NORTHERN BOBWHITE HABITAT MODELING ON A MILITARY INSTALLATION IN RELATION TO RED-COCKADED WOODPECKER MANAGEMENT

by

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(Under the Direction of John P. Carroll)

ABSTRACT

The Department of Defense (DOD) manages natural resources on military installations across about 12 million ha of land across the USA. A priority for much of this land is to restore and maintain native ecosystems and associated wildlife species (Boice 2006, 2007). However, given the typical location (i.e., threatened ecosystems) and size of DOD lands management conflicts may potentially occur among endangered/threatened species and other natural resource objectives (HydroGeoLogic 2007). Specifically, military installations in the Southeastern U.S. are commonly managed to protect red-cockaded woodpecker (*Piciodes borealis*; hereafter RCW) populations and longleaf wiregrass ecosystems (Boice 2007). However, mandated RCW management might not be entirely compatible with other declining species such as Northern bobwhites (*Colinus virginianus*; hereafter bobwhite). Land managers need to be equipped with spatially explicit habitat models that can be used to make informed decisions on how to manage lands (Letcher et al. 1998). Data collected on Fort Gordon

Military Installation, Georgia from male whistle counts during the summer of 2010 and 2011 were used to construct competing models on the relationship between RCW management and other habitat structure metrics as it relates to bobwhite habitat suitability. These data were collected using a robust occupancy sampling design to allow open and closed population assumptions. Habitat variables taken from the stand and landscape layer such as hardwood basal, percent ground cover, and fire frequency were used to predict bobwhite and RCW occupancy. These models will assist natural resources managers in making efficient decisions regarding integrated management of wildlife communities on DOD land.

INDEX WORDS: Northern bobwhite (*Colinus virginiana*), Red-cockaded woodpecker (*Piciodes borealis*), Longleaf pine (*Pinus palustris*), Maxent, robust design, military base

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MANAGEMENT

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DEDICATION

I dedicate this thesis to my mother and father. Dad, thanks for introducing me to the outdoors and a way of life that has sparked an undying interest and thirst for knowledge in me for wildlife. Momma, thank you for always being there for me no matter what. Your love and support have given me what I needed to make it this far in life.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

PURPOSE OF THE STUDY

The longleaf pine (*Pinus palustris*) and wiregrass (*Aristida stricta*) ecosystem (longleaf-wiregrass ecosystem) is a fire-maintained landscape with a large number of species adapted to early successional habitats (Clewell 1989). The longleaf-wiregrass ecosystem once covered about 30 million ha of land across the southeastern United States prior to European colonization (Clewell 1989, Georgia Wildlife Federation 2001). Today some of the largest remnant areas of longleaf-wiregrass ecosystems occur on military installations (Allen et al. 2006). Many species that depend on fire, maintained longleaf-wiregrass ecosystem have shown dramatic decline throughout their native range (Askins 2001; Kirkman et al. 2001). Military installations where these declining species still persist, such as Fort Gordon, Georgia, are managed by Department of Defense (DOD) and have had strict management and recovery guidelines for biodiversity and threatened species mandated in conjunction with the U.S. Fish and Wildlife Service (Sikes Act, Boice 2006, 2007). The red-cockaded woodpecker (*Piciodes borealis*) (RCW) is one of those species in decline and is a priority species for managers on Fort Gordon for both habitat and species restoration (Endangered Species Act 1973, Boice 2006, 2007, Department of Defense 2008).

Army guidelines state that RCW endangered species management component (ESMC) should promote ecosystem integrity (U.S. Fish and Wildlife Service 2003, Department of Defense 2008) and thus could be considered a form of umbrella species Management (Simberloff 1998) that is generally associated with recovery efforts for RCW populations. These efforts include, but are not limited to, reducing the tree stem density and amount of hardwood midstory while increasing the amount and frequency of growing season fires (U.S. Fish and Wildlife Service 2003, Department of Defense 2008). With RCW restoration in full motion, early successional bird species such as Eastern bluebird (*Sialia sialis*), Bachman's sparrow (*Aimophila aestivalis*), Northern bobwhite (*Colinus virginianus*) (bobwhite), Eastern meadowlark (*Sturnella magna*), and mourning dove (*Zenaida macroura*) should be the most abundant species during the longleaf-wiregrass ecosystem establishment period (Dickson et al. 1993; Wilson et al. 1995; Conner et al. 2002). Several of these species are considered "at risk" by DOD because their populations have demonstrated recent decline (Department of Army 2006). Uncertainty within the literature concerning limitations under umbrella species management (Simberloff 1998, Andelman and Fagan 2000, Fleishman et al. 2001) challenges the current belief in RCW restoration efforts alone as the answer to restore the longleaf-wiregrass ecosystem and residing species at risk.

Intensively monitoring these populations and their response to management actions to reduce the risk of sudden population declines and biodiversity could provide insight into the effectiveness of restoration efforts specific to Fort Gordon (Beever 2006). However, intensively monitoring each of these species is most likely not very practicable (Ralph and Scott 1981, Ralph et al. 1995). Buckland et al. (2005) suggests that a solution would be to restrict indices to data on specialist species of interest. It stands to reason that species of interest to focus data collection efforts would be a species that has been well studied, such as the Northern Bobwhite (hereafter bobwhite).

Models developed by Engstrom and Palmer (2005), support the idea that bobwhites can benefit from longleaf-wiregrass ecosystem restoration associated with RCW habitat development and thus it can be expected to observe higher bobwhite densities in areas managed for RCW specifically. Starfield (1997) argues that there is a need for managers to utilize assessment tools such as site-specific models, to assist in making management decisions. Bobwhites are a highly groundcover dependent species that have well-developed social habits. Bobwhites typically live in family groups or "coveys" during several months of the year. During breeding season however, the coveys will split up and males will begin seeking females (Stoddard 1931). A male bobwhite can be detected from the distinct "bob-white" whistle over distances up to 500 meters away (Wellendorf and Palmer 2005, Smith et al. 2009). It is this habit that managers take advantage of when monitoring male bobwhites during the breeding season; the monitoring technique is known as conducting "male whistle call counts" (Stoddard 1931; Rosene 1957; Hansen and Guthery 2001). Monitoring bobwhites using whistle call counts is an efficient and inexpensive way to keep up with relative abundance annually (Church et al. 1993). Chamberlain and Burger (2005) measured and compared breeding bobwhite abundance among three separate landscapes that had different levels of RCW management. They found bobwhite abundance was higher in areas that were more intensively managed for RCW. However, abundance estimates may not be as useful to managers' conservation plans as occupancy-estimation methods could be (Applegate et al. 2011). I monitored breeding bobwhite populations and developed models to estimate occupancy and distribution across Fort Gordon. Models specific to Fort Gordon vegetation and bobwhite populations may demonstrate just how bobwhite monitoring and modeling may potentially be used in conjunction with RCW MATRIX software and adaptive management (Wills 1995) decision processes.

The outline of this thesis covers the initial model construction, model translation spatially, and application of models relative to management on Fort Gordon. Chapter 2 of this research describes how bobwhite occupancy, immigration, and emigration rates were modeled on Fort Gordon relative to RCW management across the landscape using a variation of Pollock's robust design (Pollock 1982). Models were fit using Program MARK to test the effects of habitat variables described as being important to RCW restoration efforts (USFWS 2003).

Chapter 3 describes the development of two spatially explicit population models used to predict and measure bobwhite occupancy in and out of areas suitable/managed for RCW's under restoration guidelines. Spatially explicit population models are important assessment tools for investigating population ecology questions related to land-scale (Dunning et al. 1995). Using the model fit in Program MARK translated spatially with the raster calculator tool (ArcGIS 10) and models developed using presence only data with Maxent (Phillips et al. 2004, 2006), I outline in detail the different processes involved in predicting habitat suitability and species occupancy as they occur on Fort Gordon. Bobwhite occupancy models developed in Chapter 2 were used to predict bobwhite occupancy rates across Fort Gordon in comparison to predicted RCW occupancy rates. Bobwhite occupancy was compared to RCW occupancy, to investigate current RCW restoration efforts suitability towards supporting occupancy by bobwhites over untreated areas.

The fourth chapter is a discussion of implications of bobwhite monitoring in conjunction with red-cockaded woodpecker restoration efforts in decision making from bobwhite habitat modeling using Pollock's Robust sampling design and spatially explicit population habitat suitability modeling.

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CHAPTER 2

BOBWHITE DEMOGRAPHICS MODELED UNDER A VARIATION OF POLLOCK'S ROBUST SAMPLING DESIGN

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CHAPTER 2

BOBWHITE DEMOGRAPHICS MODELED UNDER A VARIATION OF POLLOCK'S ROBUST SAMPLING DESIGN

INTRODUCTION

The second chapter of this research describes Northern bobwhite density modeling on Fort Gordon using linear regression with Fall covey count data collected from 2009-2011 and habitat modeling using a variation of Pollock's robust sampling design (Pollock 1982). It describes how the robust sampling design used in conjunction with collecting breeding season whistle counts, could potentially assist researchers in estimating population specific abundance, probability of detection, and rates of temporary immigration and emigration, and further testing the influence of certain habitat factors.

This research investigates these population demographics using a variation of Pollock's robust sampling design. The robust sampling design is a two-stage capture mark recapture design that involves primary and secondary sampling periods of which the population is assumed demographically open and closed, respectively (Pollock 1982).

Riddle et al. (2010) investigated the use of a special case of Pollock's robust capture-recapture design in modeling bobwhite density. Their approach was more specific to combining the double-observer (Nichols et al. 2000) and time-of-detection methods (Alldredge et al. 2007) under robust sampling design. Riddle et al. (2010) first described using estimates of availability for detection, or probability of detection for bobwhites. During their research they noted that the importance of estimating detection probability is to sound inference when based on point counts as pointed out by Burnham (1981), Thompson (2002), and Rosenstock et al. (2002). This research considers probability of detection while using capture-recapture methods void of double-observer sampling. Aside from Riddle et al. (2010), there has never been a study specifically investigating the use of Pollock's robust design in sampling bobwhite population dynamics. More specifically, there have not been site-specific investigations into bobwhite immigration and emigration rates relative to RCW restoration efforts.

Models were generated to estimate bobwhite demographics on Fort Gordon as they vary across Fort Gordon as well as how they may potentially be influenced by RCW-specific management practices.

METHODS

Study Area

The 22,500-ha military installation known as Fort Gordon was originally established as Camp Gordon in 1941 along the sandhills region of east-central Georgia. Prior to a primary land use of farming, a vast majority of the installation was predominantly longleaf (*Pinus palustris*) wiregrass (*Aristida stricta*) savanna. After military establishment, succeeding farmland was replaced with pine plantations where fire was excluded, thus allowing midstory to become densely occupied with turkey oak (*Quercus laevis*), blackjack oak (*Q. marilandica*), and bluejack oak (*Q. incana*). Implementation of revenue driven siliviculture most likely caused much of the native vegetation and biologically diverse areas to recede to small patches scattered throughout the installation. With the effects of encroaching, dense midstory and fire suppression, early-successional, fire-dependent wildlife populations began to decline.

Following development of the Sikes Act in 1960, the Fish and Wildlife Conservation Committee was formed in 1962 to monitor and guide the Fish and Wildlife Section in the management of natural resources on Fort Gordon. A majority of the management efforts were focused on high-demand game species, white-tailed deer (*Odocoileus virginianus*) and Northern bobwhite. In 1996, with amendments to the Sikes Act and development of an endangered species management plan, the Forestry Section at Fort Gordon began converting the various revenue-driven silivicultural practices into RCW-driven, ecosystem restoration-based practices. Timber harvests occurred more frequently across the installation with post-harvest basal areas set according to RCW management guidelines. Prescribed burning was implemented throughout the installation annually along with midstory removal and native vegetation plantings (mainly *Aristida stricta*). In 2009 the Fish and Wildlife section and Forestry sections combined on Fort Gordon to form the current Natural Resources branch.

Natural resource management efforts on Fort Gordon have shifted with an intensive management program geared towards the recovery of the RCW while supporting military mission and training. The remaining landscapes surrounding the remnant longleaf wiregrass patches are the primary focus of ecosystem restoration and management on Fort Gordon (Department of Defense 2008).

Vegetation Analysis

Fort Gordon timber inventory is collected and updated every five years in accordance with meeting necessary stand measurements required for input into the RCW

Foraging Matrix application (Department of the Army 2007). These measurements include pine trees per hectare, stand basal area (m^2), stand, % groundcover, and hardwood midstory (qualitative value derived from photo series) and total trees per acre (U.S. Fish and Wildlife Service 2003). These data were most recently collected by LandMark Inc. (now known as F4Tech) in 2011 and provided for this research in the form of an ArcGIS geo-database. LandMark Inc. collected the data during 2010-2011. All timber stand data were collected using ArcView 9x, ArcPad RTI and TCruise software (F4Tech unpublished procedures). Sample points were allocated to stands using a systematic plot allocation tool at a rate of one plot per 1.62 ha, with a minimum and maximum allocation of three and 30 plots per stand, respectively. Each plot consisted of a main variable radius overstory sample to include fixed radius samples of midstory, ground cover, and regeneration. The overstory data were collected within a 10 BAF plot by tree according to species, diameter breast height (dbh), and product (i.e., pulpwood, chip-n-saw, sawtimber, poles, and cull). Total height was recorded for the first stem of each merchantable species on the plot. Age and radial growth were also collected for each stand.

Midstory vegetation was measured using two different methods. The first was a qualitative measurement (required for running the RCW Matrix) on a fixed, 11.43-m radius plot. Density was classified into one of three categories, sparse, moderate, or dense. Height was classified into one of three categories, low, medium, or tall. The data were exported and categorized into Microsoft Excel by percent cover for the following variables, grass, forb, vine, live woody, dead woody, leaf litter, bareground, hardwood sapling, and average total basal area. All stand measurements were standardized according to variation from the mean value. The second midstory measurement method was quantitative and was taken on a 5.7-m fixed radius plot, which classified the density and height of existing midstory vegetation. Stems were tallied if they were greater than 1.5 m and had a dbh between 0.0092 m^2 (0.1 ft^2) and 0.46 m^2 (4.9 ft^2) for pine species and dbh between 0.0092 m^2 (0.1 ft^2) and 0.55 m^2 (5.9 ft^2) for hardwood species.

Regeneration was tallied on a 3.6-m fixed radius and collected for pine and hardwood species. Seedlings were tallied if exhibiting at minimum, second year growth, no higher than 25.4 cm, and have an established terminal bud. Saplings were classified as such if there was an established root system and between 25.4 cm and 152.4 cm.

Herbaceous ground cover (groundcover) was measured on a 3.6-m, fixed radius plot and was classified in 5% increments according to seven different groundcover classifications. The seven classifications used were, grass, forb, vine, pine straw, live woody vegetation, dead woody vegetation, and bare soil/rock. The total record of each vegetation classification equaled 100% for each plot measured.

Fort Gordon timber stand management prescriptions are initiated at the training area compartment level and then deduced to the stand level with stand specific prescriptions. Training areas were classified as “RCW managed” at the compartment level if timber harvest efforts specific to those under the Management Guidelines of the RCW on Army Installations (U.S. Army 1996) have occurred.

Fall Covey Call Counts

Covey-call-count estimation methods (Bennett and Hendrickson 1938, DeMaso, 1992; Wellendorf, 2000; Seiler, 2001; Seiler, 2002; Wellendorf et al., 2004) were used to evaluate bobwhite occupancy at 24 observation points on Fort Gordon in 2009, 2010, and

2011. Wellendorf and Palmer (2005) suggest that 500m is a reasonable estimate of the maximum distance that an observer can hear calling coveys based on distributions of distances to calling coveys (estimated via triangulation from multi-observer surveys).

When conducting covey-call-counts, the observers were trained and instructed to listen for the "koi-lee" covey-calls (Stoddard, 1931) made by bobwhites early mornings during the fall and count the unique number of calling coveys at survey points. Each survey site was surveyed three times during the key estimation period of October to November each year (Seiler et al. 2002, Wellendorf et al. 2002, 2004). Survey points were separated by no less than 1000 m in an effort to minimize duplicate observations between surveys conducted in close proximity. Prior to officially participating in surveys, observers were trained by listening to recorded covey-calls and by spending a few mornings in the field listening to calling coveys pointed out by experienced observers. Observers arrived at survey points no later than 45 minutes prior to sunrise to minimize disturbance when traveling to survey points. Observers collecting data 40 minutes before sunrise, recording azimuths, estimated distances, and approximate locations for each calling covey detected. The data was recorded on standardized data sheets complete with detailed aerial photographs and distance scales originating at the survey point out to 500m in the cardinal directions. Wind and sky measurements were also recorded. Surveys ended at the official time of sunrise. Surveys were not conducted during periods of harsh weather (i.e. moderate to heavy rainfall and/or high winds).

Summer Whistle Call Counts

Using a variation of Pollock's robust occupancy design, summer male whistle call counts were conducted during the months of June-July, 2010-2011 (Terhune et al. 2009).

About eight to 10 points were generated within six separate randomly generated sample clusters using K means clustering in program “R”. The sample points were situated throughout the landscape across training areas with RCW-focused management and training areas that have not yet received RCW-focused management efforts. Survey points were separated by no less than 1000 m in an effort to minimize duplicate observations between surveys conducted in close proximity. The points were arranged on roads and or firebreaks within the installation. Roads/firebreaks on Fort Gordon are no more than 200 meters apart so there was little concern of bias with points being on roads and or firebreaks given that bobwhites can be detected at distances up to 500 meters (Wellendorf and Palmer 2005), potential for bias relevant to roads was not a concern. Habitat variables measured in standardized plots that occurred within a 500 m radius surrounding a whistle count observation point were identified using the intersect tool in ArcGIS 10. Habitat metrics were then averaged according to each variable to create a standardized measurement of habitat variables for each point.

Observers were trained by listening to recorded whistling male bobwhites and by spending a few mornings in the field listening to whistling males pointed out by experienced observers before officially participating in surveys. Each point per cluster was observed 24 times (12 per year) in three contiguous day intervals separated by two to five days. Observers were randomly assigned to a cluster for each three-day interval to avoid observer bias. Observers were instructed to begin monitoring the first point within their randomly assigned cluster at sunrise and spend no more than four minutes at a single point and no more than ten minutes traveling to and from points within the cluster. Travel time was minimized between points to ensure all points were completed within the first two hours after sunrise. Observers were instructed to drive slowly, cautiously, and carefully to ensure safety and minimum disturbance when traveling to survey points. Observers were instructed to sample cluster routes in reverse order on alternating days to avoid bias of optimal calling time and point locale. Points were observed during the first two hours after sunrise (Rosene 1969, Hansen and Guthery 2001). Observers recorded a unique individual number identification, record azimuths, estimated distances, and approximate locations for each whistling male detected on standardized data sheets that had detailed aerial photographs (Guthery 1986) and distance scales originating at the survey point and out to 500m in the cardinal directions. Wind and sky codes, with classifications equal to those described in Shackelford et al. (1999), were also recorded. Surveys were not conducted during periods of harsh weather (i.e. moderate to heavy rainfall and/or high winds > 16 kmh). The number of individuals heard calling, azimuth, and distance to each individual were saved for each point after all observations were complete. The data were saved using a database created in Microsoft Access.

Habitat Models and Data Analyses

Fall covey-call-counts were analyzed using the occupancy estimation feature in program Mark (MacKenzie et al. 2002) to determine naïve estimate of occupancy. Fall covey call count data were used to generate an index of quail abundance across Fort Gordon each observation year.

Data collected from summer male whistle call counts were analyzed using the "Robust Occupancy Estimation, Psi (1), Gamma, Epsilon" feature in Program MARK (MacKenzie et al. 2003) to investigate potentially influential habitat variables both at the forest stand (stand metric covariates) and landscape level (fire frequency covariate).

Logistic regression models were fit in Program MARK to test the effects of habitat covariates, fire frequency and stand metrics (e.g. basal area m^2), on relative occupancy (ψ), colonization (immigration) rate (γ), and extinction (emigration) rate (ε). Fitness of the models was determined based on AIC_C value and model weight (W_i) (Akiake 1973) and the "best fit" model was selected according to lowest AIC_C, Δ AIC_C value, and highest AIC_C model weight (W_i) with consideration of compatibility with Fort Gordon's management program (Burnham and Anderson 1998, 2002). The model(s) selected, averaged if necessary, and used to derive estimated bobwhite occupancy (ψ), immigration (γ), and emigration (ε) rates (MacKenzie et al. 2003, McClintock and White 2009). Models were fit to test the effects of mean total pine basal area (m^2), mean hardwood (>7.6 cm dbh) basal area (m^2/ha), mean percent total groundcover, mean frequency of fire (2003-2008), and pine basal area on bobwhite occupancy (ψ), immigration (γ), and emigration (ε) rates. The most appropriate model(s) were selected that suggested the most influential variable(s) and configurations in terms of forest structure and landscape level influence that may affect bobwhite occupancy across the landscape. Variable significance was determined by whether or not zero was contained within the 95% confidence interval; the covariate with a stronger effect on bobwhite abundance did not contain zero in the output 95% confidence interval.

RESULTS

Vegetation Analysis

An average of 48.18 (1.67 SE) of LandMark's plots occurred within each of the 61, 500-m radius areas. Vegetation measurements were averaged across these plots for analysis (Table 2.1). Average pine basal area around survey points was 16.06 (0.45 SE).

Average pine basal area of trees larger than 35 cm was 4.61 (0.30 SE). Hardwood basal area of trees larger than 7.6cm was 19.31 (0.61 SE). Percent ground cover was 35.52 (0.90 SE). Finally, fire frequency between years 2003 and 2010 was 2.05 (0.09 SE). Using program R, I constructed and fit the habitat covariates into a correlation matrix to identify any multicolinearity that existed between variables. Measurements of hardwood basal area and pine basal area were highly correlated (Table 2.2) and were not combined in any individual model during the analysis. Fire frequency showed little to no correlation with any variables used in the analysis ($\text{Correlation coefficient} \leq |0.2|$). All values were standardized and prepared for Program Mark.

Fall Covey Call Counts

We sampled 21 covey call count point locations after three of the original 24 covey call count points had to be removed for logistic complications and lack of necessary accessibility. Each point was revisited three times over the course of three weeks. Covey call survey naïve estimates of occupancy were found to be 0.18 (0.05 SE), 0.10 (0.07 SE), and 0.19 (0.09 SE) for years 2009, 2010, and 2011 respectively (Table 2.3).

Summer Whistle Call Counts

We sampled 61 male whistle call count point locations along clustered routes across Fort Gordon, each point sampled 24 times during 2010 and 2011. Each point was revisited three consecutive times during each of the four secondary sampling occasions. Average number of whistling males detected per observation was 0.23 (0.021 SE) (Max= 3) and 0.29 (0.025 SE) (Max= 5) for 2010 and 2011, respectively.

Habitat Models and Data Analyses

Using the robust design occupancy data type feature (robust design occupancy psi (1), gamma, epsilon) in Program MARK models were fit using the data collected during whistle count observations, fire records, and vegetation measurements (Table 2.4). Models were selected to test for any influence of fire frequency, mean pine basal area (m^2/ha), mean hardwood >7.6cm dbh basal area (m^2/ha), mean percent total ground cover, mean pine >36cm dbh basal area (m^2/ha), and combinations of each on immigration (γ), emigration (ε), and occupancy by bobwhites (ψ) (Table 2.4). The "best-fit" model selected with the lowest AIC_C value = 1118.35, Δ AIC_C = 0, W_i= 0.62, tested the effect of the covariates mean hardwood >7.6cm dbh basal area (m^2/ha) and mean percent ground cover on occupancy, immigration, and emigration. The selected model weight (W_i=0.62) was just under 3 times the next best model weight (W_i=0.23). The 95% confidence intervals associated with the beta estimate of hardwood basal area did not span zero and was therefore among the stronger predictors of bobwhite occupancy (-1.73, -0.2), immigration (-2.57, -0.16), and emigration (0.24, 2.14). Predictive models generated in Program MARK show the positive influence of the covariate mean hardwood >7.6cm dbh basal area (m^2/ha) on bobwhite emigration and a negative influence on bobwhite occupancy and immigration rates (Figure 2.X). Beta (β) estimates of mean percent ground cover effect were ψ = 0.60 (0.33 SE), ε = 0.24 (0.34 SE), and γ = 0.60 (0.48 SE). All estimates of percent ground cover effect had confidence intervals that spanned zero and were considered weaker predictors of bobwhite demographics in this model (Figure 2.X) (Table 2.5). The next best model, AIC_C =1120.36 (W_i=0.22), tested the effect of mean hardwood >7.6cm dbh basal area (m^2/ha), mean percent ground cover, and frequency of fire on bobwhite demographics. In this model hardwood basal area was again a strong predictor of bobwhite occupancy, immigration, and emigration. The model fitted to test the effect of mean hardwood >7.6cm dbh basal area (m^2/ha) and frequency of fire was third best (AIC_C = 1121.39). Also, the model fit to test the effect of percent ground cover alone revealed ground cover to have a negative influence on emigration rate (β= -0.003, 0.30 SE). Although it is a weak relationship, it is important to note this because percent ground cover demonstrates a positive influence on emigration rates when modeled with other covariates such as hardwood basal area. Models containing the covariates with mean pine basal area measurements ranked low relative to model weight (e.g., W_i=0.23). Confidence intervals associated with the covariates mean total pine basal area (m^2/ha) and mean pine >36cm dbh basal area (m^2/ha) spanned zero (Table 2.5) and can therefore be considered weak as predictors of bobwhite occupancy, immigration, and emigration.

Model averaging generated the final models to predict bobwhite occupancy, immigration, and emigration rates on Fort Gordon using measured habitat variables (Table 2.5). The averaged model to predict occupancy is

$$\psi_i = -2.04 + \mathrm{fire}(0.20) + \mathrm{GC}(0.60) + \mathrm{HWD_a}(0.98) + \mathrm{Pine_b}(-0.02) + \mathrm{Pine_a}(-0.17).$$

The averaged model to predict emigration is

$$\varepsilon_i = 0.32 + \varepsilon T_1(-16.9) + \varepsilon T_2(-1.62) + \mathrm{fire}(-0.53) + \mathrm{GC}(0.26) + \mathrm{HWD_a}(1.18) + \mathrm{Pine_b}(0.63) + \mathrm{Pine_a}(0.64).$$

The averaged model to predict immigration is

$$\gamma_i = -17.08 + \gamma T_1(14.81) + \gamma T_2(18.2) + \mathrm{fire}(0.64) + \mathrm{GC}(0.61) + \mathrm{HWD_a}(-1.35) + \mathrm{Pine_b}(-0.8E7) + \mathrm{Pine_a}(-0.56)$$

DISCUSSION

The models yielded results that provided insight as to what influences the estimates of bobwhite occupancy, immigration, and emigration across the Fort Gordon landscape. These models could prove to be very useful when assessing impacts of land management decisions related to single species oriented restoration efforts. The data collected during this research and associated model predictions suggest that RCW restoration efforts are having an impact on bobwhite population demographics on Fort Gordon. The findings here concur with suggestions made by Engstrom and Palmer (2005) in that basal area (m^2) reduction treatments have a positive influence on bobwhite occupancy. Additionally, findings in this research suggest hardwood basal area (m^2) has a strong negative influence of bobwhite occupancy and immigration. This could be most strongly associated with the idea that dense canopy closures and vast amounts of shade associated with hardwoods reduce the amount of preferred groundcover. While this could certainly be the case, the results from correlation matrix suggest this may not be the only reason. In other words, preferred groundcover can still persist in some areas with higher hardwood basal area, however, there is still a negative influence on bobwhite occupancy. I suspect there is somewhat of a double effect on bobwhites with hardwoods being present in the upland areas primarily in response to a probable increase in predator abundance in and around areas with higher hardwood basal area. These areas could also have negative impacts on RCW populations as well in regards to possible decrease in preferred insect abundance (Hanula and Franzreb, 1998) for both adults and nestlings.

Bowman et al. (1999) suggested manager's leave as many large oaks and hickories as allowable under current RCW management guidelines. Bowman et al.

(1999) makes this recommendation despite their findings suggested most game species would be positively influenced by RCW restoration with the exception of black bear (*Ursus Americana*) and grey squirrel (*Sciuris carolinensis*). My findings here suggest that leaving too many large hardwoods can have strong negative influence on bobwhite occupancy.

Predictive models such as these described in this thesis should be used to assist managers with making decisions related to timber management under single species oriented guidelines to avoid costly mistakes in the future.

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Table 2.1 2010-2011 Fort Gordon, Georgia habitat covariate analysis results of various *Pinus,* hardwood, and vegetative species cover as well as fire frequency.

Variable	Code	Definition	Mean	SE	Max	Min
Total Pine Basal Area	$Pine_a$	Total basal area per hectare of all pines	16.0630	0.4482	26.0901	8.1985
Large Pine Basal Area (m^2/ha)	$Pine_b$	Mean basal area per hectare of pines ≥ 36 cm dbh	4.6129	0.3037	14.1981	0.7824
Hardwood Basal Area (m^2/ha)	HWD_a	Mean basal area per hectare of all hardwood species >7.6 cm dbh	19.3100	0.6148	31.9824	9.2117
Percent Ground Cover	GC	Mean sum of ground cover variables (grass, forb, vine, and woody shrub)	32.5224	0.8993	50.1464	18.2894
Frequency of Fire	Fire	Number of times a fire has occurred on an area between 2003-2010	2.0409	0.0875	4.3444	0.4952

Table 2.2 Habitat Covariate Correlation Matrix for habitat variables used in the occupancy, immigration, and emigration modeling of bobwhite population at Fort Gordon, Georgia in 2010 and 2011.

	Fire	HWD_a	HWD_b	$Pine_b$	$Pine_d$	$Pine_c$	GC	$Pine_a$
Fire	1							
HWD_a	-0.23875418	1						
HWD_b	-0.22090207	0.4307171	1					
Large Pine	-0.17914762	0.4970071	0.08693481	1				
Pine Regen	-0.08627413	-0.26363	-0.09513111	-0.16760453	1			
Pine≤35cm	0.04959287	0.47817	0.23469148	-0.2715922	0.22996172	1		
GC	0.17549443	-0.4067912	-0.17149346	-0.16548866	-0.06345021	-0.16704417	1	
Total Pine	-0.04379596	0.6085671	0.13755547	0.13131265	0.04538645	0.807454	-0.18877085	1

HWD_a = hardwood basal area (m^2/ha) of trees greater than 7.6 cm dbh.
GC = percent groundcover including grass, forb, vine, and woody herbaceous.
PS = primary sessions included within the robust sampling design.
Fire = frequency of occurrence of fire during the years 2003-2010.
$Pine_a$ = Basal area (m^2/ha) of pines
$Pine_b$ = Basal area (m^2/ha) of pines larger than 36 cm dbh
$Pine_c$ = basal area of pines equal to or smaller than 36 cm dbh (m^2/ha)
$Pine_d$ = basal area of pine regeneration (m^2/ha)

Table 2.3 Northern Bobwhite Covey Call Results (2009-2011). Estimates of bobwhite occupancy based on calling coveys during the fall of 2009, 2010, and 2011 on Fort Gordon, Georgia.

Year	Naïve estimate of occupancy	Standard Error
2009	0.18	0.05
2010	0.10	0.07
2011	0.19	0.09

Table 2.4 Model ranking and AIC_c weights (W_i) of candidate models that assess the influence of particular habitat variables directly associated with RCW restoration on bobwhite occupancy (ψ), emigration (ε), and immigration (γ) rates on Fort Gordon, Georgia during the 2009 and 2010 breeding seasons.

Model	AICc	Δ AICc	AICc W_i	K	Deviance
ψ([a]t,[b]HWD_a+[c]GC) ε(t, HWD_a+GC) γ(t,HWD_a+GC) [d]PS1(.) PS2(.) PS3(.) PS4(.)	1118.3552	0	0.62253	15	1086.2499
ψ(t,HWD_a+GC+[e]Fire) ε(t,HWD_a+GC+Fire) γ(t,HWD_a+GC+Fire) PS1(.) PS2(.) PS3(.) PS4(.)	1120.3582	2.003	0.22867	18	1081.3182
ψ(t,HWD_a+Fire) ε(t,HWD_a+Fire) γ(t,HWD_a+Fire) PS1(.) PS2(.) PS3(.) PS4(.)	1121.3882	3.033	0.13663	16	1086.9917
ψ(t,HWD_a+Fire) ε(t,HWD_a+Fire) γ(t) PS1(.) PS2(.) PS3(.) PS4(.)	1127.8886	9.5334	0.0053	14	1098.0545
ψ(t,HWD_a+GC+Fire) ε(t,HWD_a+GC+Fire) γ(t) PS1(.) PS2(.) PS3(.) PS4(.)	1128.5696	10.2144	0.00377	16	1094.1731
ψ(t,HWD_a+GC) ε(t, HWD_a+GC) γ(t) PS1(.) PS2(.) PS3(.) PS4(.)	1129.4989	11.1437	0.00237	15	1097.3936
ψ(t,HWD_a+GC) ε(t) γ(t) PS1(.) PS2(.) PS3(.) PS4(.)	1133.1026	14.7474	0.00039	13	1105.52
ψ(t,HWD_a+GC+Fire) ε(t) γ(t) PS1(.) PS2(.) PS3(.) PS4(.)	1135.0441	16.6889	0.00015	14	1105.21
ψ(t,HWD_a+Fire) ε(t) γ(t) PS1(.) PS2(.) PS3(.) PS4(.)	1135.9611	17.6059	0.00009	13	1108.3785
ψ(t,[f]$Pine_a$+GC+Fire) ε(t,$Pine_a$+GC+Fire) γ(t,$Pine_a$+GC+Fire) PS1(.) PS2(.) PS3(.) PS4(.)	1138.0425	19.6873	0.00003	18	1099.0025
ψ(t,GC) ε(t) γ(t) PS1(.) PS2(.) PS3(.) PS4(.)	1140.0226	21.6674	0.00001	12	1114.672
ψ(t,GC+Fire) ε(t) γ(t) PS1(.) PS2(.) PS3(.) PS4(.)	1141.0586	22.7034	0.00001	13	1113.476
ψ(t,GC) ε(t,GC) γ(t,GC) PS1(.) PS2(.) PS3(.) PS4(.)	1141.1198	22.7646	0.00001	14	1111.2857
ψ(t,GC+Fire) ε(t,GC+Fire) γ(t,GC+Fire) PS1(.) PS2(.) PS3(.) PS4(.)	1141.2039	22.8487	0.00001	17	1104.4959
ψ(t,$Pine_a$+GC+Fire) ε(t,$Pine_a$+GC+Fire) γ(t) PS1(.) PS2(.) PS3(.) PS4(.)	1141.3093	22.9541	0.00001	16	1106.9128
ψ(t,[g]$Pine_b$+GC+Fire) ε(t,$Pine_b$+GC+Fire) γ(t) PS1(.) PS2(.) PS3(.) PS4(.)	1141.8801	23.5249	0	16	1107.4836
ψ(t,GC+Fire) ε(t,GC+Fire) γ(t) PS1(.) PS2(.) PS3(.) PS4(.)	1142.0633	23.7081	0	15	1109.958
ψ(t,GC) ε(t,GC) γ(t) PS1(.) PS2(.) PS3(.) PS4(.)	1142.2164	23.8612	0	13	1114.6338
ψ(t,$Pine_b$+GC+Fire) ε(t,$Pine_b$+GC+Fire) γ(t,$Pine_b$+GC+Fire) PS1(.) PS2(.) PS3(.) PS4(.)	1142.2338	23.8786	0	19	1100.8409
ψ(t,$Pine_a$+GC+Fire) ε(t) γ(t) PS1(.) PS2(.) PS3(.) PS4(.)	1143.0284	24.6732	0	14	1113.1943
ψ(t,$Pine_a$+Fire) ε(t,$Pine_a$+Fire) γ(t,$Pine_a$+Fire) PS1(.) PS2(.) PS3(.) PS4(.)	1143.218	24.8628	0	16	1108.8215
ψ(t,$Pine_b$+GC+Fire) ε(t) γ(t) PS1(.) PS2(.) PS3(.) PS4(.)	1143.306	24.9508	0	14	1113.4719
ψ(t,$Pine_a$+Fire) ε(t,$Pine_a$+Fire) γ(t) PS1(.) PS2(.) PS3(.) PS4(.)	1143.8098	25.4546	0	14	1113.9757
ψ(t,$Pine_a$+Fire) ε(t) γ(t) PS1(.) PS2(.) PS3(.) PS4(.)	1147.7689	29.4137	0	13	1120.1863

[a]t = time in months between primary sessions.

[b]HWD_a = hardwood basal area (m^2/ha) of trees greater than 7.6 cm dbh.

[c]GC = percent groundcover including grass, forb, vine, and woody herbaceous.
[d]PS = primary sessions included within the robust sampling design.
[e]Fire = frequency of occurrence of fire during the years 2003-2010.
[f]$Pine_a$ = Basal area (m^2/ha) of pines.
[g]$Pine_b$ = Basal area (m^2/ha) of pines larger than 36 cm dbh.

Table 2.5 Model average estimates of beta (β) for models fit to assess influence on bobwhite occupancy (ψ), emigration (ε), and immigration (γ) on Fort Gordon, Georgia during the 2009 and 2010 breeding season.

ModelAvg (β)	β estimate	SE	95% ucl	95% lcl
ψ Intercept	-0.2044	0.3600	0.4977	-0.9064
GC	0.5955	0.3354	1.2496	-0.0585
Fire	0.1956	0.3019	0.7843	-0.3931
HWD_a	-0.9793	0.3927	-0.2135	-1.7450
$Pine_b$	-0.0163	0.2942	0.5574	-0.5900
$Pine_a$	-0.1661	0.3020	0.4229	-0.7551
ε Intercept	0.3284	0.4769	1.2582	-0.6015
ε t1	-16.9213	1419.2132	2750.5445	-2784.3871
ε t2	-1.6246	0.7234	-0.2140	-3.0352
(ε) Fire	-0.5289	0.3402	0.1345	-1.1923
(ε) Fire	-0.5421	0.3485	0.1374	-1.2217
(ε) GC	0.2643	0.3562	0.9589	-0.4304
(ε) HWD_a	1.1797	0.4884	2.1321	0.2273
(ε) $Pine_b$	0.6330	0.3928	1.3990	-0.1330
(ε) $Pine_a$	0.6434	0.3556	1.3368	-0.0499
γ Intercept	-17.0811	371.1493	706.6601	-740.8223
γ t1	14.8130	371.1525	738.5604	-708.9343
γ t2	18.1985	371.2006	742.0397	-705.6427
(γ) Fire	0.6403	0.5454	1.7039	-0.4233
(γ) GC	0.6087	0.4938	1.5716	-0.3542
(γ) HWD_a	-1.3499	0.6120	-0.1565	-2.5434
(γ) $Pine_b$	0.0000	0.0000	0.0000	0.0000
(γ) $Pine_a$	-0.5585	0.4359	0.2915	-1.4085
PS 1 Intercept	-0.1736	0.1661	0.1504	-0.4975
PS 2 Intercept	-1.3656	0.1858	-1.0033	-1.7279
PS 3 Intercept	-0.3953	0.1356	-0.1309	-0.6598
PS 4 Intercept	-0.9391	0.2568	-0.4384	-1.4398

[a]t = time in months between primary sessions.
[b]HWD_a = hardwood basal area (m^2/ha) of trees greater than 7.6 cm dbh.
[c]GC = percent groundcover including grass, forb, vine, and woody herbaceous.
[d]PS = primary sessions included within the robust sampling design.
[e]Fire = frequency of occurrence of fire during the years 2003-2010.
[f]$Pine_a$ = Basal area (m^2/ha) of pines.
[g]$Pine_b$ = Basal area (m^2/ha) of pines larger than 36 cm dbh.

CHAPTER 3

DO WOODPECKER RESTORATION GUIDELINES SUPPORT INCREASED BOBWHITE OCCUPANCY? A SPATIALLY EXPLICIT POPULATION MODEL APPROACH

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CHAPTER 3

DO WOODPECKER RESTORATION GUIDELINES SUPPORT INCREASED BOBWHITE OCCUPANCY? A SPATIALLY EXPLICIT POPULATION MODEL APPROACH

INTRODUCTION

When managing populations across complex landscapes, it may increase managers' ability to accurately model populations using spatially explicit population models. Spatially explicit population models are important assessment tools for investigating population ecology questions related to land-scale and can bring to light information that analytical models are unable to (Dunning et al. 1995). While analytical models are important, they do not allow researchers or managers alike to easily examine the different aspects of landscape physiognomy (Dunning et al. 1995) that could potentially be correlated with population demographics.

Spatially explicit population models allow for the potential link between species population (multiple or single) demography and the landscape. They have been used for some time now in assisting managers with gaining insight to current and future demographics of wildlife populations at the landscape level (e.g., Schulz and Joyce 1992, Dunning et al. 1995, Rushton et al. 2006, Blomberg 2012). Similar models have been developed with respect to territoriality observations in several species including the red-cockaded woodpecker (e.g., Tyre et al. 2001, Letcher et al. 1998).

The U.S. Army recognizes that wildlife species are not randomly or uniformly distributed across the landscape and has developed specific guidelines encouraging managers to utilize spatially explicit models when managing threatened and endangered species as well as species populations that are of concern (Shapiro and Hohmann 2005). U. S. Army guidelines recommend that a spatially explicit approach be taken to avoid incorrectly predicting population carrying capacity on installations. Schulz and Joyce (1992) found that without spatially explicit information, smaller, separated patches of habitat could likely be interpreted as being useful habitat, a potentially detrimental mistake when dealing with species already experiencing population decline.

To apply this theory with respect to bobwhite monitoring and management in response to red cockaded woodpecker (Piciodes borealis), hereafter RCW, management, an additional objective to this research was to develop spatially explicit population models that incorporate predictive analytical models of bobwhite and RCW dispersion across the landscape as well as determining whether a difference exists in predicted bobwhite occupancy rates in areas both with and void of RCW restoration efforts.

METHODS

Study Populations

Bobwhite populations were monitored on the 22,500-ha installation of Fort Gordon with male whistle call counts. A native population, these bobwhites persist along the sandhills, longleaf pine stands, and hardwood drains/ridges of the installation. After military establishment, succeeding farmland within the installation was replaced with pine plantations where fire was excluded, thus allowing midstory to become densely occupied with turkey oak (*Quercus laevis*), blackjack oak (*Q. marilandica*), and bluejack oak (*Q. incana*). Implementation of revenue-driven siliviculture most likely caused much of the native vegetation and biologically diverse areas to recede to small patches scattered throughout the installation. With the effects of encroaching dense midstory and fire suppression, early successional, fire dependent wildlife populations began to decline.

The RCW was extirpated from Fort Gordon in 1993 following years of fire suppression and lack of timber harvests suitable to RCW populations (Department of Defens 2008). In 1996, a transient RCW took up residence on Fort Gordon. Following amendments to the Sikes Act and development of an endangered species management plan, the Forestry section at Fort Gordon began converting the various revenue driven silivicultural practices into RCW driven ecosystem restoration based practices. Timber harvests occurred more frequently across the installation with target basal areas set according to RCW management guidelines. Prescribed burning was implemented throughout the installation annually along with midstory removal and native vegetation plantings (mainly *Aristida stricta*).

Natural resource management efforts on Fort Gordon have shifted with an intensive management program geared towards the recovery of the RCW while supporting military mission and training activity. The remaining landscapes surrounding the remnant longleaf wiregrass patches have been the primary focus of ecosystem restoration and management as well as RCW population recovery on Fort Gordon. A process that has resulted in the 17 active RCW clusters inventoried 15 years after the Savannah River Site migrant.

Habitat Metrics: Collection and Spatial Analyses

The foundation of the spatial analyses described here is built by habitat metrics as they fluctuate across the Fort Gordon landscape. The Fort Gordon Natural Resources Branch supplied stand data collected at plot-tree level on Fort Gordon in 2010-2011. The data were collected in accordance with RCW MATRIX requirements (USFWS 2003) and thus supplied this research with pine and hardwood basal area, groundcover, and midstory estimates for each individual plot location. In an effort to translate the plot level measurements, I calculated mean pine (> 36 cm dbh, $\leq$ 36 cm dbh, and total) basal area (m^2/ha), hardwood (> 7.6 cm dbh) basal area (m^2/ha), high hardwood regeneration (stems/ha), and percent ground cover for the entire study landscape through interpolation of the data points with the "Kriging" tool in ArcGIS 10, transforming the data layer into multiple raster datasets. The Kriging method selected was ordinary, spherical, and output cell size was specified to be 30 m. Kriging search radius was set to be variable. A shaded color ramp was selected to clearly depict variation among variables as it occurs across the Fort Gordon landscape. Zonal statistics were used to calculate specific values pertaining to the land cover data such as mean, minimum, and maximum.

The Fort Gordon Natural Resources Branch supplied prescribed and wild fire history for Fort Gordon in a personal geo-database. The fire data were extracted sorted by year and saved in a series of overlapping, intersecting polygons spanning multiple years and multiple fires, so extraction of the data required that each of the polygons be separated into unique layers by year. Then a new field was created for each of the new layer features that contained dummy variables indicating the year it was burned (binary values, populated with 1 or 0). Each feature was converted to raster using the "feature to raster" tool in ArcGIS. After each feature was converted to raster, the "weighted sum" tool in ArcGIS was applied to equally weight and sum the raster features together. From that, fire frequency across the landscape was obtained for all measured areas. The "focal statistics" tool in ArcGIS was used to smooth out the fire frequency data and calculate the average fire frequency across the landscape by calculating the mean fire frequency within a 500 m area or "neighborhood" around each 30 m cell. A contrasting color ramp was selected to plainly depict mean fire frequency as it occurs across the Fort Gordon landscape.

Bobwhite and RCW Occupancy: Spatially Translated Analytical Models

Summer male whistle call counts were conducted in 2010-2011 across a wide array of sample clusters each containing eight to ten points. Sample clusters were generated using K means clustering in program "R". The sample points were situated throughout the landscape across training areas with RCW focused management and training areas that have not yet received RCW focused management efforts. Survey points were separated by no less than 1000 m in an effort to minimize duplicate observations between surveys conducted in close proximity. The points were arranged on roads and or firebreaks within the installation. Roads/firebreaks on Fort Gordon are no more than 200 meters apart so there was little concern of bias with points being on roads and or firebreaks given that bobwhites can be detected at distances up to 500 meters (Wellendorf and Palmer 2005), potential for bias relevant to roads was not a concern. Habitat variables measured in standardized plots that occurred within a 500 m radius surrounding a whistle count observation point were identified using the intersect and zonal statistics tool in ArcGIS 10. Habitat metrics were then averaged according to each variable and standardized to create a set of measurements of habitat variables for each point.

Observers were trained by listening to recorded whistling male bobwhites and by spending a few mornings in the field listening to whistling males pointed out by experienced observers before officially participating in surveys. Each point per cluster was observed 24 times (12 per year) in three contiguous day intervals separated by two to five days. Observers were randomly assigned to a cluster for each three-day interval to avoid observer bias. Observers were instructed to begin monitoring the first point within their randomly assigned cluster at sunrise and spend no more than four minutes at a single point and no more than ten minutes traveling to and from points within the cluster. Travel time was minimized between points to ensure all points were completed within the first two hours after sunrise. Observers were instructed to drive slowly, cautiously, and carefully to ensure safety and minimum disturbance when traveling to survey points. Observers were instructed to sample cluster routes in reverse order on alternating days to avoid bias of optimal calling time and point locale. Points were observed during the first two hours after sunrise (Rosene 1957, Hansen and Guthery 2001). Observers recorded a unique individual number id, record azimuths, estimated distances, and approximate locations for each whistling male detected on standardized data sheets that had detailed aerial photographs (Guthery 1986) and distance scales originating at the survey point and out to 500m in the cardinal directions. Wind and sky conditions were classified and recorded. Surveys were not conducted during periods of harsh weather (i.e. moderate to heavy rainfall and/or high winds > 16 kmh). The number of individuals heard calling, azimuth, and distance to each individual were saved for each point after all observations were complete. The data were saved using a database created in Microsoft Access.

Using analytical regression models developed using Program MARK (Mackenzie et al. 2003) in Chapter 2 of this thesis, I applied the model average results to the vegetation and fire data interpolated across the Fort Gordon landscape. These models run in Program MARK suggest hardwood basal area along with fire frequency and ground cover to be relatively good predictors of bobwhite occupancy on Fort Gordon. By applying the model average and using the interpolated habitat variables, I calculated bobwhite occupancy rates with the "raster calculator" tool in ArcGIS 10 and predicted across Fort Gordon. The newly created layer was given a contrasting color ramp to clearly outline areas with high and low predicted bobwhite occupancy rates.

$$pi = (1 + exp(-1(\beta o + \beta 1 * xi + \ldots + \beta j * xji)))$$

$$Where\ldots$$

$$pi = Estimated\ probability\ of\ occupancy\ by\ bobwhites\ at\ location\ i.$$

$$\beta o = Estimated\ model\ intercept.$$

$$xji = Values\ for\ j = 1, 2, \ldots, k\ measurable\ covariates\ at\ location\ i.$$

$$\beta j = Estimated\ coefficient\ for\ parameter\ j = 1, 2 \ldots k\ covariates.$$

RCW populations on Fort Gordon are likely not high enough to form accurate predictive occupancy models; therefore, for this portion of this chapter I used models developed by Scott (2011) for his dissertation involving occupancy and forecasting models on Fort Bragg. Scott found pine basal area (> 36 cm, dbh) (m^2/ha), hardwood basal area (> 7.6 cm, dbh) (m^2/ha), high hardwood regeneration (stems/ha), and basal area (m^2/ha) of pine regeneration to be good predictors of RCW occupancy on Bragg.

Fort Bragg is similar to Fort Gordon in habitat composition and Army Guideline based RCW management practices with the exception of Bragg having a relatively aged, recovered RCW population. Using the RCW occupancy predictive model developed by Scott (2011), I calculated RCW occupancy rates across Fort Gordon with respect to interpolated habitat variables.

To investigate the possibility of increasing bobwhite abundance in response to RCW specific restoration efforts, I developed raster datasets for each calculated occupancy model. The datasets were sorted into binary data using 1 and 0 for the lower and upper halves of predicted occupancy rates, respectively. Using the weighted sums feature in ArcGIS 10, I created a raster dataset to include binary data identifying areas where higher bobwhite and RCW occupancy overlap.

Bobwhite and RCW Occupancy: Spatial Interpretation of Presence Data

The second approach to spatially modeling bobwhite and RCW occupancy was done using software specifically designed for generating ecological niche and habitat suitability models. Ecological niche modeling is essentially a method for estimating species distributions as they occur in response to specific ecological parameters (Peterson 2001). Using Maxent, I was able to run models to measure maximum entropy. Maxent is a software designed to predict habitat suitability as well as generate ecological niche models from presence only data and measured ecological parameters that occur in and around the area of interest. It was important to run predictive models of bobwhite and RCW occupancy on Fort Gordon using this software because unlike the strictly analytical models described earlier, I was able to incorporate Fort Gordon site specific, RCW data to build the model for RCW habitat suitability. These modeling procedures that differed and allowed for use of RCW data specific to Fort Gordon was that I did not use presence-absence data but rather presence data alone to generate the models and predict influential ecological parameters, or habitat variables specific to Fort Gordon.

Using data collected from the summer male whistle call count surveys; I generated a table displaying presence only data for whistling male bobwhites on Fort Gordon (confined to the monitoring points). Data collected and supplied for this research by the Natural Resources Branch yielded presence data for RCW cluster sites. As part of their annual monitoring procedures for RCW, they are required to collect a full inventory on all known RCW clusters at Fort Gordon and classify them as “active”, “inactive”, or “recruitment”. If clusters were classified as “active”, it was recorded as having RCW present at that location. Although Maxent only takes into account presence data, it is important to note there were cluster sites that were inactive and therefore RCWs would have been considered absent from those locations.

The next step was gathering and formatting the necessary background data (i.e., environmental layers or habitat variables). Using vegetation data provided by the Natural Resources Branch, I formatted the interpolated habitat metrics described earlier by converting the raster datasets to ASCii files in ArcGIS 10. I selected the same habitat variables used with the analytical models including frequency of fire, mean pine (> 36 cm dbh and total) basal area (m^2/ha), mean hardwood (> 7.6 cm dbh) basal area (m^2/ha), mean high hardwood regeneration (stems/ha), and mean percent ground cover to represent the environmental layer for analysis of both species. Each environmental layer was classified as continuous rather than categorical based on format, structure, and type of data.

Models were run using Maxent to determine species distribution according to each habitat variable included in the environmental layer. Models were deemed "good" according to the calculated area under the curve (AUC) that maximizes sensitivity for low values of the false positive fraction (Engler et al. 2004). As described in Phillips et al. (2006), AUC values can be interpreted here as a measure of the degree of ability of the algorithm to distinguish suitable habitat conditions from unsuitable and thus contributed to overall confidence in the selected models.

RESULTS

Habitat Metrics: Collection and Spatial Analysis

Mean pine (> 36 cm dbh) basal area, pine (regeneration) basal area, pine (total) basal area, percent ground cover, hardwood (>7.6 cm dbh) basal area, hardwood (high regeneration) stems/ha was calculated for 11,458 sampled inventory plots. The estimated mean pine (> 36 cm dbh) basal area is 4.25 m^2/ha (0.06 SE) (max=39.03, min=0), mean hardwood (>7.6 cm dbh) basal is 19.48 m^2/ha (0.10 SE), and mean pine (total) basal area is 4.55 m^2/ha (0.06 SE) across Fort Gordon (Table 3.1). The interpolation output displays the estimated variable values averaged between sample points in shades of green. Lighter shades of green reveal areas of lower basal areas (<103ft2) where areas of higher estimated basal area (>103ft2) are shown with darker shades of green (e.g. Figure 3.1). The new "realized" estimated mean λ basal area is 91.65 (0.039 SE) (range=5.5, 201.25) based on values distributed between measured plots (511,875 individual cells).

Fire data pertinent to this study ranged from 2003-2010. The estimated mean fire frequency (number of times an area has burned between 2003-2010) calculated from 508,959 cells is 1.02 (SE=0.002) (Min=0, Max=7). The raster output was displayed using a contrasting color ramp ranging from dark blue (fire frequency=0) to yellow (fire frequency=3.5) to dark red (fire frequency=7) (Figure 3.2). The focal statistics output created more of a smoothed landscape effect to the fire frequency layer.

Bobwhite and RCW Occupancy: Spatially Translated Analytical Models

We sampled 61 male whistle call count point locations along clustered routes across Fort Gordon, each point sampled 24 times during 2010 and 2011. Each point was revisited three consecutive times during each of the four secondary sampling occasions. Average number of whistling males detected per observation was 0.23 (0.021 SE) (Max= 3) and 0.29 (0.025 SE) (Max= 5) for 2010 and 2011 respectively. Longitudinal and Latitudinal locations were recorded for point locations where bobwhites were detected (Table 3.2).

The occupancy prediction model average with estimates of beta (β) for frequency of fire, hardwood basal area (m^2/ha), pine basal area (m^2/ha), percent groundcover, and hardwood regeneration (stems/ha) as one of the top predictors of bobwhite occupancy (Figure 3.3) was used as the base for predicting bobwhite occupancy as it occurs throughout Fort Gordon. The model translated spatially with raster calculator was

$$\mathrm{yi} = 1/((1 + \exp(-(-0.05 + ((\mathrm{Fire}) * 0.04 + (\mathrm{ground\ cover}) * 0.15 + (\mathrm{HWD\_a}) * -0.245 + (\mathrm{Pine\_b}) * -0.004) + (\mathrm{Pine\_a}) * -0.042))))$$

The model developed by Scott (2011) was

$$\mathrm{yi} = 1/((1 + \exp(-(-1.0014 + ((\mathrm{HWD\_}a) * -0.2885 + (HWD\_b) * -0.0319 + (\mathrm{Pine\_b}) * 0.0135) + (\mathrm{Pine\_a}) * -0.042))))$$

which when ran with interpolated Fort Gordon habitat metrics produced a spatially explicit RCW occupancy model ranging from 0.08 to 0.48 occupancy rate (Figure 3.4). Area of overlap measured from weighted sums binary data demonstrated 45,112 30m pixels (4,052.87 ha) that contained a measure of occupancy for both RCW and bobwhites. 83,038 30m pixels (7,460.15 ha) and 73,068 30m pixels (6,564.45 ha) made up the area where only bobwhite and RCW occupancy rates were exhibited, respectively (Figure 3.5). Although there is a larger estimated area supporting bobwhite occupancy than RCW occupancy, more than half of that area occurs in overlap for both species, suggesting RCW restoration efforts support bobwhite occupancy on Fort Gordon.

Models run in Maxent demonstrated similar distribution predictions of bobwhites, to the analytical models however, the selected Maxent RCW model demonstrated much more convincing results (AUC=0.961, regularized training gain = 1.746, Max occupancy rate=0.92) than did the model fit using Scott's (2011) Fort Bragg occupancy model (Max occupancy rate=0.48). The jackknife test of variable importance run for Maxent models revealed that the most influential variable on bobwhite occupancy is groundcover (Figure 3.6, 3.9) and hardwood regeneration was most influential on RCW occupancy (Figure 3.7, 3.11). I observed similar influence of habitat variables on both species in most cases but overall weight and importance of each variable on both species models was different (Table 3.2). Frequency of fire occurrence during the seven recorded years (2003-2010) appears to be most "optimum" when burned every 2.33 years and every 3.18 years for bobwhites and RCW, respectively (Figure 3.8). Percent groundcover was predicted most optimum at 40% cover and $\geq$ 40% cover for bobwhites and RCW, respectively (Figure 3.9). Maximum hardwood (>7.6 cm, dbh) basal area (m^2/ha) to achieve 0.65 probability of presence was $\leq$ 2.5 and $\leq$ 4 m^2/ha for bobwhites and RCW, respectively, while both species reached probability of presence nearing 0 at 45.5 and 27 m^2/ha for both bobwhites and RCW, respectively (Figure 3.10). Hardwood regeneration (stems/ha) is the quantitative representative measurement of hardwood midstory and Maxent models show measurements of midstory > 0 stems/ha resulting in the steep decline of both bobwhite and RCW predicted probability of presence. Bobwhites seemed to slowly fall to lower probability of presence rates at 600 stems/ha (Figure 3.11). Probability of presence seems to decline slowly for bobwhites after about 5 m^2/ha of total pine basal area, where RCW probability of presence increases at 4 up until 8 at which point it begins to decline until reaching 0 probability of presence at 18 m^2/ha (Figure 3.12). The second pine variable is linked with the RCW's unique requirement and preference of older mature pines. Pine basal area (m^2/ha) of pines greater than 36 cm, dbh was found to have positive influence on bobwhites out to about 22 m^2/ha where a negative influence was shown after about 1 m^2/ha for RCWs (Figure 3.13). Images developed in Maxent display combined influence of these variables on the probability of occupancy by both species as they occur across the landscape of Fort Gordon (Figure 3.14).

DISCUSSION

Spatially explicit models can provide insight into variable influence and geographic distribution of species. I found that most of the habitat variables' influence on bobwhite occupancy was similar to their influence on RCW occupancy. The main variable that demonstrated a major difference at least in overall trend was pine basal area of pines larger than 36 cm, dbh. Pine basal area of these larger pines was shown to have a positive influence on bobwhite occupancy and a negative influence on RCW occupancy, which is quite the opposite of what I would have expected to see. This can probably best be explained by the high correlation and low predictive power of large pine basal area as a strongly influential variable (Figure 3.6, 3.7). Areas where only RCWs are predicted to occur are likely attributable to RCW tolerance of higher pine basal. However, bobwhite occupancy is higher in areas where RCW restoration has taken place and in some cases on Fort Gordon, bobwhites have a larger geographic distribution of predicted occupancy spanning across areas of predicted RCW occupancy. My findings here support suggestions proposed in models developed by Engstrom and Palmer (2005)

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Table 3.1 Habitat variable metrics statistics for all of Fort Gordon with associated codes used to reference each variable.

Variable	Code	Definition	Mean	SE	Max	Min
Total Pine Basal Area	Pinea	Total basal area per hectare of all pines	4.5545	0.0563	39.0320	0.0000
Large Pine Basal Area (m2/ha)	Pineb	Mean basal area per hectare of pines > 36 cm dbh	4.2497	0.0562	39.0320	0.0000
Hardwood Basal Area (m2/ha)	HWDa	Mean basal area per hectare of all hardwood species >7.6 cm dbh	19.4863	0.1028	73.9634	0.0000
Percent Ground Cover	GC	Mean sum of ground cover variables (grass, forb, vine, and woody shrub)	29.8395	0.1699	100.0000	0.0000
High Hardwood Regeneration	HWDregen	Measure of stems/ha of hardwood trees ≤7.6 cm	902.5584	13.4317	25797.2400	0.0000
Frequency of Fire	Fire	Number of times a fire has occurred on an area between 2003-2010	1.0174	0.0022	7.0000	0.0000

Table 3.2 Maxent model results showing variable comparison of percent contribution and permutation importance for both species according to each variable.

	Red-cockaded Woodpecker		Northern Bobwhite	
Variable	Percent contribution	Permutation importance	Percent contribution	Permutation importance
HWD Regeneration	49.5	16.5	11.4	4.5
HWD_a	23.2	8.2	4.3	18.9
Frequency of Fire	12.1	32.8	34.7	40.4
Ground Cover	10.3	12.2	45.1	23.4
$Pine_a$	4.9	30.3	0.4	1.9
$Pine_b$	0	0	4	10.9

HWD Regeneration = measure of hardwood stems per hectare that are less than 7.6 cm, dbh
HWD_a= Hardwood basal area (m^2/ha) of trees greater than 7.6 cm, dbh
Frequency of Fire= number of fire occurrence during the years 2003-2010
Ground Cover= measure of percent total ground cover that includes grass, vines, forbs, and woody vegetation
$Pine_a$= Pine basal area (m^2/ha) of total pines (all size classes)
$Pine_b$= Pine basal area (m^2/ha) of pines greater than 36 cm, dbh

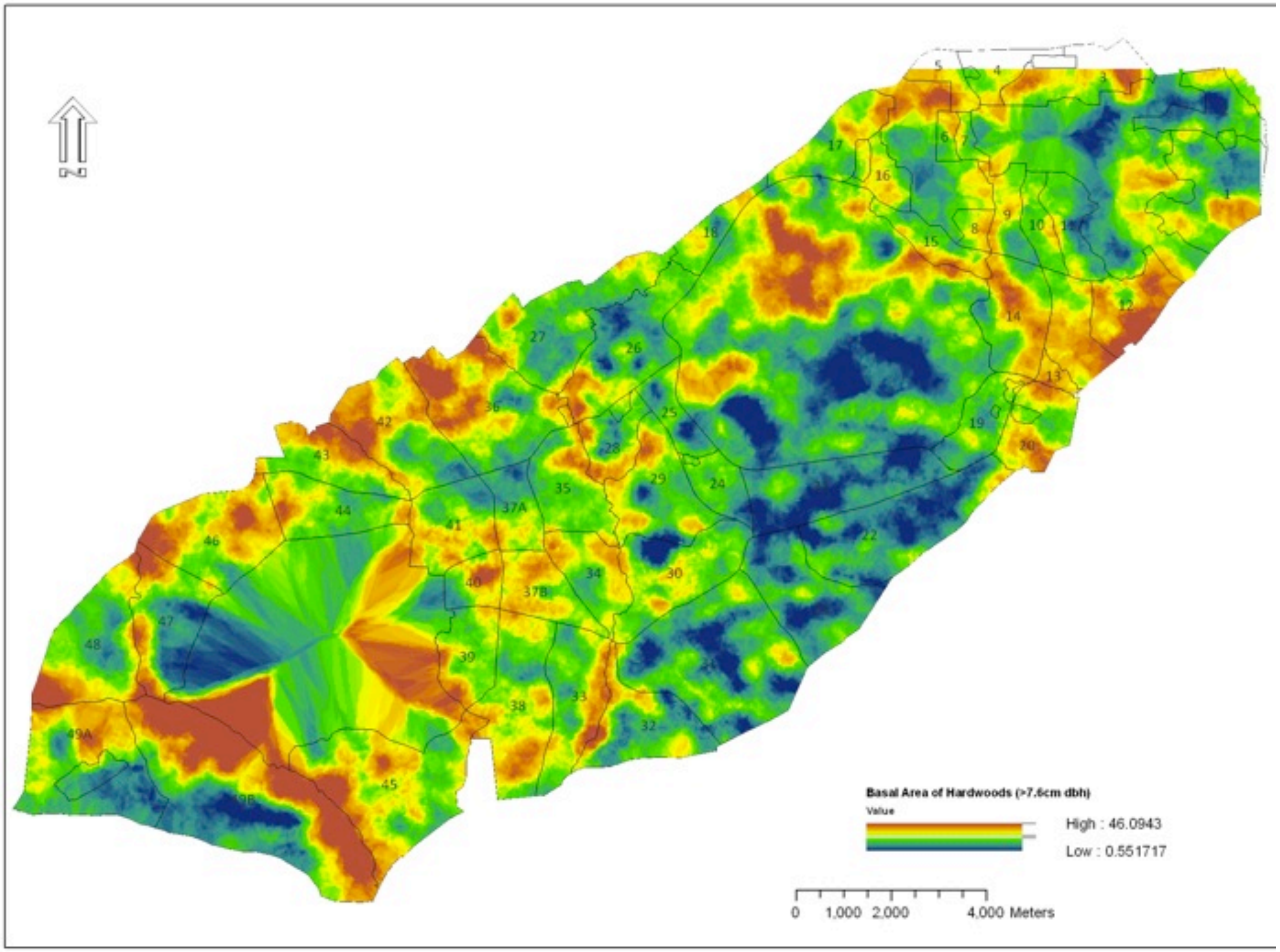

Figure 3.1 Fort Gordon compartments with hardwood basal area (m^2/ha) of trees > 7.6 cm is geographically distributed across the landscape in 2011. Areas where higher basal area measurements occur are indicated in red contrasted by areas of lower basal area indicated in blue.

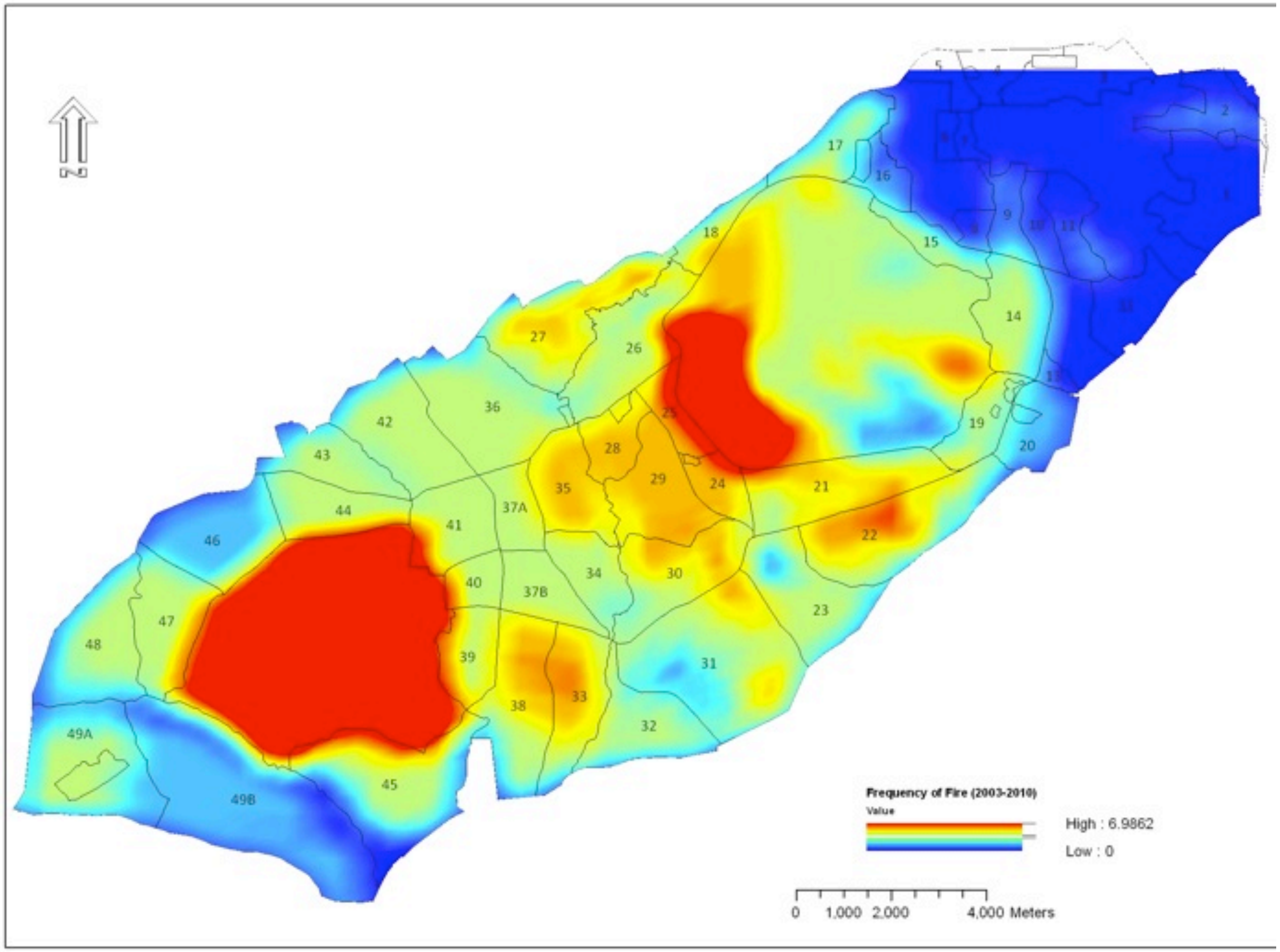

Figure 3.2 Fort Gordon compartments with fire frequency across the landscape between 2003-2010.

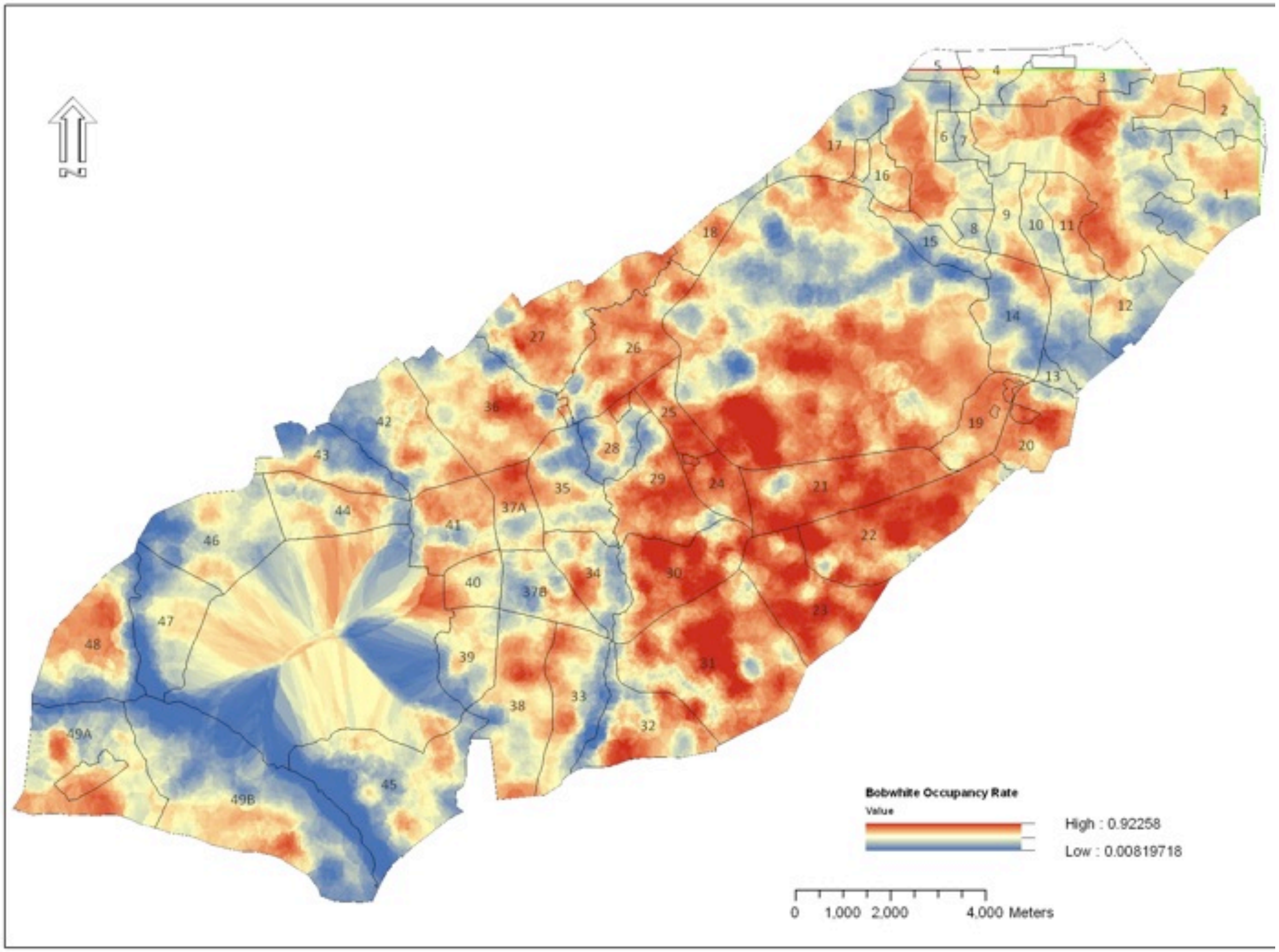

Figure 3.3 Fort Gordon compartments with predicted bobwhite occupancy rates occur across the landscape in 2011. Occupancy rates were generated using models run with Program MARK. Areas of dark red indicate areas of higher likelihood of bobwhite occurrence.

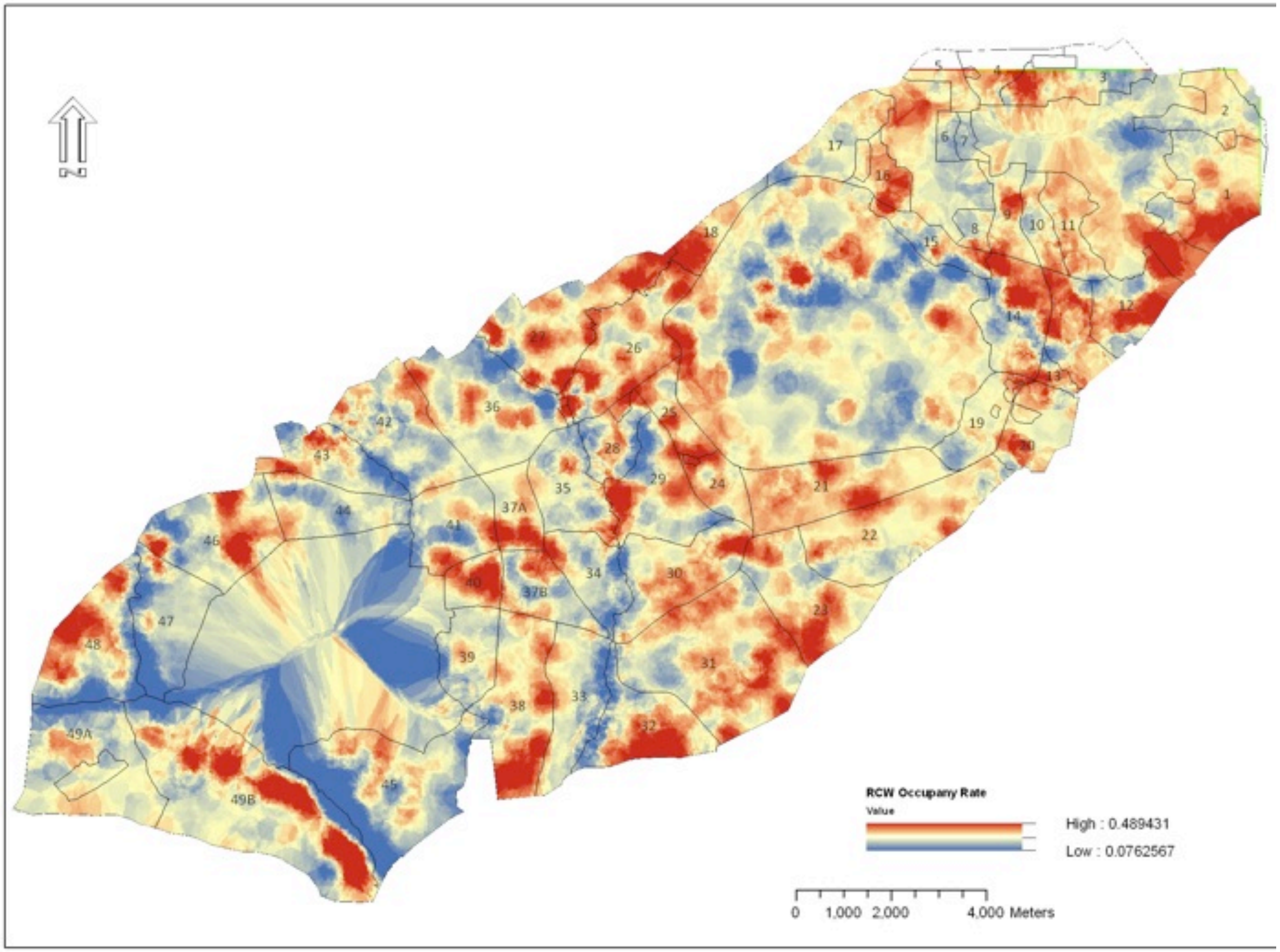

Figure 3.4 Fort Gordon compartments with predicted red-cockaded woodpecker (RCW) occupancy rates occur across the landscape in 2011. Occupancy rates were generated using models developed by Scott (2011). Areas of dark red indicate areas of higher likelihood of RCW occurrence.

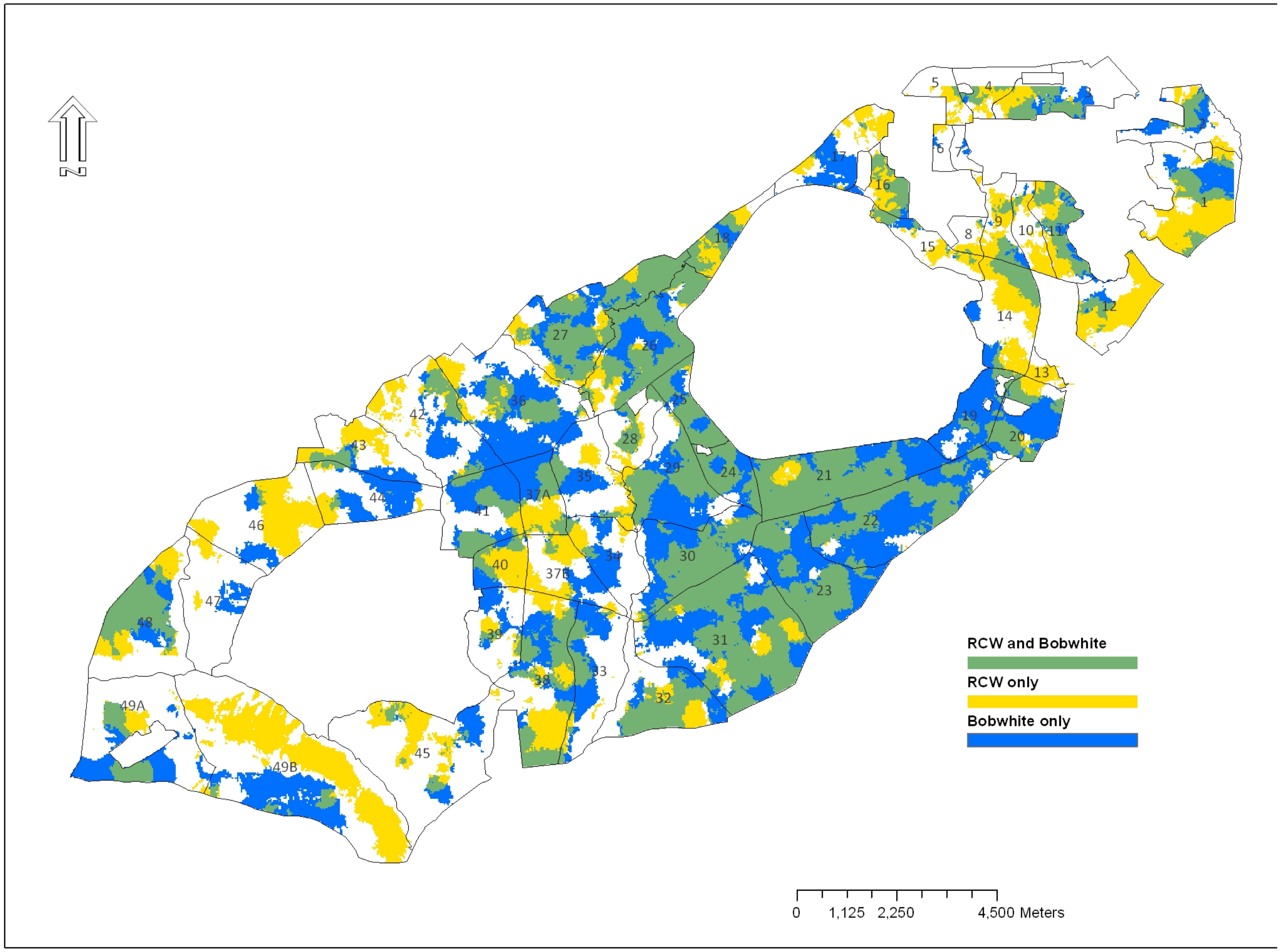

Figure 3.5 Fort Gordon compartments with predicted bobwhite and RCW occupancy rates occur across the landscape in 2011. Occupancy rates were generated using models run with Program MARK. Areas of green indicate areas of higher likelihood of occupancy overlap occurrence.

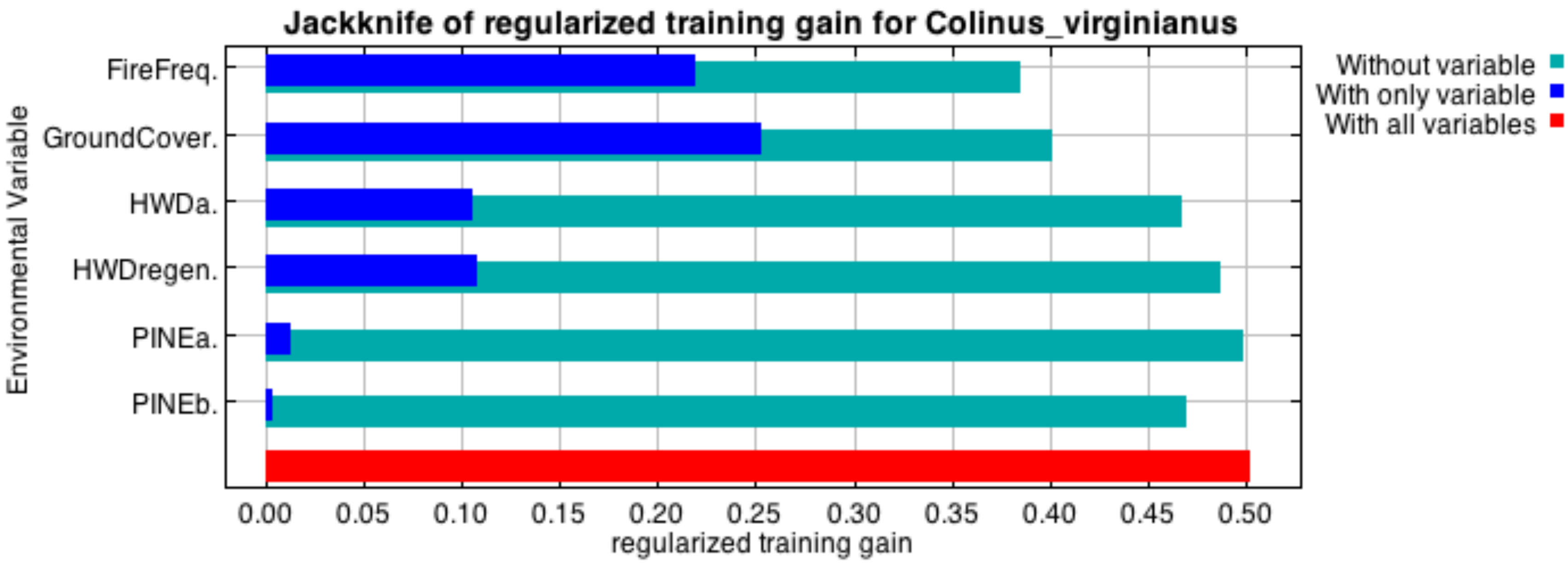

Figure 3.6 Jackknife test of variable importance under bobwhite occupancy from Maxent output. The environmental variable with highest gain when used in isolation is GroundCover indicating it as having the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted is FireFreq indicating it as having the most information that isn't present in the other variables.

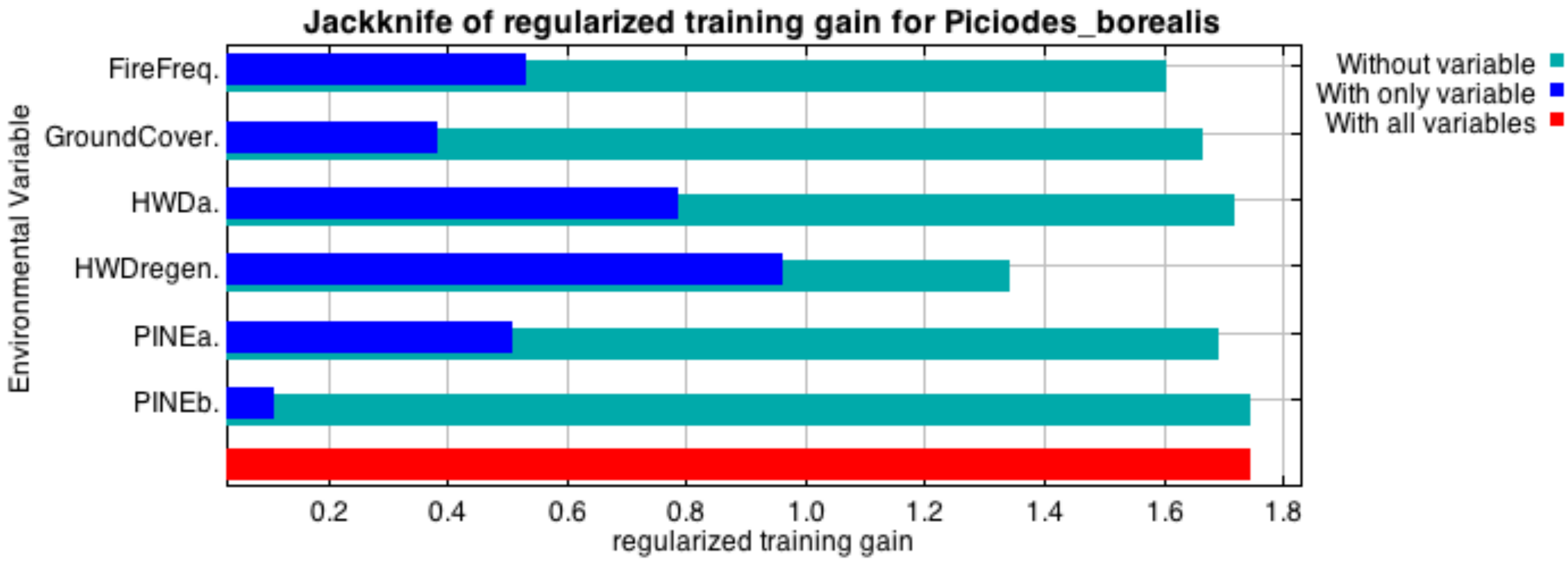

Figure 3.7 Jackknife test of variable importance using Maxent for red cockaded woodpecker data collected on Fort Gordon, Georgia. The environmental variable with highest gain when used in isolation is HWDregen indicating it as having the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted is HWDregen indicating it as having the most information that isn't present in the other variables.

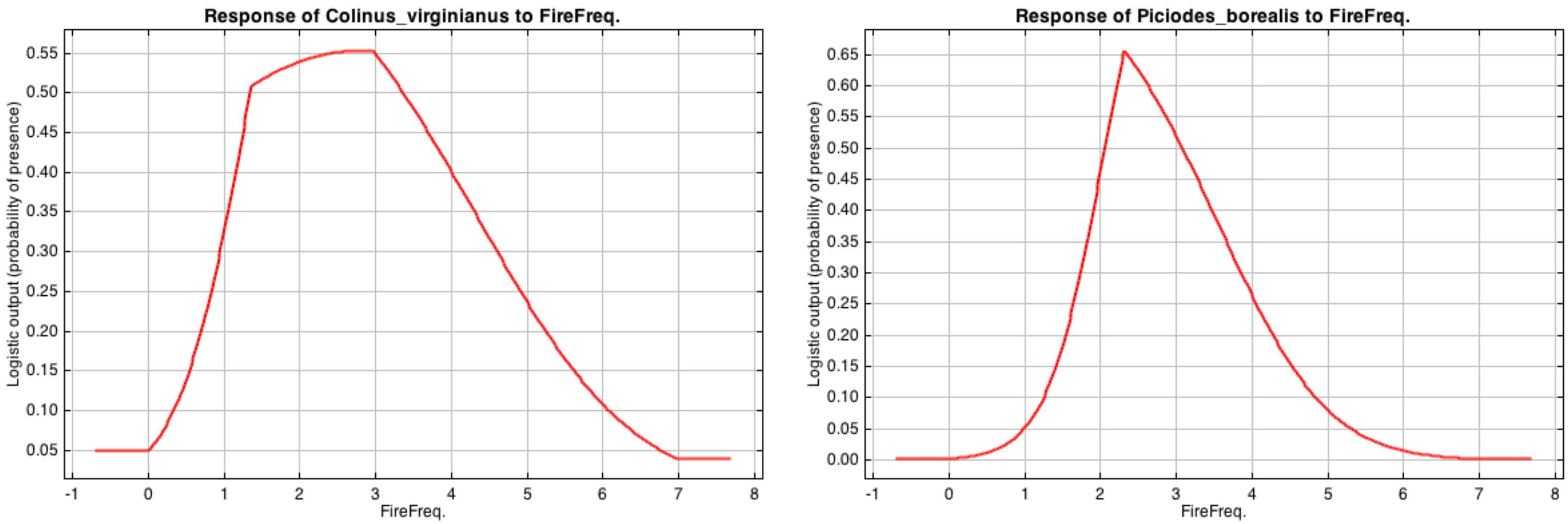

Figure 3.8 Maxent output demonstrating influence of the number of times fire has occurred during the seven year period (2003-2010) on Northern bobwhites (*Colinus virginainus*) and red cockaded woodpecker (*Piciodes borealis*) occupancy rates, namely, a Maxent model created using only the frequency of fire. These plots reflect the dependence of predicted suitability both on the frequency of fire and on dependencies induced by correlations between the frequency of fire and other variables on Fort Gordon, Georgia.

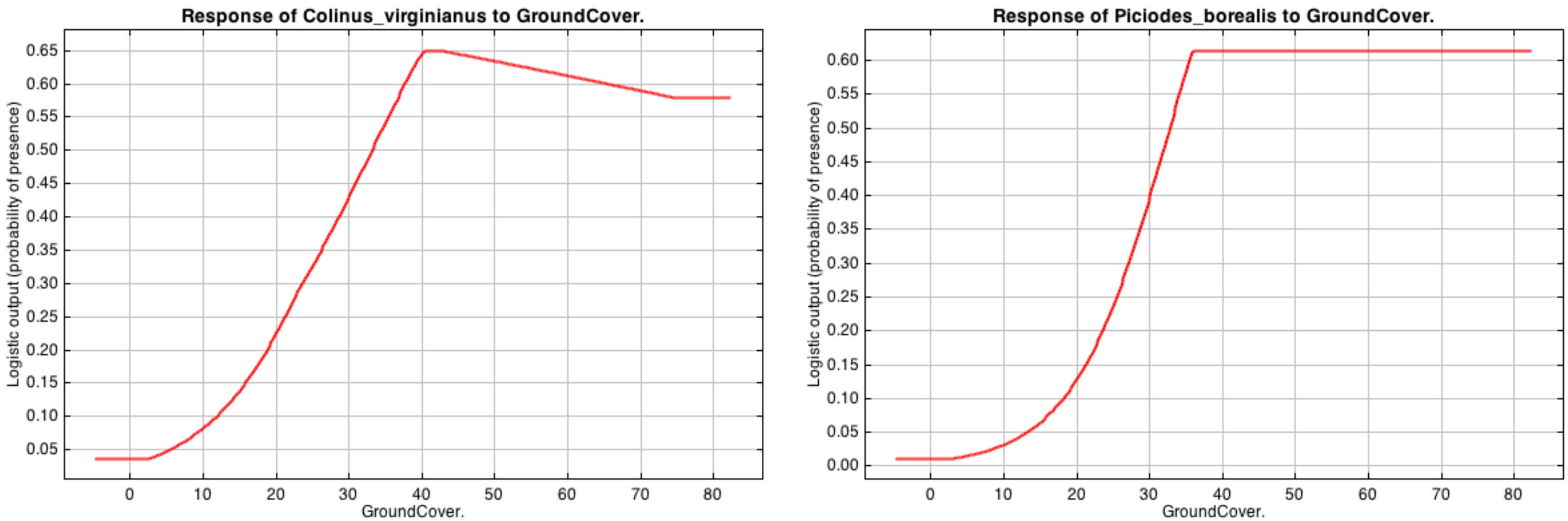

Figure 3.9 Maxent output demonstrating the influence of the 2011 estimates of mean percent ground cover on Northern bobwhites (*Colinus virginainus*) and red cockaded woodpecker (*Piciodes borealis*) occupancy rates, namely, a Maxent model created using only the mean percent ground cover. These plots reflect the dependence of predicted suitability both on the mean percent ground cover and on dependencies induced by correlations between the ground cover and other variables on Fort Gordon, Georgia.

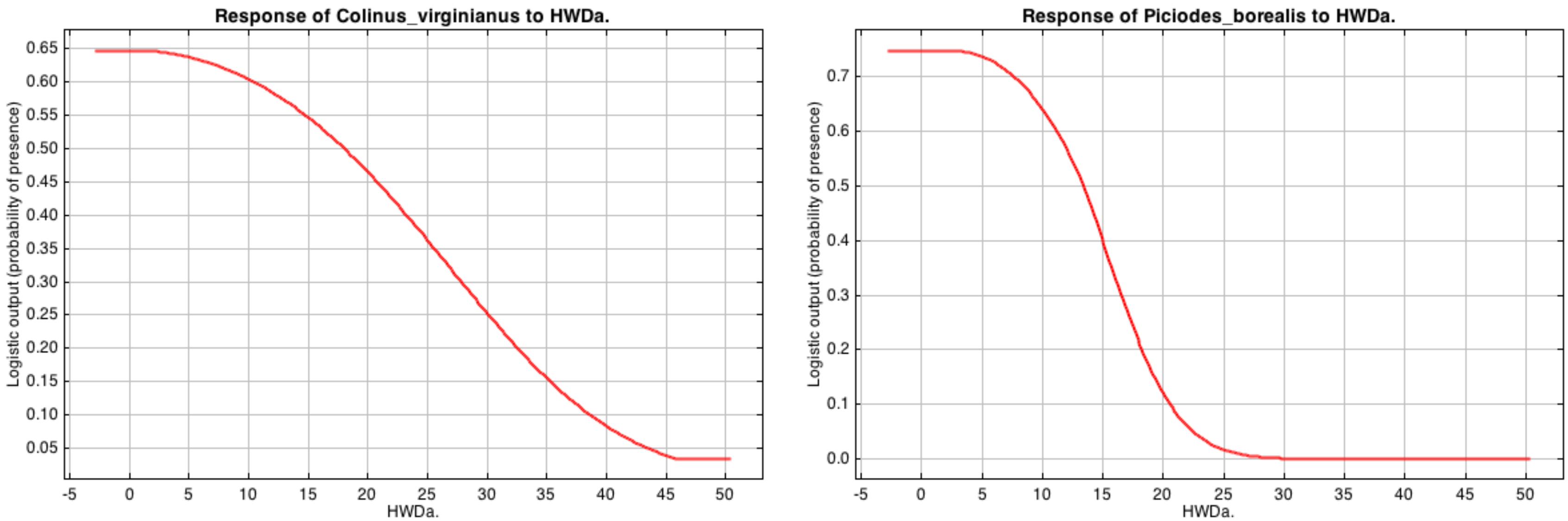

Figure 3.10 Maxent output demonstrating the influence of the 2011 estimates of mean hardwood (> 7.6 cm, dbh) basal area (m^2/ha) on Northern bobwhites (*Colinus virginainus*) and red cockaded woodpecker (*Piciodes borealis*) occupancy rates, namely, a Maxent model created using only the mean hardwood (> 7.6 cm, dbh) basal area (m^2/ha). These plots reflect the dependence of predicted suitability both on the mean hardwood (> 7.6 cm, dbh) basal area (m^2/ha) and on dependencies induced by correlations between the ground cover and other variables on Fort Gordon, Georgia.

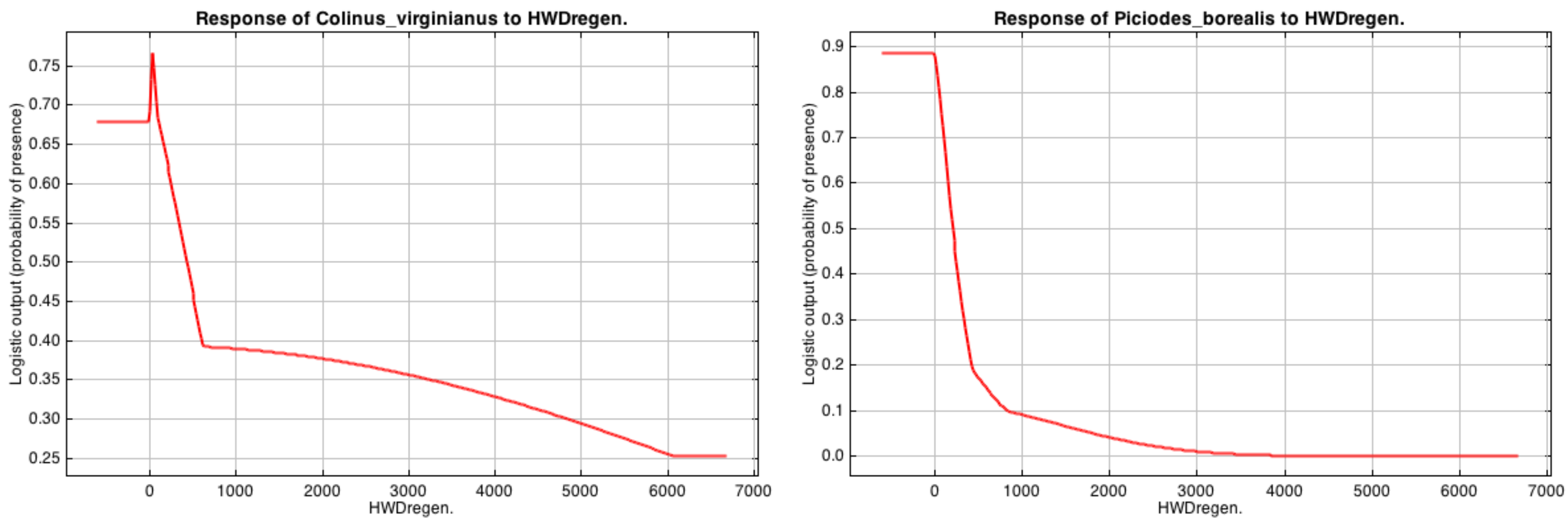

Figure 3.11 Maxent output demonstrating the influence of the 2011 estimates of mean hardwood regeneration (stems/ha) on Northern bobwhites (*Colinus virginainus*) and red cockaded woodpecker (*Piciodes borealis*) occupancy rates, namely, a Maxent model created using only the mean hardwood regeneration (stems/ha). These plots reflect the dependence of predicted suitability both on the mean hardwood regeneration and on dependencies induced by correlations between the ground cover and other variables on Fort Gordon, Georgia.

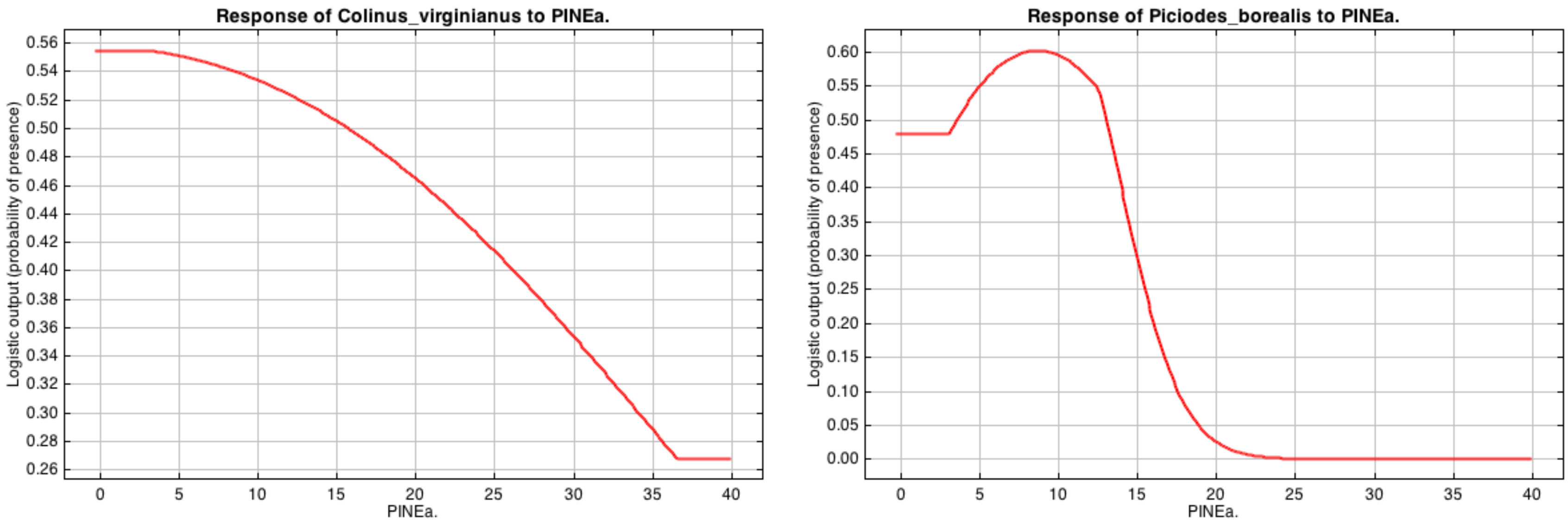

Figure 3.12 Maxent output demonstrating the influence of the 2011 estimates of mean total pine basal area (m^2/ha) on Northern bobwhites (*Colinus virginainus*) and red cockaded woodpecker (*Piciodes borealis*) occupancy rates, namely, a Maxent model created using only the mean total pine basal area (m^2/ha). These plots reflect the dependence of predicted suitability both on the mean total pine basal area (m^2/ha) and on dependencies induced by correlations between the ground cover and other variables on Fort Gordon, Georgia.

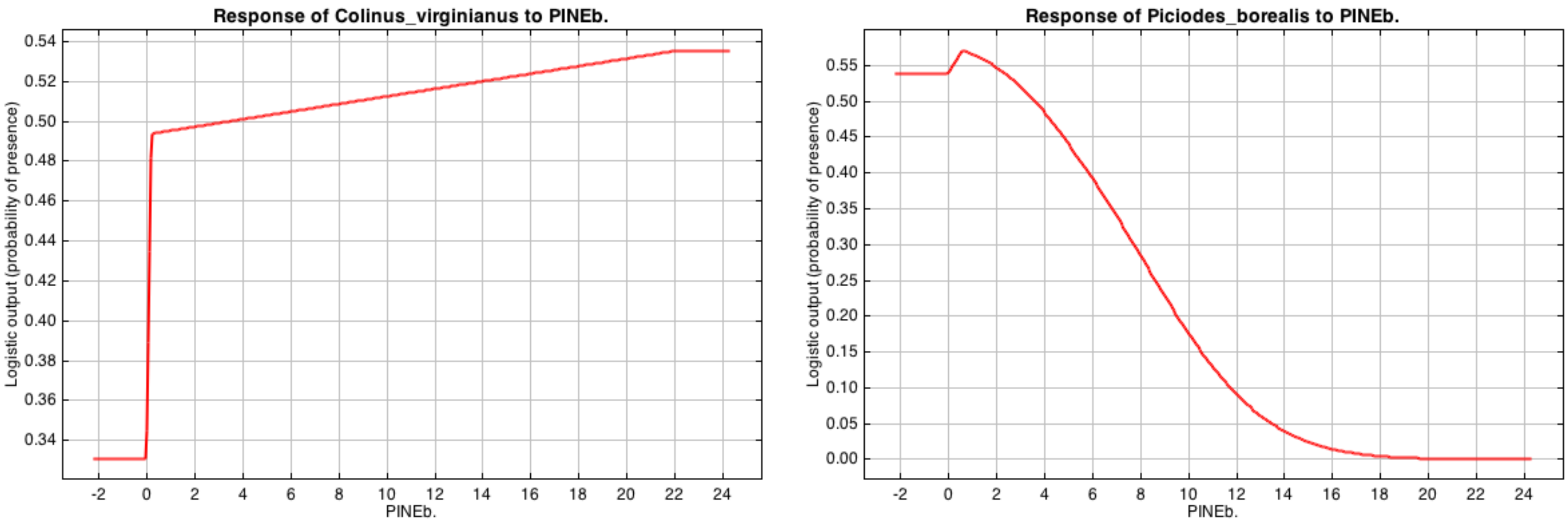

Figure 3.13 Maxent output demonstrating the influence of the 2011 estimates of mean pine (> 36 cm, dbh) basal area (m^2/ha) on Northern bobwhites (*Colinus virginainus*) and red cockaded woodpecker (*Piciodes borealis*) occupancy rates, namely, a Maxent model created using only the mean pine (> 36 cm, dbh) basal area (m^2/ha). These plots reflect the dependence of predicted suitability both on the mean pine basal area (m^2/ha) and on dependencies induced by correlations between the ground cover and other variables on Fort Gordon, Georgia.

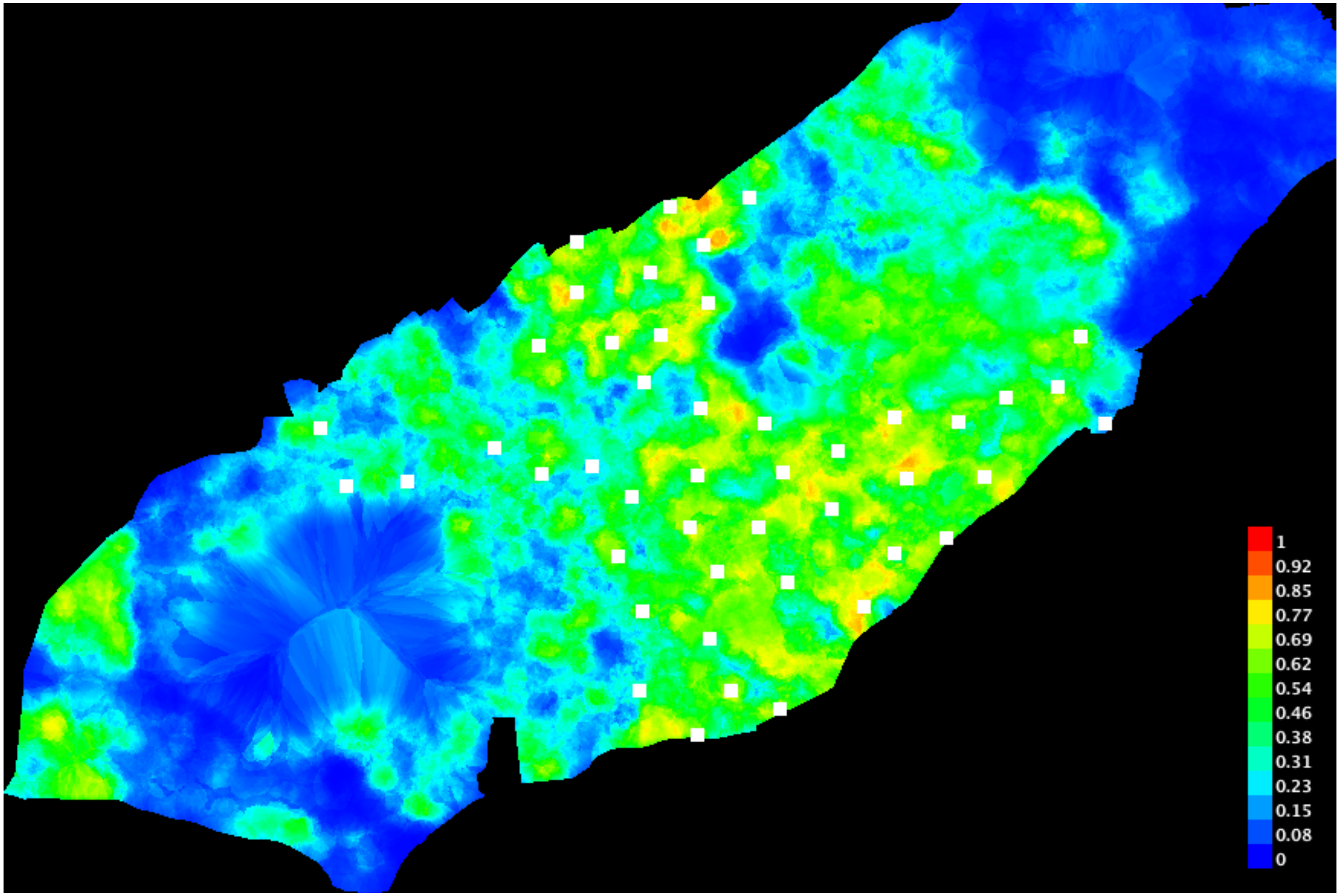

Figure 3.14 Maxent model output for Northern bobwhites (*Colinus virginianus*) on Fort Gordon, Georgia in 2011. Warmer colors show areas with better-predicted conditions. White dots show the presence locations used for training.

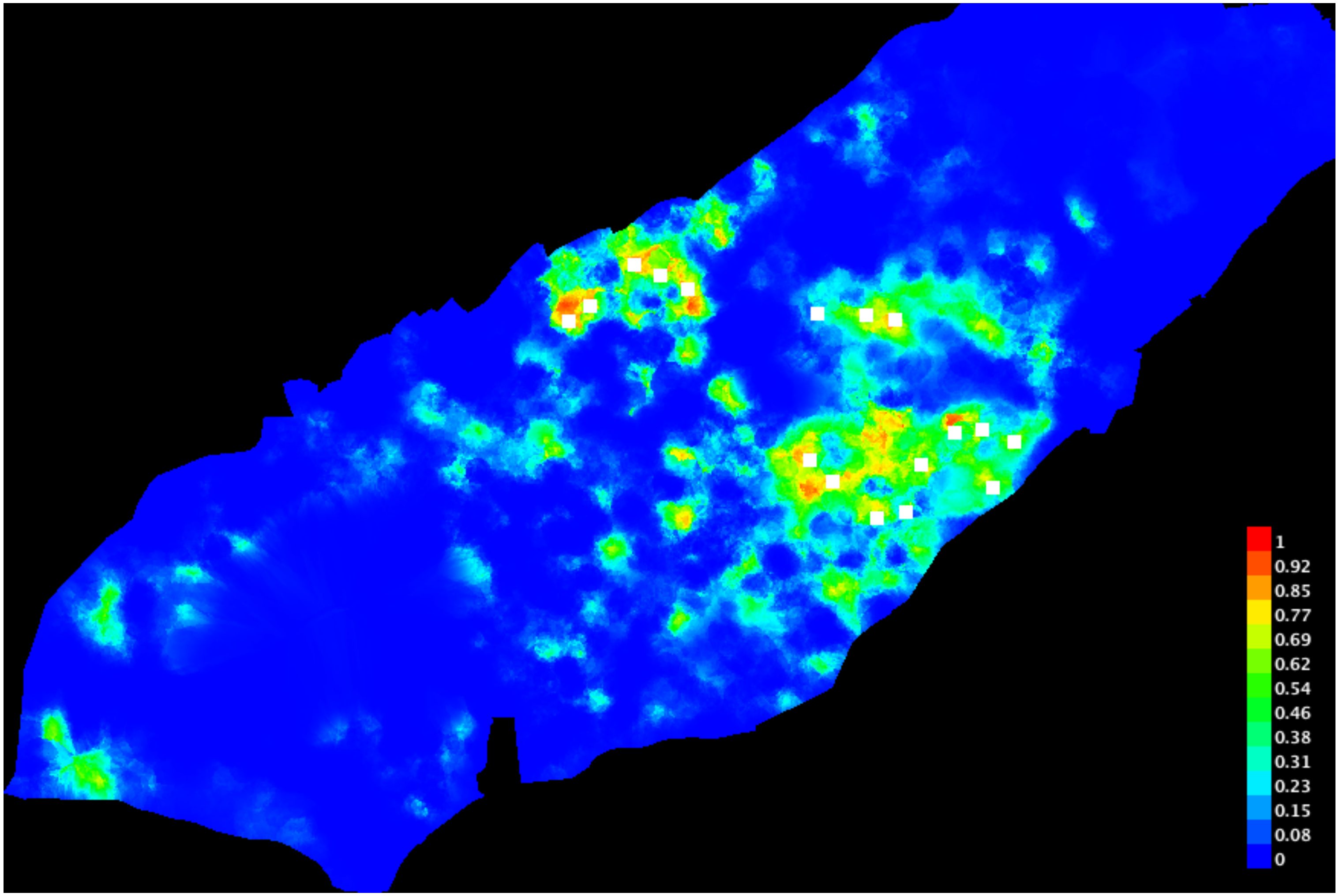

Figure 3.15 Maxent model output for red cockaded woodpecker (*Piciodes borealis*) on Fort Gordon, Georgia in 2011. Warmer colors show areas with better-predicted conditions. White dots show the presence locations used for training.

CHAPTER 4

IMPLICATIONS FOR BOBWHITE MONITORING IN CONJUNCTION WITH RED-COCKADED WOODPECKER RESTORATION IN DECISION MAKING

Monitoring of Northern bobwhite (*Colinus virginianus*) hereafter bobwhite, populations is nothing new to military installation natural resources practice (Department of Defense 2008). Choosing correct procedures along with funding and availability of personnel seem to be the current dilemma. With current primary objectives being placed on restoring pre-European ecosystems along with increasing a sustainable biodiversity among ecosystems, having a species-monitoring plan that efficiently maximizes information gained is essential. The U.S. Army recognizes this need and addresses the importance of using data to assess habitat-based goals specifically for threatened and endangered species (Shapiro and Hohmann 2005).

Combining monitoring data of two separate species that occupy separate ends of the ecological spectrum should limit the number of species potentially neglected in the wake of “umbrella” species management. Red-cockaded woodpeckers (*Piciodes borealis*) are an arboreal based species where bobwhites are terrestrial. Both species occurred in historic longleaf wiregrass ecosystems along with several other species. Monitoring bobwhites during the breeding season using a sampling design modeled after Pollock’s robust design (Pollock 1982), can give managers access to information such as immigration rate, emigration rate, and occupancy across the landscape.

Monitoring bobwhites through male whistle count procedures is relatively simple to accomplish and does not require very much manpower depending on land scale and desired accuracy. Monitoring bobwhites in addition to annual RCW population monitoring requirements would enable managers to be equipped with a foundation of data that would provide insight to biodiversity during decision-making processes through the course of ecosystem and endangered species restoration. Furthermore maintaining up to date fire records and stand data in conjunction with monitoring would provide a foundation for building site-specific habitat suitability and occupancy models.

Starfield (1997) and Conroy and Carroll (2009) suggest there is a real need for wildlife professionals to develop the skills for constructing and using models such habitat suitability and occupancy models as these described in this thesis. Shapiro and Hohmann (2005) repeatedly stress the use of spatially explicit models in developing habitat preference and occupancy of species that occur on military installations. Using these and other models built with Northern bobwhite and other monitoring data with adaptive management practices (Wills 1995) in conjunction with RCW restoration should greatly improve success and efficiency of restoration efforts on military installations through time.

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