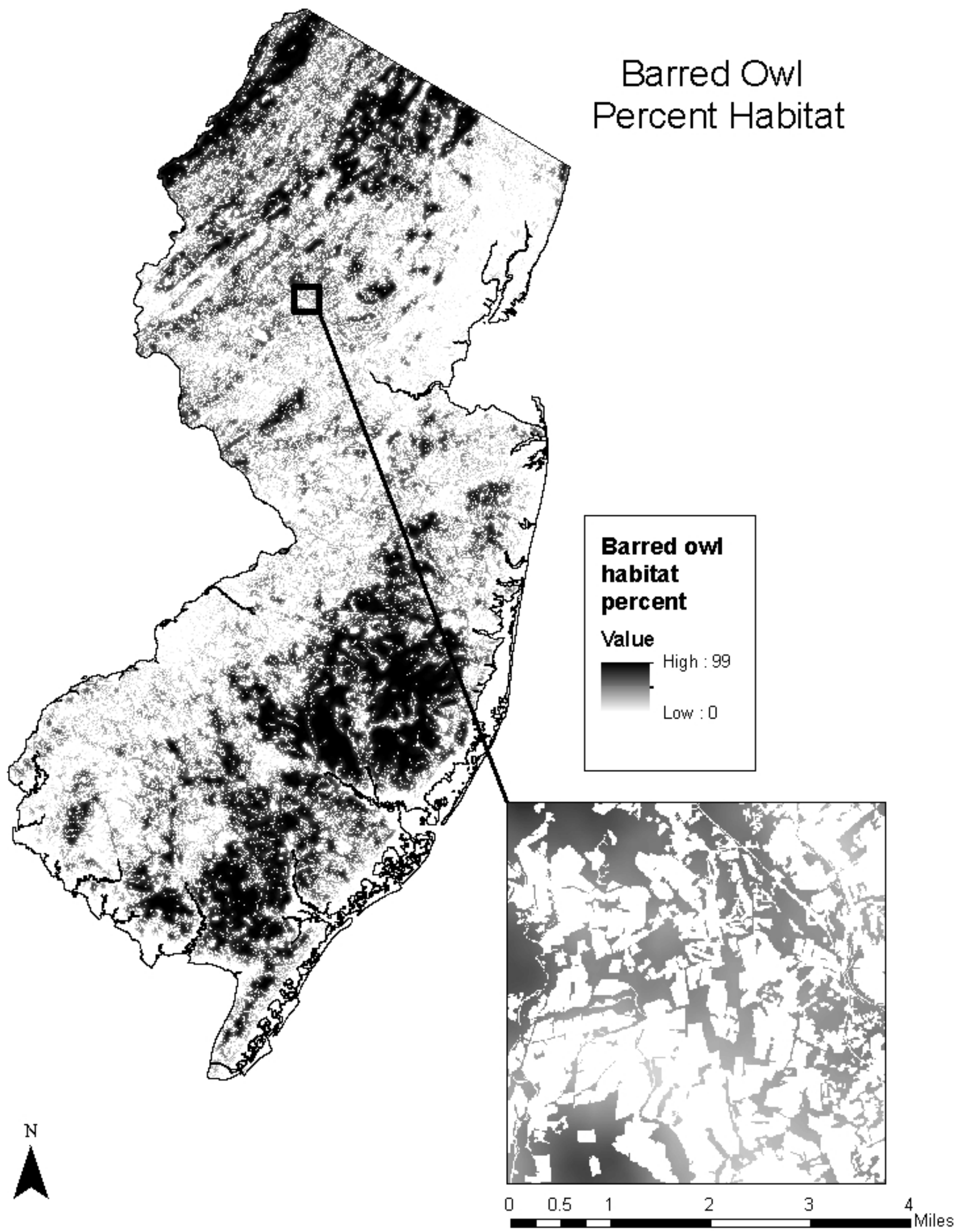



Figure 3: Barred Owl Percent Habitat: percent of the surrounding circular area of average home range size that is habitat.

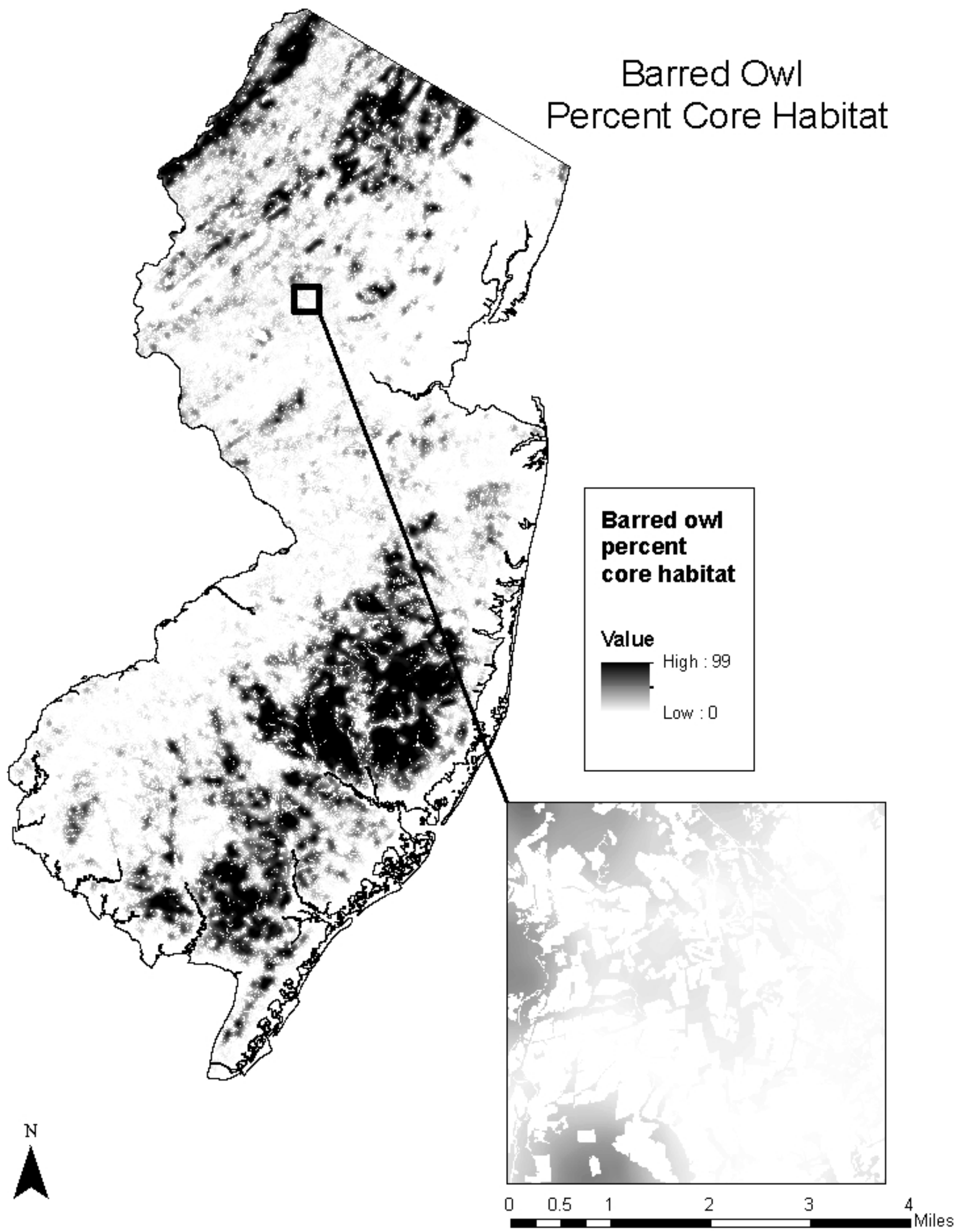



Figure 4: Barred Owl Percent Core Habitat: percent of the surrounding circular area of average home range size that is core habitat.

## Contiguity

The third measure in the habitat value calculation is a measure of the contiguity of the habitat. We gave habitat areas higher scores if the species in question could easily travel from the pixel rated to other habitat area. Our measure takes into account the size of the current patch as well as the ease of connecting to other habitat patches and the size of the connected patches. We completed the calculations in several steps.

As the first step we took the habitat and added to it the neutral landscape under the assumption that each species can easily move through habitat that is classified as neutral for that species. This may include streams, right-of-ways and other types of habitat depending on the species. Next, we zeroed out the value of certain categories of roads with the result that areas divided by a difficult to cross road were cut into pieces. We selected the road types based on the type of locomotion of the species as well as the average road speed and volume.

We then clumped the habitat plus neutral minus roads. The object here is to make “superclumps” of patches of habitat that are within travelling distance of each other (Figure 5). A superclump consists of patches of habitat combined with the neutral non-habitat that surrounds the habitat, bounded by roads which are barriers to movement. Each pixel of habitat within a superclump is given a value based on the amount of total habitat within the superclump. A superclump containing more habitat gets a higher value.

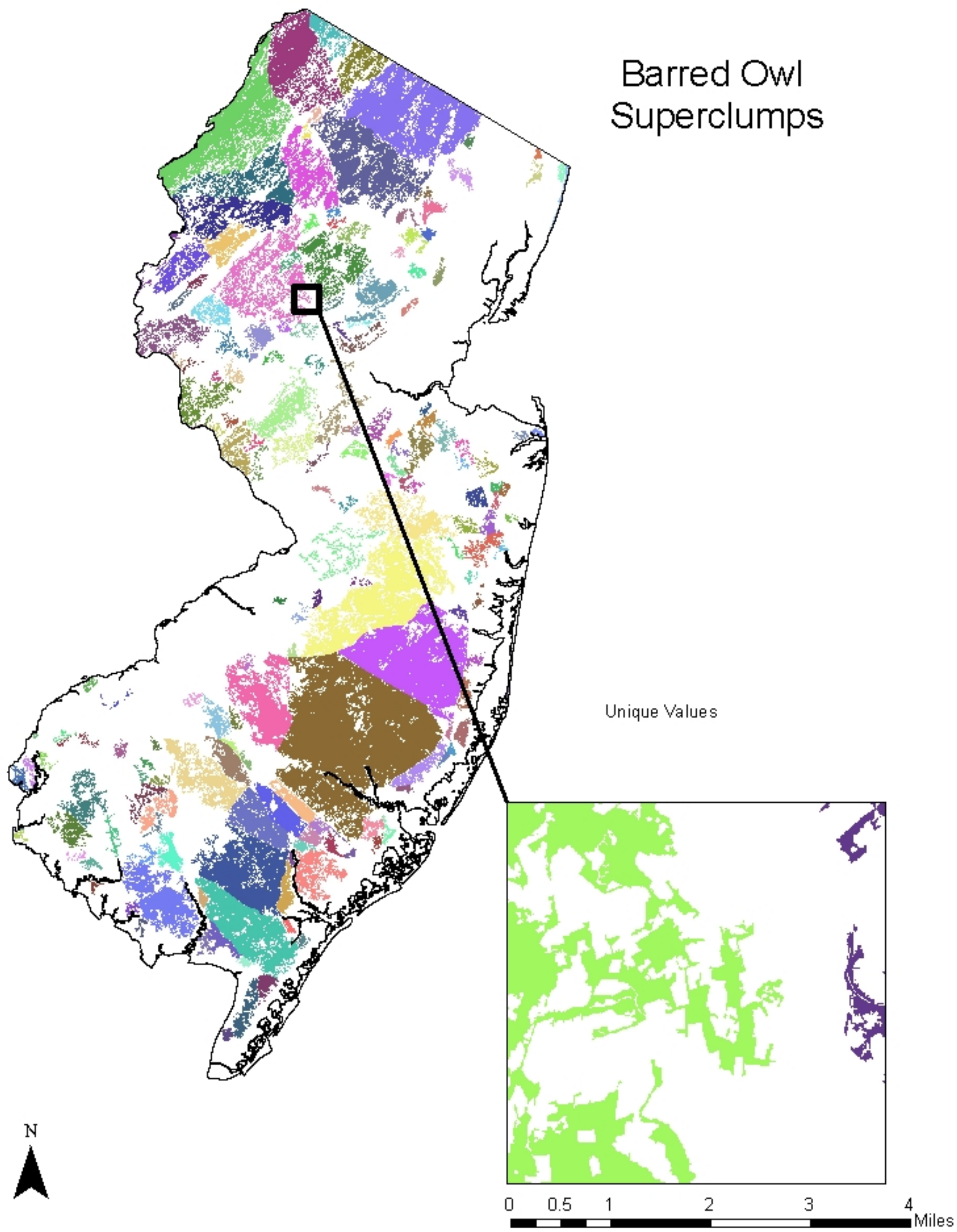



Figure 5: Barred owl superclumps of habitat: Contiguous areas of habitat. Each color represents an area to which a barred owl can easily travel (through habitat or neutral non-habitat and avoiding major roads).

Superclumps are sieved so that areas less than one home range are not included. In order to be able to combine these measures meaningfully with the 0 to 100 relative value measures of percent habitat and percent core habitat we converted the straight area values to 0-100 values where 100 is “very good” or “ideal” and 0 is nonhabitat. The number of home ranges needed to support a reasonably large population was estimated using existing literature or extrapolation from similar species. Area measures are normalized by dividing by the area of the selected number of home ranges (Table 1). The pixels of habitat in any superclumps larger than or equal to that number of home ranges noted in the table get the highest value of 100. Other values range linearly down to 0.

Table 2. Roads viewed as barriers to movement of endangered and threatened species and number of home ranges for full contiguity value.

| Species | Interstate Highway | US Highway | State Highway | Toll Road | County 599 Series Route | Other County Series Route | Local Road | Ramp | Unimproved Roads | Number of Home ranges for Full Contiguity Value |
|---|---|---|---|---|---|---|---|---|---|---|
| Barred Owl | X | X | X | X | | | | X | | 45 |
| Timber Rattlesnake | X | X | X | X | X | X | X | X | | 100 |
| Blue Spotted Salamander | X | X | X | X | X | X | X | X | X | 100 |
| Bobcat | X | X | X | X | | | | X | | 2 |
| Indiana Bat | X | X | X | X | | | | X | | 45 |
| Bobolink | X | X | X | X | | | | X | | 200 |
| Grasshopper Sparrow | X | X | X | X | | | | X | | 200 |
| Longeared Owl | X | X | X | X | | | | X | | 45 |
| Longtailed Salamander | X | X | X | X | X | X | X | X | X | 100 |
| Northern Goshawk | X | X | X | X | | | | X | | 45 |
| Redheaded Woodpecker | X | X | X | X | | | | X | | 45 |
| Red Shouldered Hawk | X | X | X | X | | | | X | | 45 |
| Savannah Sparrow | X | X | X | X | | | | X | | 200 |
| Vesper Sparrow | X | X | X | X | | | | X | | 200 |
| Wood Turtle | X | X | X | X | X | X | X | X | X | 100 |
| Bog Turtle | X | X | X | X | X | X | X | X | X | 200 |
| Black-Crowned Night Heron foraging | X | X | X | X | | | | X | | 1 |
| Black-Crowned Night Heron nest | X | X | X | X | | | | X | | 45 |
| Great Blue Heron | X | X | X | X | | | | X | | 45 |
| Northern Pine Snake | X | X | X | X | X | X | X | X | | 100 |
| The Xs mark which roads are viewed as barriers and used to cut the contiguous clumps. | | | | | | | | | | |

Finally, I created a composite Wildlife Habitat Value (WHV) map for each species by equally weighting together the three components: suitable LU/LC, core area, and habitat contiguity (Figure 1 and Figure 6). It is instructive to see the wildlife habitat values in the context of the overall condition of the state. Some of the wildlife habitat is already protected, shown in malachite green. The developed areas are shown in brown (Figure 7).

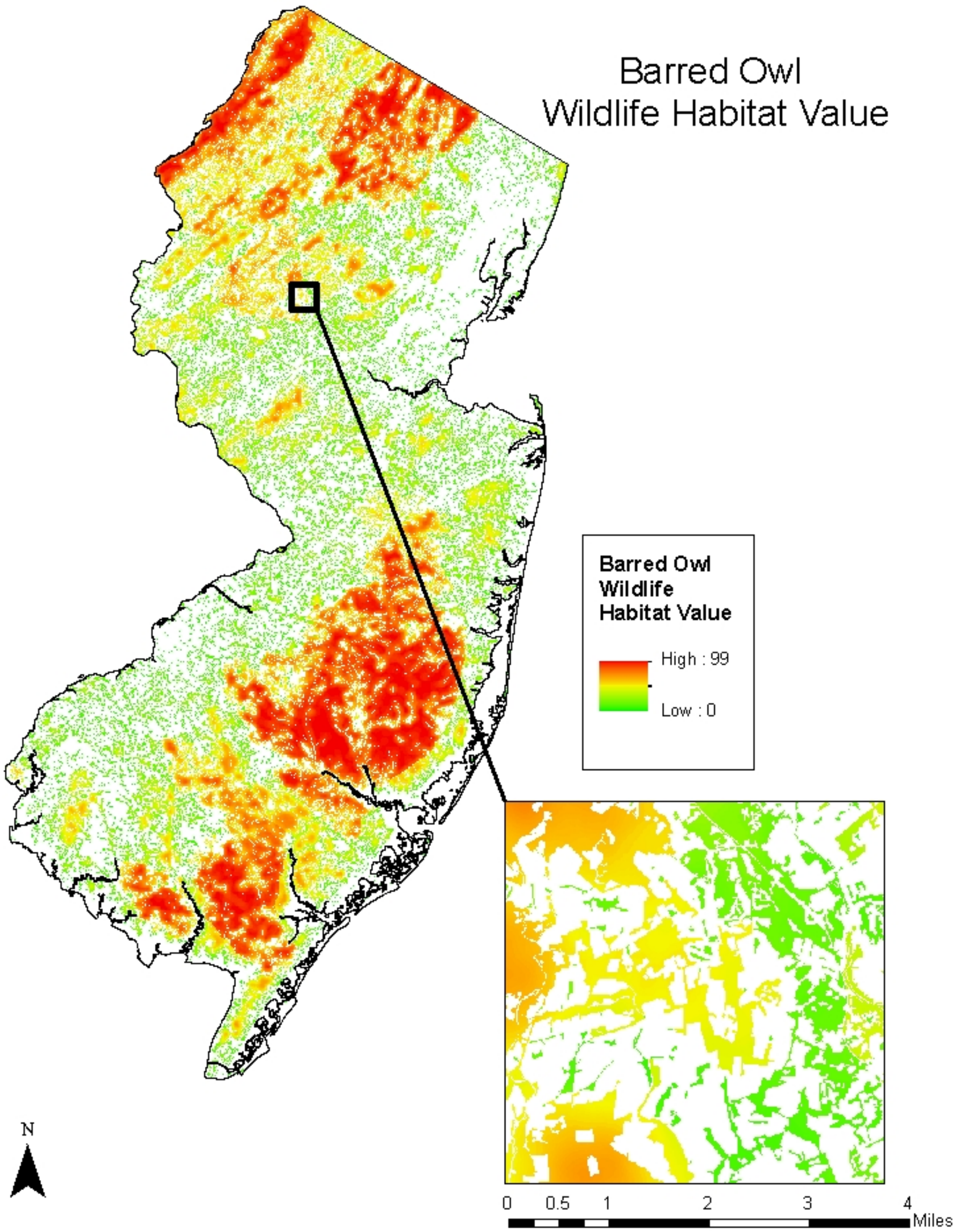



Figure 6: Barred owl wildlife habitat value: High values are shown in red and low values in green. Intermediate values range from red through orange and yellow into green.

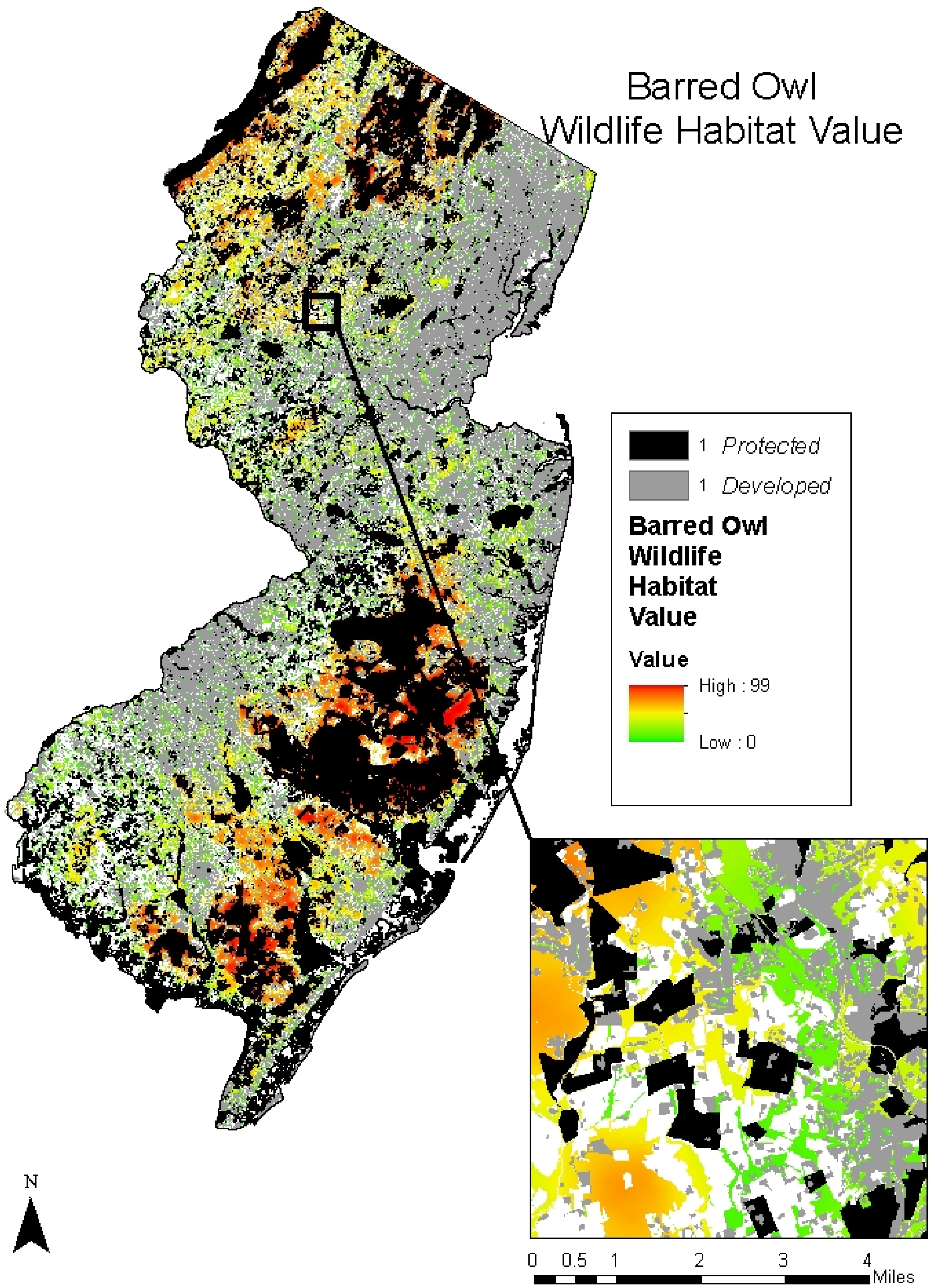



Figure 7: Barred owl wildlife habitat value shown with overlay of protected and developed land.

## Assessment

To assess the validity of the resulting models we compared the estimated habitat quality maps with an independent data set of T&E species location. As noted above, we had neither species presence nor absence data during modelling, but after completion of the models we were able to obtain presence data which was thus completely independent of the model and, therefore, suitable as an assessment tool. We sought some indication of whether our wildlife habitat value is a valid indicator of likelihood of species presence, of density of species population, or of carrying capacity for species. We attempted to determine whether the composite WHV for a grid cell location was a better indicator of species presence than random chance alone. If one assumes that the distribution of sightings across the area is uniform or random, then across Wildlife Habitat Value (WHV) classes the sightings will more likely in classes with higher areas and less likely in classes with lower areas, and the number of sightings per area will be uniform (with random variation) across WHVs. If sightings are more concentrated in areas of higher value it may indicate that the model is correctly identifying higher value habitat

## Complications from Data

There are, naturally, several complications to this evaluation. One is observation bias. Some observations are road-based which would bias observations towards roads and hence away from core habitats. Other observations (those not from a random sampling or a transect) may be biased toward areas more frequented by humans which, for many species, would be non-core areas. This observation bias is a bias toward more sightings in lower WHV areas than an unbiased observation method of assessment would indicate.

The data are not comprehensive, they are opportunistic. The sightings are over a period of 30 years.

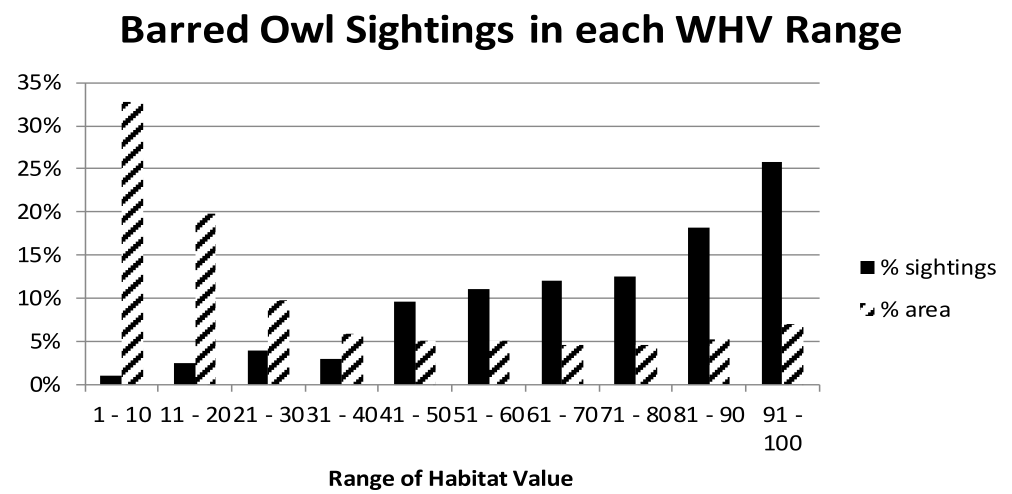
There are no absence data. If there are no sightings in an area, it is not known whether there is an absence of the species or simply whether there was no sighting.

## WHV Model Validation

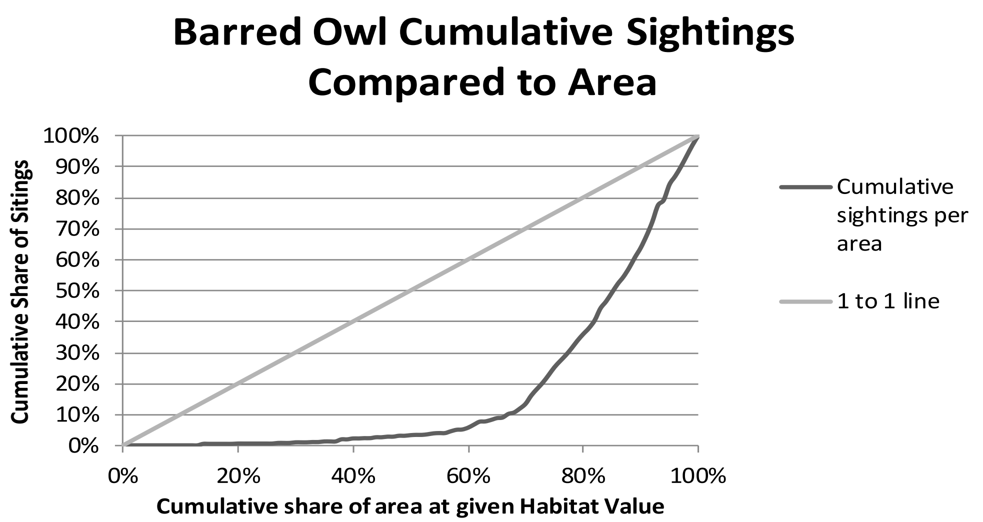
We used the NJ ENSP's Natural Heritage sightings location data as the independent data set to assess WHV. These data were collected between 1980 and 2013 and consist of three types: point sightings, line sightings, and polygon sightings. Though land use and land cover has changed in NJ since 1980, the number of data points available using just the most recent data, was insufficient in volume on its own and thus we included sightings back to 1980. Point sightings are individual sightings points that have been verified. Points are categorized into 18 categories including breeding sightings, non-breeding sightings, on road, physical evidence, etc. Locational accuracy of place is thought to be high, though there are cases, especially with some of the bird species in which the location of the observer is logged instead of the location of the bird(s). Line sightings are lines drawn from vertices which are readings from tagged individuals. In order to deal with autocorrelation issues presented from tagging, we have counted each line as one observation, the measure being the average of the measures of the individual vertices. Polygon sightings are polygons that have been drawn by ENSP using sightings, survey, and other information in order to estimate polygons inhabited by the species. In order to minimize road bias, we measured the maximum habitat value within a radius of 300 feet of the sighting point for points and vertices. For polygons, we took the maximum habitat value within the polygon. Taking the maximum minimizes road bias, but may bias the findings upward.

We analyzed the results of the wildlife habitat value models both graphically and quantitatively. For purposes of illustration we will be discussing one species, barred owl and showing graphs for point sightings. However, each species for all types of data (point, line, polygon) was analyzed similarly and results for all species are available. Graphically we looked at three measures: sightings frequency compared to area in a range of WHV, cumulative sightings compared to cumulative area, smoothed percent of sightings per percent of area. (Figure 8) Related to these are three quantitative measures: the average habitat value of the sightings divided by the average habitat value by area, the area under the curve of the graph of the cumulative share of the sightings compared to cumulative share of area for each habitat value, and the slope of the fitted line to the smoothed sightings per area.

(a)


Barred Owl Sightings in each WHV Range
35%
30%
25%
20%
15%
10%
5%
0%
1 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
Range of Habitat Value
% sightings
% area

(b)


Barred Owl Cumulative Sightings Compared to Area
Cumulative Share of Sitings
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0%
20%
40%
60%
80%
100%
Cumulative share of area at given Habitat Value
Cumulative sightings per area
1 to 1 line

(c )

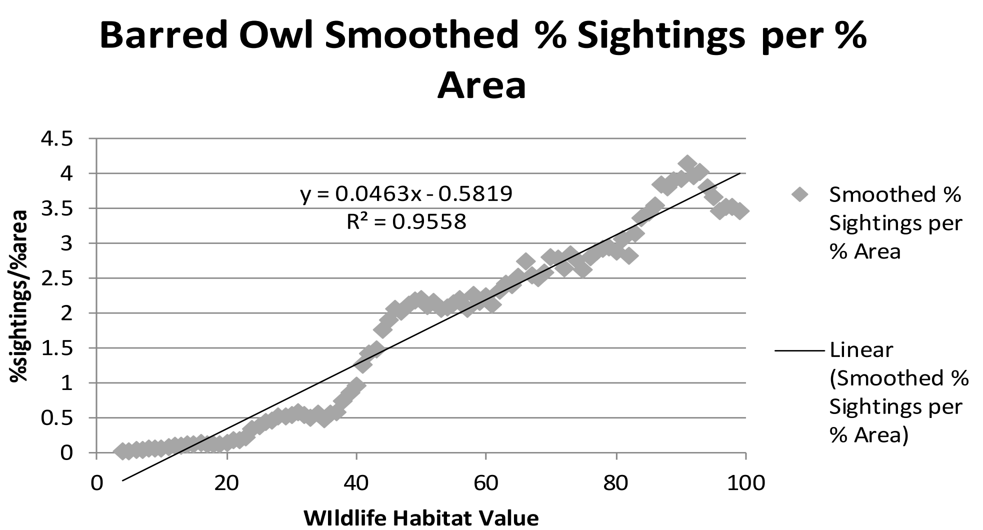

Barred Owl Smoothed % Sightings per % Area
%sightings/%area
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
WIldlife Habitat Value
y = 0.0463x - 0.5819
R² = 0.9558
Smoothed % Sightings per % Area
Linear (Smoothed % Sightings per % Area)

Figure 8: Results of assessment for barred owl 8(a) The percent of sightings and the percent of area in each decade of WHV 8(b) cumulative share of sightings compared to cumulative share of area at a given habitat value 8(c) smoothed percent sightings per percent area

### Sightings compared to Area in each decade of WHV

If the model is useful for the species modelled one would expect (before taking into account the biases listed above) that if the percent of all the sightings in each decade of the Wildlife Habitat Value (WHV) range (Figure 8 solid) were graphed with the percent of land area in those same ranges (stripe) the sightings bars would be higher than the WHV bars on the higher WHV and lower on the lower WHV.

Related to this is the quantitative measure of average habitat value of sightings divided by average habitat value by area; If greater than one, good, and higher numbers are better.

### Gini Coefficient Variant

The second measure is a variant of the Gini coefficient used to measure the equality of values. Generally the Gini coefficient is used as a measure of inequality of income or wealth. The Gini coefficient is based on the Lorenz curve. For the Lorenz curve the cumulative share of people from lowest to highest income is the independent variable and the cumulative share of income earned by those people is the dependent variable. The Gini coefficient is [1-2(area under the curve)]. A value of 0 is complete equality and 1 is complete inequality. Our variant plots the cumulative share of sightings as the dependent variable on the cumulative share of area at a given Wildlife Habitat Value, the independent variable. (Figure 8) If the sightings were uniform, one would expect these to fall exactly on the 1:1 line. If the sightings were random, one would expect them to fall with equal probability on either side of the 1:1 line. If the WHV model has predictive value one would expect the curve to have a low slope at the lower x values and a steepening slope at the higher x values.

If there are more sightings per area at the higher habitat values, then the curve will be analogous to the Gini coefficient curve. In our case the curve can be above the line of equality if, for example, the lower habitat values have more sightings per area than the higher ones. Thus, the original Gini curve is not an appropriate measure and there is a need for the variant measure. Our variant is the measure of the area under the curve. A curve with a very low area under the curve implies that there are more sightings per area at the higher habitat values and hence the WHVs are very instructive in where one is likely to find members of the species. Extreme inequality in our case is the desired state; Lower values are better. (Figure 8)

### Smoothed Sightings per Area

The third chart for each species is a graph of smoothed sightings per area (9 habitat values included in each point; the point itself, four lower, four higher) graph for each WHV. A line is fitted to points up to the highest wildlife habitat value at which sightings are present. With this measure a negative or zero slope would mean that higher WHV do not indicate higher number of sightings whereas positive slope would mean that higher WHV incur a higher number of sightings, with a higher positive slope.

## Results

We have found the model to indicate higher WHVs in the same areas where there are a higher density of sightings. For example for barred owl all three graphs as well as all quantitative measures indicate higher density of sightings at higher WHV. (Figure 8) There are many more sightings in the higher WHV areas than would be expected with a random or uniform distribution.

If sightings occurred in proportion to habitat, the solid and empty bars (Figure 8a) would be equal height when graphed by decade. Thus, the model appears to be a better predictor of presence of barred owls than random chance alone. Related to this is the quantitative measure of average habitat value of sightings divided by average habitat value by area. In this case higher numbers are better. Anything greater than one is good. The value for barred owl is 2.20.

The area under the curve of cumulative share of sightings on cumulative share of area at a given WHV for barred owl is 0.18 which is fairly low and far below the line of equality (area 0.5) indicating that the model is a good predictor of species presence in this case. There are many more sightings in high habitat value areas even normalized for area. (Figure 8b)

The slope of the line fitted to the smoothed percent sightings per percent area is 0.045 which is clearly positive. (Figure 8c)

The graphs for the other species modelled and for lines and polygons can be found in the supplementary materials.

The quantitative measures for all the species support our hypothesis that the model is a better predictor of species presence than chance alone. (Table 2 shaded areas)

Table 2. The three quantitative values for the assessment of the wildlife habitat value for each of three types of data in our independent data set and the number of sightings in each type of data. Shaded values indicate good fit for model.

| Species | Gini Coefficient Variant Area Under the Curve | | | Smoothed Sightings per Area Slope | | | Average Habitat Value of Sightings/Average Habitat Value by Area | | | Number of Sightings | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Points | Lines | Polygons | Points | Lines | Polygons | Points | Lines | Polygons | Points | Lines | Polygons |
| Bobcat | 0.34 | 1.01 | 0.28 | 0.04 | NA | 0.05 | 1.25 | 0.09 | 1.35 | 536 | 1 | 10 |
| Indiana Bat | 0.44 | 0.73 | | 0.02 | (0.03) | | 1.04 | 0.64 | | 190 | 42 | |
| Bog Turtle | 0.26 | | 0.28 | 0.11 | | 0.00 | 1.99 | | 1.79 | 20 | | 215 |
| Wood Turtle | 0.28 | 0.33 | 0.20 | 0.02 | 0.02 | 0.06 | 1.49 | 1.39 | 1.74 | 934 | 11 | 4 |
| Timber Rattlesnake | 0.34 | 0.51 | 0.46 | 0.03 | 0.00 | 0.02 | 1.14 | 0.99 | 1.05 | 736 | 74 | 29 |
| Long-tailed Salamander | 0.23 | | 0.25 | 0.03 | | 0.16 | 1.74 | | 1.45 | 140 | | 10 |
| Black-Crowned Night Heron | 0.62 | | 0.88 | (0.00) | | (0.08) | 0.65 | | 0.19 | 10 | | 93 |
| Northern Goshawk | 0.42 | | 0.40 | 0.03 | | 0.03 | 1.12 | | 1.17 | 20 | | 4 |
| Red-Shouldered Hawk | 0.21 | 0.38 | 0.40 | 0.04 | 0.18 | 0.00 | 1.90 | 1.08 | 1.19 | 339 | 2 | 7 |
| BarredOwl | 0.18 | 0.20 | 0.20 | 0.05 | 0.11 | 0.04 | 2.20 | 2.04 | 2.12 | 1,037 | 7 | 13 |
| Long-eared Owl | 0.34 | | 0.45 | 0.06 | | 0.08 | 1.67 | | 0.94 | 18 | | 4 |
| Red-headed Woodpecker | 0.21 | | 0.27 | 0.02 | | 0.01 | 1.34 | | 1.23 | 266 | | 8 |
| Bobolink | 0.06 | | 0.11 | 0.05 | | 0.05 | 2.82 | | 2.61 | 1,056 | | 90 |
| Grasshopper Sparrow | 0.09 | | 0.21 | 0.12 | | 0.07 | 3.60 | | 2.65 | 963 | | 38 |
| Vesper Sparrow | 0.10 | | 0.03 | 0.16 | | 0.34 | 3.62 | | 5.08 | 88 | | 2 |

## Assessment Indications

Our goal is to set a system of habitat valuation that would give higher value to higher quality habitat; Higher quality habitat defined as higher density of individuals of the species using or able to be supported by the habitat. Higher density in higher WHV could be assessed by whether higher WHV has higher likelihood of sightings. Our assessment indicates that the model is a better predictor of species presence than random chance alone for all but one of the species listed based on the following thresholds: the Gini coefficient variant is less than 0.5; the slope of the line fitted to the smoothed sightings per area is positive; the average habitat value of sightings divided by the average habitat value by area is greater than 1.0. The cells that meet these thresholds are shaded. (Table

2) For most of the species there were three types of data analyzed; not all species had all three types of data. Point data are verified one-time sightings. Some of these sightings were due to surveys and others were provided by the public or scientists individually. Lines are made up of observations from monitored individuals; the average of all the values for each individual has been used in the measurement. Polygons are the result of NJ ENSP Analysis and the average of each set of polygons provided was used in the measures. Not all the quantitative measures for a species indicate the same outcome in all cases. In such cases where the different types of data indicate different outcomes judgment has been used to determine which outcome is most likely most reliable. Qualitative information as well as the size of the sample has been used. Though we have indicated strict pass/fail thresholds and shaded our table accordingly, there is a continuum of outcomes with some being better than others. Lower values for the Gini Coefficient Variant are better; A higher slope of the smoothed sightings per area is better; Higher average habitat value of sightings/average habitat value by area is better.

## Discussion

The quantitative assessment values are best for fairly wide-ranging species that are more generalist in habitat whose home ranges are often vaguely circular. These species include bobcat, northern goshawk, barred owl, red-headed woodpecker, bobolink, grasshopper sparrow, and vesper sparrow. These species have some of the best values (see above for definition.) Species with more limited mobility have indications that the model is better than chance at predicting species occurrence but the values are not as good as for the wider-ranging species.

The method is not as successful for species with elongated or linear habitat such as the Black-Crowned Night Heron whose habitat of large home ranges stretch along waterways. In fact, for Black-Crowned Night Heron, the model is not a good predictor of species presence or density, and thus we are extrapolating that it is not clearly and accurately valuing the habitat from the perspective of the species. Species with small home ranges along riparian areas and waterways such as the long-tailed salamander and the wood turtle can be successfully modeled using this method as their home ranges can, within the longer narrower riparian areas, still be approximated by circles. This model contains a circular moving window used to create the WHV components of Habitat Percent and Core Habitat Percent and when the actual home range shape follows riparian areas and waterways to the extent that it cannot be approximated by a circle, the output will not be indicative of the actual habitat use. The Black-crowned night heron's colonial nesting habits may have also contributed to the difficulty in modeling using this method.

Additionally, this method may not be appropriate for species with very specific needs that cannot be approximated by land cover designations. However, bog turtle, which has fairly specific habitat needs within the land-covers has been successfully modeled. Given the large amount of on-the-ground surveying and study that has been completed by NJ ENSP for the bog turtle we recommend that the ENSP designated habitat be used in lieu of the model output for designation of areas to debit or credit for bog turtle.

The outcomes shown in the table above are not always consistent between and among the different types of data. Much of this can be explained by the data collection methods. For example, for bobcat the method appears reasonable when compared to the points and polygons, but not for the line sightings. However as there is only one tagged animal in the line sightings, this outcome is not statistically significant. For Indiana bat, the individuals that were tagged (line sightings) were known to be in some human-wildlife conflict (personal communication with Gretchen Fowles, ENSP) so it was likely that they might be using habitat near to developed areas, hence lower value areas. For Timber Rattlesnake the easier to find individuals were the ones tagged (line sightings), so likely these individuals were at least temporarily not in core habitat. For Long-eared owl there were very few sightings of any type. The rest of the measures indicate that the method is better at indicating species presence than chance alone, and usually much better.

Currently there is a great need for an objective and repeatable methodology to characterize and quantify habitat value for threatened and endangered species over broader spatial extents. Though in situ biological surveys coupled with detailed population studies may be the preferred approach to assess the relative value of habitat quality, they may be cost prohibitive when dealing with multiple species or over large areas. Our objective was to develop an alternative approach that relies on known habitat/land cover preferences and basic life history traits and available land cover GIS data to estimate and map habitat value (i.e. quality). Habitat value was based on landscape scale measures of overall habitat area, core habitat area and connectivity in relation to the species in question home range size. To assess the efficacy of our approach, we compared the estimate habitat value with an independent data set of number of observed sightings normalized per unit area. The results demonstrated a reasonably good fit for most of the selected threatened and endangered species we evaluated. As expected, the best results were obtained for wide-ranging species which are often the species with the most conflict with development and urban land conversion.

This method in its present implementation only includes measures of overall habitat area, core habitat and landscape connectivity and could include more nuanced consideration of habitat structure (age, size, understory, vegetation species composition) if these data were consistently available. For example, a wide range of studies suggest that barred owl prefer mixed coniferous/deciduous forests and deciduous forests over coniferous forests during the nesting season (Livezey 2007). Mature or old forests were used by barred owls significantly more than young forests (Livezey 2007). The type of forest, whether it is deciduous, mixed or coniferous is available in most available land cover GIS data sets. Age of the forest typically is not. Further, our present configuration of the model weights all three forest types equally as potential barred owl habitat. Similarly, we weight habitat area, core habitat and landscape connectivity equally. Altering these weights to better reflect individual species' preferences including so that there are four categories: preferred habitat, less preferred habitat, neutral non-habitat, and non-habitat, might lead to a better wildlife habitat valuation system.

However, there is a tradeoff between complication level and accuracy of results just as there is in setting up any multivariable equation. The more variables there are, the more specific and varied the results can be, but the added complication and slower processing speeds that apply with more variables can be a deterrent to adding ever more variables. One has to select a reasonable number of variables such that the outcome is sufficiently accurate for operational use, but not so overfit as to either give an air of false precision or an unreasonable GIS analysis processing time. At this point we feel our method is an adequate balance between availability of spatially detailed input data and resulting model accuracy.

Our approach fills the present void in methodology for quantitatively estimating habitat value on an individual species basis. It does not estimate an overall biodiversity value. While we appreciate some of the concerns raised about overly simplifying what is a very complex situation, policymakers are often required to distinguish between good vs. marginal habitat areas in land use planning.  Likewise, habitat values are presently being quantified when determining adequate levels of mitigation in land development decisions or for setting conservation banking debits and credits. Rather than an ad hoc approach, we are advocating for a more structured framework that can be incrementally improved as our knowledge of species life history and habitat requirements along with accompanying distribution models are improved.

## Literature Cited

Bunn D, Lubell M, Johnson CK. 2013. Reforms could boost conservation banking by landowners. California Agriculture **67**(2):86-95.

Bunn D, Moyle PB, Johnson CK. 2014. Maximizing the ecological contribution of conservation banks. Wildlife Society Bulletin. DOI: 10.1002/wsb.398

Camanclang A, Maron M, Martin T, Possingham H. 2015. Current practices in the identification of critical habitat for threatened species. Conservation Biology **29**:2:482-492

Endangered Species Act of 1973. Public Law 93-205 as amended through public law 107-136. 2002

Elith J, Leathwick J. 2009. Species distribution models:ecological explanation and prediction across space and time. Annual Review of Ecology, Evolution, and Systematics **40**:677-97

Forman RT, Sperling D, Bissonette J, Clevenger A, Cutshall C, Dale V, Fahrig L, France R, Goldman C, Heanue K, Jones J, Swanson F, Turrntine T, Winter T. 2003. Road Ecology: Science and Solutions. Island Press, Washington, D.C.

Livezey K. 2007. Barred owl habitat and prey: a review and synthesis of the literature. The Journal of Raptor Research **41** (3):177-201

Madsen B, Caroll N, Moore Brands K. 2010. State of Biodiversity markets report: Offset and Compensation Programs Worldwide. Washington, DC: Forest Trends. http://www.ecosystemmarketplace.com/documents/acrobat/sbdmr.pdf

Madsen B, Caroll N, Kandy D, Bennett G. 2011. 2011 Update State of Biodiversity markets: Offsets and Compensation Programs Worldwide. Washington, DC: Forest Trends. http://www.ecosystemmarketplace.com/reports.2011_update_sdbm

New Jersey Department of Environmental Protection. Division of Fish and Wildlife. The New Jersey Landscape Project. 2012. http://www.state.nj.us/dep/fgw/ensp/landscape/

U.S. Fish and Wildlife Service. 2012. Conservation Banking: Incentives for Stewardship. Factsheet. http://www.fws.gov/endangered/esa-library/pdf/conservation_banking.pdf

Wilcove DS, Rothstein D, Dubow J, Phillips A, Losos E. 1998. Quantifying threats to imperiled species in the United States. BioScience **48**:8:607-615

Wilcove DS, Lee J. 2004. Using Economic and Regulatory Incentives to Restore Endangered Species. Conservation Biology **18**:639.

Zampella RA, Procopio NA, DuBrul MU, Bunnell JF. 2008. An Ecological-Integrity

Assessment of the New Jersey Pinelands: A Comprehensive Assessment of the Landscape and Aquatic and Wetland Systems of the Region. The New Jersey Pinelands Commission, New Lisbon, NJ. 168 p.

http://www.state.nj.us/pinelands/images/pdf%20files/EIA_Final_Report.pdf

# CHAPTER 2 - Debits

## A method of assigning debit values for threatened and endangered species habitat trading or mitigation based on wildlife habitat value

## Abstract

Habitat of threatened and endangered species is being destroyed and or degraded increasing the pressure on these species. One method of mitigating this loss is to set up conservation banks of lands containing the natural resource values that are permanently protected and managed for conservation of the species of concern. However, a barrier to the implementation of conservation banking is the difficulty of determining how much value is lost when a property is developed. The method presented here assigns debit values relying on the wildlife habitat value estimated from GIS land use, land cover data and life history and home range/habitat use information for the species in question (please see previous chapter). The debit value is assigned using place-based decision-making. The debit value calculated is consistent over wide areas and is tied to estimated variations in use/population density. Barred owl debit value for New Jersey run from 0 up to 3.66.

# Introduction

Using the Wildlife Habitat Values (WHV) developed in chapter one, I developed a methodology to determine debits for use in mitigation or for trading in a conservation banking situation.

## Conservation Banking Background

Habitat destruction and degradation are the most pervasive threat to biodiversity and contribute to the endangerment of the vast majority of species listed as threatened and endangered (Wilcove et al. 1998). The purposes of the Endangered Species Act of 1973 (ESA) include "to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved" (Endangered Species Act of 1973). To this end, the mitigation hierarchy has been set out in regulations. The hierarchy is to avoid negative impacts to threatened and endangered (T&E) species or their habitat; if avoidance is impossible, then reduce the negative impact followed by the options of restore, offset, and compensate in order to create a positive impact elsewhere to offset the negative one. Conservation Banking has developed as an option for the last steps in the hierarchy: restoring, offsetting, and compensating for negative impacts to species habitat.

Conservation banks are lands containing natural resource values that are permanently protected and managed for conservation of species of concern (USFWS 2012) and conservation banking is the process of developers purchasing habitat or species credits from a conservation bank to offset unavoidable adverse impacts of their projects (Bunn et al. 2014, USFWS 2012). Species credits are primarily created through preservation and management of habitat, the idea being that by conserving large areas of high quality habitat with connectivity to other preserved sites and managing the land to support species recovery the species will persevere and thrive despite a net loss of habitat (Madsen et al. 2010). Preservation creates value because though preserved land carries no current extra value to the species, the future value is enhanced because the probability increases toward one that the habitat will be available longer into the future; Thus if the present value of the future habitat value is taken into account, preservation raises the overall value over time. Perpetual management and possible restoration can increase the value of habitat through control or eradication of invasive species, management of vegetation and understory, lessening of disturbance, and other methods. Though it is theoretically possible to change land use and land cover to create new habitat through restoration, due to the constrained area, high current development in NJ, and long time periods needed to restore habitat for many of the species modelled, we assume, that habitat area will not increase materially. Therefore, though there may be some habitat area created by land cover change or restoration, the net change in habitat area is overwhelmingly likely to be negative and thus I have set an objective in this project not for "no net loss of habitat *area*", but rather no net loss of habitat *value* while still meeting the broader goal of species recovery. Some current conservation banking systems, such as the wetlands conservation, are predicated upon no net loss of area while other systems allow current habitat to be protected and managed as mitigation land thus implicitly allowing loss of habitat area.

In our study area of New Jersey, USA, where conservation banking of threatened and endangered (T&E) species has yet to be implemented, many of the existing mitigation projects which have been mandated for threatened and endangered species are ad-hoc, one-off projects which may not have sufficient concern for long-term viability. Many are small, fragmented, habitat areas that are being restored or conserved.

Conservation banking facilitates pooling of mitigation resources from multiple developers or development projects, allowing larger tracts of contiguous land to be preserved and managed than would occur with permittee-responsible mitigation (Bunn et al. 2014), and the large contiguous tracts of forest, wetland, and grasslands (i.e. natural habitat) that are not fragmented by human development are especially valuable as wildlife habitat.

Another advantage of conservation banking is that it creates an economic incentive to conserve or restore endangered species habitat. Previously, owning endangered species habitat could be an economic detriment which led some people to prevent endangered species from occupying their property by proactively destroying unoccupied habitats – an approach dubbed the “scorched earth” technique by the National Association of Homebuilders (Wilcove and Lee 2004). Conservation banking creates a positive economic value and potential market for land that supports threatened and endangered species. Land-owners can sell property to conservation banks or create conservation banks.

### Current ways to determine tradable debits/credits

A great difficulty with Conservation Banking is determining the debits (quantitative measure of the adverse impacts of intended use) incurred by developers and determining the credits generated by conservation bank owners by permanently protecting, perpetually managing and perhaps restoring the habitat areas of the bank. The lack of methods for setting tradable credits is a major problem inhibiting the spread of conservation banking as a conservation tool (Madsen et al. 2010; Bunn et al. 2013). Currently many conservation banking areas use an acre-for- acre swap which leads to the task of finding an area of similar quality to preserve (Some US species conservation banks, Brazil, some South American and European banks) (Madsen et al. 2010). Others perform an ad hoc biological survey on land to be developed and a few sites that have been identified as areas for potential mitigation (Madsen et al. 2010). Biological surveys are expensive and time consuming; some surveys can only be done seasonally. Thus, if surveys are needed to determine debits and credits of conservation banking, the time lag can be long, which can add expense and uncertainty for developers. In addition, very few areas are usually surveyed, so the choice of locations of development and mitigation is constricted.

I illustrate a method of setting debits and credits that is comprehensive, can be determined over a wide area, is consistent, and is based on wildlife habitat value (WHV) determined in chapter 1. Chapter 1 was focused on quantifying a relative habitat value over a wide landscape area using easily accessible data. Chapter 2 focuses on taking the relative wildlife habitat value; grounding it; tying it to actual variations in use or estimated variations in population density; and calculating debit values based on sound, reality-based biological principles. The grounded debit values can then be used under the philosophy of no net loss of habitat value to project a possible method to maintain enough high quality habitat to continue to support at least the current levels of population of the species in question.

### No net loss of Habitat Value

My goal is to set up a system under which there is no net loss of habitat value. The system of tradeable debits and credits developed could be used in a mitigation swap or could be used as the base of a conservation banking system. This chapter sets the debits incurred under development or other land-use change which would destroy or degrade habitat. The concept of no net loss of habitat value is tricky to define. It is not the same as no net loss of habitat which is based on the acres of available habitat, but rather takes into account the variability of the quality of the habitat, such that if area is lost, but the quality of the remaining area is increased it is possible to have net loss of habitat area without net loss of habitat value. Here we define no net loss of habitat value as implying that the breeding population supportable in a region of interest remains stable and does not decrease. This is difficult in practice to measure; many of the threatened and endangered species I modelled have no current population estimates as a baseline and the population may inhabit or use areas that extend over many parcels with multiple owners and methods of management. Land is inherently heterogeneous. The number of individuals estimated in a survey is not necessarily the number able to be supported by the available habitat. Though the number of individuals theoretically supportable by a given amount and quality of habitat may not change, the number of individuals living in the habitat at any given time may change dramatically due to weather or other outside conditions, leaving it difficult to determine the number of individuals supportable. Whether habitat is being overused is sometimes difficult to ascertain until the point at which the overpopulation produces obvious degradation to habitat.

In the goal of sustaining a population, there are two definitions of sustain that need to be noted. The first is the general definition of the word sustain, to “keep up or prolong” (Webster’s Dictionary, 2016) which could be taken to mean keeping the same number of individuals. The second is the biological definition of sustainable population which is to maintain a viable population, a sufficient number of breeding individuals with enough genetic diversity and or connections to outside populations to project survival to some designated point in the future. In the 1980's the concept of minimum viable population dominated conservation biology; this concept assumed that there was some minimum number of individuals needed to keep the population sustainable (Mills 2007, p.254). This concept has since been recognized as obsolete, and so there is no specific minimum number of individuals as the goal of conservation (Mills 2007, p.254). However, through population viability analysis one can estimate the persistence of a size of a population above a certain threshold for a number of years with various probabilities (Mills 2007, p.254). If one had the data, one could select a number of years and a probability and estimate the number of breeding individuals necessary to maintain such a viable population.

The overall wider goal of species recovery, if recovery can be equated to delisting, is to change the factors that caused the species to be determined to be threatened or endangered such that it is no longer in danger of extinction throughout all or a significant portion of its range. This may include stopping present or threatened destruction, modification, or curtailment of its habitat or range; ending its overutilization for commercial , recreational, scientific, or educational purposes; curing or curtailing the disease or predation which threatens its existence; reversing any other natural or manmade factors detracting from its continued existence. These actions should allow the population of the species to thrive and end its danger of extinction. (Endangered Species Act of 1973)

Though the Endangered Species Act does not force private landowners to create or restore habitat, it does prohibit destruction or degradation (in some situations) of threatened and endangered species habitat (Endangered Species Act of 1973), so the foundation of our study is to determine how to set the debits and credits so that the habitat integrity value stays stable across the landscape and does not decrease throughout the area where the conservation banking system is in place. Without intense study it may not be apparent whether a particular habitat area with a population is actually sustaining the population, or whether the habitat used by the population is in fact a low-quality sink habitat. Sink populations are those with negative expected growth rates that would go extinct without immigration, and their habitat is known as a sink habitat. Populations may occur in sink habitats if there is sufficient dispersal from populations in higher-quality source habitats. A source population is one that has a sufficiently high growth rate when small to persist even without immigration. A source population has more emigration than immigration and its habitat is a source habitat. A sink habitat can still be important in maintaining the overall population of the region, especially if the nearby source populations exhibit large fluctuations leading to a high risk of extinction; the habitat patches supporting the source can become recolonized by members from the sink population (Hanski, 2009). Thus our minimum goal is that a system is set in place to maintain, preserve, and manage habitat over a wide landscape area such that the expected number of breeding individuals of a species able to be supported by the available habitat will not, at the very least, decrease. A multiplier can be applied to promote recovery of a species by way of increasing the available habitat and thereby the expected number of breeding individuals that the habitat can support.

By definition, for a threatened or endangered species it would be ideal to increase the population size. The question for conservation banking is whether it is possible to raise the population to the target with the current level and quality of habitat available. If not, an increase in habitat quality would be necessary. We are assuming that by increasing habitat quality we will increase the population viability and insure that reproduction exceeds mortality. Ideally the managed and preserved habitats will serve as population sources and not as population sinks.

### Methods

There are multiple ways one might determine debits from Wildlife Habitat Values. Below we will discuss several possibilities. The first step is to take the relative wildlife habitat values created in chapter 1 and ground these in reality, using the relationship of the relative values to the projected measures of population. Methods run from the best case, most scientifically grounded methods which are often the most data intensive to the methods with more assumptions and which need less data. We will discuss the data needed for each of these methods and if the data is available, will discuss outcomes of applying these methods for one or several test species.

The value of any one parcel of land is, of course, dependent upon the other parcels around it. For example, if a parcel were to have a higher value given its contiguity and connectivity to other habitat areas the value would naturally fall were it to be cut off from the other habitat due to changes in the intervening parcels. Thus it is difficult to set independent debit or credit values to land parcels. However, from a practical standpoint in order to be able to institute conservation banking, that is likely what will be done. In this portion of the chapter I focus on setting debit values for individual pixels, that is setting the value of what would be lost were the property to be developed in such a way that it is no longer habitat for the species in question.

### Debit value based on number of breeding pairs or individuals using the area

Enumerating the number of breeding pairs or individuals living in an area and being supported by the habitat in the area is a worthy method of determining the value to the species that would be lost were the area to be developed; in fact it may be the gold standard of methods. Some California species banks use number of breeding pairs as a measure (Madsen et al., 2010)

However, due to the involved, sometimes lengthy, and often expensive studies necessary to determine this number if it is even determinable on an average basis over time, I have not selected this method as one of my examined methods. In order to set debits based on the number of breeding pairs or individuals using an area, site-specific biological surveys would need to be carried out, perhaps at certain times of day or year or multiple times in a season or year. In order to make conservation banking viable for as many regions as possible including those without the vast economic resources necessary to stage large-scale biological surveys, I developed a method of calculating debit values without detailed presence/absence data. .

### Debit value based on Carrying Capacity

A highly scientifically grounded way to determine a debit value would be to determine the carrying capacity of the particular pixel or tract of land. Carrying capacity is a measure of the largest number of individuals of a species that can be supported on an area of land; generally carrying capacity is determined over a wide area. (Smith and Smith PP. 186-193) Because carrying capacity is a measure of the number of individuals that can have their overall support provided by an area, for a very small area such as a 50 foot by 50 foot pixel in isolation the concept of carrying capacity has no meaning for most species. This is because such a small area is unlikely to or cannot contain all the components necessary to support an individual. Such a small area is likely only a portion of the individual's home range size. Thus, carrying capacity for a small area can potentially be thought of as a portion of the carrying capacity of a wider area, though the determination of how the proportion is determined may be problematic. The proportion likely would not be based on area; loss of a portion of the area might decrease carrying capacity out of proportion to percentage of area lost. A loss of part of a home range might negate the value of the rest of the home range if not within travelling distance of other habitat.

Carrying capacity is not the same as the number of breeding pairs. Number of breeding pairs is a count or estimate of the actual number of breeding pairs living in the area in question and carrying capacity is the equilibrium number of individuals the environment can support at any one time (Smith & Smith, 2001, pp.186-188). Carrying capacity is a theoretical number and number of breeding pairs is an actual number. Similar to determining a debit value based on the number of breeding pairs or individuals using an area, determining a debit value based on carrying capacity would take a plethora of data, and breaking this down into each pixel of parcel would take many assumptions. In order to use this approach we would need fairly detailed information on biological cover, food availability, nesting/denning/breeding site availability, distance from other habitat, density and types of competitor, predator, mutualist species, and any limiting resource. Carrying capacity is also not necessarily the number of breeding pairs that could survive long term in the habitat; carrying capacity depends on the resources available over time and thus fluctuates with limiting resources (Smith & Smith, 2001 p.

188). There are circumstances under which a population at full carrying capacity with fluctuation might alter the habitat such that the carrying capacity would actually decline. Thus it might be advisable to keep the population below the carrying capacity. This method, like the breeding pairs method mentioned above is not calculable using available or easily obtainable data, and thus I will move on to the next option.

### Assuming that sightings frequency gives insight into density or frequency of use

One way to set debits without completing biological surveys would be to assume that sightings frequency gives insight into density or frequency of use, note the strong correlation between sightings frequency and wildlife habitat value (WHV) (chapter 1), and determine the debits from the WHV. This is an alternate approach from the survey and data intensive approaches detailed above. Based on my work in chapter one, I have developed an alternative approach to quantifying habitat value and results show that habitat value and frequency of sightings correlate strongly. Using this correlation, I aim to determine the relationship between estimated population density or possible population density and habitat value. This will be a surrogate for breeding pairs.

Step one was to determine habitat value (see chapter 1). Step two is to relate habitat value to sightings frequency in an attempt to ground the landscape model from chapter one in reality. Step three is to assume higher sightings frequency in an area implies greater number of individuals in said area and in same proportions. Step four is to use the relationship of the habitat value to sightings frequency to calculate debits.

Step three assumes direct relationship between sightings frequency and population density. If survey effort were constant across all areas it would follow the laws of large numbers and probability, that if enough trials (increments of effort) were tried one could substitute the sampling distribution for theoretical underlying probability density function or cumulative distribution function.

### Shape of curve fitted to sightings per area

As a measure of how sightings frequency may be related to wildlife habitat value, I have examined the relationship between smoothed percent sightings per percent area. This is the same relationship used in assessing the wildlife habitat value. The smoothing refers to the fact that the ratio of percent sightings to percent habitat is not for each individual WHV but a rolling nine WHVs. For example, the value at WHV 45 is in fact the percent of all sightings occurring between and including WHV 41 through WHV 49 divided by the percent of the total area which falls within and including WHV 41 through WHV 49; the value at WHV 46 is in fact the percent of all sightings occurring between and including WHV 42 through WHV 50 divided by the percent of the total area which falls within and including WHV 42 through WHV 50. These values have been graphed. (Figure 1)

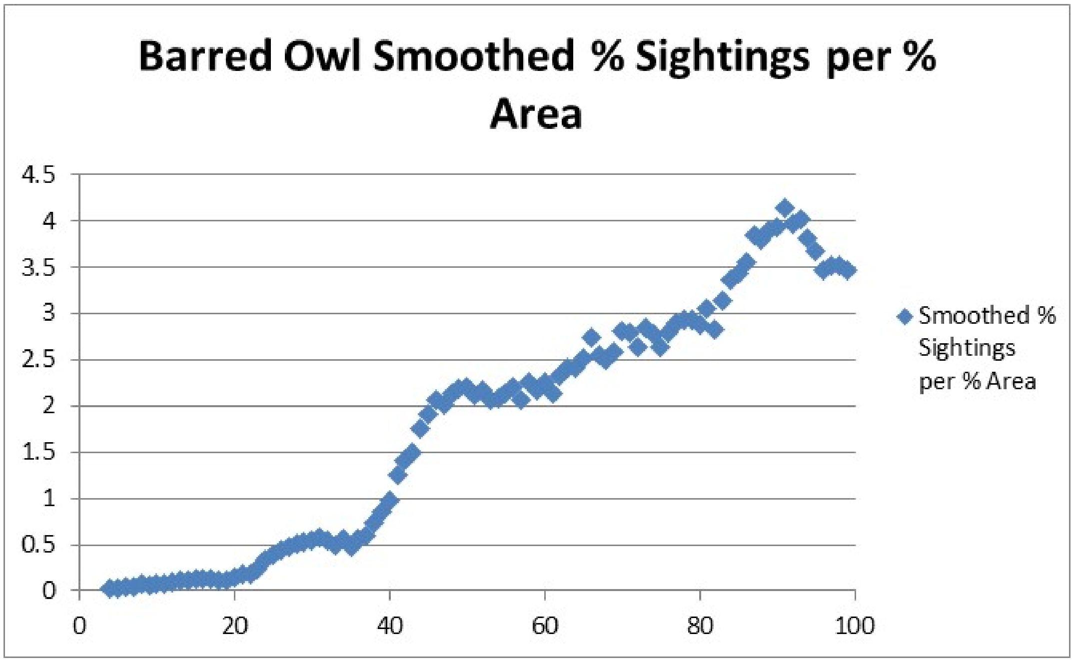



Figure 1: Barred owl smoothed percent sightings as a ratio to percent habitat area

I examined several curves for fitting including linear, exponential, logarithmic, power, and polynomial. Some of these curves asymptote either on the low end or the high end or both. A fair number of the species have smoothed percent sightings per percent area curves that approach but do not equal zero as the WHV tends toward 0. Some of the species show asymptotic behavior at the high end of the WHV range, though others show a drop-off of sightings. Because the sightings data is presence only data, it is unclear whether the dropoff in sightings indicate a drop in the value of the high WHV areas or whether it is due to the fact that much of the highest WHV areas are difficult to access and visited infrequently or not at all by scientists who could make a sighting. Theoretically, there is no reason for a drop in value to the members of the species in these high WHV areas. If there is no true drop it may make sense to assume an upper threshold beyond which the habitat is very good and supports the maximum number of individuals.

If a linear fit is used without a threshold, there could be one of two outcomes depending on whether the line is fit including the points at WHV above the maximum sightings per area. If included then the slope will be lower, if excluded the line at the highest WHV will be fairly high above actual sightings.

In the end, I analyzed several linear fits with lower and/or upper thresholds and without thresholds then selected one based on the better fit (in terms of R-squared values) for most of the species, and most of the scenarios modelled. The thresholds fit the asymptotic behavior of the data. The fact that the WHV was intended to be a linear measure of habitat value for the species also indicates a linear fit.

### Lower Threshold

I examined curve fitting sightings frequency on WHV in two major ways: setting debit values with thresholds and without thresholds. I define a lower threshold as a wildlife habitat value (WHV) below which the debit value is assumed to be 0. I examined various thresholds: the WHV below which there were no sightings, the WHV below which there were 1% of the sightings, the WHV below which there were 3% of sightings, the WHV below which there were 5% of sightings. For barred owl, putting the threshold at the point below which there were no sightings would convert the debit value of 13% of the total habitat area statewide to no value. Using 1% of sightings for the threshold would convert 30% of the total statewide habitat area to no value; 3% would convert 48% of the area; 5% would convert 58% of the total statewide habitat area to a habitat value of 0. (Figure 2)

Table 1: possible lower thresholds: example of barred owl

| BarredOwl | | |
|---|---|---|
| Wildlife Habitat Value | Cumulative Sightings % | Cumulative Area % |
| 4 | first sighting | 13% |
| 9 | 1% | 30% |
| 17 | 3% | 48% |
| 25 | 5% | 58% |

Is there a theoretical justification for using a lower threshold and, in particular, any of these lower thresholds? Since the sightings data is presence only data, it does not follow that because there are no sightings in a range of WHV that there are no individuals present in that range of WHV. It is possible that individuals were not searched for in those ranges or that individuals use the area at a time when no one was watching. Thus the lowest wildlife habitat value with a sighting may not be a reasonable threshold.

Would valuing the lowest wildlife habitat values below a certain percentage of the sightings be any more theoretically acceptable? Given that each sighting and in fact each time someone is in the area and could potentially make a sighting is in some senses a trial, one might contend that the law of large numbers would apply, in which case setting a lower threshold based on a percentage of overall sightings could, in fact, be more theoretically acceptable than using the lowest habitat sighting as a threshold.

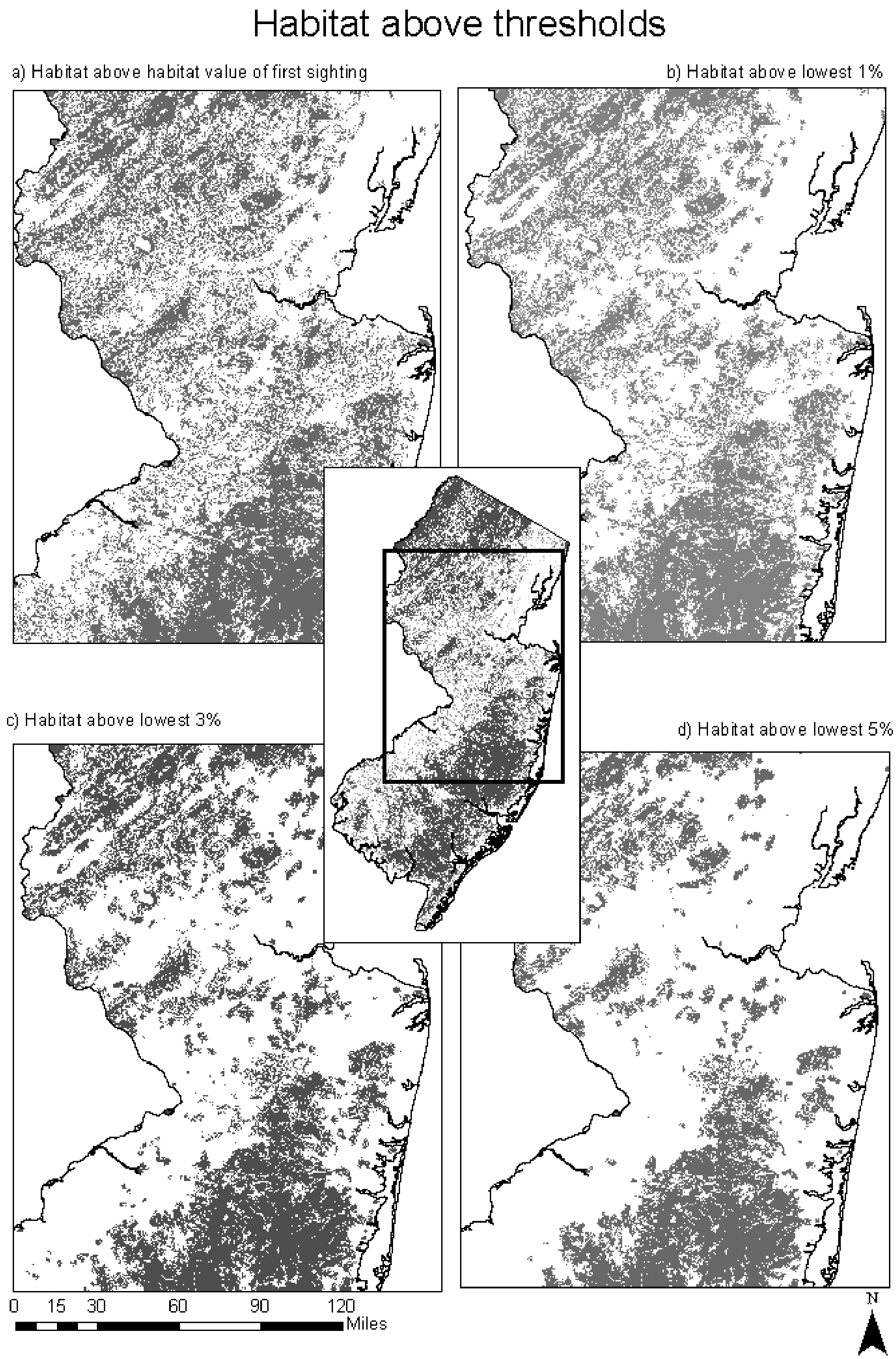



Figure 2: The barred owl habitat above various lower thresholds: a) value of first sighting, b) lowest 1%, c) lowest 3%, d) lowest 5%. Center figure is all barred owl habitat statewide.

I examined lower thresholds of 1%, 3% and 5% of cumulative sightings. For barred owl, the sightings are less frequent in lower WHV areas, so the 1% lowest WHV sightings are over the lowest 30% of the area based on WHV. Thus ignoring 1% of sightings affects 30% of the area. (Figure 2) Is there a theoretical justification for allotting this area no value? Most of the area affected is in the central portion of the state. Potentially allowing development with no mitigation, as would occur were the WHV set to 0, would allow development of areas that, though low in WHV, connect habitat areas of higher value. If these areas were to be developed, there would be islands of habitat throughout the central portion of the state which would not be connected. The level of aversion to traveling over or through developed areas differs by species and by individual, thus it is difficult to determine quantitatively how this might affect the islands of habitat that would be left and how this might affect the overall population of the species in the state.

In conclusion, it seems reasonable, though not necessary to determine a lower threshold using a percentage of sightings.

### Upper Threshold

An upper threshold is defined as the wildlife habitat value (WHV) above which the debit value no longer rises. As possible upper thresholds, I examined the highest WHV for which there are sightings and the peak frequency of sightings per area.

Using the highest WHV for which there are sightings has the same theoretical drawbacks as using the lowest WHV sighting for the lower threshold.

Setting an upper threshold would indicate that there is some WHV that is good enough and at some point higher WHV does not indicate a higher probability of a species using the habitat, a higher density of the species in the habitat, nor a higher carrying capacity of the habitat. Setting the upper threshold at the peak frequency of sightings per area has a theoretical draw that the peak is the highest sightings frequency actually measured. As an actual measure, there is no extrapolation so there is no question about the accuracy of extrapolation. Using peak frequency as an upper threshold has the advantage of being grounded in an actual measure while recognizing the possible observation bias which would lead to fewer sightings than expected in areas which are further into the core habitat and hence further from roads and edges. There is less risk of overestimating the bias than would be the case if there were an upper threshold above the peak frequency and an extrapolation of the line led to an implied higher frequency than the peak frequency actually measured.

For barred owl, the upper values involved would be WHV 99 (highest WHV sighting) or WHV 91 (max frequency). Since there was no habitat with WHV 100, using the highest WHV with sightings for barred owl does not constitute setting a threshold; there is 0% of area above this WHV. Using max frequency as a threshold sets a threshold with the highest 7% of the area set at the highest value which would then be 91. Otherwise the value in that 7% of the habitat would range from 92 up to 99. For many other species the max frequency and sightings with the highest WHV both have a lower WHV than the area with the highest WHV.

Table 2: possible upper thresholds: example of barred owl

BarredOwl

| Wildlife Habitat Value | Sightings | Sightings Frequency | Cumulative Sightings % | % of Area Above |
|---|---|---|---|---|
| 91 | max frequency | 4.140812 | 77% | 7% |
| 99 | highest WHV sighting | 3.463115 | 100% | 0% |

Selecting lower and/or upper thresholds affects the slope of the fit line as well as the minimum and maximum values. If a lower threshold above WHV 0 is selected, all else being equal, the slope of the fit line will be higher than a fit with no lower threshold. If an upper threshold is not used for many species the smoothed percent sightings per percent area drops at the highest WHV. A straight line fit to such data using points at all WHVs would indicate a lower slope than a linear fit using points excluding WHVs above the maximum sightings frequency WHV. (Figure 3)

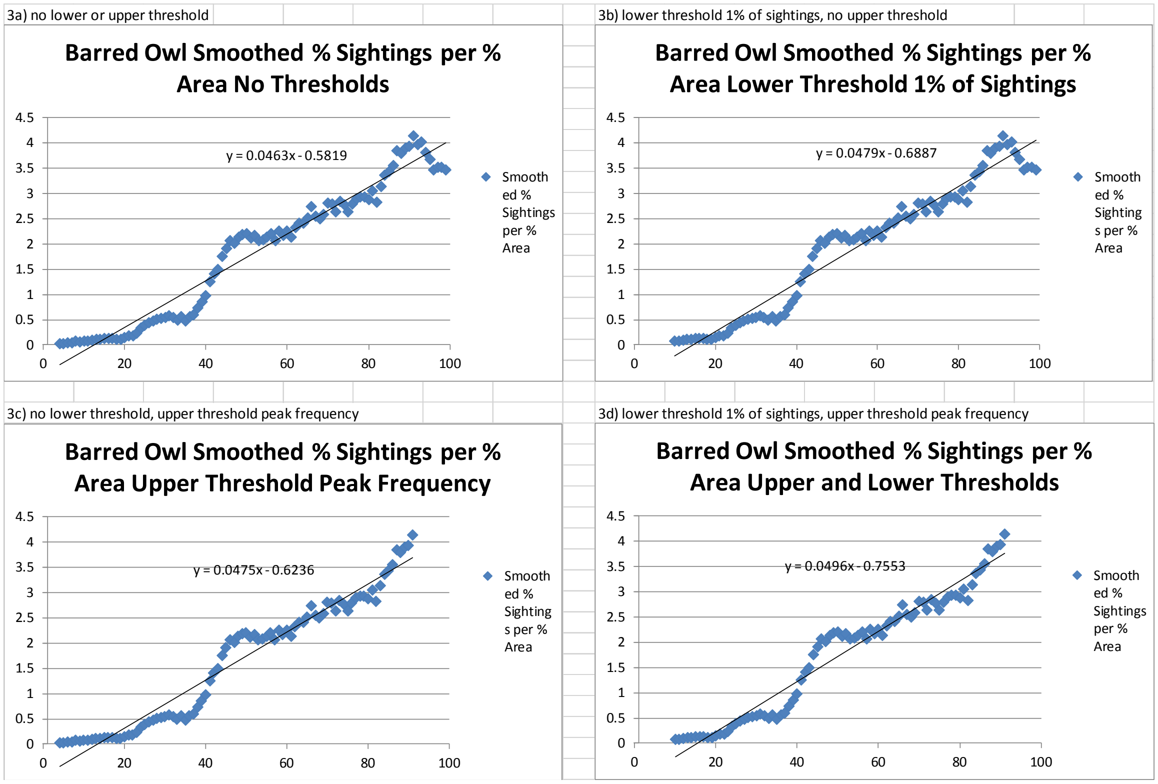



Figure 3: Comparison of barred owl smoothed percent sightings per percent area with and without thresholds. 3a) and 3c) have no lower thresholds; 3b) and 3d) have lower thresholds of 1%; 3a) and 3b) have no upper thresholds; 3c) and 3d) have upper thresholds of peak frequency. Note that the slope rises as thresholds are added over no thresholds. The highest slope is 3D) with both upper and lower thresholds and the lowest slope is 3a) with no thresholds.

I selected two scenarios both with upper thresholds.

### Scenarios Modeled

Using various combinations of thresholds or no thresholds, I selected four main scenarios to model (Figure 4). They are:

- Scenario 1 – lower threshold of 1% of sightings, upper threshold of highest WHV with sighting
- Scenario 2 – no lower threshold, upper threshold of the peak frequency of sightings

- Scenario 3 – lower threshold of 1% of sightings, upper threshold of the peak frequency of sightings
- Scenario 4 – no lower threshold, upper threshold of highest WHV with sighting

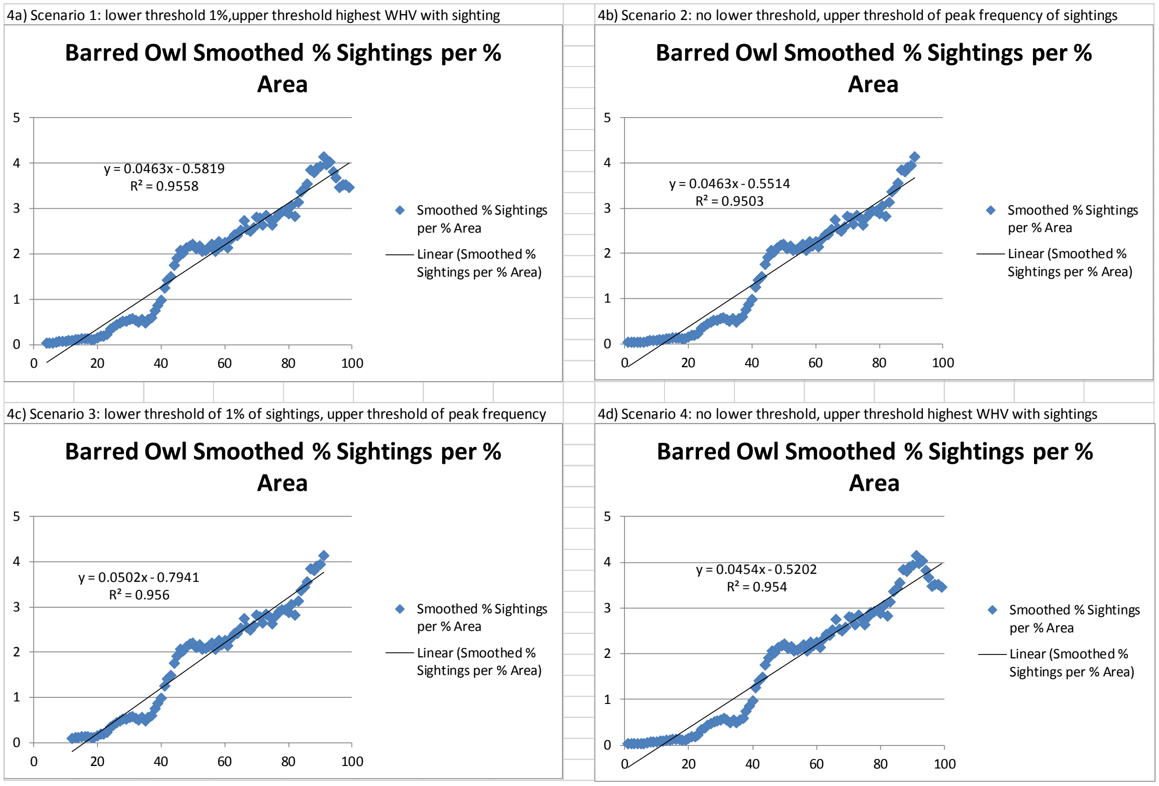



Figure 4: Barred owl smoothed percent sightings per percent area for the 4 scenarios selected for modelling. 4a) scenario 1: lower threshold 1% of sightings, upper threshold highest WHV with sighting; 4b) scenario 2: no lower threshold, upper threshold of peak frequency of sightings; 4c) scenario 3: lower threshold of 1% of sightings, upper threshold peak frequency; 4d) scenario 4: no lower threshold, upper threshold highest WHV with sightings

There are several reasons that I have chosen the two threshold combinations that define these four scenarios. The percentages of habitat that would be declared of null value if the 3% or 5% lower threshold were used are fairly substantial, ranging from 1% to 78% for the 3% threshold and 11% to 80% for the 5% threshold. So from a practical standpoint, this might cause difficulty in selecting mitigation sites. As mentioned before, the theoretical underpinnings of basing any threshold on either the lowest sighting or the highest sighting are shaky given the variability of the WHV per sighting. However, fitting a line to a set of points of which the uppermost have value 0 due to the fact that the highest WHV have no sightings creates lines with a lower slope than if the line were to be fit only up to the WHV with sightings without any seeming justification. Therefore, in an attempt not to bias the slope downward due to lack of sightings at the very highest values, I have selected as one upper threshold, the highest WHV with sightings, and, as the other, the peak frequency. Using the peak frequency as the highest WHV for the linear fit has the satisfaction of assuming that any habitat areas with WHV higher than that might be able to support a density similar or greater than that supported by the WHV with the peak frequency of sightings per area.

### Results

For the four scenarios modelled, the slopes of the lines fitted to the smoothed percent sightings per percent area range from 0.02 to 0.19 and the upper ends of the ranges range from 1.07 to 12.93 (Table 3).

Table 3: Ends of the range and slope for the four scenarios examined using point data

| | Scenario 1 | | | Scenario 2 | | | Scenario 3 | | | Scenario 4 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lower threshold 1%; upper threshold highest with sighting | | | No Lower threshold; upper threshold peak of sightings/area | | | Lower threshold 1%; upper threshold peak of sightings/area | | | No Lower threshold; upper threshold highest with sighting | | |
| | Points only | | | Points only | | | Points only | | | Points only | | |
| | Range of debit values for the linear fit | | | Range of debit values for the linear fit | | | Range of debit values for the linear fit | | | Range of debit values for the linear fit | | |
| Species | Low end of Range | High End of Range | Slope | Low end of Range | High End of Range | Slope | Low end of Range | High End of Range | Slope | Low end of Range | High End of Range | Slope |
| Bobcat | - | 3.03 | 0.03 | - | 2.69 | 0.04 | - | 4.87 | 0.07 | - | 2.32 | 0.03 |
| Indiana Bat | - | 1.72 | 0.02 | - | 2.55 | 0.05 | - | 2.94 | 0.08 | 0.01 | 1.85 | 0.03 |
| Bog Turtle | - | 5.78 | 0.11 | - | 8.00 | 0.15 | - | 8.19 | 0.16 | - | 5.67 | 0.11 |
| Wood Turtle | - | 2.48 | 0.02 | - | 2.20 | 0.04 | - | 2.31 | 0.05 | 0.09 | 2.50 | 0.02 |
| Timber Rattlesnake | - | 1.92 | 0.04 | - | 1.07 | 0.03 | - | 1.85 | 0.11 | - | 1.71 | 0.03 |
| Long-tailed Salamander | - | 3.61 | 0.04 | - | 4.10 | 0.06 | - | 4.09 | 0.06 | 0.40 | 3.74 | 0.04 |
| | | | | | | | | | | | | |
| Northern Goshawk | - | 3.15 | 0.03 | - | 5.36 | 0.06 | - | 6.24 | 0.08 | 0.22 | 2.77 | 0.03 |
| Red-Shouldered Hawk | - | 3.48 | 0.04 | - | 2.35 | 0.03 | - | 2.46 | 0.04 | - | 3.33 | 0.04 |
| BarredOwl | - | 4.00 | 0.05 | 1.00 | 3.66 | 0.05 | - | 3.80 | 0.05 | - | 3.97 | 0.05 |
| Long-eared Owl | 0.69 | 3.23 | 0.04 | 0.23 | 4.34 | 0.06 | 0.23 | 4.34 | 0.06 | 0.69 | 3.23 | 0.04 |
| Red-headed Woodpecker | - | 1.56 | 0.03 | - | 1.28 | 0.02 | - | 1.56 | 0.03 | - | 1.28 | 0.02 |
| Bobolink | - | 5.36 | 0.14 | - | 3.49 | 0.05 | - | 5.36 | 0.14 | - | 3.49 | 0.05 |
| Grasshopper Sparrow | - | 9.08 | 0.12 | - | 8.86 | 0.12 | - | 9.08 | 0.12 | - | 8.86 | 0.12 |
| Vesper Sparrow | - | 12.93 | 0.17 | - | 11.42 | 0.17 | - | 11.83 | 0.19 | - | 12.69 | 0.16 |

The slopes of the fitted lines and the high ends of the range vary as shown in Table 4. There is no inherent value to the numbers beyond relativity. For example, 12.93 percent sightings per percent area implies a high number of sightings concentrated in a small area whereas a lower sighting per area ratio such as 1.07 implies that sightings are spread out more evenly over much more of the habitat. However, the numbers do not tell us that there were 12.93 average sightings or 12.93 individuals or breeding pairs.

Grasshopper Sparrow and Vesper Sparrow have the highest values, indicating concentration of sightings at the higher WHVs, whereas Timber Rattlesnake and Redheaded woodpecker have some of the lowest values.

The ranges of the high ends of the range and the slopes among the scenarios are fairly tight as would be expected, though thresholds do have affect.

Table 4: min and max slopes and high ends of the range for each species, each scenario

| Species | Min Slope | Max Slope | | min high end of range | max high end of range |
|---|---|---|---|---|---|
| Bobcat | 0.026 | 0.068 | | 2.32 | 4.87 |
| Indiana Bat | 0.020 | 0.079 | | 1.72 | 2.94 |
| Bog Turtle | 0.108 | 0.163 | | 5.67 | 8.19 |
| Wood Turtle | 0.024 | 0.046 | | 2.20 | 2.50 |
| Timber Rattlesnake | 0.030 | 0.114 | | 1.07 | 1.92 |
| Long-tailed Salamander | 0.038 | 0.063 | | 3.61 | 4.10 |
| | - | - | | - | - |
| Northern Goshawk | 0.026 | 0.078 | | 2.77 | 6.24 |
| Red-Shouldered Hawk | 0.032 | 0.045 | | 2.35 | 3.48 |
| BarredOwl | 0.045 | 0.051 | | 3.66 | 4.00 |
| Long-eared Owl | 0.037 | 0.057 | | 3.23 | 4.34 |
| Red-headed Woodpecker | 0.016 | 0.028 | | 1.28 | 1.56 |
| Bobolink | 0.048 | 0.135 | | 3.49 | 5.36 |
| Grasshopper Sparrow | 0.116 | 0.123 | | 8.86 | 9.08 |
| Vesper Sparrow | 0.157 | 0.190 | | 11.42 | 12.93 |

The R-squared values for each of the scenarios indicate that scenarios two and three are significantly better fits for most of the species. Scenario 3 has the most maximum R-squared values of the scenarios. (Table 5) The tradeoff is whether to select the scenario with the most maximum R-squared values but which has a lower threshold which would set appreciable amounts of possible habitat to a zero value, or to go with the scenario with the second-highest number of max R-squared values which values all possible habitat with non-zero values. The percentages of possible habitat that would be valued at zero because of a 1% of sightings lower threshold range from 0% to 76% with an average of 19%.

Table 5: R-squared values for linear fits, scenarios 1 through 4. Highest shaded for each species.

| R-squared Values | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|
| Bobcat | 0.2291 | 0.7539 | 0.9008 | 0.3668 |
| Indiana Bat | 0.0891 | 0.7749 | 0.7956 | 0.2850 |
| Bog Turtle | 0.2407 | 0.3796 | 0.3775 | 0.2487 |
| Wood Turtle | 0.6339 | 0.9081 | 0.9339 | 0.6955 |
| Timber Rattlesnake | 0.4064 | 0.6120 | 0.9384 | 0.7149 |
| Long-tailed Salamander | 0.4656 | 0.8853 | 0.7242 | 0.5895 |
| Northern Goshawk | 0.2943 | 0.2677 | 0.3087 | 0.2189 |
| Red-Shouldered Hawk | 0.8545 | 0.7964 | 0.7831 | 0.8480 |
| BarredOwl | 0.9558 | 0.9503 | 0.9560 | 0.9540 |
| Long-eared Owl | 0.1213 | 0.2342 | 0.2342 | 0.1213 |
| Red-headed Woodpecker | 0.4794 | 0.5548 | 0.4794 | 0.5548 |
| Bobolink | 0.2759 | 0.3243 | 0.2759 | 0.3243 |
| Grasshopper Sparrow | 0.6870 | 0.6771 | 0.6870 | 0.6771 |
| Vesper Sparrow | 0.5841 | 0.7933 | 0.7956 | 0.6118 |

Table 6: 1% of sightings corresponds to these WHV and this % area

| Species | 1% of sightings is this WHV | 1% of sightings is this % area |
|---|---|---|
| Bobcat | 22 | 9% |
| Indiana Bat | 17 | 9% |
| Bog Turtle | 4 | 46% |
| Wood Turtle | 7 | 12% |
| Timber Rattlesnake | 31 | 15% |
| Long-tailed Salamander | 7 | 25% |
| | | |
| Northern Goshawk | 11 | 1% |
| Red-Shouldered Hawk | 10 | 18% |
| BarredOwl | 9 | 30% |
| Long-eared Owl | - | 0% |
| Red-headed Woodpecker | 44 | 23% |
| Bobolink | 57 | 76% |
| Grasshopper Sparrow | - | 0% |
| Vesper Sparrow | - | 0% |

Scenario 2 appears to present the best balance between the competing interests of the relative R-squared values and the amount of possible habitat being valued. I have selected scenario 2 to be the basis of the debit value map. Scenario 2 has no lower threshold and the upper threshold is the peak frequency of sightings. The resulting debit values range from 0 to 3.66 with higher values in the northwest (Highlands) and south (Pinelands) (Figures 5 and 6).

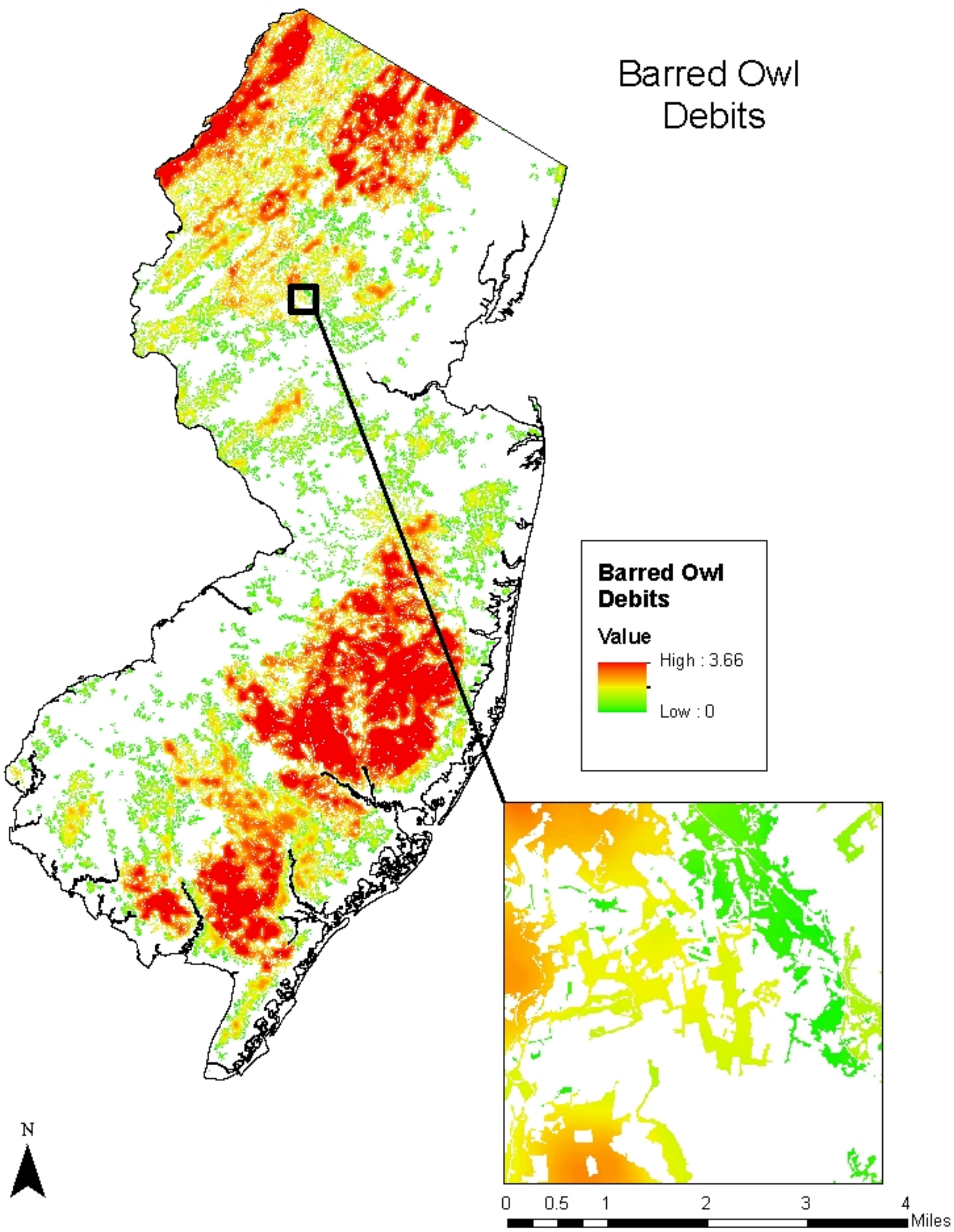



Figure 5: Barred owl debits statewide and for a selected area. High debit values are red. Low values are green. Values of 0 are white. Intermediate values range from the high of red through orange, yellow and into the low of green.

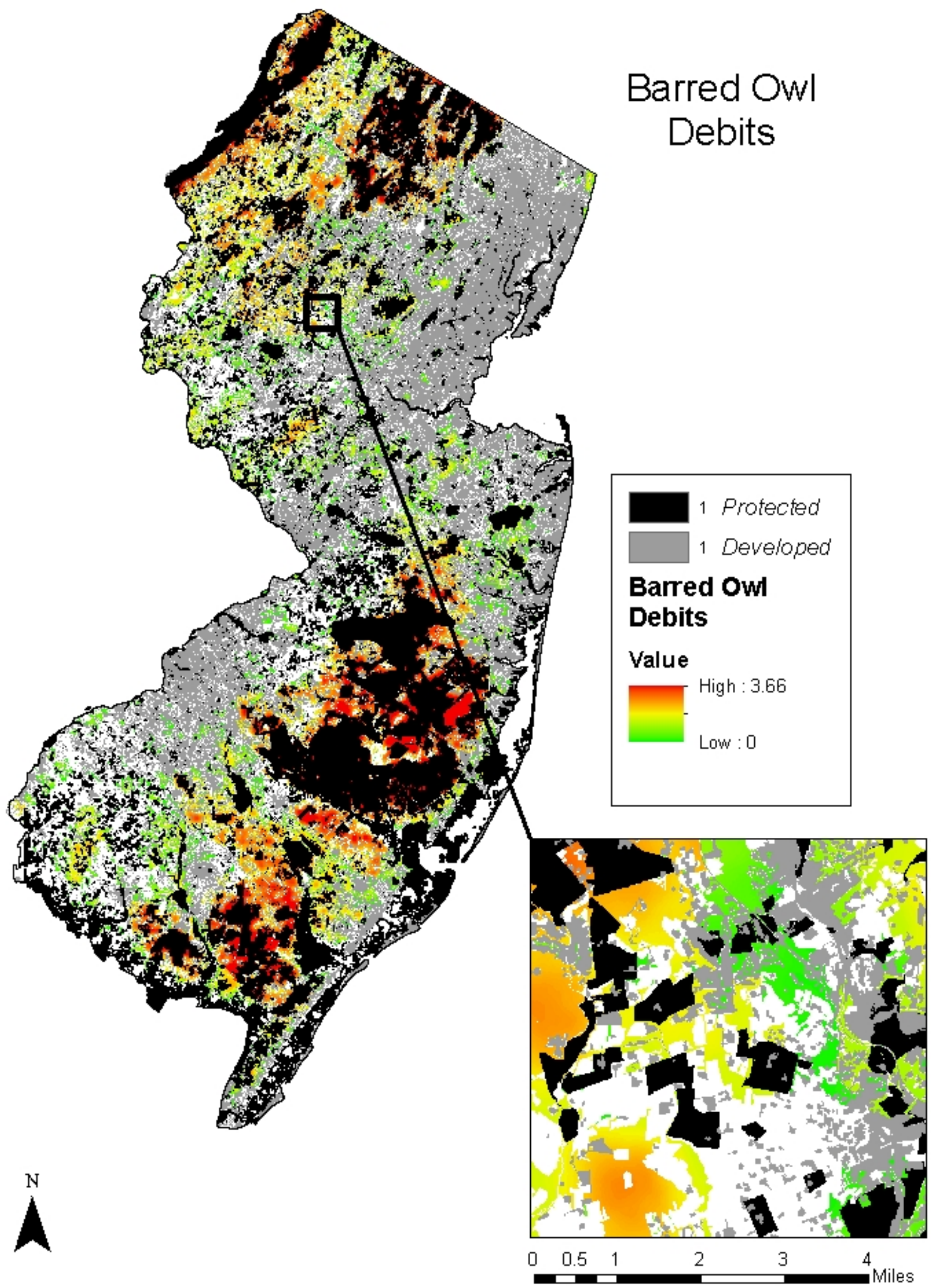



Figure 6: Barred owl debits statewide and for a selected area with an overlay of already protected land in black and developed areas in grey.

The variation in sightings frequency between the best and the worst habitat differs between species (table 3). Following from our assumption that relative numbers of sightings can be a proxy for relative density or frequency of use, would then imply that the variation of relative densities varies by species. Some of this may be explained by life history traits. For example, Grasshopper Sparrow and Vesper Sparrow all indicate fairly high slopes to the fitted lines. This may have to do with the fact that there is only one code for both agricultural fields and grass fields on the land cover coding (such that if the birds use either grass fields or agricultural fields preferentially, the outcome would be to concentrate use and thus sightings into a smaller proportion of the overall area that is coded as habitat) , or the fact that the numbers of breeding grasshopper sparrows, for example, are known to vary greatly in the same geographic area from year to year (Audubon Field Guide, 2016). The variation could stem from the variation in habitat value such that the relative goodness of habitat integrity may be more for certain types of habitat.

Species with lower slopes are modelled as if the densities are more uniform across habitat value. Since habitat value is relative it is possible that the difference between habitat areas of different values are not the same across species. Species with lower slopes, such as red-headed woodpecker and wood turtle, may potentially inhabit areas which are not as varied across New Jersey as those inhabited by species with higher slopes.

Though the habitat areas are not the same for different species, some, naturally overlap. We do not see any clear positive correlation among species that tend to share the same habitat areas. Neither grassland birds, nor forest-dwelling species are highly correlated.

It is possible that the habitat areas available in New Jersey do not include any extremely high values for the species. However, the fact that the species is extant in New Jersey and uses the habitat, means that the habitat is at least above the minimum value necessary for use. It is possible that the habitat can be improved in quality based on management of the habitat.

## Discussion

Much has been written about biodiversity offsets which have some similarity to wildlife habitat offsets, but also have different challenges and issues. Biodiversity offsets are generally legislatively mandated compensatory mechanisms, though voluntary offsets also are common around the world. Biodiversity offsets are commonly actions to create additional and/or comparable biodiversity to compensate for losses caused by development. There are difficulties in the implementation, ranging from the fact that biodiversity itself is not a tradable market commodity, to the fact that no one component of biodiversity is fixed or intrinsic, but value depends partly on spatial relationship with other components of biodiversity. There are both theoretical and practical problems with biodiversity offsets, some of which may also be challenges to wildlife habitat offsets such as the currency traded; the definition and baseline of no net loss; concept of equivalence; spatial relativity; longevity of the offset; time lag; uncertainty; compliance; measuring and tracking (Bull et al. 2013). The method presented here to calculate debits addresses some of these issues. For example, the fact that the debits are measured for each species separately reduces the complexity of the calculation and simplifies equivalence. Though there is no issue of equivalence between species, there is still an issue of equivalence in spatial area and habitat quality which is the focus of my method. One problem with biodiversity offsets is the definition of biodiversity (Bull et al. 2013). The definition of what is to be measured is slightly simpler when concerned with one species only. Longevity of the offset and time lag are addressed as the habitat to provide credits (measurement of which is in chapter 3) must be already managed and conserved before offsetting for the debit and must continue in perpetuity. This also to some extent addresses uncertainty. Spatial relativity can be addressed by regulating offsets to be in same region (defined in the regulations) in which the debits are incurred. The debit and credit methods are specifically created to address compliance and measuring of outcomes.

### Debits vs. Credits

The calculation method presented here is to calculate debits to be used in offsets. Often conservation banking literature and offset literature use credits to refer to the traded values for both sides of the equation when there are actually two distinct measures that need to be addressed. There is the debit value, the value of the habitat that is lost through development, the "loss". On the other hand there is the credit value, the increased value of the conserved, preserved, restored, or created habitat, the "gain". I present in a separate work a mechanism to quantify credits, or gains. Currently, debit and credit values are often conflated. There is often one value and a multiplier is used as a crude measure and a hedge against uncertainty. For every acre lost multiple acres must be preserved, restored, or created. I contend that it is better to have two distinct measures: a measure of what is lost (debit) and a measure of what is gained (credit), instead of using a simple multiplier.

With two distinct measures, some issues can be dealt with in a more straightforward manner.

- Uncertainty – When trying to quantify, there are two important types of uncertainty: process risk and parameter risk. Process risk is the inherent uncertainty of the ecological process including variation in births, growths, deaths, weather, etc. Parameter risk is uncertainty in estimating the exact nature of the ecological process via a model or other method; in other words the difficulty deducing the parameters of the model. By uncoupling debits and credits these uncertainties can be dealt with more effectively. Though there is parameter risk in the estimation of both debits and credits, the magnitude of the process risk varies greatly between the two. Since the debit value is the value of the loss, there is much less risk in the measure of the debit than the credit. Process risk is much greater in the credit measure, because the credit estimation, in addition to current risk also encompasses the risk of the future changes to the habitat. This is true whether they are positive changes through management, higher than expected growth of organisms with positive influence on the species or lower than expected growth of organisms detrimental to the species in question, or negative changes due to a lack of full restoration or a difficulty in conserving. Although there is uncertainty in both measures which, in theory, might imply that it would be better to create measures using a range or a probability distribution, in practice, in order to trade, the measures for both debits and credits likely need to be a best estimate of the value, while keeping in mind that there is a range of outcomes.
- Time discounting – Debits are occurring now. Credits must be created and may be ready now, but must also be continued in perpetuity. In our study area, New Jersey, the most

common reason for debit is development in the form of building which is generally an irreversible destruction of the habitat, so we will assume that the debit or loss is in perpetuity. Thus in order to match the timing, the credit must also be in perpetuity.

- Time lag – If offsets are traded through conservation banks then there should be no time lag in the credits as they must be up and running before being put up for purchase.

I have developed an objective, repeatable method to calculate debit values for conservation banking or other mitigation which is grounded in real data (Figure 7). The method starts with wildlife habitat values calculated based on habitat definition and integrity and continues with a translation of the wildlife habitat value into a debit which is a proxy for relative abundance of the members of the species. This method advances the science of conservation banking by improving upon currently available methods of setting tradeable debits which has been cited as a main reason inhibiting the spread of conservation banking as a mitigation tool (Madsen et al. 2010; Bunn et al. 2013).

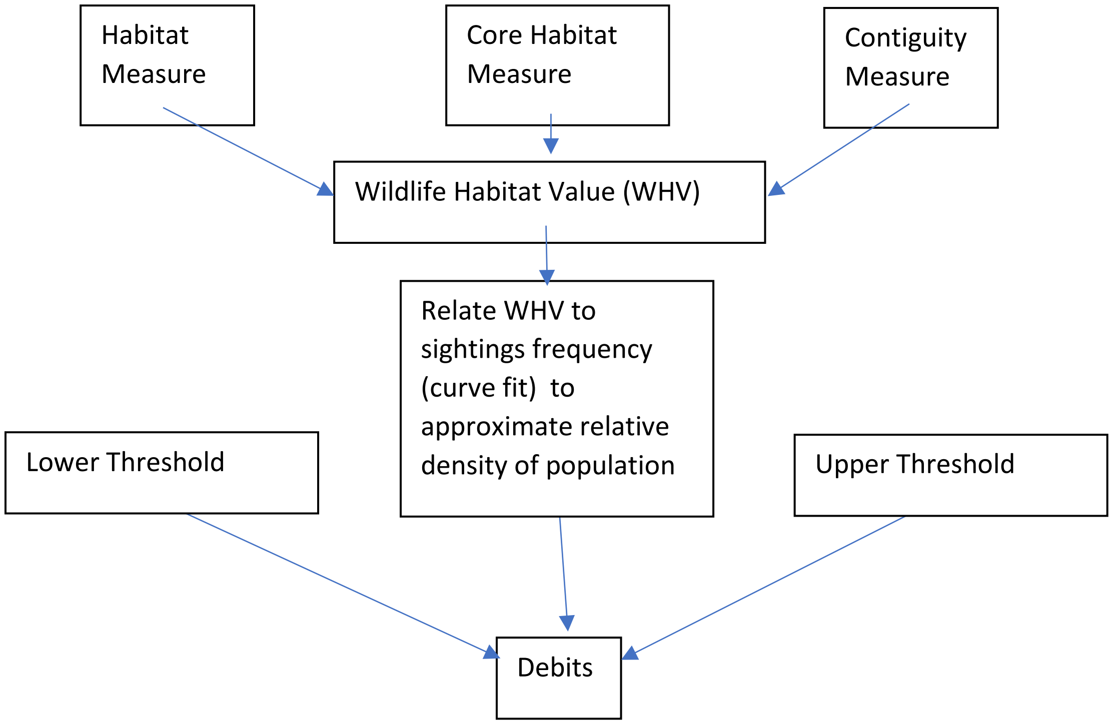



Figure 7: Flowchart of Debit Calculation

### Barred owl as example

As an example of how the method furthers the science of conservation by adding to the available methods for conservation banking. Here is a summary using barred owl as an example. Barred owl is a threatened species in New Jersey, though it is not federally listed and is an IUCN species of least concern. The barred owl is a large round-headed owl with brown barring on the upper breast and brown streaking on the lower breast and belly and dark brown eyes with a distinctive “who cooks for you, who cooks for you all” call. It occurs throughout the eastern United States from the gulf coast and Florida north into southern Canada. In recent years the barred owl has expanded its range westward to California overlapping and hybridizing with the spotted owl. Within New Jersey the barred owl range is most of the northern and southern parts of the state excluding the heavily built-up central Route 1 corridor area (Beans and Niles, 2003 pp. 129-133).

Barred owl prefers remote, contiguous, old-growth wetland forests and require mature wet woods that contain large trees with cavities suitable for nesting. They generally avoid populated areas and prefer interiors of the forest. If there are no nesting sites within a wetland forest the barred owl has been known to nest nearby a wetland. They will inhabit both deciduous wetland and cedar swamps as well as other coniferous areas, and prefer flatter lowland terrain to rocky slopes and hillsides. The barred owl is a resident species, has generally established territories with stable borders, has strong pair bonds, and strong site fidelity. The barred owl prefers fairly open understory for ease of flying and hunting. It eats predominantly small mammals but is an opportunistic predator and will also consume frogs, lizards, small snakes, salamanders, spiders, crayfish, snails, slugs, insects, fish, opossums, bats or small birds (Beans and Niles, 2003 pp. 129-133).

The owl was common in New Jersey until the early 1940s when its habitat began to be greatly reduced by cutting old-growth forests and filling wetlands; it was listed as threatened in New Jersey in 1979. Fragmentation of the remaining habitat areas is causing further declines in population. In the 1980's the population in New Jersey was estimated at 112 breeding pairs; more recent surveys in South Jersey indicate as much as a 30% decline there (Beans and Niles, 2003 pp. 129-133).

Because of the high importance of the spatial aspect of habitat selection of the barred owl, a spatial method of setting debits and credits is key. The calculation of debits begins with the calculation of a wildlife habitat value (WHV) which is described in detail in chapter 1. The calculation base is a designation of the entire statewide land area into 3 broad but specific categories: land cover that is possible habitat, neutral non-habitat, and altered nonhabitat. Possible habitat areas are those types of forests and surrounding wetlands which barred owl are known to prefer for either breeding or foraging such as wetland deciduous forests, cedar swamps, and hardwood forests. Neutral non-habitat consists of areas in which the barred owl will not generally nest or forage but which it will not necessarily avoid including water (streams, lakes, ponds) some undeveloped rights of ways and other similar areas. Altered non-habitat are areas that the barred owl will specifically stay away from such as developed areas, cities, and large roads. From this broad base, spatially related measurements are made concerning the percentage of neighboring area that is habitat, percentage of neighboring area that is core habitat, and the contiguity of habitat patches. Core habitat is defined as at least 300 feet away from altered non-habitat. Contiguity is measured as the area a member of the species can easily travel to by travelling through habitat or neutral non-habitat and crossing roads below a threshold difficulty of crossing. These three measures are combined into one Wildlife Habitat Value (WHV). For barred owl this entails large contiguous patches including remote wetland forest areas.

Because barred owls are so highly preferential towards interior and/or remote wetland forest we would hope that the debit values assessed for destroying core forest would far outweigh any debits for destroying more marginal, edge forest. Because of the strong spatial basis in the calculation of WHV, the interior areas have higher values and due to the use of relative sightings frequency to move from WHV to debits, those higher values for interior forest continue to the debits. Because the curve fit to move from WHIV has an upper threshold at the peak frequency, the highest debit value is reached in the areas with the WHIV of peak sightings which is generally interior forest. These high debit values continue to the even higher WHIV areas. The hope is that by causing a much higher amount of debits to be mitigated for interior forest than for edge and small patches of forest, developers will seek to stay away from the interior forest and thus leave the best habitat for the barred owl.

This method advances the science of conservation banking by improving upon currently available methods of setting tradeable debits, which has been cited as a main reason inhibiting the spread of conservation banking as a mitigation tool (Madsen et al. 2010; Bunn et al. 2013). This approach relates to relative numbers of breeding pairs as the debits calculated are a proxy for relative density of population. Areas with predicted higher numbers of breeding pairs are assigned higher debit values. Though the numbers are not set in actual breeding pairs, the method approximates the relative number of breeding pair. This framework of calculating debit values, may be incrementally improved as better modeling relationship equations become available.

## Works Cited

http://www.audubon.org/field-guide/bird/grasshopper-sparrow

Beans, B. Niles, L. 2003. Endangered and Threatened Wildlife of New Jersey. Rutgers University Press, New Brunswick, NJ.

Bull, J. Suttle, K. Gordon, A. Singh, N. Milner-Gulland, E. 2013 Biodiversity offsets in theory and practice. Flora and Fauna International, Oryx, 47(3), 369-380

Bunn, D. Lubell, M., and Johnson, C. K. 2013. Reforms could boost conservation banking by landowners. *California Agriculture* 67(2):86-95.

Bunn, D., Moyle, P.B., Johnson, C.K. 2014. Maximizing the ecological contribution of conservation banks. Wildlife Society Bulletin. DOI: 10.1002/wsb.398

Endangered Species Act of 1973. Public Law 93-205 as amended through public law 107-136. 2002

Hanski, I., "Metapopulations and Spatial Population Processes" in Levin, S. 2009. The Princeton Guide to Ecology. Princeton University Press. Princeton, NJ II.4

Madsen, B., Caroll, N., Moore Brands, K. 2010. State of Biodiversity markets report: Offset and Compensation Programs Worldwide. Washington, DC: Forest Trends. http://www.ecosystemmarketplace.com/documents/acrobat/sbdmr.pdf

Mills, L.S. 2007. Conservation of Wildlife Population: Demography, Genetics, and Management. Blackwell Publishing

U.S. Fish and Wildlife Service. 2012. Conservation Banking: Incentives for Stewardship. Factsheet. http://www.fws.gov/endangered/esa-library/pdf/conservation_banking.pdf

Wilcove, D.S., Rothstein, D., Dubow, J., Phillips, A., Losos, E., 1998. Quantifying threats to imperiled species in the United States. BioScience Vol. 48:No. 8:607-615

Wilcove, D.S. and Lee, J. 2004. Using Economic and Regulatory Incentives to Restore Endangered Species, Conservation Biology 18:639.

# CHAPTER 3 – Credits

## A method of assigning credit values for conservation banking based on debits and probability of development

## Abstract

Habitat of threatened and endangered species is being destroyed and degraded increasing the pressure on these species. Consolidated market-based compensatory mitigation including conservation banking has been shown to be effective in mitigating habitat loss and achieving no net loss of habitat value in many circumstances. A barrier to implementation of conservation banking is the calculation of credits, particularly the concept of additionality: assurance that credit is being given only for additional benefits that accrue from enrolling habitat as part of a conservation bank. Conservation banks assure preservation for use by the species in question and management in perpetuity. Thus the increased value of land in conservation bank is increase due to preservation and increase due to management. I developed a component-based model and using place-based decision-making assigned credits using the concept of additionality. Using these credits with the debits from chapter 2 creates a trading system with the goal of no net loss of habitat value.

# Introduction

In conservation banking or in mitigation, there is a difference between the habitat value to a threatened and endangered (T&E) species that would be lost by development and the value gained by preservation of a piece of property. If a parcel of land that is habitat were to be developed or the land use or land cover to change so that it is no longer habitat for the species in question the loss, or debit, would be the entire wildlife habitat value of the land. The method in Chapter 2 assigns debits. The increase in value of a parcel of land as habitat due to the conversion of the land from its current/prior state to the conservation bank or managed mitigation status is simply the benefits it provides beyond those that would otherwise have accrued. This concept of additionality is especially important in the assignment of credits in conservation banking. Conservation banks are lands containing natural resource values that are permanently protected and managed for conservation of species of concern (USFWS 2012), and conservation banking is the process of developers purchasing habitat or species credits from a conservation bank to offset unavoidable adverse impacts of their projects (USFWS 2012; Bunn et al. 2014). According to the USFWS new policy “A compensatory mitigation measure is “additional” when the benefits of the measure improve upon the baseline conditions of the impacted resources and their values, services, and functions in a manner that is demonstrably new and would not have occurred without the compensatory mitigation measure” (USFWS 2016).

Both the preservation and the management of the habitat can create tradable value for a parcel based on the inherent value of the property as habitat. This chapter introduces a method of determining credit values which can be used in concert with the debit values from chapter 2 to allow wildlife habitat value trading via a conservation banking mechanism. If the debits and credits are used together the result would in theory be no net loss of habitat value to each species involved.

## Incorporating the future value into debits and credits

In chapter 2 I laid out a method of determining debits for parcels of land. The debit wildlife habitat value for a parcel of land can be thought of as analogous to the stock price of a traded company. Just as a stock price can be thought of as the future cash flows (expected future dividends) discounted by the return that can be earned in the capital market on securities of comparable risk (Brealey and Myers 1996 pp. 59-60), so too the current wildlife habitat debit value incorporates the future loss of value or use to the species. For example, barred owl habitat is used by a barred owl for hunting, resting, and nesting. Each time the barred owl hunts or nests it receives a value from the habitat which can be thought of as a “dividend” from the habitat. The barred owl receives these dividends just as the stockholder would receive dividend checks in the mail. The value of the habitat to the barred owl is then a stream of dividends as long as the habitat is in use or is available for potential use. Though the value continues into the future in the form of future use of the land as habitat by the barred owl, the currently quoted debit value takes all this future into account just as the current stock price takes into account the future dividends and capital gains. In the case of the stock market the free market and competition for stocks of comparable risk set the price. In the case of the barred owl habitat we are attempting to mimic the free market process or estimate the wildlife habitat debit value, not with monetary value, but with debits that can be traded for credits if mitigation is necessary. Monetary cost could then be determined by the market price of credits which would offset the debits.

This chapter focusses on the determination of the credit value which is an estimate of the present value of the increase in wildlife habitat value which would stem from being in a conservation bank.  Land being credited is not being created and in most cases it is not being restored in the sense of having the land cover change from non-habitat to potential habitat. Rather the value to the species is being created in two ways: through permanent preservation for use by the species and by management for the species credited. Only the additional value that is created by the act of the property entering into the conservation bank should be given as credit to the entity creating or adding to the conservation bank. The original value of the land exists regardless of preservation and to include the existence of the land in the credit value would be to give credit where no credit is due. Both the elements of preservation and management have a stream of future “dividends” or values to the species which would not have existed had the land not been preserved and managed in the conservation bank and this stream of dividends can be brought to present value with or without discounting.

## Value from Preservation

Again, using the barred owl as way of example, the additional value created through preservation of existing habitat that lacks adequate protection is the use by the barred owl in the time during which the land would not have been available to the barred owl in the absence of the preservation. If, in the absence of preservation, the land would have been developed in 12 years, then the additional created value is the use which is now possible for years 13 and subsequent, which would not have been possible without the preservation. Since if land is preserved it is purely hypothetical when it would have been developed, I have used the estimated probability of development through time for each piece of property in New Jersey for the calculation.  The time after the expected development determines the increase in value due to preservation. If, for example, a parcel of land was never going to be developed, one could argue that there would be no additional value in preserving it; either way the barred owl could use the habitat in perpetuity; either way the barred owl could use the habitat in perpetuity.

## Value from Management

The additional value created through management varies from one particular parcel or habitat to another depending on the management applied and may include increased denning/nesting opportunities, increase in quality of forage or hunting, decrease in nuisance wildlife or feral animals, decrease in invasive species, decrease in disease, increase in water quality, return to more natural regimes such as periodic fire or flood or other management. It may result from restoration or enhancement of habitat, management actions such as regularly scheduled prescribed burns or an action that reduces threats from disease or predation, or captive breeding and reintroduction of individuals or populations (USFWS 2016). Because management varies so greatly, I determined an average value from literature on a wide variety of species for use in my calculations of increased value due to management.  In general the outcome of good management may often be an increase in the number of individuals of a species or of the number of threatened or endangered and other native species that are supported by any given habitat.

The combined additional wildlife habitat value created through preservation and management is the credit value attributable to a parcel of land. This value is the amount tradable against the debits determined in chapter 2.

# Methods

My study area is the entire state of New Jersey. Estimating an expected date of development of parcels of land is independent of any species. For the species-specific parts of the calculations, I have used barred owl (*Strix varia*) as the example species. All manipulation of spatial data was completed in either ERDAS Imagine 2013 or Arcmap 10.2 or 10.3.1. Unless otherwise noted, layers are raster with 50ft. pixels. Regression and other manipulation outside of the spatial realm were calculated in the open source software R (R Development Core Team 2008).

## Determining credit value due to preservation

### Theoretical considerations of the estimate of probability of development

In order to calculate credit one must first calculate the increase in wildlife habitat value due to preservation. I started by estimating the probability of development at points in time in the future. One method to estimate the future is to look at past patterns and assume that the change into future will follow the patterns of the past. There are multiple ways to do this. The simplest way to estimate the future from the past is to assume that the trends of the past will continue into the future with no change. Even this simplest case is complicated by the estimate of the trends of the past. There are many questions to ponder: In the case of development, should one examine the long-term trends over long periods of the past such as taking a many-year average? What is the definition of long-term? Should one look at the recent trends only and ignore the long-term trends such as taking an average of only the most recent years? Should one weight the long-term and recent trends with a weighted average or a weighted comparison of long and short-term averages? Should one ignore outlier observations and take an average excluding the highest or the lowest observation or both the high and low observations? What sort of bias might excluding high and low observations imply? If there is an unlimited upside (large amounts of development) but a clear lower bound on development (no development) then excluding high and low observations can bias low (since high observation could be very high and could have thus had a great impact on any average but the lowest observation could not be lower than the lower bound and thus would not have as great an impact). What if there are known anomalies created by internal or external events such as major changes in development regulation or economic shocks? These could be dealt with in several ways. One could use an average over a longer period of time and reduce the impact of the anomaly. One could make some numerical assumption about the anomaly such as taking half the value or twice the value or some set constant multiplied by the value. One could assume an anomaly of this type and or extent will happen once very so many years and implicitly average out the impact over a number of years. All these considerations go into the most basic method of determining the future from the past. (Foundations of Casualty Actuarial Science, 2001)

There are then more complex ways to estimate the future such as assuming changes in the trends from the past to the future. There are several ways to determining or estimate these changes in trends. One can restate the past history such that it mimics the perceived future. This can take a high amount of data but can be done in such cases where, for instance, regulatory changes are of paramount importance and the regulatory change in each political region are known. (Foundations of Casualty Actuarial Science 2001)

All of the methods mentioned thus far assume somewhat of an unlimited capacity for growth. If there are limits as there often are in real life, those must be taken into account such that one cannot develop past the limit. There are two main types of limits, limits to each individual transaction and limits to the aggregate number or amount of transactions. In our example the aggregate limit to development is buildout. The natural limit to each transaction is the state of being developed and in fact we are looking at each transaction as a Bernoulli trial or a binomial trial: either a parcel of land is not developed or it is developed. There are two main ways in which trends can be limited: they can be limited such that the limit has no effect on the trend other than it cuts off the development at some set point, or the development could slow as it reaches the set point. The former method is easier to estimate as one just inserts a limit into the otherwise calculable trend.

### Practical considerations of the probability of development

In our case of the estimate of future probability of development for the entire state of New Jersey, we have several practical considerations. The land-use land-cover maps on which I have based my work have been available most recently approximately every 5 years and the data is available a couple to several years after the date of the "as of" evaluation. In our case the bulk of our estimation work was completed using the as of 2007 edition of the maps. Currently there are 1986, 1995, 2002, 2007, and 2012 editions available.

During the recent past there have been regulatory changes in parts of the state dealing with zoning and other regulations that would affect development. Some areas of the state are governed by municipal planning, but there are also some regional planning bodies, most notably in the Highlands and the Pinelands. It is not apparent that there have recently been any more changes in these regulations than at other times in the past, and therefore there have been no adjustments made to the trend analysis on behalf of regulatory changes. If a more detailed development estimate is done in which each county or other smaller and more homogeneous area is examined on its own, I recommend that the regulatory history and zoning history be part of the analysis.

In 2008 there was a financial crisis which deeply affected housing lending and new construction and affected commercial construction as well. This anomaly caused an unknown change to the development trajectory of New Jersey. Statewide there was a 70% decrease in the rate of development between the 2007 and 2012 period and the previous land use mapping period of 2002-2007 (Lathrop et al. 2016). It is unknown, whether the previous pace of development will resume after the period of slowdown or whether the pattern or pace of development has been altered. It is unknown how much of the decrease in the rate of development was due to the economic shock and how much is part of a longer trend of change in development.

### Development estimate

I examined two time periods in the past in order to set up multivariate regression equations to estimate development. I examined the 5-year time period from 2007 through 2012 and the 10-year time period from 2002 through 2012. The land-use maps are available for all three of the requisite years, 2002, 2007, and 2012. Because the financial crisis of 2008 brought housing lending and new construction virtually to a halt in some markets and the recovery has been slow, I was hesitant to base my development equations on the time period 2007 through 2012, though it is the most recent timestep available.

The annualized rate of land use change into urban land use has changed over the years. From 1986 through 1995 there were an average of 13,999 acres of new urban development per year, from 1995 to 2002 the rate of development increased to 16,852 new acres of urban development per year, then there was a slight decrease from 2002 through 2007 with 16,422 new acres of urban development per year. The big drop was from 2007 through 2012 when there were only on average 4,850 acres of new development per year. (Lathrop et al. 2016) Looking at the 10 year period from 2002 through 2012 we see an average of 10,636 new acres of urban development per year which is 34% less than the 1986 through 2002 average of 15,758 new acres per year. Because of the few time steps we have with the data, it is a bit difficult to determine a trend, but we did see a reduction between the average development during 1995 – 2002 and the development in 2002 – 2007 before the economic downturn. This reduction was about 3%. If we assume that the period 1995 – 2002 was the peak of development and that we are now on the downslope of the development curve we might conservatively assume projected future development of less than 16,000 acres per year.

There are several factors indicating that there may continue to be slowdown of urbanization in New Jersey from the peak in 1995-2002. The percentage rate of population growth exceeded percent rate of growth in urban land in the 2007-2012 period, indicating that the sprawl may be receding to be replaced by denser growth. An additional sign of a turn to denser growth was that the ratio of new impervious surface vs. newly developed land increased from 23.8% average 1986 – 2007 to 26.5% in 2007-

2012. New Jersey may be entering a new "post suburban" phase that reflects a stronger push towards smart growth and a focus in urban redevelopment, but it is too soon to tell for certain. (Lathrop et al. 2016)

Though I did model the most recent five-year period available, that from 2007 through 2012, the equations selected were developed from the longer 10-year period from 2002 through 2012. Thus, though the economic downturn is recognized in the estimates with a blunted effect due to the increase in the amount of time over which the effect is spread.

To determine development between the dates, I recoded the four-digit land-use, land-cover codes into three categories: developed (1); water, wetland, beaches, and undeveloped right of ways (2); and undeveloped (5). Land that was not category (1) at the first date, but was category (1) at the second date is considered newly developed. Water, wetland, beaches, and undeveloped right of ways were separated out because of the unique regulations for these areas which lead to no development or an atypical pattern of development.

The earliest land-use change models were Markov random processes wherein the state of land in the future was a function only of the present state. Later models added dependence on neighboring states and introduced spatial and temporal non-stationarity to the transition probabilities (Veldkamp and Lambin 2001). The model I used includes dependence on the states of neighboring grid cells and is based on multivariable regression.

In order to estimate the probability of future development and probable date of future development (land-use change model) I have first identified the most important drivers of change. I drew upon several sources. In 2003 a study was completed of the development in the New York and New Jersey Highlands. The study was primarily concerned with residential development and identified several important drivers of land use change. Location variables appeared most strongly related to the probability of development. Proximity to land that was already developed increased probability of development as did proximity to train stations and water (Lathrop et al. 2003). All three of these variables were available in or calculable from my dataset. Other drivers of land-use change have been policies including zoning. However, incorporation of social, political and economic factors is hampered by lack of spatially explicit data and the difficulty of linking social and natural data (Veldkamp and Lambin, 2001).

Variables included in the regression analysis are proximity to already developed land, proximity to commuter rail stations (Path, PATCO, and NJ Transit), proximity to major roads (major defined as categories 1 through 4 by NJDOT), and proximity to major metropolitan area (as defined by distance from either Penn Station, New York or 30$^{th}$ Street Station, Philadelphia) (Table 1).

Table 1: Variables used in derivation of probability of development listed with source and units

| Variables | definition | source | derivation | units |
|---|---|---|---|---|
| distance from already developed land | land categories | lu/lc 2002 | | numbers of 50 ft pixels |
| Distance from commuter rail stations | Path, PATCO, NJ Transit stations | Port Authority of NY and NJ, Port Authority Corporation, NJ Transit | | numbers of 50 ft pixels |
| Distance from major roads | NJDOT categories 1,2,3,4 | NJDOT | | numbers of 50 ft pixels |
| Distance from major metropolitan area | Penn Station, New York City or 30th Street Station, Philadelphia | Port Authority of NY and NJ, SEPTA | | numbers of 100 ft pixels |

I am addressing land-use change due to human activity. Land-cover change without a proximate human driver (e.g. indirect effects due to climate change or natural progression from grassland to early successional to mature forest) is not a part of the model. I do not propose that the variables used in the model to estimate probability and speed of land-use change are the causation of the change, simply that they are correlated with change. I am taking into account both residential and commercial development as the main methods of land-use change.

An alternative land use change model to the one developed here could be substituted. I have developed an empirical model in order to have a fairly realistic set of probabilities to work with in order to illustrate my overall methodology.

### Regression

I extracted 10,000 randomly selected points throughout New Jersey. The points were selected using ArcMap's "create random points" tool constrained by a polygon of land that was both undeveloped (5) and not protected as of 2002. The multivariable regression was run in R using data extracted from ArcMap for each of the 10,000 randomly selected points. Data included value of the raster layers at each point. The layers used were developed land (binary) as of 2002, 2007, and 2012 and a layer for each variable: distance from already developed land, distance from commuter rail stations, distance from major roads, and distance from a major metropolitan area. I ran a variety of regressions, compared the ability of each equation to project development using an independently generated random set of 10,000 points as way of validation.

I ran both linear regressions with a variety of transformations of the variables as well as logistic regression. I ran these on all 4 variables and on combinations of fewer variables taking the significance of each variable into account. I ran the linear regression on the straight variables, on the reciprocals of the variables (slightly more intuitively appealing as proximity to instead of distance from), on the natural logs of the variables, and on the inverse square of the variables.

Because my random sample of 10,000 points included 1102 points that had been developed as of 2012 (11%) and the remainder remained undeveloped as of 2012, there was an imbalance of the “yes” and “no” strengths. Therefore, I also took all 1102 random points which developed along with 1102 of the remaining random points and created an alternate dataset, a subset of the random set and used that in a separate run of the regressions as well.

Linear models with transformations can be used to model a variety of underlying distributions. However, often with a dichotomous dependent variable, a logistic regression is used instead. The logistic function has a characteristic S-shape with asymptotes at 0 and 1 guaranteeing that the estimated response function lies between 0 and 1. The logistic function is intrinsically linear. (Montgomery and Peck, 1982) Depending on the relationship of the variables, a linear regression can be used to model dichotomous outcomes. The major advantage of the linear model is its interpretability (Hippel 2015). In the case of my data, the two most predictive models were the inverse squared and the logistic. The means, minimums, and maximums of the projected probabilities on the variables on which they were fit and on an independent set of variables were similar for the logistic and linear with inverse squared transformation. However, the drop-off of the estimated probability of development as the variable "distance from already developed land" increased was markedly faster in the logistic estimate leading me to question the practicality of the logistic measure.

I ran the linear regression on the inverse square of the distance from each of the identified areas: already developed land, commuter rail stations, major roads, and major metropolitan areas. An inverse square implies that a specified physical quantity or intensity is inversely proportional to the square of the distance from the source of that physical quantity; this generally holds true for any point source which spreads its influence equally in all directions without a limit to its range. (http://hyperphysics.phy-astr.gsu.edu/hbase/Forces/isq.html) Because Newton's law of universal gravitation follows an inverse-square law as do electric, magnetic, light, sound, and radiation fields, inverse squared measure is often used these as well as for other phenomena. For example there is an "inverse square law" for the currency market (Chakraborty et al. 2016). Following these examples I included inverse square a one of my types of analysis.

The equation for the inverse squared regression with all four variables is:

Let Developed = land developed as of 2012
frmdev = number of pixels from land already developed as of 2002
frmrail = number of pixels from commuter rail stations
frmroad = number of pixels from major roads
frmMMA = number of 100ft square pixels from either Penn Station, New York or 30th Street Station, Philadelphia

Developed = W*1/(frmdev)$^2$ + X*1/(frmrail)$^2$ + Y*1/(frmroad)$^2$ + Z*1/(frmMMA)$^2$

I compared the adjusted R-squared values to determine which type of equation (straight, log, inverse, inverse squared) and which variables and combinations of variables have the best fit. The regression equation with the highest adjusted $R^2$ is the inverse squared equation without the distance from rail station, but with all other three variables. This inverse squared equation with distance from already developed land, distance from major roads, and distance from major metropolitan areas was used to determine the probability of development of each pixel in a 10 year period. The equation was implemented using an Imagine model.

The output of the inverse squared equation is a projected probability of development in the future. I am using this without change for my entire time horizon, though if there is a reason to make adjusting assumptions such as a slowdown or speed-up of development, the projected probability can be adjusted.

### Time Horizon

In theory, a piece of property preserved and managed in perpetuity would afford a threatened or endangered species habitat forever, thus for thousands of years. However, I have selected a finite time horizon for several reasons: regulatory and or political provisions are not, in reality, ever in perpetuity; governments and empires have all been finite up until this time and there is no reason to believe that this aspect of civilization has changed; humans have difficulty perceiving infinite or even very long time horizons. One could use this same method with any finite time horizon. I have selected 100 years as my time horizon due to the fact that 99 years is a common long-term lease agreement term; 100 is a round number and humans in general and regulators in specific tend to prefer round numbers; 100 years is close to a human lifespan and thus is conceivable to most people; with discounting for time value, the value past 100 years would be very heavily discounted and thus not necessarily add a material amount to the calculation; and in 100 years circumstances may change so appreciably that current land preservation agreements or land uses may change drastically.

I calculated a credit from preservation factor using the probability of development at each 10-year period. If the probability of being developed in 10 years is denoted by $x$, the probability of not being developed in 10 years is denoted by $(1-x)$, the probability of not being developed in 20 years is $(1-x)^2$ , and the probability of not being developed in 30 years is $(1-x)^3$ etc.  The process is analogous for each 10-year period. Thus the probability of being developed in 20 years is $1-(1-x)^2$ , and the probability of being developed in 30 years is $1-(1-x)^3$ .  The credit from preservation factor is the proportion of the 100 year time horizon that the parcel would, using our probabilities, be developed. It is a value between 0 and 1 denoting what proportion of the selected time scale the habitat will be available if the property is preserved that it otherwise would not have been available.  It is calculated as the sum of the probability of being developed at 10 years, 20 years, 30 years through 90 years multiplied by one-tenth (Table 2).

Let x be probability of development. The credit from preservation factor is then:

$$0.1 * (8 + x - (1-x)^2 - (1-x)^3 - (1-x)^4 - (1-x)^5 - (1-x)^6 - (1-x)^7 - (1-x)^8 - (1-x)^9 )$$

Table 2: The derivation of the credit from preservation factor from the probability of development in 10 years for a selection of probabilities.

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1-(1-(1))^2 | 1-(1-(1))^3 | 1-(1-(1))^4 | 1-(1-(1))^5 | 1-(1-(1))^6 | 1-(1-(1))^7 | 1-(1-(1))^8 | 1-(1-(1))^9 | 1-(1-(1))^10 | sum((1):(9))*0.1 |
| Sample probabilities of development in 10 years | probability of being developed in 20 years | probability of being developed in 30 years | probability of being developed in 40 years | probability of being developed in 50 years | probability of being developed in 60 years | probability of being developed in 70 years | probability of being developed in 80 years | probability of being developed in 90 years | probability of being developed in 100 years | Credit from Preservation factor |
| 0.05 | 0.10 | 0.14 | 0.19 | 0.23 | 0.26 | 0.30 | 0.34 | 0.37 | 0.40 | 0.20 |
| 0.10 | 0.19 | 0.27 | 0.34 | 0.41 | 0.47 | 0.52 | 0.57 | 0.61 | 0.65 | 0.35 |
| 0.15 | 0.28 | 0.39 | 0.48 | 0.56 | 0.62 | 0.68 | 0.73 | 0.77 | 0.80 | 0.46 |
| 0.20 | 0.36 | 0.49 | 0.59 | 0.67 | 0.74 | 0.79 | 0.83 | 0.87 | 0.89 | 0.55 |
| 0.25 | 0.44 | 0.58 | 0.68 | 0.76 | 0.82 | 0.87 | 0.90 | 0.92 | 0.94 | 0.62 |
| 0.30 | 0.51 | 0.66 | 0.76 | 0.83 | 0.88 | 0.92 | 0.94 | 0.96 | 0.97 | 0.68 |
| 0.35 | 0.58 | 0.73 | 0.82 | 0.88 | 0.92 | 0.95 | 0.97 | 0.98 | 0.99 | 0.72 |
| 0.40 | 0.64 | 0.78 | 0.87 | 0.92 | 0.95 | 0.97 | 0.98 | 0.99 | 0.99 | 0.75 |
| 0.45 | 0.70 | 0.83 | 0.91 | 0.95 | 0.97 | 0.98 | 0.99 | 1.00 | 1.00 | 0.78 |
| 0.50 | 0.75 | 0.88 | 0.94 | 0.97 | 0.98 | 0.99 | 1.00 | 1.00 | 1.00 | 0.80 |
| 0.55 | 0.80 | 0.91 | 0.96 | 0.98 | 0.99 | 1.00 | 1.00 | 1.00 | 1.00 | 0.82 |
| 0.60 | 0.84 | 0.94 | 0.97 | 0.99 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.83 |
| 0.65 | 0.88 | 0.96 | 0.98 | 0.99 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.85 |
| 0.70 | 0.91 | 0.97 | 0.99 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.86 |
| 0.75 | 0.94 | 0.98 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.87 |
| 0.80 | 0.96 | 0.99 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.88 |
| 0.85 | 0.98 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.88 |
| 0.90 | 0.99 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.89 |
| 0.95 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.89 |
| 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.90 |

The credit from preservation factor is multiplied by the Debit value of the property which was developed from the initial wildlife habitat value. This should not be used as a projection of which parcels will be developed, but should be used to estimate the additional use of the habitat that is gained for each species by preservation of the property.

## Determining increase in value due to management

The increase in value due to perpetual management of the property for the species is an inherently variable amount as various properties have different needs for management and restoration and different types of management can have varying effects on the suitability of use for each species.  For the purposes of creating a consistent state-wide map of values, I have used average values across types of habitat. The underlying increase in value is based on the increase in the population of a habitat before restoration and management and after/during restoration and management. My values were not determined by my experiments or surveys but by peer reviewed studies in the literature on the species in question or similar species if available. If unavailable, the studies on other species and in other areas of the world have been used. I have set up a framework for development of credit values. In the future if newer coefficients of increased value due to management are developed based on newer or more directly applicable research, these could be used instead.

Theoretically restoration of habitat should improve the areas for wildlife implying that wildlife populations should increase under management. This is recognized by the USFWS in their policy wherein they state that “additional benefits may result from restoration or enhancement of habitat” and further that losses of habitat may be offset by improved management of existing habitat (USFWS 2016). However, there is a dearth of peer reviewed evidence of such an increase and in particular a lack of quantitative evidence of the amount of increase. In some cases restoration is completed, but ongoing monitoring is not done (Wayne Lehman, personal communication). I have included here a summary of a selection of recent, relevant literature. Much of the available literature involves monitoring of birds, though there are several examples of other taxa.

Luther et al. completed a wide-ranging review of ESA 5-year reviews looking at conservation actions, population trends, and funding for birds listed on the Endangered Species Act. They found population trend was not associated with any specific conservation actions, though there was a significant positive relationship between total and annual funding and population trend and a significant positive relationship between annual funding and implementation of habitat protection and education (Luther et al, 2016). They found sixteen continental and ten island species had increasing population trends at the five-year review for each listed species after implementation of the recovery plan; eighteen continental and forty island species had declining populations. In a study of globally threatened bird species, Luther et al., found correlations between positive population trends and the conservation actions reintroduction, ex-situ, invasive species control, education, and legislation. (Luther et al, 2016) However, no quantitative average percentage increase in population related to conservation actions is presented for either of these cases.

One of the potentially best examples of the value of proactive management on a species population size is for grassland birds. Grassland bird habitat may be heavily managed in order to keep it at an early successional stage. Maintenance of early successional and open habitats often requires active removal of encroaching vegetation. Thompson et al. completed a before-after control-impact study on 14 grassland sites in central North America from 2005 through 2011 and determined that tree removal did appear to improve habitat suitability for grassland birds with a weak and delayed positive response. Treatments caused short-term habitat disturbances that significantly reduced abundance of target species followed by increases. Complicating their study, grassland bird abundance dropped on untreated control sites (Thompson et al. 2016). For rare grassland birds the number of birds at the end of 6 years after treatment was approximately twice as high as the untreated areas; for all grassland birds combined, the number was approximately 1.7 times as high as the untreated area.

In another bird study, Vander Yacht et al. (2016) studies avian occupancy response to oak woodland and savanna restoration in which they found that though restoration substantially altered forest structural characteristics it did not affect the occupancy of most late-successional species. In contrast the presence of early-successional species increased after management. Three of the 41 species studies exhibited reduced occupancy after management while all others remained constant or increased.

Riparian and wetlands have had quite a bit of restoration and management over the recent years and thus may shed light on the subject of how much increase in wildlife populations one can expect under management. However, studies that assess the success of riparian restoration projects seldom focus on wildlife. Often vegetation is studied under the assumption that animal populations will recover with restored habitat. (Golet et al. 2008) Golet et al. reviewed and summarized the major findings of a suite of studies that assessed responses of four taxonomic groups (insects, birds, bats, and rodents) and found that older restoration sites showed increased abundances of many species of landbirds, bats, and the Valley elderberry longhorn beetle. Species richness also increased. (Golet et al. 2008) There is not quantitative information on the percentage increase in the species presented in the paper, however.

Gardali et al. were part of the group in the studies assessed by Golet et al. and Gardali documented for landbirds in restored riparian forests on the Sacramento River an increase of population trend for 11 of the 20 species studied, no trend for 8 of the species, and a decreasing trend for one of the species. The estimated linear trend across the revegetated plots ranged from 1.48% for the Western Kingbird to 26.88% for the Spotted Towhee. Species increased on the revegetated plots at rates that ranged from -10.91% annually to as high as 26.58% annually. (Gardali et al. 2006) There is no indication of the total expected increase or whether the annual increase is expected indefinitely.

Sadly, some literature tells us that much restoration is ineffective. Grey partridge populations showed no increase in population on managed areas compared with control and in fact the 'apparent mortality' rates increased. (Bro et al. 2004) and ring-necked pheasants, though they showed a possibility of a 70%up to 800% increase in population, actually did not show enough to reverse declines overall in a study in Pennsylvania. (Pabian et al. 2015)

As for other wildlife besides birds, brown hyena showed huge increases with management, up 367% in 10 years. This was mainly due to fencing the population and protecting them from being killed by humans (Welch and Parker, 2016). Reid et al. found an annual increase in Blanding's turtles in a restored wetland-upland complex in Wisconsin. Over the 24-year period of the study, the population increased 3%. (Reid et al.2016)

## Determining total increase in value due to preservation and management – credit value

The factor for the increase in value due to preservation is added to the factor for the increase in value due to management and the sum is multiplied by the debit value to get the credit value (Figure 1).

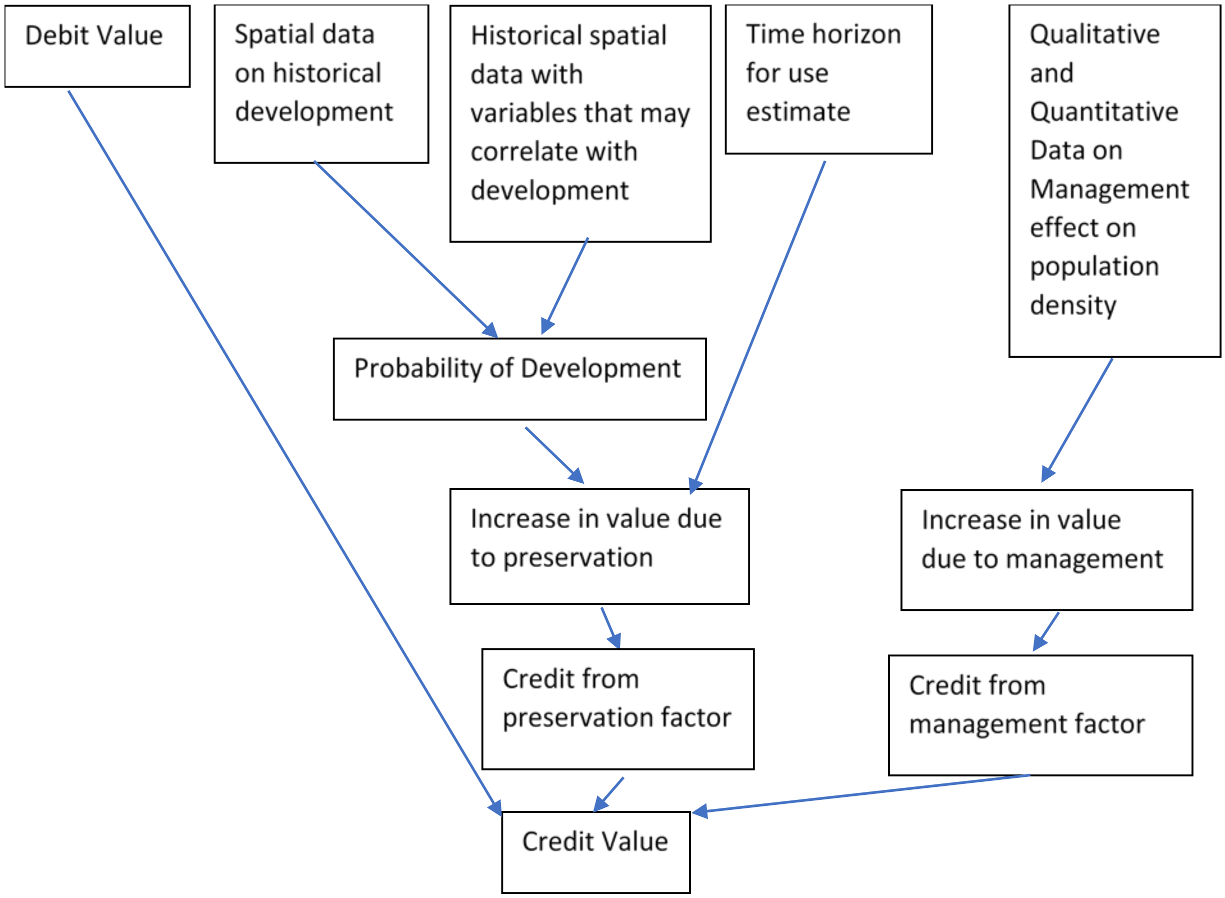



Figure 1: Workflow diagram of credit model showing the calculations modifying the debit value to include the additionality – increase in value due to preservation and management.

# Results

## Increase in value due to preservation

Using a multivariable regression on 10,000 randomly selected points, I found the coefficient of multiple determination or the explained variation as a portion of the total variation of the regression (adjusted R-squared) varied between .032 and .090 for equations using all four variables (distance from already developed land, distance from commuter rail stations (Path, PATCO, and NJ Transit), distance from major roads (major defined as categories 1 through 4 by NJDOT), and distance from major metropolitan area (as defined by distance from either Penn Station, New York or 30th Street Station, Philadelphia) depending on the transformation used. The inverse-squared transformation, which yielded the highest adjusted R-squared value, using the three most predictive variables yielded the following equation for use in determining the probability of development.

Probability of Development in 10 years

$$= 0.04684 + 0.2427/(frmdev)^2 + 0.03134/(frmroad)^2 + 0.0001328/(frmMMA)^2$$

Where

frmdev = number of 50ft pixels from land developed as of 2002 with max of 211(2 miles)

frmroad = number of 50ft pixels from main roads with max of 1056 (10 miles)

frmMMA = number of 100ft pixels from either Penn Station New York or 30th Street Station, Philadelphia with max of 2112 (40 miles)

The probabilities of development in 10 years across the New Jersey-wide study area run from a low of just under 0.047 to a high of 0.32 with a mean of 10%. (Figure 2)

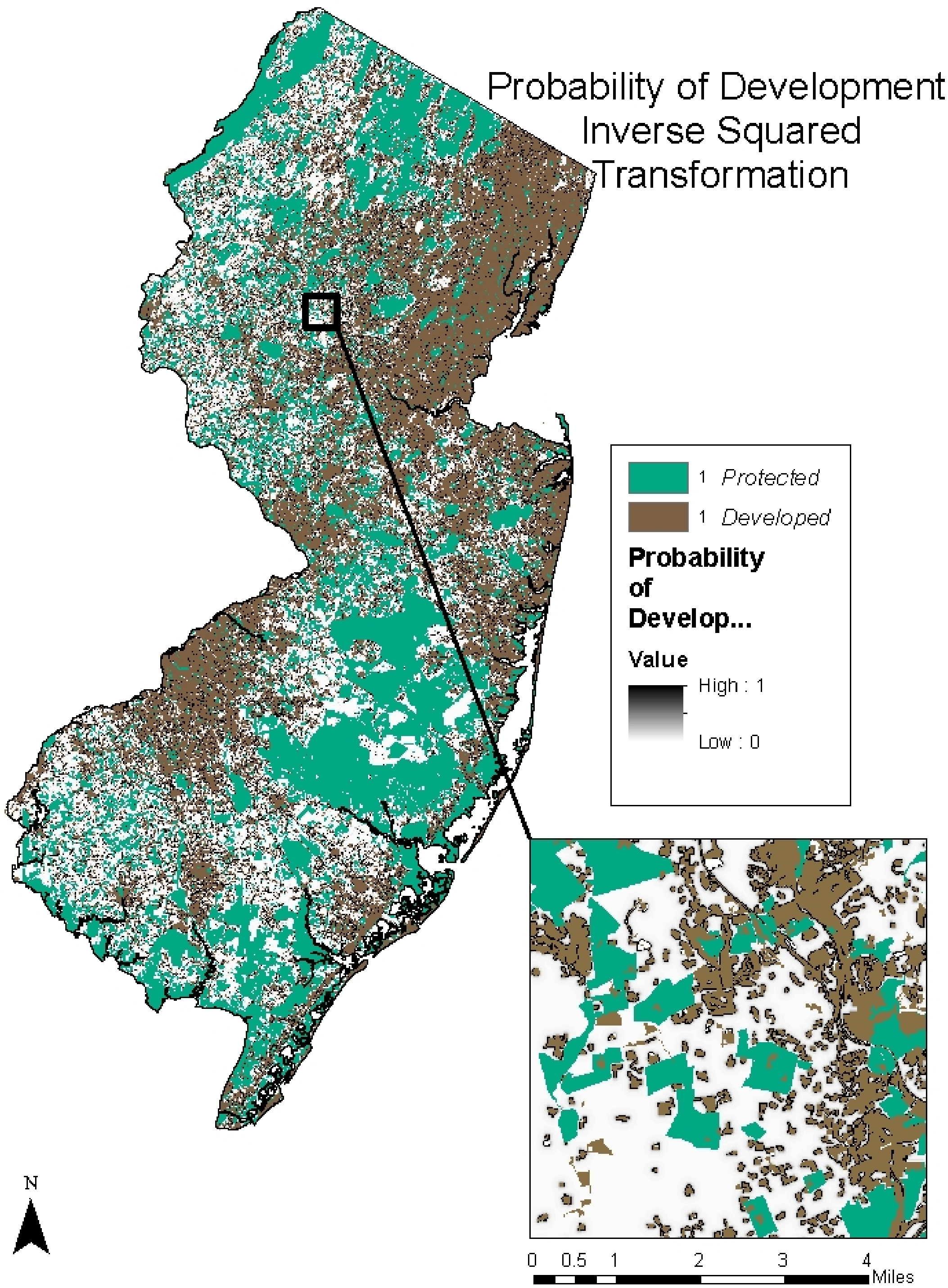



Figure 2: Probability of Development in 10 years based on the inverse square model. Existing protected lands are malachite green with a probability of development of 0 and developed lands are brown with probability of development of 1.

The values from the probability of development in 10 years (Figure 2) were then used to estimate the percentage of the next 100 years during which the properties likely be developed (Table 2) which is used as the credit from preservation factor.  The credit from preservation factor has values between 0.19 and 0.69. (Figures 3 and 4)

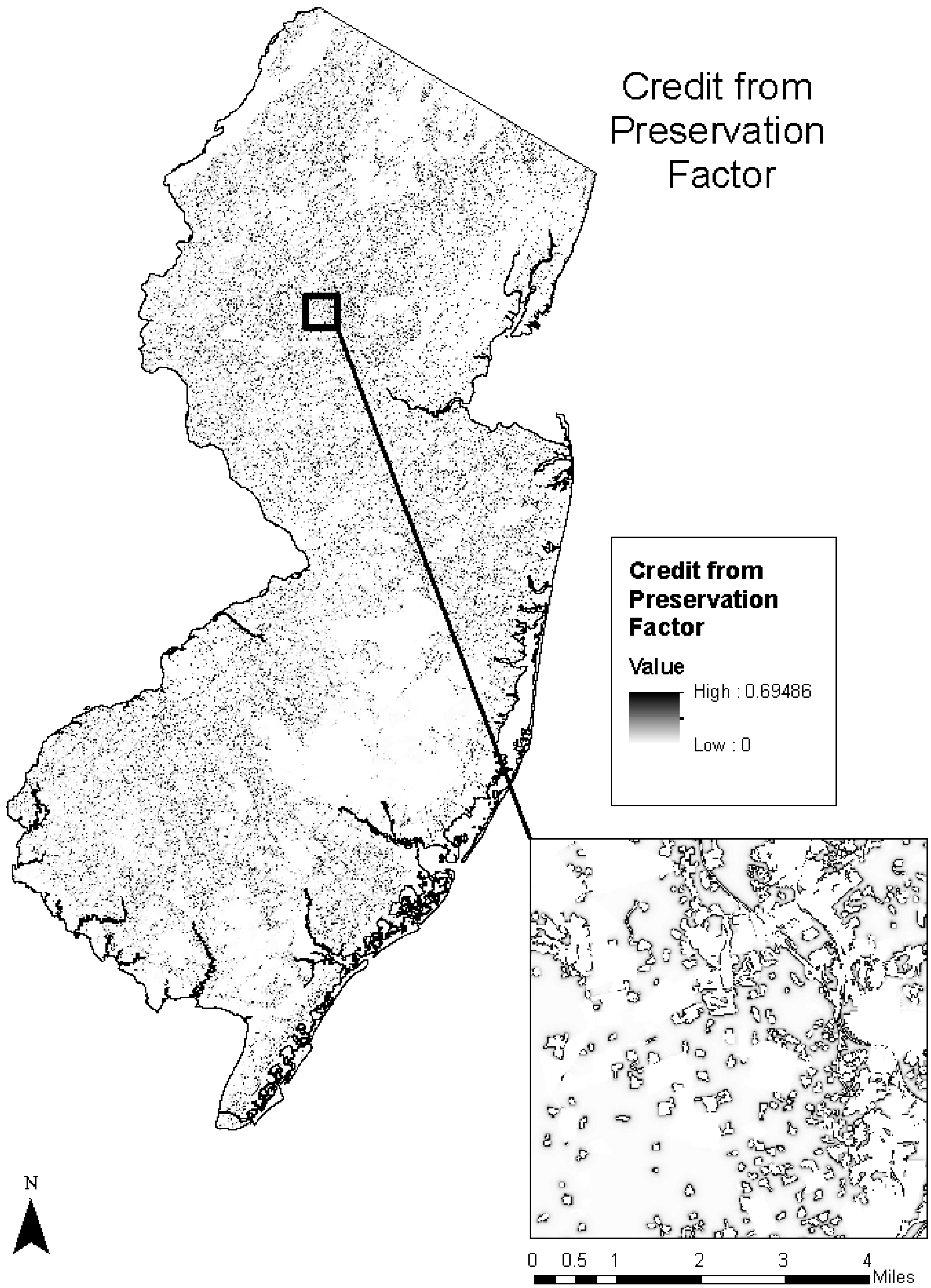



Figure 3: Credit from Preservation Factor: The credits from preservation factor are highest nearest already developed land.

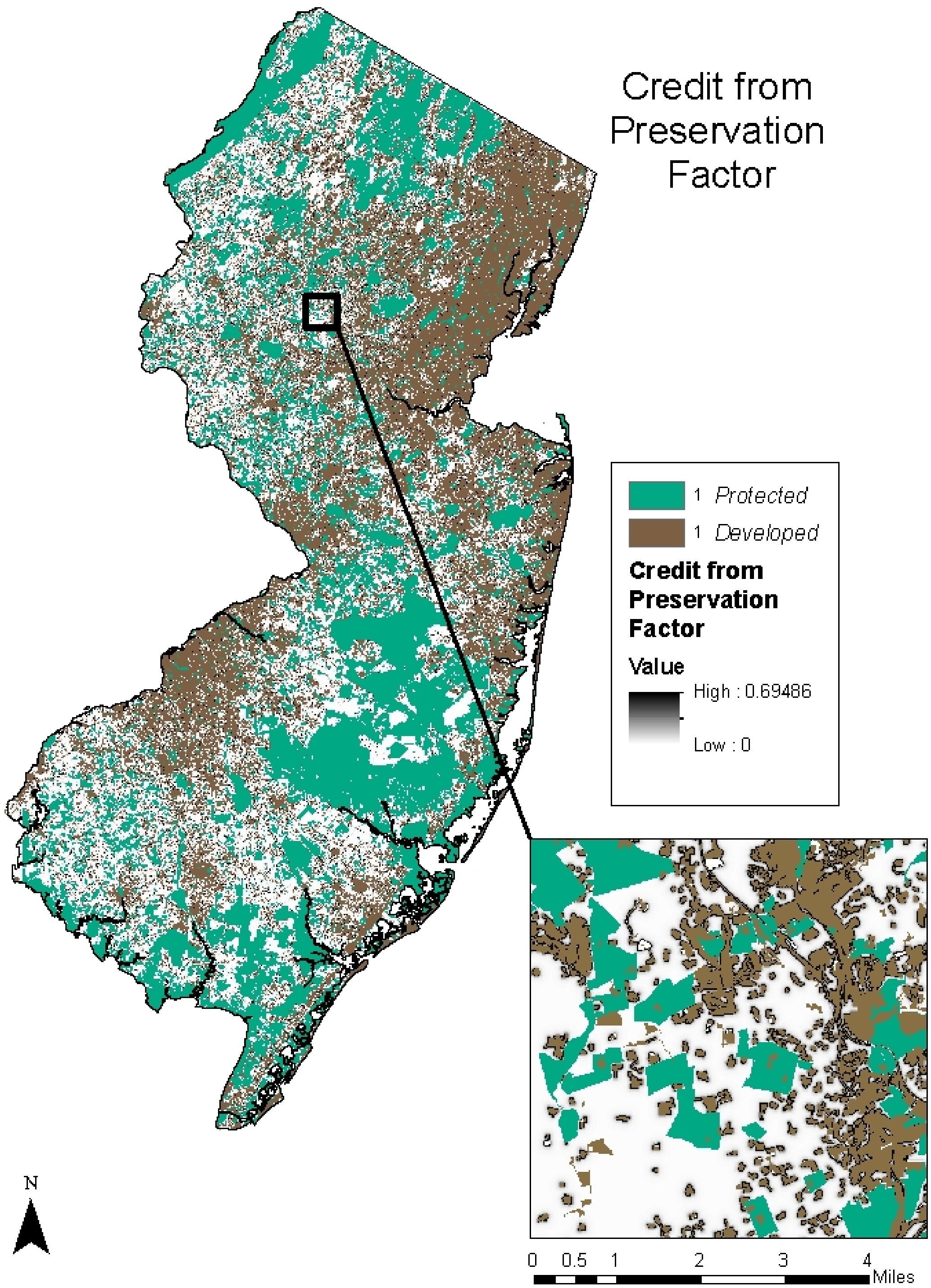



Figure 4: Credit from Preservation Factor shown with protected and developed land: The credits from preservation factor are highest nearest already developed land; higher values

are darker. Already developed land is shown in brown and protected land in malachite green.

## Increase in value due to management

Peer reviewed studies have determined that restoration and management can affect the population of threatened and endangered species. The results seen for various restoration and management schemes vary widely and are not often published. From discussions with land managers and peer reviewed, published sources I determined a range of estimates. The weighted average of the published sources indicated a range from 9% to 108% (Table 3). Studies with multiple species were weighted higher. Studies ranging over longer time periods were also given more weight. The selection included qualitative information to the extent that I was able to adjust the quantitative average based on the papers with qualitative information and based on the goals of several land managers in Delaware. The credit from management factor would vary based on the species as the habitat of some species lends itself to improvement by management more than other species'. For use in this dissertation as a case study I selected a best estimate of a potential 30% increase in population which leads to a credit from management factor of 0.3.

Table 3: Qualitative and quantitative estimates of the increase in population of species due to restoration and/or ongoing management from literature. A range and point estimate are shown as well as the number of years in the study.

| Author | year | Type of system or taxa | Result | quantitative measure of population change | number of years in study | % increase overall estimate low end of range | % increase overall estimate point | % increase overall estimate high end of range |
|---|---|---|---|---|---|---|---|---|
| Luther et al. USA | 2016 | birds on endangered species list | unknown, maybe positive | | | | | |
| Luther et al. worldwide | 2016 | IUCN endangered birds | positive, but no quantitative | | | 0% | | |
| Thompson et al. | 2016 | rare grassland birds | weak and delayed positive response especially compared to control | 1.5 to 2 times as high as control | 6 | 50% | | 100% |
| Golet et al. | 2008 | insects, birds, bats, rodents | positive, mostly qualitative, birds included in Gardali | | | 0% | | |
| Gardali et al. | 2006 | 20 species of birds | positive unlimited | annual trends from 0.06% up to 10.11% for 19 species and -5.04 for the 20th | 7 - 9 | 0.4% | | 78% |
| Vander Yacht et al. | 2016 | Avian oak woodland and savanna | increase varying by species | | | | | |
| Reid et al. | 2016 | Blanding's turtles | increase in population , varying by area | 3% annual increase with a 95% CI 1.01-1.05 | 24 | 27% | 103% | 223% |
| Pabian | 2015 | Ring-necked pheasants | if high enough percentage of managed land | up to 9 fold increase in 10 year period | 10 | 70% | | 800% |
| Welch and Parker | 2016 | Brown hyena | increase with management | from 6 to 28 individuals | 10 | 367% | 367% | 367% |
| Bro | 2004 | grey partridge | no population increase; higher overwinter 'apparent mortality' | | 6 | -10% | | 0% |
| | | | | | | | | |
| Weighted Average | | | | | | 24% | | 126% |
| **Selected** | | | | | | | **30%** | |

## Credit Value

The credit values are the sum of the factors for the increase in value due to preservation and the increase in value due to management multiplied by the debit values.

Credit value = debit value * (credit from preservation factor + credit from management factor)

A credit value is obtained for each 50ft square grid cell and these credits are added to obtain the credit value of any parcel. The resulting credit values range from 0 up through 3.65 (Figures 7 and 8). (The debit values range from 0 through 3.66 (Figures 5 and 6). The average debit value for the entire state of NJ is 1.73 and the average credit value is 0.95.

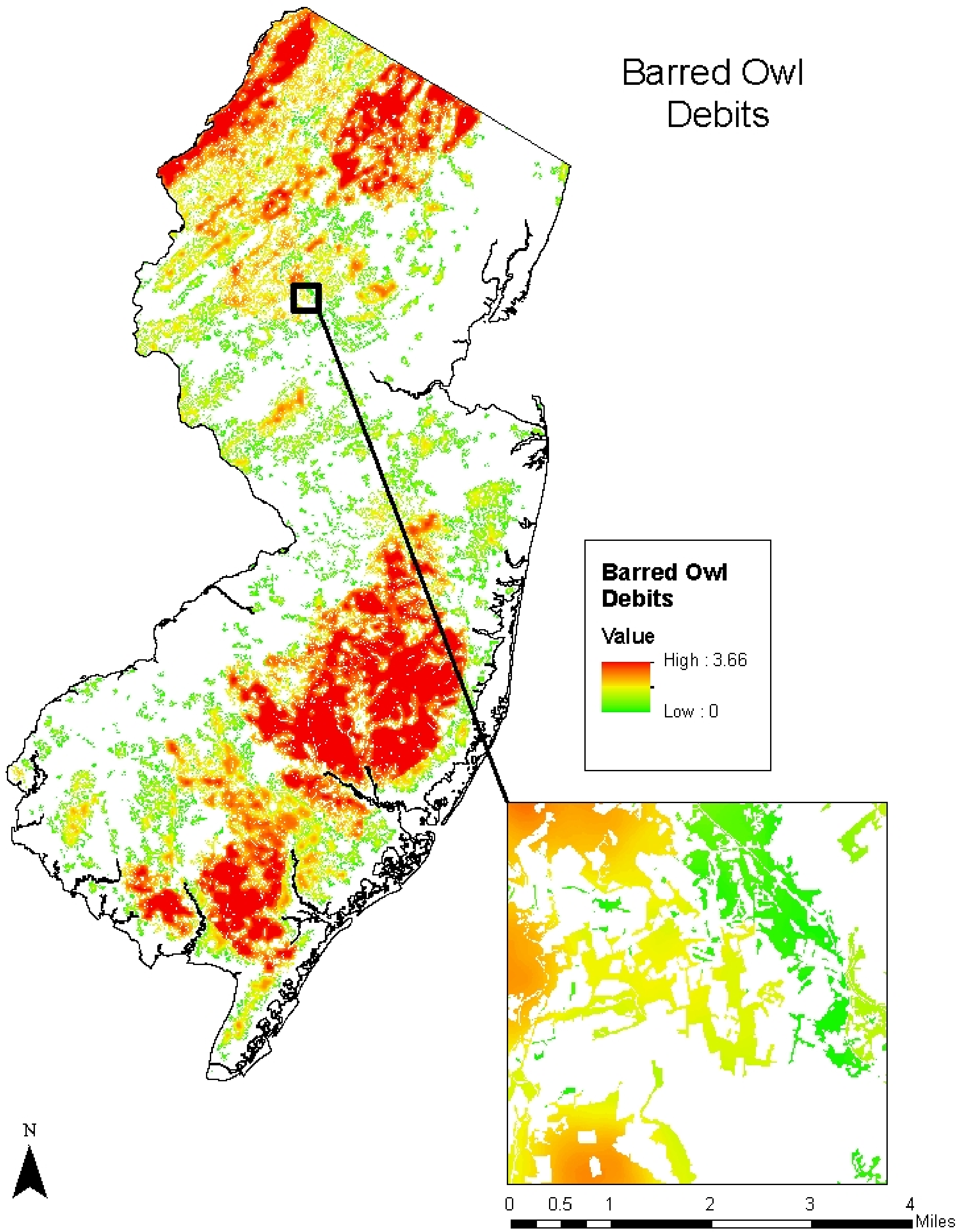



Figure 5: Barred owl debits calculated in chapter 2. Highest values are in red ranging downward through orange, yellow and into green for low values. 0 values are white. Debits are higher for higher value habitat.

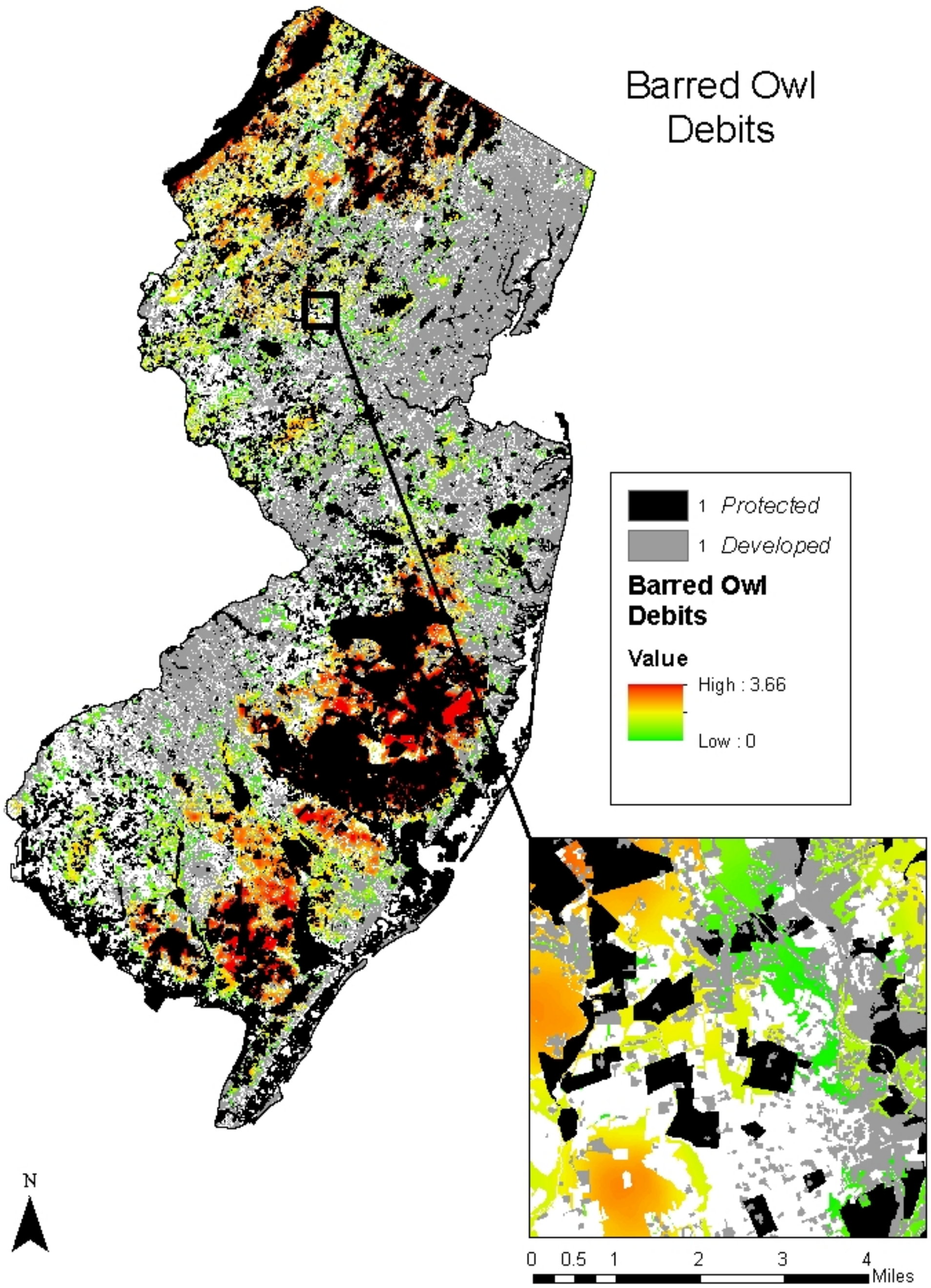



Figure 6: Barred owl debit values shown with protected and developed land. Debit values range from a high shown in red down through orange, yellow and into green for the low. No or 0 values are white. Protected land is shown in black and developed land is shown in grey.

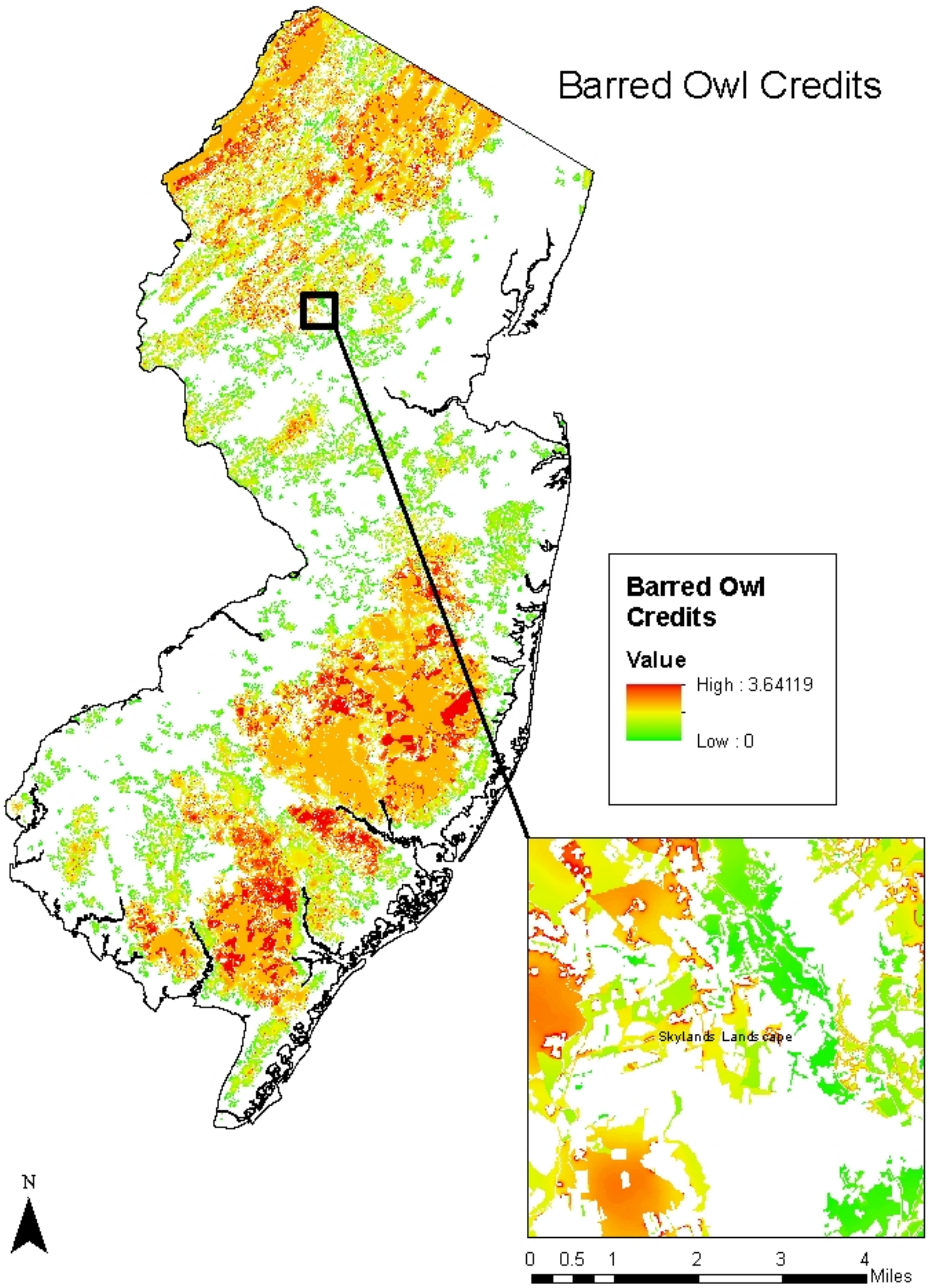



Figure 7: Barred owl credits: High values in red ranging through orange and yellow to low values in green. Higher for areas with higher wildlife habitat value especially those that are in danger of developing sooner rather than later.

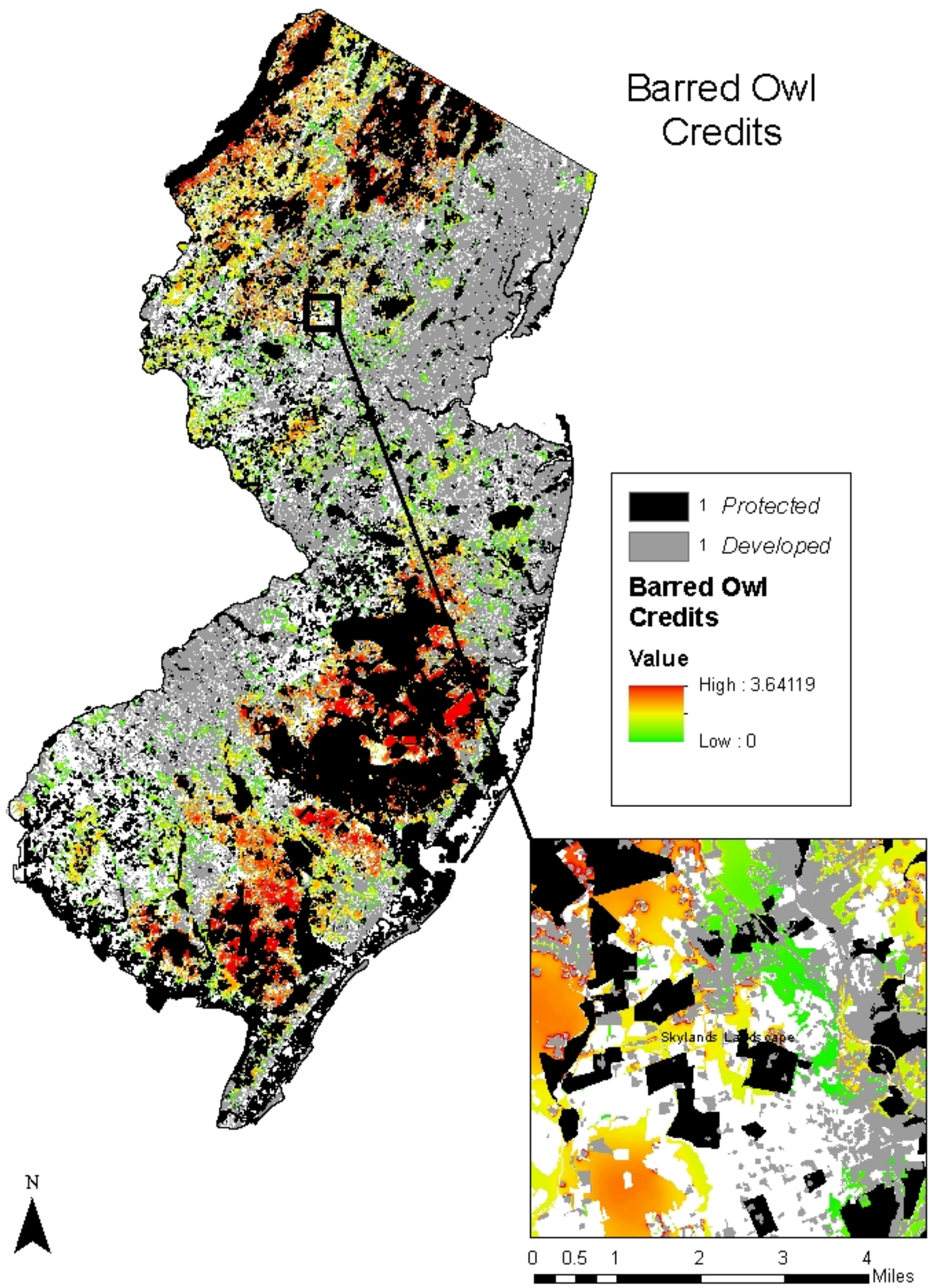



Figure 8: Barred owl credits: High values in red ranging through orange and yellow to low values in green. Protected areas shown in black. Developed areas are grey.

## Discussion

It is recognized that proactive approaches, strategic planning at the landscape level, and setting consistent standards are imperative to achieve conservation that is effective and sustainable. It is now apparent that many of the smaller, one-off conservation efforts resulted in patchy, inefficient conservation attempts and non-sustainable parcels of habitat scattered through the landscape. It has been found that market-based mitigation programs such as conservation banking facilitate the pooling of mitigation resources allowing larger tracts of contiguous land to be preserved and managed than would otherwise be aggregated; improve regulatory predictability; provide efficiencies of scale; can generate competition among mitigation sponsors thereby providing cost-effective means for complying with natural resource laws; and incentivize private investment in species conservation. (Bunn et al. 2014; USFWS 2016) The overriding mitigation principal is to improve or maintain the current status of the affected resources. This concept of "net gain" or "no net loss" as a goal of habitat mitigation or species conservation is not new, but the methods of measuring the net loss or gain have still not been solidified. There is no universally accepted or consistent measure. Each conservation bank seems to have its own measure and the translation from one measure to another is not clear. (USFWS 2016) One of the obstacles to implementing conservation banking has been noted as the lack of transparent consistent biologically-based methods of setting the debits and credits (Madsen et al. 2010, 2011, Bunn et al. 2013, USFWS 206). In this dissertation I have proposed a solution to this obstacle in the way of a model for a consistent measure of wildlife habitat value (chapter 1) and tradeable conservation banking debits (chapter 2) and credits (chapter 3) that could be used across wide areas and with a variety of species across taxa.

Especially important to any measure of the credits afforded in conservation banking is the concept of additionality, which I specifically address in this chapter. The concept of additionality is that the credit given to an entity for carrying out compensatory mitigation is the additional benefits beyond those that would otherwise have occurred (USFWS 2016). My credit from preservation factor is an estimate of the additional benefits as a ratio to wildlife habitat value that accrue to a property from preservation and the credit from management factor is an estimate of the additional benefits as a ratio to wildlife habitat value that accrue to a property from management.

The model presented here for setting credits can be used in concert with the model for setting debits. Together the two models complement each other allowing trading within service areas or whichever zones are stipulated. Both the credit and debit methods are comprehensive and consistent and are ideal for use over wide areas for which there is not comprehensive biological survey data. The data needed is land-use land cover data and information on life history and preferences of the local populations. The methods use the entire landscape taking into account the individual habitats but also their place within the larger area and the possibilities of connectivity to other habitat and potential habitat areas. The model is set as a framework and as there are gains in knowledge or methodology, sections of the model can be swapped out for the newest and best information while leaving the overall conceptual framework stable (Figure 1).

The hope would be that with this consistent, proactive method to determine tradeable debits and credits the highest wildlife habitat values areas would be preserved while development becomes more inviting in the non-habitat or very low value habitat areas. Since debit values are high in high wildlife habitat value areas, the number of credits the developers need to purchase for mitigation will also be high in those areas creating a disincentive for development by increasing the costs. The edge habitat areas, nearest developed areas have lower debit values and non-habitat areas have a 0 value; thus those areas will require the purchase of few or no credits creating an economic incentive to develop these areas before the higher wildlife habitat value areas.

Ideally in a conservation banking or credit trading scheme the trades would be made within a constrained regional area. Under the ESA these are designated service areas. In other conservation banking schemes, the areas can be defined by the states or other regulatory bodies. Ideally the debit and credit would be in the same landscape region or physiographic region. A landscape region is a large area where plant and animal communities are ecologically similar (NJDEP 2012). Keeping trades within zones assures that habitat value is maintained within each zone and that some zones do not deteriorate while others gain habitat value.

## Discussion of specific findings

The areas of New Jersey with the highest debit values are the Pinelands (in south east/central New Jersey) and areas of the Highlands (in northwest New Jersey). There are some fairly high values in patches throughout the northwest and southeast parts of the state and even a few in the central part of the state where there are still larger forested areas. (Figure 9)

The areas of the state with the highest credit values (Figure 10) are generally the same areas as those with high debit values though they do not correlate completely. Because the credit for preservation is higher if the probability of development in the near future is higher, the credits for land with the same wildlife habitat values are higher near developed areas which have a high probability of development (Figure 3). Often the wildlife habitat values are lower near developed areas, so the higher credit for preservation factor does not lead to higher overall credits in such areas. Because credits are set using preservation factor there is incentive to preserve first those areas that have higher probability of development as they will have relatively higher credit values for the same underlying wildlife habitat values.

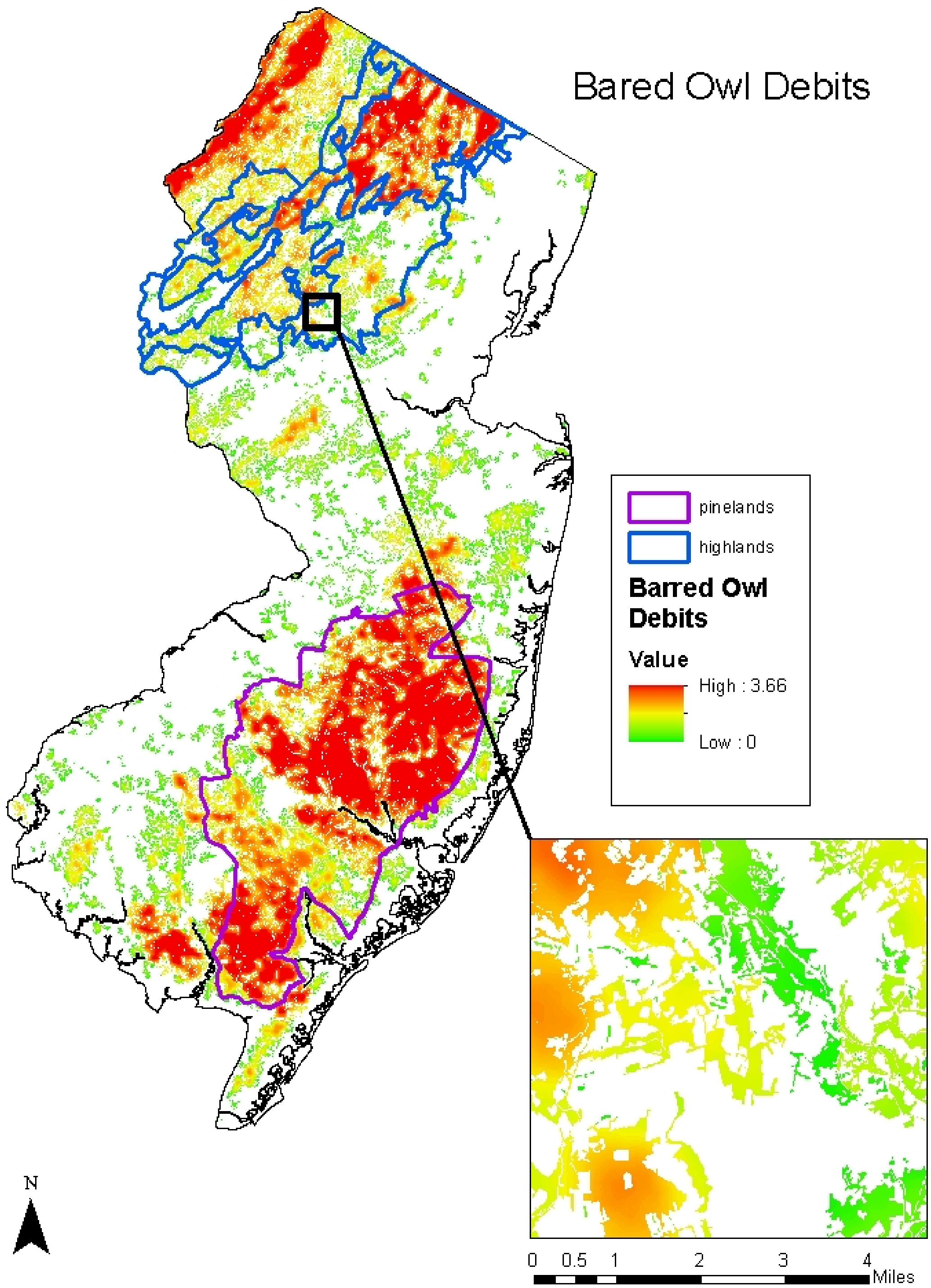



Figure 9: Barred owl debits with Highlands and Pinelands areas indicated. Highlands is outlines in blue and Pinelands in purple.

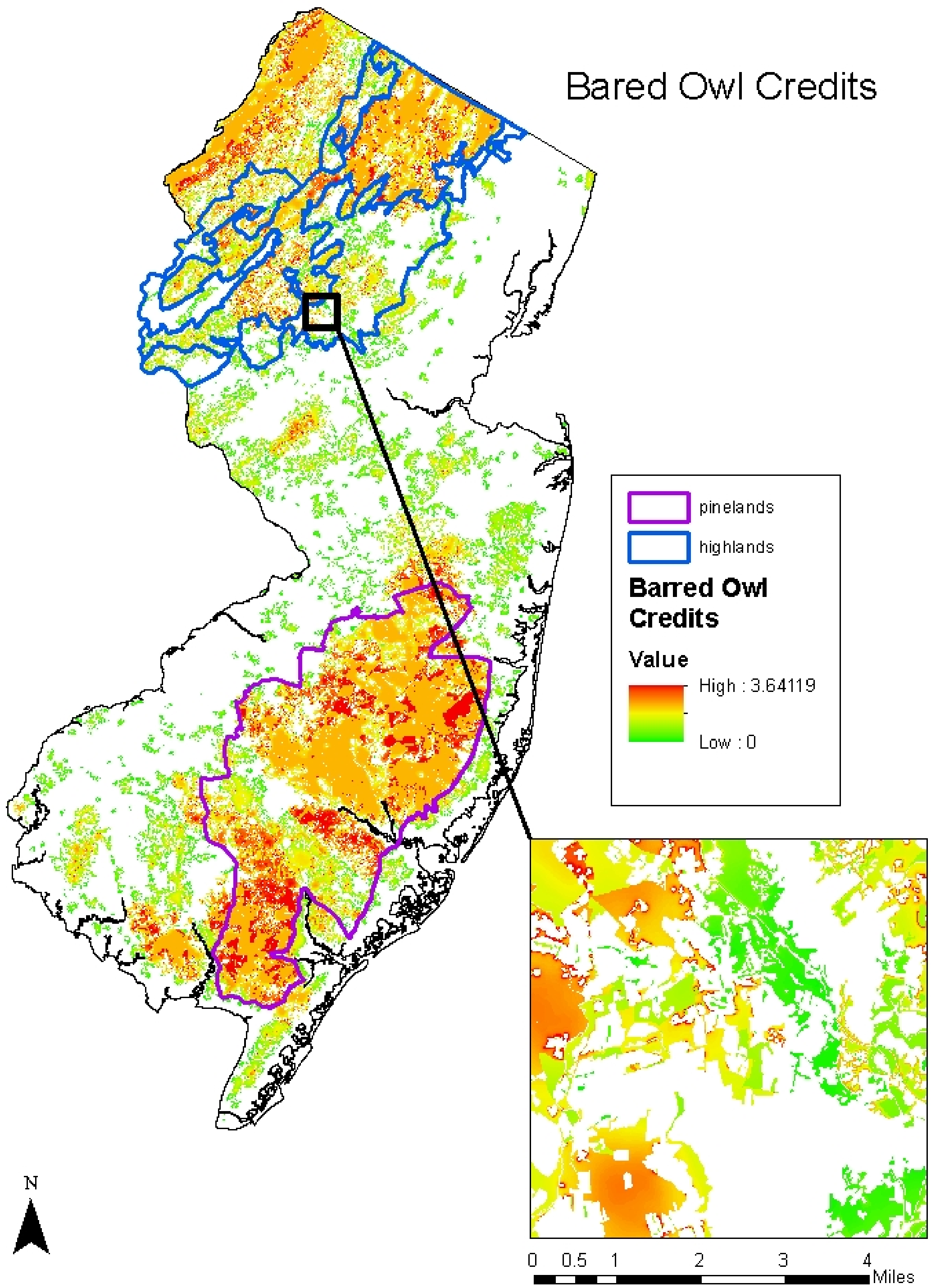



Figure 10: Barred owl credits with Highlands and Pinelands areas indicated. Highlands is outlines in blue and Pinelands in purple.

The comparison of credit to debit values can be seen in the maps of the ratio of credits to debits (Figures 11 and 12). The values vary from a low of 0.3 to the high of 0.99. In the areas with the lowest ratio of credits to debits, the additionality comes solely or almost entirely from the increase in value due to management. These are areas that are not likely to develop within the hundred-year timespan. The increase in value due to preservation grows as the probability of development increases and this causes the ratio of credits to debits to grow also as the probability of development increases.

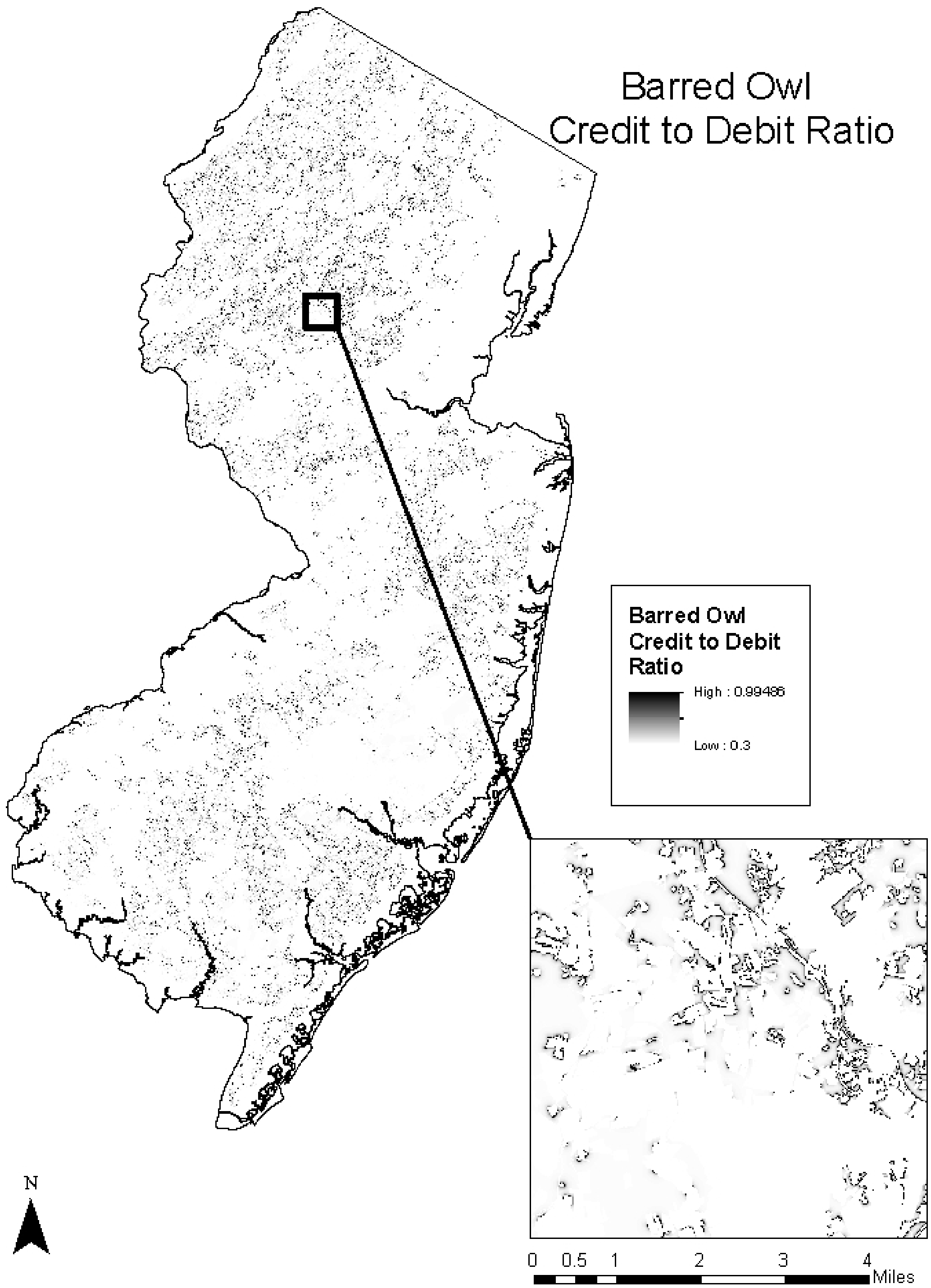



Figure 11: Ratio of Barred Owl Credits to Debits – Results show that the credit value approaches the debit value for areas with likelihood of being developed in the near future such as areas close to already developed land.

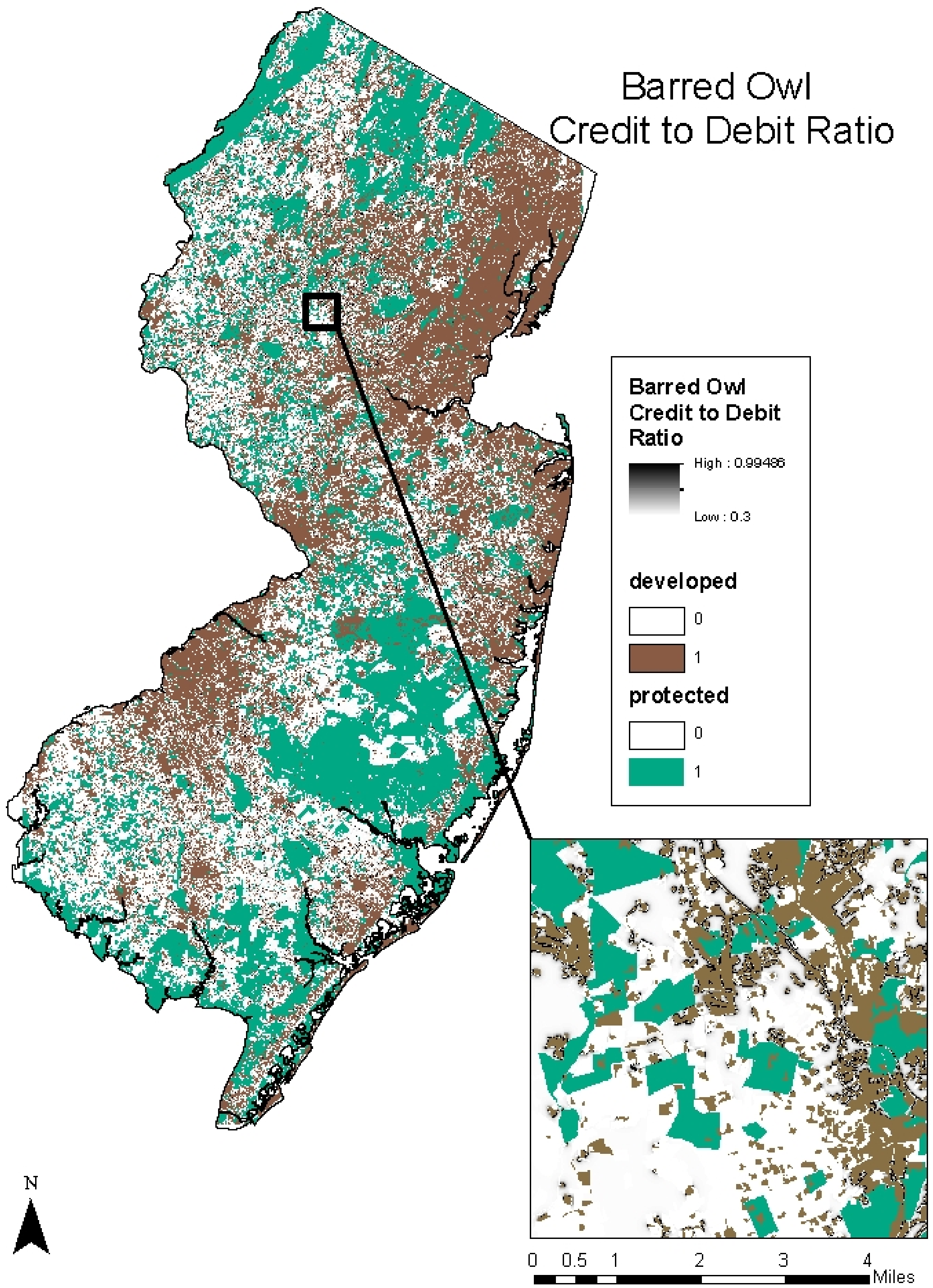



Figure 12: Ratio of Barred Owl Credits to Debits with developed land shown in brown and protected in malachite green – Results show that the credit value approaches the debit

value for areas with likelihood of being developed in the near future such as areas close to already developed land.

## Suggestions for further study

The estimate of credit due to preservation value entails quite a few different elements, some of which warrant further study. For example, the estimate of probability of development is a social science and economic analysis, primarily, which would benefit from further study. I presented and used a rather basic model using multivariable linear regression with transformation of variables using available spatial variables run at two time steps. Additional work could be done with increased numbers and types of variables (such as ones denoting variations in zoning, variations of building regulations by county and municipality) or with more time-steps. Study could be completed on the longer-term development effects using multivariate or other methods such as SLEUTH (Chaudhuri and Clarke 2012) or looking at the likely varying development patterns of regions of various current development densities within New Jersey; New Jersey is not homogeneous in its density of development. The R-squared values of the regressions in the probability of development model indicated that a large amount of variation was not accounted for by the model. In addition, the residuals of the linear and logistic regressions I analyzed plotted against the fitted values all showed a pattern. The residuals fall close to two parallel downward-sloping lines. Such a pattern often indicates that there is a missing variable. The plot of the square root of the standardized residuals against the fitted values has a pattern of two almost linear groupings which cross, again an indicator of a missing variable. Since this is a basic probability of development model it is not surprising that it shows signs of missing variables; a more comprehensive model would have more variables. The addition of variables denoting information on zoning, building regulations, and county/municipality could be added in a more complex model and may increase the R-squared values as well as leading to random residuals. The probability of development model presented and used here is a reasonable model sufficient to illustrate the case study of barred owl, but could be enhanced or replaced with a more nuanced model when the method is actually implemented.

The estimation of the credit value due to management is complicated by the fact that there is little quantitative information published on the change in population density of areas that have been restored and/or managed for conservation. Part of this may be a bias toward spending the allotted funds on actual restoration and management rather than ongoing monitoring. There is also uncertainty about the published information as there is a bias in scientific publication toward publishing positive results (da Silva, 2015). If there are many known results of no or minimal increase in population after restoration and management or results of decreases in population under management that have not been published, then the estimate here could be overstated.

The credit from management value used in practice would vary by species and the a priori value could be modified and informed by study of populations of each species. Some species, such as grassland birds benefit from heavy ongoing management of their habitat since without management in most areas of NJ the grassland or early successional forest would mature into forest. Other species, such as barred owl or other mature forest species, can have their habitat improved in some ways through the decrease in invasive species or by providing nest boxes until the trees mature more fully, but basic improvement of the habitat structure such as maturation of the forest happens on a much longer timescale than for the grassland or early successional species. It is also possible that an adaptive management approach to credits could allow the factor for credit due to management to vary from conservation bank to conservation bank based on a demonstration of their management.

## Conclusion

The model presented here for credits can be used with the model for debits to provide reasonable, biologically based tradeable debits and credits for conservation banking or another similar type of mitigation. The credit values are based on the concept of additionality. The entire model framework for wildlife habitat value, debits, and credits is efficient because it relies on available or easily obtainable data including land use land cover data and life history information; has a relatively low cost of estimation due to the fact that large areas can be calculated at the same time conserving the hours needed from the analyst and the software cost. The model is spatially based and by creating landscape and or statewide detailed maps of wildlife habitat value, debits, and credits, the model facilitates and encourages landscape level planning. Testing has shown the underlying wildlife habitat value to be an effective method of categorizing or valuing habitat for wide-ranging threatened and endangered species in New Jersey. The model fills a void in the scientific knowledge underlying conservation banking.

# Cited Sources


Brealey, R. and Myers, S. 1996. *Principles of Corporate Finance.* Mc-Graw Hill. New York, New York.

Bro, E., Mayot, P., Corda, E., Reitz, F., 2004. Impact of habitat management on grey partridge populations: assessing wildlife cover using a multisite BACI experiment. Journal of Applies Ecology 41:846-857

Brown, D., Walker, R., Manson, S., Seto, K., 2004. Modeling land use and land cover change. Chapter

Bunn, D., Moyle, P.B., Johnson, C.K. 2014. Maximizing the ecological contribution of conservation banks. Wildlife Society Bulletin. DOI: 10.1002/wsb.398

Chakraborty, A., Easwaran, S., Sinha, S., 2016. An "inverse square law" for the currency market: Uncovering hidden universality in heterogeneous complex systems, arXiv:1606.0611v1 [q-fin.ST]

*Foundations of Casualty Actuarial Science*. 2001. Casualty Actuarial Society. Arlington, Virginia. Fourth Edition

Golet, G., Gardali, T., Howell, C., Hunt, J., Luster, R., Rainey, W., Roberts, M., Silveira, J., Swagerty, H., Williams, N., 2008. Wildlife response to riparian restoration on the Sacramento River. San Francisco Estuary & Watershed Science 6:1-26

Gardali, T., Holmes, A., Small, S., Nur, N., Geupel, G., Golet, G., 2006. Abundance patterns of landbirds in restored and remnant riparian forests on the Sacramento River, California, U.S.A. Restoration Ecology Vol. 14, No. 3, 391-403

Lathrop, R., Bognar, J., Hasse, J., 2016. Changing Landscapes in the Garden State: Land use change in NJ 1986 thru 2012.

Lathrop, R., Tulloch, D., Hatfield, C., "Section 2. Land Resources", in Hoppe, M. *New York – New Jersey Highlands Regional Study Technical Report*. 2003. United States Department of Agriculture Forest Service NA-TP-04-03 pp. 45-219. http://www.fs.fed.us/na/highlands/atechnical_report/index.html

Luther, E., Skelton, J., Fernandez, C., Walters, J., 2016. Conservation action implementation, funding, and population trends of birds listed on the Endangered Species Act. Biological Conservation 197:229-234

Montgomery, D., Peck, E. 1982. Introduction to Linear Regression Analysis. Wiley Series in Probability and Mathemetical Statistics.. John Wiley & Sons. New York. Pp. 234-243

New Jersey Department of Environmental Protection. Division of Fish and Wildlife. The New Jersey Landscape Project. 2012. http://www.state.nj.us/dep/fgw/ensp/landscape/

Pabian, S., Wilson, A., Klinger, S., Brittingham, M., 2015. Pennsylvania's conservation reserve enhancement program benefits ring-necked pheasants but not enough to reverse declines. The Journal of Wildlife Management 79(4):641-646

R Development Core Team (2008). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Reid, B., Thiel, R., Peery, M., 2016. Population dynamics of endangered Blanding's turtles in a restored area. The Journal of Wildlife Management 80(3):553-562

Teixeira da Silva, 2015. Negative results: negative perceptions limit their potential for increasing reproducibility. Pubmed v. 14:12

Thompson, S., Arnold, T., Fieberg, F., Granfors, D., Vacek, S., Palaia, N., 2016. Grassland birds demonstrate delayed response to large-scale tree removal in central North America. Journal of Applied Ecology 53, 284-294

Vander Yacht, A., Keyser, P., Buehler, D., Harper, C., Buckley, D., Applegate, R., 2016. Avian occupancy response to oak woodland and savanna restoration. The Journal of Wildlife Management 80(6): 1091-1105

Veldkamp, A., and Lambin, E.F., 2001. Predicting land-use change. Agriculture Ecosystems & Environment 85:1-6

Welch, R., Parker, D., 2016. Brown hyaena population explosion: rapid population growth in a small, fenced system. Wildlife Research 43:178-187

U.S. Fish and Wildlife Service. 2012. Conservation Banking: Incentives for Stewardship. Factsheet. http://www.fws.gov/endangered/esa-library/pdf/conservation_banking.pdf

U.S. Fish and Wildlife Service. 2016. Endangered and Threatened Wildlife and Plants: Endangered Species Act Compensatory Mitigation Policy. Federal Register Vol. 81, No. 248, pp. 95316 - 95349

# Chapter 4 – Discussion/Conclusion

## Discussion/Conclusion

Loss of habitat continues to be a driving force in the decline of many wildlife species and is a major concern for both threatened and endangered species and species of concern. The piecemeal approach to habitat compensatory mitigation wherein each project is mitigated independently has often resulted in small, non-sustainable parcels of habitat scattered throughout the landscape (USFWS 2016). Moreover, the current regulatory mitigation process has caused conflict among the various stakeholders: developers, governmental bodies, conservationists, and land-owners (Lathrop 2014). Market-based compensatory mitigation is seen as a way to improve the consistency and effectiveness of compensatory mitigation while decreasing the conflict between stakeholders and providing economic incentive to care for wildlife habitat. However, there is a difficulty in instituting market-based compensatory mitigation such as conservation banking because there is a lack of acceptable, scientific methods to determine a key component of market-based compensatory mitigation, the tradeable credits. This project developed a consistent, efficient method of assessing the ecological value of the habitat in the landscape and assigned debits and credits to the habitat.

### Advantages of consolidated market-based compensatory mitigation

Market-based compensatory mitigation such as conservation banking, is generally also consolidated mitigation, meaning it facilitates pooling of resources from multiple developers and/or multiple projects, avoiding the piecemeal approach to conservation, and allowing larger tracts of contiguous land to be preserved and managed. With broader and more proactive planning, the high-value areas on a landscape level can be identified. This creates opportunities to conserve highly valued natural resources while still allowing for community development and growth. (USFWS 2016) The pooling of financial resources can lead to a higher level of scientific expertise in the larger conservation actions that is not practicable for smaller projects; the pooling also may provide efficiencies/ economies of scale thereby decreasing the unit cost for mitigation.

Not only is the consolidation financially wise, the pooling of projects also encourages proactive landscape-level planning. Landscape-scale habitat conservation plans, that are developed for use by multiple applicants to conserve multiple resources, are generally the most efficient and effective approaches (USFWS 2016). Proactive planning also minimizes conflict in regulating conservation by bringing the need for mitigation into the developers' plans early in the planning process, providing for the most flexibility in terms of selecting plots and setting footprints of development. (Lathrop et al. 2014) Conservation banking can also minimize conflict by reducing transaction costs, increasing the speed and decreasing the unit cost for mitigation. The consolidated mitigation forums provide expedited regulatory compliance processes, saving all parties time and money. (USFWS 2016)

Market-based compensatory mitigation, such as conservation banking, is known to improve regulatory predictability, provide efficiencies of scale, and incentivize private investment in species conservation. The most robust programs generate competition among mitigation sponsors and provide cost-effective means for complying with natural resource laws such as the ESA or state equivalents. Conservation banking, in particular, is generally perceived as successful at achieving effective conservation outcomes. (USFWS 2016)

In conservation banking the responsibility for mitigation is transferred to the bank sponsor. This allows the purchaser of the credits (usually the developer) to shed the liability of the responsibility for mitigation which is a positive for the developer; the developer no longer has a possibly years-long commitment to a non-core area of his business: the management of natural resources. The transfer of responsibility for mitigation allows the responsibility and the financial resources provided for the mitigation to be solely under the control of the conservation bank, which should have expertise in the management of natural resources such as threatened and endangered species habitat. The bank would be generally pooling multiple projects and often continuing to grow and acquire habitat to be conserved. This ongoing conservation focus should increase the effectiveness of the continuing management of the habitat over what it would have been under one-off individual mitigation. Thus, conservation banking is a useful tool for increasing the efficacy of conservation related to mitigation and for moving toward a net gain or no net loss system.

## Proposed solution to difficulties in implementing conservation banking

One of the major difficulties in implementing conservation banking is providing a measure for the tradeable credits. Currently there is no widely used, consistent, biologically-based measure. Credits are often expressed as a measure of surface area, linear distance of constant width, number of individuals or mating pairs of a particular species, or some measure of habitat function (USFWS 2016). More general measures such as surface area or linear distance do not take into account the quality of the habitat while very specific measures such as number of individuals or mating pairs of a particular species are information not often known at a landscape scale and difficult and expensive to procure. It is widely agreed that conservation banking would benefit from the construction or development of a biologically-based, quantifiable, repeatable, consistent measure of credits that is related to the conservation goals for the species (Goncalves et al., Lathrop et al. 2014, ten Kate et al. 2004).

As has been shown in chapters 1, 2 and 3 the model laid out here provides a pro-active, comprehensive, repeatable, consistent, science-based, landscape based approach to quantify wildlife habitat value, tradeable debits, and tradeable credits. The approach encourages comprehensive landscape-scale planning and implementing of mitigation programs and allows monitoring of the net gain or loss of habitat value. The method of assigning credits addresses additionality and duration. Timing is addressed in that the conservation bank would accrue credits only after restoration of damaged or degraded habitat, enhancement of existing habitat, establishment of new habitat, or preservation of existing habitat that had not already been protected.

## Combined Results of Wildlife Habitat Value, Debits, and Credits in New Jersey

In order to develop and test the model, I examined fifteen NJ State threatened or endangered species from a wide range of taxa. I concentrated on wide-ranging species as these cause the most conflict (Lathrop et al. 2014). The species used are: Barred owl (*Strix varia*), Black-crowned night heron (*Nycticorax nycticorax*), Bobcat (*Lynx rufus*), Bobolink (*Dolichonyx oryzivorus*), Bog turtle (*Glyptemys muhlenbergii*), Grasshopper Sparrow (*Ammodramus savannarum*), Indiana Bat (*Myotis sodalis*), Long-eared Owl (*Asio otus*), Long-tailed Salamander (*Eurycea longicauda*), Northern Goshawk (*Accipiter gentilis*), Red-headed Woodpecker (*Melanerpes erythrocephalus*), Red-shouldered Hawk (*Buteo lineatus*), Timber Rattlesnake (*Crotalus horridus*), Vesper Sparrow (*Pooecetes gramineus*), and Wood Turtle (*Glyptemys insculpta).*

As an example I have chosen barred owl (*Strix varia*). Barred owl is a large owl native to North America. It is listed as threatened in NJ though federally it is not listed and the IUCN places it as least concern. The barred owl lives throughout the eastern United States north into southern Canada and south to Florida. The New Jersey population of barred owl is year-round resident. Barred owl prefer remote, contiguous, old-growth wetland forests and nests in large trees with cavities. Barred owl was selected as an example species because habitat loss is the primary culprit in their population decline and since they require large contiguous forests, they are a good species on which to test a spatially oriented wildlife habitat value model. In fragmented forests barred owl is vulnerable to human disturbance and also predation by great horned owl. The current population is estimated around 100 breeding pair. (Beans and Niles 2003)

Of New Jersey's almost 5 million acres, approximately 2.1 million acres are potential barred owl habitat, though some forests may need to mature further to be ideal habitat. About 1.9 million acres have been assigned debit and credit values while the remaining areas were determined to be habitat so marginal that it was not assigned tradeable values. The tradeable debit and credit values refer to each square area with 50 foot side (pixels; 2500 square feet per pixel) and are additively combined to calculate the debit or credit value for a parcel of land. Fifty foot squares were selected as the unit because they are large enough to facilitate efficient manipulation of data while small enough for site-based planning and decision-making.

One acre is approximately 17.4 pixels. Thus, since barred owl debit values range from 0 to 3.66 per pixel, this implies that debit values range from 0 to 63.8 per acre.

## Designated Service areas; Landscape Regions

Generally a physiographic region, landscape region or designated service area is defined for use in habitat mitigation. This means that the development and mitigation must both occur within the same geographic area. Though this model was run for the entire state of New Jersey it is anticipated that smaller service areas will be used in the implementation of conservation banking. The model supports the use of designated service areas with the use of a masking function or an overlay function through which a planner would examine only one geographic area at a time.

For use in its landscape program, New Jersey designated six landscape regions. These are also called ecoregions and are regions within which plant and animal communities are ecologically similar and closely interlinked. They are Skylands, Piedmont plains, Pinelands, Atlantic Coastal, Delaware Bay, and Marine (Figure 1), (NJDEP 2012). I will be using these regions to discuss the wildlife habitat value, debit and credit values from the model.  References in this discussion to Pinelands or any other of the ecoregions are references to these defined Landscape Regions and not another designation of similar or the same name.

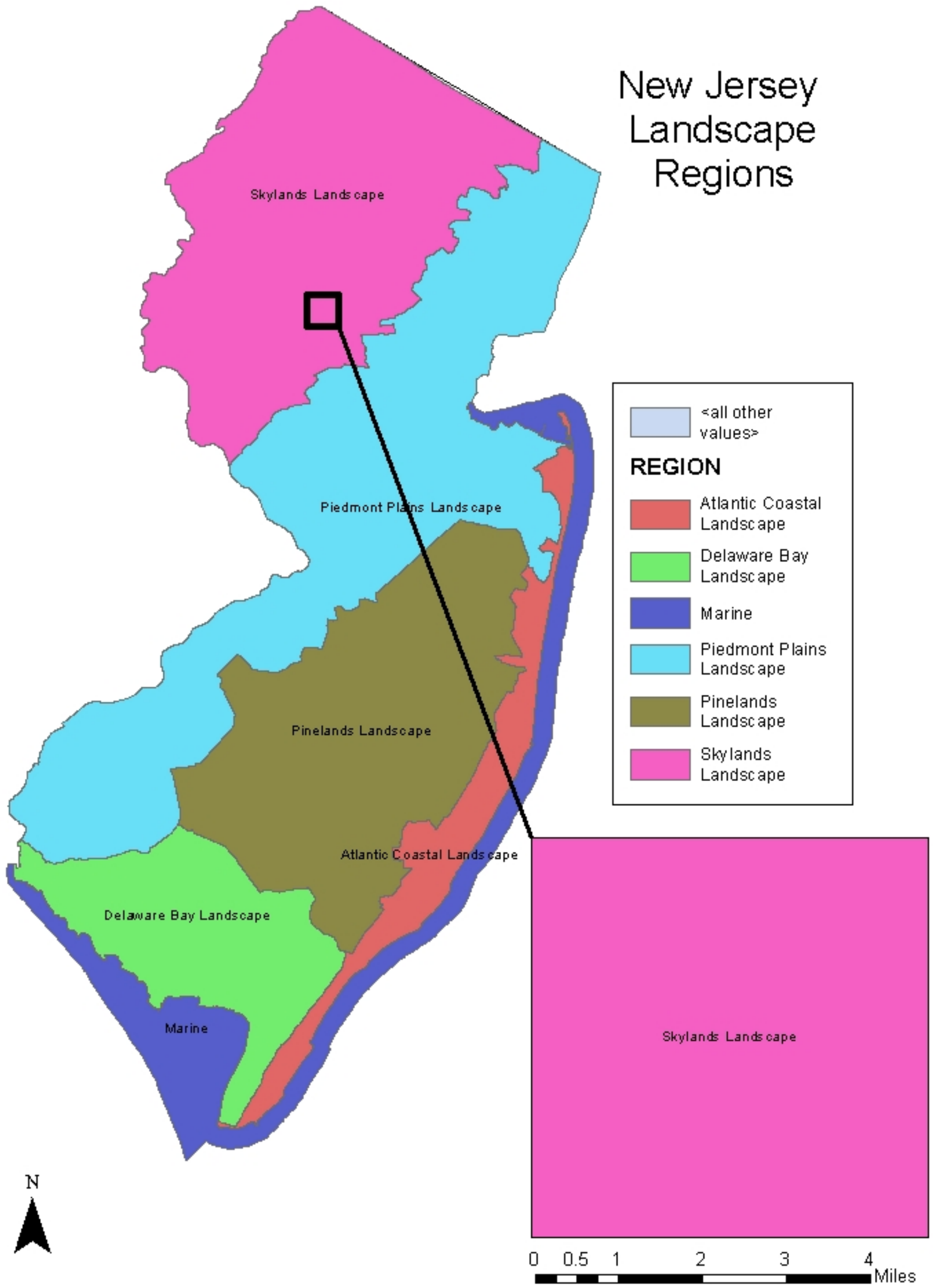



Figure 1: The six Landscape Regions designated by the State of New Jersey. These ecoregions are areas within which plant and animal communities are ecologically similar and closely interlinked.

The wildlife habitat values for barred owl are at their maximum in the Pinelands, the Skylands, and the Delaware Bay Landscapes. The average wildlife habitat value (WHV) is highest in the Pinelands followed by the Skylands and then the Delaware Bay Landscape. (Table 1 and Figure 2). These areas have quite a bit of forest left and some of the least developed areas of the state lie within the Pinelands, Delaware Bay, and Skylands. The areas nearest to Philadelphia and New York are for the most part in the Piedmont Plains as is the highly developed central portion of the state along the Route 1 corridor. Table 1 shows the number of acres total including non-habitat and the average values for WHV, debits, and credits including 0 values. The average WHV in the Pinelands is 45, whereas in the Skylands it is 31 and in Delaware Bay it is 29. In contract the average WHV in the Piedmont Plains is 5. The Atlantic Coastal Landscape has very little habitat as well and has an average WHV including non-habitat as 0 of 3. In fact the median value if non-habitat is included as 0 value is 0, meaning more than half of the values are 0 for all landscape regions except the Pinelands and the Skylands which have median values of 52 and 12 respectively.

Looking at the acres of potential habitat only and discounting the 0 values we find that there are over 0.7 million acres of potential barred owl habitat in each of the Pinelands and Skylands Landscape Regions. This is 66% and 55% of the total acreage respectively. The Delaware Bay which is about half the size of those two has 49% of its acreage designated as potential habitat. Even the Piedmont Plains Landscape indicates 26% of its acreage is potential barred owl habitat. (Table 2)

Table 1: Number of acres total per Landscape Region (including non-habitat), minimum, maximum and mean wildlife habitat values, debits and credits for barred owl. The mean includes 0 values.

| Barred Owl | | Wildlife Habitat Value | | Debits | | Credits | |
|---|---|---|---|---|---|---|---|
| REGION | Total Acres | Max | Mean | Max | Mean | Max | Mean |
| Pinelands Landscape | 1,128,647 | 99 | 45 | 3.66 | 1.70 | 3.64 | 0.65 |
| Skylands Landscape | 1,335,788 | 99 | 31 | 3.66 | 1.12 | 3.64 | 0.46 |
| Delaware Bay Landscape | 557,919 | 99 | 29 | 3.66 | 1.05 | 3.64 | 0.42 |
| Piedmont Plains Landscape | 1,579,220 | 79 | 5 | 2.92 | 0.12 | 2.88 | 0.05 |
| Atlantic Coastal Landscape | 202,358 | 63 | 3 | 2.33 | 0.06 | 1.78 | 0.02 |
| | | | | | | | |
| Total | 4,806,085 | 99 | 24 | 3.66 | 0.87 | 3.64 | 0.35 |

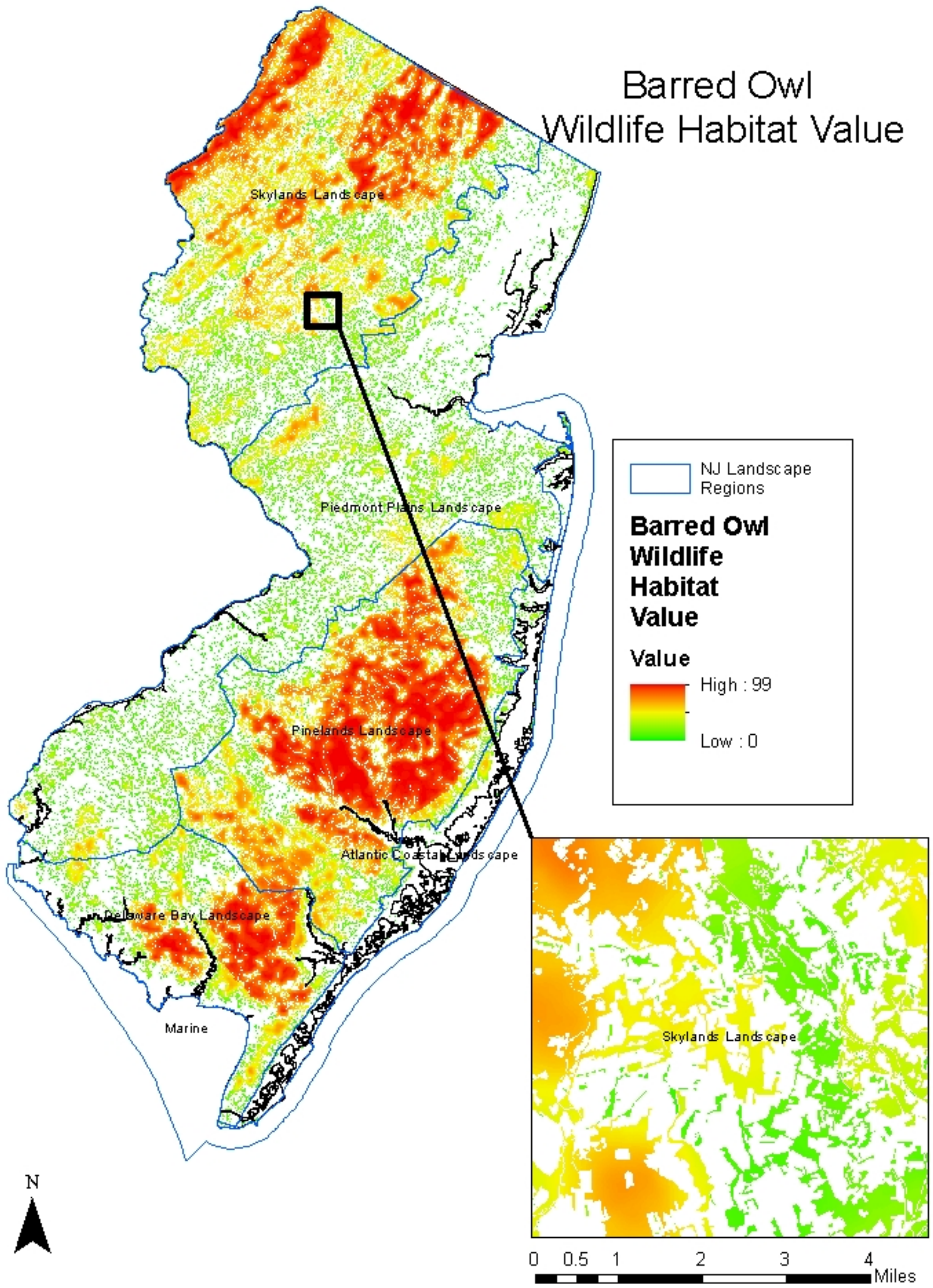



Figure 2: Barred owl wildlife habitat value shown by Landscape Region. 0 values are shown in white. Potential habitat is shown low values green ranging through yellow and orange into highest values in red. Highest values and the most high value areas are in Pinelands followed by Skylands and Delaware Bay.

Table 2: Barred owl wildlife habitat value statistics by Landscape Region. For each of the six landscape regions the max, mean, and median WHVs are given for habitat only, protected habitat only, and unprotected habitat only.

| Barred Owl | | | | Habitat Only (no 0 values) | | | Protected Habitat Only | | | Unprotected Habitat Only | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| REGION | Total Land Acres | Acres of Habitat | % Habitat | WHV Max | WHV Mean | WHV Median | WHV Max | WHV Mean | WHV Median | WHV Max | WHV Mean | WHV Median |
| Pinelands Landscape | 1,128,647 | 740,191 | 66% | 99 | 69 | 76 | 99 | 81 | 88 | 99 | 55 | 59 |
| Delaware Bay Landscape | 557,919 | 272,563 | 49% | 99 | 59 | 63 | 99 | 69 | 80 | 99 | 50 | 51 |
| Skylands Landscape | 1,335,788 | 738,400 | 55% | 99 | 56 | 57 | 99 | 69 | 75 | 99 | 44 | 48 |
| Atlantic Coastal Landscape | 202,358 | 24,465 | 12% | 63 | 21 | 17 | 63 | 25 | 23 | 55 | 12 | 8 |
| Piedmont Plains Landscape | 1,579,220 | 413,817 | 26% | 79 | 20 | 16 | 79 | 25 | 22 | 78 | 18 | 14 |
| | | | | | | | | | | | | |
| Total | 4,806,085 | 2,189,435 | 0 | 99 | 54 | | 99 | 68 | | 99 | 41 | |

The mean wildlife habitat values of the habitat only still vary greatly among the regions so it is not only the fact that there is less habitat in the Piedmont Plains, Atlantic Coastal Landscape, and Marine areas that explains why the overall WHVs are lower. The mean value of habitat only is highest in the Pinelands with 69 followed by the Delaware Bay Landscape with 59 and then the Skylands Landscape with 56.  The mean value of habitat only for the Piedmont Plains is 20 indicating that not only is there not much barred owl habitat in the Piedmont Plains, but also that the habitat that there is is low value.  The median value of the habitat in the Piedmont Plains is 16.  The median value in the Pinelands is the highest with WHV of 76.

The debit values are directly related to the wildlife habitat value and the debit values also are highest in the Pinelands landscape with a mean debit value (including 0s) of 1.70. The next highest mean debit value of 1.12 is in the Skylands followed by 1.05 in the Delaware Bay Landscape. The Piedmont Plains have a mean debit value of 0.12; This is a product of there being less habitat in the Piedmont Plains as a percent of the total acreage than in the Skylands and Pinelands and also of the debit values being much lower in the Piedmont Plains. (Table 1 and Figure 3) The potential habitat in the Piedmont Plains is

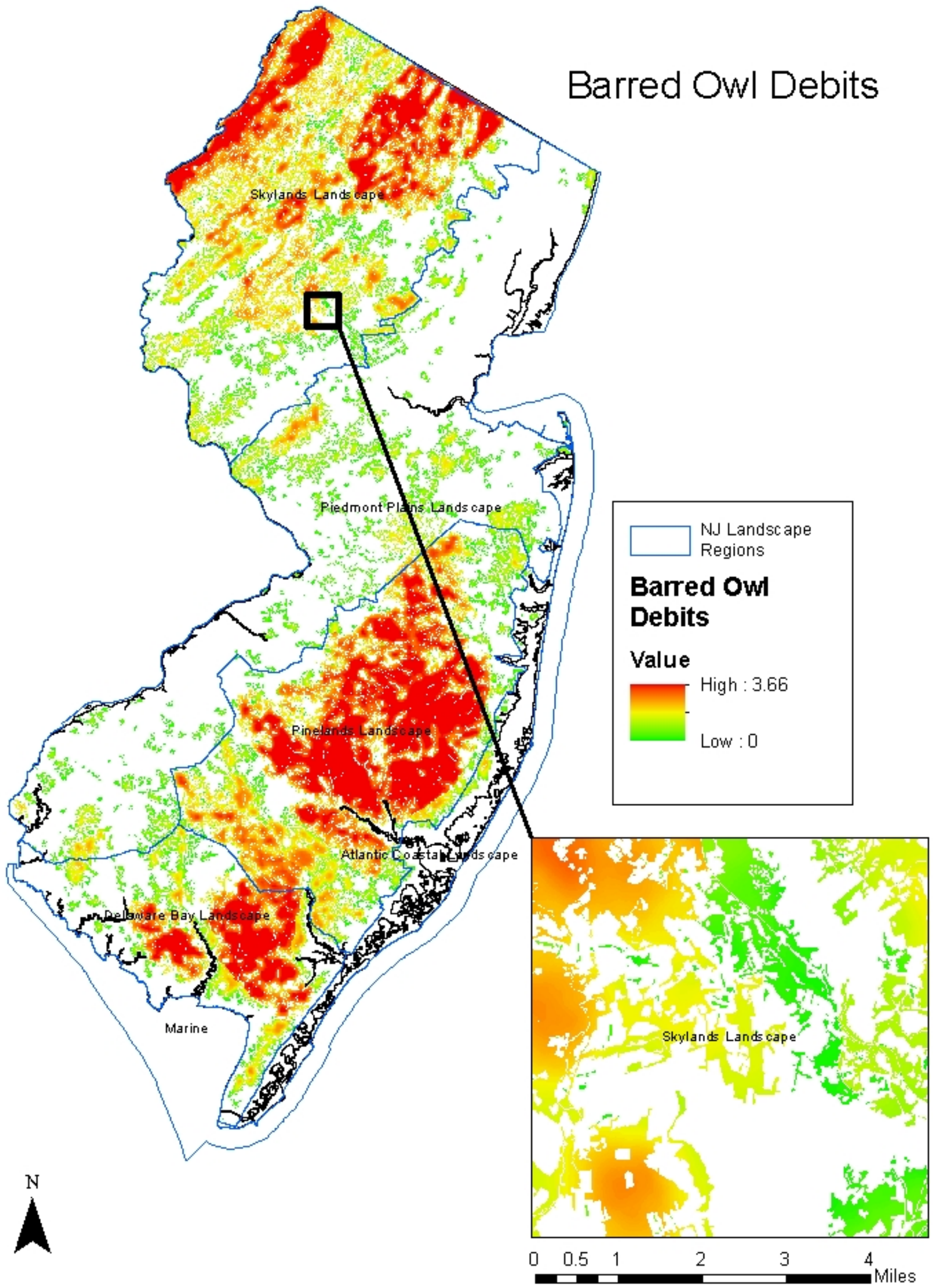



Figure 3: Barred owl debit values across the landscape regions. Highest debit values are red and are in Pinelands, Delaware Bay and Skylands. Values range downward through orange, yellow, and into green. 0 values are white.

fairly fragmented forest among developed and non-habitat areas. It is low quality leading to low debit values.

Barred owl credit values vary from 0 up to 3.64. They too are highest in the Pinelands with an average value of 0.65. The Skylands and Delaware Bay Regions have slightly lower credit values with means of 0.46 and 0.42 respectively. The Piedmont Plains has a mean credit value of 0.05. (Figure 4)

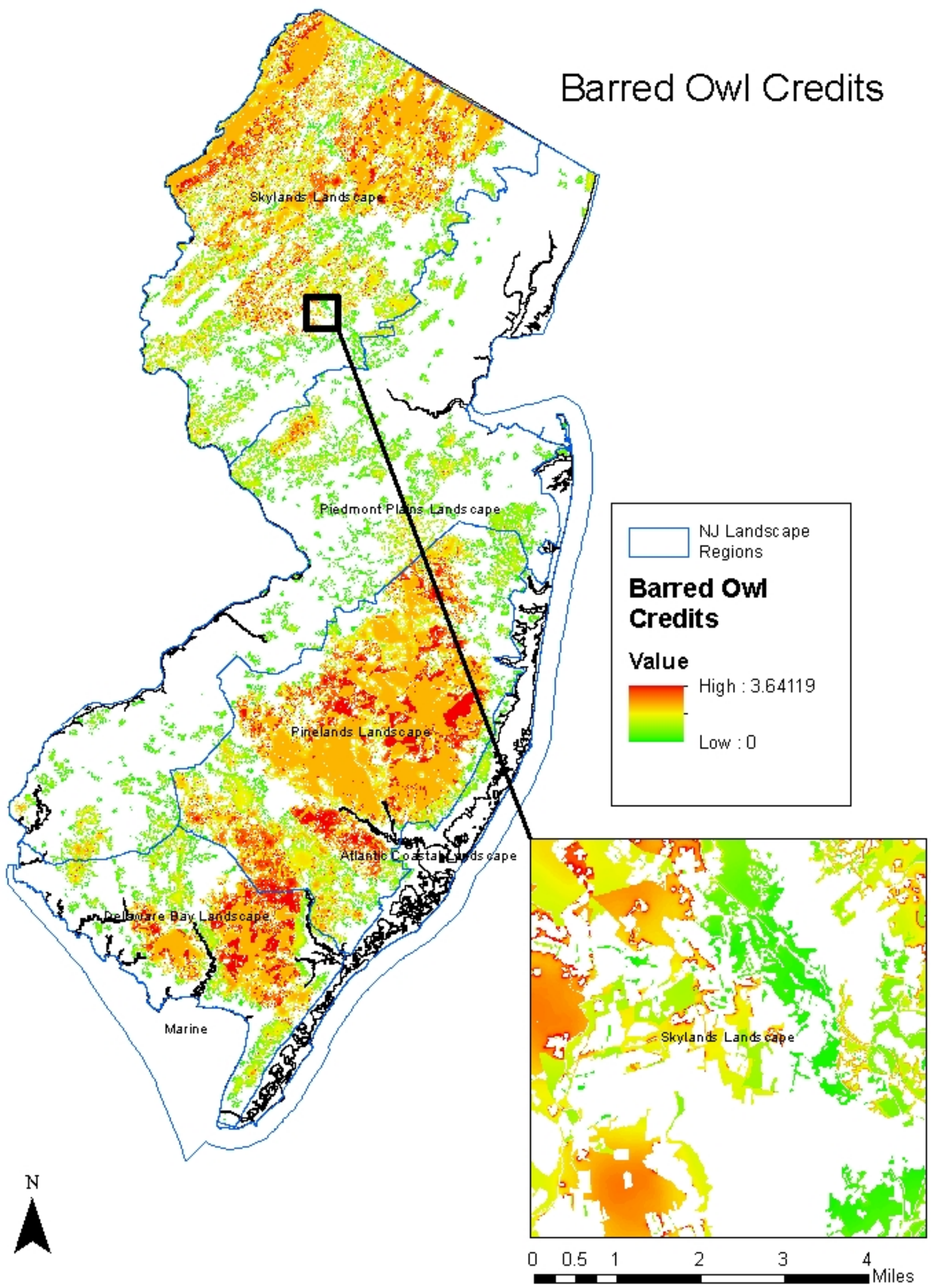



Figure 4: Barred owl credit values: Because credit values depend not only on the wildlife habitat value, but also on the probability of areas being developed, already protected areas are not the highest value and are generally shown in orange or another lower value color even though the underlying WHV is generally high on protected areas (Table 2). The highest values are in Pinelands, Delaware Bay and Skylands.

## Additionality

The concept of additionality is an important one in habitat mitigation. The concept of additionality is that the credit given to an entity for carrying out compensatory mitigation is the additional benefits beyond those that would otherwise have occurred. In terms of conservation banking, additionality is the assurance that credit is being given only for additional benefits that accrue from enrolling habitat as part of a conservation bank. (USFWS 2016) The credit is not the full debit value of the land because the habitat is not newly created. The credits assigned by the model are based on the concept of additionality: the gains from lands being part of a conservation bank are that they are permanently preserved and managed in perpetuity. Chapter 3 laid out in detail how the calculations are done to assign the credit for preservation and the credit for management.

The credit for preservation factor and the credit for management factor are added together and multiplied by the debit value. The ratio of credit to debit varies from 0.3 to .99 (Figure 5). On the low end of the range are the areas that are not likely to be developed in the next hundred years. These areas would have an increase in value due to management, but no increase in value due to preservation. Those areas more likely to be developed have a higher credit to debit ratio. (Figure 5 and Figure 6) The concept of additionality does not preclude the credit value from being higher than the debit in theory, but in our model, the credit values are always lower than the debit values. What this means practically is that for acres of the same wildlife habitat value, more than one acre must be preserved for every acre developed. If higher valued areas are conserved while lower valued ones are developed it is possible that for one low valued acre only one higher valued acre would be preserved in order to mitigate. It may even occur that for one low value acre developed less than one high valued acre must be preserved.

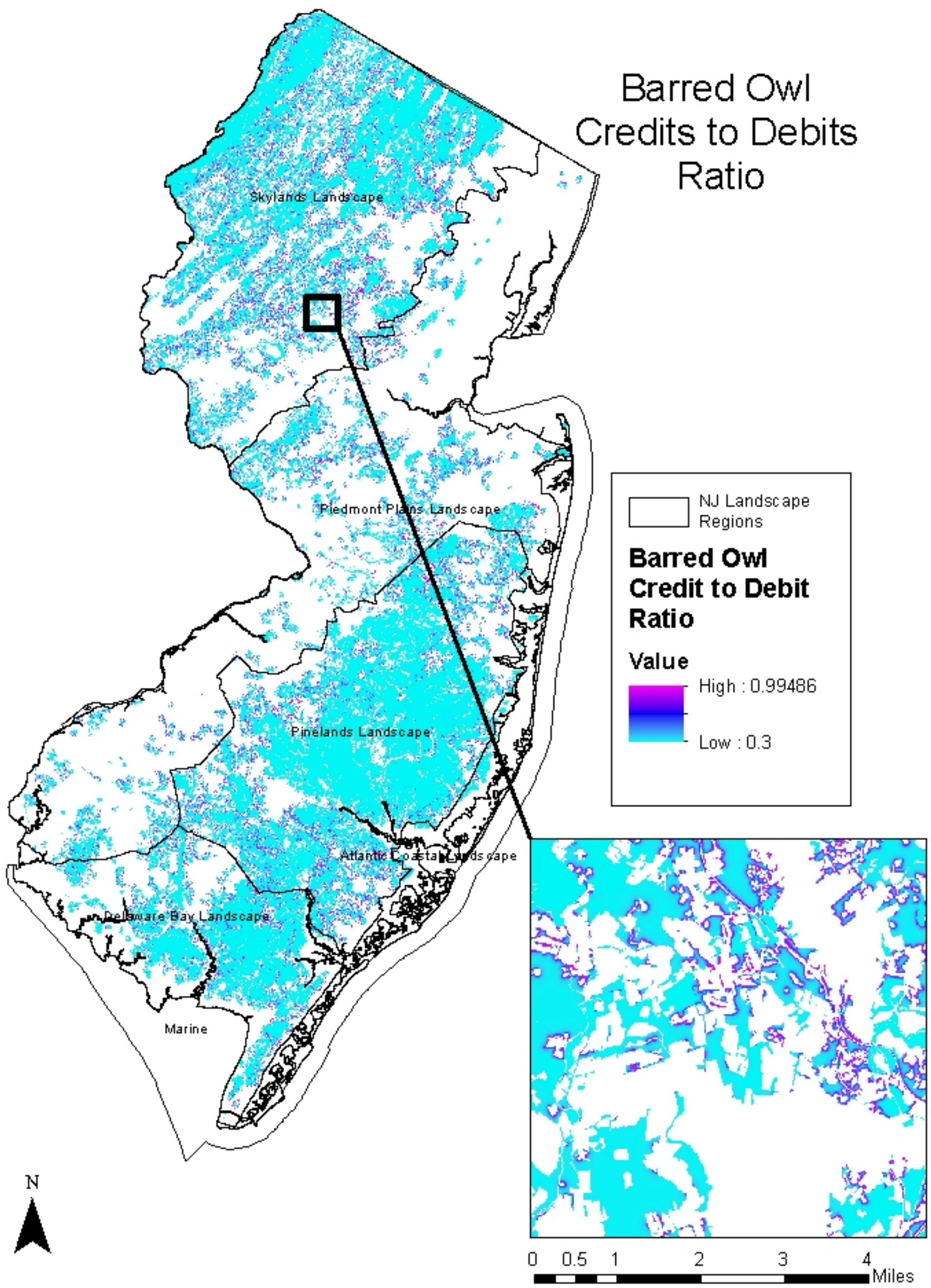



Figure 5: Barred owl credit to debit ratio: The highest values are near developed areas because the credit for preservation is higher in those areas. The overall credits at the highest credit to debit ratio areas are not generally high since the debit values at these edge areas are lower than average.

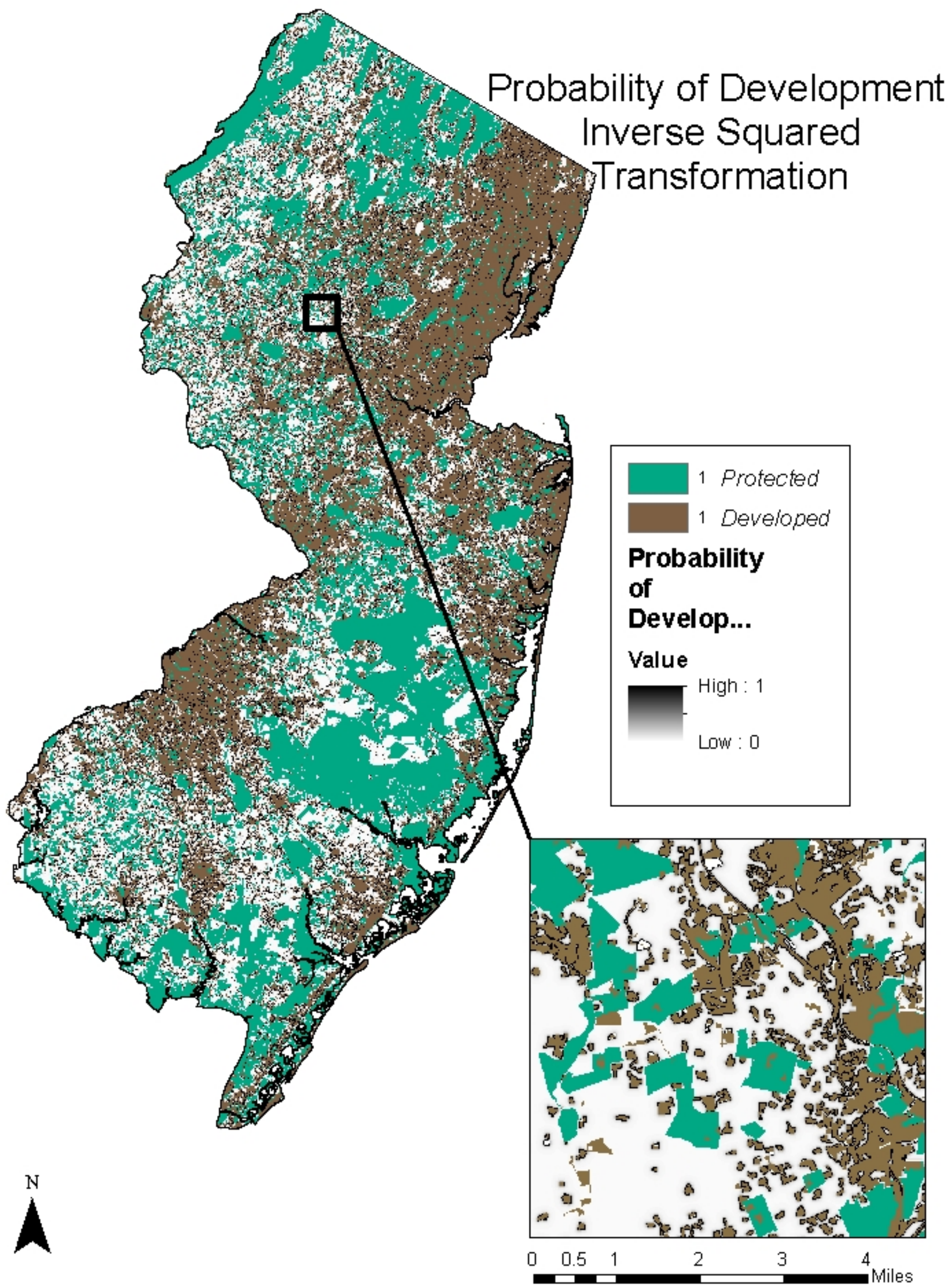



Figure 6: Probability of Development. The probability of development is shown grayscale with higher values black while the already developed land is brown and the protected land is green. Any reasonable probability of development model could be used here.

## Pre-emptive vs. Firefighting theory of conservation

Setting up the model based on additionality may seem in some sense to correspond to setting up the model under the theory of conservation which has been dubbed the "fire-fighting" approach (Spring et al. 2007) meaning we have given higher credits to those areas with a higher risk of the habitat being lost. There is an opposing theory, the pre-emptive approach to conservation, whose tenet is that one should conserve areas long before they are in danger of being developed or lost. Purchasing properties for conservation before they are at risk for development would likely allow larger areas to be conserved for a lower per unit costas land prices generally rise as the risk of development increases. Also as the risk of development increases it is likely that the surrounding areas are already developed or at high risk and that the remaining areas are fragmented. Thus, the pre-emptive approach to conservation argues that in order to conserve large blocks of habitat for reasonable prices, conservation is better done before the risk of development is high. (Spring et al. 2007) The fire-fighting approach theorizes that since the land at most risk for development will soon be lost as habitat, it must be conserved as soon as possible and thus the land at highest risk for development is prioritized for conservation ahead of less at risk areas. (Spring et al. 2007) Both theories have valid points and are reasonable theories for conservation. Habitat mitigation, however, is a special case of conservation. With the case of mitigation, the concept of additionality comes into play. The habitat is being conserved in order to mitigate for a loss of habitat elsewhere. If the preservation of the land does not have additional benefit over what the value would have been without preservation, no credit is given. Property under little threat of development has little increase of value due to preservation. The habitat is there to be used by the species whether it is protected or not; the value to the species does not change.

## Credits for already preserved or publicly owned land

Approximately 940,000 of the 1.9 million acres in New Jersey with debit or credit values are already protected; they are state, county, municipally, or federally owned, privately owned conservation areas, or private easements. One could argue whether or not those areas could be used as a part of a conservation bank.

It is controversial whether credits should be allowed to be earned on already protected land. Already protected land could be publicly or privately owned. Under the concept of additionality credits can only be earned based on any additional benefit to the species that accrues by the mitigation being performed. Thus, if habitat enhancement or restoration could be performed that would benefit the species, in theory credits could be earned. Proponents of this theory point out that allowing mitigation on already protected land including publicly owned land would provide much needed funds to manage and restore or enhance land. There are some differences of opinion between offering credits on privately owned preserved land and publicly owned properties. Opponents of offering credits on publicly-owned land often point out that by funneling private mitigation funds into publicly-owned properties those funds are taken away from the private conservation that could otherwise be done. In addition, some object to publicly owned lands going to private gain -i.e. allowing private individuals to benefit through the clearing of their debits by purchasing credits on public land.

Wildlife habitat values are higher on protected land than on unprotected (Table 2). Much of the reason is the percent core habitat is often higher on protected land as is the contiguity since large blocks of habitat frequently are protected. For example, in the Pinelands the mean wildlife habitat value for habitat only (no 0s) is 69 over both protected and unprotected land while the mean on protected land is 81 and the mean on unprotected land is only 55. (The median on protected land is 88 while on unprotected land it is 59.) All the Landscape Regions have this property. (Figure 7 and Figure 8)

Even taking into account the concept of additionality, there are credit values for already protected land. There is no value given for the credit for preservation since there is no additional preservation assurance given by adding already protected land to a conservation bank. However, there is credit for management for the species which could also include habitat enhancement or restoration. Figure 9 shows the credits available according to the model on protected land.

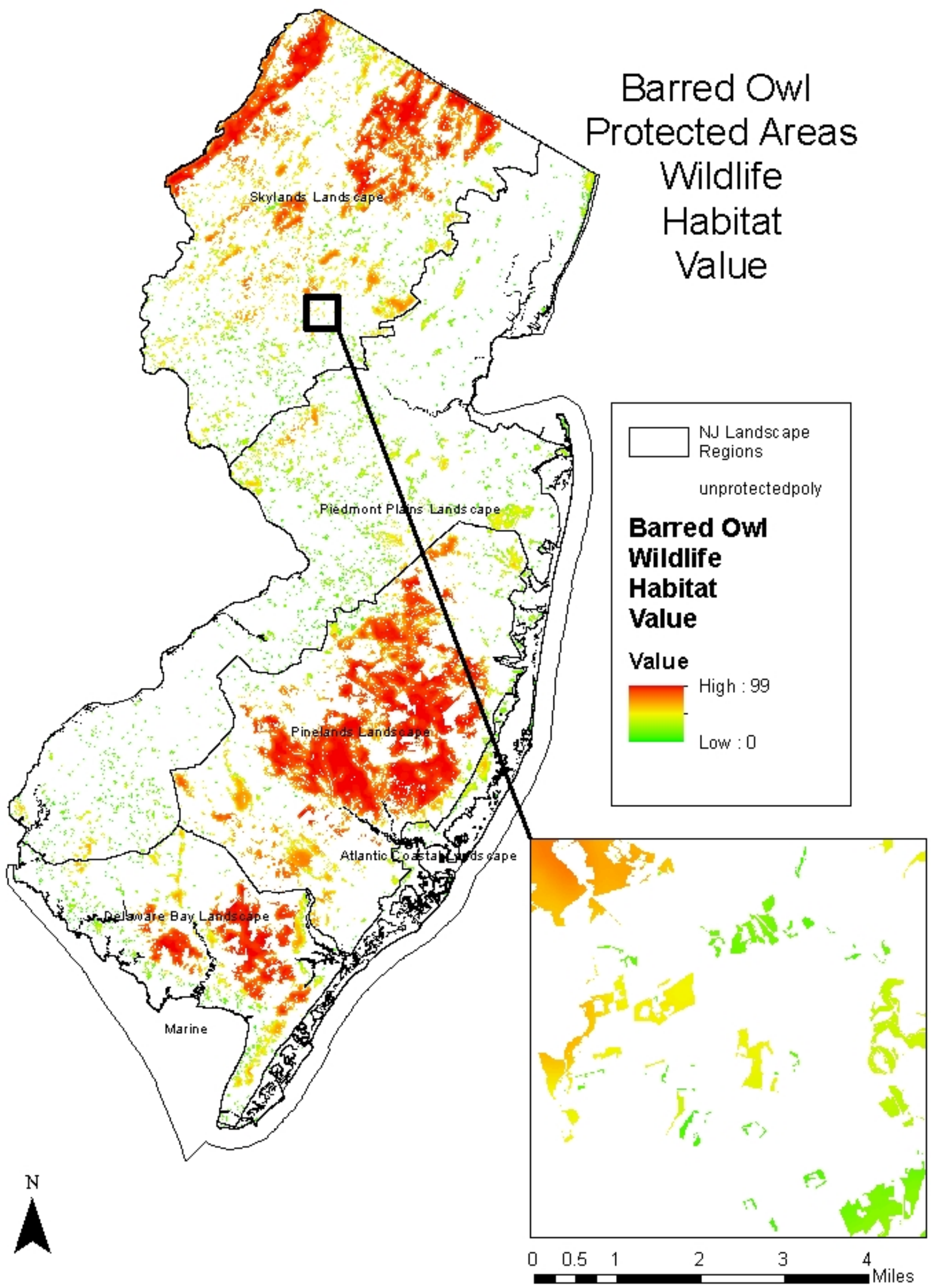



Figure 7: Barred Owl Wildlife Habitat Value for protected areas only. WHVs are higher on average for protected land than unprotected.

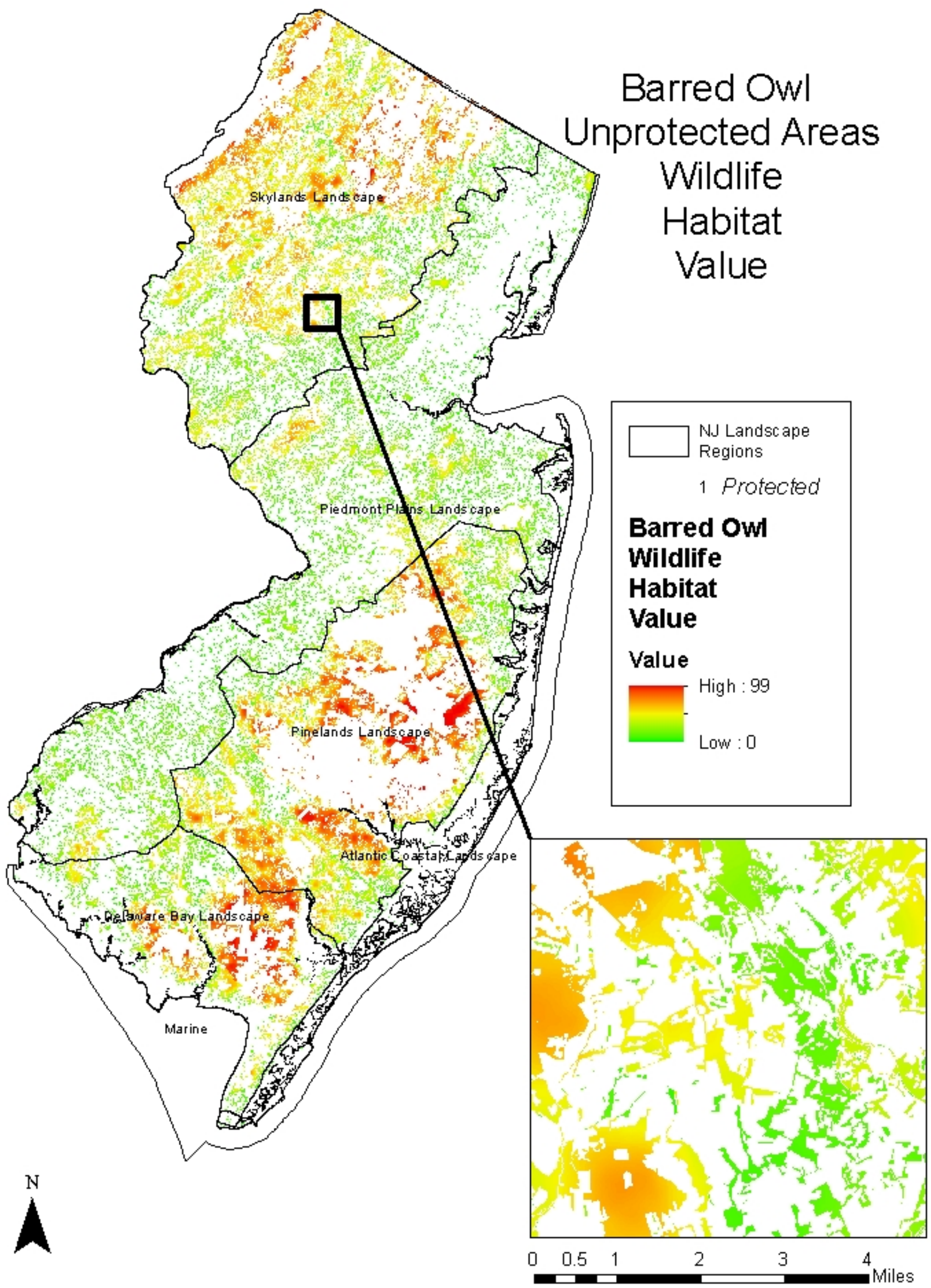



Figure 8: Barred owl Wildlife Habitat Values for unprotected areas only. WHVs for unprotected areas are lower on average than for protected areas.

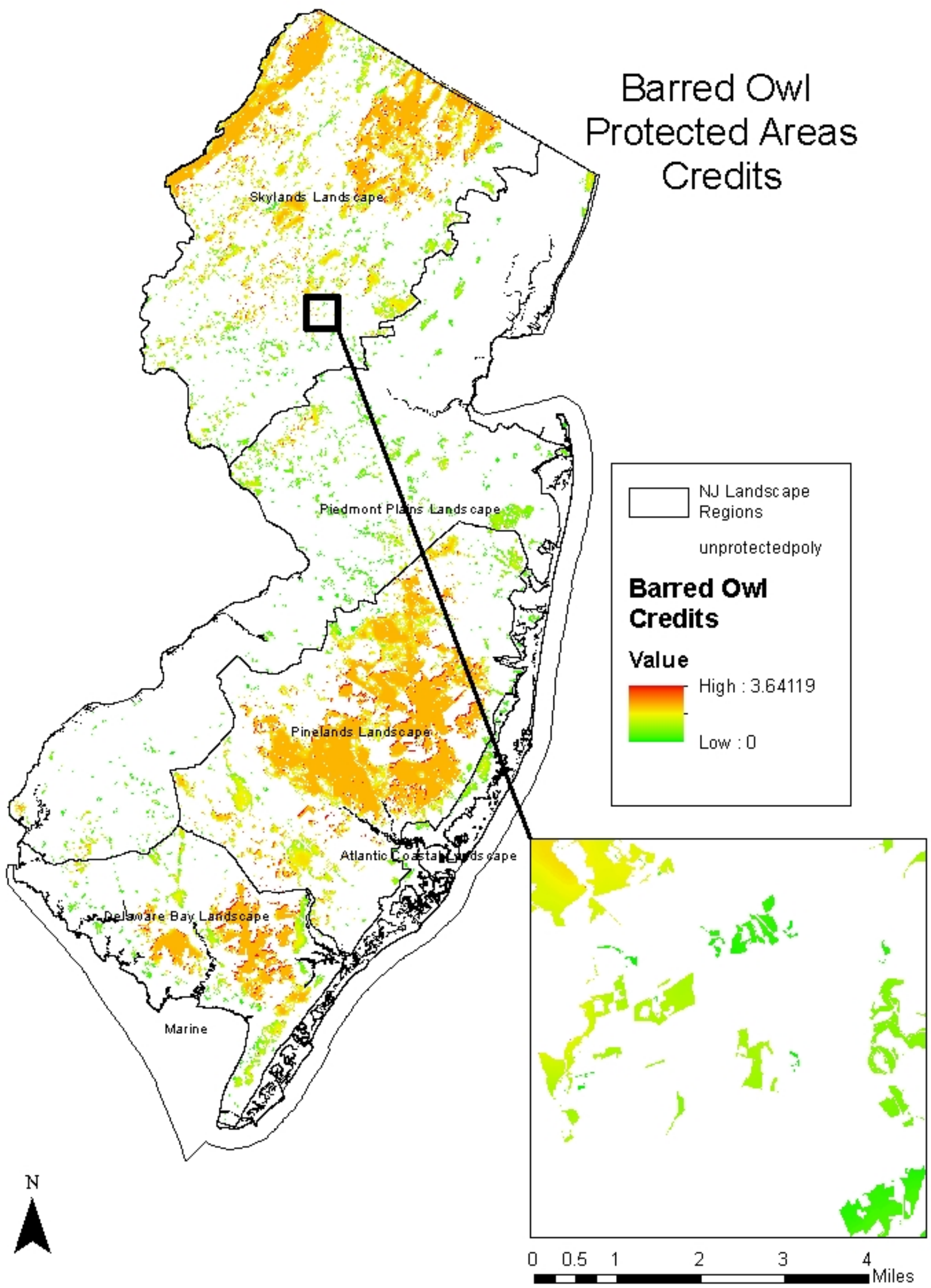



Figure 9: Barred owl credits on already protected land. There is still an increase in value possible from the management in perpetuity. The credit factor is fairly low, but since the WHVs are high the overall credit values are middling.

## Unprotected Land

Most if not all of the conservation banking as well as the areas for which there is mitigation would be in the unprotected areas of New Jersey. There are 1.0 million unprotected acres in New jersey-wide that have been assigned debit and credit values for barred owl habitat mitigation under this model. These unprotected habitat acres generate 28.8 million debits and 15.8 million credits. The proportion of acres in each debit or credit value range can be seen in Table 3.

Clearly the credit values for the unprotected acres are quite a bit lower than the debit values. Of the 955 thousand unprotected acres with debit or credit values, only 32 thousand acres are made up of pixels with a credit value higher than 2.0. In comparison, 399 thousand unprotected acres have been assigned debit values greater than 2.0. (Table 3, Figure 10 and Figure 11)

The average debit value statewide is 1.7 per pixel (30.1 per acre). The average credit value is 1.0 per pixel (16.6 per acre)

Table 3: Statistics on barred owl debits and credits on unprotected land in New Jersey

| Range of Values | | Unprotected Acres with Debit Values in range | Unprotected Acres with Credit Values in range | Number of Debits in each range unprotected | Number of credits in each range unprotected |
|---|---|---|---|---|---|
| 0.0 | 0.5 | 176,849 | 277,641 | 705,944 | 1,082,546 |
| 0.5 | 1.0 | 122,239 | 229,073 | 1,599,383 | 3,040,870 |
| 1.0 | 1.5 | 105,402 | 247,612 | 2,308,178 | 5,356,993 |
| 1.5 | 2.0 | 152,029 | 168,527 | 4,670,457 | 4,956,696 |
| 2.0 | 2.5 | 136,217 | 20,520 | 5,316,680 | 789,916 |
| 2.5 | 3.0 | 119,735 | 8,350 | 5,717,603 | 395,723 |
| 3.0 | 3.5 | 82,693 | 3,059 | 4,665,759 | 170,452 |
| 3.5 | 4.0 | 60,211 | 392 | 3,808,534 | 24,301 |
| | | | | | |
| Total nonzero | | 955,374 | 955,175 | 28,792,537 | 15,817,497 |

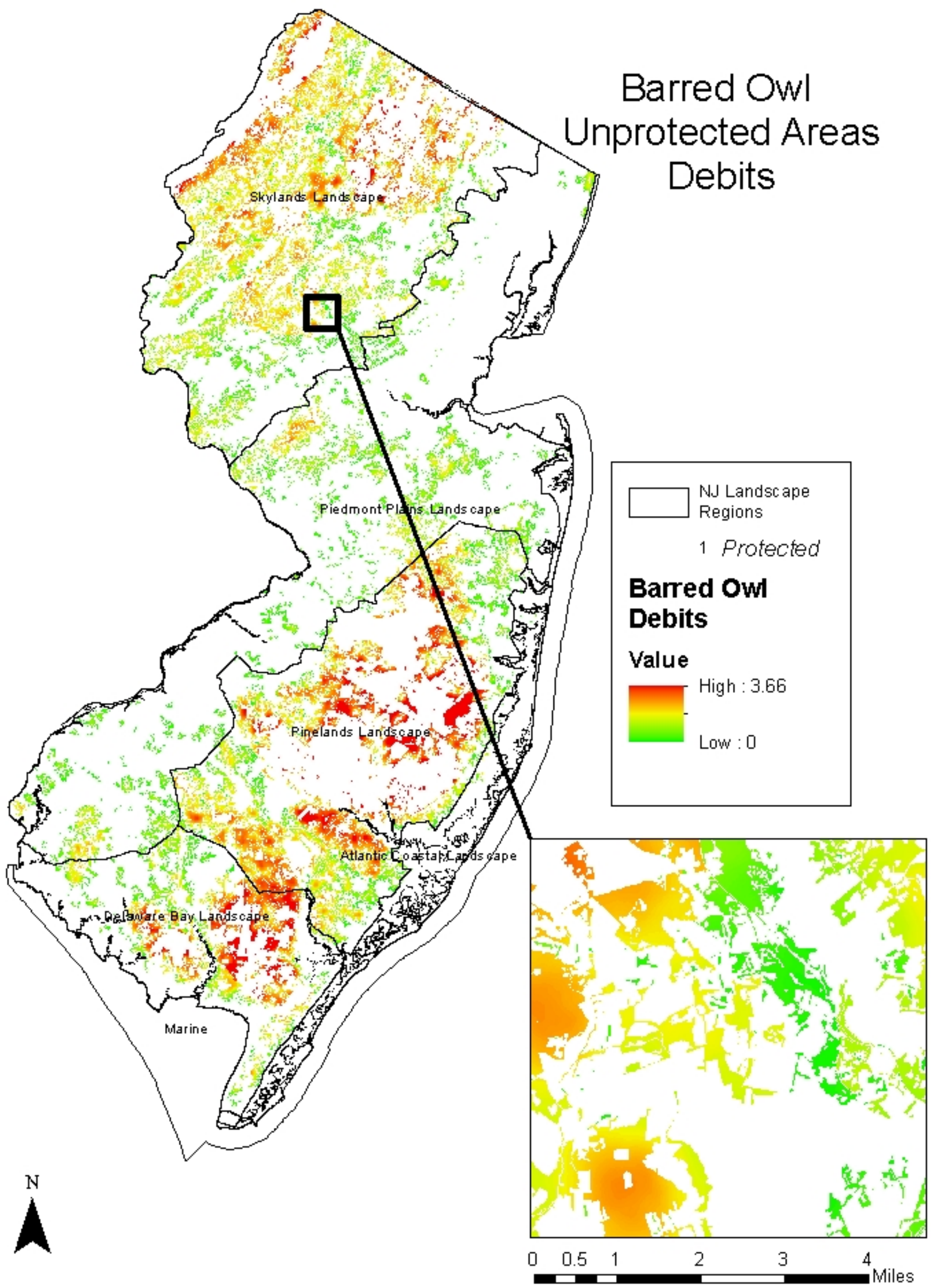



Figure 10: Barred owl debits on unprotected areas only. Note that there are some high valued areas surrounded by protected land. Highest debit values are in Pinelands, Delaware By and Skylands.

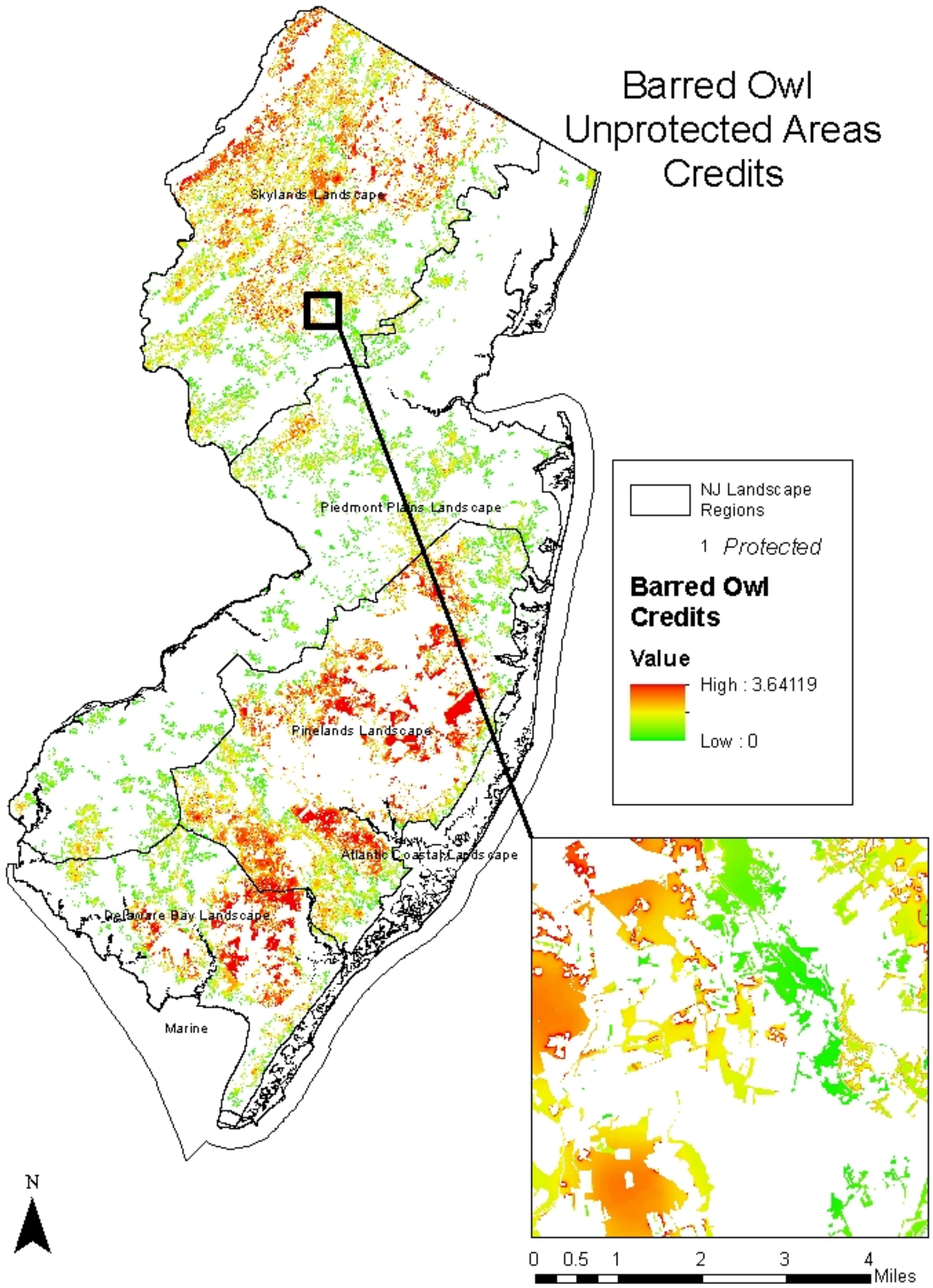



Figure 11: Barred owl credits on unprotected land only. The highest credit values are near or surrounded by protected areas. The highest values are in the Pinelands, Delaware Bay and Skylands.

## Hypothetical partial buildout scenario

A hypothetical partial buildout scenario for barred owl habitat statewide illustrated below assumes that the lowest habitat value areas are developed while the largest blocks of the highest habitat areas available are put in conservation banks. In step 1 of the partial buildout scenario the large blocks of highly valued barred owl habitat are conserved resulting in 78 thousand acres protected and conserved in conservation banks. This generates 2.3 million credits. This does not include all the highest credit valued area, but concentrates the banks in the largest blocks of high habitat value which have high and middling values. The wildlife habitat values in the areas generating the credit values range from 44 to 99. The 2.2 million debits that these credits offset was selected from lands of low-quality habitat mixed with non-habitat that are subsequently developed. The habitat destroyed due to conversion to urban land uses is 253 thousand acres and the wildlife habitat values of these areas range from 12 to 38. In theory, there is no habitat value lost in these transactions (i.e., no net loss of habitat value is achieved) and the overall effect on the barred owl as a species is neutral (Table 4). Recall that according to the rate of urbanization of New Jersey this amount of urbanization would be over a period of many years as some of the development would likely also be in non-habitat areas. In order to develop 248 thousand acres, decades would likely pass.

Table 4: Step 1 of a hypothetical statewide partial buildout scenario for barred owl where 0.3 million acres of habitat are developed but no habitat value lost.

| Hypothetical statewide partial buildout situation just for barred owl | | | | | |
|---|---|---|---|---|---|
| Range of Values | | Number of Debits used in transaction from each range | Number of Acres Debited | Number of Credits used in transaction from each range | Number of Acres Credited |
| 0.0 | 0.5 | 529,458 | 132,636 | - | - |
| 0.5 | 1.0 | 1,199,537 | 91,679 | - | - |
| 1.0 | 1.5 | 544,445 | 28,470 | - | - |
| 1.5 | 2.0 | - | - | 2,204,420 | 75,949 |
| 2.0 | 2.5 | - | - | 39,496 | 1,026 |
| 2.5 | 3.0 | - | - | 19,786 | 418 |
| 3.0 | 3.5 | - | - | 8,523 | 153 |
| 3.5 | 4.0 | - | - | 1,215 | 20 |
| | | | | | |
| Total nonzero | | 2,273,440 | 252,786 | 2,273,440 | 77,565 |
| | | | | | |
| Hypothetical buildout situation for barred owl | | | | | |
| Total Acres developed and mitigated (debit acres) | | | | | 252,786 |
| Total Acres preserved in conservation banks (credit acres) | | | | | 77,565 |
| | | | | | |
| Total Acres of habitat lost | | | | | 252,786 |
| Total Value of habitat lost | | | | | (0) |

Step 2 of this partial buildout scenario occurs after the large blocks of habitat have already been protected in step 1. Thus, the remaining lands with credits are smaller non-contiguous areas close to developed areas or lower credit areas. In this continuation, a further 64 thousand acres are developed generating 1.7 million debits. Some of the developed areas are now in higher habitat valueareas as buildout is approached and the lower habitat value areas are no longer available. The wildlife habitat values of the debited area range from 38 to 48 with a median and a mean of 43. These 1.7 million debits are balanced with 1.7 million credits earned with through the protection and management in conservation banks of 95 thousand acres. (Table 5) Since the largest blocks of contiguous habitat were protected in step 1 in conservation banks, now only smaller areas with lower credit values are available for conservation. The wildlife habitat values of the newly conserved areas creating the credit values range from 25 to 77. At this point more acres are newly protected than newly developed.

Table 5: Step 2 of a hypothetical statewide partial buildout scenario. A further 64 thousand acres are developed and 95 thousand are protected in conservation banks.

| Hypothetical statewide partial buildout situation just for barred owl | | | | | |
|---|---|---|---|---|---|
| Range of Values | | Number of Debits used in transaction from each range | Number of Acres Debited | Number of Credits used in transaction from each range | Number of Acres Credited |
| 0.0 | 0.5 | - | - | - | - |
| 0.5 | 1.0 | - | - | 608,174 | 45,815 |
| 1.0 | 1.5 | 770,600 | 32,697 | 1,071,399 | 49,522 |
| 1.5 | 2.0 | 908,972 | 31,850 | - | - |
| 2.0 | 2.5 | - | - | - | - |
| 2.5 | 3.0 | - | - | - | - |
| 3.0 | 3.5 | - | - | - | - |
| 3.5 | 4.0 | - | - | - | - |
| | | | | | |
| Total nonzero | | 1,679,572 | 64,547 | 1,679,573 | 95,337 |
| | | | | | |
| Hypothetical buildout situation for barred owl | | | | | |
| Total Acres developed and mitigated (debit acres) | | | | | 64,547 |
| Total Acres preserved in conservation banks (credit acres) | | | | | 95,337 |
| | | | | | |
| Total Acres of habitat lost | | | | | 64,547 |
| Total Value of habitat lost | | | | | (0) |

To go to total buildout an iterative method would be followed wherein areas would be selected as either developed or added to conservation bank. An iterative approach is used to illustrate as the same acres hold both debit and credit values. Once an acre is debited, it cannot be credited and vice versa.

## Multiple species on the same property

Under some regulations there are rules against “double dipping” or credit stacking on the sale of credits (USFWS 2016). In the case of threatened and endangered species habitat mitigation in New Jersey if there is more than one species habitat on the developed property, mitigation for the habitat of each individual species must be completed. Thus for one property there could be “stacked” debits for each species using the habitat. Thus, it seems logical that the same could be done for credits. If a property is potential habitat for more than one threatened or endangered species, credits could be sold for each of them. This would not undermine the idea of no net loss of habitat value.

## Multiplier to take into account risk

This model assigns debits and credits based on the theory of no net loss of habitat value. This means that the habitat value would in theory stay the same over time if a system of conservation banking was implemented using this model as a basis for the assignment of debits and credits. With one-off habitat mitigation projects, especially on-site mitigation projects, there is risk stemming from the timing of the mitigation and the uncertainty of the mitigation outcome. This risk is often hedged by setting a multiplier. Thus if 10 acres of successful current habitat management and preservation would suffice for a project were the ideal outcome to occur, 15, 20 or 30 acres is called for in case the outcome is not ideal. The structure of conservation banking cuts the risks drastically. In conservation banking, the restoration and enhancement of the habitat is completed before the credits can be sold, thus there is no loss of habitat for a time. The newly enhanced habitat is ready to go. Thus, in theory there is no risk from timing or uncertainty of outcome of habitat in a conservation bank.

In conservation banking there is still a risk that there will not be no net loss of habitat value stemming even from the best-intentioned program. There is variation in all the assumptions and in all the processes involved. A measure of debit or credit value is really more of a distribution, not a point estimate. However, for practical purposes a best point estimate would be used. It would be a hard sell to tell a developer that he or she had to buy "somewhere between 100 and 150 credits depending on how the mitigation is working out at some point in the future. Such a system would undermine the ability of the conservation bank to accept the liability for the restoration from the developer. However, just because a point estimate is used does not mean that the underlying risk of variation vanishes. Thus, in order to stay conservative, there could still be a multiplier applied to the credits. This would be easy to implement in the model component or outside it. For example, for every 1,000 debits one might be compelled to buy 1,500 credits. This would imply a multiplier of 1.5. Within the model the risk multiplier need not be equal across the different service areas or even within the service areas, but could vary based on some measurable geographic variable.

## Adaptive Management of Model

The structure of the model is such that each major section is a component. If enhanced methods or data relating to a specific component is upgraded the enhanced component can easily be substituted while keeping the overall theory and framework of the model intact. The components could be traded out based on new research in one of the areas or on a change in regulatory direction. Changes in theory could include judgements on whether credits could be earned on already protected lands, definition of service area, new information on the probability of development, or comprehensive corridor mappings by wildlife agencies.

## Pricing of Credits

Pricing of credits in conservation banks is up to the marketplace. Property prices, wages and projected wages, and tax rates all influence the price of credits as the price includes the land purchase as well as management in perpetuity and other stewardship costs including property taxes, insurance, security etc. The size of service area influences the price of the credits as well. A smaller service area tends to lead to higher credit prices: a smaller service area leaves fewer possibilities for competition among multiple conservation banks; smaller service areas are more likely to only relatively high-priced property or more homogeneously priced property. Service areas that are too large, may have an ecological detriment because localized loss of habitat can then occur.

## Conclusion

The use of this method to consistently, fairly and accurately assess habitat quality using widely available data such that consistent, accurate estimates of conservation banking debits and credits can be assigned would make conservation banking more accessible and transparent. It would also reduce the transaction costs, allowing those funds to be funneled into conservation. Testing indicates that the method created here, whether it succeeds in becoming the go-to method for setting conservation banking debits and credits or whether it informs future attempts to create other methods, is a unique and major contribution to conservation biology.

## Cited Sources

Beans, B. Niles, L. 2003. Endangered and Threatened Wildlife of New Jersey. Rutgers University Press, New Brunswick, NJ.

Goncalves, B., Marques, A., Soares, A., Pereira, H. 2015. Biodiversity offsets: from current challenges to harmonized metrics. Current Opinion in Environmental Sustainability 14:61-67

Lathrop, R., Niles, L., Conroy, M., Smith, J., Danihel, M. 2014. Creating a more effective protection of endangered and threatened species habitat through conservation banking

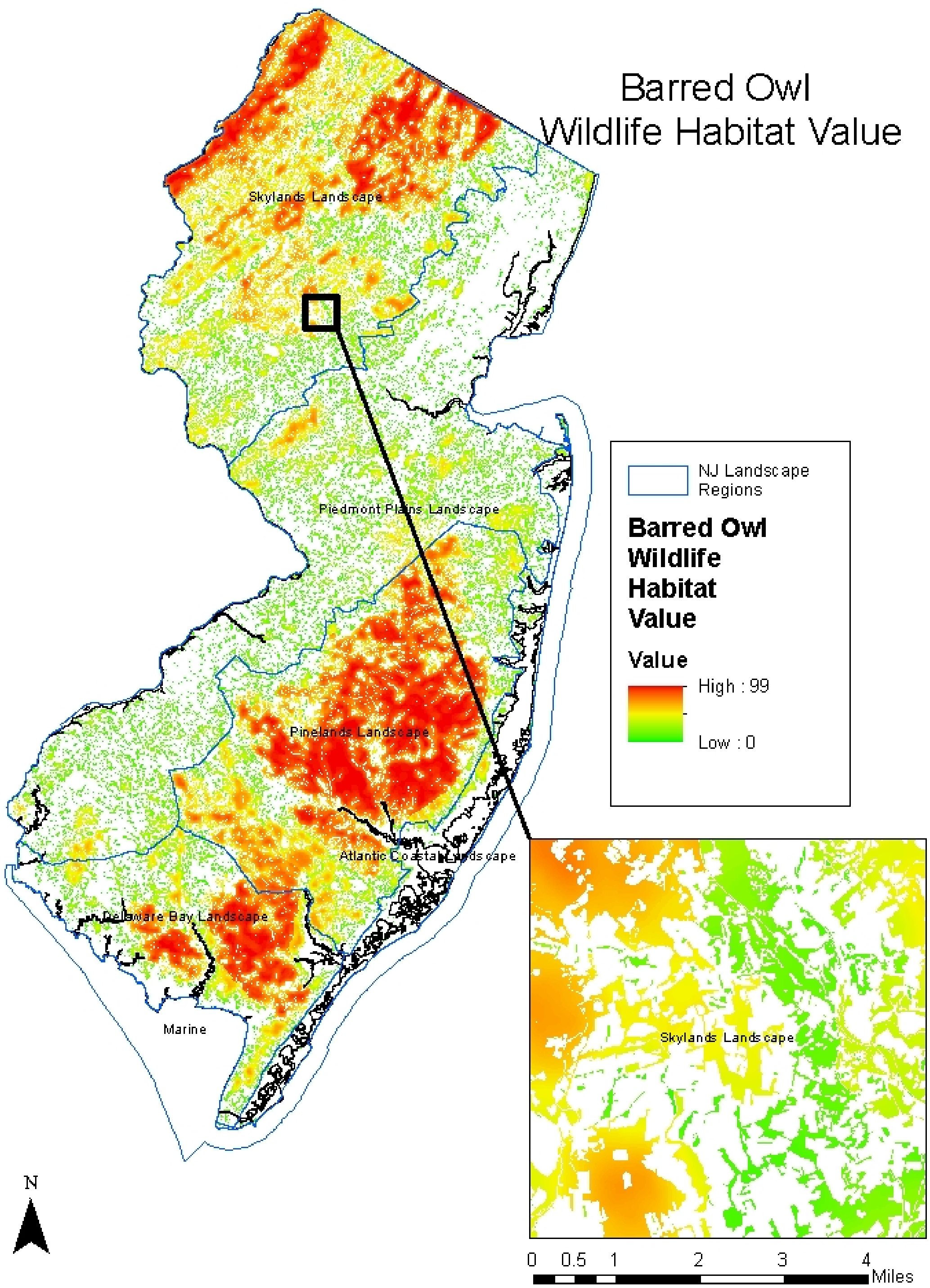
New Jersey Division of Fish and Wildlife. 2012. New Jersey Landscape Project, Version 3.1. New Jersey Department of Environmental Protection, Division of Fish and Wildlife, Endangered and Nongame Species Program. P. 15 http://www.state.nj.us/dep/fgw/ensp/landscape/lp_report_3_1.pdf

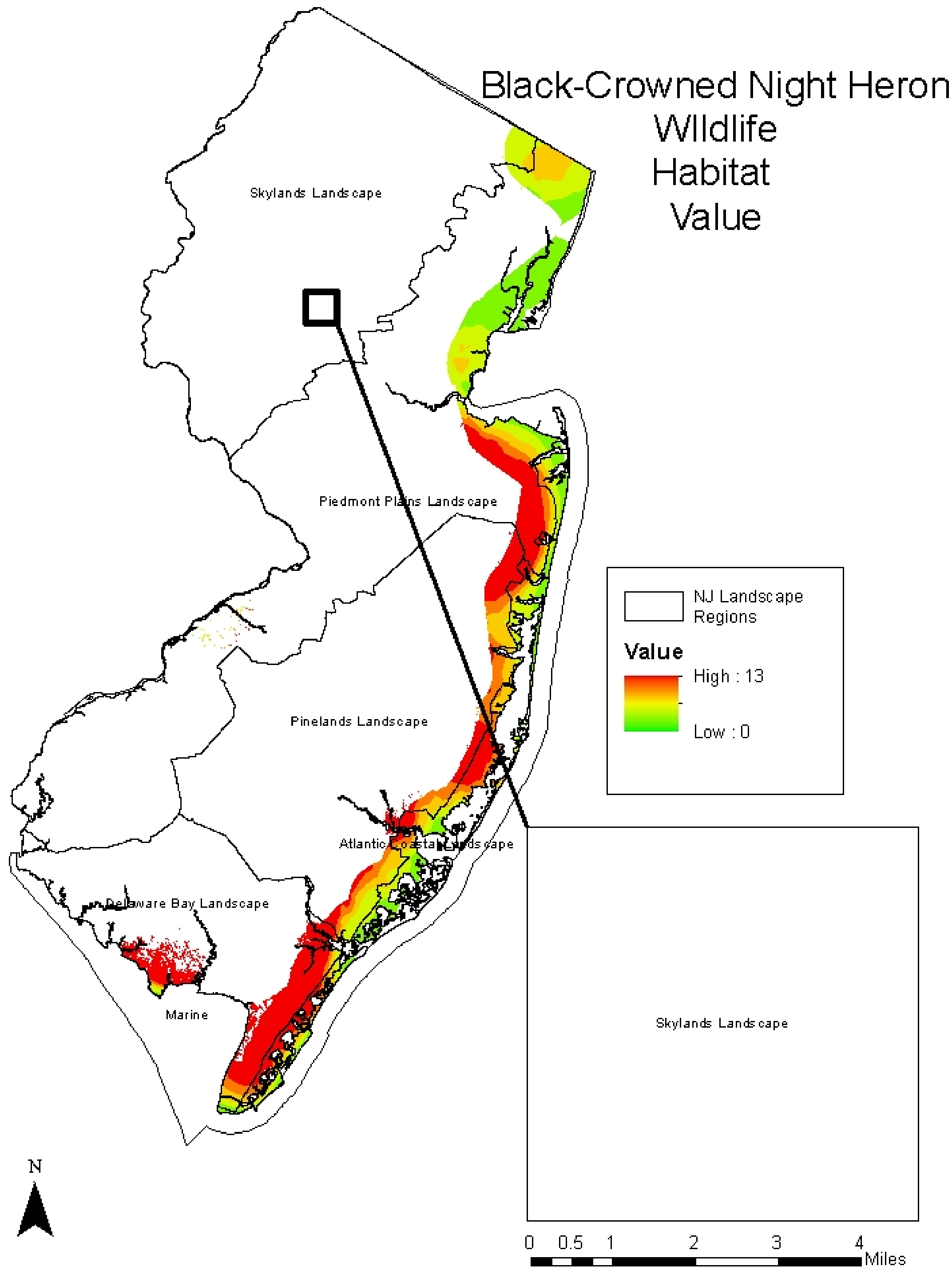
Spring, D., Cacho, O., Nally, R., and Sabbadin, R. 2007. Pre-emptive conservation versus "fire-fighting":A decision theoretic approach. Biological Conservation 136:531-540

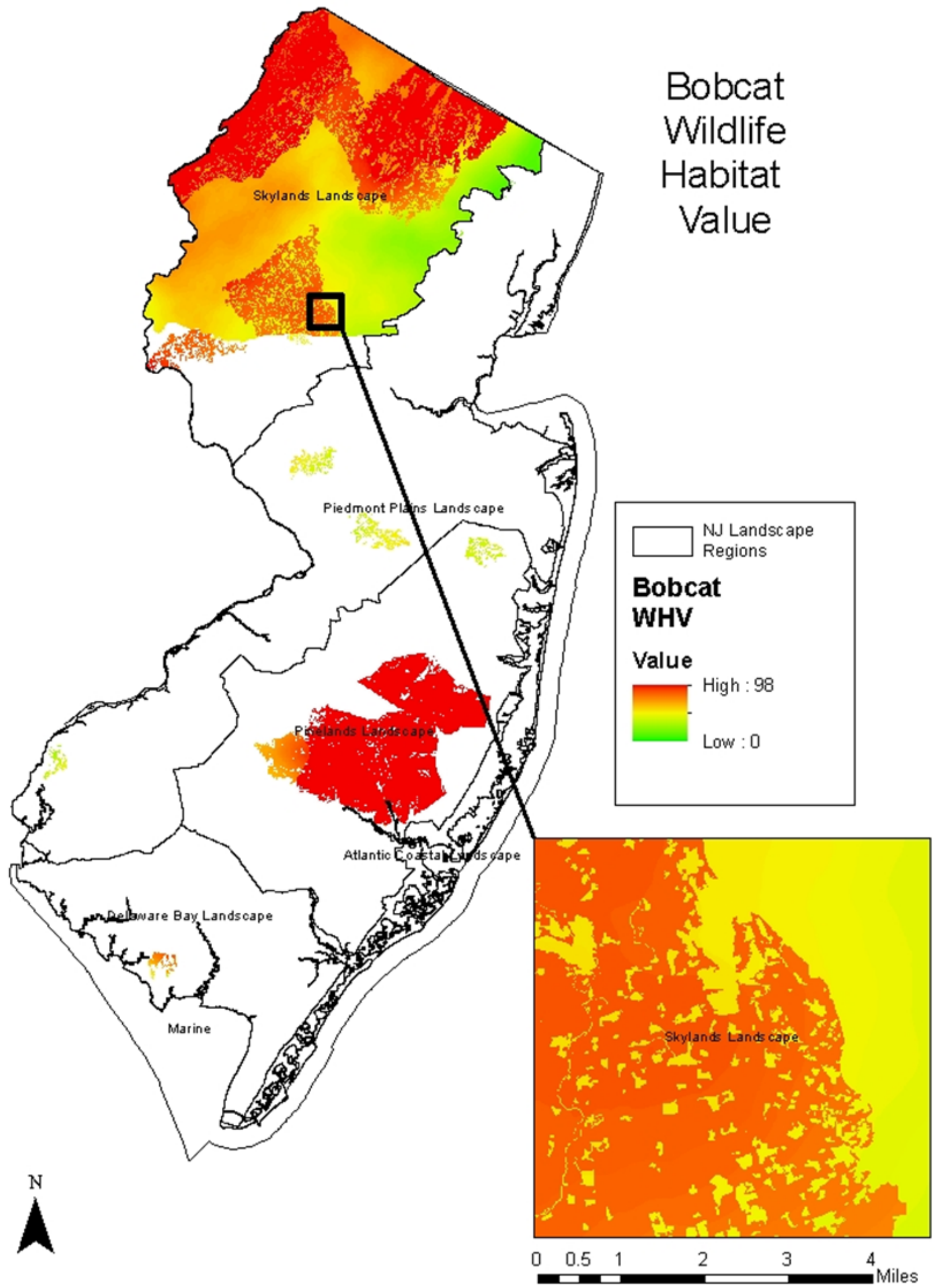
Ten Kate, K., Bishop, J., and Bayon, R. 2004. Biodiversity offsets: views, experience, and the business case. International Union for the Conservation of Nature. http://www.insightinvestment.com/Documents/responsibility/Executive_ Summary_Biodiversity_Offsets_Report.pdf

U.S. Fish and Wildlife Service. 2016. Endangered and Threatened Wildlife and Plants: Endangered Species Act Compensatory Mitigation Policy. Federal Register Vol. 81, No. 248, pp. 95316 - 95349

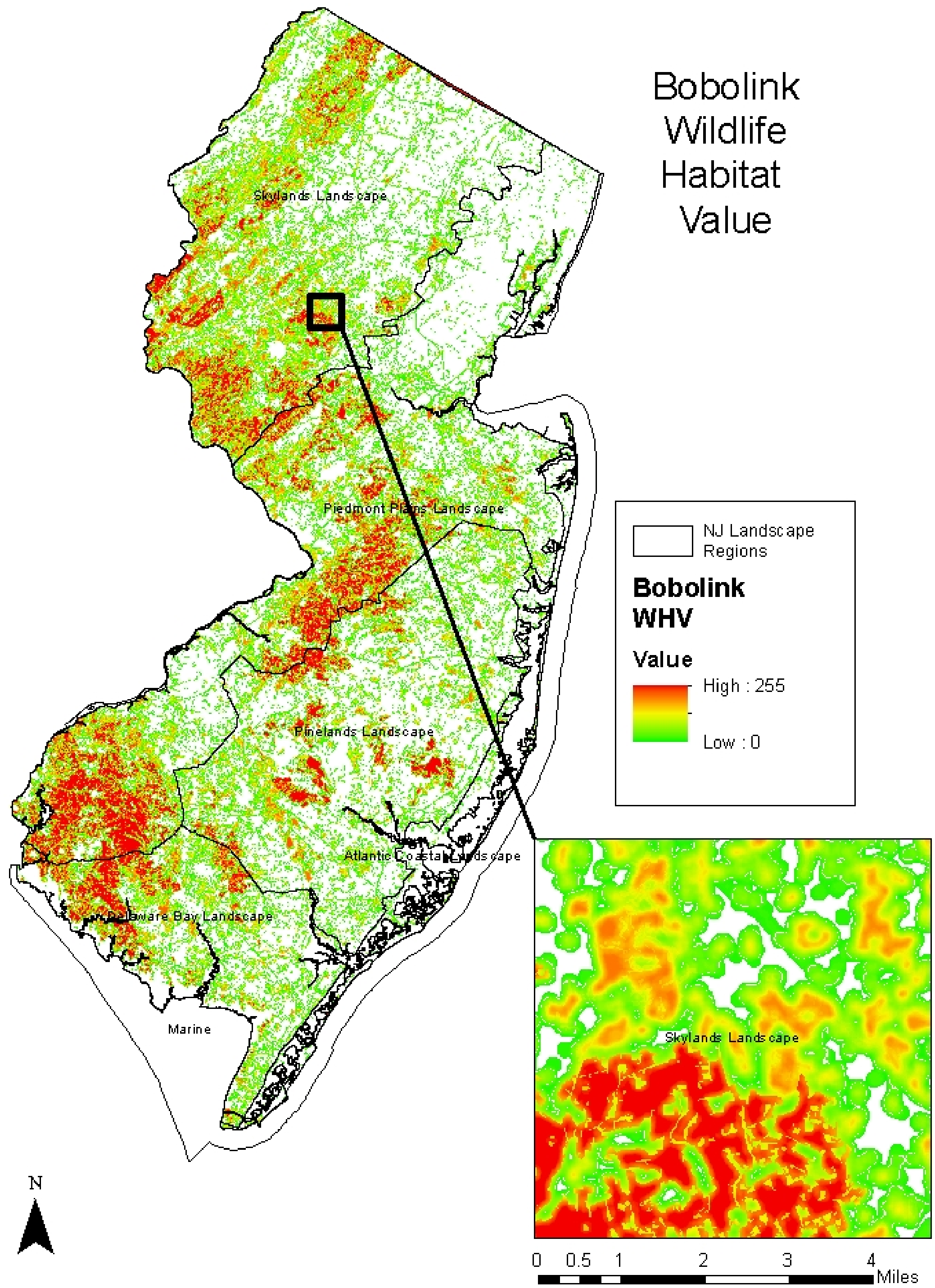
Appendix A: Wildlife Habitat Values for all species

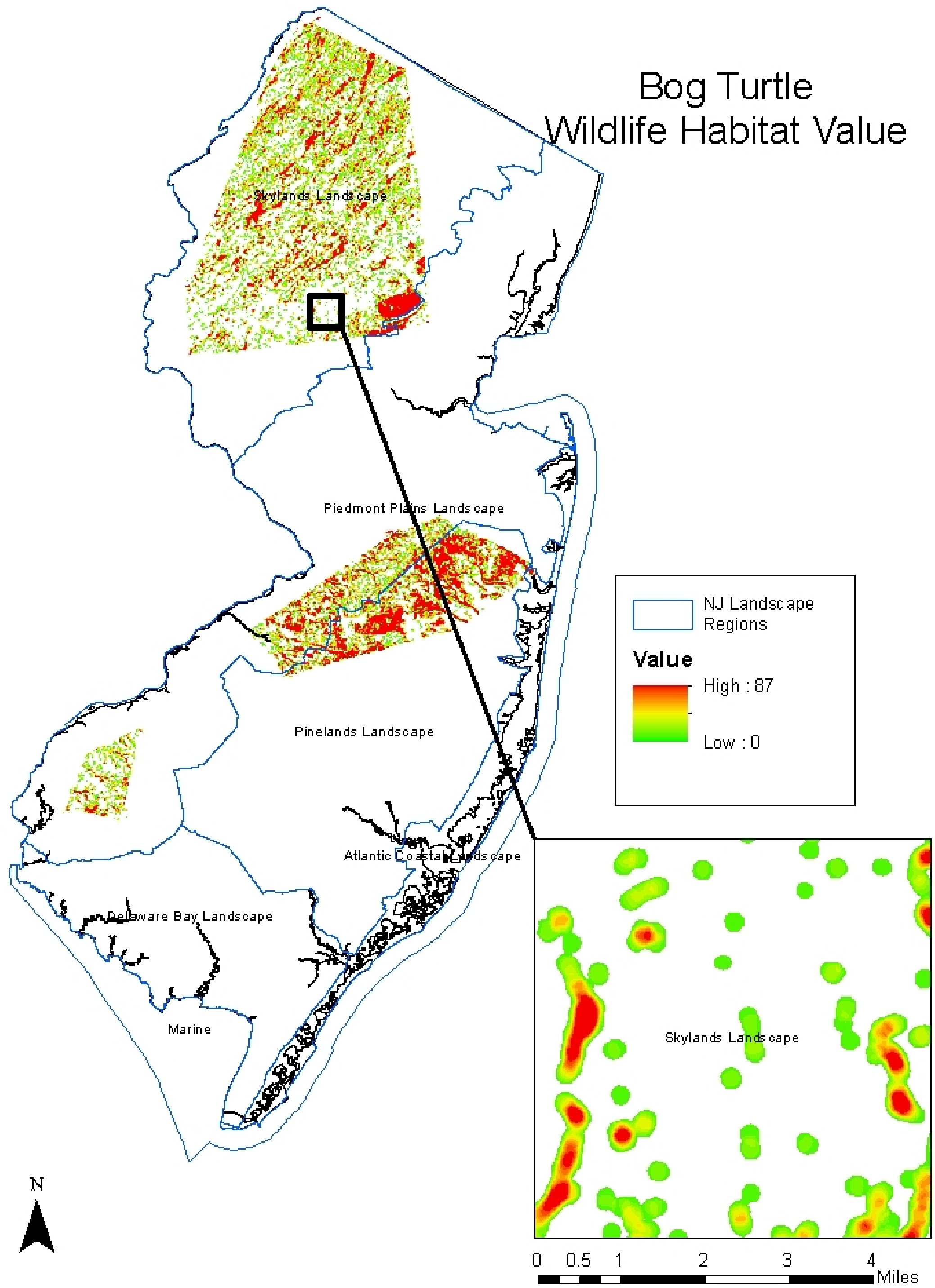


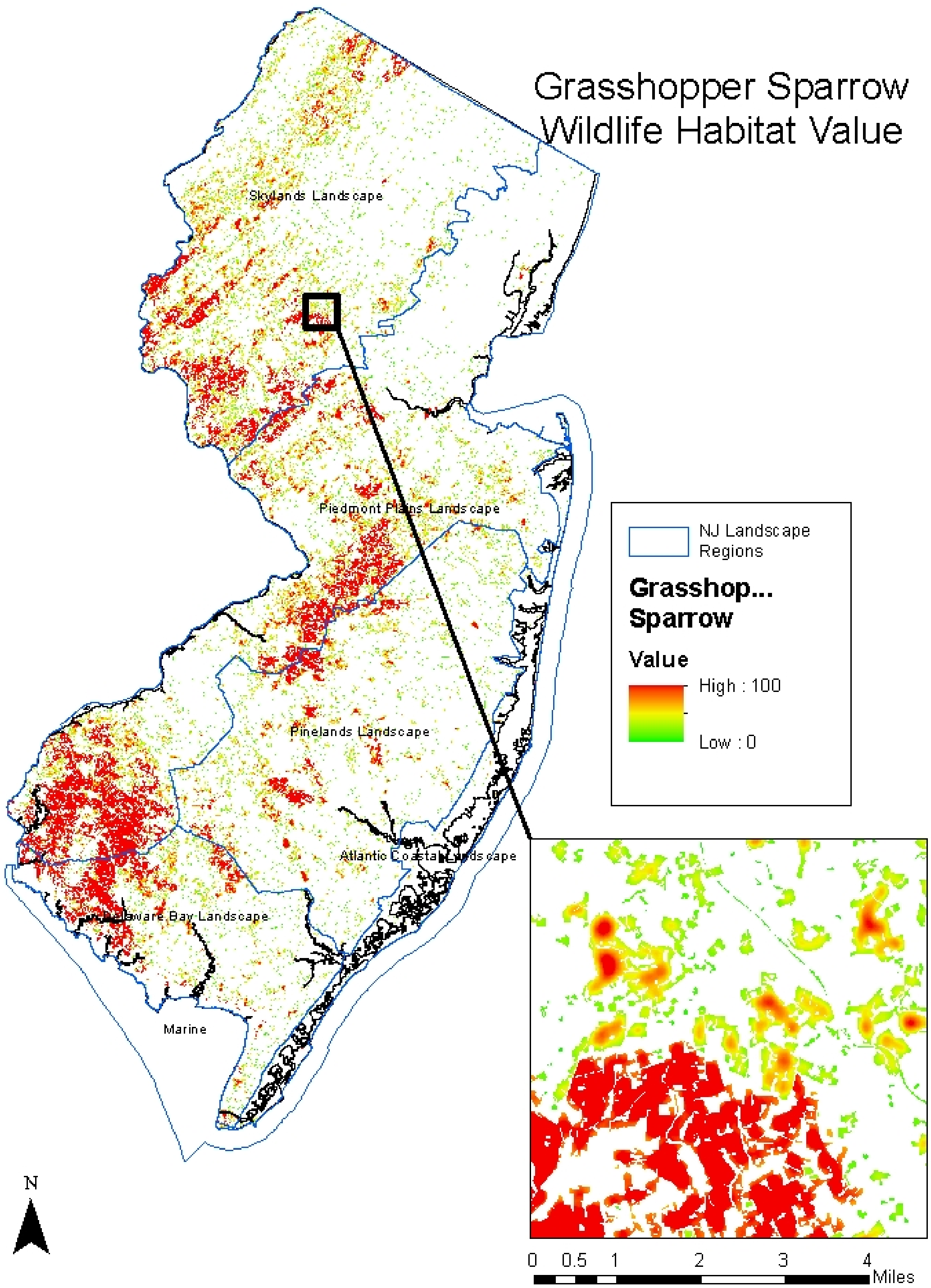

Black-Crowned Night Heron
Wildlife
Habitat
Value
Skylands Landscape
Piedmont Plains Landscape
Pinelands Landscape
Atlantic Coastal Landscape
Delaware Bay Landscape
Marine
NJ Landscape Regions
Value
High : 13
Low : 0
Skylands Landscape
N
0 0.5 1 2 3 4
Miles

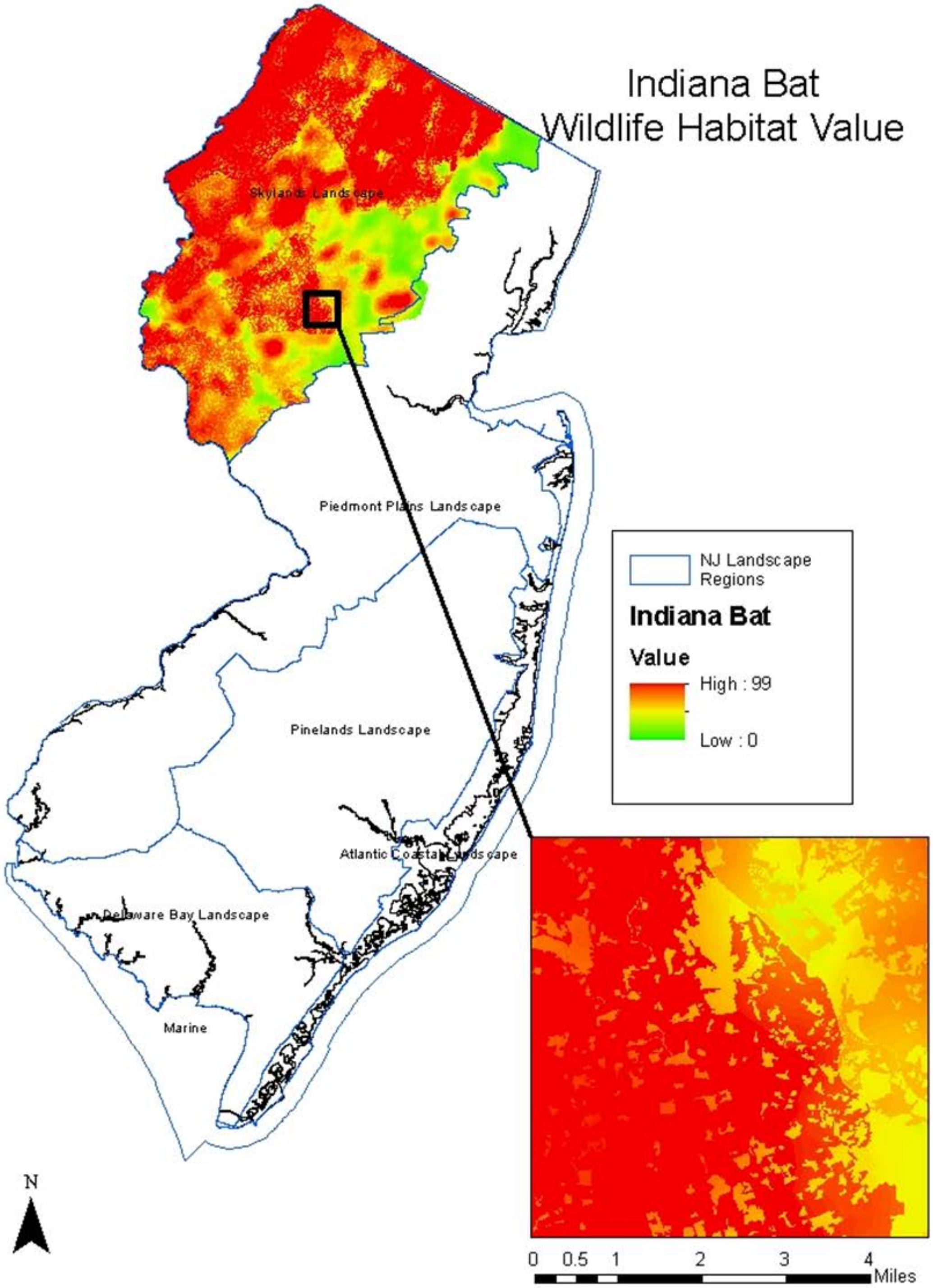


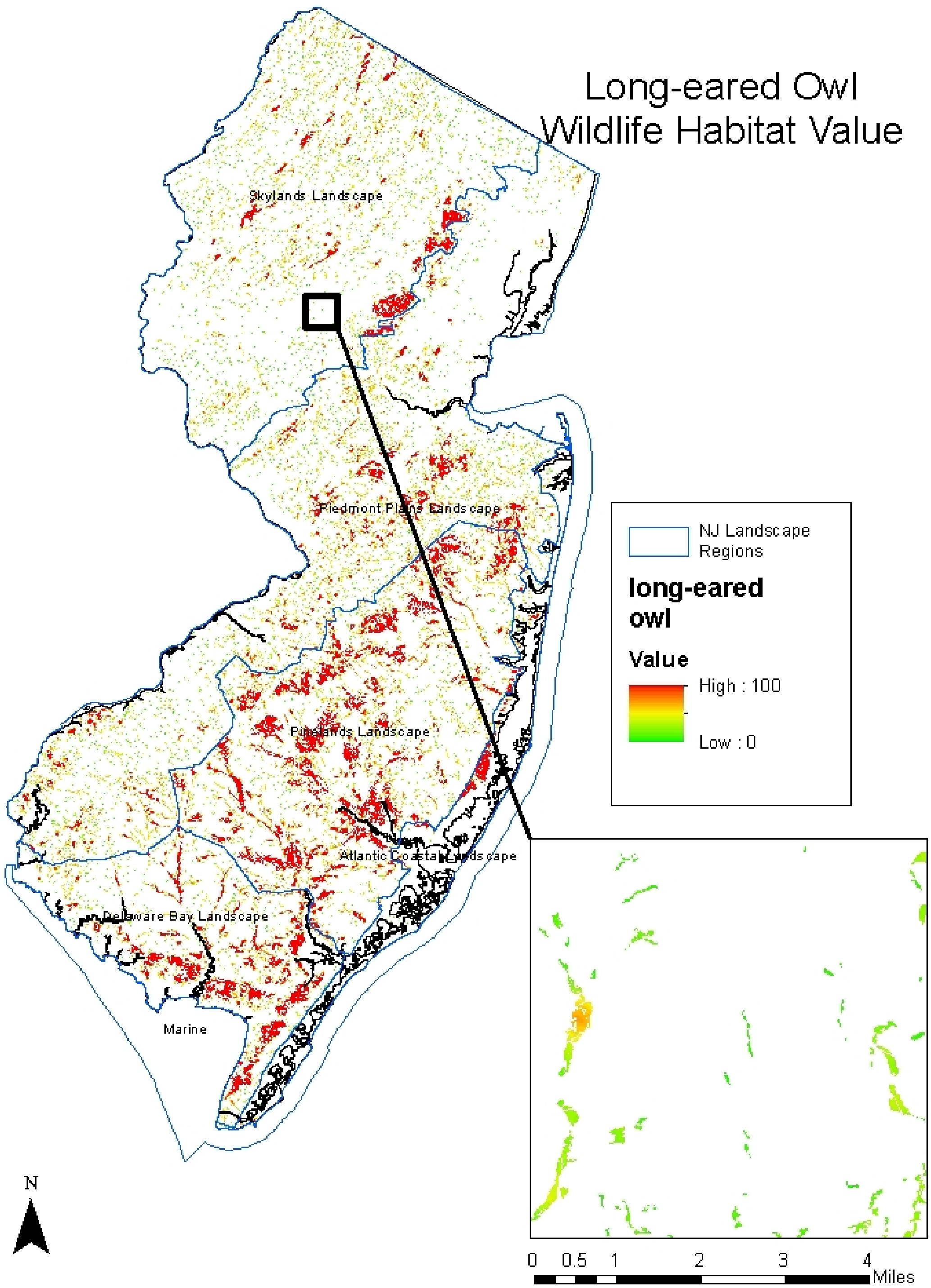
Bobcat Wildlife Habitat Value
Skylands Landscape
Piedmont Plains Landscape
Pinelands Landscape
Atlantic Coastal Landscape
Delaware Bay Landscape
Marine
NJ Landscape Regions
Bobcat WHV
Value
High : 98
Low : 0
N
0 0.5 1 2 3 4 Miles

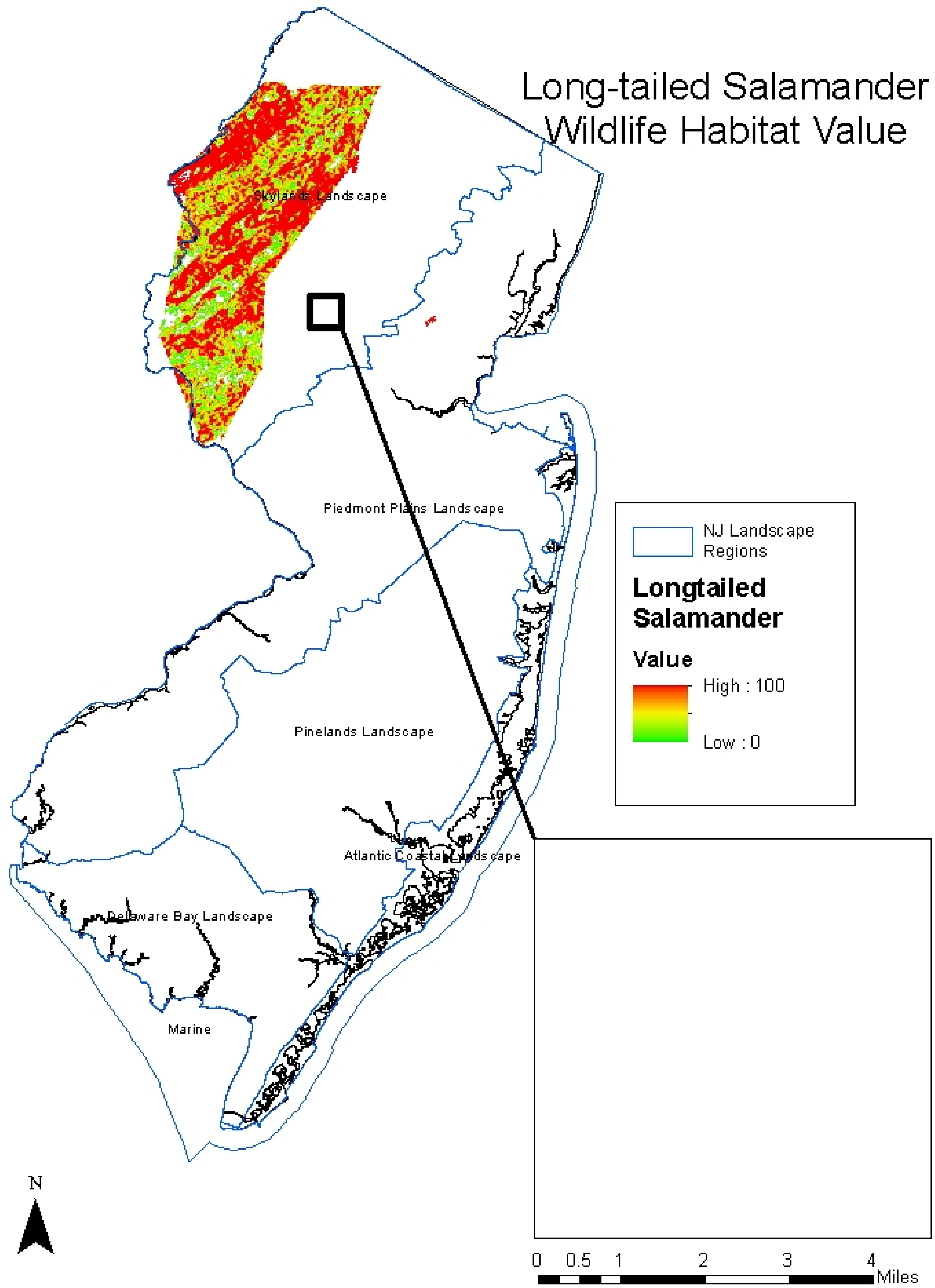

Bobolink
Wildlife
Habitat
Value
Skylands Landscape
Piedmont Plains Landscape
Pinelands Landscape
Atlantic Coastal Landscape
Delaware Bay Landscape
Marine
NJ Landscape Regions
Bobolink WHV
Value
High : 255
Low : 0
N
0 0.5 1 2 3 4
Miles

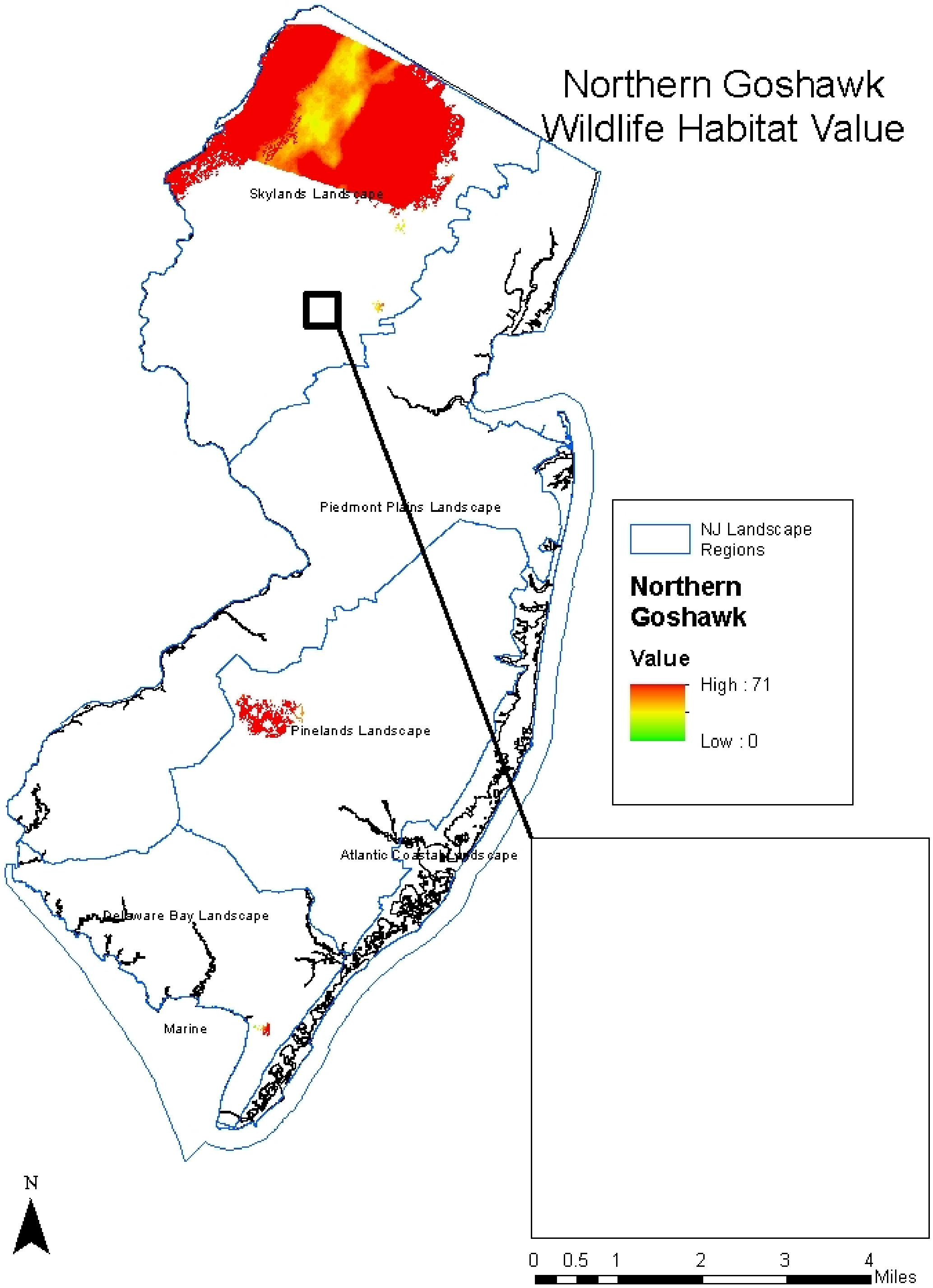

Bog Turtle
Wildlife Habitat Value
Skylands Landscape
Piedmont Plains Landscape
Pinelands Landscape
Atlantic Coastal Landscape
Delaware Bay Landscape
Marine
NJ Landscape Regions
Value
High : 87
Low : 0
N
0 0.5 1 2 3 4
Miles

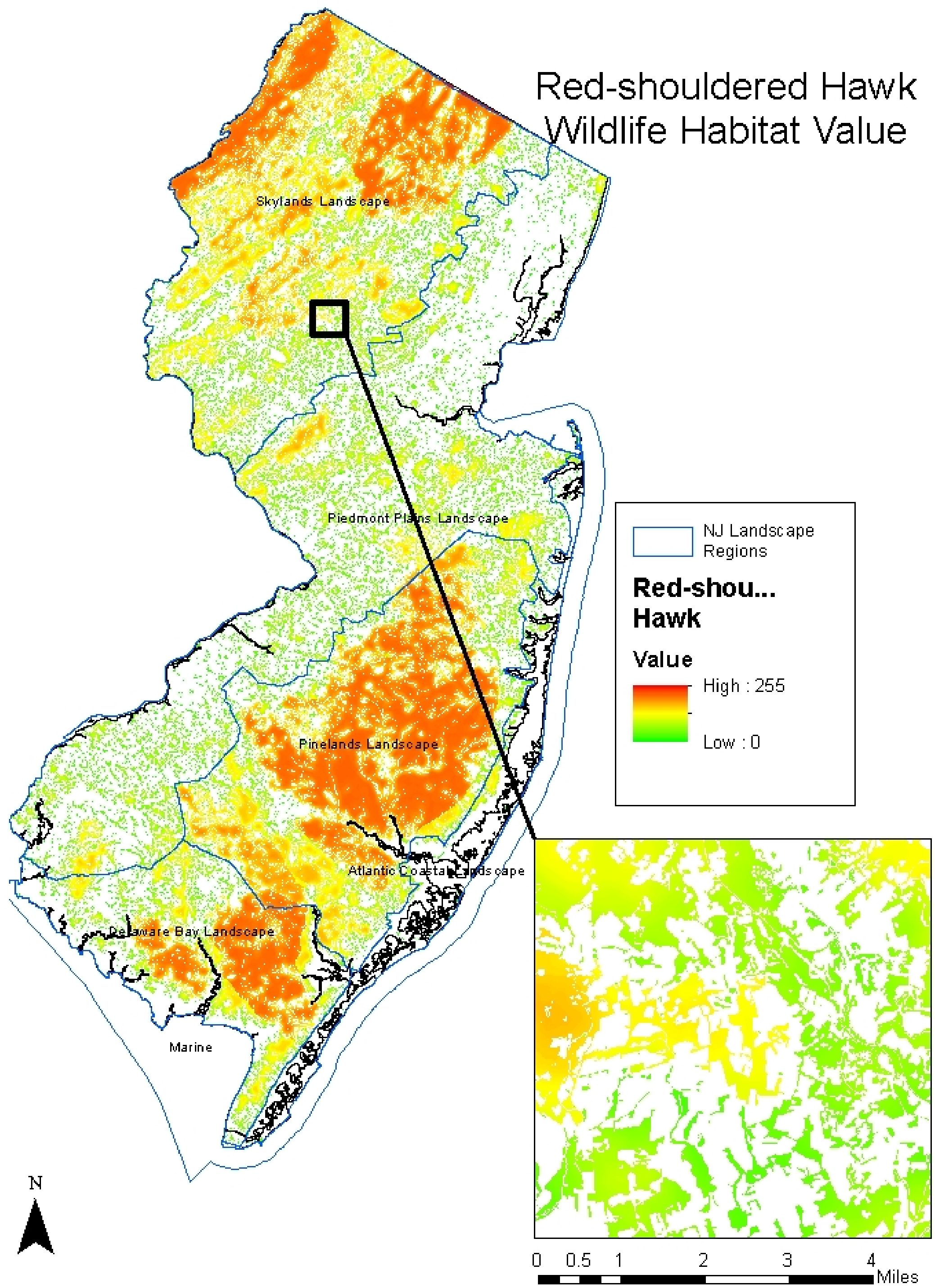

Grasshopper Sparrow
Wildlife Habitat Value
Skylands Landscape
Piedmont Plains Landscape
Pinelands Landscape
Atlantic Coastal Landscape
Delaware Bay Landscape
Marine
NJ Landscape Regions
Grasshop... Sparrow
Value
High : 100
Low : 0
N
0 0.5 1 2 3 4 Miles

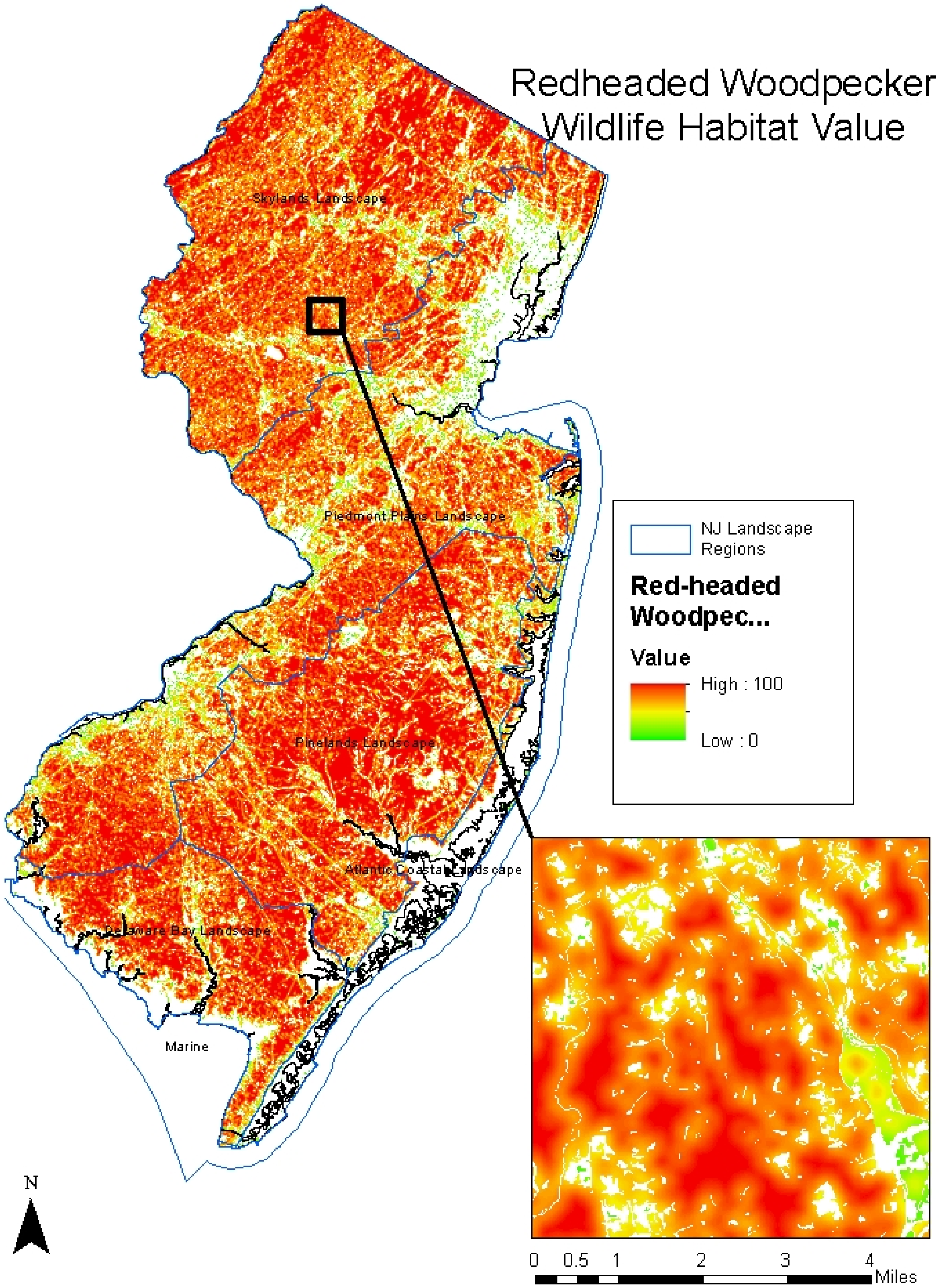

Indiana Bat
Wildlife Habitat Value
Skylands Landscape
Piedmont Plains Landscape
Pinelands Landscape
Atlantic Coastal Landscape
Delaware Bay Landscape
Marine
NJ Landscape Regions
Indiana Bat
Value
High : 99
Low : 0
N
0 0.5 1 2 3 4
Miles

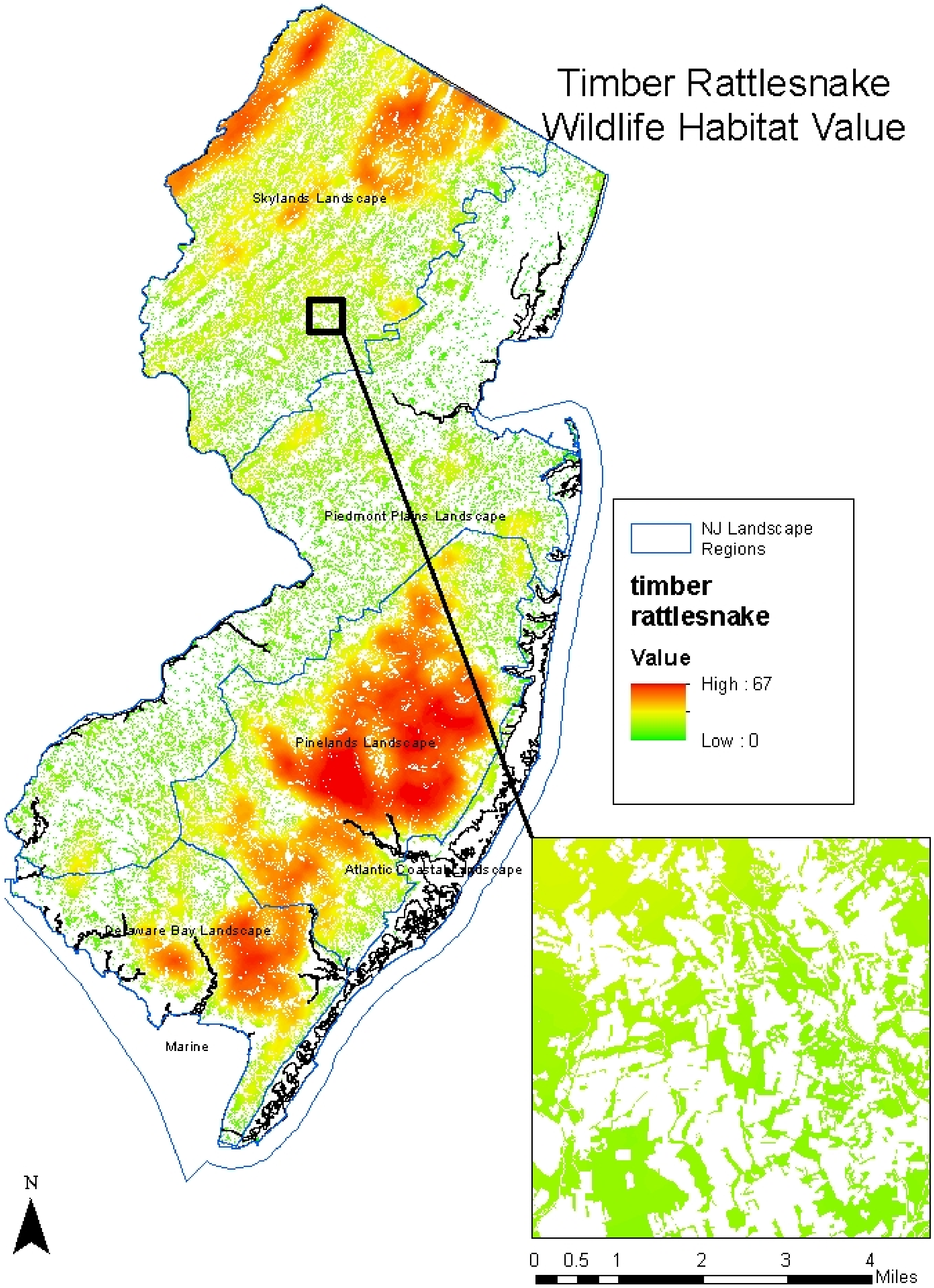

Long-eared Owl
Wildlife Habitat Value
Skylands Landscape
Piedmont Plains Landscape
Pinelands Landscape
Atlantic Coastal Landscape
Delaware Bay Landscape
Marine
NJ Landscape Regions
long-eared owl
Value
High : 100
Low : 0
0 0.5 1 2 3 4
Miles
N


Long-tailed Salamander
Wildlife Habitat Value
Skylands Landscape
Piedmont Plains Landscape
Pinelands Landscape
Atlantic Coastal Landscape
Delaware Bay Landscape
Marine
NJ Landscape Regions
Longtailed Salamander
Value
High : 100
Low : 0
N
0 0.5 1 2 3 4
Miles

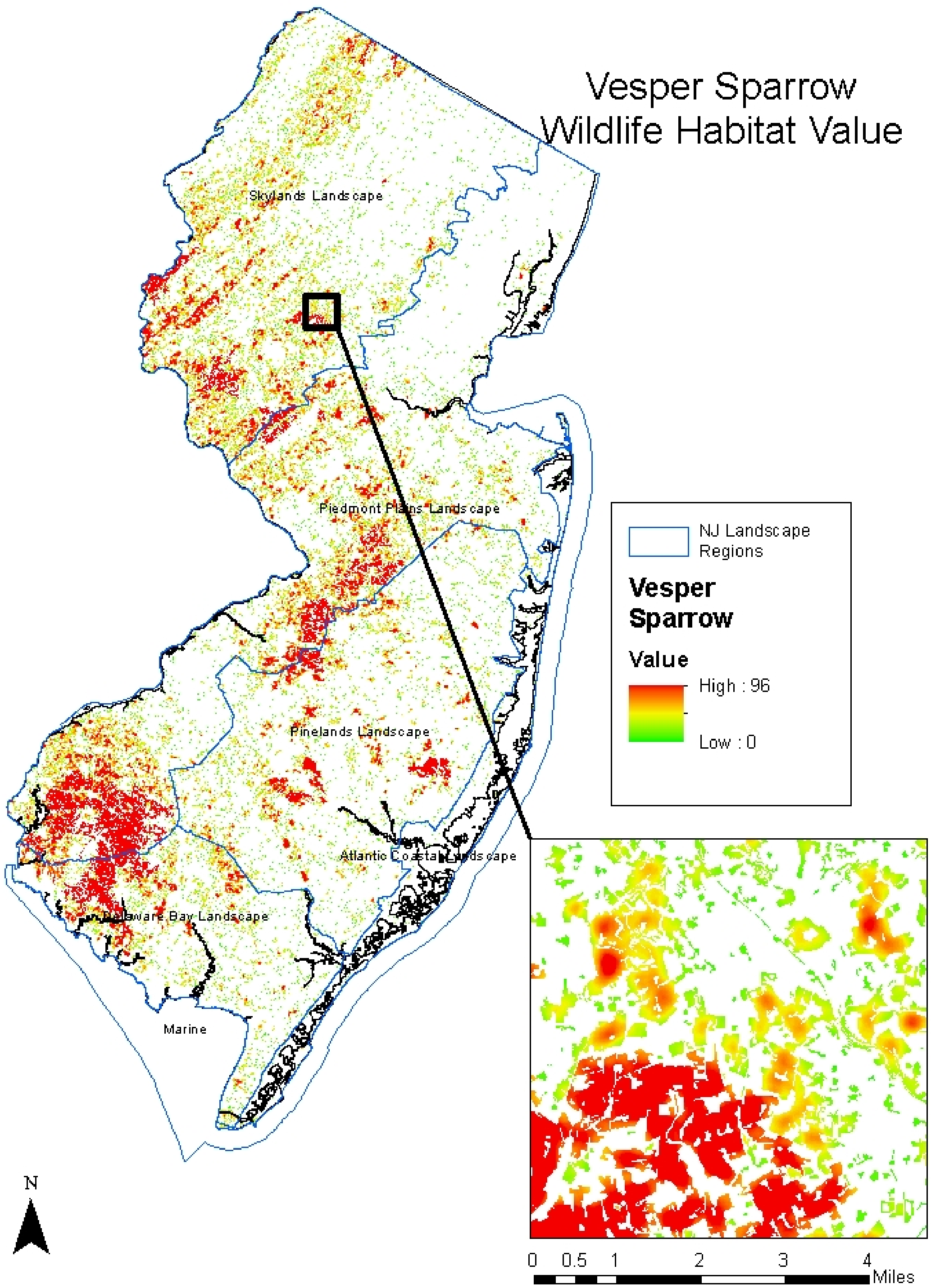

Northern Goshawk
Wildlife Habitat Value
Skylands Landscape
Piedmont Plains Landscape
Pinelands Landscape
Atlantic Coastal Landscape
Delaware Bay Landscape
Marine
NJ Landscape Regions
Northern Goshawk
Value
High : 71
Low : 0
N
0 0.5 1 2 3 4
Miles

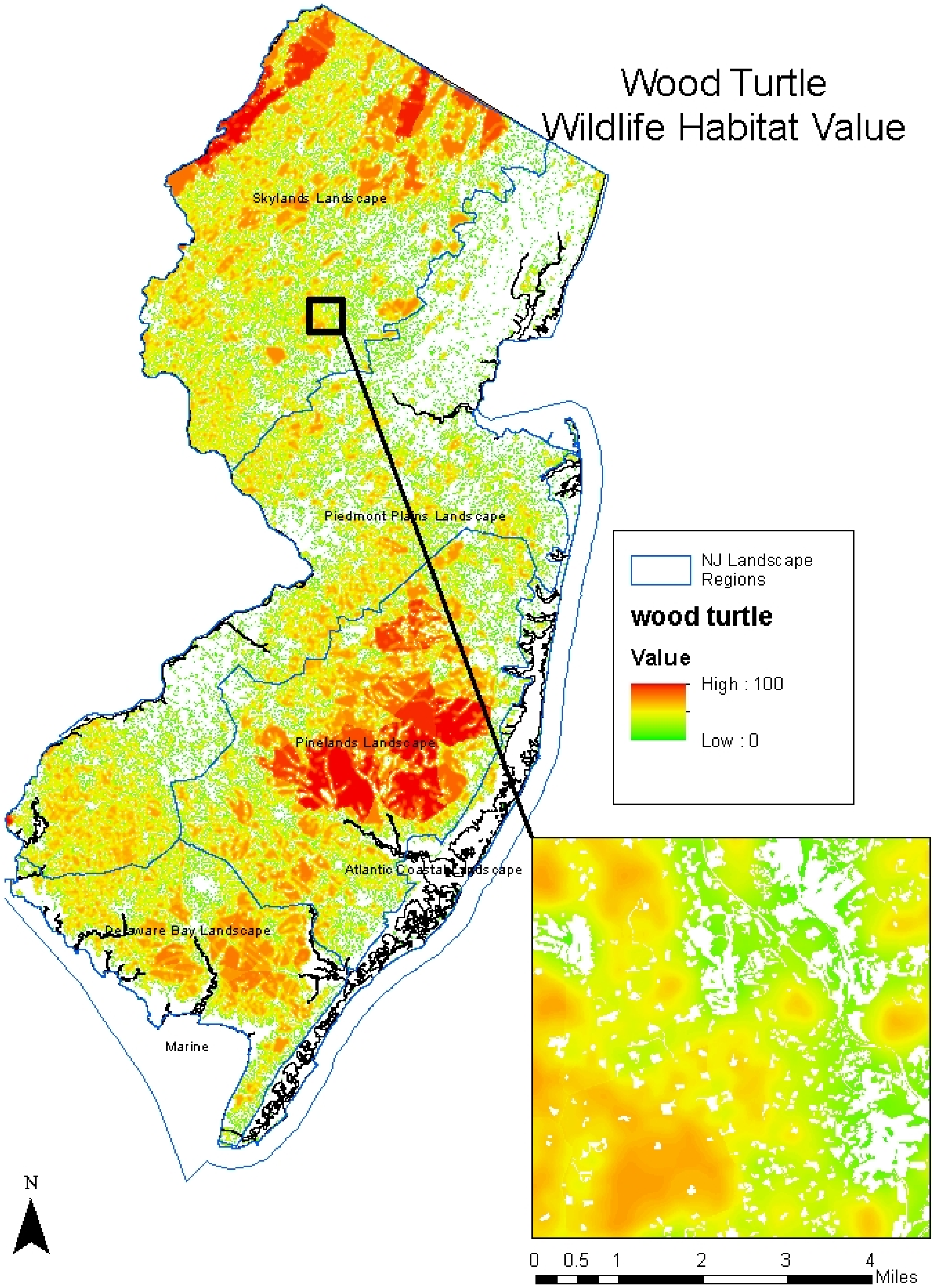

Red-shouldered Hawk
Wildlife Habitat Value
Skylands Landscape
Piedmont Plains Landscape
Pinelands Landscape
Atlantic Coastal Landscape
Delaware Bay Landscape
Marine
NJ Landscape Regions
Red-shou... Hawk
Value
High : 255
Low : 0
N
0 0.5 1 2 3 4
Miles


Redheaded Woodpecker
Wildlife Habitat Value
Skylands Landscape
Piedmont Plains Landscape
Pinelands Landscape
Atlantic Coastal Landscape
Delaware Bay Landscape
Marine
NJ Landscape Regions
Red-headed Woodpec...
Value
High : 100
Low : 0
N
0 0.5 1 2 3 4 Miles

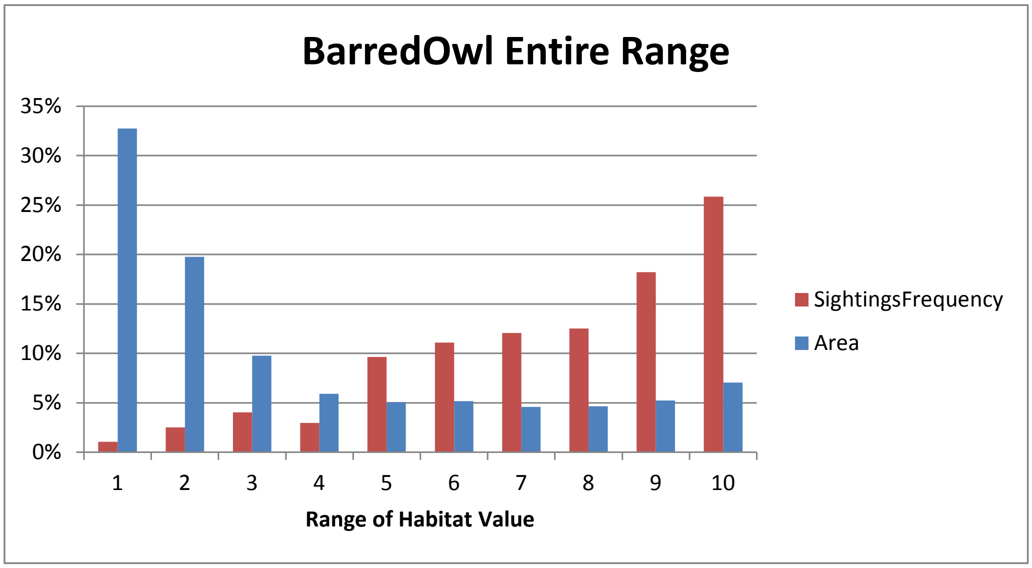


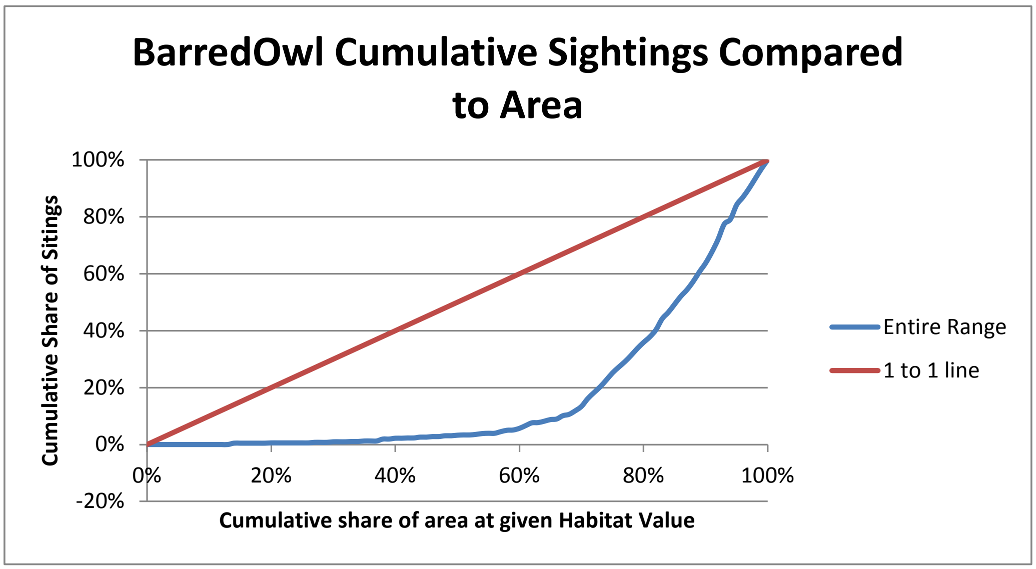
Timber Rattlesnake
Wildlife Habitat Value
Skylands Landscape
Piedmont Plains Landscape
Pinelands Landscape
Atlantic Coastal Landscape
Delaware Bay Landscape
Marine
NJ Landscape Regions
timber rattlesnake
Value
High : 67
Low : 0
N
0 0.5 1 2 3 4
Miles

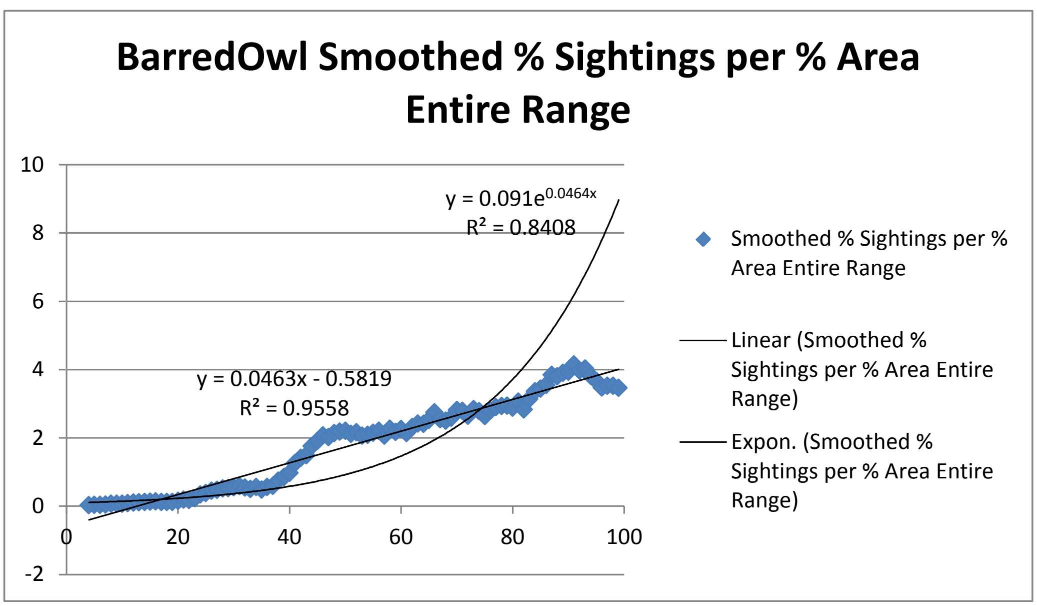

Vesper Sparrow
Wildlife Habitat Value
Skylands Landscape
Piedmont Plains Landscape
Pinelands Landscape
Atlantic Coastal Landscape
Delaware Bay Landscape
Marine
NJ Landscape Regions
Vesper Sparrow
Value
High : 96
Low : 0
N
0 0.5 1 2 3 4
Miles

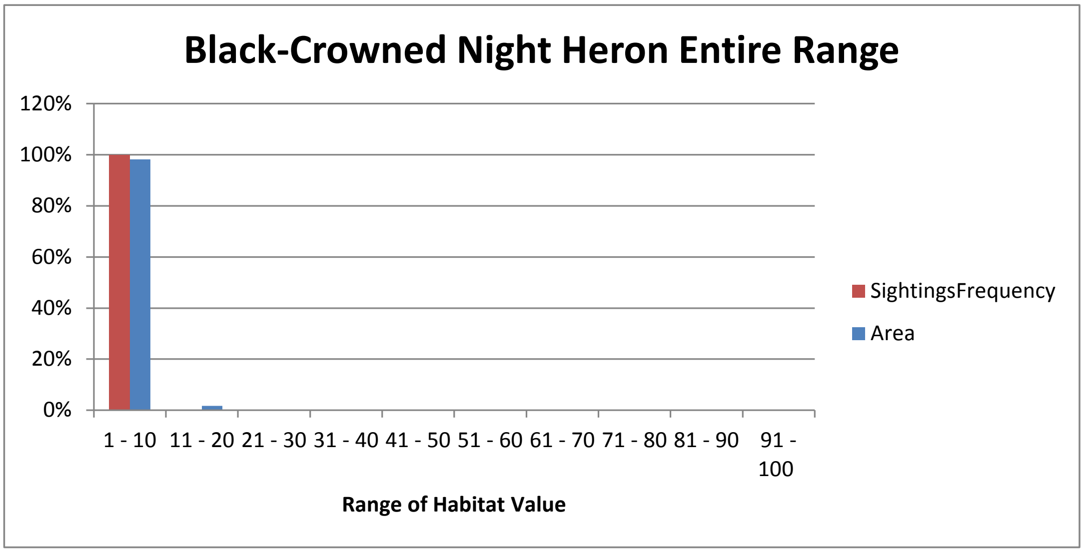

Wood Turtle
Wildlife Habitat Value
Skylands Landscape
Piedmont Plains Landscape
Pinelands Landscape
Atlantic Coastal Landscape
Delaware Bay Landscape
Marine
NJ Landscape Regions
wood turtle
Value
High : 100
Low : 0
N
0 0.5 1 2 3 4
Miles

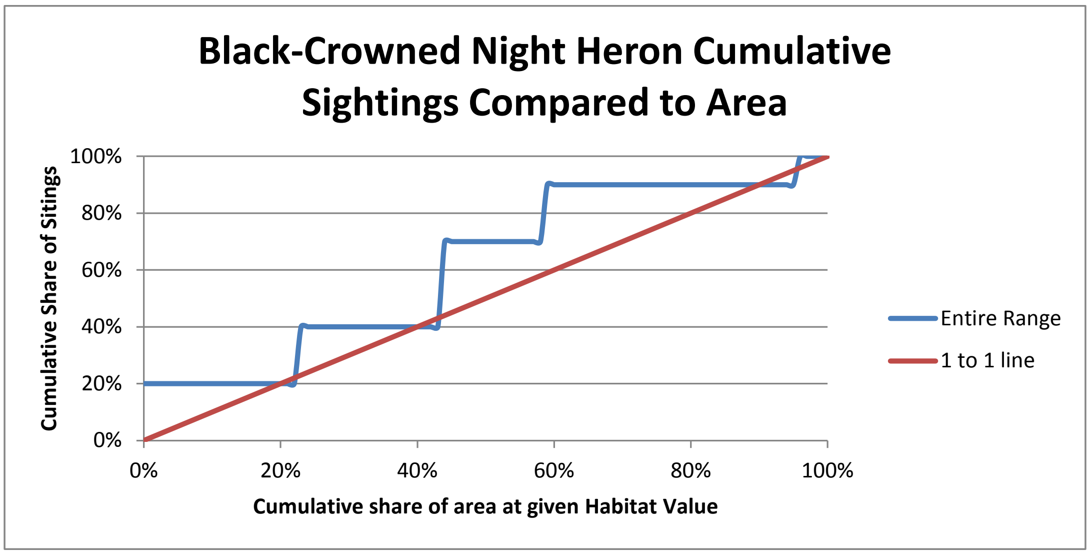
Appendix B - Assessment of Wildlife Habitat Value

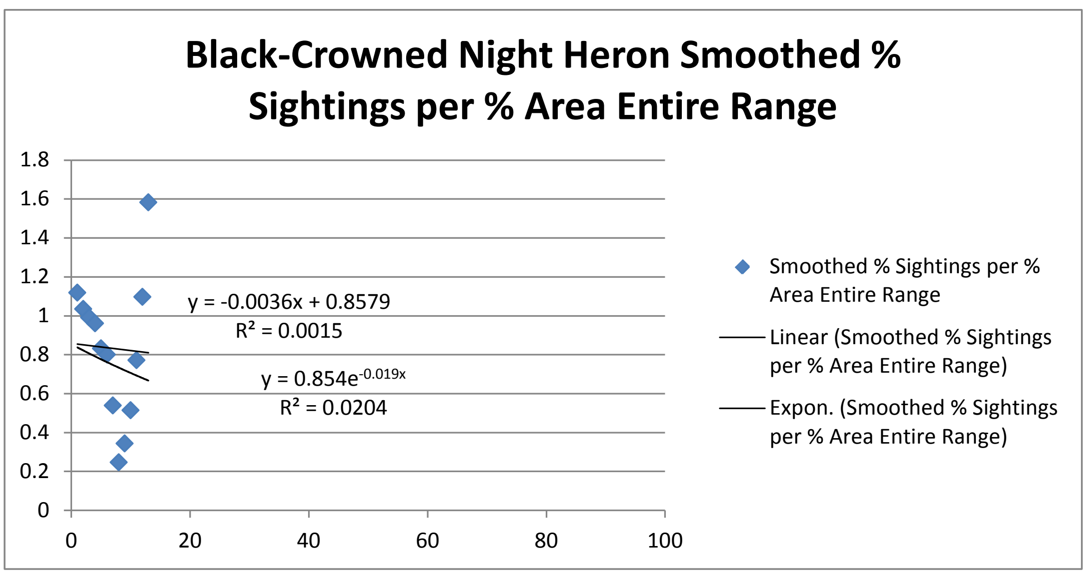


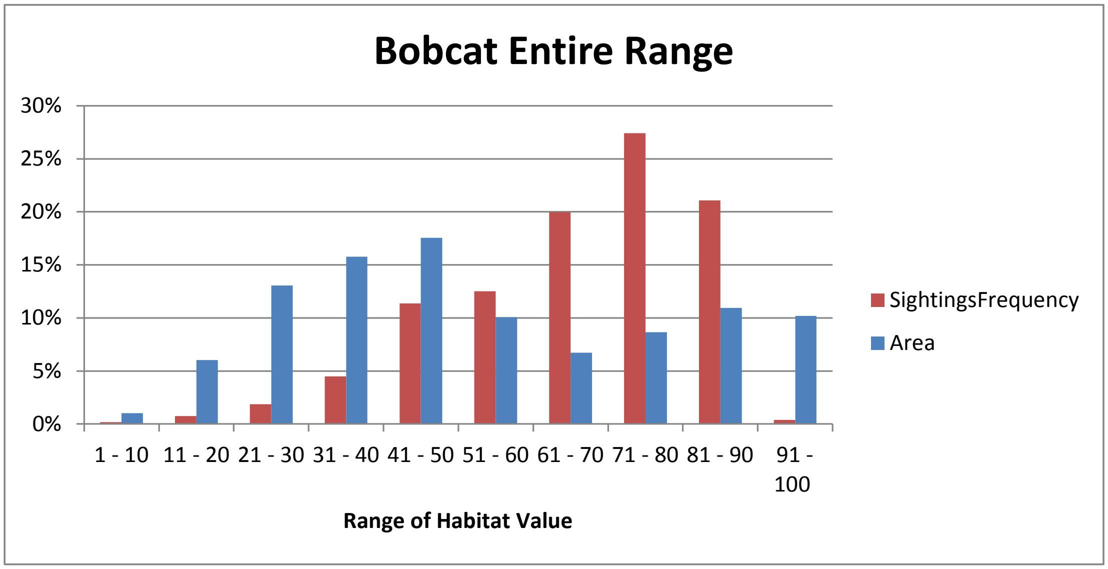



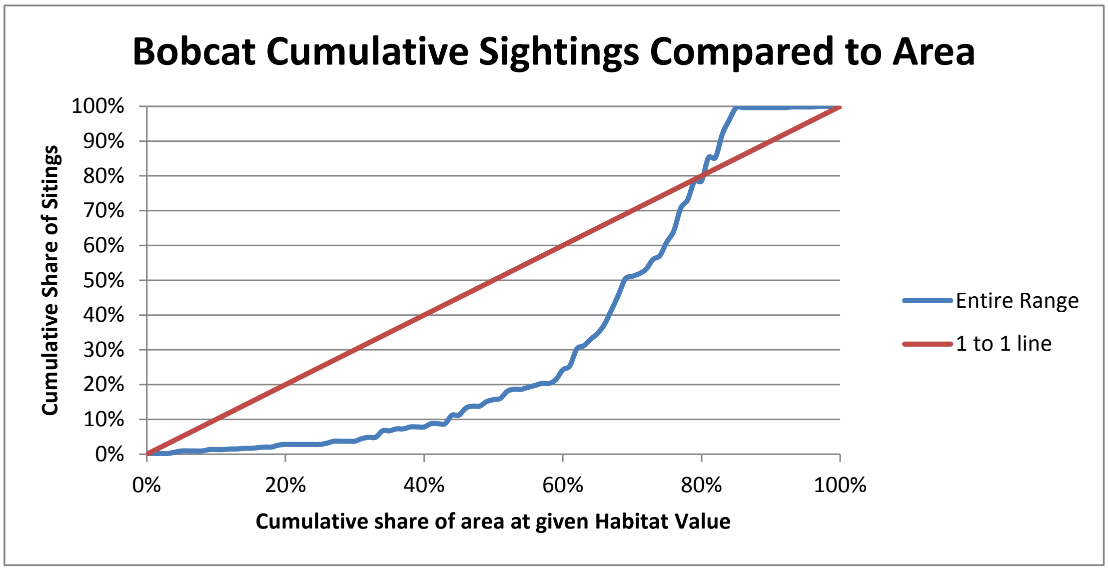



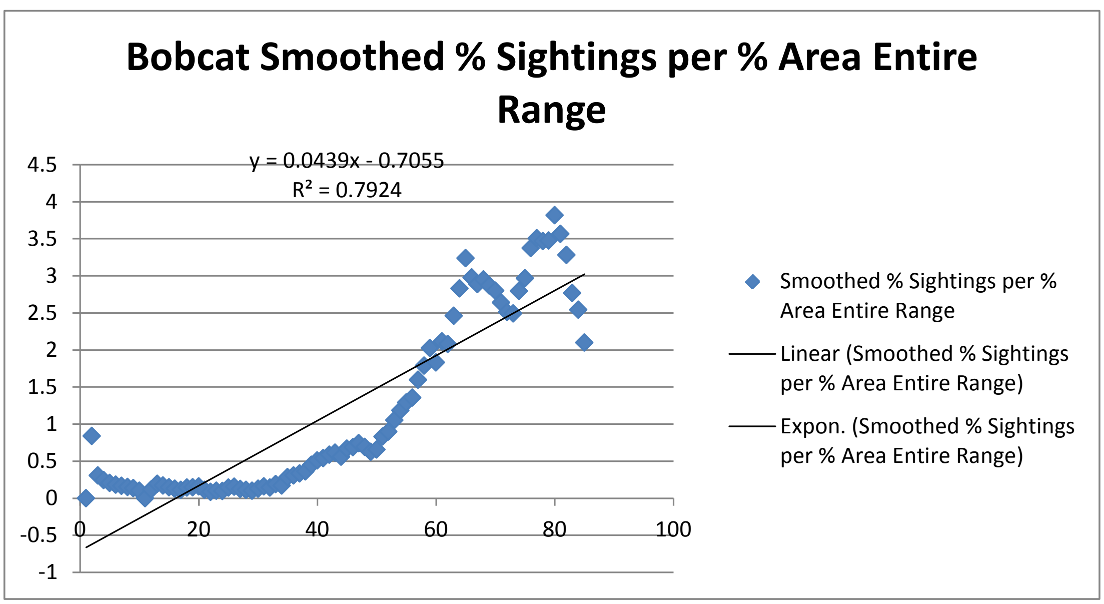

Black-Crowned Night Heron Entire Range
120%
100%
80%
60%
40%
20%
0%
1 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
Range of Habitat Value
SightingsFrequency
Area

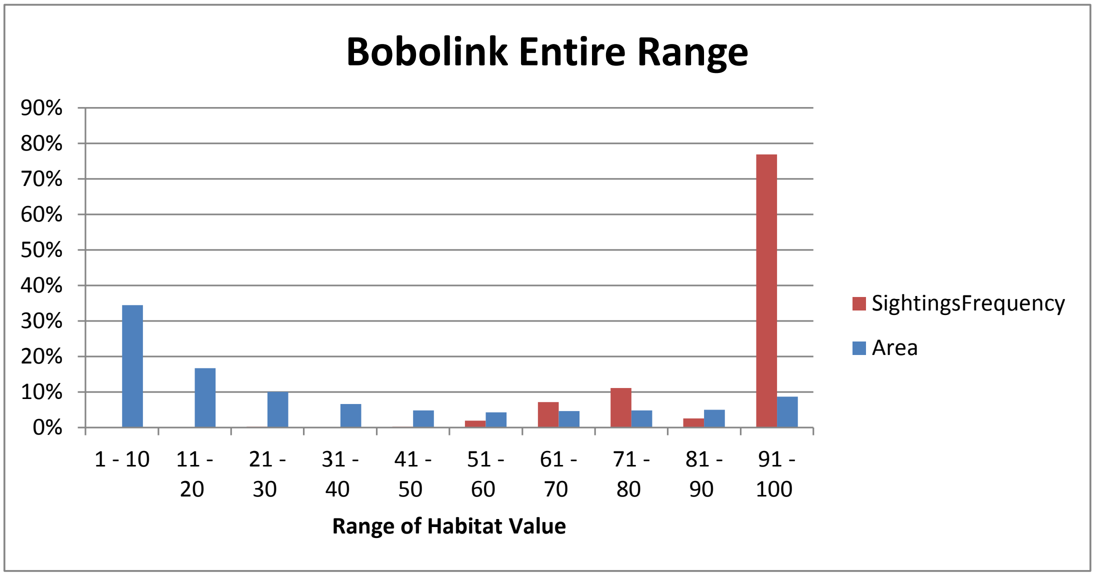

Black-Crowned Night Heron Cumulative Sightings Compared to Area
Cumulative Share of Sitings
100%
80%
60%
40%
20%
0%
0%
20%
40%
60%
80%
100%
Cumulative share of area at given Habitat Value
Entire Range
1 to 1 line

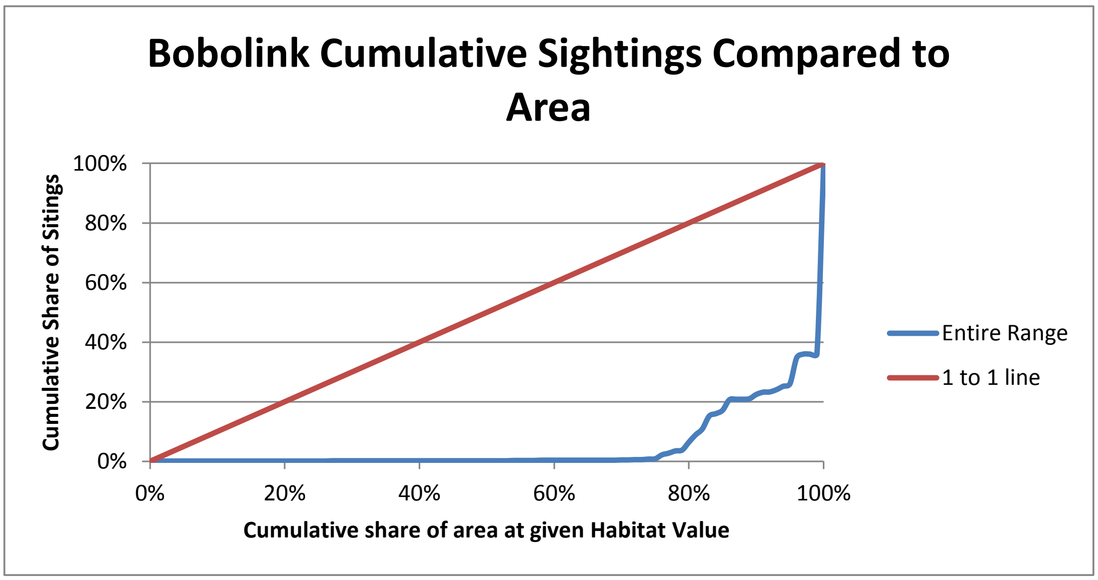

Black-Crowned Night Heron Smoothed % Sightings per % Area Entire Range
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
y = -0.0036x + 0.8579
R² = 0.0015
y = 0.854e^-0.019x
R² = 0.0204
Smoothed % Sightings per % Area Entire Range
Linear (Smoothed % Sightings per % Area Entire Range)
Expon. (Smoothed % Sightings per % Area Entire Range)

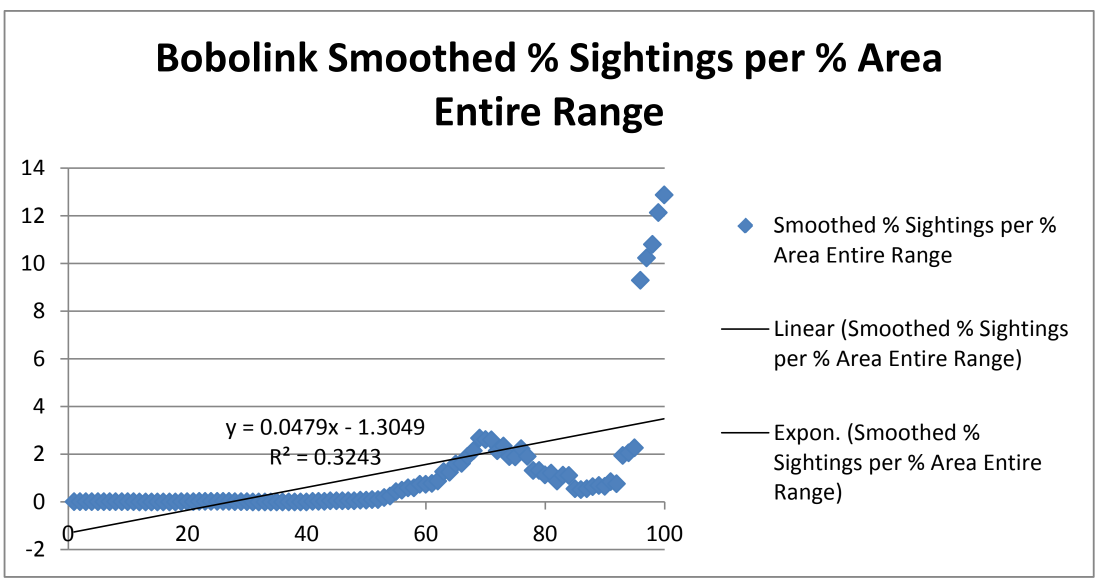

Bobcat Entire Range
30%
25%
20%
15%
10%
5%
0%
1 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
Range of Habitat Value
SightingsFrequency
Area

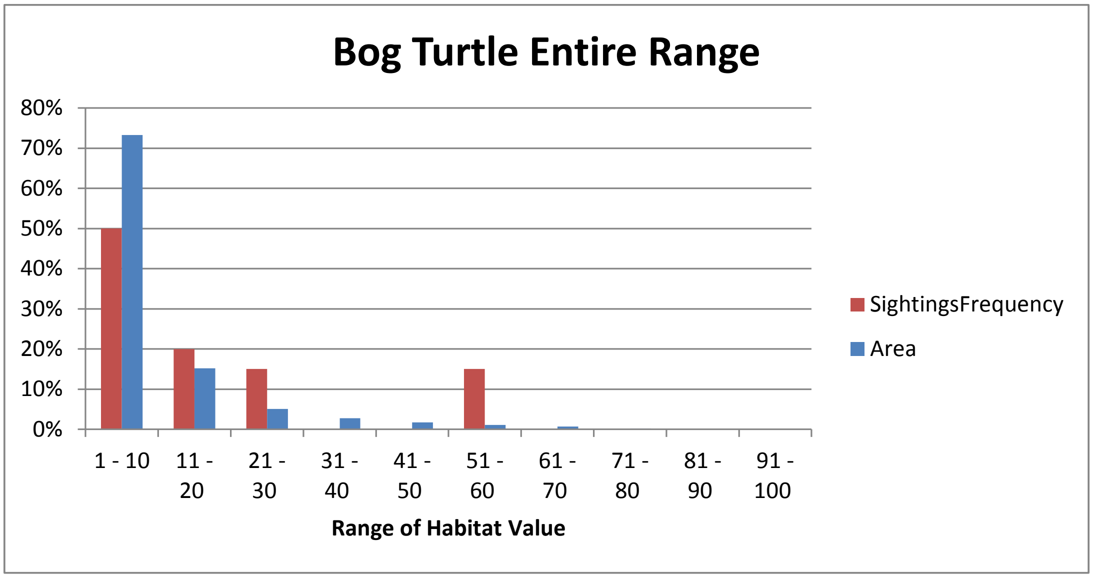

Bobcat Cumulative Sightings Compared to Area
Cumulative Share of Sitings
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0%
20%
40%
60%
80%
100%
Cumulative share of area at given Habitat Value
Entire Range
1 to 1 line

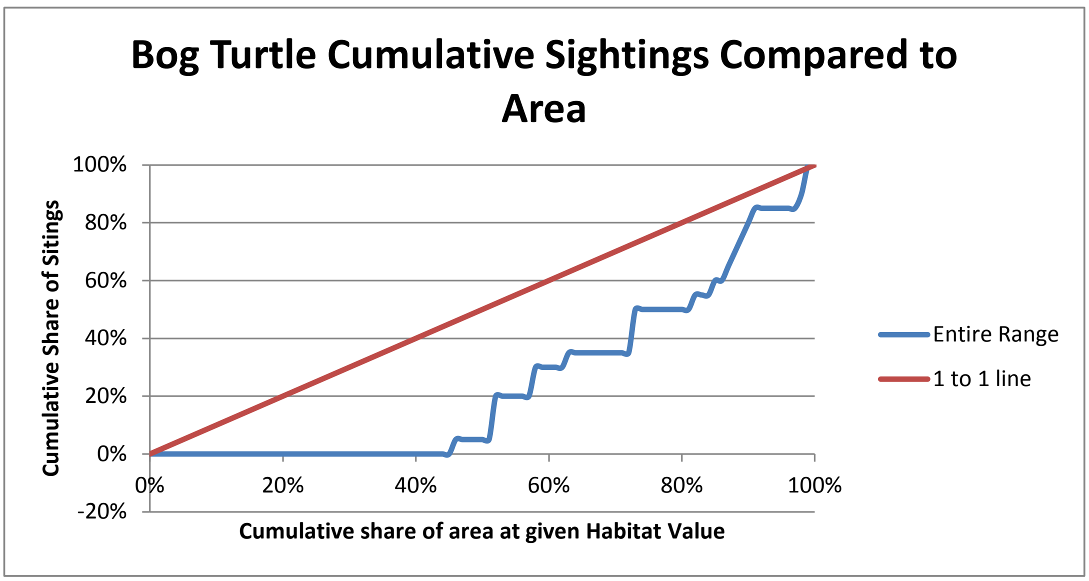

Bobcat Smoothed % Sightings per % Area Entire Range
y = 0.0439x - 0.7055
R² = 0.7924
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
20
40
60
80
100
Smoothed % Sightings per % Area Entire Range
Linear (Smoothed % Sightings per % Area Entire Range)
Expon. (Smoothed % Sightings per % Area Entire Range)

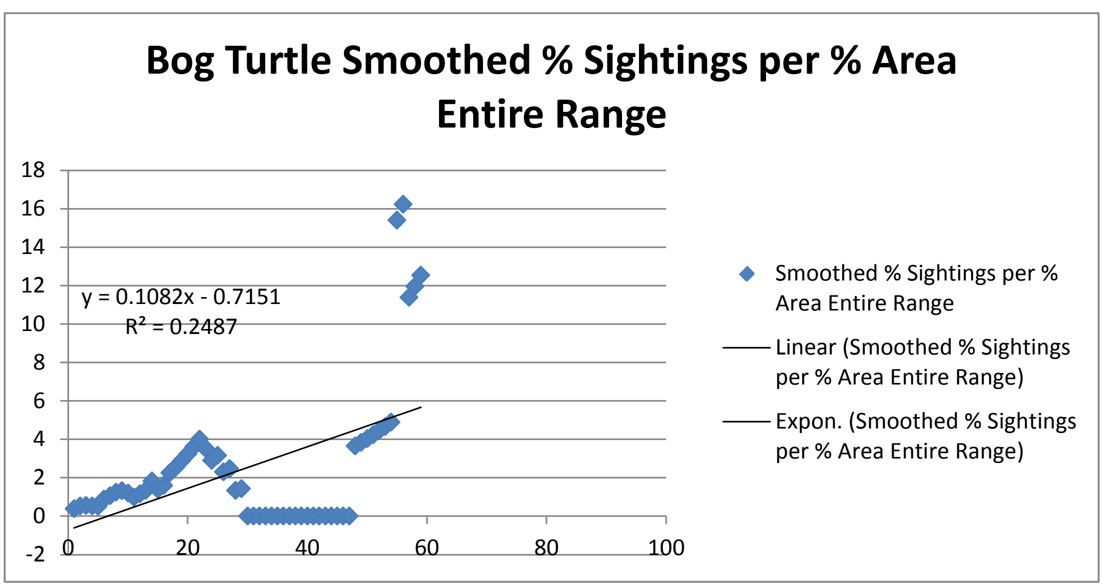

Bobolink Entire Range
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
Range of Habitat Value
SightingsFrequency
Area

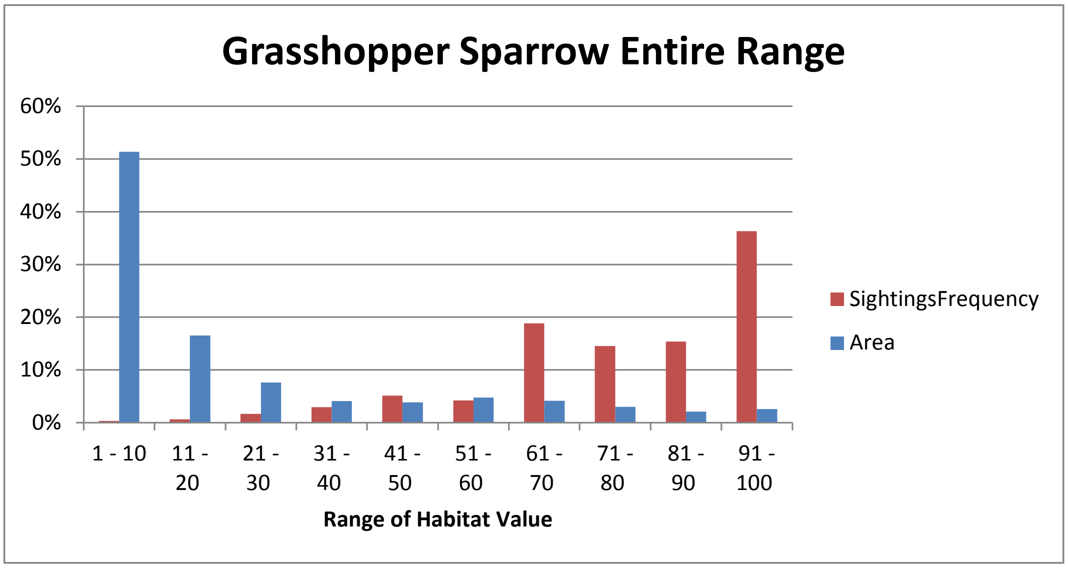

Bobolink Cumulative Sightings Compared to Area
Cumulative Share of Sitings
100%
80%
60%
40%
20%
0%
0%
20%
40%
60%
80%
100%
Cumulative share of area at given Habitat Value
Entire Range
1 to 1 line

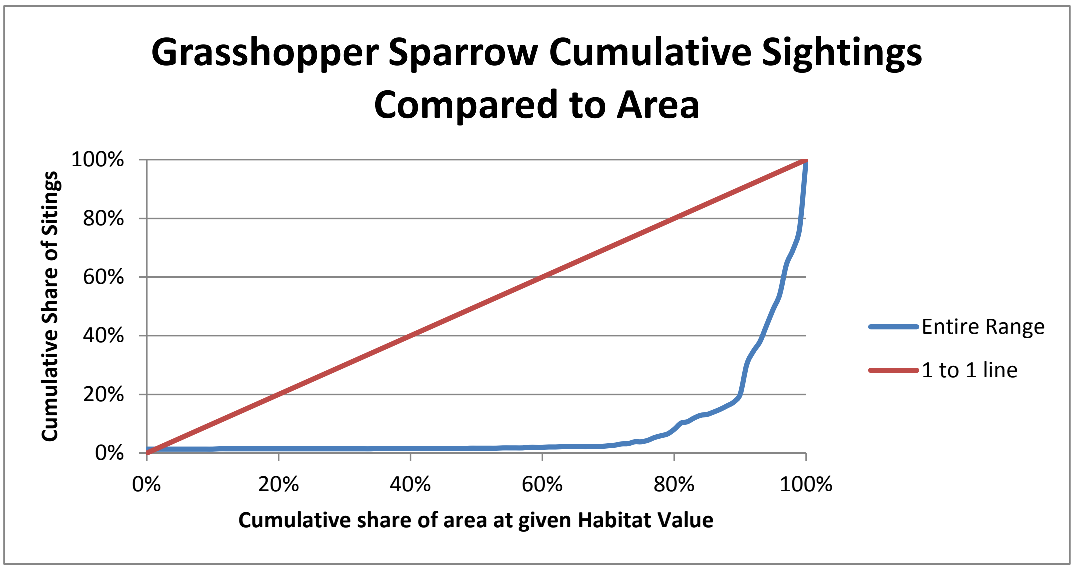

Bobolink Smoothed % Sightings per % Area Entire Range
14
12
10
8
6
4
2
0
-2
0
20
40
60
80
100
y = 0.0479x - 1.3049
R² = 0.3243
Smoothed % Sightings per % Area Entire Range
Linear (Smoothed % Sightings per % Area Entire Range)
Expon. (Smoothed % Sightings per % Area Entire Range)

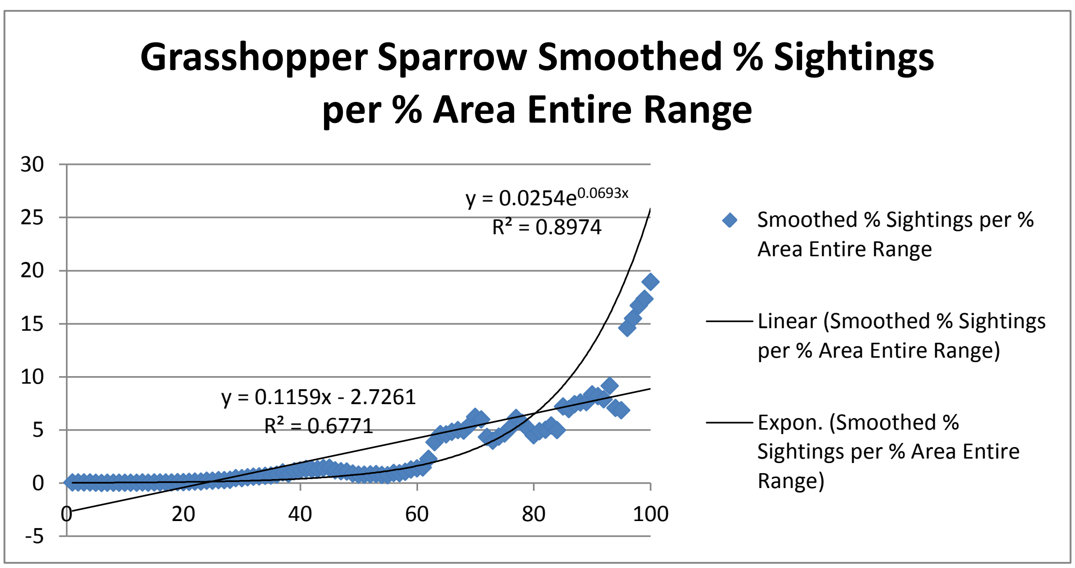

Bog Turtle Entire Range
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
Range of Habitat Value
SightingsFrequency
Area

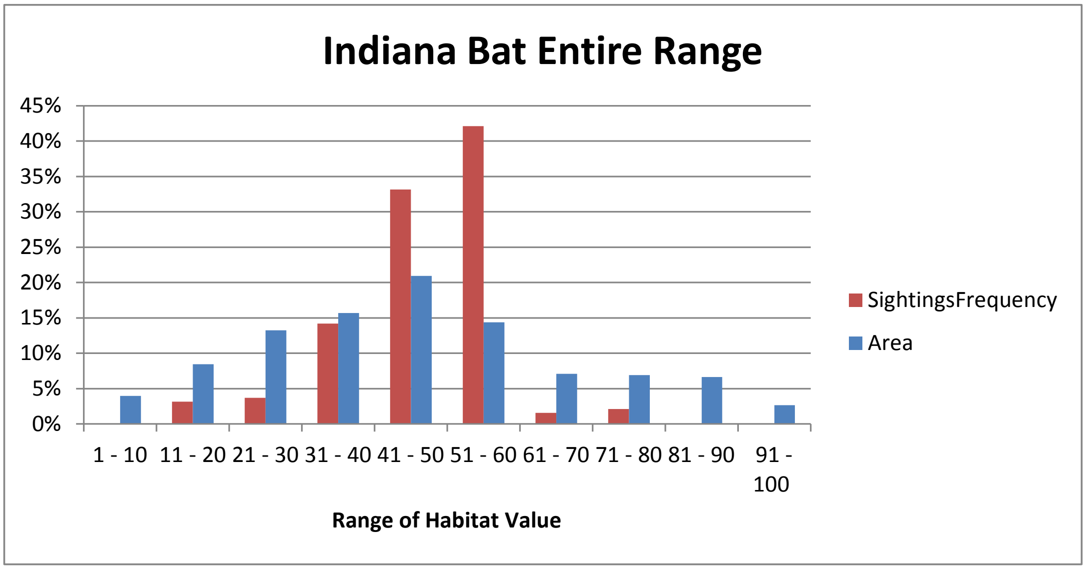

Bog Turtle Cumulative Sightings Compared to Area
100%
80%
60%
40%
20%
0%
-20%
Cumulative Share of Sitings
0%
20%
40%
60%
80%
100%
Cumulative share of area at given Habitat Value
Entire Range
1 to 1 line

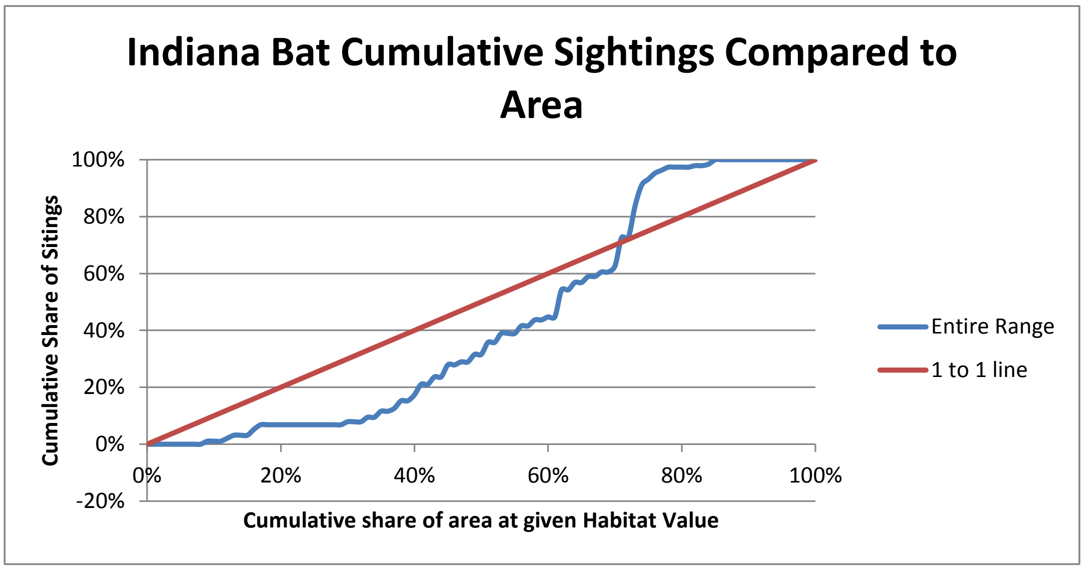

Bog Turtle Smoothed % Sightings per % Area Entire Range
18
16
14
12
10
8
6
4
2
0
-2
0
20
40
60
80
100
y = 0.1082x - 0.7151
R² = 0.2487
Smoothed % Sightings per % Area Entire Range
Linear (Smoothed % Sightings per % Area Entire Range)
Expon. (Smoothed % Sightings per % Area Entire Range)

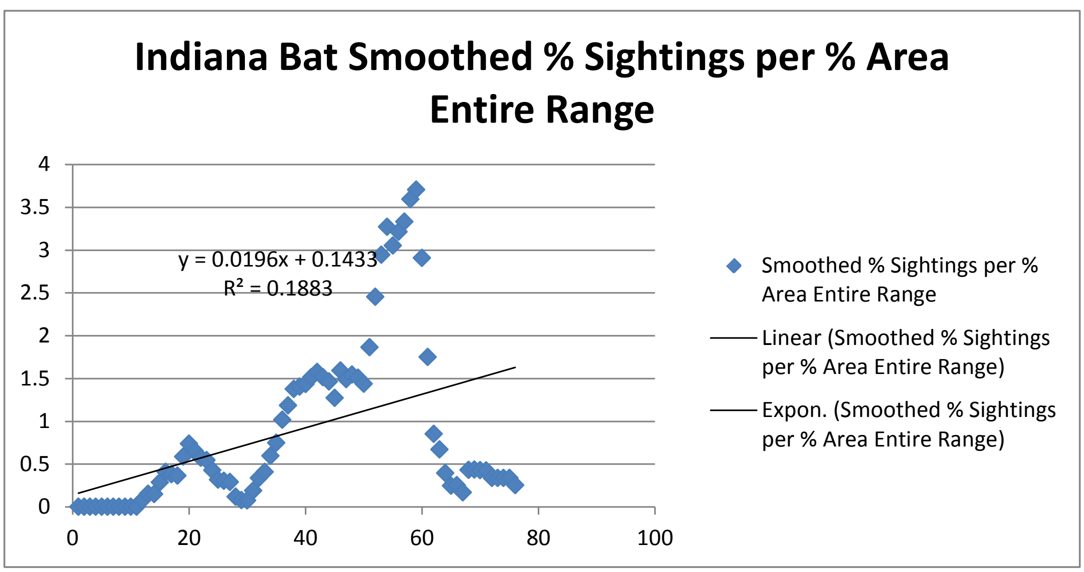

Grasshopper Sparrow Entire Range
60%
50%
40%
30%
20%
10%
0%
1 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
Range of Habitat Value
SightingsFrequency
Area

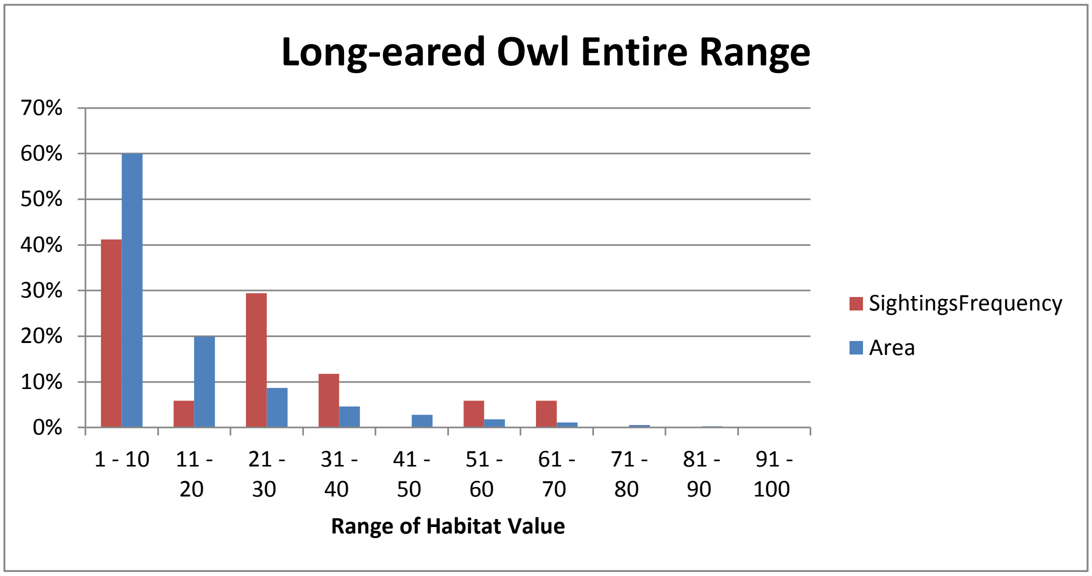

Grasshopper Sparrow Cumulative Sightings Compared to Area
Cumulative Share of Sitings
100%
80%
60%
40%
20%
0%
0%
20%
40%
60%
80%
100%
Cumulative share of area at given Habitat Value
Entire Range
1 to 1 line

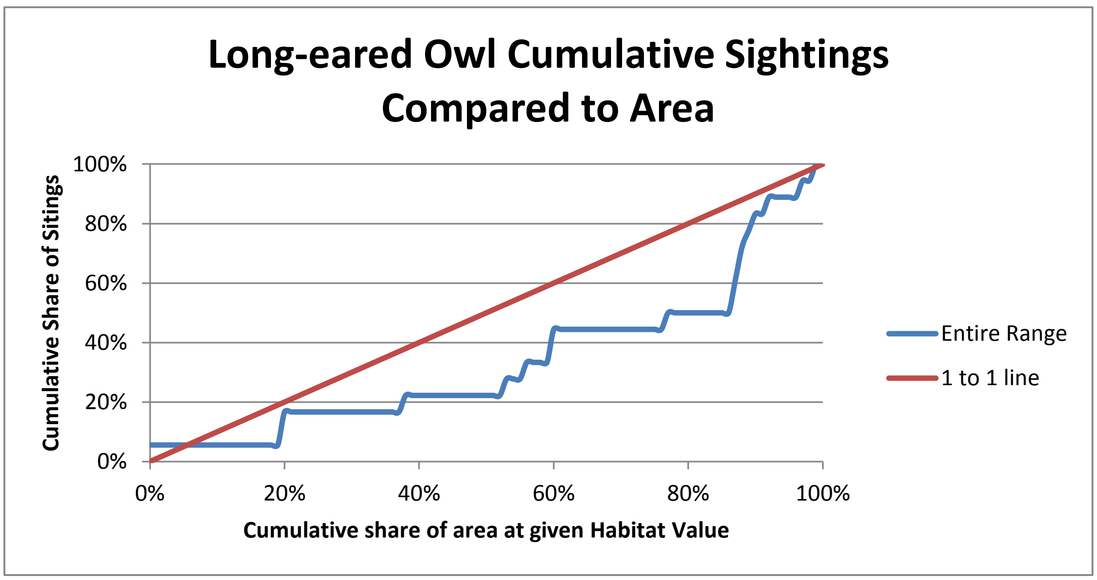

Grasshopper Sparrow Smoothed % Sightings per % Area Entire Range
30
25
20
15
10
5
0
-5
0
20
40
60
80
100
$y = 0.0254e^{0.0693x}$
$R^2 = 0.8974$
$y = 0.1159x - 2.7261$
$R^2 = 0.6771$
Smoothed % Sightings per % Area Entire Range
Linear (Smoothed % Sightings per % Area Entire Range)
Expon. (Smoothed % Sightings per % Area Entire Range)

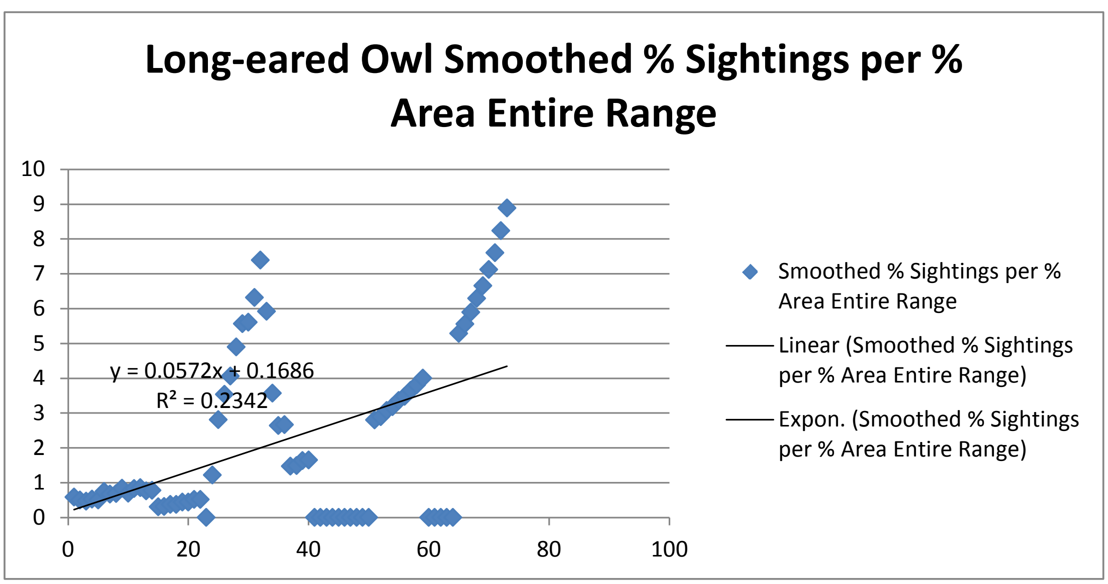

Indiana Bat Entire Range
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
1 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
Range of Habitat Value
SightingsFrequency
Area

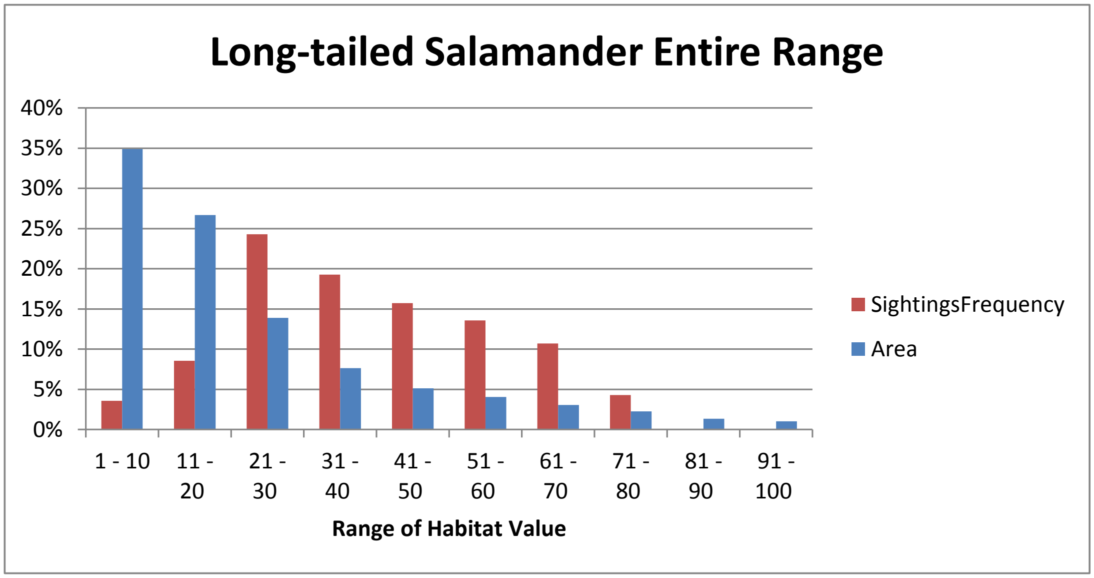

Indiana Bat Cumulative Sightings Compared to Area
Cumulative Share of Sitings
100%
80%
60%
40%
20%
0%
-20%
0%
20%
40%
60%
80%
100%
Cumulative share of area at given Habitat Value
Entire Range
1 to 1 line

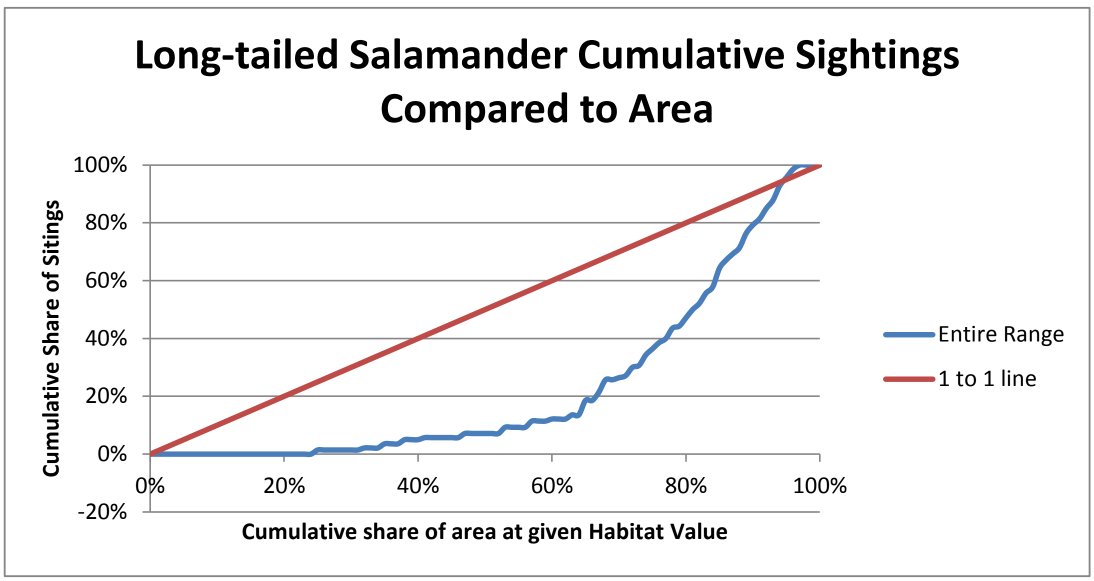

Indiana Bat Smoothed % Sightings per % Area Entire Range
4
3.5
3
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
y = 0.0196x + 0.1433
R² = 0.1883
Smoothed % Sightings per % Area Entire Range
Linear (Smoothed % Sightings per % Area Entire Range)
Expon. (Smoothed % Sightings per % Area Entire Range)

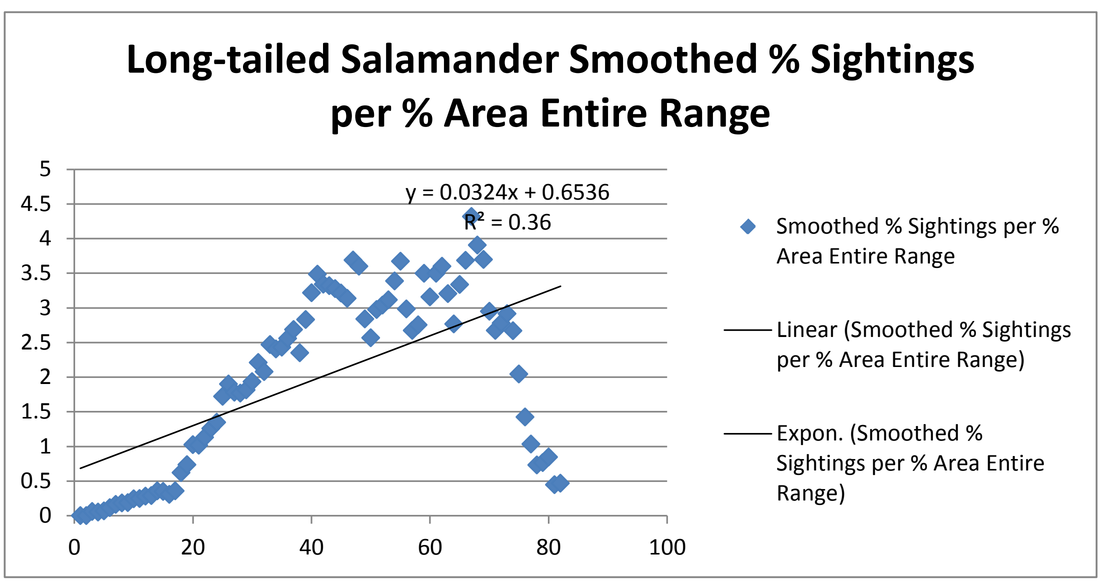

Long-eared Owl Entire Range
70%
60%
50%
40%
30%
20%
10%
0%
1 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
Range of Habitat Value
SightingsFrequency
Area

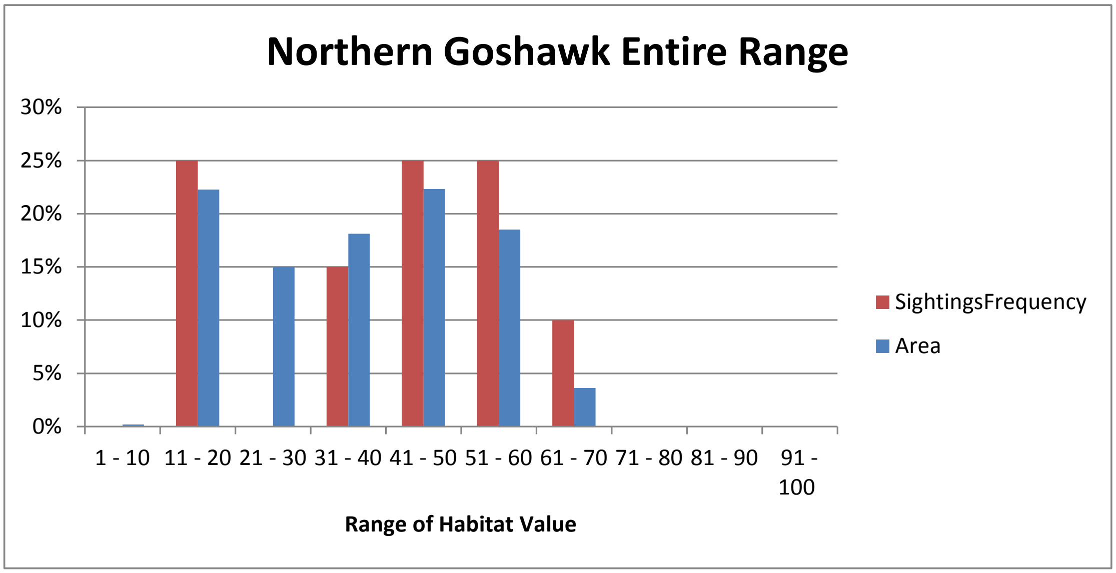

Long-eared Owl Cumulative Sightings Compared to Area
Cumulative Share of Sitings
100%
80%
60%
40%
20%
0%
0%
20%
40%
60%
80%
100%
Cumulative share of area at given Habitat Value
Entire Range
1 to 1 line

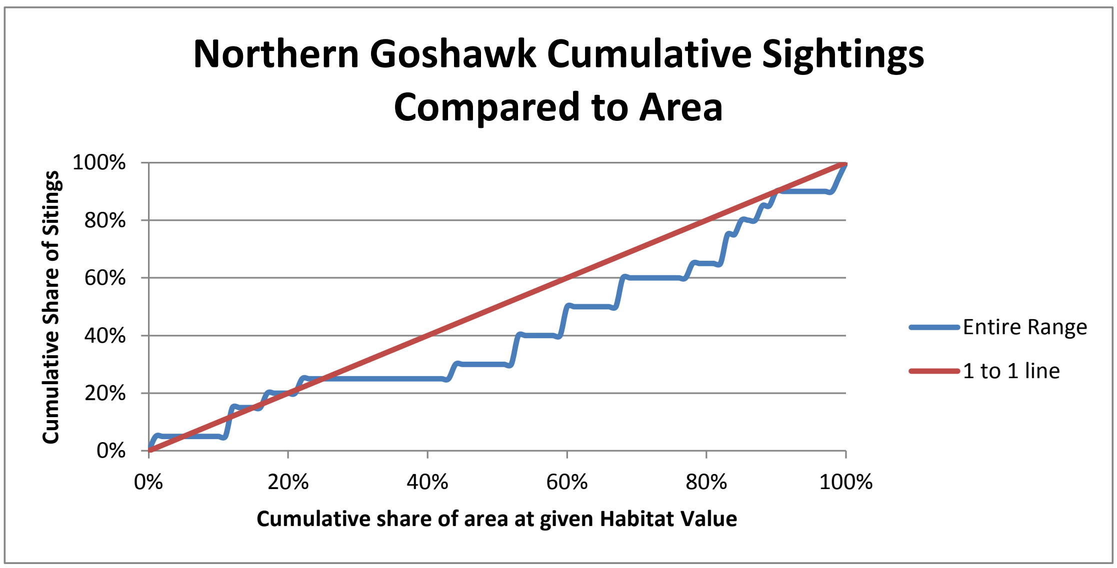

Long-eared Owl Smoothed % Sightings per % Area Entire Range
10
9
8
7
6
5
4
3
2
1
0
0
20
40
60
80
100
y = 0.0572x + 0.1686
R² = 0.2342
Smoothed % Sightings per % Area Entire Range
Linear (Smoothed % Sightings per % Area Entire Range)
Expon. (Smoothed % Sightings per % Area Entire Range)

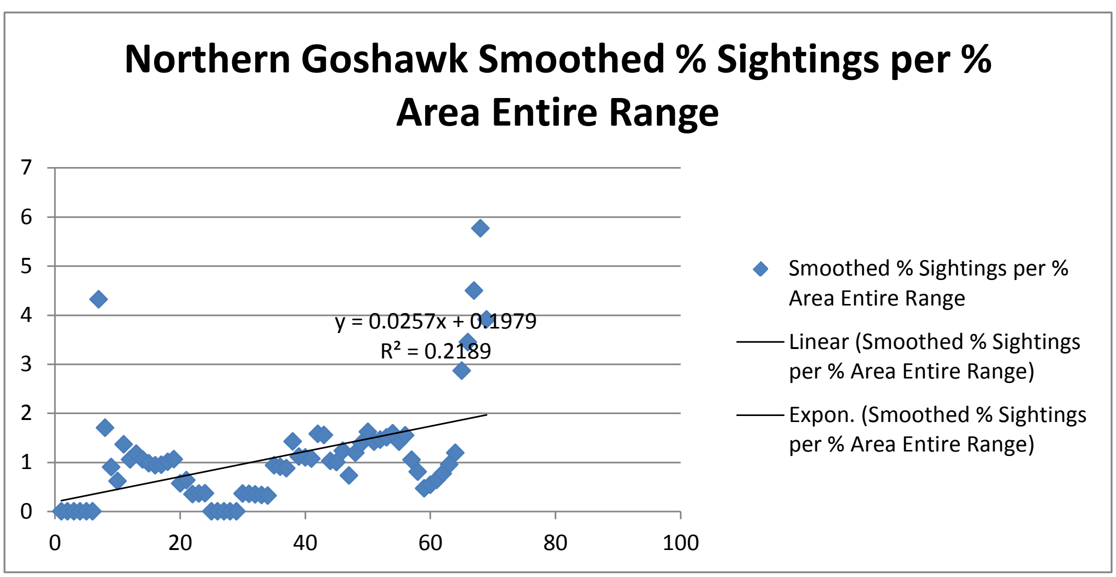

Long-tailed Salamander Entire Range
40%
35%
30%
25%
20%
15%
10%
5%
0%
1 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
Range of Habitat Value
SightingsFrequency
Area

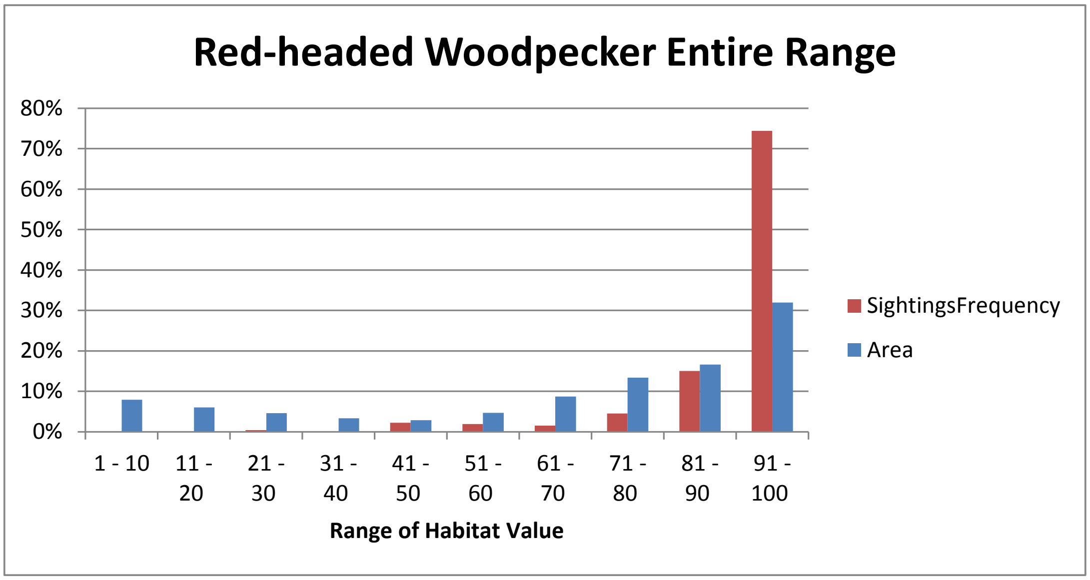

Long-tailed Salamander Cumulative Sightings Compared to Area
Cumulative Share of Sitings
100%
80%
60%
40%
20%
0%
-20%
0%
20%
40%
60%
80%
100%
Cumulative share of area at given Habitat Value
Entire Range
1 to 1 line

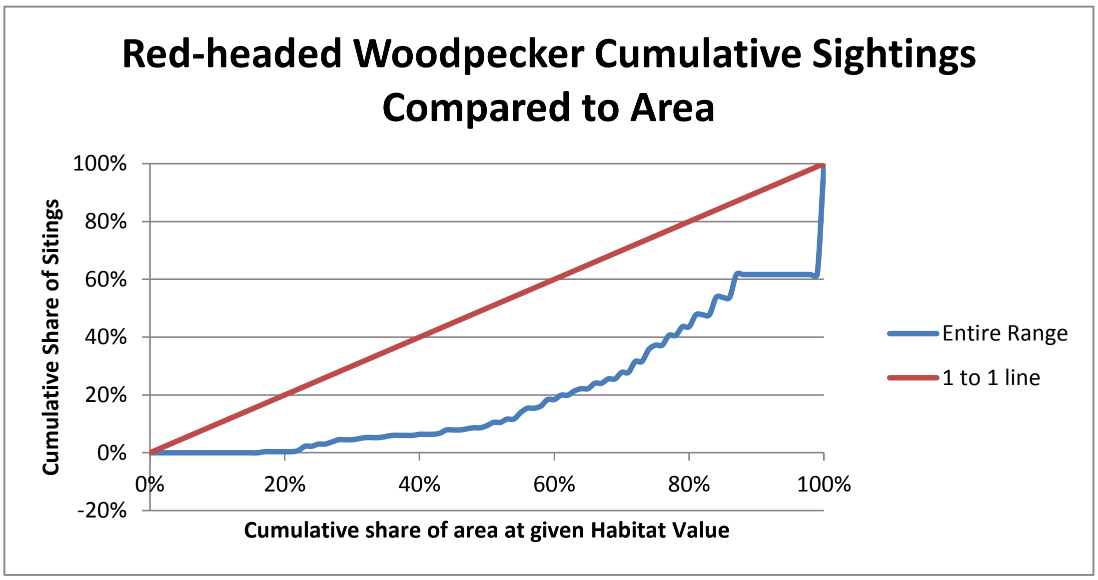

Long-tailed Salamander Smoothed % Sightings per % Area Entire Range
y = 0.0324x + 0.6536
R² = 0.36
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
Smoothed % Sightings per % Area Entire Range
Linear (Smoothed % Sightings per % Area Entire Range)
Expon. (Smoothed % Sightings per % Area Entire Range)

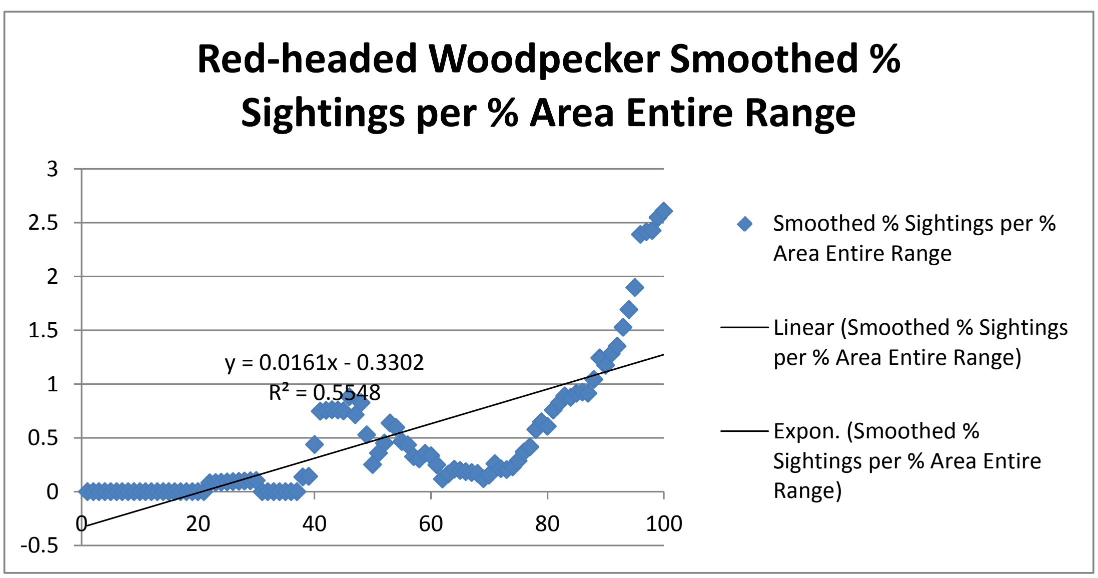

Northern Goshawk Entire Range
30%
25%
20%
15%
10%
5%
0%
1 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
Range of Habitat Value
SightingsFrequency
Area

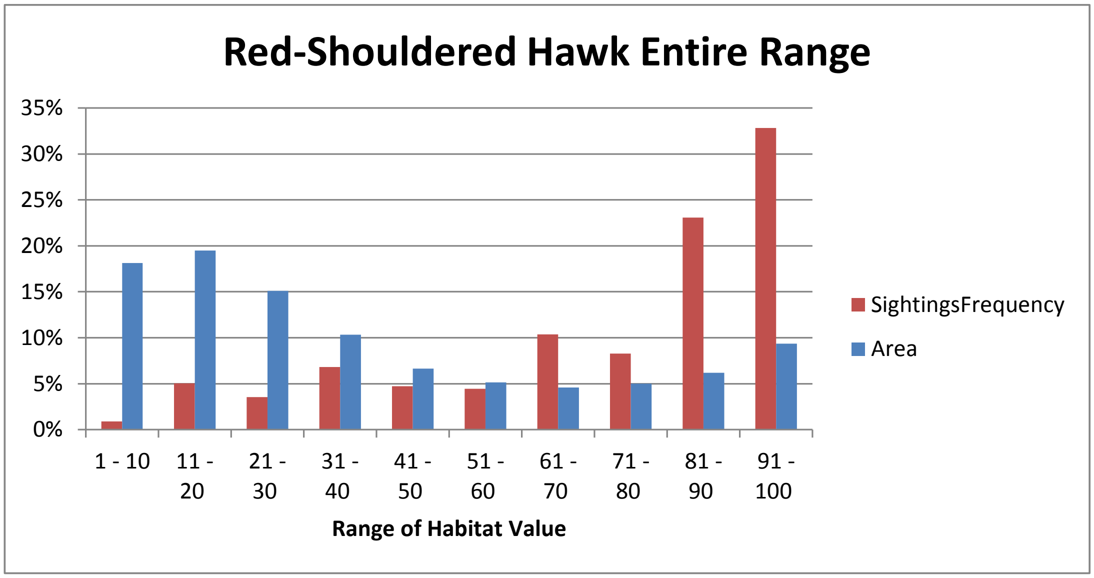

Northern Goshawk Cumulative Sightings Compared to Area
Cumulative Share of Sitings
100%
80%
60%
40%
20%
0%
0%
20%
40%
60%
80%
100%
Cumulative share of area at given Habitat Value
Entire Range
1 to 1 line

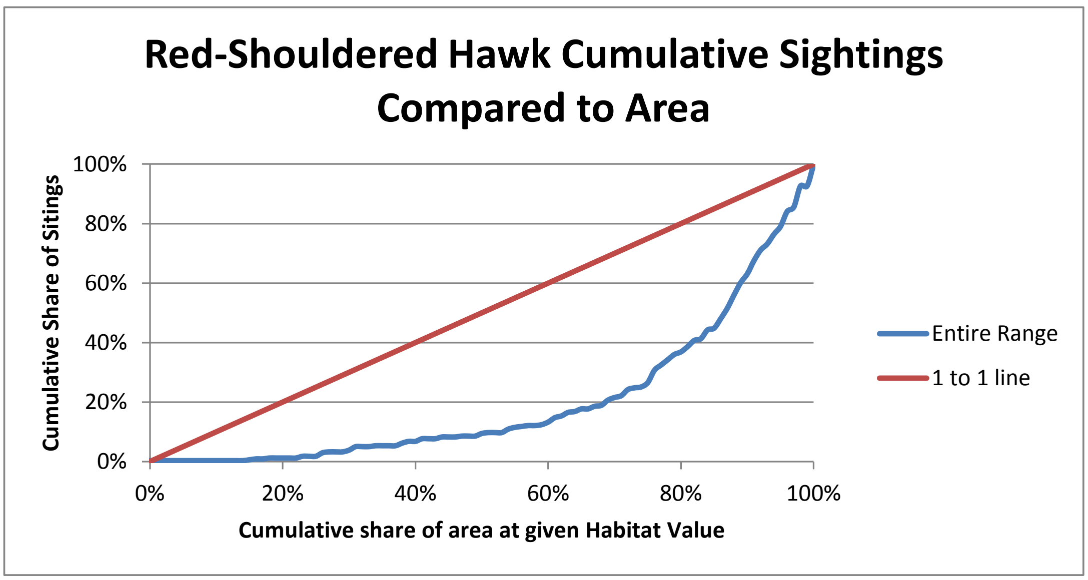

Northern Goshawk Smoothed % Sightings per % Area Entire Range
7
6
5
4
3
2
1
0
0
20
40
60
80
100
y = 0.0257x + 0.1979
R² = 0.2189
Smoothed % Sightings per % Area Entire Range
Linear (Smoothed % Sightings per % Area Entire Range)
Expon. (Smoothed % Sightings per % Area Entire Range)

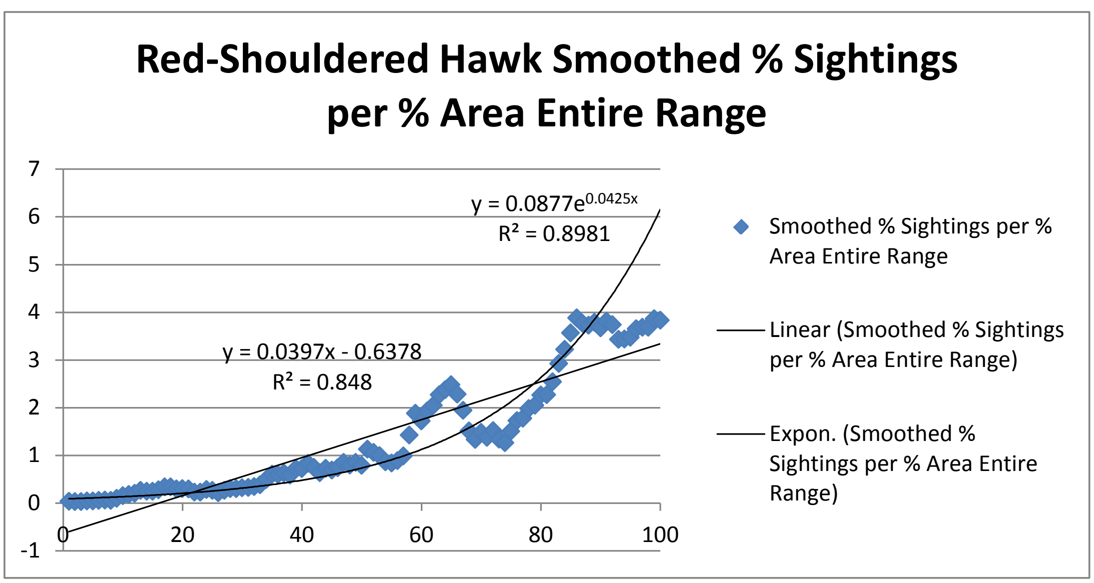

Red-headed Woodpecker Entire Range
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
Range of Habitat Value
SightingsFrequency
Area

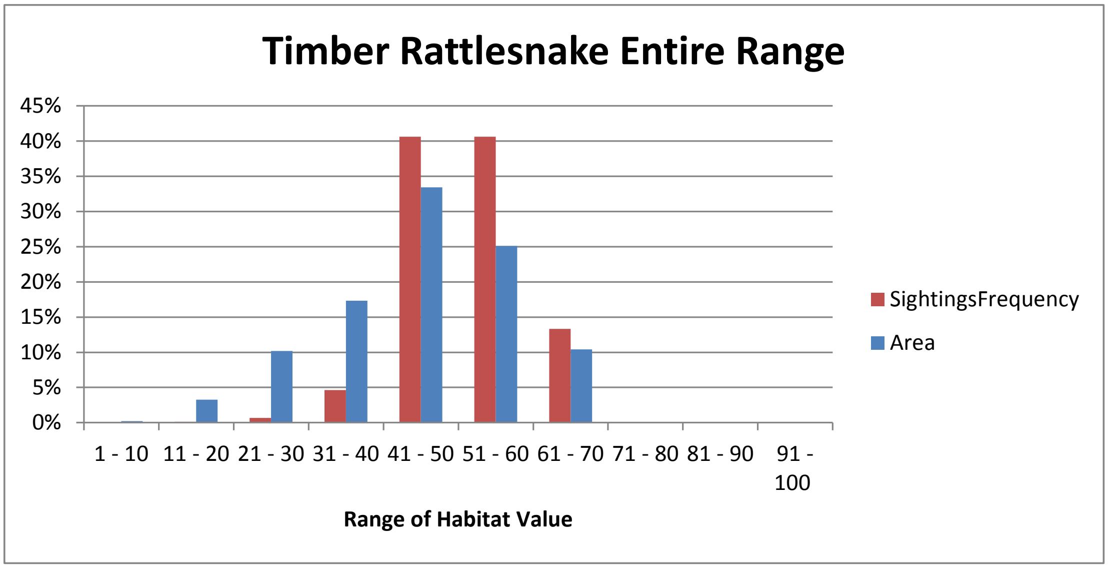

Red-headed Woodpecker Cumulative Sightings Compared to Area
Cumulative Share of Sitings
100%
80%
60%
40%
20%
0%
-20%
0%
20%
40%
60%
80%
100%
Cumulative share of area at given Habitat Value
Entire Range
1 to 1 line

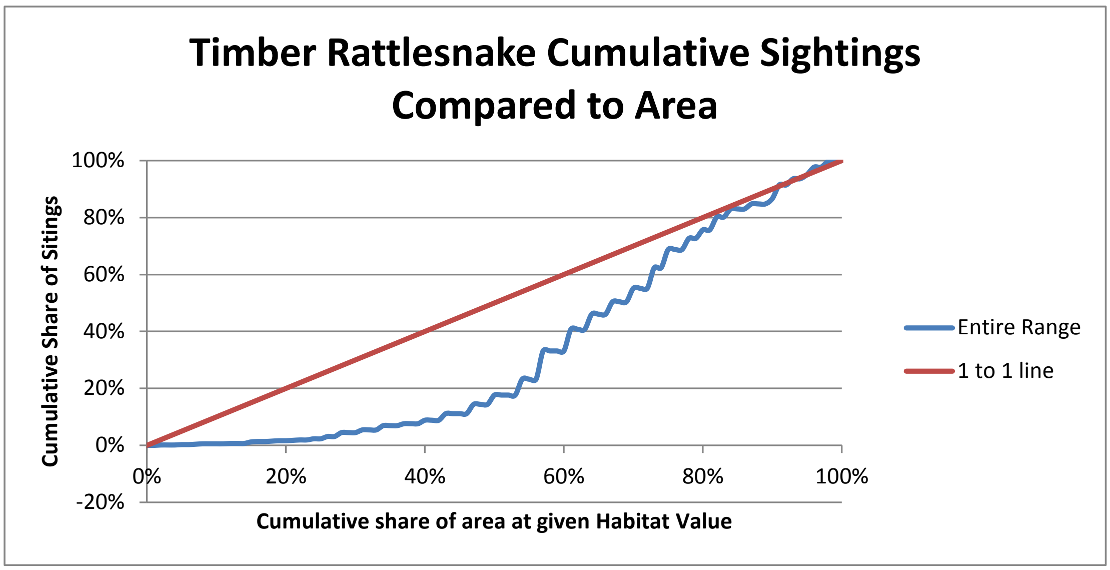

Red-headed Woodpecker Smoothed % Sightings per % Area Entire Range
3
2.5
2
1.5
1
0.5
0
-0.5
0
20
40
60
80
100
y = 0.0161x - 0.3302
R² = 0.5548
Smoothed % Sightings per % Area Entire Range
Linear (Smoothed % Sightings per % Area Entire Range)
Expon. (Smoothed % Sightings per % Area Entire Range)

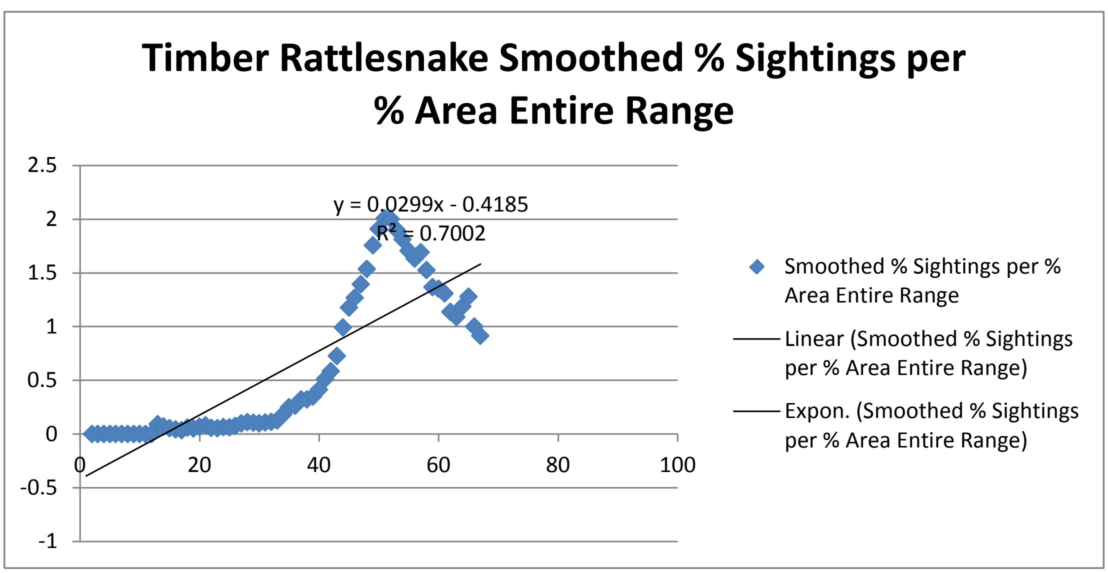

Red-Shouldered Hawk Entire Range
35%
30%
25%
20%
15%
10%
5%
0%
1 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
Range of Habitat Value
SightingsFrequency
Area

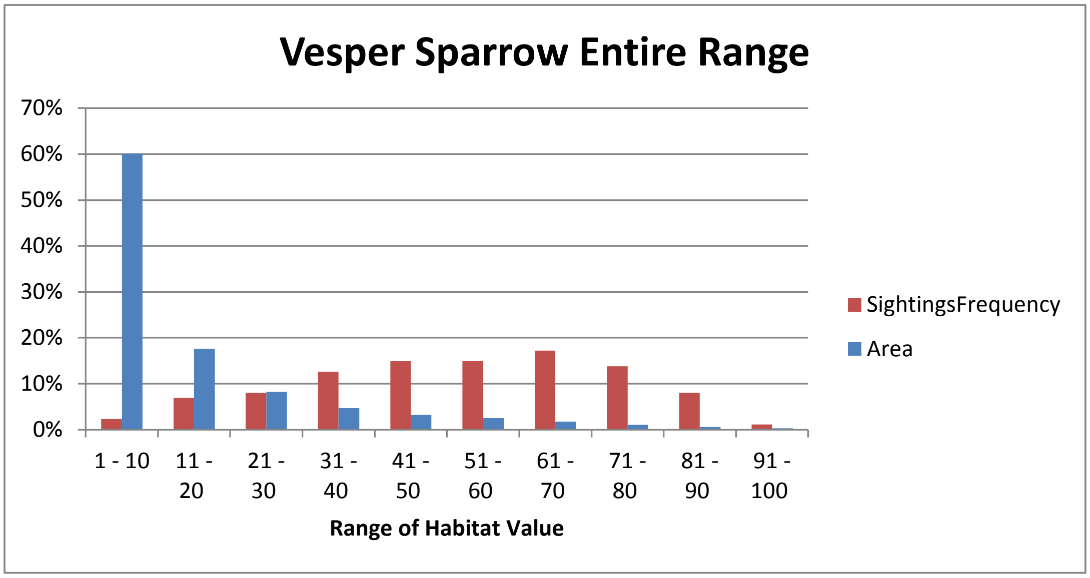

Red-Shouldered Hawk Cumulative Sightings Compared to Area
Cumulative Share of Sitings
100%
80%
60%
40%
20%
0%
0%
20%
40%
60%
80%
100%
Cumulative share of area at given Habitat Value
Entire Range
1 to 1 line

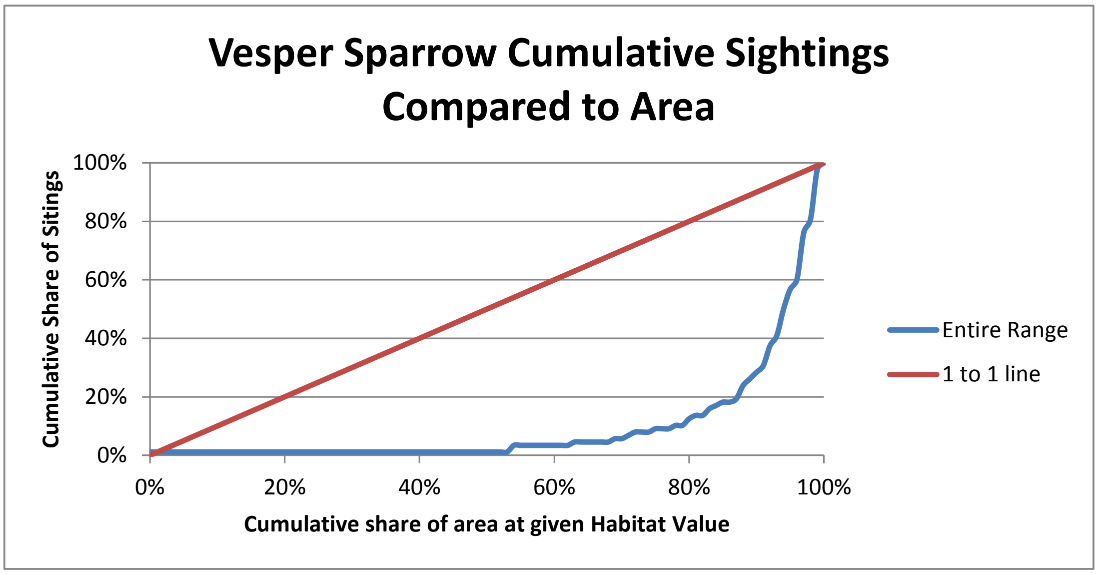

Red-Shouldered Hawk Smoothed % Sightings per % Area Entire Range
7
6
5
4
3
2
1
0
-1
0
20
40
60
80
100
$y = 0.0877e^{0.0425x}$
$R^2 = 0.8981$
$y = 0.0397x - 0.6378$
$R^2 = 0.848$
Smoothed % Sightings per % Area Entire Range
Linear (Smoothed % Sightings per % Area Entire Range)
Expon. (Smoothed % Sightings per % Area Entire Range)

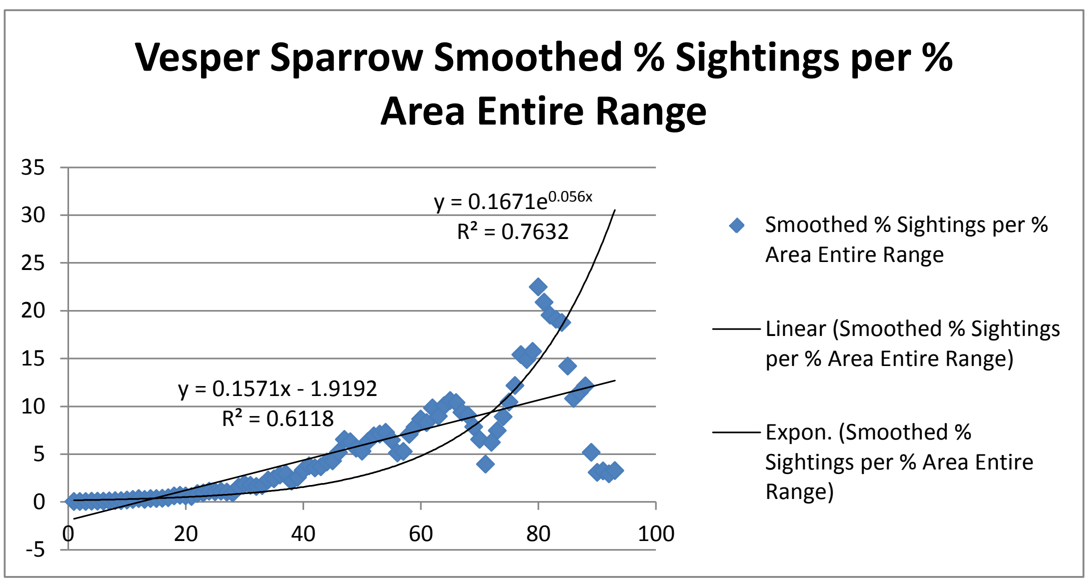

Timber Rattlesnake Entire Range
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
1 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
Range of Habitat Value
SightingsFrequency
Area

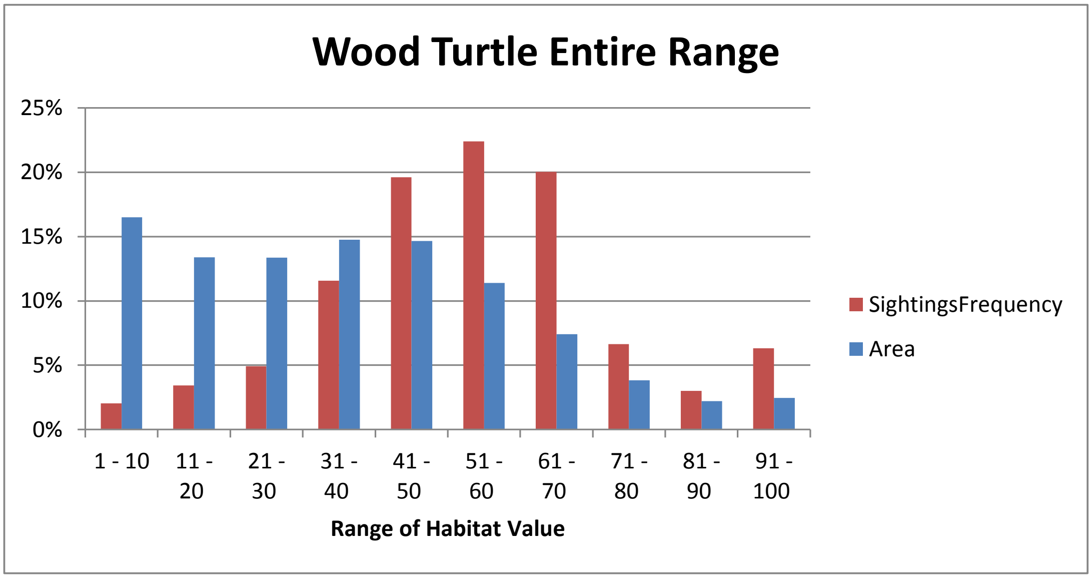

Timber Rattlesnake Cumulative Sightings Compared to Area
Cumulative Share of Sitings
100%
80%
60%
40%
20%
0%
-20%
0%
20%
40%
60%
80%
100%
Cumulative share of area at given Habitat Value
Entire Range
1 to 1 line

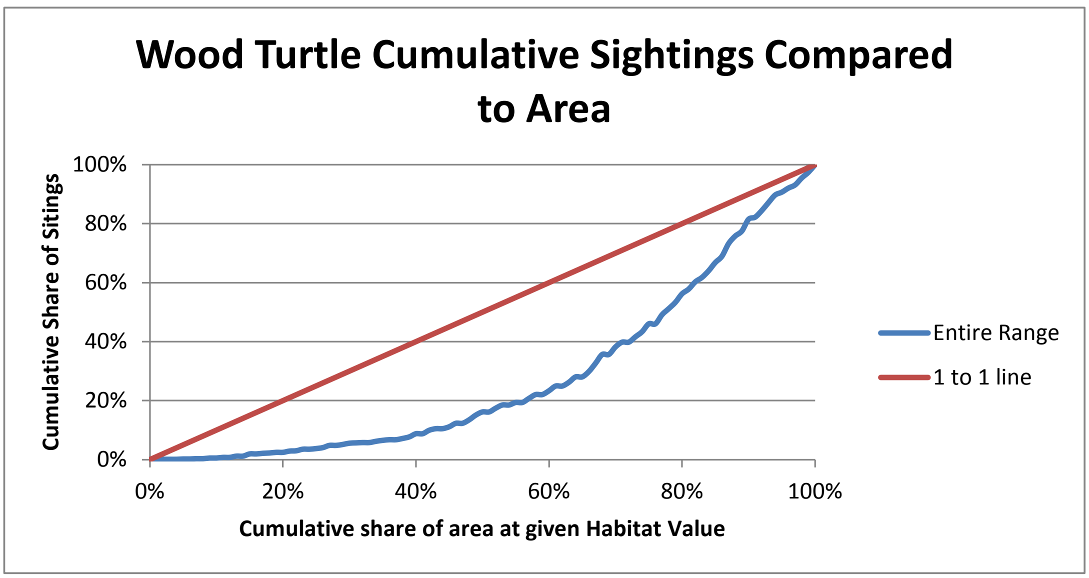

Timber Rattlesnake Smoothed % Sightings per % Area Entire Range
2.5
2
1.5
1
0.5
0
-0.5
-1
0
20
40
60
80
100
y = 0.0299x - 0.4185
R² = 0.7002
Smoothed % Sightings per % Area Entire Range
Linear (Smoothed % Sightings per % Area Entire Range)
Expon. (Smoothed % Sightings per % Area Entire Range)

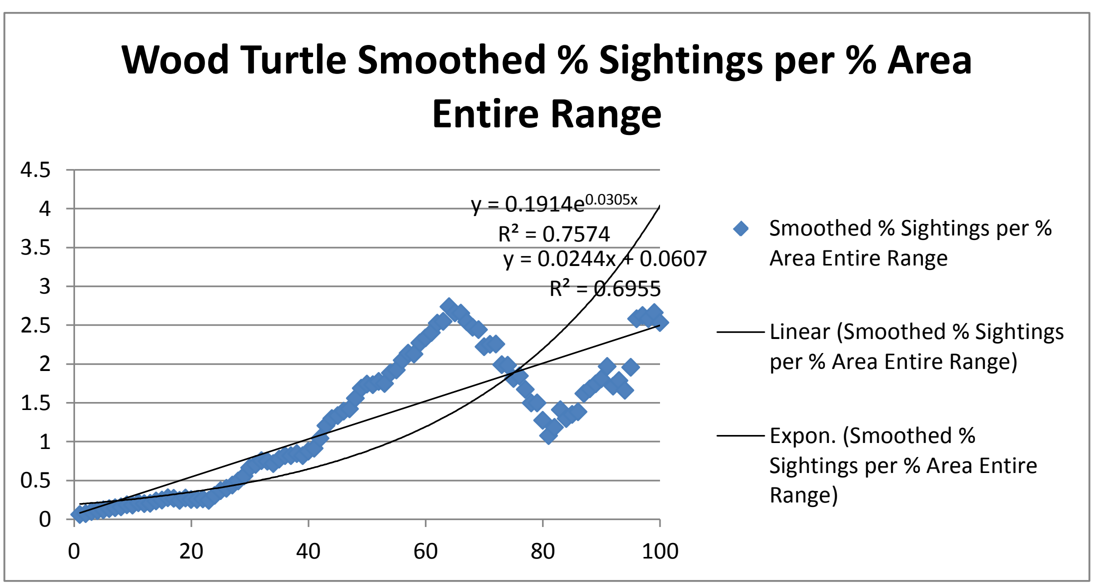

Vesper Sparrow Entire Range
70%
60%
50%
40%
30%
20%
10%
0%
1 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
Range of Habitat Value
SightingsFrequency
Area


Vesper Sparrow Cumulative Sightings Compared to Area
Cumulative Share of Sitings
100%
80%
60%
40%
20%
0%
0%
20%
40%
60%
80%
100%
Cumulative share of area at given Habitat Value
Entire Range
1 to 1 line


Vesper Sparrow Smoothed % Sightings per % Area Entire Range
35
30
25
20
15
10
5
0
-5
0
20
40
60
80
100
y = 0.1671e^0.056x
R² = 0.7632
y = 0.1571x - 1.9192
R² = 0.6118
Smoothed % Sightings per % Area Entire Range
Linear (Smoothed % Sightings per % Area Entire Range)
Expon. (Smoothed % Sightings per % Area Entire Range)


Wood Turtle Entire Range
25%
20%
15%
10%
5%
0%
1 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
Range of Habitat Value
SightingsFrequency
Area


Wood Turtle Cumulative Sightings Compared to Area
Cumulative Share of Sitings
100%
80%
60%
40%
20%
0%
0%
20%
40%
60%
80%
100%
Cumulative share of area at given Habitat Value
Entire Range
1 to 1 line


Wood Turtle Smoothed % Sightings per % Area Entire Range
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
y = 0.1914e^0.0305x
R² = 0.7574
y = 0.0244x + 0.0607
R² = 0.6955
Smoothed % Sightings per % Area Entire Range
Linear (Smoothed % Sightings per % Area Entire Range)
Expon. (Smoothed % Sightings per % Area Entire Range)