The Pennsylvania State University

The Graduate School

College of Agricultural Sciences

NORTHERN GOSHAWK HABITAT SUITABILITY AND MONITORING PLAN

A Thesis in

Forest Resources

by

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Abstract

The Northern Goshawk (Accipiter gentilis) is an umbrella species of large mature forests in the northeastern United States and has recently shown a breeding population decline. It has been declared “Vulnerable” in Pennsylvania, “Critically Imperiled” in West Virginia and Maryland, and “Extirpated” in Virginia. While much of the natural history and habitat preferences of this species is known, the breeding distribution and regional population size is not. I identified two objectives to determine those unknowns: 1) Create a habitat suitability model for Northern Goshawk in Pennsylvania, West Virginia, Maryland, and Virginia; 2) Develop a monitoring plan and define conservation guidelines for Northern Goshawk in the region. The entire study is based on a 600-hectare grid network of sampling units that was overlain on the region. Confirmed nest locations from 1980 to 2013 were compiled. Sampling units that intersected a 600-hectare buffer around the nest points were categorized as being occupied (1) and all others as unoccupied (0). A habitat envelope was created to constrain the study to only potential habitat using a threshold of 40% forest canopy cover. Sampling units with an average canopy cover less than 40% were labeled as non-habitat and removed from the analysis. The following predictor covariates were averaged for each sampling unit: canopy bulk density, canopy height, canopy cover, dominant forest group, edge/core forest proportion, elevation, slope, annual precipitation, maximum temperature. These covariates represent forest habitat, topography, and climate parameters. Because the study area is so large, it was divided by level III ecoregions and tested using a Multiple Comparisons of Means Tukey Test to compare habitat preferences of goshawks in each ecoregion. Northern Goshawk habitat preferences for elevation, slope, annual precipitation, and maximum temperature were all significantly different between each ecoregion and substantiated splitting the study area into three ecoregions: Allegheny Plateau, Central Appalachians, and Ridge and Valley. Habitat suitability models for each ecoregion were then calculated using logistic regression between sampling unit occupation (1,0) and habitat covariates (forest, topography, and climate covariates). The top models were selected for
each ecoregion by using AIC (Akaike Information Criterion) weights. The top Allegheny Plateau ecoregion model equation suggested Northern Goshawks prefer habitats with higher canopy bulk density (above-ground tree biomass), canopy cover, canopy height, and mean annual precipitation, a dominance of Northern hardwood tree species (maple/beech/birch forest group), lower elevation, slope, and mean temperature during breeding season, and less edge habitat based on significant covariates. The top Central Appalachians ecoregion model equation suggested Northern Goshawks prefer habitats with high canopy cover, elevation, and mean annual precipitation, a dominance of Northern hardwood tree species, and lower canopy bulk density, slope, and mean temperature during breeding season. The top Ridge and Valley ecoregion model equation suggested Northern Goshawks prefer habitats with higher canopy bulk density, canopy height, mean annual precipitation, a dominance of Northern hardwood tree species, and lower elevation, slope, and mean temperature during breeding season. Sampling units for each ecoregion were then ranked as primary or secondary using predicted probabilities. Much of the primary habitat coincided with state and federal land, which is generally managed as contiguous mature forest. Logistic regression should be used to revise the habitat suitability models every five years and include new occupation and habitat covariate data when available.

A limited field season was used to test the breeding Northern Goshawk survey protocols established by Hargis and Woodbridge (2006). Playback-based field surveys were conducted in the Allegheny Plateau (Allegheny National Forest) and Ridge and Valley ecoregion (Rothrock, Moshannon, and Bald Eagle State Forests). Ten primary and ten secondary sampling units were randomly selected in each ecoregion within the public land boundaries. Surveys were conducted during the nestling (mid-May to mid-June) and fledgling (mid-June to mid-July) phases of goshawk development. 120 playback points were uniformly distributed along transects 250 meters apart in each sampling unit. Three-minute playbacks of goshawk territorial vocalizations were broadcast at each point. Due to poor weather and a limited number of surveyors, only 5 primary and 4 secondary sampling units were surveyed in Allegheny
Plateau, and 7 primary and 6 secondary sampling units were surveyed in Ridge and Valley ecoregion. Surveys were only conducted once per sampling unit. Two Northern Goshawks were detected for 246 work-hours in the Allegheny Plateau surveys. One Northern Goshawk was detected for 393 work-hours in the Ridge and Valley surveys. Therefore, one goshawk was detected for every 213 work-hours within 22 sampling units surveyed. Because only one survey was conducted at each sampling unit, population estimates could not be calculated. Our limited surveys were constrained by lack of funding to employ additional survey personnel. To maximize use of funds and decrease the work-hours involved in detecting goshawks, a reduced protocol using 60 playbacks per sampling unit could be implemented. Simply reducing the number of playback points by half will drop the estimated 24-32 work-hours per sampling unit by three hours.

The Pennsylvania Game Commission, U.S. Forest Service, PA Department of Conservation and Natural Resources, and MD Department of Natural Resources should use the following set of conservation guidelines for monitoring and conserving Northern Goshawk potential and established breeding habitat: 1) Revise the Habitat Suitability Model for the four-state region every 5 years using logistic regression with latest Northern Goshawk occurrences and any more accurate habitat parameters. 2) By 2026, targeted surveys should be conducted on public land with a concentration of primary sampling units and potential threats of forest fragmentation, such as those identified in Figure 13 for north central Pennsylvania. 3) Conduct further research on Broadcast Acoustical Survey protocol to determine if revised survey of reduced playback points is effective for determining frequency of occupation in sampling units. 4) Establish two concentric buffer zones around active or presumed active (within 10 years of activity) nest trees. No disturbances should be permitted within the 300-meter radius of the first buffer zone. Only limited disturbances, such as low-impact silvicultural practices, should be permitted within the 800-meter radius of the second buffer zone. Disturbances should be isolated to the non-breeding season (October – February).
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Chapter 1

Introduction

The Northern Goshawk has recently been declared “Vulnerable” in Pennsylvania, “Critically Imperiled” in West Virginia and Maryland, and “Extirpated” in Virginia due to a decline in the number of detected breeding pairs (Pennsylvania Natural Heritage Program 2014). These four states represent the southern extent of this elusive forest raptor’s range in the eastern United States; however, the current population status of the Northern Goshawk in the entire eastern United States is estimated to be stable or increasing (Brauning 1992; DeStefano 2005). To address this disparity, I developed a habitat suitability model to understand the current and future population and distribution at a finer, landscape level and established a regional monitoring plan for Northern Goshawk in these four states: Pennsylvania, West Virginia, Maryland, and Virginia.

The recent local decline of this species is not well understood, but we do have clues to its historic status. The distribution of the species from the pre-colonial era through the 19th century is assumed to be quite extensive through much of the Northeast. Many historical records exist for Northern Goshawks in Pennsylvania, but no surveys or inventories were ever completed before the Pennsylvania Breeding Bird Atlas in 1983-1989 (Brauning 1992). Prior to European settlement, Northern Goshawks are believed to have preyed predominantly on passenger pigeons (Ectopistes migratorius), which maintained a population of billions in the eastern United States (Bent 1937; Ellsworth and McComb 2003). This species quickly went extinct due to overhunting by the early 20th century and most certainly led to a decline in goshawk numbers.

The industrial revolution and subsequent booming railroad industry led to extensive logging and deforestation throughout the eastern United States, particularly in the study region of Pennsylvania, West Virginia, Maryland, and Virginia. In the decades surrounding 1900, a majority of the land had been
stripped of trees at one point or another. The Pennsylvania Game Commission also instituted a bounty on Northern Goshawks beginning in 1929 that continued until the signing of the Migratory Bird Treaty Act in 1972. These factors have most certainly reduced the population of Northern Goshawks (Curnutt 2007; Speiser and Bosakowski 1987). However, due to recent reforestation in the last 100 years, the percent of forested land in Pennsylvania (59%) is at its highest since pre-industrial revolution. Nearly 40% of that forested land is at least 80 years old (McCaskill et al. 2009). With this steady increase in available habitat and federal protection of this species, populations have been increasing and expanding in the eastern United States, particularly New England and the Great Lakes region (Andrle and Carroll 1988; Brauning 1992; Bevier 1994; Brewer et al. 1991; Veit and Petersen 1993). Yet the decline in the southern extent of the species’ distribution, New York and south, occurred after federal protection and despite abundant potential habitat.

Environmental changes due to invasive forest pests in the region are reducing the quality of the potential forest habitat. Historically, Northern Goshawks were recorded nesting as far south as the Great Smoky Mountains National Park (Haney 1981). The goshawk’s breeding range reached furthest south during the 1970s and ‘80s, which corresponded to a boom in population, as evidenced by cyclical fall irruptions (Hawk Mountain 2014). But since that time, the Northern Goshawk’s breeding range has retracted north to Pennsylvania’s southern border and irruptions have declined. In fact, no significant fall migration has occurred since the early 1990’s (Hawk Mountain 2014). This trend suggests that the population has declined on a larger scale than just the Southern Appalachian Mountains. But at the same time, the montane forest communities of the Southern Appalachians have also changed. The high elevation spruce-fir forests have declined significantly due to invasive forest pests, most notably the hemlock wooly adelgid (Adelges tsugae). This invasive insect has caused the large-scale destruction of frasier fir (Abies fraseri) starting in the 1980’s and thus reduced the canopy cover of the high elevation spruce-fir forests (Rabenold et al. 1998). The hemlock wooly adelgid has significantly expanded its range
throughout the Appalachian Mountains and into southern Maine (Kislinski et al. 2003). Because of the
goshawk’s preference for conifers and especially hemlock-hardwood communities in the Eastern United
States, the hemlock wooly adelgid outbreak has impacted habitat suitability (Kislinski et al. 2003). The
effect of this forest pest on hemlock-dominant forest communities could be responsible for at least
some of the present and future declines in the southern portion of the Northern Goshwawk’s range in
Pennsylvania, Maryland, West Virginia, and Virginia. Therefore more studies such as this one are
necessary to determine the current and future population and distribution of this species throughout its
northeastern range.

The natural history and habitat use by this species is important to this study. Northern
Goshawks breed in extensive mature forest and occupy this habitat on many spatial levels. Habitat use
by Northern Goshawks during the breeding season can be divided into the home range, primary foraging
area, post-fledgling family area, and nest site as illustrated in Figure 1. None of these habitat use zones
can be defined as being uniform in size or centered on the active nest. The nest site is defined as the
habitat immediately surrounding the active nest and can be 8-10 hectares in size. Post-fledgling Family
Area (PFA) is the forest stand that is primarily used by fledglings before gaining independence from the
adults. Kennedy (1991) defined the PFA as 122-243 hectares in New Mexico and was supported by
Kimmel (1995) in his Pennsylvania studies. Northern Goshawks build three to nine nests per territory
and most of these can be found within a radius of one kilometer from the active nest, which
corresponds roughly to the PFA size. Expanding beyond the PFA is the Primary Foraging Area (PRFA),
which is used by adults to hunt during breeding and rearing of chicks. It tends to fluctuate depending on
whether one adult or both are hunting. The female rarely leaves the nest during incubation, leaving the
male to forage in a more condensed area. After the chicks hatch, the female alternates with the male to
protect the chicks and hunt for prey. The time between the chicks hatching and fledging is when the
PRFA is the largest, roughly 250 hectares. The most variable habitat use zone is the home range, which is
defined as the total area occupied during the breeding season. It can vary from 212 to 2,465 hectares across North America (Reynolds et al. 1992), but is accepted as 1,800 – 2,000 hectares for the Northeast (Kimmel 1995). During non-breeding and winter months, *A. gentilis* expands its range by several miles in radius or completes a short-distance migration to find an area with a sustainable prey population (Brinker, personal communication 2013).

Habitat selection by Northern Goshawks is determined by available habitat, interspecific territoriality, and availability of prey but generally follows an ideal free distribution model (Kennedy and Gray 1993; Reynolds and Joy 1998). Under this model, primary habitat is occupied first and secondary habitat is occupied only when competition for resources in primary habitat is greater than the perceived quality of resources available in secondary habitat. Goshawks are also fiercely territorial and more dominant individuals force others to occupy secondary habitat before resources become a limiting factor in primary habitat. Therefore, a fixed number of goshawk territories are usually present in ideal habitat even during population booms of prey species. Additionally, when goshawk populations decline, secondary habitats should show a decline in occupancy rate before primary habitats (Miller et al. 2014).

General characteristics of nest sites include a preference for mixed northern hardwood-hemlock forests in an extensive, mature forest (Brauning 1992). These stands feature trees with diameters between 20-40 cm diameter-at-breast height (dbh), and greater canopy height and basal area than surrounding forests (Bush 2006; Speiser and Bosakowski 1987). Nest sites with adjacent small openings (< 0.1 ha) are also preferentially selected. Bogs or ponds, and forested roads or trails are typical causes of these openings (Kimmel 1995). Mature conifers coupled with small openings provide cover and foraging areas for preferred prey species that include woodpeckers (Picidae), crows and jays (Corvidae), ruffed grouse (*Bonasa umbellus*), and tree squirrels (Sciuridae). Waterfowl such as American black duck (*Anas rubripes*) and mallard (*Anas platyrhynchos*) are also preyed upon and tend to breed on the small ponds and bogs (Eng and Gullion 1962).
Figure 1. Spatial Layers of Habitat Use by breeding Northern Goshawk (NOGO). Habitat Use is split into four Territory Layers in eastern United States: Nest Site (~10 ha), Post-fledgling Family Area (~200 ha), Primary Foraging Area (~1,260 ha), and Home Range (~1,960 ha) (Kimmel 1995).
The entire study region contains several different geographic and forest regions, and habitat preferences vary between them. Only two studies have addressed this and focused on differences between Northern Hardwood and Appalachian Oak forests in Pennsylvania and New Jersey. Kimmel (1995) conducted a habitat analysis in northwest and north-central Pennsylvania, while Speiser and Bosakowski (1987, 1991) analyzed field sites in northern New Jersey and southern New York. In these studies, Northern Hardwood and Appalachian Oak forests were identified as having distinctly different composition and nest site preferences by goshawks. The Northern Hardwood region contains a dominant mixture of yellow birch (*Betula alleghaniensis*), American beech (*Fagus grandifolia*), and sugar maple (*Acer saccharum*), while the dominant tree species in the Appalachian Oak region contains several oak species (*Quercus sp.*) along with hickory (*Carya sp.*), red maple (*Acer rubrum*), white pine (*Pinus strobus*), and black birch (*Betula lenta*) (Whitney 1990). Goshawks nesting in Northern Hardwood forests showed a preference for conifers, such as white pine (*Pinus strobus*) and eastern hemlock (*Tsuga canadensis*), while those in Appalachian Oak forests were more likely to choose stands of northern hardwood trees (Speiser and Bosakowski 1987). These forest regions dominate the focal area for this study as well and are addressed in the following section.

**Objectives**

My goal for this project is to create a monitoring plan for Northern Goshawks in Pennsylvania, Maryland, Virginia, and West Virginia. The first step in creating a monitoring plan is to create a habitat suitability model. The habitat suitability model identifies preferred goshawk habitats throughout the regional landscape and is informed by preferred habitat characteristics and the locations of confirmed nest territories. The information gained from the habitat suitability model is used to inform monitoring efforts and management of Northern Goshawk habitat and known nest territories.
A habitat suitability model and monitoring plan are required to effectively determine and manage the current and future population of Northern Goshawks. Both have already been established for several states including Arizona, Utah, Minnesota, Wisconsin, and Michigan (Boal et al. 2003; Bruggeman et al. 2011; Kennedy 1997; Reynolds et al. 1992; Zarnetske et al. 2007). These plans produced various habitat requirements due to differences in vegetation, topography, and climate and are specific to the regional locations for which they were developed. Following suit, this study was created to develop a habitat suitability model and monitoring plan for PA, MD, VA, and WV.

The specific objectives of this study are as follows:

1) Create a habitat suitability model for Northern Goshawk in Pennsylvania, West Virginia, Maryland, and Virginia.

2) Develop a monitoring plan and define conservation guidelines for Northern Goshawks in the region.
Chapter 2

Habitat Suitability Model

Introduction

A habitat suitability model is an effective classification of potential habitat used by a species. Many regional monitoring plans for Northern Goshawks across the United States and Canada have been based on habitat suitability models (Beck et al. 2011; Bruggeman et al. 2011; Bush 2006; Reich et al. 2004; Zarnetske et al. 2007).

Most monitoring plans were based on a form of habitat analysis through logistic regression using forest metrics and known nest sites. But each study used different forest and topography metrics. Reich et al. (2004) analyzed Northern Goshawk habitat at the nest site level (10-30 square meters), while Zarnetske et al. (2007) analyzed habitat at both the nest site (30 square meters) and nest area levels (250 square meters). Bush (2006) analyzed habitat at several levels of spatial resolution from nest tree to home range (12-3500 hectares). While each study is useful for determining habitat suitability and occupancy for each particular region, interregional comparisons are very difficult due to the variability in sampling scale. In order to produce comparable habitat and occupancy analysis of Northern Goshawks throughout the United States, Hargis and Woodbridge (2006) produced the Northern Goshawk Monitoring and Technical Guide. They set the spatial area at 600 hectares for bioregional analysis. A 600-hectare area is large enough to maximize sampling efforts while minimizing the chance of a sampling unit having more than one Northern Goshawk territory.

While the sampling unit size was standardized in this guide, the habitat variables were not. Regional variability in habitat preferences between forest ecosystems has been well studied throughout the United States (Beck et al. 2011; Bruggeman et al. 2011; Bush 2006; Kimmel 1995; Morrison 2006; Reich et al. 2004; Reynolds et al. 1992; Speiser and Bosakowski 1987; Zarnetske et al. 2007). Northern
Goshawks have specific habitat preferences in different regions of the United States. Hargis and Woodbridge (2006) separated the Northern Goshawk’s breeding range into bioregions of similar habitat and preferences (Cascade Sierra, Central Rocky Mountains, Colorado Plateau and Southwest Mountains, Great Lakes, Intermountain Great Basin, North Rockies and Blue Mountains, Northeast and Central Appalachians, West Coast, Coastal Alaska, and Interior Alaska Forests). This study developed a monitoring plan for Pennsylvania, Maryland, Virginia, and West Virginia, a subset of the Northeast and Central Appalachians Bioregion.

**Methods**

The habitat suitability model was created in four steps: 600 Hectare Grid, Habitat Envelope (potential habitat within the species’ range), Habitat Suitability Model, and Suitability Map, as outlined in Figure 2. The model incorporates several data sources including the range and distribution, known breeding locations, and influential habitat characteristics of the Northern Goshawk.

First, a grid was overlaid on the entire four-state region. This grid network provides a standardized format to analyze the entire region. The grid cell size was set at 600 hectares, which is the smallest area size that can be used while ensuring that there is little or no chance of finding more than one Northern Goshawk territory in a sampling unit. Each grid cell, hereafter referred to as a sampling unit, in the region-wide grid was categorized as a “1” or “0” based on whether an active Northern Goshawk nest had been recorded within its boundaries. However, this method would almost never result in a nest centered in a sampling unit. Therefore, a 600-hectare polygon was overlaid and centered over each nest point. Those sampling units with any portion intersecting the overlaid polygons were also categorized as a “1.” This can be seen in Figure 3.
Figure 2. A Workflow Diagram of the Northern Goshawk Habitat Suitability Model for PA, MD, WV, and VA. The model flows from the ‘600 Hectare Grid’ to the ‘Suitability Map,’ with boxes connected with thin black arrows identifying data sources incorporated in each step of the workflow. (EPA – Environmental Protection Agency. NLCD – National Land Cover Database. DEM – Digital Elevation Model. FIA – Forest Inventory and Analysis).
Figure 3. “Occupied” Sampling Units based on Goshawk Nest Location. Sampling units are defined as “Occupied” if a nest territory has been confirmed within the boundaries of sampling unit. Additionally, when a 600-hectare square is overlaid on a nest point and that square overlaps an adjacent sampling unit, that sampling unit will also be categorized as “Occupied”.
To determine potential habitat in the region, I compiled known breeding territories from the 1st and 2nd Pennsylvania Breeding Bird Atlases (Brauning 1992; Wilson et al. 2012), West Virginia Breeding Bird Atlas (Buckeley and Hall 1994), and published and private research from Dr. T. Kimmel (Penn State University, unpublished data), Doug Gross (Pennsylvania Game Commission personal communication 2012), and David Brinker (Maryland Department of Natural Resources personal communication 2013). Breeding Bird Atlas records were categorized as “Observation,” “Possible,” “Probable,” and “Confirmed.” The accepted records included locations where goshawks were confirmed on nest and/or with young, and where probable breeding was witnessed. Supporting evidence for the latter includes a pair observed in suitable habitat, agitated behavior, visiting probable nest site, courtship, display, or copulation, and a territory held for at least seven days (Brauning 1992). Since some of these records were over thirty years old, those locations with major disturbances (major highways, large agricultural fields, and urban areas) were removed from the dataset.

Level III Ecoregions (US EPA) were included to further break down habitat preferences within the region and increase model accuracy (Hargis and Woodbridge 2006). The Blue Ridge, Northern Appalachian and Atlantic Maritime Highlands, and Ridge and Valley were consolidated into the Ridge and Valley region. The North Central Appalachians and Northern Allegheny Plateau were merged into an extended Allegheny Plateau region and the Central Appalachians remained as an independent model area. The grid cells were clipped by these boundaries.

While some studies have shown a difference in Northern Goshawk habitat preferences between Northern Hardwood and Appalachian Oak forest types, no studies have been conducted to determine a change in habitat preference between the Allegheny Plateau, Ridge and Valley, and Central Appalachians ecoregions. Therefore, a pairwise mean comparison test was used to determine if this is an effective method (Kimmel 1995; Speiser and Bosakowski 1987). Habitat variables for “Occupied” Northern Goshawk sampling units were summarized and tested through pairwise comparisons between
each ecoregion (Ridge and Valley, Allegheny Plateau, and Central Appalachians). The null hypothesis for each test was that the two datasets being tested (mean “Occupied” habitat variables for each of two ecoregions) were taken from the same population. The alternate hypothesis was that the two datasets were not taken from the same population. A “Multiple Comparisons of Means Tukey Test” was then conducted in R Statistical Software (R Development Core Team 2008) using the following habitat variables: canopy bulk density, canopy cover, canopy height (Landfire 2010), elevation, slope (Digital Elevation Model 2008), mean annual precipitation (1981-2010), and mean maximum temperature in July (1980-2010) (Kutner et al. 2005).
Table 1. Results of Multiple Comparisons of Means Tukey Test Comparing Habitat Preferences of Northern Goshawks Per Ecoregion in Pennsylvania, Maryland, West Virginia, and Virginia. Habitat variables were summarized for each “Occupied” sampling unit per ecoregion. The ecoregions are abbreviated as AP (Allegheny Plateau), RV (Ridge and Valley), and CA (Central Appalachians). Sample size for each ecoregion is Ridge and Valley (81), Allegheny Plateau (412), Central Appalachians (62).

### Canopy Bulk Density

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<tbody>
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<tr>
<td>RV – AP</td>
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<tr>
<td>RV – CA</td>
<td>1.935</td>
<td>0.126</td>
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</table>

**Kilograms$^3 \times 100**

### Canopy Cover

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<th>Ecoregions</th>
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<th>p-value</th>
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<tbody>
<tr>
<td>CA – AP</td>
<td>3.077</td>
<td>0.0059*</td>
</tr>
<tr>
<td>RV – AP</td>
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<tr>
<td>RV – CA</td>
<td>-3.765</td>
<td>&lt;0.001*</td>
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*Significant p-value, <0.05
**Percent Forested

### Canopy Height

<table>
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<th>p-value</th>
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</thead>
<tbody>
<tr>
<td>CA – AP</td>
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<td>&lt;0.0001*</td>
</tr>
<tr>
<td>RV – AP</td>
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<tr>
<td>RV – CA</td>
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*Significant p-value, <0.05
**Meters x10

### Elevation

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<th>p-value</th>
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<tbody>
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<td>CA – AP</td>
<td>26.519</td>
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<tr>
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</table>

*Significant p-value, <0.05
**Meters above sea level
### Slope

<table>
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</tr>
<tr>
<td>RV – AP</td>
<td>3.968</td>
<td>0.0002*</td>
</tr>
<tr>
<td>RV – CA</td>
<td>-1.236</td>
<td>0.424</td>
</tr>
</tbody>
</table>

*Significant p-value, <0.05
**Degrees

### Mean Annual Precipitation (1980-2010)

<table>
<thead>
<tr>
<th>Ecoregions</th>
<th>t value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA – AP</td>
<td>17.66</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td>RV – AP</td>
<td>-6.01</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td>RV – CA</td>
<td>-18.58</td>
<td>&lt;0.0001*</td>
</tr>
</tbody>
</table>

*Significant p-value, <0.05
**Millimeters x100

### Mean Maximum Temperature in July (1980-2010)

<table>
<thead>
<tr>
<th>Ecoregions</th>
<th>t value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA – AP</td>
<td>-9.737</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td>RV – AP</td>
<td>19.409</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td>RV – CA</td>
<td>21.840</td>
<td>&lt;0.0001*</td>
</tr>
</tbody>
</table>

*Significant p-value, <0.05
**Degrees Celsius x100
The results in Table 1 substantiate splitting the four-state region into three ecoregions, Allegheny Plateau, Ridge and Valley, and Central Appalachians, in order to create an effective habitat suitability model. Goshawk habitat preference was significantly different between at least two ecoregions for all but one habitat variable, canopy bulk density. Elevation, annual precipitation, and mean annual temperature in July preferences were all significantly different between each ecoregion. Northern Goshawks preferred higher canopy cover in the Central Appalachian ecoregion. Higher canopy height and less steep slopes were preferentially selected in the Allegheny Plateau ecoregion. Regional biologists also postulated these differences in habitat preference and perhaps available habitat between ecoregions (Brinker, personal communication 2013; Gross, personal communication 2013).

Ecological information was used to create a habitat envelope in order to constrain the distribution of potential habitat. Previous studies have ignored ecological information by comparing known presence areas to areas of low-suitability or across a broad study region (Parra-Olea et al. 2005; Lutolf et al. 2006). These studies do not account for presence-only bias by sampling outside of the species known distribution. By excluding the non-habitat we improve the fit and predictive capability of the habitat suitability model. Non-habitat includes areas of extensive agriculture, urban, suburban, and other non-forested areas. Potential habitat is defined as forested habitat that could be used for either nesting or foraging during the breeding season. The known and potential habitats are then collectively referred to as the habitat envelope (Zarnetske et al. 2011).

I created the habitat envelope for Northern Goshawks in Pennsylvania, Maryland, West Virginia, and Virginia using the most recent canopy cover data from the National Atlas (U.S. Geological Survey 2013). Canopy cover has been recommended by Hargis and Woodbridge (2006) for eliminating Northern Goshawk non-habitat and has been used effectively by Bruggeman et al. (2011) in the Great Lakes Bioregion. Sampling units below a certain canopy cover percentage were excluded in this study. I created multiple habitat envelopes using different canopy cover percentage thresholds. The selected
habitat envelope excluded the most sampling units while not excluding any ‘Occupied’ sampling units. I determined this threshold to be at 40 percent forest canopy cover (Figure 4). Any sampling units with a mean canopy cover percentage below 40 percent were excluded from the habitat envelope and labeled as non-habitat.

With the habitat envelope created, I summarized the habitat covariates for each sampling unit and consolidated them into a table for each ecoregion: Allegheny Plateau, Central Appalachians, and Ridge and Valley. Since the response variables were categorical (1,0) and predictors continuous, a logistic regression was the best option to create a habitat suitability model for the study region. Zarnetske et al. (2007), as well as other studies based upon the Northern Goshawk Monitoring and Technical Guide (Hargis and Woodbridge 2006) support this method in order to create an effective model of habitat suitability (Beck et al. 2011; Bruggeman et al. 2011).
Figure 4. Habitat Envelope of Potential Breeding Habitat of Goshawks in PA, MD, WV, and VA.
The Habitat Envelope contains sampling units (600 ha grid cells) that are declared potential breeding or foraging habitat for Northern Goshawks. Potential habitat is defined as a sampling unit with average forest canopy equal to or greater than 40% (National Atlas 2013). The habitat envelope is split into three ecoregions (Allegheny Plateau, Central Appalachians, and Ridge and Valley) based on different habitat preferences.
I regressed the following habitat covariates against the sampling units to create the selected model equation output: elevation, slope (USGS Digital Elevation Model 2008), forest canopy bulk density, forest canopy cover, forest canopy height (Landfire 2008), forest group type (FIA 2008), forest edge to core proportion 1980-2010 (National Land Cover Database 2011), mean annual precipitation, and mean maximum July temperature (PRISM 2008; Table 2 and Figures 5-8).

Elevation and slope parameters were included to account for topographic preferences by Northern Goshawks in breeding territories. Previous studies in the region have shown that goshawks prefer to nest in areas with low slope while elevation preferences change based on ecoregion (Kimmel 1995; Speiser and Bosakowski 1987). Northern Goshawks tend to nest at higher elevations in the Central Appalachians, lower elevations in Allegheny Plateau, and lowest of all in the Ridge and Valley ecoregion.

Canopy bulk density, canopy cover, and canopy height parameters were included to account for forest structure. Previous regional studies show Northern Goshawks have a preference for higher canopy cover and canopy height, while canopy bulk density has not been tested locally (Kimmel 1995; Speiser and Bosakowski 1987).

The dominant forest group for each sampling unit was calculated to categorize the forested landscape into basic forest communities (e.g. oak/hickory, maple/beech/birch, and white/red/jack pine groups) and can be found in Figure 6 (Ruefenacht et al. 2008). Northern Goshawks prefer to nest in certain forest communities within different landscapes across the United States (Beck et al. 2011; Bush 2006; Reich et al. 2004; Zarnetske et al. 2011). Within the study region, this species has been shown to prefer nesting in forests with a large component of Northern hardwood species (maple/beech/birch group) and conifers (white/red/jack pine groups) (Speiser and Bosakowski 1987).

A forest fragmentation covariate was also included. Northern Goshawks prefer to nest away from disturbances that cause forest fragmentation regardless of bioregion or forest community (Bush 2006; Reynolds and Joy 1998; Speiser and Bosakowski 1987; Squires and Kennedy 2006; Wilson et al.
Forest land was classified as either “core” or “edge” using the NLCD data in conjunction with the Center for Land Use Education and Research’s (CLEAR) forest fragmentation tool (Figure 7). “Edge” forest was quantified as forested land that is within 100 linear meters of non-forested land, such as agriculture, urban, suburban, bare ground, and shrubland. Forest patches that were less than 200 meters in diameter were entirely classified as “edge” forest, as no section of forest was at least 100 meters from the edge of the patch. A proportion of “core” to “edge” was calculated for each sampling unit and included as a predictor covariate in the logistic regression (National Land Cover Database [NLCD] 2006; Center for Land Use Education and Research [CLEAR] 2013; Figure 6).

Mean annual precipitation and mean maximum July temperature 1980-2010 (Figure 8) were also included to account for different climate preferences of Northern Goshawks throughout the region (Northwest Alliance for Computational Science & Engineering [NACSE] 2013; Table 2). Northern Goshawks in the eastern U.S. prefer cool microclimates and only maintain nest site fidelity until the young fledge in mid-July (Brinker, personal communication 2013; Hargis and Woodbridge 2006; Kennedy 1991; Reynolds et al. 1992). Therefore, the maximum temperature for July variable was included, as a measure of the most extreme temperatures nesting goshawks would experience on the breeding territory.

These nine habitat covariate tables were merged with the sampling unit attribute table that included “Occupation” status. A logistic regression of the habitat predictor covariates was applied to the “Occupation” response variable using R statistical program (R Core Team 2013).
Table 2. Geographical Information System (GIS) Data Sources and Types Referenced in Northern Goshawk Habitat Suitability Model and Monitoring Plan. Data Source, Data Type and Resolution, and Covariate are listed.

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Data Type/Resolution</th>
<th>Covariate(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tim Kimmel nest points (unpublished data 2012)</td>
<td>Vector</td>
<td>Active nest year, location</td>
</tr>
<tr>
<td>PA Breeding Bird Atlas data</td>
<td>Vector</td>
<td>Active nest year, location</td>
</tr>
<tr>
<td>David Brinker nest points (personal communication 2013)</td>
<td>Vector</td>
<td>Active nest year, location</td>
</tr>
<tr>
<td>Doug Gross nest points (personal communication 2012)</td>
<td>Vector</td>
<td>Active nest year, location</td>
</tr>
<tr>
<td>Falconer nest points (Mike Dupuy personal communication 2013)</td>
<td>Vector</td>
<td>Active nest year, location</td>
</tr>
<tr>
<td>PRISM Climate Group 2010</td>
<td>Raster/100m</td>
<td>Mean maximum temperature in July 1980-2010 (degrees Celsius x100), Mean annual precipitation 1980-2010 (millimeters x100)</td>
</tr>
<tr>
<td>Landfire 2010</td>
<td>Raster/30m</td>
<td>Canopy Bulk Density (kilograms^3 x100), Canopy Cover (percentage), Canopy Height (meters x10)</td>
</tr>
<tr>
<td>United States Geological Survey: Digital Elevation Model 2008</td>
<td>Raster/30m</td>
<td>Elevation (meters above sea level), Slope (degrees)</td>
</tr>
<tr>
<td>National Atlas 2013</td>
<td>Raster/100m</td>
<td>Canopy Cover (percentage)</td>
</tr>
<tr>
<td>U.S. Department of Commerce 2000</td>
<td>Vector</td>
<td>State counties</td>
</tr>
<tr>
<td>USDA Forest Service 2004</td>
<td>Vector</td>
<td>Type III Ecoregions</td>
</tr>
<tr>
<td>National Land Cover Database 2006, 2011</td>
<td>Raster/30m</td>
<td>Land Cover</td>
</tr>
<tr>
<td>Forest Inventory and Analysis 2008</td>
<td>Raster/30m</td>
<td>Forest Group Type (maple/beech/birch, oak/hickory, white/red/jack pine groups)</td>
</tr>
</tbody>
</table>
Figure 5. Digital Elevation Model (2010) for PA, MD, WV, and VA. Values represent meters above sea level. The highest elevation levels within the study region are found in eastern West Virginia. Because of the high elevation, the climate features cooler temperatures and more precipitation than the surrounding area and thus influences the forest composition. As seen in Figure 5, this area contains a dominant Maple/Beech/Birch forest group.
Northern Goshawks prefer Northern Hardwood forest types (maple/beech/birch Group). This forest type is dominant in northcentral Pennsylvania and eastern West Virginia. These regions coincide with large State and National Forests and the most consistently occupied breeding territories by Northern Goshawks.
Figure 7. Core and Edge Forest (NLCD 2006) in PA, MD, WV, and VA. The CLEAR Landscape Fragmentation Tool was used to identify edge forest (forest within 100 meters of non-forested land cover) and core forest (forest at least 100 meters from non-forested land cover).
Figure 8. Mean Maximum Temperature in July (1980-2010) in PA, MD, WV, and VA. Values represent degrees Celsius x100 (PRISM). The lowest mean maximum temperatures for July in the region are recorded in northern Pennsylvania and down the Allegheny Mountains through eastern West Virginia and into western Virginia.
I then created separate models with different predictor covariates and tested them to determine which best fits the data. The best model is one that provides adequate descriptive accuracy of the data while using the fewest number of parameters (Wagenmakers and Farrell 2004; Zarnetske et al. 2011). Instead of using an automated stepwise regression method to select the best model per ecoregion, I created multiple candidate models by hand for a more controlled analysis (Myung et al. 2000; Royall 1997). I used 129 candidate models and included all possible model combinations with none to three covariates removed.

I then ranked these models using Akaike Information Criterion (AIC) value and evidence ratios between the top models (Akaike 1973). The AIC value is an estimation of information loss between the true model of the data and a candidate model. The lower the AIC value, the closer a candidate model is to the true model. To determine the best model among those tested, AIC, ΔAIC, and AIC weight was calculated. The ΔAIC is the difference in AIC between the candidate model with lowest AIC value and other candidate models (Akaike 1973; Kutner et al. 2005). However, AIC weight is the only value that provides comparable statistical information. The AIC weight of a model provides the amount of statistical confidence for the model with the lowest AIC value. AIC weights are essentially the probability that a candidate model is the best model by accounting for and comparing every candidate model included in the model selection process (Burnham and Anderson 2002; Wagenmakers and Farrell 2004). The top models were determined using the AIC weight, and evidence ratios were included to quantify the difference in AIC weight between the top two models.

I then applied each final regression model to the respective ecoregion to determine the habitat suitability rank for individual sampling units. To achieve this, I inserted the summarized habitat data for each sampling unit into the final regression model for each ecoregion, and calculated the predicted probabilities. Predicted probabilities measure the likelihood that a sampling unit contains ideal habitat on a scale of 0-1. Sampling units with predicted probabilities at or below the mean of all predicted
probabilities in each ecoregion were categorized as Secondary sampling units and those above the mean as Primary sampling units. This categorization method was used in Zarnetske et al. 2007, but with four categories (very low [0-0.25], low [0.26-0.50], moderate [0.51-0.75], and high [0.76-1.0] habitat suitability levels) and a much larger dataset. Since the nest location data is assumed to be incomplete in the study region I only created two categories, split by the mean of the predicted probabilities.

The top models for each ecoregion included the dominant forest group covariate (DOM; FIA 2008). The Maple/Beech/Birch group, also known as the Northern Hardwood group, was selected as the preferred dominant forest group for every model.

The top model for each ecoregion, Allegheny Plateau, Ridge and Valley, and Central Appalachians, was selected as the final model (Table 3, 4, and 5). In the Allegheny Plateau ecoregion, the AIC weights of the top three models were 0.35, 0.34, and 0.16 (Table 3). The top two models are very close and have an evidence ratio of only 1.03. The AIC weights of the top five models in the Central Appalachians ecoregion were 0.26, 0.21, 0.20, 0.18, and 0.15 (Table 4). These models are also similar in AIC weight but the evidence ratio was larger at 1.26. In the Ridge and Valley ecoregion, the AIC weights of the top three models were 0.39, 0.20, and 0.15 (Table 5). The difference in the top models was greater and the top two models had an evidence ratio of 1.92, which was the largest difference of any ecoregion. The spatial output of the selected habitat suitability models for each ecoregion can be seen in Figure 9.
Results

The top five models for each ecoregion were selected using logistic regression (Tables 3-5). The highlighted models are those with the highest AIC weight and therefore selected as the best models for the ecoregion. Evidence ratios compare the top two ranked models and are listed below each table.

Table 3. Selected Habitat Suitability Models for Northern Goshawk in Allegheny Plateau Ecoregion

<table>
<thead>
<tr>
<th>Model</th>
<th>AIC</th>
<th>Δ AIC</th>
<th>AIC weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP4. CBD + CC + CH + DOM - Edge - Elev - Slope + PPT - Tmax</td>
<td>56.58</td>
<td>0.00</td>
<td>0.35</td>
</tr>
<tr>
<td>AP1. CBD + CC + CH + DOM - ___ - Elev - Slope + PPT - Tmax</td>
<td>56.63</td>
<td>0.05</td>
<td>0.34</td>
</tr>
<tr>
<td>AP6. CBD + CC + CH + DOM - Edge - Elev - Slope + ___ - Tmax</td>
<td>58.15</td>
<td>1.57</td>
<td>0.16</td>
</tr>
<tr>
<td>AP5. CBD + __ + CH + DOM - ____ - Elev - Slope + PPT - Tmax</td>
<td>59.26</td>
<td>2.67</td>
<td>0.09</td>
</tr>
<tr>
<td>AP9. CBD + __ + CH + DOM - ____ - Elev - Slope + ___ - Tmax</td>
<td>59.92</td>
<td>3.34</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Evidence Ratio between top two models: 1.03

Table 4. Selected Habitat Suitability Models for Northern Goshawk in Central Appalachians Ecoregion

<table>
<thead>
<tr>
<th>Model</th>
<th>AIC</th>
<th>Δ AIC</th>
<th>AIC weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA21. - CBD + ___ + CC + DOM + ____ + Elev - Slope + PPT - Tmax</td>
<td>-11543.04</td>
<td>0.00</td>
<td>0.26</td>
</tr>
<tr>
<td>CA25. - CBD + ___ + CC + DOM + Edge + Elev - Slope + PPT - ____</td>
<td>-11542.57</td>
<td>0.47</td>
<td>0.21</td>
</tr>
<tr>
<td>CA3. - CBD + ___ + CC + DOM + Edge + Elev - Slope + PPT - Tmax</td>
<td>-11542.95</td>
<td>0.59</td>
<td>0.20</td>
</tr>
<tr>
<td>CA87. - CBD + ___ + CC + DOM + ____ + Elev - Slope + PPT - ____</td>
<td>-11542.31</td>
<td>0.73</td>
<td>0.18</td>
</tr>
<tr>
<td>CA27. - CBD + CH + ___ + DOM + ____ + Elev - Slope + PPT - Tmax</td>
<td>-11541.95</td>
<td>1.09</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Evidence Ratio between top two models: 1.26

Table 5. Selected Habitat Suitability Models for Northern Goshawk in Ridge and Valley Ecoregion

<table>
<thead>
<tr>
<th>Model</th>
<th>AIC</th>
<th>Δ AIC</th>
<th>AIC weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>RV27. CBD + CH + ___ + DOM + ____ - Elev - Slope + PPT - Tmax</td>
<td>-20729.06</td>
<td>0.00</td>
<td>0.39</td>
</tr>
<tr>
<td>RV4. CBD + CH + ___ + DOM + Edge - Elev - Slope + PPT - Tmax</td>
<td>-20727.76</td>
<td>1.30</td>
<td>0.20</td>
</tr>
<tr>
<td>RV6. CBD + CH + CC + DOM - ____ - Elev - Slope + PPT - Tmax</td>
<td>-20727.13</td>
<td>1.93</td>
<td>0.15</td>
</tr>
<tr>
<td>RV100. CBD + CH + ___ + DOM + ____ - Elev - Slope + ____ - Tmax</td>
<td>-20726.64</td>
<td>2.42</td>
<td>0.11</td>
</tr>
<tr>
<td>RV1. CBD + CH + CC + DOM + Edge - Elev - Slope + PPT - Tmax</td>
<td>-20726.20</td>
<td>2.86</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Evidence Ratio between top two models: 1.92

Covariates: CBD = canopy bulk density, CC = canopy cover, CH = canopy height, DOM = dominant FIA forest group (maple/beech/birch was selected in each model), Elev = Elevation, Slope = degree slope, Tmax = mean minimum temperature for July 1980-2010, PPT = mean annual precipitation 1980-2010, Edge = proportion of edge to core forest; all included in Table 1.
Figure 9. Spatial Output of Habitat Suitability Model for Northern Goshawk in PA, MD, WV, and VA.
The Habitat Suitability Model is split into three ecoregions (Allegheny Plateau, Ridge and Valley, and Central Appalachians) based on different habitat preferences in each ecoregion. A logistic regression of habitat variables and known nest locations was used to rank sampling units as primary or secondary habitat within each ecoregion.
Discussion

The top models in the Allegheny Plateau were ranked very closely. The evidence ratio between the top two models was $1.03$ (Table 3), meaning that the top ranked model is $1.03$ times more likely to be the best model for that set of data. If these models were tested using new sampling units, the results might vary enough to change the rank order of the models. In that case, the habitat suitability model may be improved by including multimodal inference or model averaging in order to account for the low evidence ratio. However, since I created the models using all of the sampling units, I selected the highest ranked model for the Allegheny Plateau ecoregion. This model includes all nine habitat covariates, while the next highest ranked excluded the Core/Edge Forest covariate, which represents forest fragmentation. Therefore, this fragmentation covariate might not be very influential at predicting habitat suitability when included in a model with the other predictor covariates, but it still contributes positively to the model.

The other influential predictor covariates were canopy bulk density, canopy cover, canopy height, forest group dominance (maple/beech/birch group), elevation, slope, annual precipitation, and mean annual temperature in July. The coefficients for these covariates suggest that goshawks prefer establishing territories in habitat with denser forests, higher canopies, greater canopy cover, a dominance of Northern Hardwoods (maple/beech/birch group), less forest fragmentation, lower elevation, more level slope, and a wetter and colder climate. Previous studies in the Allegheny Plateau region of Pennsylvania have also supported that Northern Goshawks prefer nesting in forests with higher canopy, greater canopy cover, a dominance of Northern Hardwoods, less forest fragmentation, lower elevation, and more level slope (Kimmel 1995; Speiser and Bosakowski 1987). The other covariates, canopy bulk density, mean annual precipitation, and mean maximum temperature, have not been tested previously.
The primary sampling units selected in the habitat suitability model output for the Allegheny Plateau show some correlation with public land. The large sections of primary habitat coincide with the Allegheny National Forest, Loyalsock State Forest, Susquehannock State Forest, and several state game lands and state parks. These areas are managed and protected as large patches of forest in the landscape. Many known nest locations also coincide there, but aside from Allegheny National Forest are sparsely distributed and rarely surveyed. Allegheny National Forest is the only location where Northern Goshawk nesting surveys are conducted consistently. These intensive surveys have revealed a high concentration of nests in the national forest, especially compared to the rest of the region. Therefore, an effort bias may exist in the model for the Allegheny Plateau region. Conducting more field surveys in the primary habitat identified in the model, especially on public land, could reveal many more active territories than have been documented so far and reduce the effort bias from the intensive surveys in Allegheny National Forest.

The top models of the Central Appalachians ecoregion all had similar AIC weights, but the top model held a distinct advantage in evidence ratio (1.26) over the second highest ranked model. The highest ranked model only has a probability ratio of 0.26 that it is the best model to represent the data. This was not a very strong model, but it is the best one available given the predictor covariates included. The selected model excluded canopy height and core/edge forest, which can be assumed to be fairly poor predictors of habitat suitability when used in combination with other predictors for the ecoregion. The remaining influential covariates included in the model suggest the same habitat preferences by goshawks in the Allegheny Plateau except for elevation and canopy bulk density. In combination with the other covariates, Northern Goshawks prefer less densely vegetated forests and higher elevation in the Central Appalachians ecoregion during the breeding season.

The distribution of primary habitat in the spatial output of the Central Appalachians ecoregion model followed the high elevation forests in West Virginia, Maryland, and the Allegheny Front in
Pennsylvania. Most of these forests lie within state and federal land such as Monongahela National Forest in West Virginia, and Garrett, Savage River, and Potomac State Forests in Maryland. This southern spur of high elevation forest is used by many more ‘northern’ and cooler climate breeding species such as Red Crossbill, Dark-eyed Junco, Winter Wren, Canada Warbler, and Yellow-rumped Warbler (Buckelew et al. 1994; Sibley 2000).

The top five habitat suitability models for the Ridge and Valley ecoregion had the largest difference in AIC weights. While the top model only had an AIC weight of 0.39, the evidence ratio was 1.92 between it and the next highest ranked model. The model I selected for the Ridge and Valley ecoregion excluded the canopy cover and core/edge forest predictor covariates. Therefore, the combination of canopy bulk density, canopy height, dominant forest group, elevation, slope, annual precipitation, and mean annual temperature in July was the most influential for predicting habitat suitability in this ecoregion. The coefficients for these covariates were identical to those selected in the Allegheny Plateau ecoregion model. Northern Goshawks prefer denser forests, higher canopy height, a dominance of Northern Hardwoods (maple/beech/birch group), lower elevation, more level slope, and a wetter and cooler climate. Previous studies tested canopy height, forest composition, elevation, and slope and found the same trends (Kimmel 1995; Speiser and Bosakowski 1987). Canopy bulk density, and climate variables (mean annual precipitation and mean maximum temperature in July) had not been studied for this region before.

The Maryland/Pennsylvania border divides habitat suitability in the Ridge and Valley ecoregion (Figure 9). Most of the known Northern Goshawk nest locations for this ecoregion are found north of this state boundary. The Pennsylvania Ridge and Valley ecoregion contains large patches of core forest that are managed by the state: state forests, parks, and game lands. The state forests, Rothrock, Bald Eagle, and Tuscarora, contain large patches of mature contiguous forest and consist almost entirely of primary habitat according to this model. Many confirmed nests have been found in these core forest
patches, but only one has been located south of the Maryland/Pennsylvania boundary. The spatial output of the selected habitat suitability model shows that habitat is not ideal in this region; however there are small islands of primary habitat in southwestern Virginia, which coincide with high elevation forests as was seen in the Central Appalachians ecoregion. The habitat in central Maryland and central-western Virginia might be better defined as non-habitat, but the canopy cover fits the criteria of >40 percent under the habitat envelope. Therefore, the southern portion of the Ridge and Valley ecoregion was determined to contain potential, but at best marginal habitat.

Eastern hemlock (Tsuga canadensis), while not included in this study, has been recorded at higher densities in Northern Goshawk territories in the study region (Speiser and Bosakowski 1987). Within the Ridge and Valley ecoregion, this tree species has been hardest hit by hemlock woolly adelgid (Adelges tsugae) and many notable stands of eastern hemlock (Tsuga canadensis) have been nearly entirely defoliated. The loss of eastern hemlock as a dominant forest species in this region could alter the forest community and forest structure greatly (Morin et al. 2003). Further research will be needed to determine if this forest composition change and/or other limiting factors have prevented Northern Goshawks from nesting in this region.

Northern Goshawks have unique preferences for breeding habitat throughout their continental range, and even within three distinct ecoregions in the eastern United States we can see differences between habitat suitability models. Of nine potential covariates used to predict habitat suitability, all nine were used in the Allegheny Plateau model, and seven were used in both the Central Appalachians and Ridge and Valley models. Because these models were created using covariates in logistic regression, the predictor variables cannot be interpreted individually, but we can compare models as a whole. Every model contained the same four covariates and coefficients for those covariates: preference for dominant forest group (maple/beech/birch), more level slope, greater annual precipitation, and lower maximum temperature. Additionally, two covariates were included in each model (canopy bulk density...
and elevation), but the +/- direction of the coefficients varied. Goshawks preferred more densely vegetated forests in Allegheny Plateau and Ridge and Valley, while they preferred less densely vegetated forests in the Central Appalachians when combined with other covariates. More research is needed to understand this difference as no studies have shown a preference for less densely vegetated forests throughout the species’ range. Lower elevation was preferred in both the Allegheny Plateau and Ridge and Valley, but higher elevation was preferred in the Central Appalachians. The higher elevation forests in the Central Appalachians coincide with northern hardwoods (maple/beech/birch), and cooler, wetter climates, which were all preferred in the ecoregion’s suitability model.

Three other covariates were only included in one or two ecoregion habitat suitability models. Higher canopy height was only preferred by goshawks in the Allegheny Plateau and Ridge and Valley ecoregions when combined with other covariates. Similarly greater canopy cover was only preferred by goshawks in the Allegheny Plateau and Central Appalachians ecoregions when combined with other covariates. The edge/core forest proportion covariate was only included in the Allegheny Plateau ecoregion model. Therefore, Northern Goshawks preferred less forest fragmentation in this ecoregion when combined with the other selected covariates. Goshawks most likely show preference for each individual predictor variable, but that was not tested in this study. The goal of the habitat suitability models was to rank habitat by suitability to better understand breeding distribution within the four-state region.

Woodbridge and Hargis (2006) recommend creating a new habitat suitability model every five years with the most recent forest metric data and goshawk occurrence data within the study region. Habitat metrics are consistently being refined with technological advancements. As an example, these improved metrics have already been utilized in Utah. Forest Inventory and Analysis (FIA) data have been verified and extrapolated using Moderate Resolution Imaging Spectroradiometer (MODIS) imagery (Zarnetske et al. 2011). This data should soon become available in the Mid-Atlantic region. In the
following section, we will discuss how to determine the frequency of Northern Goshawk occurrence within a study region. The change in frequency of occurrence as well as a change in habitat should also be calculated every five years. By understanding these changes, we can effectively track changes in population and habitat over time and hopefully understand the reason for any change that is detected. The next five years of surveys and analysis will then be based on the revised habitat suitability model that accounts for these changes and provides a more accurate understanding of Northern Goshawk population and habitat in the region.

The spatial output of the habitat suitability models shows a majority of primary habitat in areas of forested public land, including national forests, state forests, state parks, and state game lands. Conveniently, these are the only areas where systematic breeding goshawk surveys can be consistently conducted. Most public lands in the study region contain a high percentage of primary habitat, but beyond Allegheny National Forest the territory density is much lower than expected. The low numbers could be due to sampling bias and pseudo-absence data, but similar declines have also been noticed in New York, just to the north (Andrle and Carroll 1988). And the low density observed in this study is noticeable region-wide, but especially so in the Ridge and Valley and Central Appalachians ecoregions. By using the habitat suitability models to influence the monitoring plan for these areas, Northern Goshawk breeding distribution can be better understood and possible threats to breeding success can be identified.

One reason for the decline Northern Goshawks that I did not consider for this study was West Nile Virus (WNV). Northern Goshawks are susceptible to the virus, but no studies have been conducted to determine the impact the virus has on a population (Wunschmann et al. 2005). However, it is difficult to ignore the coincidence of the first detections and spread of West Nile Virus and the decline in Northern Goshawk detections between Breeding Bird Atlases. The first detection of West Nile Virus was in New York City in 1999, which falls right between Breeding Bird Atlas dates (1983-1989, 2004-2009).
The virus has also been shown to impact Ruffed Grouse and Corvidae (jays and crows) populations (Owen and Garvin 2010), which are a common prey species for Northern Goshawks. Another interesting trend occurs with West Nile Virus and Ruffed Grouse populations in different regions of Pennsylvania in the years since 1999. All grouse populations throughout the state experienced an initial decline, followed by a recovery just a few years later. None of the populations in the regions experienced a return to pre-WNV levels except for the north-central population. After this brief recovery period another WNV-induced decline was detected. Ruffed Grouse experience natural boom and bust cycles in population, but the declines experienced since 1999 have been greater than any recorded previously, except for the north-central region (Williams, unpublished data 2016). Northern Goshawks have also experienced a decline in detections throughout the study region, except for the north-central region of Pennsylvania, particularly Allegheny National Forest (Wilson et al. 2012). The literature does not contain published studies that test the transmission rates of WNV through predation between birds. Studies that track Northern Goshawks throughout the year and test blood samples for WNV antigens should be conducted throughout the study region to determine whether West Nile Virus could be responsible for the decline in Northern Goshawk detections.
Chapter 3

Monitoring Plan

Introduction

The habitat suitability models in the previous section revealed the spatial distribution of suitable habitat and were used to influence the monitoring plan. The monitoring plan establishes a protocol for surveying breeding Northern Goshawks and calculating population estimates throughout the region over time. A few targeted surveys have been conducted in state and national forests in the past, but none have been systematic or long term other than the continued work in Allegheny National Forest by David Brinker of the Maryland Department of Natural Resources. No population estimates have been conducted in the region.

Dr. Tim Kimmel conducted surveys across the state of Pennsylvania by enlisting outdoor enthusiasts (falconers, hunters, hikers, and bird-watchers), augmented by his own knowledge and experience, and a nest site habitat suitability model in Bald Eagle State Forest (Kimmel 1995). These methods produced 83 nests statewide in Pennsylvania and contributed to the 1st Pennsylvania Breeding Bird Atlas. The 2nd Pennsylvania Breeding Bird Atlas recorded about 55 of the breeding Northern Goshawk territories that Dr. Kimmel had located, and most of the sources for those records came from cooperating licensed falconers and biologists (Brauning 1992; Wilson et al. 2012). Dr. Kimmel’s expertise as both a falconer and biologist bridged the divide between these groups and allowed him to gather much more information. He also sent out surveys to turkey hunters who occasionally encounter territorial Northern Goshawks because of the coinciding timing (the entire month of May) of the spring turkey season and Northern Goshawk breeding season (Kimmel 1995; Pennsylvania Game Commission 2013). These records are integral to our understanding of regional Northern Goshawk distribution. A systematic coverage of the entire four-state region can be achieved by incorporating knowledge from
these surveys and establishing a monitoring protocol based on *The Northern Goshawk Inventory and Monitoring Guide* (Hargis and Woodbridge 2006).

This section establishes the protocol for long-term systematic surveys by analyzing a sample of limited field surveys conducted in Pennsylvania. Northern Goshawks are notoriously elusive, yet aggressively territorial when their nest site is encroached upon. We can discover and document these cryptic territories by systematically monitoring potential habitat with targeted playback surveys. The ultimate goal of these surveys is to estimate the regional Northern Goshawk breeding population and spatial distribution throughout the landscape of Pennsylvania, Maryland, West Virginia, and Virginia.

**Methods**

**Survey Protocol**

I utilized the survey protocol established by Hargis and Woodbridge (2006) under the Section 3-13, “Broadcast Acoustical Survey”, in *The Northern Goshawk Inventory and Monitoring Guide* and adapted it to the region by following local studies (Kimmel 1995; Speiser and Bosakowski 1987). The objective of this protocol is to systematically survey potential Northern Goshawk habitat and determine frequency of occurrence and detection probabilities throughout the region.

Northern Goshawks are sensitive to disturbances during nesting and the timing of surveys is critical. Hargis and Woodbridge (2006) strongly recommend only attempting playback surveys after chicks have hatched so as to not disrupt nesting pairs during the most sensitive time period when Northern Goshawks might abandon the nest if disturbed or stressed. The development period of Northern Goshawks is split into two stages, nestling and fledgling. One survey should be conducted at each sampling unit during each development period. In the western United States, chicks hatch in mid- to late-May and remain entirely dependent on the adults until they start to develop flight feathers. The fledgling stage is defined as the time after the birds grow flight feathers and begin flying. This stage
begins in late June or early July in the western United States. However, these stages occur earlier in the eastern United States because there is no snowmelt period to delay reproduction. Therefore, we adjusted survey periods by half a month in the East (Brinker, Personal Communication 2013). Nestling stage occurs between mid-May and mid-June. Fledgling stage occurs between mid-June and mid-July. We were not able to visit sampling units once for each development stage in this study, but it should be done in future surveys to adequately determine presence and calculate detection probabilities based on each visit (Hargis and Woodbridge 2006).

The 600-hectare sampling units from the habitat suitability model were thoroughly surveyed using playback calls along parallel walking transects. Within each 600-hectare sampling unit, 120 playback points were created and spaced at least 250 meters apart along ten parallel transects (Figure 10). The spacing was not always uniform along transects. Some transects followed the topography or were adjusted to avoid bodies of water and roads. Surveys were conducted with at least two people and started up to 30 minutes before dawn and can be continued until 30 minutes prior to sunset. Alarm calls, wail calls, and fledgling begging calls were broadcasted for 30 seconds total in three opposing directions from each playback point. With two surveyors, one-half to three-quarters of a sampling unit were covered in one day. Three or four surveyors could complete a sampling unit survey in one day, depending on terrain. Therefore, 24-32 total work-hours (total hours per surveyor) were needed to complete a sampling unit survey.

Broadcast playbacks were performed at all 120 points except where land was inaccessible or inappropriate. Inaccessible land was defined as a large waterway, steep slope, and private land. Inappropriate land included active oil and natural gas drilling sites, roadways, and developed land. Access limitations and excessive noise in a sampling unit were also acceptable grounds to skip broadcast playback points.
Weather also impacted survey attempts. Rain events and high winds will reduce the broadcast ability of the playback recordings and effectively reduce the sampling effort. Surveys were only attempted with calm, or at most, light winds and precipitation no more intense than a drizzle.

When a Northern Goshawk was detected in a sampling unit the Broadcast Acoustical Survey was concluded and an Intensive Area Survey was initiated to provide important breeding data. Details of the encounter were recorded immediately after the sighting. Time, date, last playback point number, location coordinates, and flight direction were documented. The purpose of the Intensive Area Survey is to find an active nest. This survey was conducted by walking parallel transects 100 meters apart in a block that extends one kilometer in four cardinal directions from the Northern Goshawk sighting. All large stick nests, active or non-active, were recorded. Tree species, approximate height, and location coordinates were written down for each potential Northern Goshawk nest. If an active nest was found, we recorded as many observational details as possible without disturbing the nest site. Disturbances can be dangerous to the birds, but also to the surveyor. Northern Goshawks are known to inflict serious talon wounds when defending an active nest. Observations included age and sex of birds present, size and height of nest, and evidence of successful breeding. If no potential nests were found, all surveys in the sampling unit were concluded for that development stage and the sampling unit was categorized as “Occupied”.

The goal of conducting presence/absence surveys for Northern Goshawks within a specified region is to determine the proportion of occupied sampling units ($P$). The proportion ($P$) is determined by the frequency of occurrence. $P$ can be calculated for the entire region and for each habitat suitability type (primary and secondary).

$$P = \frac{N_1P_1 + N_2P_2}{N_1 + N_2}$$

However, since it is nearly impossible to survey every sampling unit in one year, the proportion ($P$) is estimated with the frequency of occurrence of surveyed sampling units ($P_i$) and the probability of
detection for each survey visit ($q_n$ and $q_f$). The probability of detection for the nestling stage is $1 - q_n$, and $1 - q_f$ for the fledgling stage. A likelihood function ($L$) is the product of the probabilities of the five detection types (10, 11, 01, 1*). The detection 1* is interpreted as a positive detection on the nestling stage survey, and no survey for the fledgling stage. Maximizing the likelihood function ($L$) will be the same as $P$ (proportion of occupied sampling units). A bootstrap process can determine standard error for the parameter estimate (Hargis and Woodbridge 2006). When surveys are conducted in successive years, a change in frequency of occurrence can be calculated and population change over time can be estimated (Bruggeman et al. 2011).

**2013 Surveys**

I conducted limited surveys in the breeding season of 2013 in sections of the Allegheny Plateau and Ridge and Valley ecoregions. Due to time and funding constraints, I only conducted one survey per sampling unit. I randomly selected ten primary and ten secondary sampling units in Allegheny National Forest, within the Allegheny Plateau, and Broadcast Acoustical Surveys were conducted from May 16 to June 15. This time period coincides with the nestling development stage. I also selected the same number and type of sampling units in Rothrock, Moshannon, and Bald Eagle State Forests, within the Ridge and Valley ecoregion, and conducted surveys from June 17 to July 15. This time period coincides with the fledgling development stage.

I also used three days to train the surveyors with Northern Goshawk identification by volunteering for David Brinker's banding project in Allegheny National Forest. We visited two nest sites, lured, trapped, and banded the adults and nestling birds. This training was essential to improve the identification of Northern Goshawk nests as well as flight characteristics, vocalization, and plumage.

The surveys I conducted in 2013 were used to locate new territories and develop the monitoring plan using first hand knowledge. The frequency of occurrence and population estimates could not be calculated because sampling units were only visited once and the sample size was too low.
Figure 10. Playback Point Distribution for Goshawk Monitoring Plan within a Sampling Unit.
The Points are located approximately 250 meters apart to effectively cover the entire 600-hectare grid cell.
Figure 11. Primary and Secondary Sampling Units Surveyed in the Ridge and Valley Ecoregion.
Six primary and seven secondary 600-hectare sampling units were surveyed for Northern Goshawks June 16 – July 15, 2013 in Rothrock, Bald Eagle, Moshannon, Tiadaghton, and Sproul State Forests. A Northern Goshawk was detected in one secondary sampling unit.
Figure 12. Primary and Secondary Sampling Units Surveyed in the Allegheny Plateau ecoregion.
Five primary and four secondary 600-hectare sampling units were surveyed for Northern Goshawks May 16 – June 15, 2013 in Allegheny National Forest. Northern Goshawks were detected in two primary sampling units.
Results

The surveys in Allegheny Plateau and Ridge and Valley ecoregions were limited due to weather and terrain, but still produced three Northern Goshawk detections. Initially ten primary and ten secondary sampling units were randomly selected for both regions. Unfortunately, frequent rain events during the survey time periods reduced the number of actual survey days. Access to areas of difficult terrain further reduced the number of sampling units. Because of these setbacks only five primary and four secondary sampling units were surveyed in the Allegheny Plateau. Seven primary and six secondary sampling units were sampled in the Ridge and Valley (Figures 11 and 12).

Two Northern Goshawks were detected in the Allegheny Plateau ecoregion. These two sampling units are recorded as Northern Goshawks “Present,” and the others as “Absent.” Both responses occurred in Primary sampling units within the national forest, as determined by the Habitat Suitability Model. Despite Intensive Area Surveys after the initial Acoustic Broadcast Surveys, no active nests were found. One Northern Goshawk was seen in a sampling unit that contained a historical confirmed nest territory from over 20 years prior, while the other was detected in a previously unoccupied sampling unit. A total of 246 work-hours were involved in these surveys. Therefore, the surveys produced one Northern Goshawk detection for every 123 work-hours.

One Northern Goshawk was detected in the Ridge and Valley ecoregion. The sampling unit was recorded as Northern Goshawks “Present,” and the others as “Absent.” The detection was recorded in a secondary sampling unit according to the Habitat Suitability Model. One potentially active nest was found during the Intensive Area Survey. It could not be confirmed as active perhaps because the survey occurred at the end of the fledgling development stage. Regardless, no evidence of recent activity could be confirmed and the nest status was recorded as non-active. Overall, 393 work-hours were involved in
the Ridge and Valley ecoregion surveys. With one detection, the work-hours per detection remained at 393 work-hours.

Therefore, the average number of work-hours per detection for both ecoregions was 213 work-hours. This effort represents 22 sampling units surveyed in two patches of public land in Pennsylvania.

**Discussion**

The field surveys were productive but limited due to a lack of surveyors, funding, and poor weather, which provided insight toward practical alterations to the survey protocol. Northern Goshawks were detected in 3 of 22 sampling units, 2 of 9 in Allegheny National Forest, and 1 of 13 in Rothrock, Moshannon, Bald Eagle, Tiadaghton, and Sproul State Forests. These parcels of public land represent the Allegheny Plateau, and Ridge and Valley ecoregions, respectively. Each sampling unit was surveyed only once. While this method provided valuable observational data, surveying each sampling unit twice, once in each stage of development as recommended by Hargis and Woodbridge (2006), is integral to estimating the population in the ecoregions and the region as a whole.

Two Northern Goshawks were detected in primary sampling units and one was detected in a secondary sampling unit, suggesting that the habitat suitability model might not be very precise. While we detected two Northern Goshawks in primary sampling units in the Allegheny Plateau, we detected one in the Ridge and Valley in a secondary sampling unit. That secondary sampling unit was adjacent to a primary sampling unit with a historic nest. However, the region hasn’t had a Northern Goshawk detection reported in over a decade. Therefore, the model does show some lack of precision, which can be expected with a potentially declining and rare species. Records are few enough when the species population is stable and a decline from that is difficult to model accurately throughout the study region. So this section of Bald Eagle State Forest should be surveyed more frequently and extensively, as it could very likely contain active territories and improve the model.
Reducing the number of playback points in a sampling unit will reduce the work hours required per sampling unit, while potentially negatively affecting detection probabilities. A lack of funding and surveyors were the only controllable limiting factors during the 2013 surveys in Pennsylvania. Reducing the time spent surveying each sampling unit will increase the total number of sampling units surveyed with the same funds. As mentioned in the previous Methods section, playback calls are broadcasted for three minutes. By surveying 120 points per sampling unit, six hours alone are spent broadcasting playbacks. Simply reducing the number of playback points by half will drop three hours off the estimated 24-32 work-hours per sampling unit. Private surveyors have already instituted this protocol adjustment for surveys in NE Pennsylvania, but results are not available yet (Doug Gross, personal communication 2014). This reduction in playback points will hinder the probability of detecting a Northern Goshawk in a sampling unit. But the same transect routes are walked regardless of the number of playbacks conducted along them, so detections shouldn’t decrease significantly. Surveying sampling units once for each development stage would be even more critical for population estimation with this reduced survey protocol. So the trade-offs of reducing the number of playback points are ultimately beneficial to the monitoring effort.

Several parcels of public land have been identified for surveys within the next 5 years based on potential threats to forest contiguity, including urban development and oil and Marcellus shale natural gas drilling, and a high density of primary sampling units selected by the habitat suitability model. The Pennsylvania Game Commission and the PA Department of Conservation and Natural Resources suggested parcels of public land with potential threats to core forests. The Habitat Suitability Models determined concentrations of primary sampling units. These targeted surveys can provide us with nest territory locations, and valuable population estimates prior to disturbances. Hargis and Woodbridge (2006) suggest calculating a change in frequency of occurrence in a study region after five years. By conducting these surveys in five-year segments, we can gain an understanding of population changes in
an area before and while available habitat is altered. These data are essential for successful
cconservation efforts in areas with potential and extant habitat loss threats.

The suggested surveys should be conducted in Tiadaughton, Susquehannock, Bald Eagle, and
Loyalsock State Forests as well as State Game Lands 013, 057, and 134 (Figure 13). These areas are
potentially under threat of forest fragmentation from Marcellus shale natural gas drilling and contain
several known and rumored Northern Goshawk territories (Gross, personal communication 2012).

Surveys should be based on the protocol used for reduced playback surveys in NE
Pennsylvania: 60 playback point transects for each 600 ha sampling unit block within the public land
boundaries. Results from the surveys should be compiled into a secure geospatial database for
confidentiality and to facilitate revising the habitat suitability model every five years as new habitat data
is made available.
Figure 13. Recommended Public Lands for Targeted Northern Goshawk Surveys in Pennsylvania. Bald Eagle, Loyalsock, Susquehannock, and Tiadaghton State Forests, and State Game Lands 013, 057, and 134 are public lands with high densities of primary habitat (represented as primary sampling units). Surveys should be conducted within five years due to increasing threats of habitat loss and fragmentation.
Northern Goshawks have been documented nesting in mature red pine (*Pinus resinosa*) plantations throughout Pennsylvania and should be considered for targeted surveys (Wilson et al. 2012). The Civilian Conservation Corps originally established these conifer plantations in state forests, parks, and gamelands across Pennsylvania (e.g. Black Moshannon and S.B. Elliot State Parks and several sites in Bald Eagle State Forest) in the 1930’s. The orderly rows of pine in the plantations have reached maturity in the last few decades and provide supplemental nesting habitat for Northern Goshawks. Northern Goshawks prefer conifers in nest sites for cover from predators as well as habitat for prey species such as ruffed grouse (*Umbellus bonasa*) and red squirrel (*Tamiasciurus hudsonicus*). The even-spaced rows between trees also provide ideal line-of-sight to defend the active nest (Brinker, personal communication 2013; Dupuy, personal communication 2013). However, formal records for these red pine stands are difficult to compile for the entire region and may take a focused ground effort to locate and document them. Once located, each plantation should be surveyed in the breeding season for Northern Goshawk presence.

The Northern Goshawk is also an umbrella species for many remaining large patches of core forest and dependent wildlife. This habitat should be conserved not only to maintain Northern Goshawk populations, but all the other species that it supports. Based on the breeding ecology of Northern Goshawks, all nest sites should be protected and treated as active for at least 10 years after the last known year of activity. This species is known for occupying multiple alternate nests between breeding seasons and also abandoning the area for several years at a time (Barlett 1977; Reynolds et al. 1992). I recommend establishing two buffer zones around all active (or presumed active) nests, which is supported by Kimmel (1995). The first zone would extend 300 meters, the second zone extending to 800 meters from the nest tree. The 300-meter radius corresponds to the nest site (10-20 ha) and 800-meter radius to the post-fledgling family area (200 ha; Figure 1). No disturbance of any kind should be allowed
within the first buffer zone. Only limited disturbance in the form of low impact silvicultural practices such as thinning should be conducted inside the second buffer zone and only in non-breeding season, October through February (Bloom et al. 1985; Nelson and Titus 1989; Reynolds et al. 1992). By effectively managing known Northern Goshawk habitat, a stable population can be established and managed to ensure future survival of the species.

**Conservation Guidelines**

The Northern Goshawk has experienced a noticeable population decline in recent years and a specific set of conservation guidelines should be followed to protect and study the habitat and known nest territories. This elusive forest raptor is listed as Near Threatened in Pennsylvania and Extirpated or Critically Imperiled (depending on breeding success in a given year) in Maryland, West Virginia, and Virginia. The Pennsylvania Game Commission, U.S. Forest Service, PA Department of Conservation and Natural Resources, and the MD Department of Natural Resources should use the conservation guidelines for monitoring and conserving Northern Goshawk potential and established breeding habitat.

1. Revise the Habitat Suitability Model for the four-state region every 5 years using logistic regression with latest Northern Goshawk occurrences and any more accurate habitat parameters.

2. Conduct targeted surveys on public land where a high density of primary habitat and/or potential threats to the habitat occur, such as the state forests, parks, and game lands identified in Figure 13 for north central Pennsylvania. These surveys are the first priority and should be completed by the year 2021. Two visits, one during each stage of Northern Goshawk offspring development, are required to estimate the population within targeted survey regions.
3. Conduct further research on Broadcast Acoustical Survey protocol to determine if a revised survey of reduced playback points is effective for determining frequency of occupation in sampling units.

4. Establish two concentric buffer zones around active or presumed active (within 10 years of activity) nest trees. No disturbances should be permitted within the 300-meter radius of the first buffer zone. Only limited disturbances, such as low-impact silvicultural practices, should be permitted within the 800-meter radius of the second buffer zone. Disturbances should be isolated to the non-breeding season (October through February).
Chapter 4

Conclusions

The Northern Goshawk population in the southern portion of the eastern United States distribution is most likely in decline. I did not uncover the reason for the decline in this study, but I did identify possible reasons for it. I also created a habitat suitability model and monitoring plan to determine the extent and cause of the decline.

The habitat suitability models revealed the habitat preferences for Northern Goshawks in each ecoregion. Throughout the study region, this species prefers habitat with a dominant Northern Hardwoods species component, more level slope, and wetter and colder climate. When canopy height and canopy cover were included in the model, Northern Goshawks showed a preference for higher canopies and greater canopy cover. However, the ecoregion models differed in stand density and elevation preferences. Northern Goshawks in the Allegheny Plateau and Ridge and Valley ecoregions preferred denser forest stands and lower elevations. The opposite was true for birds in the Central Appalachians ecoregion.

The habitat suitability model for the Allegheny Plateau ecoregion revealed that most public lands (state and federal) coincided with primary sampling units, suggesting that a lot of the most suitable habitat lies on public, managed lands. This is an excellent opportunity to conduct surveys to determine the present territory distribution and give us clues to the cause of the recent decline. Specific state forests and game lands are identified in Monitoring Plan Discussion (pg. 45, Figure 13).

The Central Appalachians ecoregion has shown the most drastic decline in Northern Goshawk detection. This species is likely extirpated from the ecoregion except for the northern portion in Pennsylvania that follows the Allegheny Front (Brinker, personal communication 2013; Buckelew et al.)
Recent and historic nest sites should still be monitored, but survey efforts should be focused on the northern portion of this species’ range to learn more about the current territory distribution.

The Ridge and Valley ecoregion is the most fragmented, but still contains many historic nest sites. However, the portion of this ecoregion south of Pennsylvania is likely non-habitat as it has only one recorded nest site from extreme southwestern Virginia and very few sampling units categorized as primary between that area and the Pennsylvania border.

There are three leading hypotheses for the cause of the recent decline in Northern Goshawk detections in the study region. The first is the impact of hemlock woolly adelgid on Eastern Hemlocks. This conifer species has been shown to be a major component in older closed-canopy forests where Northern Goshawks are found. This invasive insect has decimated whole hemlock stands, containing trees over 300 years old (Kizlinski et al. 2003; Morin et al. 2003). The second hypothesis is climate change. The southern extent of this species’ range is probably determined by available habitat and climate conditions. Since they are shown to prefer wetter and colder climates, a shift in climate toward drier and warmer conditions would logically push the Northern Goshawks distribution north, which we have seen in recent detection rates (Beckage et al. 2008; Parra-Olea et al. 2005). The third leading hypothesis is the impact of West Nile Virus. Despite little physical evidence of infection of wild birds, the sudden, region-wide decline leads us toward a cause that can cover large distances in a short amount of time, like disease that spreads using winged vectors. In this case those vectors are mosquitoes and certain bird species, such as Corvidae species (jays and crows) and American Robins (Turdus migratorius) (Huffman et al. 2010; Owen and Gardin 2010; Wunschmann et al. 2005). New evidence from the Pennsylvania Game Commission shows a decline in Ruffed Grouse that roughly correlates with declines in Northern Goshawks on a spatial and temporal scale (Williams, unpublished data 2016). Individual studies that address each of these hypotheses could finally give us an answer for the cause of this species’ decline.
New habitat suitability models should be created every five years using updated data from surveys and any more recent habitat parameters. These models can be compared to each other and show the change in predicted breeding distribution over time. Since systematic surveys are not feasible across the entire range, habitat suitability models are the best alternative.

Based on the literature review and limited 2013 broadcast acoustical surveys, I have made several conclusions about the monitoring plan for Northern Goshawks in the study region. The 2013 surveys produced new territory detections despite only surveying 22 sampling units. This suggests that the current distribution of Northern Goshawks is still unknown and more surveys are needed to gain a better understanding. Broadcast acoustical surveys are the most effective method for finding active territories, but they must be done twice per year per sampling unit in order to calculate probability of detection, frequency of occurrence, and ultimately population change over time. Based on the 2013 surveys, an average of 213 work-hours were needed per detection. Therefore, surveys should be conducted systematically and strategically to maximize effort. Reducing the number of playback points per sampling unit by half is one way to maximize effort and would reduce survey time by about 3 work-hours per sampling unit. Red pine plantations should also be identified and surveyed. These orderly stands act as supplemental primary habitat and are preferred if surrounded by mature forest.

I began this study to help reveal the reason(s) for the decrease in detections of Northern Goshawks in Pennsylvania, West Virginia, Maryland, and Virginia. I have determined the three leading hypotheses for this decline and detailed the methods needed to determine an estimated change in population for the study region. The next step is for state and federal agencies, such as the Pennsylvania Game Commission, Department of Natural Resources, Western Pennsylvania Conservancy, Maryland Department of Natural Resources, Pennsylvania Biological Survey, and the U. S. Forest Service to apply the conservation guidelines as described on pages 51-52. Only then can we determine the change in population and distribution over time and reveal the cause of the detection decline.
**Literature Cited**


Wunschmann, Arno, Shivers, Jan, Bender, Jeff, Carroll, Larry, Fuller, Susan, Saggese, Miguel, van Wettere, Arnaud, Redig, Pat. 2005. Pathologic and Immunohistochemical Findings in Goshawks (Accipiter gentilis) and Great Horned Owls (Bubo virginianus) Naturally Infected with West Nile Virus. Avian Diseases 49:252-259.
