Modeling Habitat Availability of Red-shouldered and Red-tailed Hawks in Central Maryland

by

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ABSTRACT

Once considered an abundant species in the eastern United States, local populations of red-shouldered hawks, *Buteo lineatus,* have declined due to habitat destruction. This destruction has created suitable habitat for red-tailed hawks, *Buteo jamaicensis*, and therefore increased competition between these two raptor species. Since suitable habitat is the main limiting factor for raptors, a computer model was created to simulate the effect of habitat loss in central Maryland and the impact of increased competition between the more aggressive red-tailed hawk. These simulations showed urban growth contributed to over a 30% increase in red-tailed hawk habitat as red-shouldered hawk habitat decreased 62.5-70.1% without competition and 71.8-76.3% with competition. However there was no significant difference seen between the rate of available habitat decline for current and predicted development growth.

To my mother for always pushing me to be and do my best.

ACKNOWLEDGMENTS

I would like to thank Dr. Gary Whysong for all of his support and assistance in the formation and completion of this project. I would also like to thank Dr. William Miller for his input and Dr. Eddie Alford for agreeing to a last minute addition to my committee.

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INTRODUCTION

"I believe our biggest issue is the same biggest issue that the whole world is facing, and that's habitat destruction."

-Steve Irwin

All organisms have specific habitat requirements needed for survival. Destruction and degradation of habitat is caused by either natural disasters, animal or human activity, and can occur in two basic ways: quantitative and qualitative losses. Quantitative loss is the reduction in the amount of habitat area, and qualitative change is the change or degradation in the structure, function, or composition of the habitat. Humans have destroyed natural habitat in both of these ways (United States Environmental Protection Agency [EPA], 2003).

Habitat area is the main constraint to raptor populations. Their habitat provides area for nesting, hunting areas, food, and protection, and a deficiency in any one of these factors can severely limit a population of raptors (DeLong, 2000). Therefore looking at trends of habitat destruction is a good indicator of trends in raptor populations. Raptors feed at the top of food pyramids and are important parts of our ecosystems because they help control animal populations, which is an integral part of ecosystem stability. For that reason, raptor population densities provide a good indicator of the underlying health of natural ecosystems (Chase, 1995).

Prior to the 1900s, the red-shouldered hawk was one of the most common hawks in eastern North America. Since then, population densities have declined substantially, especially during the 20th century. The degradation of habitat through destruction of wetlands and habitat fragmentation has been a major effect in many areas, and has created more suitable habitat for larger and more aggressive raptors such as the red-tailed hawk, leading to increased competition for nest sites with red-shouldered hawks (Crocoll, 1994; Krischbaum and Miller, 2000).

In order to see the change in habitat quality and quantity of red-shouldered and red-tailed hawks in central Maryland, an integrative approach to ecological situations via a dynamic spatial model will be used. This has the advantage of allowing the effects of both urban development and competition on the availability of red-shouldered and red-tailed hawk habitats to be seen over time and space. This model could be used to predict future conditions or scenarios.

Chapter 2

LITERATURE REVIEW

Maryland

Wildlife abundance and distribution is dependent on both the ecological health and diversity of habitats and this is particularly true in Maryland due to its wide variety of geographic elements (Maryland Department of Natural Resources [MD DNR], 2005). The state is a mixture of everything from mountains to coastal flatlands and beaches, which includes hills, valleys, wetlands and freshwater rivers and streams. Maryland's landscape is broken into 5 physiographic regions that are based on soil types and underlying geology (Figure 1) (MD DNR, 2005).

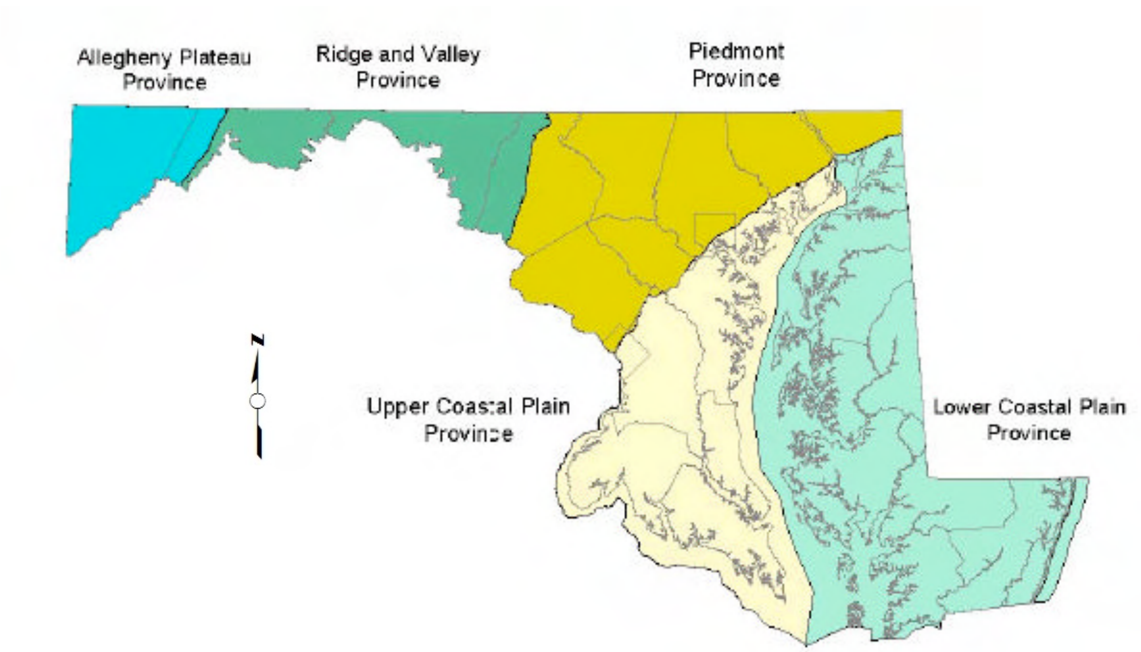

Figure 1. Physiographic provinces of Maryland. (MD DNR, 2005).

The Costal Plain Province is mostly flat and consists of low-lying landscapes. This region is separated into the Lower and Upper Costal Plain based on elevation. Before the settlement of the English, the Costal Plain was mainly hardwood habitat. The majority of Maryland's wetlands occurs in these regions and is extremely diverse, ranging from freshwater to estuarine marshes and tidal swamps. Of all the physiographic regions in the state of Maryland, the Costal Plain area is the most heavily used (Figure 2). In the Lower Costal Plain agriculture and forestry are the main land usages. Development is a large portion in the upper regions of the Costal Plain, especially throughout central Maryland, which is in the Baltimore-Washington corridor (MD DNR, 2005).

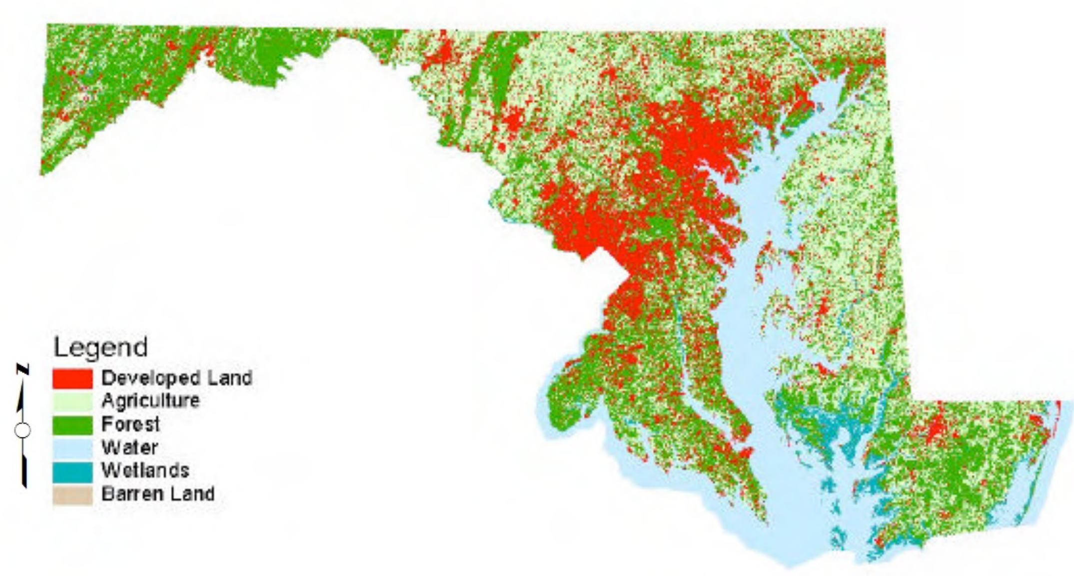

Figure 2. Maryland's land use (MD DNR, 2005).

Landscapes are dynamic and under constant pressure to change from both natural and anthropogenic forces. Native Americans were the first to modify Maryland habitat by burning forested areas for hunting and to mitigate fire hazards (Pyne, 1982; MD DNR, 2005). In 1634, Maryland was colonized and, due to the rapid increase of settlers, the ecological balance in the area was severely impacted. These colonists brought livestock and other nonnative species into the area causing competition for resources with native species. Further disturbance was caused when they hunted native species not only for food, but also for the fur trade and to kill species considered to be vermin or pests (Powell and Kingsley, 1980; MD DNR, 2005). The Industrial Revolution brought an increase in pollution, the conversion of wetlands to agricultural land, and a network of highways that fractured the underlying landscape.

The current primary threat to Maryland's habitat is development, mainly urban sprawl due to population increase (Trauger et al., 2003). Consequences of development are habitat loss, fragmentation, and both point and non-point pollution. Between 1997 and 2002, urban land use was expected to increase by over 25% (Weber, 2003) making 20.4% of Maryland landscape developed, which is the sixth highest developed state in the country (MD DNR, 2005). As a result of this change in landscape, Maryland has lost 73 percent of its wetlands between pre-Columbian settlement and the 1980's (Whitney, 1994; MD DNR, 2005). Forests have decreased by about 3 percent between 1986 and 1999 (United States Forest Service [USFS], 2004). Fully characterizing the impact of this changing landscape requires a dynamic spatially explicit modeling framework that can combine this habitat information with population data.

Dynamic Spatial Modeling

In the mid-1960s the term Geographical Information System (GIS) was coined, and in the United States, it was considered a system for extracting data to be used for analysis and visualizing results as maps. Currently, GIS is used for any application where spatial descriptions and correlations are important including modeling environmental phenomena and policy development (Goodchild, 1993). The power of GIS modeling comes in its ability to interface with other computer languages and incorporate a variety of data across disciplines. In this way, it often acts as a bridge facilitating the identification, manipulation and synthesis of relationships between data and map layers (Berry, 1993). The importance and versatility of GIS is evidenced in the multitude of GIS software; one of these is GRASS (Geographic Resources Analysis Support System), which was developed by the U.S. Army Corps of Engineers' Construction Engineering Research Laboratory. GRASS has extensive capabilities in the field of spatial modeling and has become a "significant public-domain" GIS software and often used to model environmental processes (Goodchild, 1993).

These environmental processes are often highly interconnected at various micro and macro scales, dependent on time, and three-dimensional. Because of these complexities and the difficulty of working with a large study area, it is typically unrealistic to get enough sampling resolution to see the relationship between the components of the environment and humans (Steyaert, 1993; Joy, Reich, and Reynolds, 2000). Therefore, in these cases dynamic spatial modeling can be beneficial because it takes not only space, but also time into consideration. However, not every component of the environment can be taken into consideration in a dynamic spatial model. Even though it is the intention of this thesis to accurately model the fundamental processes and drivers, these models are necessarily simplifications of real world phenomena. Models are based on physical laws, observations and assumptions (Steyaert, 1993). Care needs to be taken when looking at resulting layers and maps of a GIS model because these resulting objects are creations resulting from the modeling process and not the real world (Goodchild, 1993).

GIS is a versatile tool extending over a wide variety of application from inventory and management to analysis and modeling (Goodchild, 1993). The focus of many dynamic spatial modeling has been that of urban development (Deal & Schunk, 2004; Barredo, Kasanko, McCormick, and Lavalle, 2002), where the economic impact of land use transformations are modeled. Environmentally focused dynamic spatial models focus on species interactions as well as the impact of human development on biodiversity (Bekessy et. al, 2009; Carrete, Tella, Blanco, and Bertellotti, 2009). However, distinct species interact differently with human development and these models that attempt to predict the impact of habitat fragmentation need to be species-specific. Using population and habitat models as complements to each other may improve how we predict species reactions to changes in their environment and improve how we manage our natural resources (Wiegand, Moloney, Navea, and Knauer, 1999; Aurambout, Endress, and Deal, 2005).

With the help of several partners in natural resource conservation, the Maryland Department of Natural Resources is promoting habitat conservation and protection of Maryland's natural environments (MD DNR, 2005). This serves to protect the wide variety of wildlife including many different raptor species including red-shouldered hawks

Red-shouldered Hawk

The red-shouldered hawk, *Buteo lineatus*, is a medium-sized (43-61 cm) hawk distinguished by its reddish shoulder patches. Male and females are alike in appearance, however, they show reverse sexual dimorphism (Crocoll, 1994; Jacobs & Jacobs, 2002). Having relatively long tails for a *Buteo*, the red-shouldered hawk's tail has wide dark bands separated by narrow white bars. Their flight feathers are also black and white barred with the wings of adults appearing two-toned below, with reddish-brown underwing coverts (Figure 3) (Crocoll, 1994 Krischbaum & Miller, 2000). Juveniles appear similar to adults, but have creamy underparts with dark brown spots and streaks.

Figure 3. Red-shouldered hawk (Krischbaum & Miller, 2000).

The red-shouldered hawk is found east of the Great Plains, from southern Canada southward to eastern Texas and Florida. Northern birds are migratory, moving into Florida and as far south as Mexico for the winter. They are also found on the Pacific Coast from southwestern Oregon to Baja California (Figure 4) (Clark & Wheeler, 1987).

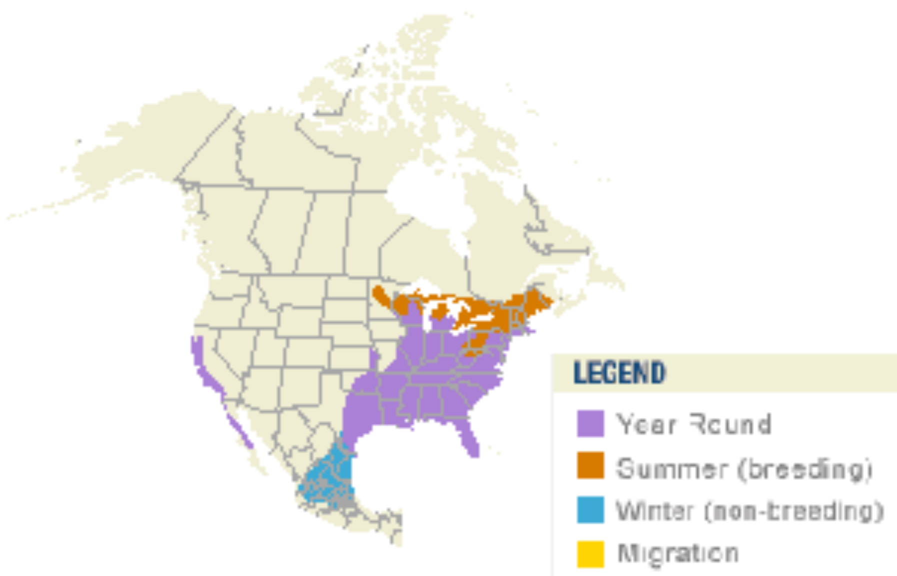

Figure 4. Red-shouldered hawk distribution (Cornell Lab of Ornithology, 2003a).

Red-shouldered hawks begin courting, establishing their territory and building or refurbishing nests between mid-February and mid-March (Crocoll, 1994; Jacobs and Jacobs, 2002). In the eastern population of red-shouldered hawks, most egg laying occurs in April. Eggs hatch about 5 weeks later, and young usually depart from nest in June (Crocoll, 1994). Even though the same nest is usually used for many years, when choosing a nest site, red-shouldered hawks appear to avoid sites near red-tailed hawks (Bent, 1937; Bednarz & Dinsmore, 1982; Bryant, 1986; Dykstra, Hayes, Daniel, and Simon, 2001).

Water is a vital characteristic in red-shouldered hawk breeding habitat (Woodford, Eloranta, and Rinaldi, 2008). These habitat areas vary from bottomland hardwood, riparian area, and flooded deciduous swamps to upland mixed deciduous-coniferous forest adjacent to ponds, wetlands or streams (Bent, 1937; Henny, Schmid, Martin, and Hood, 1973; Crocoll, 1994; Morman & Chapman, 1996; Dykstra et al., 2001; Jacobs & Jacobs, 2002). The breeding habitat of eastern populations of red-shouldered hawks generally consists of extensive forest stands with mature to old-growth canopy trees. Size, rather than age, appears to be the defining characteristic, with trees having a diameter at breast height (DBH) between 17 and 40^{+} cm being generally used for nesting (Jacobs & Jacobs, 2002). Another critical nest site characteristic is canopy closure. It appears that red-shouldered hawks nest in sites having greater than 70% canopy closure (Bryant, 1986; Moorman & Chapman, 1996; Jacobs &

Jacobs, 2002). Wintering habitat even for non-migrants, are frequently more open lowland areas near water such as swamps, marshes, and river valleys (Henny et al., 1973; Crocoll, 1994).

Eastern populations of red-shouldered hawks have a home range anywhere from 108.9 to 339 ha. A territorial species, especially during the breeding season, red-shouldered hawks have been known to chase conspecific and interspecific intruders, such as red-tailed hawks and great horned owls. In these home ranges, red-shouldered hawks usually nest in mature deciduous trees in wet woodland areas (Moorman & Chapman, 1996). Nests are built in the middle to two-thirds the way up the tree around 6-15 m (20-60 ft.) above ground in trees near water such as swamps or streams. To get an unobstructed view of the forest floor for hunting, red-shouldered hawks prefer to have dead trees nearby (Crocoll, 1994).

The diet of red-shouldered hawks consists primarily of small mammals, reptiles, amphibians and even small birds. Sight and hearing are the senses used by red-shouldered hawks to hunt successfully. Hunting is done by searching for prey while perched on treetops or soaring over woodland, and in open land they may hunt by flying low like a harrier. Red-shouldered hawks kill their prey by dropping directly onto it from the air (Crocoll, 1994).

Before the 1900s, the red-shouldered hawk was one of the most common hawks in eastern North America. Since then, population densities have declined substantially, especially during the 20^{th} century. Hunting, particularly along the Appalachian ridge, was a historical problem (Brown, 1949). Pesticides such as

DDT were found in eggs and tissues causing a thinning of eggshells. The effects of these pesticides, however, were not as severe as those in other raptors.

The degradation of habitat through destruction of wetlands and habitat fragmentation has been a major effect in many areas. In the state of Maryland, a reduction in breeding pairs, and therefore red-shouldered hawks nests, have been seen in areas where habitat has been altered or destroyed due to human activities such as construction (Henny et al., 1973; Martin, 2004). This conversion of land has generated more suitable habitat for red-tailed hawks and great horned owls. This leads to not only increased competition for nest sites, but also increased predation on red-shouldered hawks (Bednarz & Dinsmore, 1982; Crocoll, 1994; Krischbaum & Miller, 2000; Martin 2004).

The red-shouldered hawk is listed as threatened or endangered in several US states, and is protected under the Migratory Bird Treaty Act of 1978 (Krischbaum & Miller, 2000). Several management actions have been proposed. Managing large areas of mature contiguous forest is a necessity for red-shouldered hawks to prevent them from being displaced by red-tailed hawks and great horned owls (Crocoll, 1994; Moorman & Chapman, 1996; Jacobs & Jacobs, 2002). It is further recommended that populations in the central, north central and northeastern parts of the U.S. be monitored via census counts (Crocoll, 1994).

Red-tailed Hawk

The red-tailed hawk, *B. jamaicensis,* is a stout-bodied, broad-winged hawk ranging in size from 45-65 cm. Both sexes are similar in appearance and overlap considerably in size, with females slightly larger than males (Clark & Wheeler, 1987). Although they are similar to other North American buteos, red-tailed hawks are distinguished by their reddish tail, and most individuals in the species has a dark bellyband present (Preston & Beane, 1993). Within a population, plumage patterns can vary greatly and therefore individuals are classified by having either a light or dark morph (Figure 5). Juveniles are similar to adults except they have a pale brown tail with dark uniform bars.

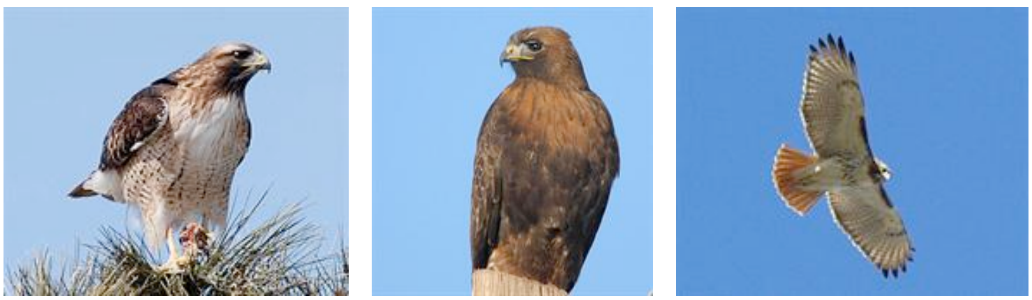

Figure 5. Red-tailed hawk (*left:* light morph *middle:* dark morph *right:* soaring) (Cornell Lab of Ornithology, 2003b).

Being one of the most widespread and common raptors in North America, the red-tailed hawk ranges throughout the continent. Red-tailed hawks have a year round distribution that ranges from panama to the Canada, and from coast to coast. They also have a breeding range that reaches as far north as central Alaska and into Canada below the Arctic Circle (Figure 6) (Preston & Beane, 1993).

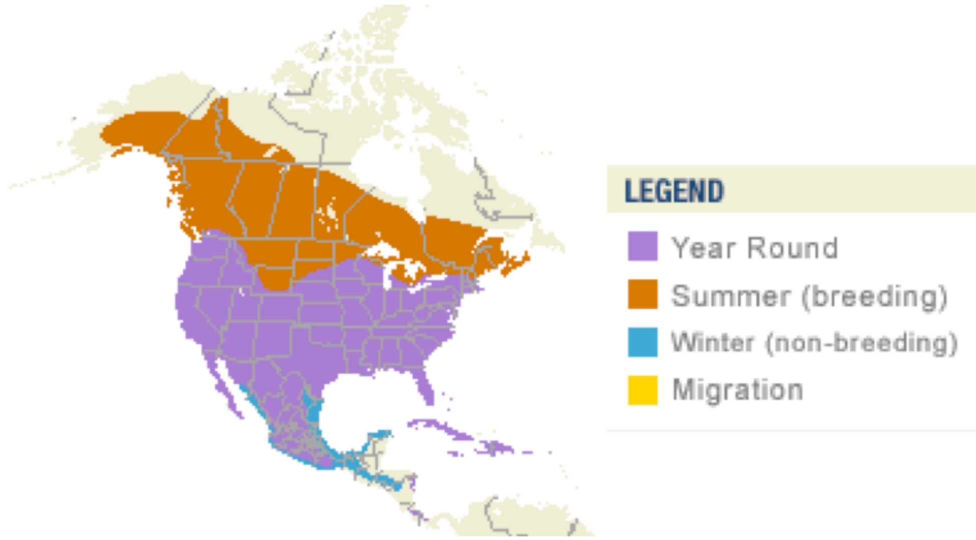

Figure 6. Red-tailed hawk distribution (Cornell Lab of Ornithology, 2003b).

Courtship through aerial displays can occur any time of the year, but are more common in late winter and early spring. Nest building or refurbishing usually begins in February or early March, but has been seen as early as late December and January (Mader, 1978; Orians & Kuhlman 1956). Nests from previous years are visited by both members of a pair and repaired before one is chosen. For most of North America, egg laying occurs in mid-late March and hatch 4-5 weeks later. After hatching, red-tailed hawk young fledge in about 6 weeks (Bent, 1937; Preston & Beane, 1993).

Red-tailed hawks are adaptable and opportunistic and therefore use a wide variety of habitats, but generally prefer open areas. The presence of scattered, elevated perches is a vital characteristic of breeding and wintering habitats. These habitats include areas such as: desert scrub, agricultural fields, pastures, urban parkland and broken coniferous and deciduous woodland. The species is usually not seen in areas with large stretches of treeless terrain and dense forest. Water is not a critical characteristic in their breeding habitat (Preston & Beane, 1993).

The home range of a red-tailed hawk varies anywhere from 130 to 390 ha. Edges of territories often follow alongside physical features such as roads, waterways or a forest edge. During the breeding season, red-tailed hawks are highly territorial and display intra- and interspecific aggression. Intruders may be harassed, chased or even attacked with wings and talons. However, conspecifics flying above their territory are usually unchallenged (Preston & Beane, 1993). In these home ranges, red-tailed hawks generally nest in the canopy of large trees (9-27 m above ground) near openings of mature woodlands or in small groves in open habitat. Since red-tailed hawks are opportunistic, if large trees are scarce, they will use cliff ledges or even man-made structures, such as building roofs or ledges (Bechard, Knight, Smith, and Fitzner, 1990; Preston & Beane, 1993). These nesting sites give red-tailed hawks access to nests from above and an unobstructed view of the surrounding environment.

The diet of red-tailed hawks consists of small to medium-sized mammals, birds and reptiles. Vision is relied upon by red-tailed hawks to hunt successfully, and most hunting is done by surveying the surrounding area from elevated perches. Occasionally, red-tailed hawks soars over open areas to hunt. Once prey is detected, it is attacked from above, with the red-tailed hawk dropping onto it from the air.

During 1965-1975 the red-tailed hawk population had a dramatic increase in most of its range in North America, and between 1970 and 1980, Christmas

Bird Count data show a more than 33% in increase in winter populations. Urban areas do not adversely affect red-tailed hawks, and may even be beneficial to reproductive success. Red-tailed hawks nesting in man-made structures have been seen to have a higher reproductive success than those nesting in trees. However, heavily developed areas are avoided because of insufficient hunting and nesting sites (Stout, 2006). During the 20th century, the range of red-tailed hawks has expanded into urbanized landscapes and also has replaced red-shouldered hawks in much of Eastern North America. This expansion is mainly due to deforestation, which results in fragmentation of woodland and creates open areas (Bednarz & Dinsmore, 1982; Robbins, Bystrak, and Geissler, 1986; Preston & Beane, 1993; Martin, 2004).

Two factors that limit red-tailed hawk populations are nest sites and food supply. In some regions, like prairie ecotones, populations are limited by the scarcity of suitable nesting sites even though prey may be abundant. Distribution of prey and abundance of appropriate perches has more of an influence on red-tailed hawk populations than prey density because it directly affects hunting efficiency (Preston & Beane, 1993). Presently, shooting, automobile collision and direct human interference are the greatest threats to red-tailed hawks. Raptor education and law enforcement are the two most critical efforts for conserving red-tailed hawks (Preston & Beane, 1993).

Previous Research

Traditional research on red-shouldered and red-tailed hawks has focused on identifying key characteristics of their habitats and behaviors (Stewart, 1949; Henny et. al, 1973; Bednarz & Dinsmore, 1982; Morman & Chapman, 1996). Some of the most recent research has focused in the interface between their habitat and behavior with human and urban encroachment (Martin, 2004; Stout, 2006). Anthropomorphic changes to the environment have had dramatic short term and long-term impacts. This combined with direct interactions with humans, accounts for the dramatic change in population sizes and ranges of both red-shouldered and red-tailed hawks. While this impact has been deleterious to red-shouldered hawks, red-tailed hawks have benefited. This thesis attempts to illuminate the nature of human impact on both red-shouldered and red-tailed hawk habitat using the framework of GIS modeling.

Chapter 3

METHODOLOGY

A dynamic spatial model was used to observe predicted changes over both time and space. Geographic Resources Analysis Support System (GRASS) was used to generate a series of maps that work together with the dynamic spatial model. Computer simulations are then employed to discover the result of the effect that urban sprawl is having on the red-shouldered and red-tailed hawks. The purpose of using these models is to construct a model that can 1) mimic what is occurring, and 2) predict future hawk population trends.

Study Area

The study area is a section of central Maryland that is just northeast of Washington, DC and south of Baltimore, Maryland. The western boundary of the area follows the Prince Georges County border along Washington, DC and Montgomery County and goes as far east as the Chesapeake Bay. The north and the south edges of the study area follow MD State Highways. The Patuxent Freeway, Highway 32, is to the north and MD State Highway 214, Central Avenue, is to the south (Figure 7).

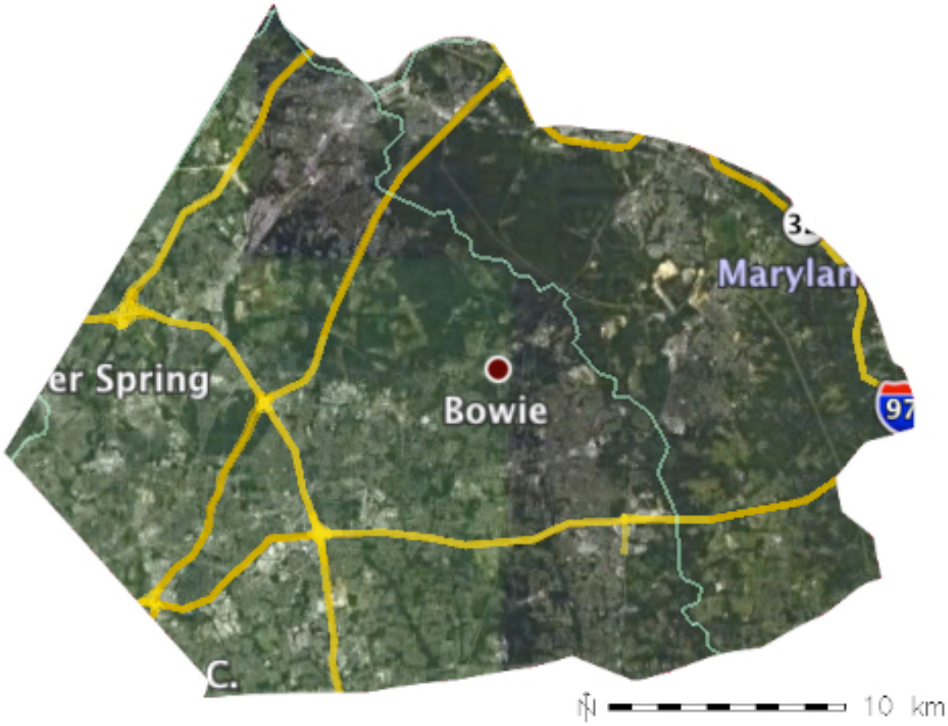

Figure 7. Section of central Maryland used for study area.

This area includes the section of the Patuxent River valley in northern Prince Georges County and Western Anne Arundel. It also contains the Patuxent Wildlife Research Center and wildlife sanctuary, and the major cities in the study area are Laurel (39°6'31"N, 76°53'33"W) and Bowie, Maryland (38°59'5"N, 76°44'7"W). This is an area consisting of almost 674 km^2 and a wide variety of habitat. However the natural habitat is steadily disappearing due to development. Laurel, MD, a highly developed area, has 9.9 km^2 of land, and as of 2000 had a population of 19,960. Bowie, MD is 41.8km^2 and had a population of 50,269 as of 2000 (Marchex Inc., 2006). This area did not change into a densely developed area as quickly as Laurel, but the amount of developed areas is quickly growing.

Geographic Resources Analysis Support System (GRASS)

To begin the GIS work of the project, the following GIS layers were downloaded from the USGS Seamless website at www.seamless.usgs.gov :

- Landsat image
- National Elevation Data (NED)
- BTS roads
- Land cover 2001
- Canopy cover 2001
- Impervious surface
- National atlas streams

A polygon shape file was created in order to extract the region of interest by multiplying the rasterized polygon by the above layers. All the layers had a resolution of 30 m, and once they were reduced to the region of interest the map calculator was used to create the initial layers of the model.

In order to create the habitat suitability layer for the red-shouldered hawk, buffer zones were created at different distances from wetlands since the defining characteristic of red-shouldered hawk habitat is distance to wetland. This was done by first reclassifing the land cover layer using the map calculator. Cells that were classified as wetlands were given a value of one and everything else was reclassified as zero. Three distances were used for distance from wetland: 60 m, 150 m, and 230 m (Bednarz & Dinsmore, 1982). This layer along with the original land cover layer created a habitat suitability map resulting in a GIS layer with values from 0-1 (Table 1). This new layer describes the preference and the expected usage of the habitat by red-shouldered hawks. Areas that have been given a value of 1 such as woody wetlands and emergent herbaceous wetlands are more preferred and therefore used if available. The value of the habitat decreases if it is less preferred but used if more preferred habitat is not available.

Table 1. Values given to red-shouldered hawk habitat based on distance from wetland areas.

Distance (m)	Deciduous forest	Mixed forest
60	0.98	0.7
150	0.7	0.5
230	0.25	0.17
>230	0	0

In order to create a habitat suitability layer for the red-tailed hawk, the canopy cover layer was reclassified to values between 0-1 based on red-tailed hawk preference. The land cover layer was also reclassified with development types getting values between 0-1 based on usage, and everything else had a value of 0. These two layers were multiplied together creating a layer with values between 0-1 with percent canopy cover between 0-50% having a value of 1 if not in a developed area. Habitat suitability decreases as canopy cover increases. If development is present, then the suitability decreases with the density of development (Table 2).

Table 2. Red-tailed hawk habitat values based on canopy cover and the presence of development type.

Development	Canopy Cover Percent		
	0-50	**50-75**	**75-81**
None	1	0.5	0.2
Open	0.75	0.375	0.15
Low	0.5	0.25	0.1
Medium	0.25	0.125	0.05
High	0	0	0

The Land Cover 2001 layer downloaded from USGS contained four development types. Open development is defined as an area containing less than 20% impervious surfaces. These areas include single-family homes on large lots, parks, golf courses, etc. Both low and medium development types are areas that also contain single-family homes, except the percentage of impervious surfaces increase as development intensity increases. High development is an area where people reside or work in high densities such as, apartment complexes, row houses, and industrial and commercial areas.

The initial development layer was created from the land cover map by giving cells classified as open development a value of 1, low development a value of 2, medium development a value of 3, high development a value of 4, and all other cells were giving a value of zero. Along with this map, a layer was created of areas where no development can take place. This was done by giving a value of one to everything except areas that cannot be developed such as, areas already developed, state parks and wildlife reserves, open water and wetland. Lastly, a development type layer was created for each of the development types used in the model.

Dynamic Spatial Model

This model was created using Perl, a general-purpose interpretive computer language, in order to simulate development growth and show the effects on the two raptor species. First a buffer layer with distances from 30-300 meters was created for each of the individual development maps that were created earlier. Distances were categorized in 30 meter increments, and each distance category was assigned a value using a normal distribution with the closest being 1 and the values decreasing as you get farther from the developed area. In order to exclude places already developed, open water, wetlands and wildlife reserves, this layer was multiplied by a layer containing possible areas that development can take place. The resulting layer created the probability maps for each development type.

A random number map containing values between 0 and 1 was created and compared to a minimum value selected to simulate the desired rate of development. For current development, 0.98 was chosen in order to achieve a 2.4% increase in developed areas and 0.977 to obtain a predicted 2.7% increase in development per year (MD DNR, 2005). To create the mask of potential development each cell in the random layer was compared to the minimum value. If the cell value was greater than the chosen minimum, it became a 1, meaning the cell had the potential to be developed; if not, it became a 0. This mask of potential development was multiplied by a second random number layer and also by all development probability maps created earlier.

The second random number layer and the development probability maps, were compared with each other to determine the designation of the new development cells (Figure 8). First, a cell must contain a larger value in at least one of the development probability maps than that of the second random number layer. Then each of the development probability layers are compared with each other, and the type of development a cell becomes is determined by whichever probability map has the larger value. In the event that two development probability maps have the same value for a cell, then the lower development type wins because it is predicted that there will be greater development growth in the open and low development types (MD DNR, 2005).

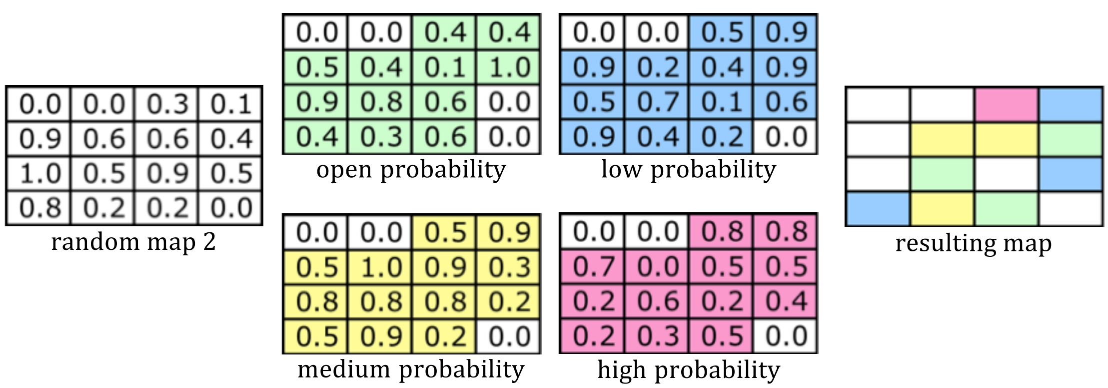

Figure 8. Example of how development type is chosen based on random number and development probability maps.

Once development type was determined, the land cover layer was modified and as well as each development type map. After these changes were made, the canopy cover layer changed to reflect the new development (Table 3). This change was based on the classified development amount of impervious surfaces.

Table 3. Percent decrease of original canopy cover based on type of development present.

Development	**Percent decrease**
None	0
Open	25
Low	50
Medium	75
High	100

Once these layers were created and modified, they were used to modify the red-shouldered and red-tailed hawk habitat. These layers were created in the same way the initial layers were created. Then the habitat suitability maps were reclassified to usable habitat and given values of 1 (good) and 2 (excellent). For red-shouldered hawk, habitat with a value of 0.7-0.9 was classified as good habitat and anything above 0.9 as excellent. Red-tailed hawk habitats with a value of 0.5-0.9 were reclassified as good, and above that as excellent. Another copy of these layers were created and classified as 1 for all usable habitats and 0 for no habitat.

This process (Figure 9) of modifying the development and both red-shouldered and red-tailed hawk habitat layers is done once during every loop of the model, which had a time scale of a year. Since the initial layers were based on land and canopy cover maps from 2001, the initial starting point of the model is the year 2001 and each simulation of the model ran for a total of 100 years. These layers were then saved yearly and analyzed to see how urban sprawl affects the habitat availability of red-shouldered and red-tailed hawks.

Analysis of Maps

In order to analyze the maps, vector maps of the two reclassified red-shouldered and red-tailed hawk habitats for every five years were exported into ArcGIS. Once imported, the field "area" was added to the attribute table of the layer containing 1 and 0. The field was created to contain long integers and geometry was calculated in square kilometers. A selection was then done to select areas that were at least the size of the minimum territory size. For red-shouldered hawks, the area was selected for areas greater than or equal to 1 km^2 and 1.3 km^2 for red-tailed hawks. A layer was created from the selection and converted into a raster. This layer of selected habitat acts as a mask and was multiplied by the map, which contains habitat classified as good and excellent. This resulting layer was composed of the habitat that was available to be used. This process was done for each pair of maps for each raptor for both simulations.

A layer was then created for every 5 years that contained area where red-shouldered and red-tailed hawk habitat overlaps. This was done in order to determine area where there is possible competition between the two species.

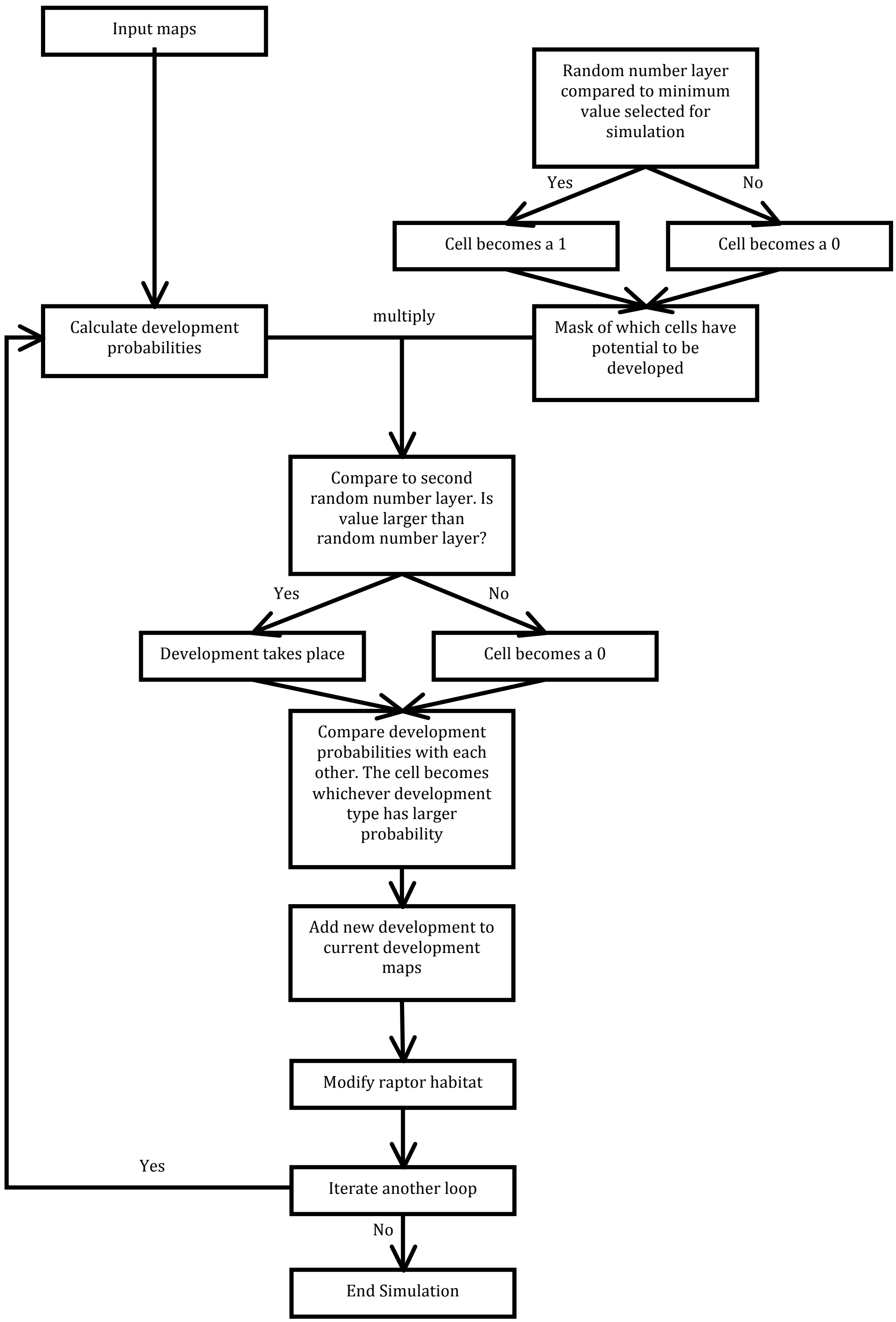

Figure 9. Flow chart of the implementation of the dynamic spatial model.

Because red-shouldered hawks nest later in the year, it was assumed that if an area is usable by red-tailed hawks then it would not be available to red-shouldered hawks. Therefore, this area of over lap was subtracted from red-shouldered hawk habitat only. Once these new layers of red-shouldered hawk habitat was created the same process of selecting available habitat as above was performed on these layers. This resulted in layers of usable, available red-shouldered hawk habitat under the constraints of competition.

Chapter 4

RESULTS

After both model simulations (current and predicted development) ran for 100 years each, the amount of available habitat was compared in order to see how the growth of urban development impacted the availability of red-shouldered and red-tailed hawk habitat.

Red-Shouldered Hawk

When looking at the total amount of red-shouldered hawk habitat, I see that there is a change in the habitat over time, however there is no statistical difference at a 95% confidence level in the rate of total habitat change over time between current and predicted developments (Figure 10). There is a 39% change in total habitat where development is increasing at the current rate and a 44% decrease when development grows at the predicted rate.

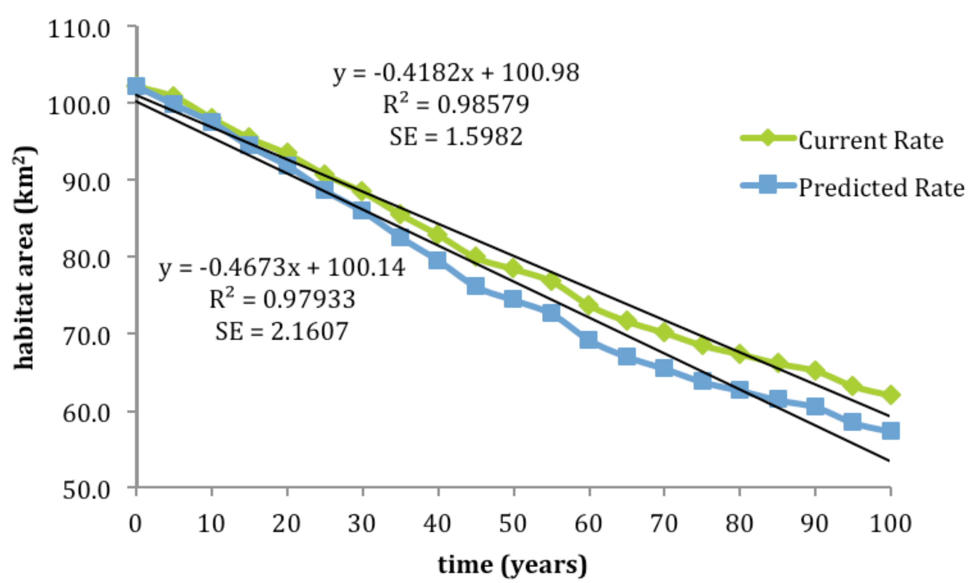

Figure 10. Change in total red-shouldered hawk habitat (with trend line), after current and predicted rate of development over 100 years.

With a little more than 50% of the initial total habitat available as suitable habitat, I see what looks to be a difference in how available habitat decreases. However, when analyzed linearly there is no significant difference (Figure 11). During the predicted rate of development growth, the available red-shouldered hawk habitat initially decreases at a faster rate than when development increases at the current rate

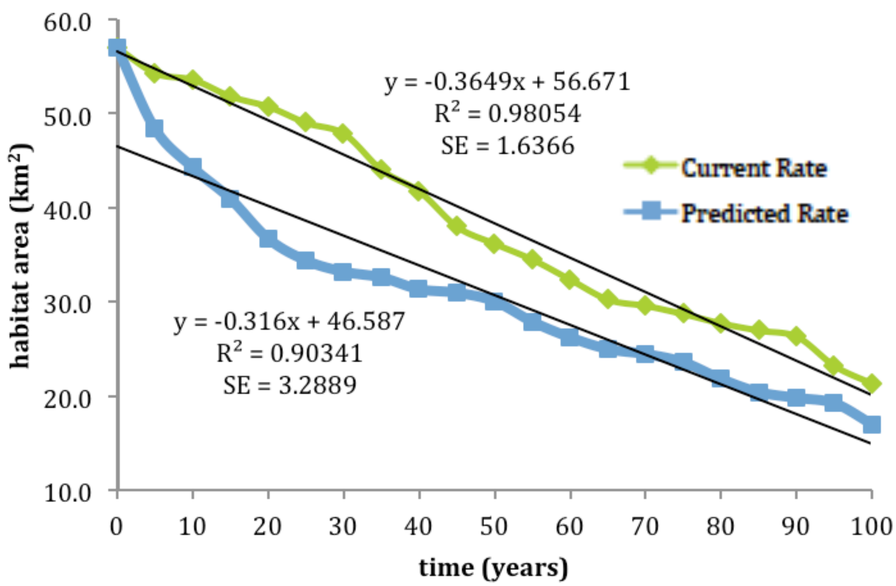

Figure 11. Change in usable red-shouldered hawk habitat (with trend line), after current and predicted rate of development over 100 years.

The figures below show the locations where available red-shouldered hawk habitat was lost (Figure 12). As development occurred, habitat was taken from outside edges and therefore eliminating lower quality habitat first. Differences can be seen between the two development scenarios, with the habitat available simulated for the predicted development rate consisting of narrower strips.

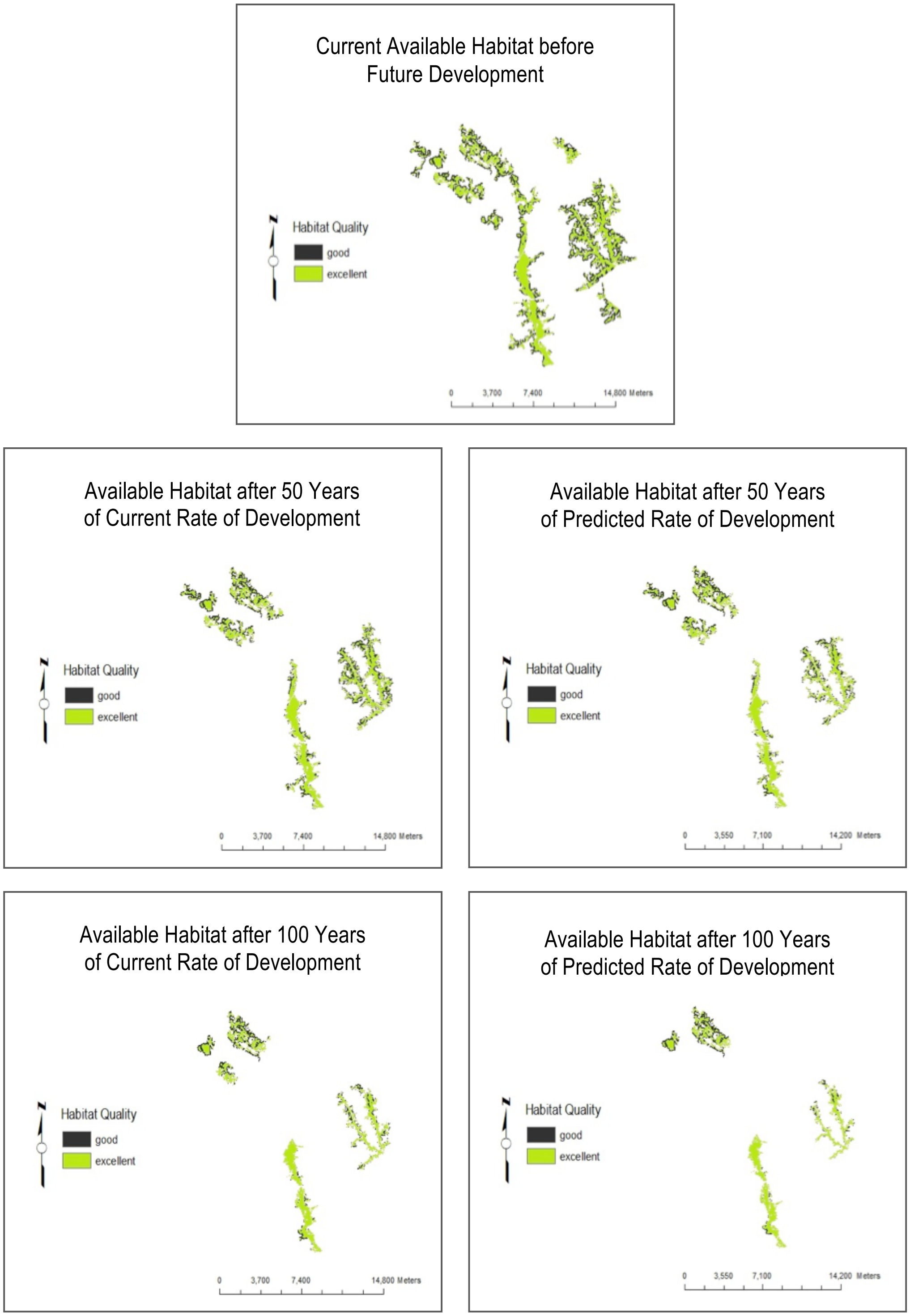

Figure 12. Available red-shouldered hawk habitat without competition before (top) and after new development at current (left) and predicted (right) development rates.

Red-Tailed Hawk

As seen in change in total habitat over time for red-shouldered hawk, there is no significant difference between current and predicted developments in the rate of change in total red-tailed hawk habitat over time. However, instead of a decline, the amount of habitat increases in both simulations (Figure 13). Even when looking at the available habitat, which is based on minimum territory size, we see no significant difference between simulations (Figure 14). However, when comparing the graph of total and usable habitat I can see that the usable habitat is increasing at a faster rate than the total habitat (Figure 13 & 14). This is true for both current and predicted development rates.

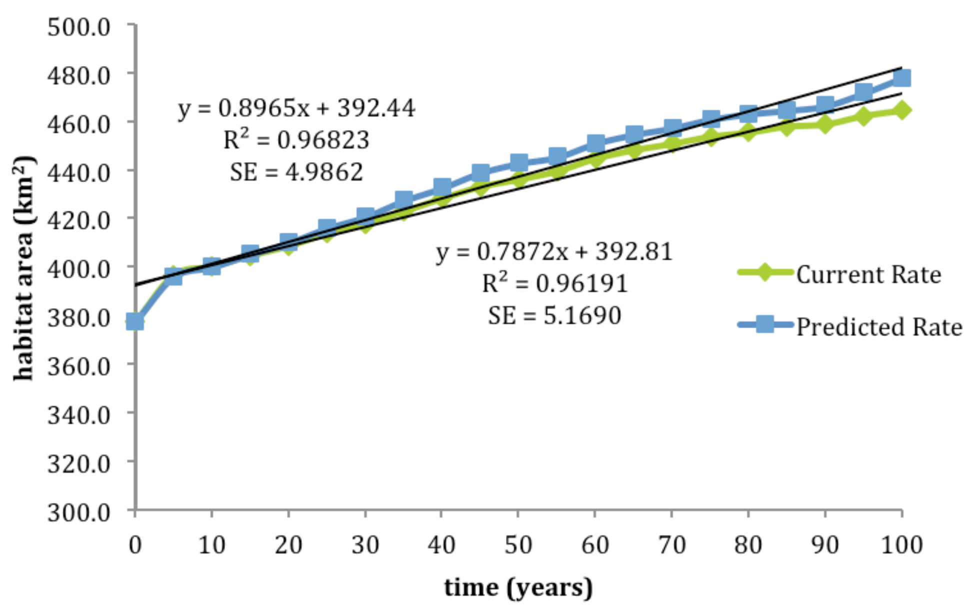

Figure 13. Change in total red-tailed hawk habitat (with trend line), after current and predicted rate of development over 100 years.

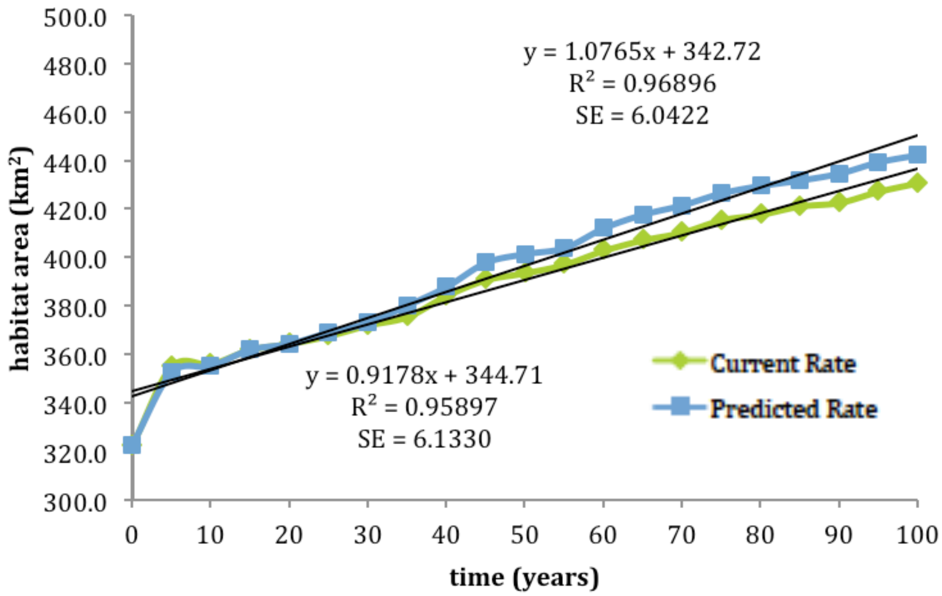

Figure 14. Change in usable red-tailed hawk habitat (with trend line), after current and predicted rate of development over 100 years.

Again, looking at the figures of available habitat yields more insight into where and how habitat is changing. When looking at the maps of available red-tailed hawk habitat, I see that the total area available is increasing, however there is a decrease in high quality areas (Figure 15). Initially the available habitat is about 38% excellent habitat, which decreases to 11.5% for current development rate and 9.5% in the predicted development rate.

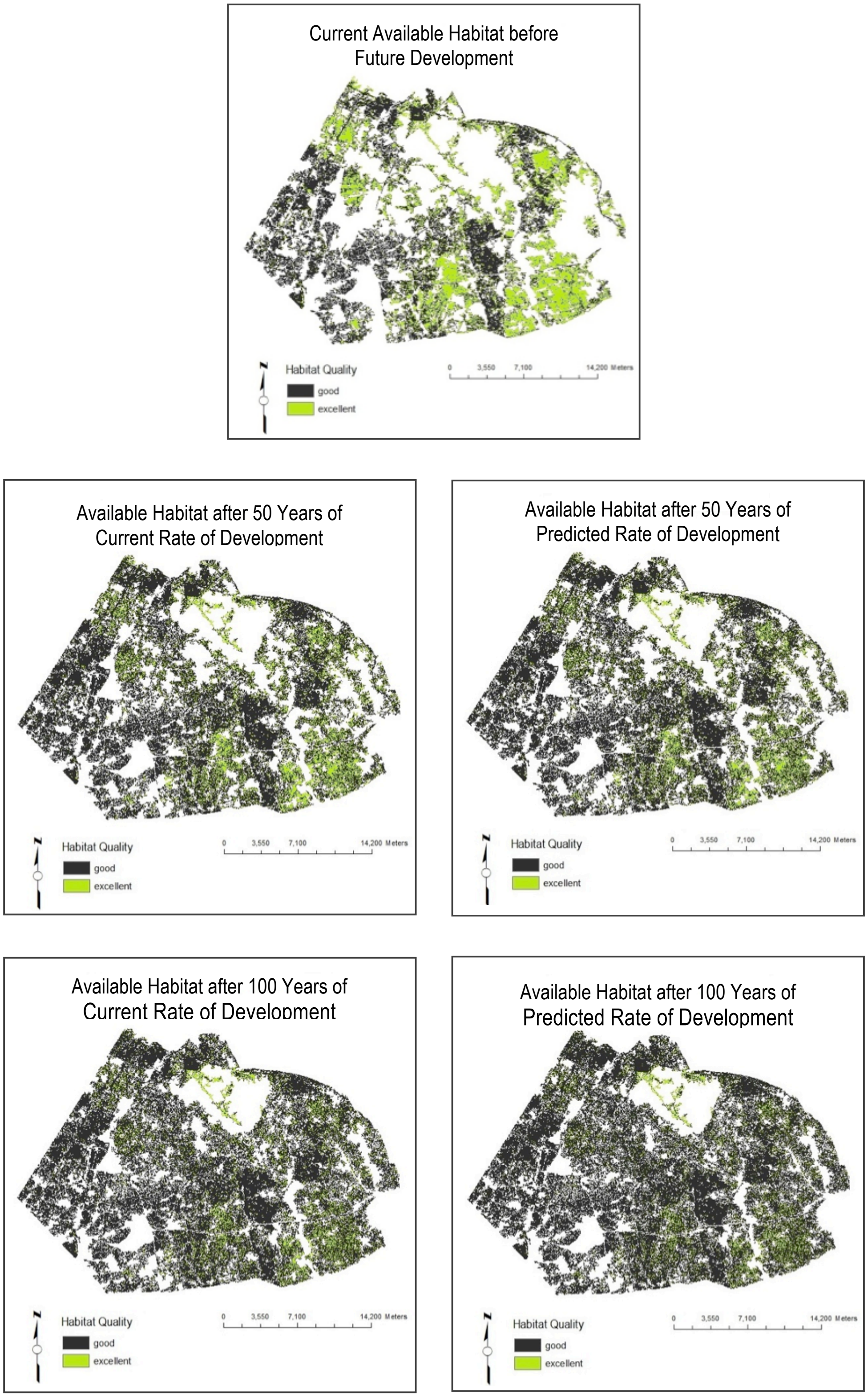

Figure 15. Available red-tailed hawk habitat without competition before (top) and after new development at current (left) and predicted (right) development rates.

Competition

Interspecific competition for habitat between red-shouldered and red-tailed hawks causes a decrease in available habitat for red-shouldered hawks, and this reduction of habitat is similar for both current and predicted rates of development, and showed no significant difference in how fast this change takes place (Figure 16). Also, the amount of available habitat with and without competition is compared, I see that for the current development rate no significant difference between the rates of change of two trends for either simulation (Figure 17). The simulation of predicted development growth resulted in what looks like less variation between the two lines.

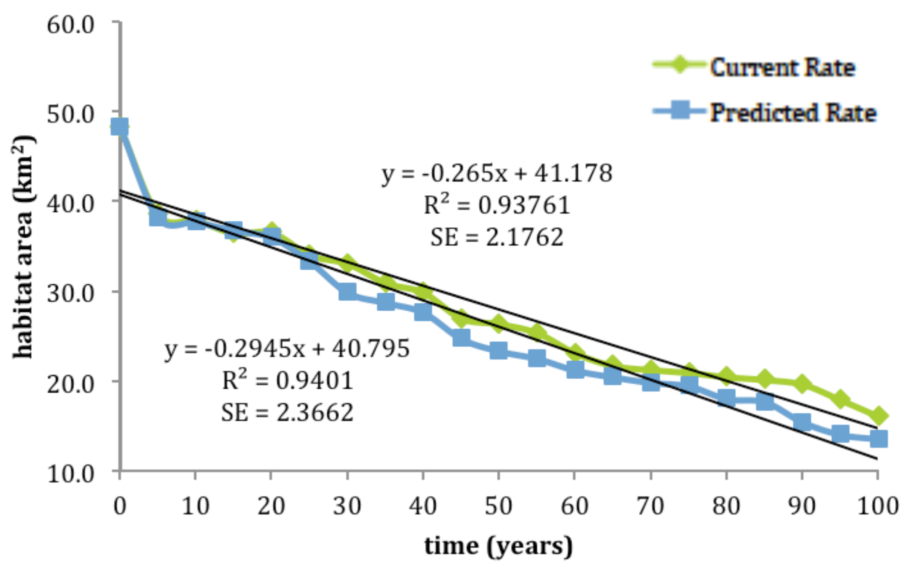

Figure 16. Change in usable red-shouldered hawk habitat with competition (with trend line), after current and predicted rate of development over 100 years.

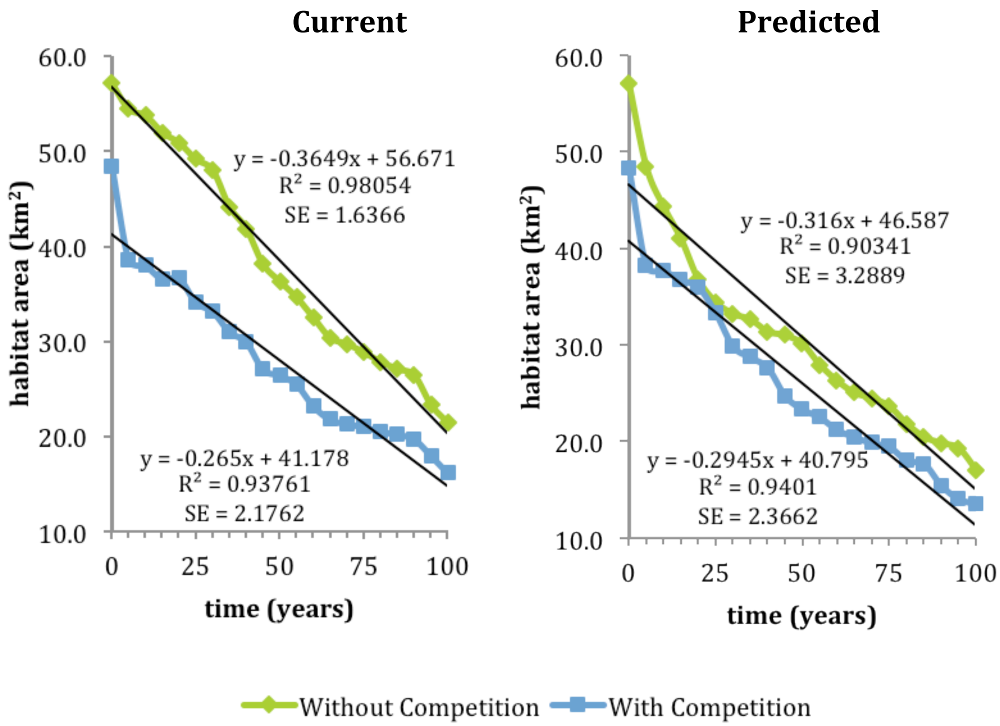

Figure 17. Change in usable red-shouldered hawk habitat with and without competition with red-tailed hawks (with trend lines), after current (left) and predicted (right) rate of development over 100 years.

Lastly, looking at the maps of available habitat with competition reveals similar behavior as when we did not included competition (Figure 18). Lower quality habitat farthest away from wetlands are taken away first, leaving more desirable habitat. However, there is more habitat of both qualities removed due to the overlap of red-tailed hawk habitat growing along with increases in development.

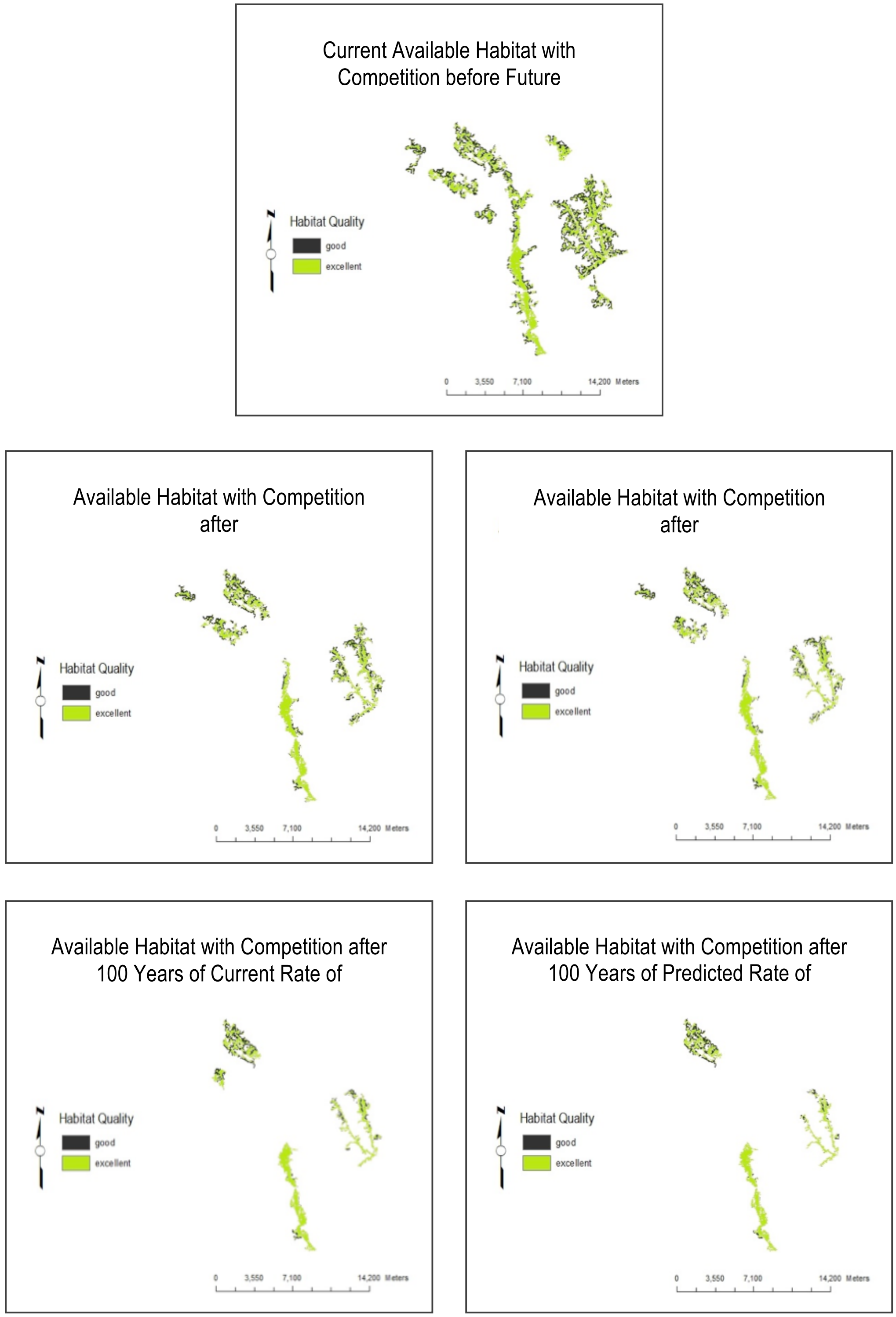

Figure 18. Available red-shouldered habitat with competition before (top) and after new development at current (left) and predicted (right) development rates.

Proportional Habitat

From looking at table 4 we can see that the red-shouldered hawk habitat with competition had the largest percent change in not only total area, but also in each quality category. There were greater differences between red-shouldered habitat with and without competition in the current rate of development than the predicted. Also, the amount of good quality red-tailed hawk habitat almost doubled, while losing more than half of excellent quality, which lead to a net growth of 33.6% and 37.1% in current and predicted development rates.

Table 4. Percent change from initial available habitat after 100 years of development at the current and predicted rate.

	Current Rate of Development			**Predicted Rate of Development**		
	Excellent	Good	Total	Excellent	Good	Total
Red-shouldered Hawk						
w/o competition	-54.5	-76.0	-62.5	-62.4	-83.3	-70.1
w/ competition	-64.6	-83.9	-71.8	-69.4	-88.2	-76.3
Red-tailed Hawk	-59.3	89.9	33.6	-65.5	99.2	37.1

It is interesting to note that there is a greater percentage difference between suitable habitat and total habitat. Figures 19-20 shows that over time a small percentage of habitat is available for use for red-shouldered hawks, but a smaller percentage is available when competition is considered. It is also seen that there is no difference in red-shouldered hawk habitat with competition between current and predicted development change. In red-tailed hawks, I see that there is an increase in the proportion of total habitat that is available to be used (Figure 21). However, there is no significant difference in the rates of change between current and predicted developments.

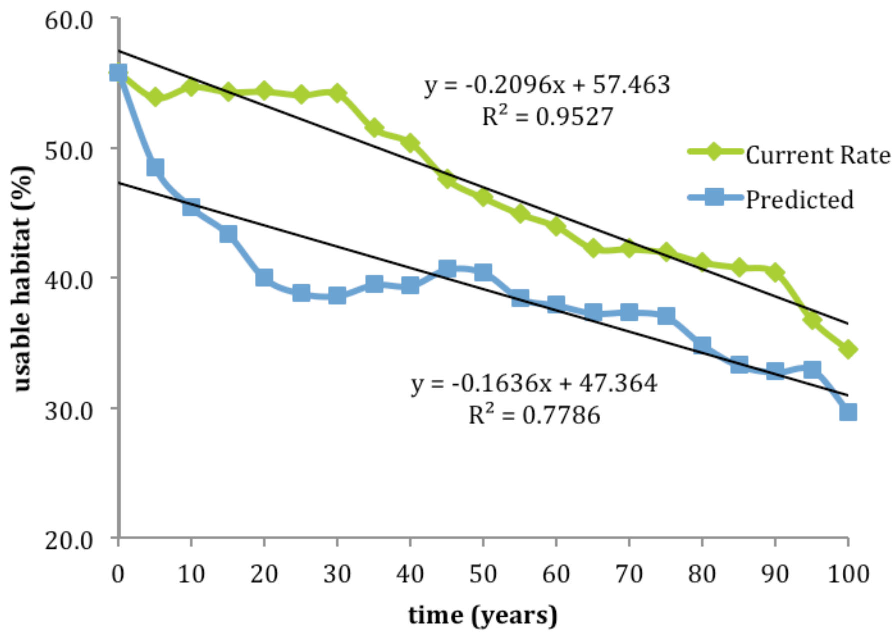

Figure 19. Change in percentage of total habitat that is available to red-shouldered hawks (with trend lines), after current and predicted rate of development over 100 years.

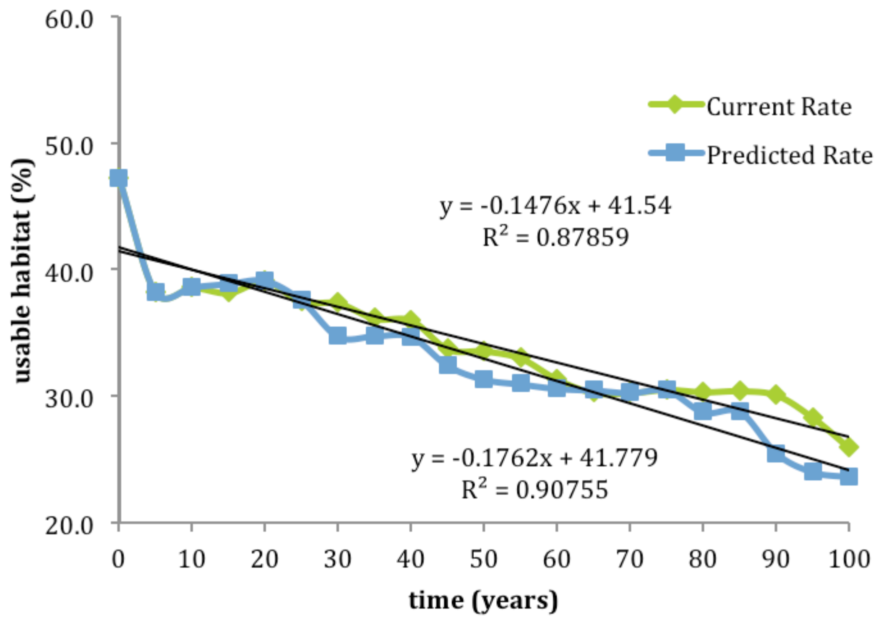

Figure 20. Change in percentage of total habitat with competition that is available to red-shouldered hawks (with trend lines), after current and predicted rate of development over 100 years.

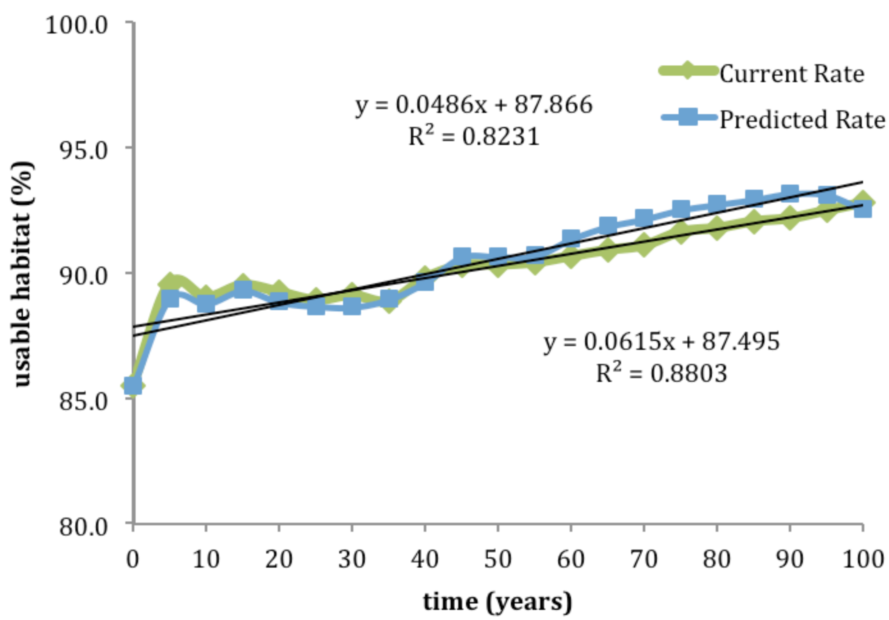

Figure 21. Change in percentage of total habitat that is available to red-tailed hawks (with trend lines), after current and predicted rate of development over 100 years.

Chapter 5

DISCUSSION

"Humankind has not woven the web of life. We are but one thread within it. Whatever we do to the web, we do to ourselves. All things are bound together. All things connect."

-Chief Si'ahl

Habitat area is critical because it determines how many individuals or pairs can be supported by the available habitat (DeLong, 2000). This carrying capacity has no way of being measured directly and therefore models that evaluate habitats are left to rely mainly on habitat use/availability data instead (Hobbs and Hanley, 1990). However this relationship between an area's carrying capacity and the species' preferred habitat type is not clearly understood. It has been observed that populations do not always occupy potential habitat areas, and therefore do not reach the carrying capacity of the area (Hobbs and Hanley, 1990; Schlossberg and King, 2009).

All habitat models have their sources of error because of many reasons. Mainly, errors in modeling arise because (1) they tend to be formulated based on the assumptions and opinions of experts, which leads to subjectivity; (2) population dynamics often get ignored and (3) patterns in habitat selection and use are oversimplified (Schlossberg and King, 2009). Therefore, the results of this thesis imply the patterns of how urban development growth affects the amount and quality of available red-shouldered and red-tailed hawk habitats in central

Maryland. This can then be used to make inferences to the population of these species of raptors.

Woodford, et al., (2008) found that the distance to the nearest wetland to not only be a significant variable but was the best distinguishing variable for red-shouldered hawk habitat. The results of these simulations showed a decrease in red-shouldered hawk habitat, and the resulting habitat was located away from developed area in wetlands, as found by Woodford, et al., (2008), and also in protected areas. Although not significant, there seems to be a faster decrease in the available habitat during the predicted development growth (Figure 11). Moorman and Chapman concluded that contiguous floodplain forest needed to be left relatively undisturbed in the effort to conserve red-shouldered hawks. This contiguous forest reduces habitat fragmentation. Therefore, it can be inferred that the faster development would cause an increased rate of habitat fragmentation. This in turn, would decrease areas that were already small to a size smaller than the minimum territory size. Consequently, the deceptively small changes in aggregate area lead to a relatively large change in suitable area (Figure 19).

Red-tailed hawks are an adaptive species. Urban landscapes have not been seen to adversely affect reproductive success (Stout, 2006) and red-tailed hawks have not been correlated to any land cover type (Dysktra, et al., 2001). Therefore, as the percentage of development in the study area increased, the amount of available red-tailed hawk habitat increased because development created more available habitat. Both habitat and non-habitat areas were converted to developed areas causing a decrease in habitat quality (Figure 15; Table 4). Despite these two competing factors, there was a net increase of habitat, which allows for an increased number of red-tailed hawk pairs that can inhabit the study area.

Stout (2006) observed an increase in red-tailed hawk population found in urbanized areas. There was over a 160% increase in the red-tailed hawk population in 14 years, and the birds expanded into urbanized landscapes; making the developed areas 58.7% of the red-tailed hawk nesting habitat. A similar occurrence was seen in Hamburg, Germany goshawk population (Rutz, 2008). As the goshawk numbers in the rural periphery of the city increased so did the population in the urban areas. So the question is, are these raptors attracted to the urban areas or are they being pushed into them? Either way, the important aspect is that they are able to adapt and thrive in the new habitat type (Stout, 2006; Rutz, 2008).

Red-tailed hawks nest earlier in the year and are the more aggressive of the two species (Bednarz & Dinsmore, 1982; Crocoll, 1994; Krischbaum & Miller, 2000; Martin 2004). When red-shouldered habitat, such as a floodplain, is opened up they have been replaced by red-tailed hawks (Bednarz and Dinsmore, 1982; Moorman and Chapman, 1996), and it has also been seen that the number of red-shouldered hawks present in an area is inversely correlated to the number of red-tailed hawks (Dysktra, et al., 2001). For that reason I conclude that the increase in red-tailed hawk habitat increases the competition between red-shouldered and red-tailed hawks and reduces the amount of habitat available for red-shouldered hawks (Figure 16). With competition there are two factors playing on the available habitat, even so, we did not see available red-shouldered hawk habitat being eliminated at a significantly faster rate (Figure 17).

One notable imperfection in the model is that when selecting for available habitat from the total, area was the only variable used. In addition to this variable, distance travelled from nest should be included. This inclusion would possibly eliminate long, thin areas that have the correct area but are too thin to be used. Another factor that would affect the amount of available habitat of both hawks would be how red-tailed hawk habitat is reclassified. The values chosen in the model were used for lack of available research. Modification to these two areas in the model would possibly have an effect on the available habitat to both red-shouldered and red-tailed hawks.

In conclusion, the overall results imply that development effects the quantity of usable habitat to red-shouldered and red-tailed hawks. However, in this case there was no significant difference found in the rates of habitat change between the two rates of development, nor between red-shouldered hawk habitat with and without competition. This can be attributed to the lack of significant difference in rate of development change. Perhaps with a statistically significant difference in how fast the land cover was changing to developed areas, there would be a statistically significant difference in available habitat for both red-shouldered and red-tailed hawks.

In general, development can benefit red-tailed hawks to a marginal extent. Stout (2006) attributes this to an avoidance of highly-developed area because of a limited number of nest and hunting sites, and therefore this high-density development makes land unsuitable and cannot support red-tailed hawks. However tall, mature trees stands in close proximity to open areas can support local red-tailed hawk populations (Preston and Beane, 1993).

Development can also be detrimental to the population of red-shouldered hawks. A growing population of red-shouldered hawks needs to have large areas of wetland and forest. There needs to be enough open areas to support a growing red-tailed hawk population and enough wetland forest for red-shouldered hawks as concluded by Bednarz and Dinsmore (1982) in their Iowa study as well as Moorman and Chapman's 1996 study of red-shouldered and red-tailed hawks in Georgia. This is the only way to reduce the competition between the two species of raptors and ensure that the red-shouldered hawk population is not replaced by the more aggressive red-tailed hawk.

Again, habitat area is critical but does not allude to the carrying capacity of an area. (Hobbs and Hanley, 1990). Models that use cover type as a basis of describing habitat, as this model does, have been tested to have on average a 60-70% accuracy rate (Schlossberg and King, 2009). This error occurs as two types. The first is omission error in which a species occupies an area where the model does not predict. Therefore this leads to predicting an area smaller than what is actually used. Second, and the most common, is commission errors. In this type of error, the model predicts a species to be present, but does not occur. In this case the area is larger than what is used (Schlossberg and King, 2009).

On a regional scale (>100 ha), which my study area would be classified as, birds, in general, have a 77% accuracy rate and 14% commission and 9%

omission rate (Schlossberg and King, 2009). These values were based on 42 tests comparing results from various models to actual animal occurrences. Therefore when we look at the data resulting from this model, we must keep in mind that the data resulting from this model is a best-case scenario of how many pairs red-shouldered hawk and red-tailed hawks are present in the study area. This can be assumed because first of all the model uses the minimum territory size, the largest amount of error is that the bird species is predicted to be in an area that it does not occupy and the idea that carrying capacity is never reached (Hobbs and Hanley, 1990; Schlossberg and King, 2009). The next step would be to test the accuracy of the results of the model. In order to do that fieldwork would have to be done on the occurrence of the raptors in their predicted habitat (Schlossberg and King, 2009).

REFERENCES

Aurambout, J.P., A.G. Endress and B.M. Deal. (2005). A spatial dynamic model to simulate population variations and movements within fragmented landscapes. *In* MODSIM 2005 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, Zerger, A. and R.M. Argent, (Eds.) 1339-1345

Barredo, J.L., M. Kasanko, N.McCormick, and C. Lavalle. (2002). Modeling dynamic spatial processes: simulation of urban future scenarios through cellular automata. Landscape and Urban Planning. 64: 145-160

Bechard, M.J., R.L. Knight, D.G. Smith, and R.E. Fitzner. (1990). Nest sites and habitats of sympatric hawks (*Buteo* spp.) in Washington. Journal of Field Ornithology 61:159-170.

Bednarz, J.C., and J.J. Dinsmore. (1982). Nest-sites and habitat of Red-shouldered and Red-tailed Hawks in Iowa. Wilson Bull. 94:31-45

Bekessy, S.A., B.A. Wintle, A. Gordon, J.C. Fox, R. Chisholm, B. Brown, T. Regan, N. Mooney, S.M. Read, M.A. Burgman. 2009. Modeling huan impacts on the Tasmanian wedge-tailed eagle (*Aquila audax fleayi*). Biological Conservation. 142: 2438-2448

Bent, A.C. (1937). Life histories of North American birds of prey. U.S. Natl. Mus. Bull. 167, Washington, DC.

Berry, J.K. (1993). Cartographic modeling: The analytic capabilities of GIS. *In* Environmental Modeling with GIS, M.F. Goodchild, B.O. Parks, and L.T. Steyaert (Eds.) New York, New York: Oxford University Press.

Brown, M. (1949). Hawks aloft: the story of Hawk Mountain. Kutztown Publ. Co., Kutztown, PA

Bryant, A.A. (1986). Influence of selective logging on Red-shouldered hawks, *Buteo lineatus*, in Waterloo region, Ontario, 1953-1978, Can. Field-Nat. 100: 520-525

Carrete, M., J.L. Tella, G. Blanco, M. Bertellotti. (2009). Effects of habitat degredation on the abundance, richness and diversity or raptors across Neotropical biomes. Biological Conservation. 142: 2002-2011

Chase, C. February (1995). Raptors: maintaining nature's balance. http://www.sdearthtimes.com/et0295/et0295s4.html. Accessed December 9, 2004

Clark, W.S., and B. K. Wheeler. (1987). A field guide to the hawks of North America. Houghton Mifflin, Boston, MA

Cornell Lab of Ornithology. (2003a). Red-shouldered hawk. http://www.allaboutbirds.org/guide/Red-shouldered_Hawk/id. Accesses June 16, 2010

Cornell Lab of Ornithology. (2003b). Red-tailed hawk http://www.allaboutbirds.org/guide/Red-tailed_Hawk/id. Accessed June 18, 2010

Crocoll, S.T. (1994). Red-shouldered hawk, *Buteo lineatus*. The Birds of North America, no.107.

Deal, B. and D. Schunk. (2004). Spatial dynamic modeling and urban land use transformation: A simulation approach to assessing the cost of urban sprawl. Ecological Economncs. 51: 79-95

DeLong, John, P. October (2000). HawkWatch International Raptor Conservation Program: issues and priorities, Interim Conservation Scientist HawkWatch International, Inc. Salt Lake City, UT

Dykstra, C.R., J.L. Hayes, F.B. Daniel and M.M. Simon. (2001). Correlation of red-shouldered hawk abundance and macrohabitat characteristics in southern Ohio. Condor 103:652-656

Goodchild, M.F. (1993). The state of GIS for environmental problem-solving. *In* Environmental Modeling with GIS, M.F. Goodchild, B.O. Parks, and L.T. Steyaert (Eds.) New York, New York: Oxford University Press.

Henny, C.J, F.C. Schmid, E.M. Martin and L.L Hood. (1973). Territorial behavior, pesticides, and the population ecology of red-shouldered hawks in central Maryland, 1942-1971. Ecology 54:545-554.

Hobbs, N.T., and T.A. Hanley. (1990). Habitat evaluation: Do use/availability data reflect carrying capacity? J. Wildl. Manage. 54(4): 515-522

Jacobs, J.P. and E.A. Jacobs. (2002). Conservation Assessment for Red-shouldered Hawk: National Forests of North Central States. Unpublished report to USDA Forest Service Eastern Region

Joy, S.M., R.M. Reich, and R.T. Reynolds. (2000). Modeling small-scale variability in the composition of goshawk habitat on the Kaibab National Forest. Proceedings of the eighth biennial Forest Service remote sensing applications conference, 10–14 April, 2000, Albuquerque, NM.

Kirschbaum, K. and S. Miller. (2000). "Buteo lineatus", Animal Diversity Web. http://animaldiversity.ummz.umich.edu/site/accounts/information/Buteo_linaetus.htm Accessed April 16, 2006

Mader, W.J. (1978). A comparative nesting study of red-tailed hawks and Harris' hawks in southern Arizona. The Auk. 95(2): 327-337

Marchex Inc. (2006). Maryland. http://www.50states.com/Maryland. Accessed April 15, 2006

Martin, E.M. (2004). Decreases in a population of red-shouldered hawks nesting in central Maryland. J. Raptor Res. 38(4): 312-319.

Maryland Department of Natural Resources [MD DNR]. (2005). Maryland wildlife diversity conservation plan. Maryland Department of Natural Resourses, Annapolis, Maryland

Moorman, C.E. and B.R. Chapman. (1996). Nest-site selection of red-shouldered and red-tailed hawks in a managed forest. Wilson Bull. 108(2): 357-368

Orians, G. H., and F. Kuhlman. (1956). Red-tailed hawk and horned owl populations in Wisconsin. Condor 58:371-385.

Powell, D.S., and N.P. Kingsley. (1980). The forest resources of Maryland. Resource Bulletin. NE-61. United States Department of Agriculture, Forest Service, Northeastern Forest Experiment Station.

Preston, C.R. and R.D. Beane. (1993). Red-tailed hawk (*Buteo jamaicensis*). *In* A. Poole and F. Gill (Eds.) The birds of North America, No. 52. The Academy of Natural Sciences, Philadelphia, PA and The American Ornithologists' Union, Washington, DC.

Pyne, S.J. (1982). Fire in America: A cultural history or wildland and rural fire. Princeton University Press, Princeton, NJ

Robbins C.S., D. Bystrak, and P.H. Geissler. (1986). The breeding bird survey: Its first fifteen years, 1965-1979. US Department of the Interior. Fish and Wildlife Resources, Washington, DC

Rutz, C. (2008). The establishment of an urban bird population. Journal of Animal Ecology. 77: 1008-1019

Schlossberg, S. and D.I. King (2009). Modeling animal habitats based on cover type: A critical review. Environmental Management 43: 609-618

Stewart, R.E. (1949). Ecology of a nesting Red-shouldered Hawk population. Wilson Bull 61: 26-35

Steyaert, L.T. (1993). A perspective on the state of environmental simulation modeling. *In* Environmental Modeling with GIS, M.F. Goodchild, B.O. Parks, and L.T. Steyaert (Eds.) New York, New York: Oxford University Press.

Stout, W.E. (2006). Landscape features of red-tailed hawk nesting habitat in an urban/suburban environment. J. Raptor Res 40(3): 181-192

Trauger, D.L., B. Czech, J.D. Erickson, P.R. Garrettson, B.J. Kernohan, and C. A. Miller. (2003). The relationship of economic growth to wildlife conservation. Wildlife Society Technical Review 03-1:1-22.

United States Environmental Protection Agency [EPA]. (2003). Mid-Atlantic Integrated Assessment: Habitat Loss. http://www.epa.gov/emfjulte/tpmcmaia/html/habitat.html. Accessed September 14, 2006

United States Forest Service [USFS]. (2004). Northeastern forest inventory and analysis statewide results: Maryland. U.S. Department of Agriculture, Forest Inventory and Analysis Program, Newtown Square, Pennsylvania.

Weber, T. (2003). Maryland's green infrastructure assessment: a comprehensive strategy for land conservation and restoration. Maryland Department of Natural Resources, Watershed Services Unit, Annapolis, Maryland.

Whitney, G. G. (1994). From coastal wilderness to fruited plain: a history of environmental change in temperate North America 1500 to the present. Cambridge University Press, Cambridge, U.K.

Wiegand, T., K.A. Moloney, J. Naves, and F. Knauer. (1999). Finding the missing link between landscape structure and population dynamics: A spatially explicit perspective. The American Naturalist 154(6): 605-627

Woodford, J.E., C.A. Eloranta, and A. Rinaldi. (2008). Nest density, productivity, and habitat selection of red-shouldered hawks in a contiguous forest. J. Raptor Res. 42(2): 79-86