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Avian Species Distribution Models: Using Location Data to Inform Management Decisions

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AVIAN SPECIES DISTRIBUTION MODELS:

USING LOCATION DATA TO INFORM

MANAGEMENT DECISIONS

by

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ABSTRACT

Avian Species Distribution Models:

Using Location Data to Inform Management Decisions

by

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We used species distribution models for avian focal species at different scales to inform applied management decisions. Focal species are often chosen for both their sensitivity to disturbance and their relationship to quality habitat, which is the case for both the northern goshawk (*Accipiter gentilis*) and white-headed woodpecker (*Dryobates albolarvatus*) used in this study. We conducted a statewide nest site selection model for northern goshawks in Utah using an analytical hierarchy process that we were then able to use in conjunction with the Forest Vegetation Simulator to predict changes to nesting habitat over the next 150 years in Utah under different climate scenarios. Based on consensus between all predictions, we identified potential refugia, especially in the Uinta-Wasatch-Cache and Ashley National Forests, that remains intact as high suitability nesting habitat under all climate scenarios. For white-headed woodpeckers, we used a resource selection analysis to determine how white-headed woodpeckers responded to thinning and burning treatments, part of the ponderosa pine restoration program in the

Payette National Forest. White-headed woodpeckers displayed some positive associations with recent thinned and burned areas but also displayed wide variation in response to treatment type, canopy cover, and slope, suggesting that white-headed woodpeckers benefit from habitat heterogeneity across the landscape. Finally, we used a behaviorally segmented integrated step selection analysis to examine northern goshawk habitat selection across an annual cycle in northeastern Nevada, part of the interior Great Basin. The interior Great Basin represents a naturally patchy habitat. Goshawks consistently selected for higher canopy cover across both breeding and non-breeding behavioral states but showed variation in response to other landscape characteristics, suggesting, like white-headed woodpeckers, that goshawks may benefit from habitat heterogeneity and the ability to utilize different habitat types throughout the annual cycle.

(163 pages)

PUBLIC ABSTRACT

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Both state and federal wildlife agencies strive to conserve and protect wildlife and their habitats as an important public resource. Applied management decisions often rely on being able to obtain data that can efficiently and effectively enhance the understanding of these systems for informing management actions. Wildlife managers often focus efforts on a small subset of species from an ecosystem, typically called focal species, who can serve as surrogates for understanding the health and function of the system. Models that consider how these focal species interact with the ecosystem are often used to better understand important aspects of their life history, ecology, and conservation needs.

Birds are ideal candidates for use as focal species as they often are sensitive to disturbance, tied to a narrow subset of habitat characteristics for different parts of their life cycle success, and are often easy to monitor and study. The recent advent of advanced GPS and spatial technology allows managers the chance to consider birds and their relationship with their habitat on a deeper level by considering interactions at finer spatial scales. However, GPS and spatial technology as well as the methods to analyze the spatially explicit data have only recently been available for many avian species.

In this study, the Utah State University partners with the U.S. Forest Service in Utah, U.S. Forest Service Rocky Mountain Research Station, and the Nevada Department of Wildlife to analyze spatial data collected for northern goshawks (*Accipiter gentilis*) and white-headed woodpeckers (*Dryobates albolarvatus*). While the spatial data for this project was previously collected as part of other management objectives, the collaborations for this project make it possible to analyze this data with some of the latest methods in spatial and movement ecology. We used methods such as predictive modeling with the Forest Vegetation Simulator, resource selection analysis, and integrated step selection analysis to examine each of these species' relationships with their habitat on a finer scale than previously considered and to help create management recommendations based on our findings.

DEDICATION

I would like to dedicate my dissertation work to my parents, Larry and Cathy Wright. You have been a steadfast example of faith, love, and tenacity throughout my life. Your constant support and encouragement have helped me to overcome so many obstacles and to consistently develop into a better version of myself. There are not enough words to express the gratitude and appreciation I have for everything you have done and continue to do for me. I love you.

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CHAPTER I

INTRODUCTION

In the United States, wildlife management is based on the premise that government wildlife agencies use scientific knowledge and expertise to conserve, restore, and maintain natural resources for the public (Clark et al. 2010). However, conservation biology and natural resource management are often a crisis discipline involving extremely difficult and complex processes, and thus decisions must be made with some tolerance for uncertainty (Burgman et al. 1993, Regan et al. 2002, Chase and Geupel 2005, McCarthy and Possingham 2007). Since their seminal work in the late 1970s, Walter and Hilborn (1976) and Holling's (1978) theory of adaptive management has gained traction as an essential tool for the conservation of biodiversity and management of resources under uncertainty (Wilhere 2002, Keith et al. 2011) Adaptive management relies on the systematic collection and application of reliable information to improve management over time (Holling 1978) and may be either passive in which policy changes are implemented when sufficient monitoring data become available to support the change or active in which management strategies are conducted as deliberate experimental treatments with monitoring as a key component for determining cause-and-effect relationships between different management actions and associated outcomes (Walters and Hilborn 1978, Wilhere 2002). In both instances, monitoring is a key component of adaptive management, and monitoring and management planning are developed concurrently (Walters 1997, Possingham et al. 2000).

While there are several approaches to monitoring, one of the most common practices is to choose a subset of species from a particular system of interest to serve as a focal species, using biological knowledge and careful analysis of monitoring data to guide management decisions (Gibbs et al. 1999, Chase and Geupel 2005). Focal species management can be useful in both passive and active adaptive management strategies, provided that focal species are chosen on the basis that developing conservation plans around their life history characteristics will confer benefits to other cooccurring species facing similar threats (Fleishman et al. 2000, Beazley and Cardinal 2004, Roberge and Angelstam 2004, Nicholson et al. 2013). Criteria for identifying ideal focal species focuses primarily on ecological processes that are generally associated with demographic parameters in the population biology framework (Henle et al. 2004) including: 1) area-limited species with large area requirements and low population densities, 2) dispersal-limited species with poor dispersal capabilities, or 3) species with low reproductive potential or fecundity (Lambeck 1997, Beazley and Cardinal 2004, Henle et al. 2004, Nicholson et al. 2013). Additionally, species may be chosen on the basis of status as indicators of environmental change such that characteristics of their life history and behavioral responses may be used as an index of measuring attributes that are expensive or unfeasible to measure for other species (Caro and O'Doherty 1999, Landres et al. 1999, Chase and Geupel 2005).

Given their sensitivity to change, focal species are often designated as species of "special concern" by local or national governments (Caro and O'Doherty 1999, Chase and Geupel 2005). This study deals with two species that have this type of designation: the northern goshawk (*Accipiter gentilis*) and the white-headed woodpecker (*Dryobates* *albolarvatus*). The northern goshawk has been used as a management indicator species for the U.S. Forest Service throughout the west (Hoffman and Smith 2003, Boyce et al. 2006) and has also been designated as a species of concern by the U.S. Fish and Wildlife Service (Squires and Kennedy 2006). Northern goshawks are an important top-tier avian predator (Graham 1999) that typically have a close association with a narrow set of habitat requirements, including mature stands of either conifers (*Pinus spp., Abies spp., Pseudotsuga menziesii*) or aspen (*Populus tremuloides*) with at least partially closed canopy cover for nesting (Reynolds 1983, Hall 1984, Reynolds et al. 1992, Graham 1999). Northern goshawks are also sensitive to anthropogenic disturbances such as grazing, timber harvest, and the effects of climate change (Graham 1999). White-headed woodpeckers are similarly closely tied to habitat and sensitive to anthropogenic disturbance. They have been identified as a species at risk both locally and regionally (Garrett et al. 1996, Rich et al. 2004). They are endemic to dry conifer forests of the inland northwest (Garrett et al. 1996) and closely tied to mixed-severity fire regimes that create a mosaic of open- and closed-canopy with mature, large trees (Garrett et al. 1996, Wightman et al. 2010, Hollenbeck et al. 2011, Latif et al. 2015, 2020). As primary cavity nesters, they are also considered ecosystem engineers as they provide important nesting and roosting habitat for other species (Jones et al. 1994). Because both northern goshawks and white-headed woodpeckers are sensitive to changes within their habitat and occupy important roles in the species community assemblages, they are ideal candidates for monitoring the effects of management activities, both passively and actively.

One of the most effective ways to use monitoring data collected from species like the northern goshawk and white-headed woodpecker for informing management decisions is to construct species distribution models. Species distribution models (SDMs) use known locality data and information on environmental and habitat conditions to predict hypothetical distributions, often mapping habitat suitability for a species related to these variables (Loiselle et al. 2003, Franklin 2010, Sofaer et al. 2019). The conceptual underpinnings of SDMs are related to niche theory in which attempts are made to describe a species' niche in terms of both environmental and geographical space (Colwell and Rangel 2009). The increasing availability of geospatial data along with advances in computing technology have allowed for a rapid expansion of analytical methods for calculating SDMs (Elith and Leathwick 2009, Sofaer et al. 2019), making it easy to facilitate model fit and visualization (Thuiller et al. 2009, Morisette et al. 2013, Kass et al. 2018). Additionally, SDMs provide flexibility for gaining inference from biased and sparsely sampled populations (Peterson et al. 2000, Loiselle et al. 2003, Phillips et al. 2009, Sofaer et al. 2019), like the northern goshawk and white-headed woodpecker, and use of SDMs in conservation efforts has demonstrated successful outcomes in other cases (Guisan et al. 2013).

The SDM approach has been used widely for both white-headed woodpeckers (Saab et al. 2007, 2009, Kozma 2009, Wightman et al. 2010, Hollenbeck et al. 2011, Kozma and Kroll 2012, Latif et al. 2015, 2020, Linden and Roloff 2015, Lorenz et al. 2015, Kehoe 2017) and northern goshawks (Reynolds et al. 1982, 1992, 2006, Hayward and Escano 1989, Greenwald et al. 2005, Boyce et al. 2006, Carroll et al. 2006, Squires and Kennedy 2006), however, there remain many ways in which SDMs can be used to further inform management decisions for these species. For SDMs to be effectively implemented into the decision process, it is important to consider the uncertainty in the modeling technique and the scale of all components of the SDM, including input data, output distribution predictions, and the scale at which the SDM will be used to inform management decisions (Seo et al. 2009, Porfirio et al. 2014, Sofaer et al. 2019) to avoid incorrect predictions and uses of SDM information that can lead to spatially flawed conservation planning (Smith and Catanzaro 1996, Seo et al. 2009). This study deals with multiple scales of SDMs and describes the ways in which SDMs may effectively inform management at different levels, relative to these scales. The following chapters include a broadscale SDM, an analytical hierarchy-based habitat suitability model of goshawk nesting habitat across the state of Utah that we then used to project effects under different climate change scenarios (Chapter 2), a finer-scale SDM, a second-order resource selection function of white-headed woodpecker space use in relation to harvest and prescribed burning treatments (Chapter 3), and a very-fine-scale SDM, step selection function of northern goshawks in the Interior Great Basin, a unique naturally fragmented habitat (Chapter 4). Finally, I conclude with a summary chapter on the results and their importance for informing management decisions, both passively and actively, for these species and for demonstrating the use of different scales of SDMs for focal species management at the appropriate level (Chapter 5).

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CHAPTER II

AN ANALYTICAL HEIRARCHY PROCESS-BASED HABITAT SUITABILITY MODEL FOR NESTING GOSHAWKS IN UTAH NATIONAL FORESTS: CURRENT CONDITIONS AND FUTURE CLIMATE SIMULATIONS WITH THE FOREST VEGETATION SIMULATOR

INTRODUCTION

Climate controls the distribution of ecosystems and species ranges globally, and global climate change is already having a significant impact on species and ecosystems, including shifts in species distributions, changes in timing of life-history events, decoupling of coevolved interactions, effects on population size and demographics, loss of habitat, and increased spread of disease and invasive species (Hannah et al. 2002*a*, *b*, 2005, Stenseth et al. 2002, Van Putten 2002, Walther et al. 2002, Parmesan and Yohe 2003, Parmesan 2006). Predictions of biological changes over the next century include large-scale biome shifts, with somewhere between one-seventh to one-third of North American ecosystems classified as highly vulnerable to these changes (Aber et al. 2001, Gonzalez et al. 2010). Large-scale biome shifts can have dramatic negative impacts on ecosystem structure and function at multiple scales, and feedbacks within these systems can stabilize biome shifts, making it very difficult to reverse the changes (Grimm et al. 2013). Rapid biome shifting is predicted under a variety of climate scenarios and is likely to continue driving significant changes in plant and animal species composition (Mawdsley et al. 2009), creating a need for adaptive management strategies to help ameliorate the potential adverse effects of climate change (Hannah et al. 2002*a*, Inkley et al. 2004, Da Fonseca et al. 2005, Parry et al. 2007, Mawdsley et al. 2009).

Despite more than two decades of data produced from federally funded research programs that frames potential impacts of climate change on U.S. public lands, efforts to integrate climate change as a factor in planning and management strategies has been minimal (Hannah et al. 2002*a*, Littell et al. 2012). While awareness of the need to consider broadscale forest changes in relation to climate has increased following several high-profile reports on regional climate trends (Hayhoe et al. 2004, Mote et al. 2005, Knowles et al. 2006), forest management often still reflects approaches that are based on historical forest conditions as a means for quantifying forest health (Lackey 1998, Landres et al. 1999, Millar et al. 2007). Attempts to maintain and restore forest conditions that do not consider rapid environmental changes may leave forests ill-adapted to these conditions and vulnerable to undesirable outcomes (Millar et al. 2007). Additionally, the stressors created by climate change can have additive effects when interacting with other common stressors such as pollution, habitat fragmentation, land-use changes, invasive plants, animals, and pathogens, and altered fire regimes (Holmgren and Scheffer 2001, Zavaleta 2006, Millar et al. 2007).

In order to create more effective management strategies for forests facing rapid environmental change, emphasis has been placed on creating practical strategies that integrate science and decision-making into a flexible management framework (Spittlehouse and Stewart 2003, Millar et al. 2007, Julius and West 2008, Mawdsley et al. 2009, Littell et al. 2012, Grimm et al. 2013). The increasing uncertainty associated with environmental changes and ecosystem responses necessitates approaches that include both short-term and long-term strategies that embrace flexibility, the capacity to reassess conditions frequently, and the ability to change course based on evolving conditions and needs (Hobbs et al. 2006, Millar et al. 2007). Current mathematical models produced for environmental decision making rarely predict future conditions with enough accuracy or precision to be useful for managers (Pilkey and Pilkey-Jarvis 2007), and managers often struggle with a lack of financial and personnel resources to implement climate change mitigation strategies into current management plans. However, resource managers at the local administrative level often have a strong interest in understanding the effects of climate change on resources and are interested in adapting to changing systems (Littell et al. 2012). This is encouraging as much of the important work in climate change adaptation is likely to occur at finer scales in individual parks, forests, and reserves (Opdam and Wascher 2004, Mawdsley et al. 2009).

Adaptive management, with its integration of climate change at fine scales necessitates addressing the challenges faced by different management agencies. One of the main challenges for effective implementation is the ability to create fine-scale models of climate impacts on wildlife distributions and vegetation communities that are easy to create and financially feasible to implement (Carroll 2005, Mawdsley et al. 2009, Littell et al. 2012). Mawdsley et al. (2009) outlined a framework of different climate change adaptation strategies for wildlife management and biodiversity conservation including familiar approaches such as direct sensitive species management and the use of monitoring data to facilitate adaptive planning. Both state and federal agencies have used these strategies as components of previous management planning, providing an opportunity to transition these ideas in order to facilitate adaptation of ecosystems under climate change (Mawdsley et al. 2009).

Some of the most useful indicators of environmental changes are raptors which generally inhabit large home ranges, occupy positions at the top of most food webs, and display trackable sensitivities to anthropogenic and environmental disturbances (Bildstein 2001, Hoffman and Smith 2003). One species that has been used extensively for forest health monitoring in is the Northern Goshawk (hereafter 'goshawk') (Martin et al. 1998, Hoffman and Smith 2003). The largest Accipiter in North America, goshawks represent an important avian predator in forested ecosystems (Graham et al. 1999). While goshawks inhabit a wide variety of habitats across their range, they tend to nest within a subset of forest structural characteristics (Bosakowski 1999), including older-growth areas with at least partially closed canopy and open understory (Reynolds 1983, Hall 1984, Squires and Ruggiero 1996, Bosakowski 1999). This pattern is especially prevalent in North American montane regions, where the association with high quality forest habitat has led to goshawks being used as a Management Indicator Species in US national forests to track management plan implementation (Martin et al. 1998). The wealth of monitoring data generated for this species along with their status as a species sensitive to environmental change (Graham et al. 1999) make goshawks an ideal candidate for using previously collected monitoring data to test the efficacy of implementing a model for fine-scale climate impacts.

We used an Analytical Hierarchy Process (AHP) to create a habitat suitability model (HSM) for goshawks in Utah national forests. The AHP approach allowed us to use a decision-making framework combining quantitative and qualitative metrics to determine the relative significance of our selected habitat variables. This approach allows for the analysis of large areas without the necessity of robust presence data (Perera et al. 2012). We focused on nesting habitat as there is a great deal of information available on goshawk nesting habitat requirements as well as a monitoring history of goshawk nest locations in Utah national forests. HSMs are based on the identification of environmental factors influencing the spatial distribution and abundance of animals in a specific area. HSMs create a conceptual model relating environmental variables to the suitability of a location for a species (USFWS 1996, Burgman et al. 2001). For effective management and conservation, it is important to determine which combination of variables are strongly associated with the species' success. Our HSM incorporates the Forest Vegetation Simulator (FVS), a U.S. Forest Service program that uses an individual tree, distance independent growth and yield model to predict changes to forest structure under a different growth and management scenarios. FVS is used by many forest biologists, and the program has a dedicated team that works to provide resources, workshops, training, and troubleshooting assistance for all facets of the program. This allowed us to predict how nesting habitat might change over the next 150 years and to identify important refugia by considering where the modeled present nesting distributions intersects with projected distributions (Fløjgaard et al. 2009, Keppel et al. 2012).

STUDY AREA

Our study area included national forests within the state of Utah including Ashley, Uinta-Wasatch-Cache, Fishlake, Dixie, and Manti-La Sal. Non-forested land within these boundaries were excluded from the study to include only habitat considered viable for goshawk nesting. Dominant forest types in Utah national forests include the following species: quaking aspen (*Populus tremuloides*), Engelmann spruce (*Picea engelmannii*), Douglas-fir (*Pseudotsuga menziesii*), lodgepole pine (*Pinus contorta*), and ponderosa pine (*P. ponderosa*). Additionally, other woodland species such as pinyons (*P. edulis*), juniper (*Juniperus osteosperma* and *J. scopulorum*), Gambel oak (*Quercus gambelii*), and bigtooth maple (*Acer grandidentatum*) are common across the state forested area.

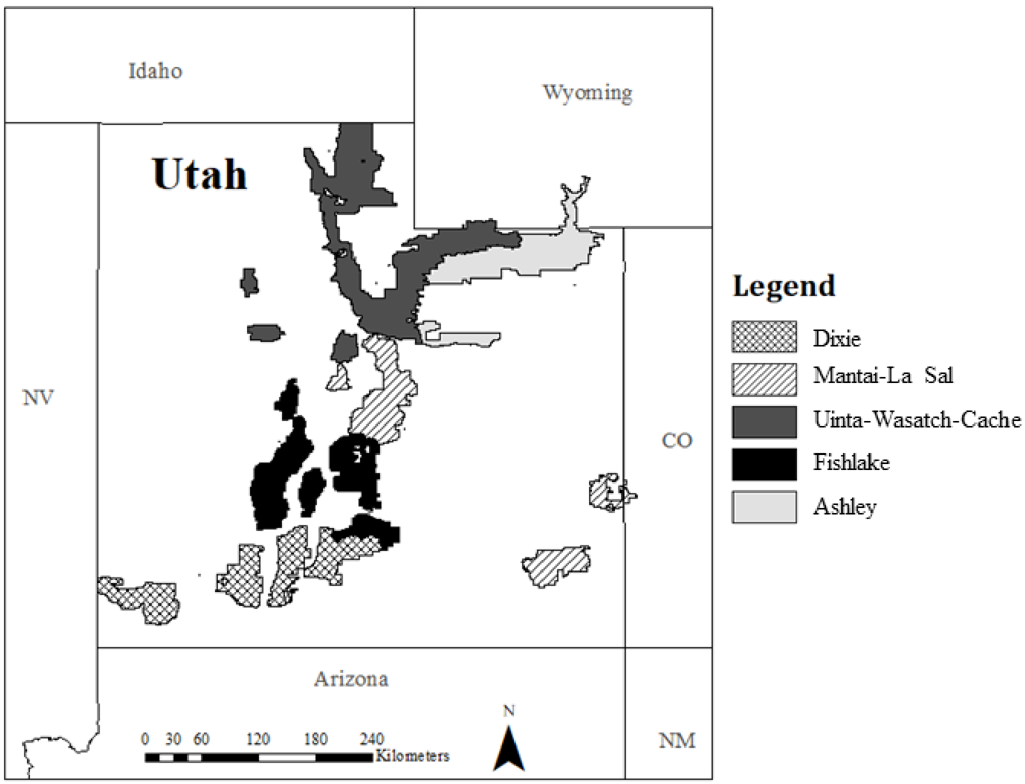

Figure 2.1 Utah national forests administrative boundaries, USA. Though the administrative boundaries for Ashley National Forest, Uinta-Wasatch-Cache National Forest, and Manti-La Sal National Forest extend outside of the state border into Wyoming and Colorado respectively, we still included these areas in our analysis as the management offices for these forests are based in Utah.

METHODS

Identifying Factors Influencing Habitat Suitability

We conducted a literature review of papers on goshawk field studies in the mountain states (Montana, Idaho, Wyoming, Colorado, Utah, Arizona, and New Mexico) (Hennessy 1978, Fischer 1986, Hayward and Escano 1989, Spencer 1995, Siders and Kennedy 1996, Squires and Ruggiero 1996, Patla 1997, Graham et al. 1999, Clough 2000, Joy 2002, Marvel 2007, Zarnetske et al. 2007), the Pacific Northwest (Oregon, Washington, and northern California) (Reynolds et al. 1982, Moore and Henny 1983, Hall 1984, Finn 2000, Keane 2000, McGrath et al. 2003), and South Dakota (Black Hills area; (Erickson 1987), ranging in publication date from 1978 – 2007. From these papers, we chose eight variables to represent the main features of suitable habitat for goshawk nesting (forest type, canopy cover, stand age, canopy base height, basal area, slope, aspect, and elevation) as these variables were the most common explanatory variables for nesting site selection models. We compiled minima and maxima values for each of these variables from the selected literature and used geometric means to create threshold minima and maxima for each variable from the reported minima and maxima from previous experiments (sensu Zarnetske et al. 2007). Forest type was classified as a categorical variable where forest types including ‘conifers’ and/or ‘aspen’ were determined to be suitable for nesting.

Analytical Hierarchy Process

In the process of habitat evaluation, an important step is to determine the relative significance of each contributing variable. The Analytical Hierarchy Process (AHP) was first developed by Saaty (1977) as a decision-making process combining quantitative and qualitative metrics to solve complex problems. AHP provides a unique approach to developing HSMs because it allows for the analysis of large regions without necessitating presence data for a species (Perera et al. 2012). AHP relies on creating a pairwise comparison matrix where each variable is weighted against every other variable by asking field experts to assign relative dominant values between one and nine (Table 2.1.; Saaty 1977). We recruited eight experts to complete the pairwise comparison survey including a graduate researcher, Intermountain Bird Observatory raptor researcher, Utah Division of Wildlife biologists, US Forest Service wildlife biologists and ecologists, and US Forest Service – Rocky Mountain Research Station researchers. Before scoring the variables, we provided experts with a detailed description of AHP protocols as well as examples of AHP matrices. Pairwise comparisons were completed by each expert individually and returned to us for processing.

Table 2.1 Scale of binary comparisons from Saaty (1977)

Importance	Definition	Explanation
1	Equal importance	Both variables contribute equally
3	Weak importance of one variable over another	Experience and judgement slightly favor one variable over another
5	Strong importance	Experience and judgement strongly favor one variable over another
7	Dominant importance	One variable is strongly favored, and its dominance is demonstrated in practice
9	Absolute importance	One variable is completely favored over the other with the highest order of affirmation
2, 4, 6, 8	Intermediate values	When compromise is needed between levels of importance

All data analyses were conducted in R version 3.6.3 (R Core Team 2021). After eliciting responses from our team of experts, we used the packages *ahp* (v0.2.12; Glur 2018) and *ahpsurvey* (v0.4.1; Cho 2019) to aggregate responses and calculate eigenvector values and consistency ratios for the variables. We adjusted for inconsistencies in individual pairwise comparisons using the Harker method to transform inconsistencies and replace them with more logical values (Harker 1987), running a total of ten iterations. We then compiled the transformed pairwise comparison matrices to calculate final eigenvector values for each variable. Eigenvector values represent the relative importance of each variable, based on the expert evaluation (Saaty 1977). Habitat variables receiving higher eigenvector scores represent a greater perceived importance to goshawk nest site distribution, relative to variables with lower scores.

Data Acquisition and Preparation for Modeling

We downloaded raw raster and vector files for each of the selected variables. Forest type, canopy cover, and basal area were obtained from the USDA FSGeodatabase Clearinghouse (Reufenacht et al. 2008, Wilson et al. 2013, Coulston et al. 2016). The files for basal area were downloaded as separate tiles for specific tree species. They were fit the full study area extent and then summed together into a complete raster layer for total basal area of all tree species. Canopy base height was obtained from LANDFIRE (LANDFIRE 2008). Stand age was obtained from the USGS LandCarbon database (USGS LandCarbon 2014), and elevation was obtained as a Digital Elevation Model (DEM) from the Shuttle Radar Topography Mission EROS Archive download portal (EROS 2018) (Table 2.2). The DEM files were also downloaded as separate tiles and merged into one raster file. We derived slope and aspect from the DEM layer using the *landsat* package (v 1.1.0, Goslee 2011).

We set each raster file to a standard resolution of 250 meters based on the constraint on input variables for basal area, canopy cover, and stand age measured at 250-meter resolution. We used a standard projection (Albers Equal Area, GRS80 ellipsiod). We resampled all rasters using bilinear interpolation and matches them to the grid for forest type. We then cropped the rasters to the extent of the Utah national forest boundaries.

Table 2.2 Variables used to create a habitat suitability model for goshawk nesting sites in Utah national forests based on literature review and analytical hierarchy process (AHP). Description and range of each variable was determined through literature review. Source and resolution refer to the raw vector and raster files downloaded to create the habitat suitability model (HSM).

Variable	Description	Range	Source	Resolution
Basal Area	Total average basal area per ha	20 - 52 m^2/ha	USDA	250 m
Canopy Cover	Percent canopy cover	45 - 88%	USDA	250 m
Forest Type	Dominant tree species	Conifers, aspen, mixed	USDA	30 m
Canopy Base Height	Average height of lowest live branches	10 - 20 m	Landfire	30 m
Stand Age	Average age of stand in years	77 - 227 yrs	USGS	250 m
Elevation	In meters from DEM	1800 – 3000 m	SRTM	30 m
Slope	Derived from DEM as percent slope	5 - 42%	Derived from DEM	30 m
Aspect	Derived from DEM as northness and eastness	Values for N- and NE-facing slopes	Derived from DEM	30 m

Habitat Suitability Model

After preparing the data files for modeling, we created Boolean raster files for each variable where cells falling in the established minima and maxima thresholds were coded as “1” and cells with values outside those thresholds were coded as “0”. Any cells with NA values were assumed to be in non-forested habitat and were automatically assigned a “0” value. We then multiplied each Boolean layer by the corresponding eigenvector scores calculated in the AHP process and added all weighted variable layers together to generate prediction raster files for each forest. We then calculated Jenks natural breaks (Jenks 1967) for all national forests within Utah based on the prediction raster files with AHP weights, setting four total breaks to categorize habitat into low suitability, medium suitability, and high suitability. We compared the percentage of habitat classifications across each forest. We verified the model with existing nest site location data for both Ashley National Forest and Fishlake National Forest.

Forest Vegetation Simulator

We used the Utah variant (DeRose et al. 2010) Forest Vegetation Simulator (FVS; Release date 06/30/2021) to simulate forest growth metrics. FVS predictions are based on input data collected from Forest Inventory and Analysis (FIA) plots throughout the state. We downloaded FIA vegetation data for the state of Utah from the FIA DataMart website (Forest Inventory and Analysis Database, n.d.) in the SQLite Database format and imported this data into FVS. For each forest in Utah, we completed two FVS base runs. The first base run included all stands for FIA measurement year 2009 to 2019 within each forest. We used a reporting interval of 150 years, starting in 2020 and projecting simulated data out to 2170 with a report generated every 10 years. We selected the SVS table from the optional outputs, and then downloaded the FVS_Summary2 table once the run had completed. For the second base run, we kept the same selected stands and included an additional ten years in our time interval, running from 2020 to 2180, to account for a lag in reporting for pests and computed variables. We used the Event Monitor to add in a component to calculate percent canopy using the “Compute Stand Variables with SpMcDBH Fucntion” and set the upper limit for trees to include to 500 inches diameter at breast height (DBH) to capture all classes of trees in the output. We selected the SVS and Fire and Mortality tables from the optional outputs and downloaded the FVS_Compute and FVS_PotFire tables once the run had been completed. Stands that had a starting stand age of zero were assumed to have no input data and were filtered out of the data set. We also filtered down the output to correspond with only the most recent FIA sampling protocol.

To complete the FVS runs for altered climate scenarios, we first compiled a list of all Utah FIA forest stands used to generate data in our initial base runs. We submitted this list to the FVS help desk to obtain FVS-climate ready data. To copy the FVS base run structure, we used the tools available in FVS to download a compressed file for all the saved base runs, and we copied the structure of the base runs over to a new project for projecting forest characteristics under different relative concentration pathways (RCPs) to simulate forest succession under climate change. We used the Climate-FVS Extension (Crookston et al. 2010) to choose a climate scenario for each set of runs, and we completed three sets of FVS-climate runs based on ensembles for RCP45, RCP60, and RCP85. At the end of each set of climate runs, we downloaded the FVS_Summary2, FVS_Compute, and FVS_PotFire tables, and extracted values for basal area, stand age, canopy base height, forest type, and percent canopy cover.

Forecasted Habitat Suitability Model

For both the base FVS and climate FVS runs, we selected data from the year 2150 and created dataframes that included FVS values for percent canopy cover, basal area per acre, stand age, and forest type (Table 2.3). For each stand with FIA data, we attached each stand-level projection to the corresponding FIA location. To convert point-level projections to projected covariate rasters, we fit variograms to the data with the *gstat* package (Pebesma 2004, Gräler et al. 2016) and then used kriging over a grid fit to the extent of Utah national forests to spatially interpolate values for continuous variables across the space. For forest type (categorical variable), we created a matrix of proximity polygons to interpolate forest type based on nearest neighbor values. We used the same minima and maxima thresholds to create Boolean raster layers for each variable and then multiplied each layer by the corresponding eigenvector scores. We then used the same Jenks natural breaks calculated for the original HSM in order to calculate each projected climate model in order to facilitate comparison across each model. We compared the percentage of habitat classifications between forests and succession scenarios and quantified the area of high suitability habitat that is preserved in each succession scenario.

RESULTS

Analytical Hierarchy Process

Based on the equally weighted responses from eight field experts, our combined AHP matrix rated canopy cover as the most important variable for goshawk nesting habitat with a 25.5% raw weight. Aspect was the second highest contributor (13.5%) and elevation, slope, forest type, and basal area were all weighted around 11%. Stand age (8.3%) and canopy base height (7.7%) had the lowest raw weights. There was a 46.1% consensus rating among respondents.

From individual responses, we identified four response matrices with a consistency ratio higher than the 10% acceptable threshold that we transformed through the Harker Method (Harker 1987). Final calculated weights for each variable retained the original order of importance from the raw value calculations (Table 2.3).

Table 2.3 Final variable weights for selected northern goshawk nest site characteristics in Utah national forests, USA. Variable weights were determined using the dominant eigenvector method from analytical hierarchy process surveys. Variables are listed in descending order of importance based on dominant eigenvector score.

Variable	Weight
Canopy Cover	0.1588
Aspect	0.1187
Slope	0.0973
Elevation	0.0950
Basal Area	0.0728
Forest Type	0.0706
Stand Age	0.0607
Canopy Base Height	0.0526

Habitat Suitability Model

For all national forests within the state of Utah, the majority of forested habitat was classified as low suitability for goshawk nesting and only 22% of the total forest habitat was classified as highly suitable for goshawk nesting (Fig 2.2). Forests farther north in the state had the highest percentage of high suitability nesting habitat. The Jenks natural breaks optimization placed our bin values at 0, 0.217, 0.347, and 0.717. All values within the 0 to 0.217 range were interpreted as “low suitability”, values within the 0.217 to 0.347 range were interpreted as “medium suitability”, and values within the 0.347 to 0.717 range were interpreted as “high suitability” for goshawk nesting.

Our HSM performed better for national forests in the northern part of the state, with 77% of confirmed nest sites for Ashley National Forest falling in high suitability areas. Out of 302 total nests, 232 were in high suitability areas, 54 in medium suitability, and 16 in low suitability. For Fishlake National Forest, a forest in the southern part of Utah, 55% of confirmed nest sites were in high suitability areas. Out of 194 total nests, 107 were located within high suitability, 39 in medium suitability, and 54 in low suitability.

Figure 2.2 Utah national forest habitat suitability model classifications for northern goshawk nesting based on analytical hierarchy process-weighted values and Jenks natural breaks. The highest proportion of national forest land is represented as low suitability habitat for goshawk nesting (44.48%; white), followed by medium suitability (33.81%; light green), and high suitability (21.71%; dark green).

Forecasted Habitat Suitability Models

With increasing emissions, represented by higher level RCPs, Utah national forests are projected to have a greater degree of habitat homogenization. The amount of high suitability nesting habitat available to goshawks decreases with increasing emissions for most forests, though there is a slight increase in high suitability nesting habitat for the isolated eastern portion of Manti – La Sal National Forest under RCP60 (Fig 2.3). Across the base simulation and all RCPs, there are areas of preserved high suitability habitat that could serve as refugia, but for most forests, these areas are restricted patches that decrease in size with increasing emissions. The largest area of preserved high suitability nesting habitat is in the Uinta-Wasatch-Cache and Ashley National Forests. This area represents the only preserved high suitability habitat that maintains connectivity across the forested area.

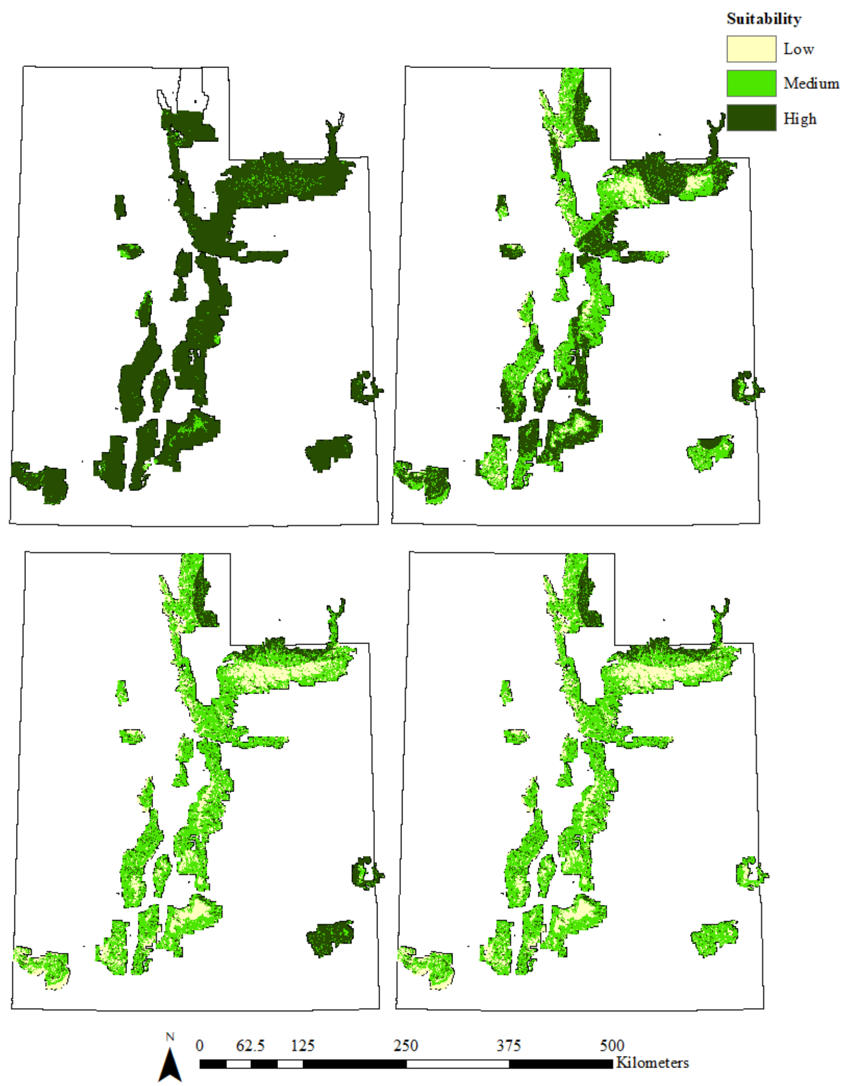

Figure 2.3 Habitat suitability models for northern goshawk nesting habitat in Utah national forests under Forest Vegetation Simulator (FVS) succession simulations predicted to the year 2150. Simulations represented are (*top left*) the base run with no altered climate, (*top right*) succession under ensemble climate scenario representative concentration pathway (RCP) 45, (*bottom left*) succession under ensemble climate scenario RCP 60, and (*bottom right*) succession under ensemble climate scenario RCP 85. For all FVS simulations, we excluded simulated management activity. The whitespace depicted in the top left figure reflects a lack of data for proper interpolation.

DISCUSSION

The analytical hierarchy process-based habitat suitability model that we built in this study provides proof of concept for a habitat suitability model that is easy to implement, especially with limited financial and personnel resources. Additionally, this model integrated easily with the predictive simulations from the Forest Vegetation Simulator for different climate scenarios. By analyzing the full set of simulations, we can identify areas of high habitat quality that are preserved in all potential climate change scenarios. We were also able to demonstrate that Utah national forests are likely to undergo increasing homogenization, depending on the rate and severity of climate change. The homogenization of forests and other habitat can lead to the rapid loss of species biodiversity (Clavel et al. 2011, Nordberg and Schwarzkopf 2019). The areas identified as retaining high suitability are extremely important for focused management and conservation to ensure patches of suitable habitat for goshawk nesting in the Utah national forests of the future.

Fine-scale models of climate impact on wildlife distributions and vegetative communities are likely to be the most useful for informing adaptive management planning at the level of individual national forests (Carroll 2005, Mawdsley et al. 2009, Littell et al. 2012). The analytical hierarchy process model was easy to adapt for Utah national forests at multiple scales as it did not require intensive monitoring data for model building at either the local or state level. Additionally, while we did not include modeling of management activities in our Forest Vegetation Simulator runs, it is possible to consider different arrangements of management activities to predict their effect on habitat in a similar manner. Since managing in the face of uncertainty requires flexible input with the capacity to adapt (Millar et al. 2007), it is likely that analytical hierarchy process models may be a useful tool for addressing variability in future climate and habitat conditions (Hobbs et al. 2006). Analytical hierarchy process-based habitat suitability models can be built for any species or community for which exists a good understanding of the most significant environmental conditions driving distributions of those species or communities (Imam and Tesfamichael 2013). Because lack of funding often presents a challenge to integrating and implementing climate change into management plans, the success of our analytical hierarchy process-based habitat suitability models suggests that effective models may be built without necessitating collecting new data sets (Littell et al. 2012, Imam and Tesfamichael 2013). Furthermore, national forests have a wealth of data related to species monitoring programs, and the analytical hierarchy process-based habitat suitability model provides a way to use this valuable data to continue informing management decisions and practices. Considering that species monitoring often focuses on sensitive or at-risk species (Noss 1999), this is a valuable opportunity to use existing data

One of the most promising areas of this approach was the ease with which the analytical hierarchy process-based habitat suitability model was incorporated with Forest Vegetation Simulator to identify areas of potential refugia for goshawk nesting habitat under all potential climate scenarios. In the past, refugia have facilitated the persistence of diverse species under changing climates (Taberlet and Cheddadi 2002, Tzedakis et al. 2002, Hampe and Petit 2005, Keppel et al. 2012), however, refugia can often be difficult to identify without complex data and analysis processes (Keppel et al. 2012). This approach relied on inferring areas of refugia based on mapping the areas of preserved habitat suitability in all climate scenarios, an approach that necessitates minimal time and effort. Because climate change mitigation is unlikely at this point, management and policy has shifted its focus to minimizing the impacts of climate change and preserving biodiversity (Keppel et al. 2012). Maintaining refugia where climate change impacts are predicted to be less severe provides a flexible means to focus efforts on small areas that may have a large impact (Allan et al. 2005, Julius and West 2008). Because these areas are already identified as important for goshawk nesting in present conditions, additional conservation efforts focused on the refugia identified in this study are likely to represent an opportunity to adapt the goals and efforts of current monitoring programs for the species in Utah national forests into a flexible plan. Efforts to minimize additional stressors in these areas may help to give goshawks and other species the maximum flexibility to evolve and adapt to climate change over time (Lovejoy 2005, Robinson et al. 2005, Mitchell et al. 2007, Julius and West 2008).

In addition to providing an important nesting refugia for northern goshawks, some of the most critical habitat identified in this study is likely to also benefit other species. Northern goshawks are a top-tier predator in forested systems, and thus may indicate some degree of forest health and ecosystem stability. Forests that can continue to support goshawk populations in the face of climate change are likely to support other important forest species as well (Beier and Drennan 1997, Squires and Kennedy 2006). The majority of habitat designated as an important refugia for goshawk nesting also fell within areas of Uinta-Wasatch-Cache and Ashley National Forests, representing sections of the Uinta Mountains. This area has been identified as an important habitat component of the regional corridor connecting the Greater Yellowstone Ecosystem and Northern

Rockies to the Uinta Mountains and Southern Rockies (Noss et al. 2001, USDA 2003) and has been the focus of conservation efforts for other sensitive species. The Uinta Mountains of northern Utah have been identified as a core area for Canada lynx (*Lynx canadensis*) (Bates and Jones 2007) and the rivers and watersheds in this area provide important habitat for native fish species like the Colorado River cutthroat trout (*Oncorhynchus clarkii pleuriticus*) (Kershner et al. 1997) and Bonneville cutthroat trout (*Oncorhynchus clarki utah*) (Hilderbrand and Kershner 2000, Budy et al. 2007). Additionally, bighorn sheep (*Ovis canadensis*) and Rocky Mountain elk (*Cervus canadensis nelsoni*) as well as many other mammal and bird species rely on these watersheds (Carter et al. 2020), thus our designation of this area as important habitat for goshawks only furthers the assertion that management policy should consider a more rigorous protection of this area to benefit multiple species.

While this modeling approach shows considerable promise both for goshawks and other species with a rich monitoring background, there are some important considerations moving forward. Our conceptual models include many sources of error, both from input data and analysis methods that have not yet been evaluated. Additionally, prior studies have suggested the tendency for estimates from the Forest Vegetation Simulator to lack precision and accuracy (Canavan and Ramm 2000, Smith-Mateja and Ramm 2002, Tinkham et al. 2021), and, since our forecasted maps include point-level data interpolated to a landscape scale, it is likely that our maps suggest an over-simplification of future forest structure with the tendency to overestimate homogenization . While the broad context of our results is still important, we suggest that our results should not be used deterministically for setting management boundaries.

Our simulation models did not include any forest management activities. While this provides a good baseline for identifying important refugia, it is unrealistic to consider forest change without also considering the role of management activities (Spittlehouse and Stewart 2003, Julius and West 2008, Mawdsley et al. 2009). The Forest Vegetation Simulator has many capabilities for simulating traditional management practices such as harvesting, thinning, and prescribed burning (Crookston and Dixon 2005). To create a more integrated model, it would be beneficial to consider a variety of management actions and how they may impact the distribution of nesting habitat over time. The Forest Vegetation Simulator also has extensions for considering the effects of insect pest outbreaks (Crookston and Dixon 2005) and wildfire (Beukema et al. 2000, Reinhardt and Crookston 2003). The complex interactions between climate change, fire, and pests are likely to contribute to rapid ecosystem transitions (Grimm et al. 2013), so it is important to consider these risk factors as a critical component of adaptive management, especially for spatially limited refugia. Finally, we also recommend a closer examination of the effect of forest habitat homogenization on forest resilience and integrity in the Uinta Mountains. Forest Vegetation Simulator modeled variables suggested decreases in the species richness and forest structure composition with increasing emissions. Forest homogenization can weaken the relationship between species distribution and environmental gradients (Vellend et al. 2007), so it is possible that the relationships between habitat and nest site distribution may not hold through climate change, an important consideration that we were not able to address with this approach.

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CHAPTER III

WHITE-HEADED WOODPECKER (*Dryobates albolarvatus*) HABITAT SELECTION IN THE CONTEXT OF PONDEROSA PINE FOREST RESTORATION

INTRODUCTION

Prior to European settlement, the dry conifer forests of the Inland Northwest were comprised of fire-tolerant trees such as ponderosa pine (*Pinus ponderosa*) and low, patchy cover of associated fire-tolerant shrubs. These historic forests were characterized by mixed-severity fire regimes that created patches of high-severity fire interspersed within the mosaic of low- to moderate-severity fire patches, creating forests referred to as complex early seral forests (Schoennagel et al. 2004, Saab et al. 2005, Dellasala and Hanson 2015). Complex early seral forests exhibited low tree densities, simple forest structure, and minimal, sparsely distributed ground fuels (Harrod et al. 1999, Everett et al. 2000, Hessburg et al. 2005, 2007, Kozma and Kroll 2012, Latif et al. 2016), however they were comparable to old-growth forests in biodiversity, supporting a wide array of species whose evolutionary histories were often intimately entwined with these biological disturbances (Fontaine et al. 2009, Fontaine and Kennedy 2012). The introduction of anthropogenic fire suppression, historical timber harvest, and heavy livestock grazing has dramatically altered natural forest disturbance regimes (Hessburg et al. 1999, Everett et al. 2000, Wright and Agee 2004), leading to a drastic change in forest composition and structure (Harrod et al. 1999, Hessburg et al. 1999). Northwestern dry conifer forests today are characterized by higher stem densities, smaller and younger trees, and a greater abundance of shade tolerant species in the understory such as Douglas fir (*Pseudotsuga* *menziesii*) and grand fir (*Abies grandis*) (Agee 1996, Hessburg and Agee 2003, Keeling et al. 2006). Additionally, these forests lack the complex heterogeneity created by mixed-severity fire (Wightman et al. 2010, Latif et al. 2016). These changes in structure and composition have increased forest vulnerability to catastrophic wildfires, representing a serious ecological, environmental, and socioeconomic threat (Wu and Kim 2013).

In order to reduce the risk of catastrophic wildfire and reestablish a full suite of ecological functions to western forests, an emphasis has been placed on landscape-scale management projects that aim to restore forest health and beneficial disturbance, reduce fuel loads, improve wildlife habitat, promote biodiversity of flora and fauna, and create sustainable industries (Gundale et al. 2005, Saab et al. 2019). Treatments to achieve these goals typically include a combination of thinning and prescribed burning treatments intended to increase landscape heterogeneity (Swanson et al. 1994, Landres et al. 1999, Agee 2003, Hessburg et al. 2005, Hood et al. 2016). Previous efforts have been associated with changes in soil properties (Gundale et al. 2005), reduced tree density and canopy fuel load (Roccaforte et al. 2010), increased stand resistance to bark beetle outbreaks (Hood et al. 2016), and positive impacts on habitat for birds and other wildlife (Kotliar et al. 2002, Gaines et al. 2007, Kalies et al. 2010, Bagne and Purcell 2011, Fontaine and Kennedy 2012, Latif et al. 2020*b*, 2021). While these results suggest promising support for continued implementation of these treatments as a management tool, assessing the impact of these management efforts on wildlife communities and individual species remains a key challenge.

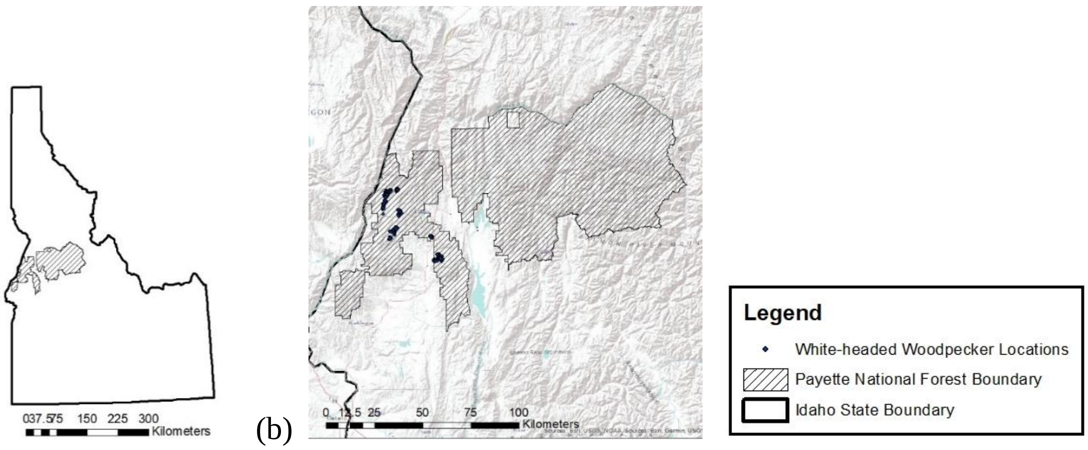
One of the goals of dry conifer forest management is improvement of wildlife habitat. Understanding the ways in which thinning and burning treatments affect wildlife is a critical element of understanding the full efficacy and effectiveness of this type of management (Germaine and Germaine 2002, Saab et al. 2019). For ponderosa pine forests in the interior northwest, one of the main focal species for assessing forest treatments is the white-headed woodpecker (*Dryobates albolarvatus*) (Hessburg et al. 2005, Gaines et al. 2007, 2010, Mellen-McLean et al. 2013, Saab et al. 2019). White-headed woodpeckers are regionally endemic to the dry conifer forests of inland North America (Garrett et al. 1996, Latif et al. 2015). Coevolution with these ecosystems has created a close association with heterogenous forests that are a mosaic of open- and closed-canopy with mature, large trees (Garrett et al. 1996, Wightman et al. 2010, Hollenbeck et al. 2011, Latif et al. 2015, 2020*a*). Additionally, white-headed woodpeckers rely, at least in part, on the seeds of large-coned pine, such as ponderosa pine and sugar pine, for a portion of their diet (Ligon 1973, Raphael and White 1984). Their limited distribution makes white-headed woodpeckers particularly vulnerable to environmental change, with reported broadscale habitat declines for the species (Wisdom et al. 2000, Saab et al. 2019). As a result, white-headed woodpeckers have been designated as a species at risk both locally and regionally (Garrett et al. 1996, Rich et al. 2004). In addition, white-headed woodpeckers are primary cavity nesters and thus are important ecosystem engineers as they create nesting and roosting locations for other species (Jones et al. 1994) and may have the ability to strongly influence forest species assemblages (Daily et al. 1993, Drever and Martin 2010, Kozma and Kroll 2012, Linden and Roloff 2015).

While white-headed woodpeckers have been the focus of extensively evaluated habitat distribution in the context of ponderosa pine forest restoration, most studies have focused on nest site selection and occupancy (Kozma 2009, Wightman et al. 2010, Hollenbeck et al. 2011, Kozma and Kroll 2012, Latif et al. 2015, 2020*a*, Linden and Roloff 2015). Information gained from these studies have helped to shape management recommendations for the species, encouraging the retention of large snags for nesting and foraging (Russell et al. 2007, Saab et al. 2007, 2009) and the creation of more open stands with a mosaic of open- and closed-canopy (Wightman et al. 2010, Hollenbeck et al. 2011, Kozma and Kroll 2012, Latif et al. 2015). While this has had a positive impact on white-headed woodpecker management with evidence suggesting the species is positively responding to treated stands (Kotliar et al. 2002, Gaines et al. 2007), there has been minimal effort to explore white-headed woodpecker habitat selection and space use independent of nesting. The advent of very high frequency (VHF) radiotelemetry technology small enough to be fitted to white-headed woodpeckers provides a unique opportunity to further examine the response of this species to forest treatments and can better inform management decisions aimed at species conservation (Guisan et al. 2013). To date, there have only been a few studies incorporating radiotelemetry technology with white-headed woodpeckers, and the focus of these studies has been to characterize foraging behavior (Lorenz et al. 2016, Kehoe 2017) or habitat selection in the context of a home range (Lorenz et al. 2015, Kehoe 2017). Consideration of habitat selection and space use in a broader sense may help to further describe the relationship between forest treatments and white-headed woodpecker habitat needs.

In order to characterize white-headed woodpecker space use in the context of ponderosa pine forest restoration, we designed a study to explore white-headed woodpecker space use in response to ponderosa pine restoration treatments over a period from 2014 to 2019. Our main objective was to characterize habitat selection for all woodpeckers in our study across the study area. Selection at this scale is described as second order selection or selection of home ranges within a larger species range (Johnson 1980). While not all of the woodpeckers in our study could be described as maintaining a home range within the post-fledging season, we still have used second order selection as a means of characterizing the spatial extent of movement for birds in relation to the broader available habitat. We were interested in whether woodpeckers demonstrated a preference or avoidance for harvesting and prescribed burning treatments classified either by treatment type or by the time elapsed since treatment. We also included habitat variables identified as important characteristics of nest-site selection from other studies to determine if space use choices were related to or independent of these variables.

STUDY AREA

Our study area included the Council (44°44'N, 116°26'W) and New Meadows (44°58'N, 116°17'W) districts of the Payette National Forest (Fig 3.1). The Payette National Forest is located in west-central Idaho, near the Idaho-Oregon border. The forest complex comprises 2.3 million acres (9300 km^2) of federally managed land that ranges in elevation from 1100 to 2400 meters. The Payette contains a diverse mix of habitats including patches of dry desert grassland, dense forest, and grass and shrub communities. The majority of the forest at lower and mid-elevations (1000 – 2000 m) is dominated by ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*), with grand fir (*Abies grandis*) and western larch (*Larix occidentalis*) codominant at mid-elevations (1400 – 2000 m) and lodgepole pine (*Pinus contorta*), Engelmann spruce (*Picea *engelmannii*), and subalpine fir (*Abies lasiocarpa*) found at higher elevations (2000 – 2500 m).



(a) (b)

Figure 3.1 Location of the Payette National Forest in western Idaho, USA (a) and the White-headed Woodpecker locations recorded in the Weiser-Little Salmon Headwaters Collaborative Forest Landscape Restoration Program area with very high frequency (VHF) telemetry in the post-fledging seasons from 2014 to 2019 (b).

METHODS

Bird Location Data

Between the years 2014 to 2019, 27 birds (F=12; M=15) were captured by USFS Rocky Mountain Research Station field crews. After active nests were identified through systematic search and broadcast surveys (Dudley and Saab 2003, Mellen-McLean et al. 2013), adult birds were trapped at nest sites during the early nestling period. A pole-mounted hoop net was placed over the cavity entrance after adult birds entered to feed nestlings, and the adult bird was captured upon exiting the cavity (Dudley and Saab 2007). Only one adult was selected from each nesting pair, and different individuals were selected between years to avoid pseudoreplication. To represent different treatment conditions, 15 birds were captured from nests in treated areas and 12 birds were captured from nests in non-treated areas. Selected birds were fitted with a 1.3g transmitter (Advanced Telemetry Systems, model A1065), according to the specifications outlined in Saab et al. (2013, 2014). Transmitters were approximately 2% of the average mass of the birds in the study and were attached to the dorsal side of the two central rectrices using cyanoacrylate glue and braided fishing line (Saab et al. 2013, 2014, Kehoe 2017). Birds were also fitted with a unique combination of colored leg bands and U.S. Fish and Wildlife Service aluminum leg bands to facilitate identification. All captures were approved under Montana State University Institutional Care and Use Committee Protocol number 2014-46, state of Idaho permit (# 950228), and USGS federal bird banding permit (# 22607).

Radio-tagged birds were tracked in the post-fledging period (approximately July to September) two to three times per week. A standardized tracking protocol with a randomly selected order was used to distribute sampling across individuals and spatiotemporal stratum. Birds were tracked both visually and with Telonics receivers (Model TR-4K, 164-166 MHz) and H-antennas (164-166 MHz). Birds were located at least once per scheduled tracking day, and additional locations were obtained where time permitted. Successive locations were recorded at least 20 minutes apart to control for spatial autocorrelation (Seaman et al. 1999). The majority of locations represented birds engaged in foraging activity on a variety of substrates (Kehoe 2017).

Habitat Variables

Habitat predictor variables were chosen based on previous nest-site selection and occupancy models (Wightman et al. 2010, Hollenbeck et al. 2011, Latif et al. 2015, 2020*a*, Linden and Roloff 2015). All geospatial layers were obtained at a 30-meter resolution. We included elevation from a digital elevation model (DEM; part of the USGS 3D Elevation Program (3DEP)), slope, aspect (LANDFIRE 2008), and canopy cover (MRLC 2011, 2016) as continuous variables. We converted aspect to a categorical variable with the following designations: north (0° – 45°), northeast (45° – 90°), east (90° – 135°), southeast (135° – 180°), south (180° – 225°), southwest (225° – 270°), and west (270° – 360°). We also obtained a forest type layer categorized by dominant tree species (Ruefenacht 2008). For quantifying Weiser – Little Salmon Headwaters Collaborative Forest Landscape Restoration Program (CFLRP) treatment activities, we obtained management activity polygons from the Payette National Forest and cross-referenced these polygons with management codes from the Forest Service Activity Tracking System (FACTS) database to filter activities that were part of the Weiser – Little Salmon Headwaters CFLRP. Because harvesting of both small and large diameter trees often occurred simultaneously, we did not attempt to make distinctions between types of harvest and simply classified treatment within a space as no treatment (0), harvest (1), burn (2), or coinciding harvest and burn (3). Because there were no significant wildfires in our study area during our study period, we did not account for wildfire as a variable. All cells classified as "burn" reflect areas that were treated with low-intensity prescribed fire and intermittent slash pile burning. We also used the treatment layer to derive a layer for time since harvest and time since burn. Because harvest and burning took place on different temporal scales, we treated these variables as if they were independent, though it is important to consider that areas treated as part of the Weiser-Little Salmon Headwaters CFLRP were generally first harvested and subsequently burned.

Table 3.1 Candidate variables used for development of resource selection models for white-headed woodpeckers in the post-fledging season (mid-July to September) from 2014 to 2019, Payette National Forest, Idaho, USA.

Variable Name	Abbreviation	Description
Elevation	Elev	Pixel elevation from Digital Elevation Model
Slope	Slp	Pixel slope as % rise over run
Aspect	Asp	Categorical representation of slope orientation (N, NE, E, SE, S, SW, W, NW)
Canopy Cover	CC	Percent canopy cover
Forest Type	FT	Forest classification based on dominant tree species
Treatment Type	Trt	Pixels for harvest and burn Weiser – Little Salmon Headwaters CFLRP treatments
Time Since Harvest	HTst	Categorical representation of the number of years since harvest
Time Since Burn	BTst	Categorical representation of the number of years since burn

Resource Selection Function

All data cleaning and analyses were conducted in R v4.1.2 (R Core Team, 2021). We defined available area by calculating a minimum convex polygon (MCP) around the locations for each bird. To smooth our boundary for available habitat, we then buffered the individual MCPs by the longest recorded step length or distance between two consecutive points for birds in the study (5,054 m). The buffered MCPs created two core areas for all woodpeckers in all years that we defined as available habitat for 2^{nd} order habitat selection (Johnson 1980). We sampled background points uniformly across the available habitat at six different levels (1000; 5000; 10,000; 50,000; 100,000; 500,000). Uniformity in sampling points is recommended as it provides a way to evaluate the integral numerically (Warton and Shepherd 2010, Aarts et al. 2012, Benson 2013, Fieberg et al. 2021, Street et al. 2021). Additionally, the different number of sampling points is recommended to ensure reaching stability in estimated parameters as habitat selection functions can be sensitive to both the defined area of availability and the number of background points chosen at that scale (Northrup et al. 2013, Gerber and Northrup 2020). To reduce issues with collinearity among predictor variables, we calculated correlations between all pairwise combinations of covariates. Because no correlation coefficients were >0.60, we did not omit any covariates based on this assumption (Dormann et al. 2013). We examined the variation in used and background points for each continuous variable using density plots and plotted the proportion of used and background points for each categorical variable to determine which categories should be collapsed into more meaningful categories. Based on density plots, we omitted elevation, aspect, and forest type from further analysis. We collapsed ‘Time Since

Harvest' into two levels (0-6 years and 7+ years), and we also collapsed 'Time Since Burn' into two levels (0-4 years and 5+ years) (Fig 3.2).

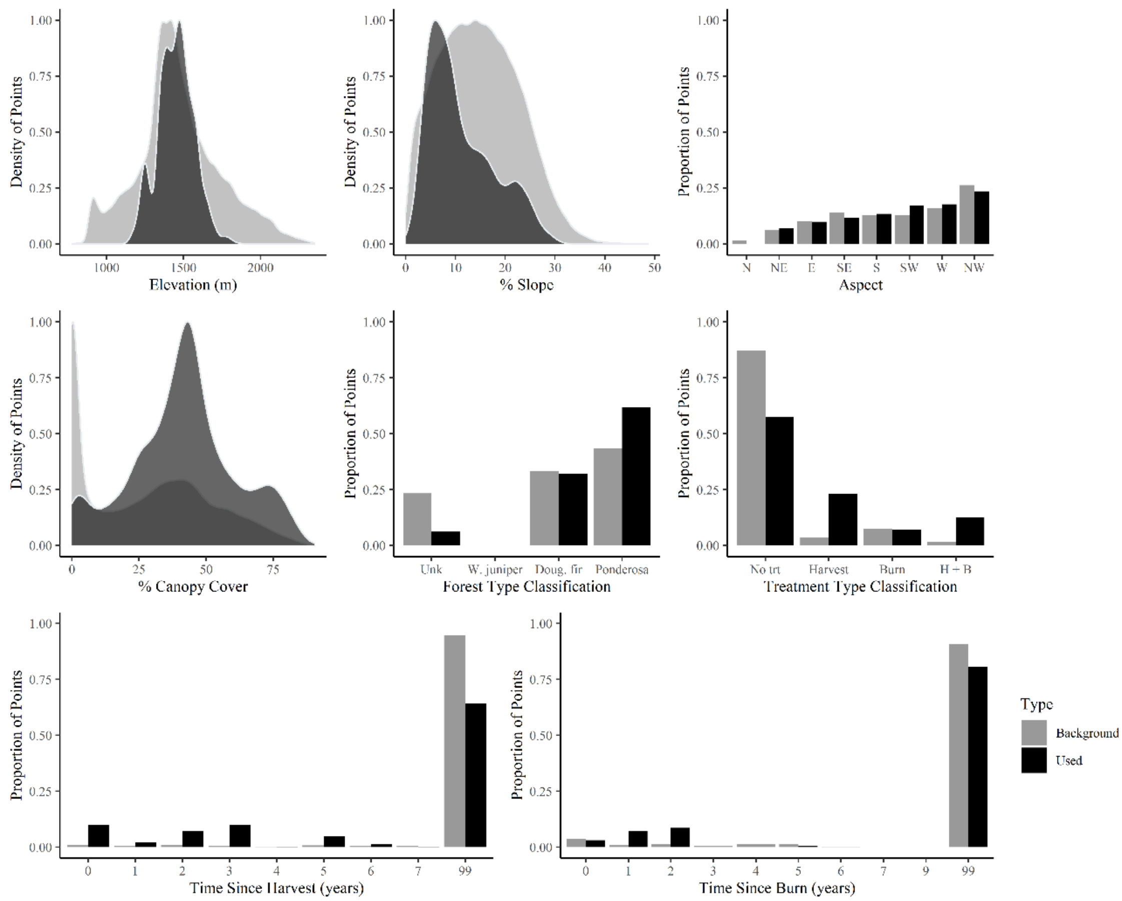


Figure 3.2 Density plots of proportion of background (available) and used points in each habitat condition for white-headed woodpecker telemetry locations in Payette National Forest, Idaho, USA. Density plots were used to determine which variables indicated selection or avoidance where used points suggested selection or avoidance of a particular variable relative to the availability of that variable.

We used resource selection functions (RSF) (Manly et al. 2002) to assess the overall habitat preference of all woodpeckers in our study (n = 27) in the post-fledging season (mid-July to September) at the study area level (2nd order RSF; (Johnson 1980)). Though our sample size is small, prior research on RSF implementation has suggested that the most biologically relevant effects can be estimated with only a few animals (Street et al. 2021). RSFs compared values of covariates at the GPS locations for all woodpeckers (used points given a value of 1) with values at the uniformly drawn background points across our defined available area (available points given a value of 0). We weighted the background points by 5000 to facilitate model fit (Fithian and Hastie 2013).

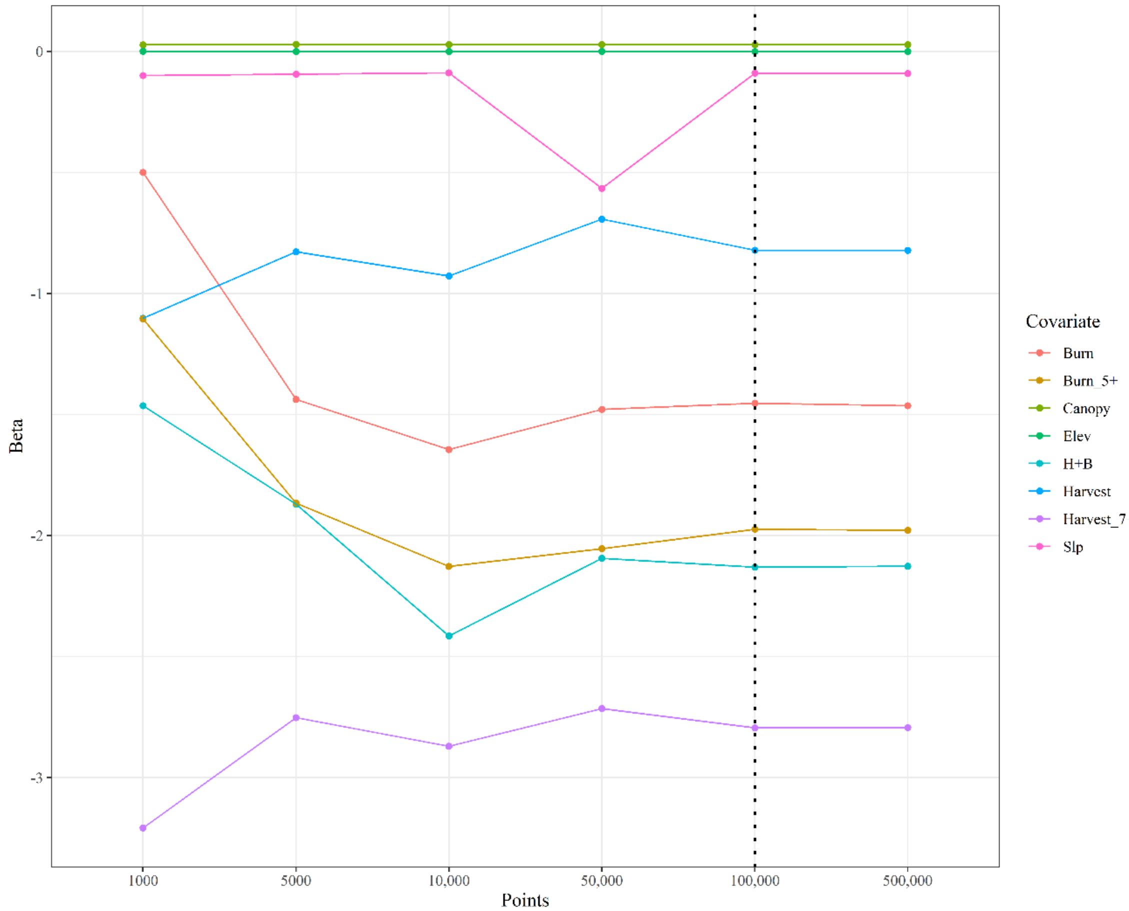


Figure 3.3 Coefficient (β) values for the initial resource selection function model fit with different number of background points for white-headed woodpeckers in Payette National Forest, Idaho, USA. We have only shown coefficients for variables that were considered significant in the model. We reached stabilization in parameter estimates near 100,000 background points.

We used a generalized linear model (GLM), with a binomial distribution, to estimate the RSF parameters (Boyce et al. 2002). To control for the sensitivity of RSFs to the number of background points, we fit an initial model including all our selected covariates at the six different levels of background points to determine at which number of background points the parameter values stabilized (Northrup et al. 2013) and determined 100,000 background points to be sufficient for parameter stability (Fig 3.3). We then fit a multivariate fixed-effects model with our selected covariates and conducted a backward-stepwise model selection procedure, removing all non-significant variables from the multivariate model until the effects of all remaining variables were significant (Hosmer and Leshow 2000). We fit our top fixed-effects model as a set of mixed-effects models, where individual and year were modeled as random intercepts and random slopes were fit for all covariates (Gillies et al. 2006). We used Aikaike's Information Criterion with an adjustment for small sample size (AIC_c) to rank competing models (Boyce et al. 2002, Burnham and Anderson 2004). We validated our top model internally with the pseudo-r^2 calculation function for mixed effects models in the R package *MuMin* (Bartoń 2022). We then completed a *k*-folds cross validation with five folds to determine how well the model could predict a subset of test data from each fold.

RESULTS

Bird Location Data

Relocations for individual birds ranged from 30 to 121, with a mixture of both visual and non-visual relocations for each bird. We used a total of 1505 relocations to conduct our RSF analysis, ignoring individual variation. Though this approach can weight models more heavily towards individuals with a greater number of observed locations, the distribution of relocations from our sampled birds was centered near the mean ($\bar{x}$ = 56) and points were not heavily weighted in one spatial area, so we feel this is still a good representation of selection across sampled birds.

Resource Selection Function

White-headed woodpeckers in our study had a moderate selective preference for higher slopes and minimal selective preference for higher canopy cover. While there was high individual variation in response to treatment and time since treatment, overall, there was a selective preference for untreated areas relative to all treatment types and more recently harvested or burned areas relative to areas where disturbance had been >7 years since harvest or >5 years since burn (Fig 3.4).

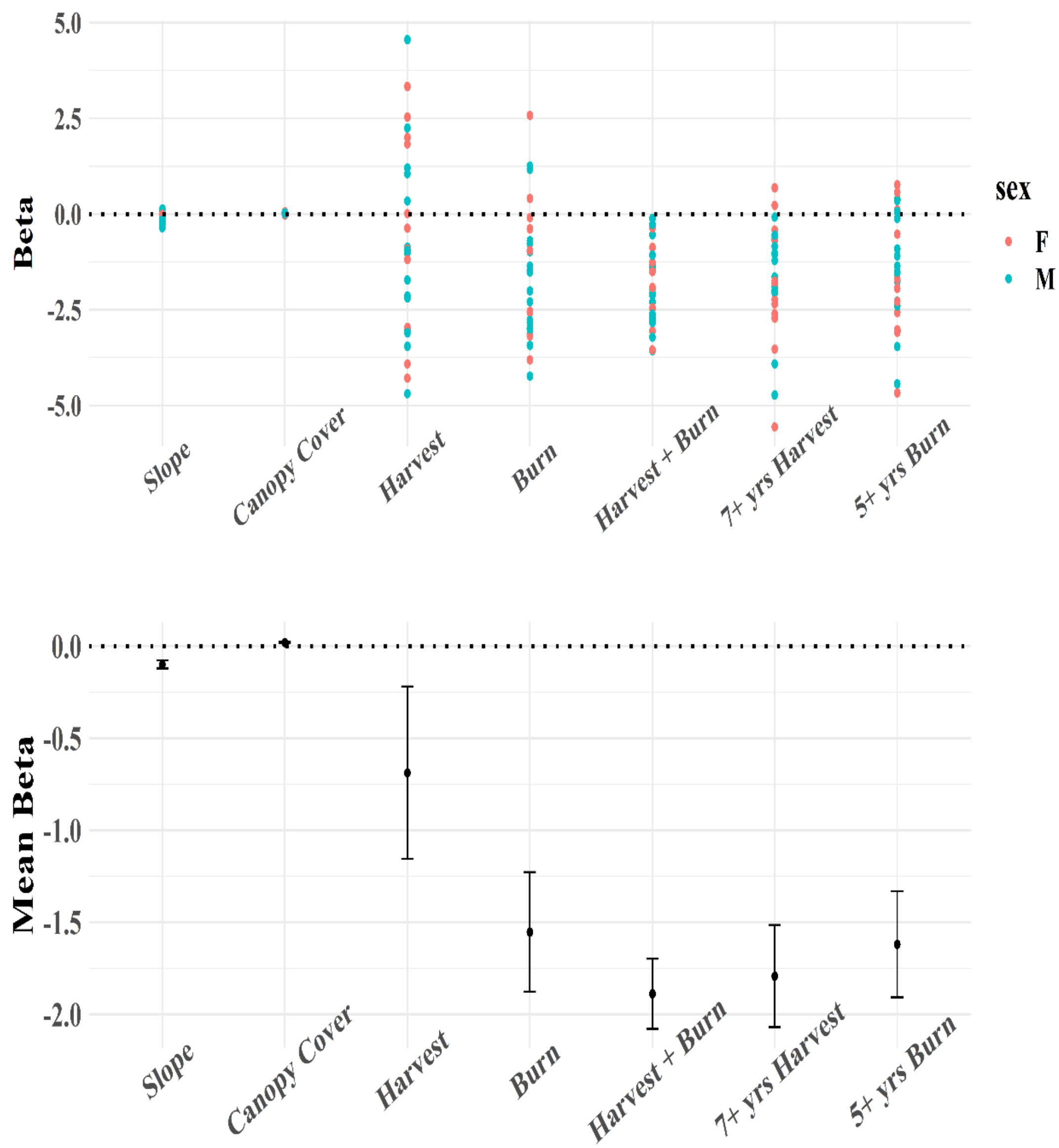


Figure 3.4 The variation in individual selection coefficients estimated from the top resource selection function mixed effects model for male and female white-headed woodpeckers in the Payette National Forest, Idaho, USA (*top*) and the mean coefficient values for all woodpeckers with standard error (*bottom*). White-headed woodpeckers in our study generally avoided treated areas in the context of ponderosa pine forest restoration, but there was a large amount of individual variation in response to treatment types and time since treatment variables.

Our top ranked model included slope, canopy cover, treatment, time since harvest, and time since burn with random intercepts for individual and year and random correlated coefficients for all covariates (Table 3.2). The majority of variance was explained by inclusion of the random effects in the model, with a marginal pseudo-r^2 score of 0.11 and a conditional pseudo-r^2 score of 0.54. Under *k*-folds cross validation, the mean AUC score was 0.902 (+/- 0.005). The greatest amount of variation in selection preference were for harvested and burned areas with the least amount of variation in selection preference for slope and canopy cover. At the population level, woodpeckers in our study had a selection preference for less slope and slightly higher canopy cover. They showed a population-level selection preference for untreated areas over all types of treatment, but also showed a positive selection preference for recently treated areas (<7 years since harvest and <5 years since burn) (Table 3.3).

Table 3.2 The top four models for 2nd order resource selection by white-headed woodpeckers in the Payette National Forest, Idaho, USA from 2014-2019.

Model	Log-likelihood	AICc	ΔAICc	W_i
Slp + CC + Trt + HTst + BTst + (1|year) + (1 + Slp + CC + Trt + HTst + BTst | id)	-18360.65	36811.3	0	0.671
Slp + CC + Trt + HTst + BTst + (1 + Slp + CC + Trt + HTst + BTst | id)	-18362.36	36812.8	1.43	0.329
Slp + CC + Trt + HTst + BTst + (1 + Slp + CC + Trt + HTst + BTst | year/id)	-18363.53	36887.2	75.86	0
Slp + CC + Trt + HTst + BTst	-19465.44	38946.9	2135.55	0

The log-likelihood, AIC_c value, difference in AIC_c between the model and the top model (ΔAIC_c), and model weights (w_i) are shown. Abbreviations are as follows: slope (SLP), canopy cover (CC), treatment type (Trt), time since harvest (HTst), time since burn (BTst), bird individual identification (id).

Table 3.3 Estimated model coefficients from fixed-effects in the top model for white-headed woodpecker second-order resource selection function model, Payette National Forest, Idaho, USA from 2014-2019.

Coefficient	β	SE	*P*
Intercept	-6.81	1.36	0.00
Slope	-0.57	0.13	0.00
Canopy Cover	0.02	0.01	0.00
Harvest*	-2.16	1.29	0.09
Burn*	-2.19	1.17	0.06
Harvest + Burn	-3.54	1.21	0.00
7+ years since harvest	-3.01	1.20	0.01
5+ years since burn	-2.11	0.71	0.00

* No significant effect in the model

DISCUSSION

White-headed woodpeckers in the Payette National Forest displayed a great deal of variation in habitat selection preference in the post-fledging timeframe. Variation in selection preference is especially pronounced in the response to treatment types. While the grouped habitat selection preference was for untreated areas over any type of treatment, individual preferences suggested a range of selection and avoidance with several birds having a positive selection preference for harvested or burned areas. All woodpeckers in our study did avoid areas that had recently overlapping harvest and burn treatments, however, most of the woodpeckers in our study did demonstrate a selection preference for recently harvested or recently burned areas, suggesting that recent treatments have benefits for the species in the post-fledging timeframe.

The woodpeckers in our study were primarily engaged in foraging activities when locations were recorded. The habitat selection preference for recently harvested or burned areas suggests that there may have been more foraging opportunities for woodpeckers in these areas. This observation is consistent with previous research that has suggests thinning and burning treatments lead to increased snag decay and insect activity immediately following a treatment (Chambers and Mast 2005, Covert-Bratland et al. 2007, Kalies et al. 2010). Kalies et al. (2010) described a similar positive response among woodpeckers to thinning and burning treatments in Southwestern forests. White-headed woodpeckers rely partially on invertebrates including ant (Hymenoptera), beetles (Coleoptera), and scale insects (Homoptera) (Raphael and White 1984, Garrett et al. 1996). Attraction and infestation of different bark beetle and wood borer species to fire-injured ponderosa pine has been well-documented (Peterson and Ryan 1986, Kelsey and Joseph 2003, Fettig et al. 2008, Costello et al. 2011, Davis et al. 2012, Powell et al. 2012, Negrón et al. 2016). Prescribed burning typically leads to variable mortality and fire injury within a stand (Negrón et al. 2016) thus promotes insect infestations, leading to potentially greater foraging opportunities for white-headed woodpeckers and other insectivores in recently burned stands (Farris et al. 2002, Shea et al. 2002, Farris and Zack 2005).

Some of the variation in habitat selection preference that we observed may have been related to timing and differences in weather patterns between years. While white-headed woodpeckers do rely on invertebrates for a large portion of their diet, they also forage on pine seeds and sap (Ligon 1973, Garrett et al. 1996). As temperatures cool, insect activity and development decreases (Bale et al. 2002, Jaworski and Hilszczański 2013), leaving fewer invertebrate food resources available to woodpeckers and other insectivores (Elchuk and Wiebe 2003, Gaylord et al. 2008, Kozma 2009). Cooler temperatures and less insect activity may cause white-headed woodpeckers to shift to pine crops for a more reliable source of food later in the year, a pattern that has been observed in both in Idaho and Washington (Ligon 1973, Raphael and White 1984, Lorenz et al. 2016). If cone crops were a primary food source during the post-fledging period in our study area, then this may explain why woodpeckers in our study showed a habitat selection preference for untreated areas overall during this timeframe. It is important to note, however, that thinning and burning treatments will improve sources of cone crop for white-headed woodpeckers in the longer term (Tepley et al. 2020). Avoidance of treated areas is likely highly temporally variable. Additional studies considering space use during the excavating and breeding seasons may help elucidate patterns of foraging substrate shifts to better explain the temporal trends of foraging behavior and how these relate to habitat selection preferences throughout the year. Inclusion of additional predictor variables such as those derived through Tasseled Cap Transformations may also help to explain the variability in space use as it relates to foraging behavior and insect availability (Sharma 2000, Baig et al. 2014).

The results of our study further emphasize the importance of habitat heterogeneity for white-headed woodpeckers. Though our results suggested avoidance of harvested and treated areas in the post-fledging period, previous studies have demonstrated the importance of these areas for nesting and occupancy (Russell et al. 2007, Saab et al.

2007, 2009, Wightman et al. 2010, Kozma and Kroll 2012, Latif et al. 2020*a*). White-headed woodpeckers are weak primary excavators, and they rely on snags with moderate to advanced decay states to successfully excavate nesting cavities (Raphael and White 1984, Milne and Hejl 1989, Garrett et al. 1996, Buchanan et al. 2003, Kozma 2009). Increasing snag density and decreasing live tree density has been tied to improving habitat for white-headed woodpeckers (Wightman et al. 2010, Hollenbeck et al. 2011, Kozma 2011), and our findings suggest some positive association with treatment and time since treatments, though variable among birds. The avoidance of treated areas relative to untreated areas suggests that white-headed woodpeckers rely on undisturbed forest patches to some degree, but positive selection for recently treated areas also emphasizes the dichotomy of selection preference for diverse habitat types.

Our findings support continued management activities that promote heterogenous forest landscapes, similar to the mosaics of open- and closed-canopy forests common under historical mixed-severity fire regimes (Hessburg et al. 2005). Varied space use between the nesting and post-fledging period for white-headed woodpeckers suggest that CFLRP treatments may provide important diversity in forest structural characteristics for a variety of ecological needs for this species. Further analysis of variation in space use may include functional response models to further elucidate which habitat variables are driving variation in selection preferences during the post-fledging period (Mysterud and Ims 1998, Bjørneraas et al. 2012, Street et al. 2016).

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CHAPTER IV

ANNUAL SPACE USE BY NORTHERN GOSHAWKS (*Accipiter gentilis*) IN NORTHEASTERN NEVADA: A CASE STUDY USING BEHAVIORALLY SEGMENTED INTEGRATED STEP SELECTION ANALYSIS

INTRODUCTION

Habitat loss and fragmentation are wildly regarded as the leading causes of biodiversity loss worldwide (Vitousek et al. 1997, Pereira et al. 2010, Rands et al. 2010, Newbold et al. 2015). While there is ongoing debate over the extent to which habitat loss and fragmentation are intertwined and the scale at which these forces may impact species richness (Fahrig 2003, 2013, Prugh et al. 2008, Thornton et al. 2011, Hanski 2015, Fletcher et al. 2018), anthropogenic disturbances have been identified as the main drivers altering the extent and spatial patterns of habitats (Barnosky et al. 2011, Halstead et al. 2019). Habitat loss and fragmentation have been linked to negative impacts such as loss of genetic diversity, decreased population growth rate, abundance, and distribution, alterations to species interactions, reduced breeding, dispersal and foraging success, and reduced number of large-bodied specialist species (as reviewed in Fahrig 2003). In order to mitigate the impacts of habitat loss and fragmentation and conserve biodiversity, it is important to identify species that are the most vulnerable to these habitat loss (With and King 1999, Fahrig 2001, 2003) and to focus conservation efforts on understanding the amount of habitat required for conservation of species of concern as well as preservation and restoration of important areas for these species (Fahrig 2003). Critical habitat is vital for long-term population viability as it supports a variety of demographic, environmental, and genetic traits unique to each species (Lande 1988, 1993, Hanski 2011).

Much of our understanding of the ecological consequences of landscape change has come from research focusing on avian communities, especially forest-dwelling species (Donovan et al. 1995, Hawrot and Niemi 1996, Major et al. 2001, Watson et al. 2004, Herse et al. 2018). Bird groups are diverse and found in nearly every habitat on the globe, however they tend to have specialized habitat requirements related to different aspects of their life history. They are generally easy to detect and monitor, typically positioned at higher trophic levels, and their population trends tend to mirror those of species from other groups. Some of the most useful indicators of environmental changes are raptors which generally display trackable sensitivities to anthropogenic and environmental disturbances (Bildstein 2001, Hoffman and Smith 2003). One species of interest for management and forest health monitoring in is the Northern Goshawk (hereafter ‘goshawk’) (Martin et al. 1998, Hoffman and Smith 2003). While goshawks inhabit a wide variety of habitats across their range, they tend to nest within a subset of forest structural characteristics (Bosakowski 1999), including older-growth areas with at least partially closed canopy and open understory (Reynolds 1983, Hall 1984, Squires and Ruggiero 1996, Bosakowski 1999). This association with a narrow set of habitat characteristics has led to the belief that goshawks may be particularly vulnerable to habitat loss and fragmentation, especially when exacerbated by risk factors such as wildfire, climate change, and invertebrate infestation (Graham 1999, Squires and Kennedy 2006).

The majority of prior research on goshawk habitat and ecology has been conducted in areas with contiguous, dense coniferous forests (Reynolds 1992, Penteriani 2002, McGrath et al. 2003, Andersen et al. 2005, Byholm et al. 2020). The assertion that goshawks may be particularly vulnerable to habitat loss and fragmentation in these systems is consistent with research involving other avian forest species where reproductive success was positively correlated with percentage of forest cover, percentage of forest interior, and average patch size (Donovan et al. 1995, Robinson et al. 1995). While species like the goshawk that are adapted to contiguous habitat may be particularly vulnerable to landscape change, evidence also suggests that the spatial configuration of habitat may be important for species occurrence, abundance, and richness beyond the effects of habitat amount (Andrén and Andren 1994, Haddad et al. 2015, Hanski 2015, Pfeifer et al. 2017, Halstead et al. 2019).

One way to further the understanding of how goshawks may be impacted by habitat loss and fragmentation is to consider how they interact with habitat that is different from previously studied contiguous forest habitat. Goshawks in the interior Great Basin offer the opportunity to study the species occurring in a naturally fragmented habitat (Hasselblad 2004, Fairhurst and Bechard 2005, Bechard et al. 2006, Miller et al. 2013, Jeffress 2020). They are primarily restricted to nesting in late-succession aspen or conifer stands, often isolated in perennial drainages. These naturally fragmented patches are surrounded by large expanses of sagebrush steppe and sagebrush shrubland communities (Hasselblad 2004, Miller et al. 2013, Jeffress 2020), areas often thought to be low-quality for goshawks, especially during the breeding season. As forests throughout the west face increasing threats of habitat loss and fragmentation (Heilman et al. 2002), understanding how goshawks interact with habitat within the interior Great Basin may provide insight into the adaptability of the species.

In addition to understanding the unique dynamics of goshawk interactions with naturally fragmented habitat, it is also important to gain a better understanding of goshawk movement and space use. The movement ecology of goshawks, especially in wintering or non-breeding months, is poorly understood, in part due to a lack of robust data (Drennan and Beier 2003, Sonsthagen et al. 2006, Squires and Kennedy 2006). Additionally, understandings of space use and resource selection have relied heavily on classifying home ranges for goshawks, regardless of whether the pattern of locations suggested such behavior (Sonsthagen et al. 2006, Moser and Garton 2019, Blakey et al. 2020) or considering only resident bird behavior in wintering months (Drennan and Beier 2003). Studies of space use have also been frequently situated around nest sites (Greenwald et al. 2005, Carroll et al. 2006). This can be problematic for considering the full suite of movement ecology for the species, especially in months where they are not centrally tied to a nest location. When movement strategies and behavior were explored for goshawks, the definitions were often based on a simple arbitrary distance threshold instead of analyzing point patterns (Stephens 2001, Sonsthagen et al. 2006), and timing of behavioral state switching (i.e. breeding to non-breeding) was often assumed based on date cutoffs from the literature instead of considering the unique behavioral patterns of birds in the area (Underwood et al. 2006). space use of goshawks without the assumption of bounding them to either a nesting territory or a home range, allowing for a less biased approach to considerations of space use and resource selection. High-resolution tracking data allows us to consider goshawk movement and interaction with habitat across an annual scale, allowing us to better explain the associations with habitat variables in this unique ecosystem.

The objectives of our descriptive study of goshawks in northeastern Nevada were to characterize movement behavior and timing of state switching (i.e., breeding behavior to non-breeding behavior) to inform a step selection analysis for birds in a naturally fragmented landscape throughout the year. We hypothesized that goshawks in the interior Great Basin would display similar selection preferences for higher elevations, higher canopy cover, moderate slopes, and north to northwest aspects located in forested patches during the breeding season, similar to the findings for goshawks breeding in contiguous forest (Hayward and Escano 1989, Squires and Ruggiero 1996, Daw and DeStefano 2001, Reich et al. 2004). Because water may be a limiting resource in the interior Great Basin, we also included distance to the nearest water source in our analysis and hypothesized that goshawks would have a positive selection preference for shorter distances to water during the nesting season. While there have been few previous studies for goshawks in winter months in North America (Titus et al. 1995, Pendleton et al. 1998, Stephens 2001, Drennan and Beier 2003), we hypothesized that, during the non-breeding season, goshawks in our study would select for lower elevations, lower slope, less canopy cover, south to southwest-facing aspects with less selection preference for forested areas over non-forested, consistent with results of wintering goshawks in other studies (Stephens 2001, Drennan and Beier 2003). We also hypothesized that distance to water would be less important in the winter months than in summer months in our study area as temperatures are cooler and snow is readily available.

STUDY AREA

Our study area included initial capture locations for goshawks at monitored nest sites in the Pinon Range, Pequop Mountains and East Humboldt Range (sub-range of the Pequops), Jarbridge Mountains and Bruneau Range (sub-range of the Jarbridges), Bull Run Mountains, and Independence Mountains, all located in Elko County, Nevada and considered part of the Great Basin Region. Land management of these ranges is divided between the Nevada Department of Wildlife, Bureau of Land Management, and U.S. National Forest, and the ranges can be considered isolated island ranges with little to no connectivity to neighboring mountain ranges. The Great Basin region is characterized by a continental climate with cold winters and warm, often dry summers. Additionally, these areas are classified by their aridity, frequent summer droughts, and low annual precipitation (Comstock and Ehleringer 1992).

Elevation in our study area ranges from 1700 to 3000 meters. Vegetation is comprised mostly of open sagebrush steppe and sagebrush shrubland habitat (*Artemisia sp.*) with highly fragmented and isolated stands of mixed conifer (*Pinus albicaulis* and *Pinus flexilis*) at >2500 meters and aspen (*Populus tremuloides*) found in lower-elevation perennial drainages (Bechard et al. 2006; Jeffress 2020). Other dominant species in these areas include grasses (*Poa sp.*, *Elymus sp*., and *Festuca sp.*), rabbitbrushes (*Ericameria nauseosus, Chrysothamnus viscidiflorus*), bitterbrush (*Purshia tridentata*), and horsebrush (*Tetradymia canescens*). Some goshawk nesting stands also occur in pinyon-juniper woodlands dominated by species such as single-leaf pinyon (*Pinus monophylla*), Utah juniper (*Juniperus osteosperma*), and Rocky Mountain juniper (*Juniperus scopulorum*). Plant communities, especially aspen stands, are particularly sensitive to invasive cheatgrass (*Bromus tectorum*). Land use and management in these mountain ranges includes activities such as mining and exploration, cattle ranching, pinyon-juniper removal treatments, and outdoor recreation (hunting, camping, off-road vehicle use, etc.). Additional movements of goshawks in our study covered areas from southern Idaho to southern Nevada, which area still part of the larger Great Basin ecosystem but may represent slightly different vegetation community composition and dominant species.

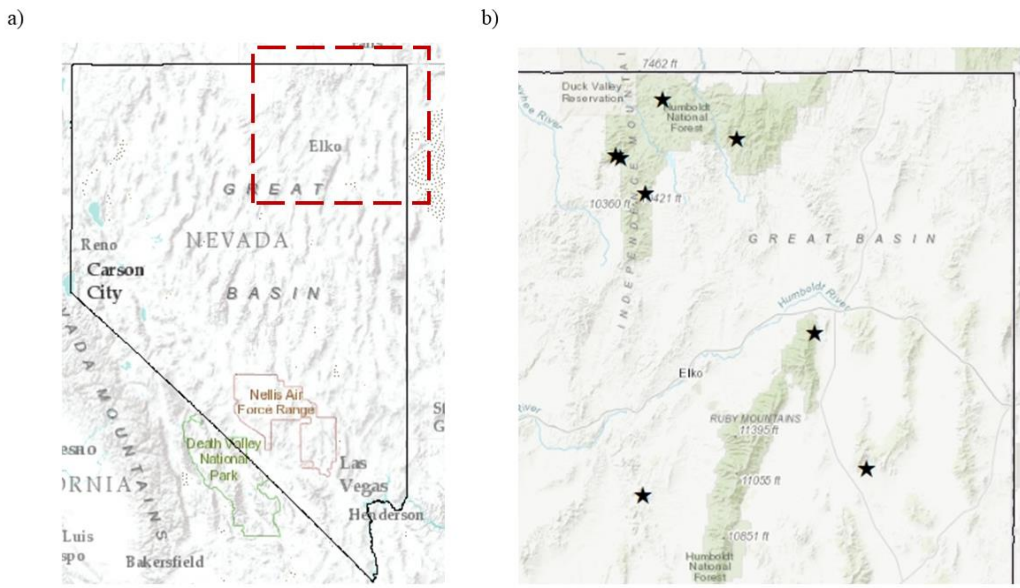

Figure 4.1 Northern goshawk initial trapping area, located in the interior Great Basin, northeastern Nevada, USA (a). Approximated locations of trapping sites are displayed as stars, though annual goshawk movements between the years 2017-2021 covered the state of Nevada (b).

METHODS

Telemetry Data Collection

The Nevada Department of Wildlife (NDOW) purchased three 22g Solar Argos/GPS PTT satellite backpack transmitters from Microwave Telemetry, Inc. and four 20g Solar Argos/GPS PTT satellite backpack transmitters (Rainier-S20) from Wildlife Computers. All transmitters were pre-programmed to collect data including position, battery voltage, altitude, course heading, speed, and air temperature on two unique duty cycles, chosen to reflect approximate seasons for breeding and non-breeding. For the Microwave Telemetry, Inc. units, the first duty cycle collected data at midnight and hourly from 0700 – 1900 PST from April 1 to August 31(breeding and post-fledging stages). The second duty cycle collected data at midnight, 0800, 1000 – 1200, 1400, and 1600 (non-breeding season). For Wildlife Computers units, the first duty cycle collected data at midnight and hourly from 0700 – 1900 PST from March 2 to October 31 (breeding and post-fledging stages), and the second duty cycle collected data at midnight, 0800, 1000 – 1200, 1400, and 1600 from November 1 to March 1 (non-breeding season). Less frequent collection of data during the non-breeding season was selected to account for reduced winter daylight hours that can lead to battery drain on solar-powered units (Jeffress 2020).

Adult goshawks were targeted for trapping near active nest site when nestlings were aged at least 14 days. NDOW used a dho gaza net with a mounted robotic Great Horned Owl (*Bubo virginianus*) and owl callback playing as a lure (Bloom et al. 1992). Once captured, morphometric measurements including weight, wing, leg, and tail measurements were taken, and each bird was marked with a unique U.S. Geological

Survey aluminum leg band. Transmitters were fitted as a backpack unit with a Teflon ribbon harness (Humphrey and Avery 2014), and then the birds were released and observed for a short time to be sure that the transmitter was not impacting flight abilities. All trapping, sampling, and banding was conducted under Federal Bird Banding Permit 24006.

Data from all active satellite telemetry units was downloaded and reviewed weekly. Location data from the Microwave Telemetry units was downloaded from the Argos CLS America website and processed using the Microwave Telemetry, Inc. GPS parsing software available from the company website. Location data from the Wildlife Computers units was downloaded in .csv format from the Wildlife Computers Data Portal. To account for stress related to capture that may have impacted movements, we omitted location data from the first 24 hours. We also omitted the last day of recorded location data to account for any changes in behavior that may have occurred leading up to the death of the bird. We removed records that did not include GPS coordinates and duplicated records. We used X-Y plots of locations to determine if there were any obvious outlier locations for each bird, and these were also omitted from data analysis. All our data analysis was run in R version 4.1.2 (R Core Team 2021).

Net Squared Displacement Movement Models

We used the movement models described in Bunnefeld et al. (2011) to characterize movement strategies and timing of state switching for each bird. Bunnefeld et al. (2011) describes movement strategies for migration, dispersal, mixed migration, resident, and nomad. These movement models explain movement strategies as a function of net squared displacement (NSD). NSD represents the squared distance between the current location in an individual's track and the initial location recorded for that individual. Distances are squared to omit directional information, creating unbiased measurements of displacement from the origin of the GPS track. While NSD models have not been thoroughly evaluated at temporal and spatial scales less than a year, we still fit these models to our goshawk data to determine if NSD could be used to help elucidate movement strategy and state switching in our data (Bunnefeld et al. 2011, Papworth et al. 2012).

To compress our data, we used the *adehabitatLT* package (Calenge 2006). to resample locations to one daily record. We then used the *migrateR* package (Spitz 2019) to fit movement models to all goshawks. In order to achieve model convergence, we adjusted the initial values of starting paraments for delta and rho successively. *migrateR* also uses AIC adjusted with Arnold's Rule (Arnold 2010) to rank models. We evaluated the best fit models to characterize the movement strategies of each goshawk and examined plots of the fitted data to determine time periods when state switching was likely to have occurred. We appended the location data with either state 1, corresponding to lower-value, clustered NSD (breeding season), or state 2, corresponding to higher-value, less clustered NSD (non-breeding season).

Habitat Covariates

Habitat predictor variables were chosen based on previous nest site selection, space use, and wintering space use studies (Squires and Ruggiero 1996, Stephens 2001, Drennan and Beier 2003, Hasselblad 2004, Sonsthagen et al. 2006, Miller et al. 2013, Moser and Garton 2019). Because water may be a limiting resource in the interior Great Basin, especially during the months from June to September (Comstock and Ehleringer

1992) when goshawks are our area are typically nesting and fledging, we decided to also include distance to water as a habitat variable. Though water is not always cited as a significant variable for nest site selection, nest areas often include close proximity to streams (Hall 1984, Kennedy 1988, Reynolds 1992, Graham et al. 1997). suggesting that a water source may be an important feature, especially in the interior Great Basin and other areas where precipitation is limited. All geospatial layers were obtained at a 30-m resolution. We included elevation from a digital elevation model (DEM), slope, aspect (LANDFIRE 2008), and canopy cover (MRLC 2016) as continuous variables. We included the national land cover layer (MRLC 2019), which we reclassified into four categories: water, forest, shrub and grassland, and other. Finally, we obtained coordinates for known springs from the Springs Stewardship Institute of the Museum of Northern Arizona (Ledbetter et al. 2014) and the U.S. Geological Survey nation hydrography dataset for Nevada (U.S. Geological Survey 2022).

Table 4.1 Candidate variables used for development of individual state 1 and state 2 step selection models for northern goshawks satellite transmitter tagged in northeastern Nevada, USA between the years 2017 - 2021.

Variable	Abbreviation	Source	Description
Elevation	Elev	Landfire	Pixel elevation from Digital Elevation Model
Slope	Slp	Landfire	Pixel slope as % rise over run
Aspect	Asp	Landfire	Categorical representation of slope orientation (N, NE, E, SE, S, SW, W, NW)
Canopy Cover	CC	MRLC	Percent canopy cover
Land Cover	Land	MRLC	National land cover class categories
Distance to Water	Water	SSI	Distance to nearest water source (m)

MRLC = Multi-Resolution Land Characteristics Consortium
SSI = Spring Stewardship Institute of the Museum of Northern Arizona

State-based Integrated Step Selection Analysis

We used the *amt* package in R (Signer et al. 2019) to prepare our data. For each bird, we resampled GPS locations to a common interval of one hour with a tolerance of +/- 15 minutes. Resampling creates burst identifications to control for gaps in the data. For each observed step, we calculated 20 random steps, randomly sampled from the empirical distributions of the step lengths and turn angles (Fortin et al. 2005, Duchesne et al. 2010, Thurfjell et al. 2014, Avgar et al. 2016). We then extracted covariate values at the end of each step. To determine distance to water, we determine the distance in meters to the nearest spring and to the nearest water features in the USGS hydrography layer.

We then took the minimum of these two values. We omitted any steps where there were NA values for any covariates.

We examined collinearity among predictor variables by calculating correlations between all pairwise combinations. Because no correlation coefficients were >0.60, we did not omit any covariates based on this assumption (Dormann et al. 2013). We examined the variation between used and random steps for each variable, and, based on proportion plots, we collapsed the categories for land cover into only two factor levels: forest and non-forest. We also centered and scaled all continuous variables.

We split our data into state 1 and state 2 specific data for each bird (Thurfjell et al. 2014) to account for movement and selection differences between breeding and non-breeding. We fit an integrated step selection model, a variation of the Cox Proportional Hazard test, to each individual bird and for each behavioral state. In order to facilitate comparison across individuals, we fit only a full model with all predictor variables. We also included movement parameters (log of step length and cosine of turn angle) in our model in order to account for the interacting influences of habitat selection and movement (Rhodes et al. 2005, Avgar et al. 2013, 2015, 2016). Inclusion of movement parameters in the model results in less biased estimates of habitat selection (Forester et al. 2009) by creating a mechanistic movement model (Potts et al. 2014, Avgar et al. 2016). After fitting the models, we updated the distributions for step length and turn angles for all models. We extracted estimated coefficient values and standard errors for each bird and state. We only considered coefficients that were significant in individual models for comparison across individuals. This method yields similar coefficient estimates to a mixed effects model but is less computationally intensive and a statistically simpler approach (Fieberg 2018). We felt this was a good approach for data analysis in our study, especially since we are only able to draw inference for eight birds in state 1 (breeding) and seven birds in state 2 (non-breeding).

RESULTS

Net Squared Displacement Models

Of the eight goshawks monitored, only four were monitored through at least one year. The lack of a full year of movement data in four birds led to poor NSD model fit and required adjusting starting parameters to achieve full model convergence for three of the four birds. For one bird (Jarbridge), full model convergence was not achieved, and only four out of the five NSD models were fit to the data (excluding the ‘mixed migrant’ model) (Table 4.2). Of the four goshawks with at least one year of data (n = 4), 75% were classified as ‘mixed migrants’ and one goshawk (Bruneau) was classified as a ‘resident.’ Of the four goshawks with less than one year of movement data, two were classified as ‘migrant,’ one was classified as ‘disperser,’ and one was classified as a ‘mixed migrant’ (Table 4.2). The classifications of ‘migrant’ and ‘disperser’ could be due to the lack of data to represent a full annual cycle for these birds in which return to a common starting range was not recorded. Based on NSD plots, seven of the eight birds were classified as having at least one period in state 1 (breeding) and one period in state 2 (non-breeding) (Fig 4.2). The Bull Run-4 bird could only be classified into the state 1 behavioral pattern as this bird was only monitored for a total of 46 days.

Table 4.2 Net squared displacement behavioral pattern classifications of goshawks tagged in northern Nevada, USA between the years 2017-2021.

Bird Identification	Behavioral Classification	Locations (n)	Duration of Monitoring (days)
East Humboldt	mixed migrant	4218	514
Pinon*	migrant	1080	99
Jarbridge	disperser	812	142
Bruneau	resident	4839	444
Pequop*	mixed migrant	2716	223
Bull Run-4	migrant	1119	46
Bull Run-3	mixed migrant	2431	480
Independence	mixed migrant	740	108

* Poor model fit to data, likely due to <1 year of monitoring observations; models fit with adjusted starting parameters

** Mixed migrant model not supported by data

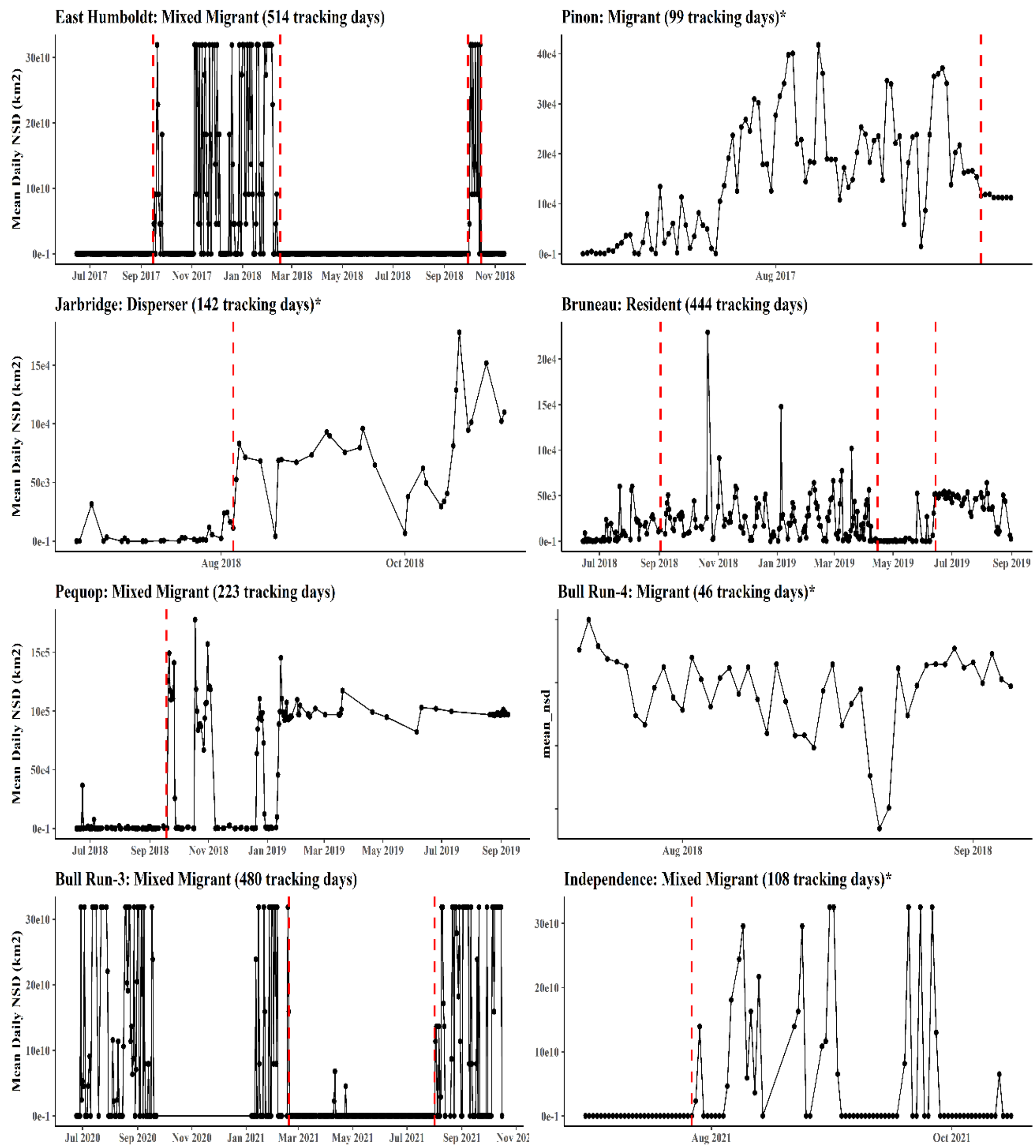

Figure 4.2 Plots of net squared displacement (NSD) over time for northern goshawks fitted with satellite telemetry devices in northeastern Nevada, USA. Red lines indicate the timing of behavioral state switching from breeding to non-breeding. Birds that were tracked for a short time-period and had poor NSD movement model fit are indicated by an asterisk next to the number of tracking days. The y-axis is not intended to be interpreted as it is an index value, but the point pattern suggests the behavioral state.

State-based Integrated Step Selection Analysis

Goshawks in our study showed a stronger selection preference for selected environmental variables in the breeding season than in the non-breeding season. In the breeding season, goshawks had selection preferences for lower slopes, higher canopy cover, and forested habitat (Fig 4.3). Some birds had a selection preference for aspects corresponding to north- or north-east facing slopes. Though distance to water was not significant for most birds, two birds (Bruneau and Pequop) had very slight selection preferences for less distance to water, and one bird (Bull Run-3) had a very slight selection preference for more distance to water (Fig 4.4).

In the non-breeding season, the only variable that was important for all birds was canopy cover, with all birds selecting for similar amounts of canopy comparative to breeding season (Fig 4.3). Elevation, slope, aspect, and forest were not significant in most individual models, though for birds that did have a selection preference for these variables, they favored lower elevations, lower slopes, and similar north- to northeast-aspects as compared to the breeding season. Two birds (Pinon and Jarbridge) did have a slight selection preference for areas that were farther from water (Fig 4.4).

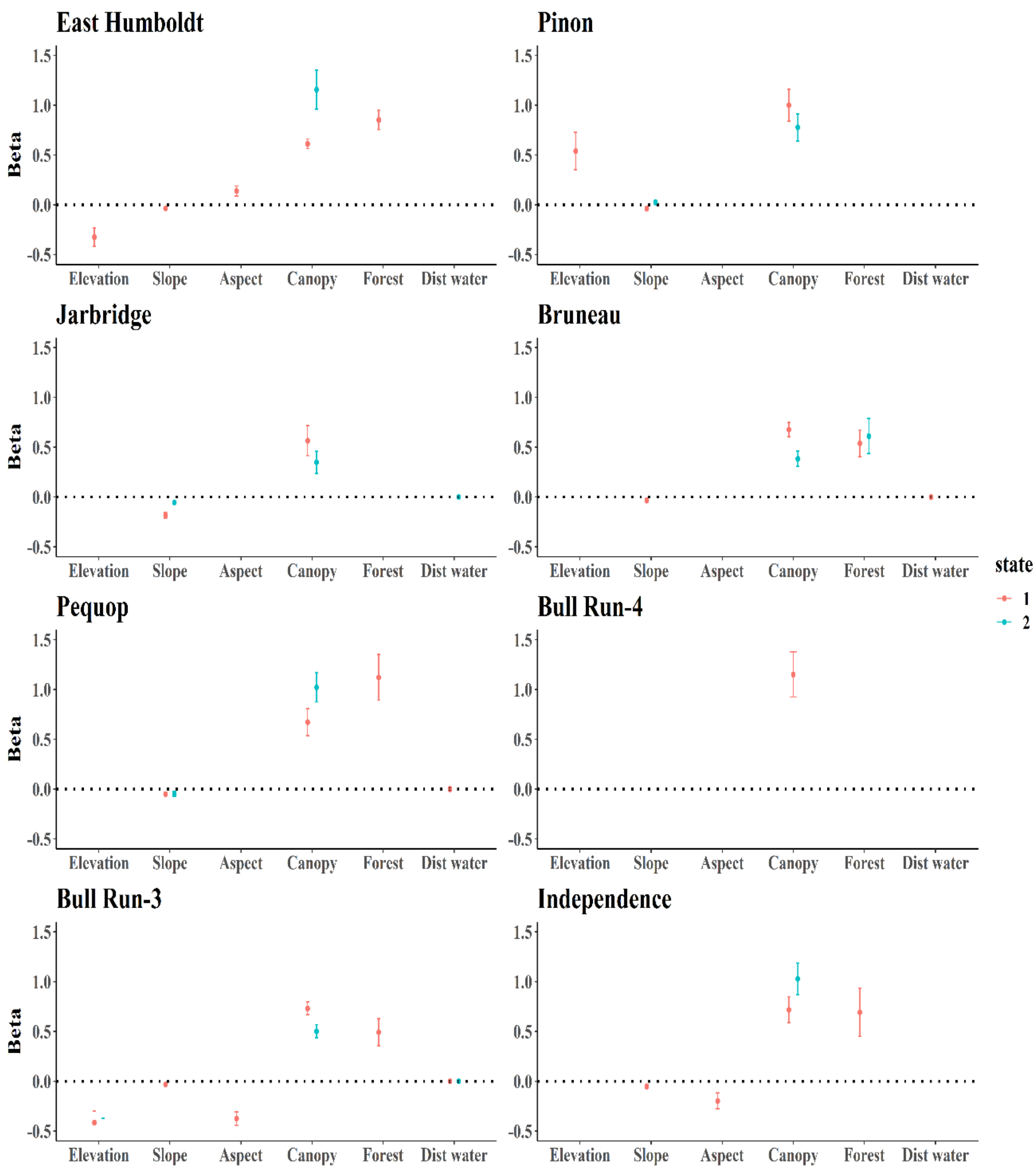

Figure 4.3 Comparison of mean β coefficient values for environmental variables in state 1 (breeding) and state 2 (non-breeding) for northern goshawks fitted with satellite telemetry in our descriptive study, tracked in northeastern Nevada, USA. Coefficient values for variables that were not significant in individual models were not considered in calculating mean values. Mean values were not calculated for variables that were significant for at least four birds in each behavioral state.

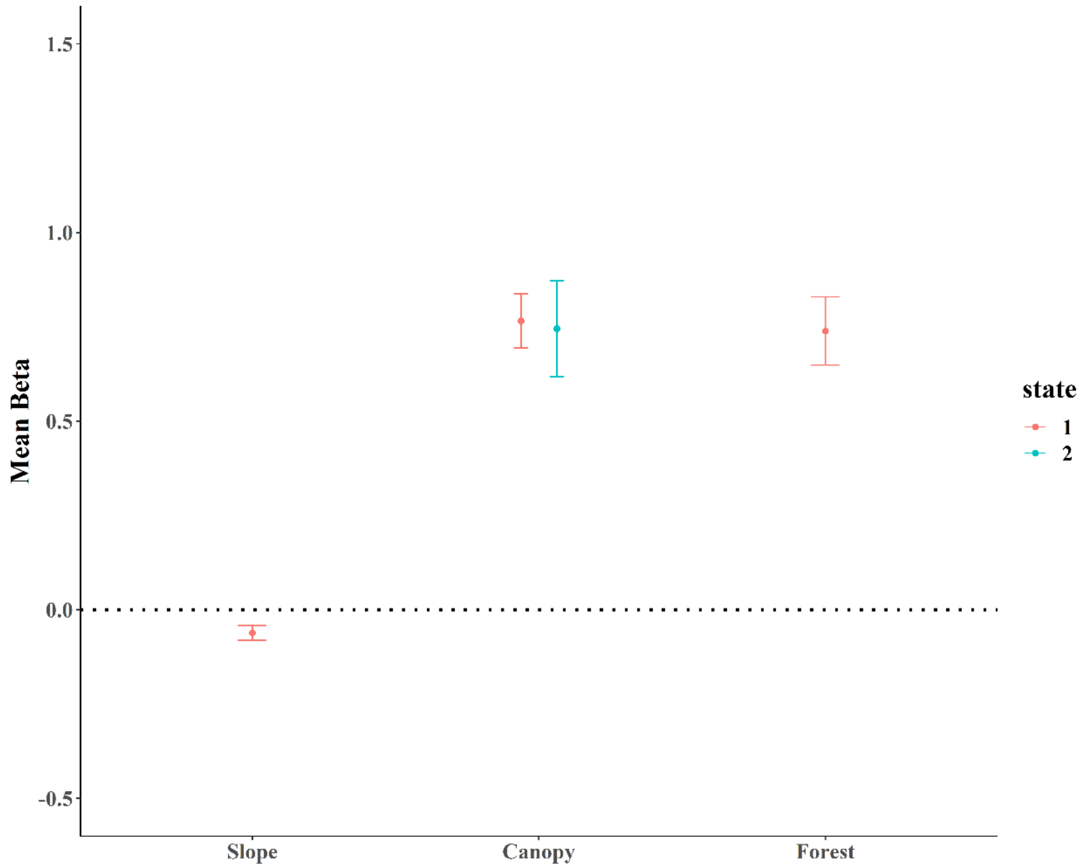

Figure 4.4 Comparison of β coefficients and standard errors for environmental variables in state 1 (breeding) and state 2 (non-breeding) for all combined northern goshawks, tracked in northeastern Nevada, USA. Coefficient values for variables that were not significant in the individual models for at least half of the birds are not reported.

DISCUSSION

Our study suggests that goshawks in the naturally fragmented habitat of the interior Great Basin select for habitat variables that have been identified in other studies such as lower slopes, higher canopy cover, and forested habitat (as reviewed by

Penteriani 2002), however, the individual variation and lack of strong patterns across all birds suggests that goshawks in this naturally fragmented area may have different adaptive strategies for coping with fragmentation. Most birds in our study were classified as mixed migrants, but the Bruneau bird was classified as a year-round resident. This pattern is consistent with previous studies of the species, both in North America and Europe (Squires and Ruggiero 1996, Stephens 2001, Underwood et al. 2006). Differences in timing of movement and behavioral state switching also suggest behavioral plasticity in relation to movement strategies. Additionally, step selection patterns suggested that birds in our study are less selective for particular habitat variables in the wintering or non-breeding months, suggesting that goshawks in the interior Great Basin are able to utilize a variety of different habitat types when not directly tied to a nest location.

The similar finding between our study and studies of goshawks in areas with more contiguous forest suggest that goshawks do have selection preferences that hold even in a naturally fragmented habitat. In breeding seasons, goshawks in our study had a group selection preference for lower slopes, higher canopy cover, and forested habitat, and these variables have been identified as important variables for goshawk nest site selection in contiguous ponderosa pine- and lodgepole pine-dominated forests (as reviewed in Penteriani 2002). Though we did not explicitly consider nest site selection in this study, we suggest that our findings support these variables as potentially more impactful for nesting goshawks across their range relative to other variables such as elevation, aspect, and distance to water. The lack of significant findings for response to these variables in our study is consistent with the assertion that goshawks are a forest generalist capable of exploiting diverse habitat types (Reynolds 1992, 2004). In addition, goshawks in our study showed consistent selection for higher canopy cover in the non-breeding months, consistent with studies of goshawks in other areas (Underwood et al. 2006). In winter months, goshawks in our study were able to use a wide variety of habitat and cover types and had no selection preference for forest, also consistent with previous studies (Kenward and Widén 1989, Hargis 1994, Underwood et al. 2006). Higher canopy cover across habitat and vegetative type has been associated with increased prey abundance and is important for providing protective cover and food sources for small mammals commonly taken as prey by goshawks (Chapman and Flux 1990, Underwood et al. 2006). Though we were unable to test this directly in our study, selection preference for higher canopy cover throughout the annual cycle in our area is likely closely related to the ability to forage successfully (Underwood et al. 2006).

Previous studies have suggested that movement in raptors is largely driven by prey availability and/or interaction with conspecifics (Newton 1986, Underwood et al. 2006). Additionally, Squires and Ruggiero (1995) suggest that local weather patterns may drive goshawk migration and movement. Consideration of these factors is an important next step in further analysis of goshawk movement in the interior Great Basin. Though weather was not cited as an important factor affecting the timing of migration for goshawks in Utah (Underwood et al. 2006), weather patterns have been closely linked to variation in reproduction in the interior Great Basin (Bangerter et al. 2021), and weather and climate effects have been linked to changes in avian migratory phenology for other species (as reviewed in Gordo 2007). Additionally, consideration of wintering space use between successive seasons may be an important factor. Goshawks in Alaska demonstrated wintering site fidelity (McGowan 1975), and wintering space use has been linked to fidelity to the location that a goshawk or other raptor survived its first winter (Harmata and Stahlecker 1993, Tornberg and Colpaert 2001, Underwood et al. 2006). Additional years of space use data are critical for elucidating these patterns.

Our findings suggest that goshawks in naturally fragmented habitats display a wide range of behavioral plasticity when interacting with their environment across the annual cycle, and this may suggest that goshawks throughout their range can adapt to a variety of disturbances if management considers certain key factors such as canopy cover and prey abundance. Goshawks in contiguous forest habitat evolved in close association with natural fire regimes that would have created an interspersion of vegetative structural stages, often not represented in forest landscapes today (Graham et al. 1997). The interaction of goshawks and habitat in the interior Great Basin with a lack of strong selection preference suggests that spatial configuration of habitat patches may be more important that maintaining undisturbed contiguous forest, consistent with the findings that the spatial configuration of habitat may be important for species occurrence, abundance, and richness beyond the effects of habitat amount (Andrén and Andren 1994, Haddad et al. 2015, Hanski 2015, Pfeifer et al. 2017, Halstead et al. 2019). Moving forward, continued studies of goshawks, especially in fragmented landscapes, may help inform the degree of disturbance and particular spatial configuration of landscape heterogeneity that may be critical for goshawks throughout their range (Reynolds 1992, Graham et al. 1997, Underwood et al. 2006).

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CHAPTER V

CONCLUSIONS

Species distribution models (SDM) created for focal species at different spatial and temporal extents provide important insight into effective conservation and management planning, especially in the context of landscape-level changes (Porfirio et al. 2014). The proceeding chapters explored the relationships between different scales of species distribution models for northern goshawks and white-headed woodpeckers in the context of different management-specific questions. In chapter two, I addressed the use of previously collected monitoring data for nesting goshawks in Utah national forests. We were able to create a nest site habitat model for forests in Utah that was easy to implement and integrated well with the predictive capabilities of the Forest Vegetation Simulator to examine the potential impacts of climate change on goshawk nesting habitat in Utah forests as well as identifying potential nesting habitat refugia for the species. This represents one of the first attempts to use spatially explicit data and nest site SDMs to attempt to identify areas of conservation interest for goshawks. In chapter two, I used resource selection analysis to characterize white-headed woodpecker space use in relation to ponderosa pine forest restoration efforts that included harvest and prescribed burns. I demonstrated that white-headed woodpeckers show a variety of selection preference for treated and untreated sites as well as sites with varying time since treatment, suggesting that white-headed woodpeckers are not negatively impacted by efforts to restore a diverse mosaic of habitat heterogeneity. In chapter four, I used finer-scale step selection analysis to examine the space use of goshawks in the interior Great Basin of Nevada, both in breeding and non-breeding season. To my knowledge, this is the first attempt to segment goshawk GPS tracking data with a modelled behavioral state in order to examine space use and habitat selection across an annual cycle. Additionally, we were able to demonstrate that goshawk space use in a naturally fragmented habitat is highly variable, suggesting that goshawks have a high degree of behavioral and adaptive plasticity, potentially suggesting that the species may be more adaptable to disturbance in contiguous forest habitat than previously believed by some.

MANGEMENT IMPLICATIONS

The overall goal of this dissertation was to consider the use of SDMs at different scales and extents as an effective management tool. Chapter two provided important insight into how forests in Utah may change under different climate scenarios. Across all climate scenarios (and without the consideration of management activities), there was an important area in the Uinta-Wasatch-Cache and Ashley National Forests that was preserved as high-suitability nesting habitat. Planning and managing for the anticipated effects of climate change in public lands is an important step towards creating flexible and effective adaptive management (Jantarasami et al. 2010, Littell et al. 2012, Hagerman and Pelai 2018), however, lack of financial resources and personnel can be a huge barrier to effective integration of climate change mitigation plans and strategies (Littell et al. 2012). Identification of refugia, where climate impacts are expected to be less severe, help to alleviate these difficulties by providing a minimum area of focus for conservation efforts (Julius and West 2008). If wildlife managers in Utah National Forests can focus on preservation of goshawk nesting within these refugia or at least reduce pressures from sources other than climate (i.e. timber harvest, grazing, and other habitat alteration), this may provide enough protected high-quality nesting habitat to facilitate maximum flexibility for goshawks and associated wildlife to adapt and evolve responses to climate change (Lovejoy 2005, Robinson et al. 2005, Mitchell et al. 2007, Julius and West 2008).

The second major management implications came from chapters three and four. For both white-headed woodpeckers in Payette National Forest and goshawks in the interior Great Basin, Nevada, there was not a strong selection preference for particular habitat characteristics, and there was variation in individual responses to treatment and seasonality. While it is important to consider other factors that may drive variation for these two species, it is also worth noting that both white-headed woodpeckers and goshawks have evolved in systems with natural disturbance, and variation in behavioral response may simply be a sign of plasticity and ability to adapt. For both species, our results suggest that they thrive in diverse habitats containing a mosaic of vegetation types and structural classes, a finding consistent with prior research (Reynolds 1992, Garrett et al. 1996, Graham et al. 1997, Wightman et al. 2010, Hollenbeck et al. 2011, Latif et al. 2015, 2020). This finding suggests that continued management to increase forest heterogeneity is likely to be beneficial for both species.

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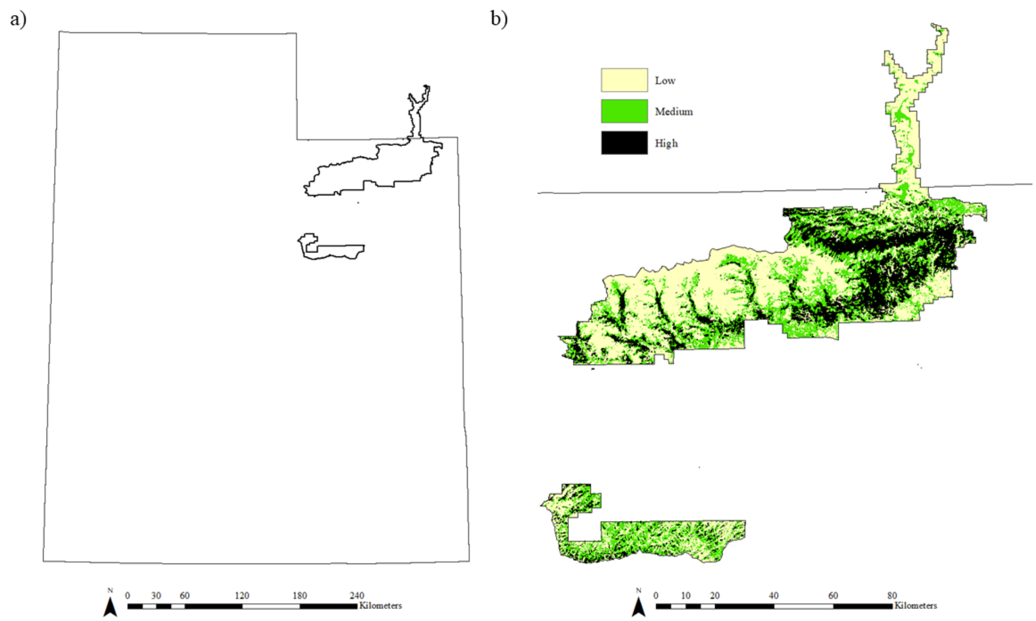
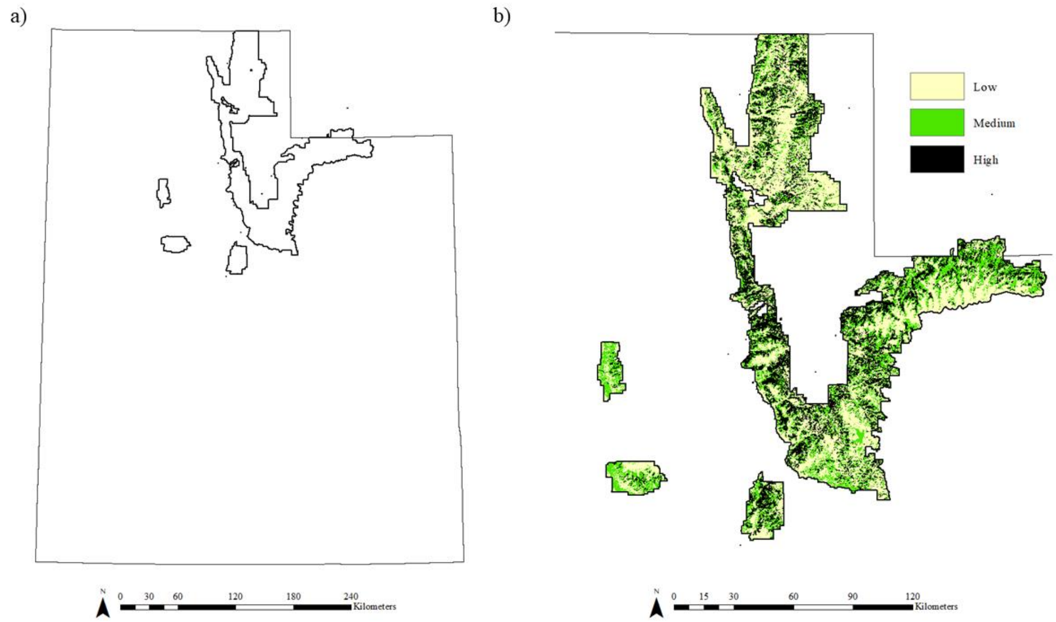
APPENDIX

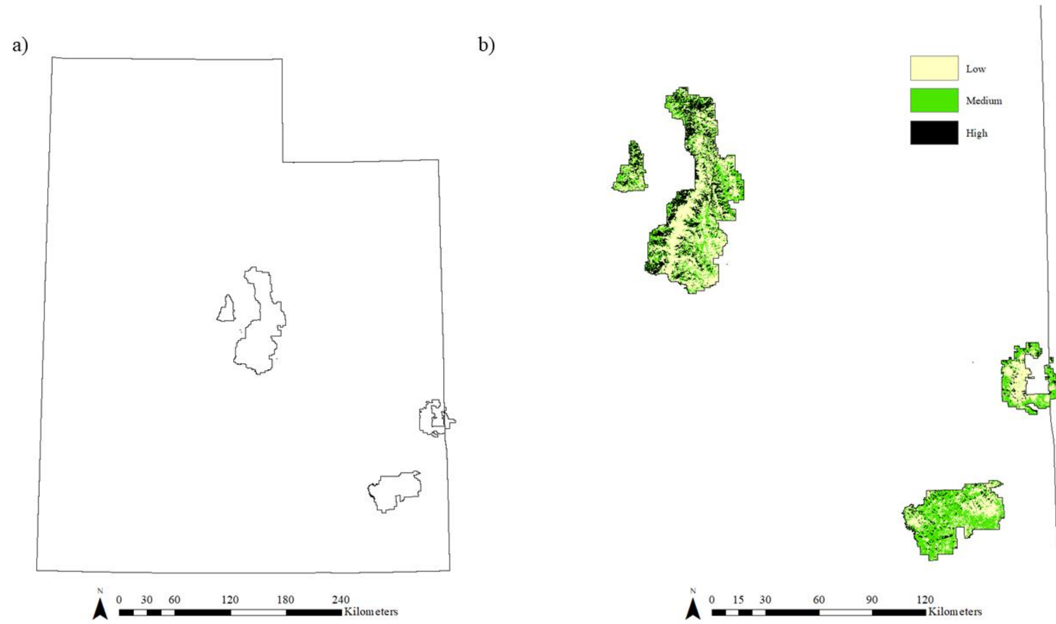
CHAPTER II SUPPORTING MATERIALS



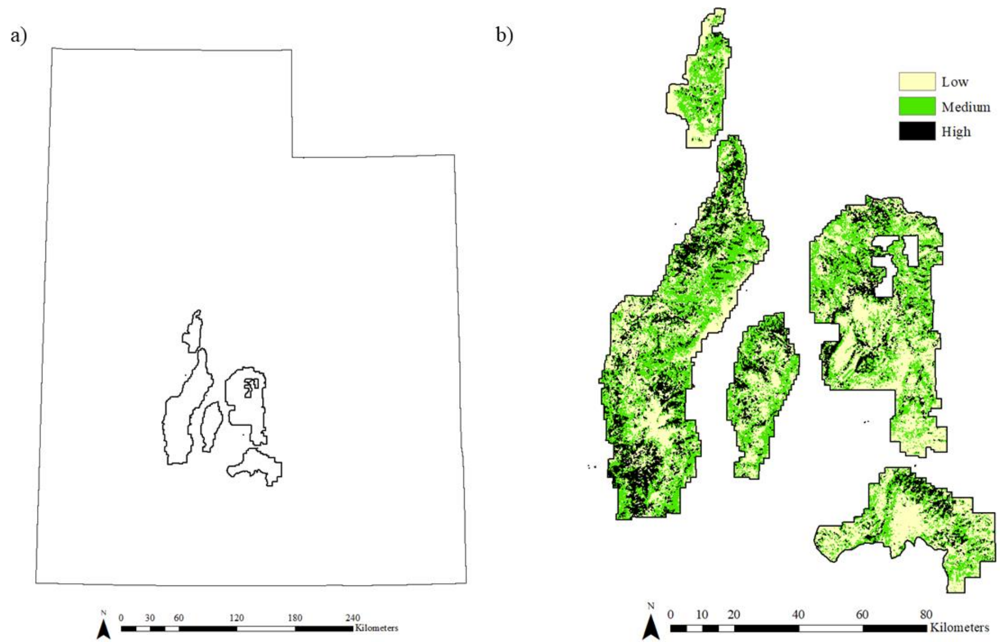
A1. Current habitat suitability model for northern goshawks nesting in Ashley National Forest, Utah, USA. The forest is in the northeastern corner of the state (a) and the majority of high suitability habitat is distributed in the north and north-central sections of the forest (b).



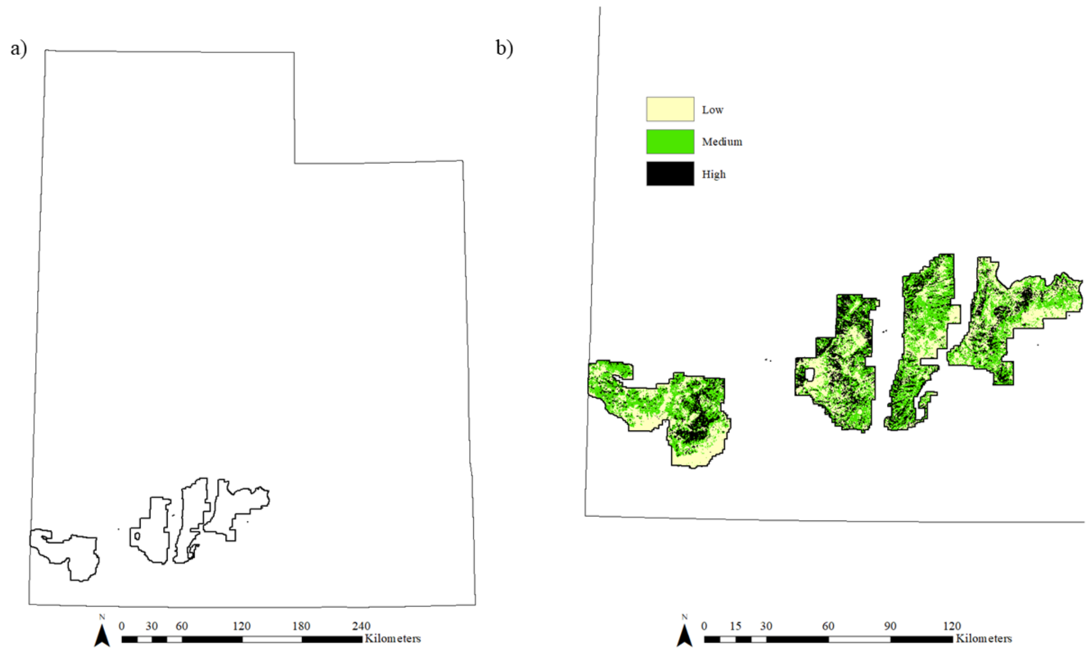
A2. Current habitat suitability model for northern goshawks nesting in the Uinta – Wasatch – Cache National Forest, Utah, USA. The forest is in the north-central area of the state (a) and high suitability habitat is distributed throughout the forest (b).



A3. Current habitat suitability model for northern goshawks nesting in the Manti – La Sal National Forest, Utah, USA. The forest is split into two major sections. The original boundary of the Manti National Forest is in the central area of the state, and the original boundary of the La Sal National Forest is in the southeastern area of the state (a). The majority of high suitability habitat is located in the western section of the Manti area (b).



A4. Current habitat suitability model for northern goshawks nesting in the Fishlake National Forest, Utah, USA. The forest is in the south-central area of the state (a) and high suitability habitat is distributed throughout the forest (b).



A5. Current habitat suitability model for northern goshawks nesting in the Dixie National Forest, Utah, USA. The forest is in the southwest area of the state (a) and high suitability habitat is distributed throughout the forest (b).

CURRICULUM VITAE

Marilyn Wright

EDUCATION

Ph.D. in Ecology — September 2022

Defense: May 2022

Utah State University

Advisor: Kimberly Sullivan, PhD

Dissertation Title: Avian Species Distribution Models: Using Location Data to Inform Management Decisions

I. An analytical hierarchy process-based habitat suitability model for nesting goshawks in Utah national forests: current conditions and future climate simulations with the Forest Vegetation Simulator
II. White-headed woodpecker (*Dryobates albolarvatus)* habitat selection in the context of ponderosa pine forest restoration
III. Annual space use by northern goshawks (*Accipiter gentilis*) in Northeastern Nevada: a case study using behaviorally segmented integrated step selection analysis

MS in Biology (Wildlife Emphasis) — May 2017

Magna Cum Laude

University of Nebraska at Kearney

Thesis Title: Understanding the Northern Goshawk (*Accipiter gentilis*) Habitat and Behavior

I. Identifying goshawk nesting habitat with remote sensing and identification of the important control habitat variables
II. A comparison of prey availability at active and inactive goshawk nest areas in a dry forest landscape
III. A comparison of nest defense behaviors in Oulu, Finland and the Little Belt Mountains, Montana

BA in Biology (Fish and Wildlife Emphasis) — May 2015

Suma Cum Laude

University of Great Falls, Great Falls, MT

TEACHING EXPERIENCE

Utah State University August 2017 - Present

Graduate Teaching Assistant, Salary: $23,000 USD per year, Hours per week: 30

General Biology 1615/1625 (in person and online)

- Led laboratory sections of up to 30 students
- Facilitated in-class experiments
- Taught general statistics analysis of data sets and interpretation of results
- Prepared students for writing research proposals and scientific articles
- Graded and provided feedback on student work
- Lab techniques: PCR, animal behavioral analysis, microscopes (compound and dissecting), scales and balances

Ecology (in person)

- Prepared and guest lectured selected topics in Ecology
- Facilitated review sessions for students as requested
- Graded and provided feedback on student work
- Set up a mock review panel for student research proposals

Animal Behavior (in person)

- Assisted with lab activities
- Provided feedback on research proposals and research reports
- Directed students in poster design and presentation
- Set up and maintain guppy tanks for behavior experiments
- Assisted in the design and implementation of guppy mating behavior experiments

Ornithology (in person)

- Set up and assisted with pigeon dissection
- Instructed students in proper lab protocol and procedures
- Facilitated activities designed to teach students avian orders and species with lab specimens
- Led birding field trips
- Assisted in bird identification with museum specimens and in the field
- Taught students to properly use binoculars and spotting scopes
- Instructed students in methods for keying out birds in the field
- Prepared and guest lectured as needed on avian ecology, systematics, and biology

Organismal Biology Lab (online)

- Assisted with lab exercise preparation
- Provided feedback on research proposals, writing assignments, and lab exercises
- Developed and implemented rubrics based on department objectives
- Graded assignments based on department objectives

University of Nebraska at Kearney August 2015 – May 2017
Graduate Teaching Assistant, Salary: $10,000 USD per year, Hours per week: 20

Biology Teaching Assistant

- Teach general biology lab courses for up to 25 students
- Facilitated in-class experiments
- Assisted students in basic statistics analysis and data interpretation
- Graded assignments, quizzes, and tests
- Proctored general biology exams

PROFESSIONAL EXPERIENCE

Intermountain Herbarium May 2021 – August 2021
Graduate Assistant, Salary: 1900 USD per month, Hours per week 12+

- Mounted and labeled specimens for inclusion in the herbarium collection
- Entered specimen data into the Symbiota database
- Entered specimen data into the GBIF database
- Cleaned and managed data issues within Symbiota and GBIF databases
- Filed specimens in herbarium cabinets alphabetically by family, genus, and species
- Collected specimens from designated field sites
- Recorded detailed information on specimen location and quality
- Developed outreach event ideas for all ages

Rocky Mountain Research Station May 2019/20 – August 2019/20
Biological Science Technician, Crew Lead GS-06, Salary: 18.13 USD per hour, Hours per week: 40+

- Contributed to USFS goals and objectives using all available resources
- Performed duties in a manner consistent with Equal Opportunity and Civil Rights policies
- Routinely informed supervisor of problems and challenges that arise
- Accurately applied field protocols for WHWO, point count surveys, nest searching and monitoring, and vegetation surveys
- Oversaw application of methods and protocols by field crew to ensure protocol standards

- Developed and maintained organized work setting for forms, materials, field data, and equipment
- Prepared field equipment and forms in advance for all crew members
- Reported and worked to resolve all work-related conflicts
- Collected points with Trimble GPS unit
- Led discussions regarding JHA/Risk Assessment and work site hazards
- Oversaw completion of all field work by crew
- Reviewed, organized, and maintained all data for completeness and accuracy
- Maintained radio operation and monitored radio for crew check-ins
- Initiated and performed routine radio and SPOT checks to ensure safety
- Performed monthly vehicle inspections and maintenance
- Actively led and participated in crew tailgate sessions and safety assessments
- Demonstrated collaboration and flexibility to build effective partnerships
- Developed and maintained working relationships with the Prairie City and John Day offices
- Assisted other crews in timely completion of additional work assignments
- Conducted surveys of wildlife habitats/species following standardized protocols
- Led, coordinated, and oversaw work activities of a field crew
- Organized, communicated, and accounted for the daily work assignments of crew members
- Organized and maintained data collection of crew members
- Safely completed work assignments following check-in procedures
- Identified and applied guidelines, work methods, techniques, and procedures to conduct a variety of routine biological science tests and analyses
- Determined and selected procedures, methods, and techniques to be used
- Selected equipment appropriate to be used
- Operated scientific instruments/equipment including data recorders
- Identified aberrant data, conducting mathematical and statistical analysis of data
- Collected and maintained data from study/project
- Verified data for accuracy, legibility, and thoroughness
- Collected data using field forms or electronic data recorders
- Developed spreadsheets, tables, charts, or other graphics displaying data for use in progress reports or publications
- Transferred field observations to written records
- Used computer programs/software to enter/analyze data

Utah State University August 2018 – December 2018

Graduate Research Assistant, Salary: $23,000 USD per year, Hours per week: 30

- Used ArcGIS to build a habitat suitability map for goshawks on the Ashley National Forest
- Wrote research grant proposals to seek funding for work
- Collaborated with research groups in Finland to assess goshawk populations
- Helped other students with statistics and spatial analysis

Utah State University May 2017 – August 2018 (summers)

Goshawk Crew Lead (Ashley National Forest), Salary: 15 USD per hour, Hours per week: 39

- Managed the USFS-ANF goshawk monitoring field crew (2 technicians, 1 USFS technician)
- Worked collaborative with the USFS to complete the USFS goshawk protocols and collect data for the goshawk monitoring project
- Collaborated with USFS biologist and ecologist to write annual report
- Held meetings with USFS supervisors to resolve issues related to field work and plan data collection, field methods, and analysis
- Conducted surveys of wildlife habitats/species following standardized protocols
- Led, coordinated, and oversaw work activities of a field crew
- Organized, communicated, and accounted for the daily work assignments of crew members
- Organized and maintained data collection of crew members
- Safely completed work assignments following check-in procedures
- Identified and applied guidelines, work methods, techniques, and procedures to conduct a variety of routine biological science tests and analyses
- Determined and selected procedures, methods, and techniques to be used
- Selected equipment appropriate to be used
- Operated scientific instruments/equipment including data recorders
- Identified aberrant data, conducting mathematical and statistical analysis of data
- Collected and maintained data from study/project
- Verified data for accuracy, legibility, and thoroughness
- Collected data using field forms or electronic data recorders
- Developed spreadsheets, tables, charts, or other graphics displaying data for use in progress reports or publications
- Transferred field observations to written records
- Used computer programs/software to enter/analyze data
- Navigated with compass, field maps, and field maps
- Conducted play-back/acoustic surveys
- Conducted searches for goshawk nests
- North American bird identification
- Collected data and samples in the field

- Collected feather samples
- Point count surveys for birds and mammals
- Transect surveys for birds and mammals
- Technical tree climbing
- Backpacked to remote sites
- Built mechanical owl lure
- Trapped adult goshawks with Dho-Gazza net and mechanical owl lure
- Banded adult and nestling goshawks with federal and colored bands
- Took blood samples from adult and nestling goshawks
- Completed vegetation analysis including surveys of nest stand using densiometers, DBH tape, woody debris estimates, stand type classification
- Identified tree species and understory vegetation to genus/species
- Compiled data in Access Database and ArcGIS
- Assessed surveyed area with ArcGIS

University of Nebraska at Kearney May 2016 – August 2016
Research Field Crew Lead, Salary: $10,000 USD per year, Hours per week: 20

- Led a technician and volunteer in backcountry field work in Lewis and Clark National Forest
- Navigated with compass, field maps, and GPS
- Identified goshawk nest areas with playback/acoustic surveys
- Conducted searches for goshawk nests
- Collected data and samples in the field
- Collected feather samples
- Organized and collected data on goshawk nesting areas, behavior, and prey selection
- Filmed and characterized goshawk nest defense against predator lures
- Set up goshawk nest site cameras and identified prey brought to nests from pictures taken
- Conducted point count and transect surveys of birds and mammals
- Technical tree climbing
- Led goshawk research project in Oulu, Finland
- Collaborated with Finnish research team
- Conducted independent research and data collection
- Compiled and analyzed data
- Led, coordinated, and oversaw work activities of a field crew
- Recorded detailed notes on wildlife behavior
- Identified and applied guidelines, work methods, techniques, and procedures to conduct a variety of routine biological science tests and analyses
- Collected and maintained data from study/project
- Verified data for accuracy, legibility, and thoroughness
- Collected data using field forms or electronic data recorders

- Developed spreadsheets, tables, charts, or other graphics displaying data for use in progress reports or publications
- Transferred field observations to written records
- Used computer programs/software to enter/analyze data

First People's Buffalo Jump State Park — April 2015 - August 2015
Montana Fish, Wildlife, and Parks
Seasonal Park Ranger, Salary: $15 USD per hour, Hours per week: 40

- Led interpretive talks, hikes, and programs for all ages
- Managed the welcome desk and phone lines
- Answered visitor questions about park history, ecology, and geology
- Led interpretive programs on Native American traditional games, history, and anthropology
- Led guided hikes in the park
- Taught visitors about ecology and wildlife
- Managed wildlife in the park including safe protocol for snake capture and relocation and bird nest monitoring
- Gave introductory lectures on park history
- Collaborated with local Native American tribes
- Assisted in coordinating interpretive and educational programs

University of Great Falls — December 2012 – May 2015
Lab Manager, Salary: $1200 per month, Hours per week: 20

- Managed and organized laboratory and collections
- Conducted research and assisted with student projects
- Prepared museum specimens
- Calibrated lab equipment
- Managed flesh-eating beetles
- Assisted students in research projects and data analysis
- Conducted independent research on macroinvertebrate communities in the Missouri River

Montana Wilderness Association — July 2014 – September 2014
Wilderness Research Intern, Salary: $1500 per month, Hours per week: 30

- Organized and carried out field data collection trips on the Middle Fork of the Judith
- Collected pertinent documents, transcripts, public comments, and interviews

- Collected data and sediments samples in the field
- Collaborated with MWA, USFS, and private land owners to propose alternatives to the Middle Fork River travel plan
- Developed habitat improvement recommendations for the Forest Service

Montana Fish, Wildlife, and Parks May 2013 – August 2013
Fisheries Intern, Salary: $1500 per month, Hours per week: 30

- Collected and analyzed water samples
- Operated jet boat below dam
- Maintained and organized field data
- Used drift net to collect macroinvertebrates
- Used flow meter, dissolved oxygen reader, and turbidity tube
- Collaborated with MTFWP to identify and classify larval fish collected at the site

ADDITIONAL FIELD EXPERIENCE

- North American bird identification
- Mist net with pigeon harness raptor trapping
- Red-tailed Hawk trapping (Bal-Chatri)
- Northern Goshawk trapping (owl lure and Dho-Gazza)
- Ferruginous Hawk (chick) federal banding
- Ferruginous Hawk (chick) blood draw (needle and syringe)
- Ferruginous Hawk (chick) measurements (foot pad, hallux chord, tarsus width/depth, culmen, beak depth with manual and electronic calipers and mass)
- Ferruginous Hawk (chick) avian parasite collection (w/ dilute pyrethrin)
- Optimal Foraging Theory simulation activity (middle school students, Kearney Outdoor Expo)
- High school science fair judging
- Boat electrofishing
- Backpack electrofishing
- Bag seining
- Gill netting
- Surber sampling
- Fish tagging (VIE and PIT)
- Small mammal trapping (Sherman traps)
- Spotlight transects for jackrabbits

PUBLICATIONS

Wright, M.E., Tornberg, R., Ranglack, D. H., & Bickford, N. (2019). Comparison of Nest Defense Behaviors of Goshawks (*Accipiter gentilis*) from Finland and Montana. *Animals*, *9*(3), 96.

Williams, B. and **Wright, M.E.** (2018). Northern Goshawk inventory, monitoring, and research performance report. US Forest Service Technical Report.

Williams, B. and **Wright, M.E.** (2017). Northern Goshawk inventory, monitoring, and research performance report. US Forest Service Technical Report.

Wright, M.E., Jackson, J., Tornberg, R., Higa, E., Clayton, A., McCartney, S., Murphy, V., Conway, L., and Bickford, N. Identifying goshawk nesting habitat with remote sensing and identification of the important control habitat variables. *In review.*

PRESENTATIONS

Breeding and wintering space use by Northern Goshawks in northern Nevada. (February 9, 2022). Poster presentation. The Western Section of the Wildlife Society Conference, Reno, Nevada.

A simple and effective model of Northern Goshawk nesting habitat in Utah national forests. (October 12, 2021). Poster presentation. Raptor Research Foundation Conference, Virtual.

White-headed Woodpecker space use in the context of forest restoration. (September 15, 2021). Oral presentation. Rocky Mountain Research Station, AGORA Meeting, Virtual.

Climate risk assessment of Utah national forests: a case study of Northern Goshawks. (April 21, 2020). Oral presentation, guest speaker. University of Providence Research Symposium, Virtual.

Climate risk assessment of Northern Goshawks (Accipiter gentilis) in Utah national forests. (December 5, 2019). Oral presentation. Utah State University Climate Adaptation Science Project Presentation Meeting, Logan, UT.

What the goshawk knows: understanding northern forests. (March 26, 2019). Utah State University Biology Seminar Series, Logan, UT.

Goshawks as a bio-indicator species for climate change in the boreal forest. (September 7, 2018). Oral presentation (secondary author, not in attendance). UArctic Congress, Helsinki, Finland.

When goshawks attack: a comparison of nest defense behavior between Finland and North America. (April 14, 2018). Oral presentation. American Ornithological Society, Tucson, AZ.

A novel approach to diet analysis: next-generation sequencing of raptor pellets and fecal material. (April 13, 2018). Lightning talk oral presentation. American Ornithological Society, Tucson, AZ.

When goshawks attack: a comparison of nest defense behavior between Finland and North America. (November 10, 2017). Oral presentation. Raptor Research Foundation, Salt Lake City, Utah.

Northern Goshawk monitoring on the Ashley National Forest: a framework for species conservation. (November 9, 2017). Poster presentation. Raptor Research Foundation, Salt Lake City, Utah.

Using GIS for habitat comparisons: a case study with Northern Goshawks. (April 12, 2017). Poster presentation. Nebraska Academy of the Sciences, Lincoln, Nebraska.

Prey availability of northern goshawks in the Lewis and Clark National Forest, Montana. (February 8, 2017). Oral presentation. Midwest Fish and Wildlife Conference, Lincoln, Nebraska.

Quantifying northern goshawk (Accipiter gentilis) habitat in the Lewis and Clark National Forest, Montana. (April 22, 2016). Oral presentation. Nebraska Academy of the Sciences, Lincoln, Nebraska.

Macroinvertebrate community assemblage from Canyon Ferry to Great Falls along the Missouri River. (April 11, 2015). Oral presentation. Montana Academy of the Sciences, Butte, Montana.

Cost benefit analysis of cattle on public lands. (April 11, 2014). Poster presentation. Montana Academy of the Sciences, Butte, Montana.

GRANTS AND FELLOWSHIPS

Utah State University Biology Department 2021
Travel Grant Amount: $500

Utah State University Biology Department 2019
Palmblad Research Award Amount: $2,000

Utah State University Ecology Center 2018
Graduate Research Grant Amount: $5,000

NASA Nebraska Space Grant Consortium 2017
Student Research Fellowship Amount: $6,000

UNK Research Services Council 2015
Collaborative Grant (Student Writer) Amount: $10,000

UNK Biology 2015
(Student Writer) Amount: $5,000

Montana Academy of the Sciences 2014
Undergraduate Research Grant Amount: $500

CERTIFICATIONS

*Official documentation available upon request

Technical tree climbing May 2018
Canopy Watch International No expiration

Wilderness First Aid June 2017
Wilderness Medical Associates International Expires: June 2020

ACADEMIC SERVICE

Graduate Council Representative August 2015 – May 2017
University of Nebraska at Kearney

Student Board Representative 2014 – 2015
Montana Wilderness Association, Island Range Chapter

AWARDS

Great Lakes STEM Scholarship 2016 - 2017
Great Lakes Student Loan Service

Riechenbach Scholarship 2015 - 2016
University of Nebraska at Kearney

Presidential Scholar Award 2014 - 2015
University of Great Falls

Courage Award 2012 - 2015
University of Great Falls

Conservation Award 2012 - 2015
Pheasants Forever, Chapter 535

Phil Tawney Memorial 2014
Montana Wildlife Federation

VOLUNTEERING

Citizen Science 2017 – Present
eBird, Christmas Bird Count, HawkWatch winter raptor surveys, kestrel box monitoring, Projects WAFLS (Western *Asio Flammeus* Landscape Study)

Undergraduate Research Symposium 2022
Student poster judge

Utah Conference on Undergraduate Research 2020
Conference volunteer

Wildlife Rehabilitation Center of Northern Utah 2018 – 2019
Wildlife care and rehab, public education program development, and outreach

Utah Division of Wildlife Mule Deer Capture 2018
Data recording and measurements

Nebraska Outdoor Expo 2017
Avian predator presentation and optimal foraging theory game for middle and elementary school students

MEMBERSHIPS

Backcountry Hunters and Anglers

The Wildlife Society

American Ornithologist's Union

Raptor Research Foundation