ASSESSING THE EFFECTS OF MANAGEMENT FOR NORTHERN BOBWHITE (*COLINUS VIRGINIANUS*) ON AVIAN COMMUNITY STRUCTURE AND FUNCTIONAL DIVERSITY: IMPLICATIONS FOR ECOSYSTEM SERVICES

by

DAVID ANTHONY WEBER

(Under the Direction of James A. Martin)

ABSTRACT

Much of the grassland and savanna ecosystems across the United States have been fragmented or lost due to development, intensive agricultural expansion, and fire suppression. With the degradation of these ecosystems has come the loss of native biodiversity and ecosystem function. Restoring function to open-canopy systems is an important conservation focus and may aid in restoring ecosystem services. Land managers seeking to promote populations of northern bobwhite (*Colinus virginianus*), a popular gamebird that has declined for decades, employ management strategies consistent with restoration of early-successional, open-canopy environments such as frequent prescribed burning and hardwood reduction. We investigated the relationships among northern bobwhites, the avian community, ecosystem function, and habitat characteristics created by intensive bobwhite management. We found that differences in habitat characteristics associated with bobwhite management are largely independent of effects on ecosystem function within the context of a landscape managed intensively for bobwhite.

INDEX WORDS: Northern bobwhite, *Colinus virginianus*, Pine savanna, Ecosystem services, Functional diversity, Bayesian

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DEDICATION

I dedicate this thesis to two important women in my life. To my mother, Christine Weber, who nurtured my love for the natural world and raised me to be brave, independent, and empathetic, just as she was. And to my grandmother, Lois Jelneck, who taught me compassion, patience, and resilience. Both of you are going through major life transitions, and I admire the grace with which you move through change. I love you both very much and hope you both experience the joy for yourselves that you bring others.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

GENERAL INTRODUCTION

Grassland ecosystems provide crucial benefits to humans such as forage production for livestock, global climate regulation, maintenance of soil fertility, erosion regulation, water quality regulation, and conservation of biodiversity (Bardgett et al. 2021). However, the widespread conversion of grasslands to other uses has made native grasslands among the most endangered ecosystems, globally (Carbutt et al. 2017), threatening the services they provide. Grasslands of the United States are no exception. Approximately half of all grasslands in the country have been converted to cultivated cropland or other uses, relative to their extent before European settlement (Samson and Knopf 1996). Conserving and restoring grasslands is a national and global conservation priority.

As a facultative grassland species that requires herbaceous vegetation with shrub components, the northern bobwhite (*Colinus virginianus*; hereafter, “bobwhite”) has suffered significantly from the loss of grassland habitat. Despite conservation efforts, bobwhite have declined consistently between 1966 and 2019 at a rate of about 3.1% per year throughout their range (Pardieck et al. 2020). Bobwhite have likely declined in parts of their range since at least the early 1900s (Stoddard 1931). Habitat management to maintain open forest canopies is now necessary to promote the mix of herbaceous and woody ground cover required by bobwhite (Little et al. 2009). Management strategies used to promote bobwhite habitat vary somewhat regionally but generally include prescribed burning, forest management, strip disking, and herbicide treatment (Welch et al. 2004, Gruchy and Harper 2014, Palmer and Sisson 2017).

Other management strategies used to maintain or increase bobwhite populations include supplemental feeding and predator removal (McGrath et al. 2017, Palmer et al. 2019, Henry et al. 2022). The bobwhite is a culturally important species with a long tradition of hunting throughout its range, and as such, much attention has been given to its management in the hopes of reversing its decline. However, bobwhite management may also play a role in restoring grassland ecosystems.

In addition to increasing or maintaining bobwhite populations, managing habitat for bobwhite may have broader effects on ecosystem services by restoring the function of native grassland and shrubland ecosystems. Ecosystem services are the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life (Daily 1997). In the Millennium Ecosystem Assessment (2005), ecosystem services are categorized into four main types: *supporting services* are services that are necessary for the production of all other ecosystem services; *regulating services* are benefits obtained from the regulation of ecosystem processes; *provisioning services* are products obtained from ecosystems; and *cultural services* are the non-material benefits obtained from ecosystems. In this study, we focus our attention primarily on how habitat characteristics associated with bobwhite management affect *supporting* ecosystem services through their influence on native bird diversity.

Biodiversity is a *supporting* ecosystem service that is vital to maintaining ecosystem functions and other services (Daily 1997, Hooper et al. 2005, Balvanera et al. 2006, Cardinale et al. 2006, 2012). There is some evidence to suggest that bobwhite management may contribute to the maintenance of grassland and shrubland biodiversity within its range, but this hypothesis has not been studied directly. Birds are commonly used as indicators of biodiversity (Alexander et al.

2017). Brennan and Kuvlesky (2005) propose that maintaining and restoring habitat to stabilize and increase populations of wild bobwhite provides habitat that supports many other species of grassland and shrubland birds. Crosby et al. (2015) support this claim with their findings that bobwhite presence is a positive predictor for the occurrence of many grassland and shrubland bird species, including species of conservation concern, such as Bell's vireo (*Vireo bellii*), dickcissel (*Spiza americana*), and grasshopper sparrow (*Ammodramus savannarum*). It is thus plausible that managing land for bobwhite could benefit other declining grassland birds that depend on open-canopy habitats and contribute to the maintenance of overall biodiversity in grassland and shrubland ecosystems. By supporting populations of other grassland and shrubland birds, bobwhite management may support the overall ecosystem function of grasslands and shrublands and the services they provide.

Bobwhite management may contribute to *regulating* ecosystem services by supporting grassland ecosystem function and populations of diverse bird communities. In the southeastern United States, bobwhite management generally attempts to promote pine savanna (Brennan et al. 2014, Malone et al. 2022), a type of grassy system characterized by a dependence on frequent fire, the dominance of perennial C4 grasses, diverse herbaceous plant cover, and an open tree canopy made up primarily of pines (Bond and Parr 2010, Ratnam et al. 2011). Restoration of pine savanna by re-introduction of frequent fire has been shown to increase regulating ecosystem services such as carbon sequestration, wildfire risk reduction, and erosion reduction (Dixon et al. 2022).

In addition to supporting grassland ecosystem services, diverse bird communities provide ecosystem services of their own. Insectivorous birds control agricultural pests, granivores and frugivores disperse seeds, pollinators pollinate plants, and scavengers scavenge carcasses, regulating natural processes in a way that is beneficial to humans (Sekercioglu 2012, Gaston 2022). Managing land in a way that sustains more native birds, bird diversity, and grassland ecosystem function could thus increase the land's capacity to provide regulating services.

Native grasslands and the bird communities they support contribute to *cultural* services by providing aesthetic value and hunting opportunities. Quail hunting is a tradition that sportsmen have enjoyed for generations. Many states are proud of their quail hunting heritage, with Georgia, Missouri, and Tennessee recognizing bobwhites as their official state game bird. Associated expenditures on hunting leases, bird dogs, shotguns, hunting trucks, horses, guides, and staff at hunting camps all contribute to struggling rural economies in areas where quail still remain (Burger et al. 1999, Brennan and Kuvlesky 2005). Birds other than quail contribute to other recreational activities such as birdwatching and ecotourism, which can have positive impacts on human physical, psychological, and social wellbeing (Gaston 2022). Understanding the effects of bobwhite management on grassland and shrubland bird communities is necessary to characterize the full range of value that quail lands provide.

Bobwhite management occurs at the management unit scale. However, specific habitat characteristics are often better determinants of community diversity than broad management strategies (Müller et al. 2010, Penone et al. 2019). Advances in remote sensing and Light Detection and Ranging (lidar) technologies present novel opportunities to measure subtle differences in habitat over large areas. These methods can help improve our understanding of how bobwhite management affects bird communities by allowing us to assess how birds respond to differences in habitat characteristics associated with bobwhite management.

While there are many ways to characterize the effects of habitat management strategies on bird communities, we focus on the relationships between habitat variables associated with bobwhite management and bobwhite density to avian community composition and functional diversity on lands managed intensively for bobwhite. Functional diversity metrics describe the diversity of species traits, which influences ecosystem services like stability and productivity more directly than broader measures of diversity such as species richness (Tilman 2001, Luck et al. 2013). Functional richness, functional evenness, functional divergence, and functional dispersion are four independent metrics often used to represent functional diversity (Mason et al. 2005, Villéger et al. 2008, Laliberte and Legendre 2010, Mouchet et al. 2010). Functional richness is a measure of the volume of the functional space occupied by a community, functional evenness describes the regularity of the distribution of abundance in this space, functional divergence is the divergence in the distribution of abundance in this space, and functional dispersion is the spread of the community components in this space (Laliberte and Legendre 2010, Mouchet et al. 2010).

Private lands managed for bobwhite in the Red Hills physiographic region of South Georgia and North Florida, USA, are known to have high relative densities of threatened species such as red-cockaded woodpecker (*Dryobates borealis*; Engstrom and Palmer 2005) and gopher tortoise (*Gopherus polyphemus*; Hermann et al. 2002). However, there is variation in management intensity and habitat structure within and among these lands. For example, in upland pine forested habitats in this region alone, the basal area of timber may range from 4.62 - 19.56 m^2/ha (Little et al. 2009). Other habitat types on these lands include hardwood bottomlands, wetlands, or planted pine forests (Rush et al. 2014). The variation in habitat on these properties presents an opportunity to better understand the relationships between habitat variables and bird communities in the context of lands managed for bobwhite.

It is unclear how bobwhite management affects grassland and shrubland bird communities and the capacity of these lands to provide ecosystem services. In this study, we attempt to quantify the effects of habitat characteristics associated with bobwhite management on grassland and shrubland bird communities within private lands managed for bobwhite. With grassland ecosystems in steep decline in the United States and globally, it is crucial that we understand how management practices on these lands affect biodiversity and the land's capacity to provide ecosystem services.

There is evidence that managing land for bobwhite to promote cultural services, namely recreational hunting, could have synergy with supporting services by supporting populations of other grassland and shrubland birds and maintaining native biodiversity. As the intensity of management increases, we would expect the value of these services to increase. There may be a point at which increasing management intensity produces progressively smaller benefits to ecosystem services, following the diminishing returns principle (Hone 2007). Some aspects of bobwhite management, such as minimizing mid-story vegetation or converting non-quail habitat into habitat suitable for bobwhite, could reduce bird diversity and have trade-offs on ecosystem services. Thus, known benefits derived from bobwhite management may operate synergistically, antagonistically, or independently of ecosystem function and other ecosystem services. However, the relationship between habitat characteristics associated with bobwhite management and supporting ecosystem services has yet to be studied directly. This research will help fill this knowledge gap by analyzing the relationship between habitat variables associated with bobwhite management and grassland bird communities on lands managed for bobwhite.

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CHAPTER TWO

BIRD COMMUNITY RESPONSES TO HABITAT VARIABLES ASSOCIATED WITH INTENSIVE MANAGEMENT FOR NORTHERN BOBWHITE (*COLINUS VIRGINIANUS*)[1]

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ABSTRACT

Managing land to promote populations of wild northern bobwhite (*Colinus virginianus*) contributes to cultural ecosystem services by creating recreational hunting opportunities. However, it is unknown whether the benefits to cultural services of bobwhite management have synergy, trade-offs, or are independent of supporting ecosystem services related to ecosystem function and diversity. We investigated whether habitat characteristics associated with intensive bobwhite management promote biodiversity and ecosystem function and how bobwhite presence and abundance relate to bird community composition and functional diversity on quail properties in the Red Hills region of South Georgia and North Florida, USA. We conducted 232 point-count bird surveys on 165 points across 18 private properties intensively managed for bobwhite and collected data on habitat characteristics at each site. We modelled the effects of each habitat characteristic on bird density, accounting for imperfect bird availability and detection, and analyzed the relationships between bobwhite abundance and bird community structure. We found that habitat characteristics associated with bobwhite management had few noticeable impacts on avian abundance or occupancy at the diet guild level, although many effects at the individual species level were significant. We found no relationship between bobwhite abundance and abundance of other bird species or any functional diversity indices, suggesting that the intensity of bobwhite management has little impact on supporting ecosystem services within the context of lands managed intensively for bobwhite.

INTRODUCTION

Functioning ecosystems provide a myriad of services to society such as regulation of climate, purification of air and water, mitigation of floods and droughts, maintenance of biodiversity, provision of wild foods and medicines, control of agricultural pests, pollination of crops, contribution to recreational activities like hunting and bird watching, and countless others (Daily 1997, Bardgett et al. 2021, Gaston 2022). Ecosystem services may operate synergistically, in which case benefits to one ecosystem service result in benefits to others; for example, riparian restoration for fish habitat may enhance scenic vistas for recreational boaters and increase carbon storage (Tomscha and Gergel 2016). Alternatively, trade-offs may occur when a service results in the loss of other services, such as the conversion of mangroves to shrimp farms resulting in the loss of flood control services (Howe et al. 2014). Lastly, ecosystem services may operate independently, in which case benefits to one service confer no benefits or harm to other services (Bennett et al. 2009). The relationship between cultural services, or the non-material benefits of ecosystems, and other ecosystem services is understudied (Howe et al. 2014). Specifically, the relationships among recreational services, such as hunting for sport, supporting services, and ecosystem function need further study given the prevalence of hunting and the intensity of management required for many game animals worldwide.

The pine savanna (*Pinus* spp.) ecosystem and hunting of northern bobwhite (*Colinus virginianus*; hereafter, bobwhite) provide a study system well-suited for understanding the interplay of game management, supporting ecosystem services, and ecosystem function. Changes in land use, including plant succession, urbanization, and the expansion of agricultural and silvicultural practices that maximize commodity yield, have led to the loss and fragmentation of open-canopy wildlife habitat throughout the United States (Brennan 1991, Hernández et al.

2013). The longleaf pine (*Pinus palustris*) savanna of the southeastern United States' Coastal Plain presents a severe example of this loss. At the time of European settlement, longleaf pine savanna dominated the Coastal Plain, but only 3% of that original extent now remains, much in isolated fragments (Van Lear et al. 2005). The loss of longleaf pine savanna reflects dramatic declines in grasslands, including savannas with scattered trees and open-canopy grassy woodlands, more broadly (Samson and Knopf 1996, Nosetto et al. 2005, Carbutt et al. 2017). With this critical loss and fragmentation of native pine savanna has come the loss of associated native wildlife diversity and ecosystem function (Guyer and Bailey 1993, Engstrom et al. 2001, Noss et al. 2015). Many species associated with the pine savanna ecosystem, including bobwhite, are now declining or rare (Van Lear et al. 2005). Conserving declining species and restoring ecosystem function to landscapes historically dominated by pine savanna on private and public lands are important conservation focuses in the region (McIntyre et al. 2018, NRCS 2020) and may contribute to the restoration of ecosystem services associated with these landscapes such as carbon storage, bee pollinator abundance, erosion control, water yield, and others (Dixon et al. 2022).

Managers of properties intensively managed for wild northern bobwhite (i.e., quail properties) in the Red Hills region of South Georgia and North Florida widely employ frequent burning, tree thinning, other mechanical vegetation treatment, herbicide, supplemental feeding, and predator control tactics to promote populations of wild bobwhite (Palmer and Sisson 2017, Jackson et al. 2018). These management strategies create conditions characterized by low basal area, diverse grass and forb understory cover, and low proportion of hardwoods relative to pine cover (i.e., pine savanna). Although these actions are taken primarily to increase bobwhite abundance, many other grassland and shrubland bird species depend on similar habitat characteristics (Engstrom 1993). Bachman's sparrow (*Peucacea aaestivalis*), for example, is a species of high conservation concern that depends on herbaceous understories characteristic of frequently burned longleaf pine stands (Tucker et al. 2004). However, there may be a tipping point where bobwhite management becomes a disservice to other ecosystem services and function.

It is uncertain whether the known ecosystem service benefits of bobwhite management have synergistic effects on other ecosystem services, come with trade-offs, or have no strong costs or benefits to other services. Bobwhite management could benefit ecosystem services by promoting the biodiversity of pine savanna systems, harm ecosystem services by excluding service-providing species intolerant of frequent disturbance, or the benefits it produces may be independent of other ecosystem services. Fully understanding the value of bobwhite management to ecosystems and society requires an understanding of how it influences underlying ecosystem function.

Previous research has shown that bobwhite presence is associated with higher species richness and occupancy probability of grassland and shrubland birds, suggesting bobwhite may serve as an "umbrella species" whose conservation may confer protection to many other species (Crosby et al. 2015). However, a large body of literature demonstrates that functional diversity, rather than species diversity, is a key driver of ecosystem function (Bellwood et al. 2004, Waldbusser et al. 2004, Hooper et al. 2005) and ecosystem services (Díaz et al. 2007). Functional diversity describes the value and range of organismal traits that influence a community's performance and thus ecosystem functioning (Díaz and Cabido 2001). To compute functional diversity indices, multidimensional functional spaces are generated in which species' positions are defined based on their position along functional trait-based axes. Four functional diversity indices are commonly used to characterize functional diversity of assemblages: functional dispersion, which is the abundance-weighted deviation of species trait values from the center of the functional space filled by the assemblage; functional richness, which is the proportion of functional space filled by species of the studied assemblage; functional divergence, which is the proportion of the abundance supported by the species with the most extreme functional traits; and functional evenness, which is the regularity of abundance distributed in the functional space (Villéger et al. 2008, Laliberte and Legendre 2010, Magneville et al. 2022). Taken together, these four independent components of functional diversity provide important detail in understanding the relationship between biodiversity and ecosystem function.

Functional diversity may be associated with disturbance, as very high levels of disturbance may exclude certain functional traits, and very little disturbance may allow for only highly competitive functional traits. Intermediate levels of disturbance have been shown to maximize ecosystem productivity (Bernhardt-Römermann et al. 2011), which may reflect ecosystem function and functional diversity. Unraveling the effects of bobwhite management, which is intimately tied to disturbance, on functional diversity could help conservation decisionmakers evaluate the efficacy of bobwhite conservation as a means of restoring ecosystem function and ecosystem services to pine savanna systems.

In this study, we use bird survey data from intensively managed pine savannas and hierarchical models to investigate the relationships between bobwhite abundance (a proxy for cultural services through its relationship to recreational value) and bird diversity (a proxy for supporting services). We also used 5 indicators of bobwhite management intensity—fire frequency (greater is more intense), ground cover (greater is more intense), vegetation height (lower is more intense), tree basal area (lower is more intense), and deciduous tree cover (less is more intense)—to explore the relationship between bobwhite management and the bird community. Lastly, we explored the relationship between bobwhite abundance and ecosystem function as measured using functional diversity indices. Understanding how avian communities respond to habitat characteristics associated with intensive bobwhite management will help illuminate whether bobwhite management is an effective means of restoring native biodiversity and ecosystem function on pine savanna ecosystems.

METHODS

Study Area

We collected data on 18 privately-owned properties in the Red Hills physiographic region of South Georgia and North Florida (Figure 1). We selected properties that were intensively managed for wild bobwhite with landowners who were willing to allow surveys on their properties. The Red Hills region was historically dominated by longleaf pine (*Pinus palustris*) and shortleaf pine (*P. echinate*) savanna. Mature upland pine forests dominated by loblolly (*P. taeda*), slash (*P. elliotti*), and shortleaf pine with associated old-field ground cover vegetation now comprise most of our study area (Carr et al. 2010). However, smaller portions of the study area also included shrub-dominated habitat, mixed forest, bottomland hardwood forest, ponds, wetlands, planted pine stands, and agricultural fields. Management activities on the properties surveyed include prescribed burning, roller-chopping (mechanical shrub reduction), mowing, herbicide application for invasive species control, year-round supplemental feeding for bobwhite, and meso-mammalian predator removal. Properties ranged from 318 to 5,824 ha.

Survey Point Selection

We randomly selected enough points at each property to cover >5% of the property area. We selected additional random points as backup points in case any of the originally generated random points turned out to be inaccessible. As a constraint, we made the minimum distance between points 500m. We translated each random point to the nearest point on the nearest agricultural road for ease of access, while ensuring each point count radius did not significantly extend beyond the property boundary. Agricultural roads were primitive unpaved roads used for accessing remote areas of the properties.

Bird Surveys

We conducted 232 bird point count surveys at 165 unique points from May through June of 2022. We used survey data from 2 observers. One of these observers surveyed all 165 points and the other surveyed 54 of these points. Surveys began no earlier than 30 minutes before sunrise and no later than 3 hours after sunrise. We waited 2 minutes after exiting the vehicle before beginning each survey to avoid any influence of vehicle noises on bird behavior. During this time, we recorded the date, observer name, start time, temperature (ºF), wind (Beaufort scale), and noise code on datasheets. After the 2-minute buffer period, we began the survey. Each survey lasted 10 minutes. During this time, we recorded the American Ornithological Union (AOU) bird code of any bird seen or heard on a datasheet map at the estimated location of first detection, within an estimated range of 250m. We also recorded the time interval of the first detection for each individual. If the bird was not first detected by song, we recorded the method by which it was first detected (e.g., call or visual) and the sex, if known. We noted whether birds flew over the survey area that did not appear to originate from within the survey area. After the surveys were complete, we manually transcribed the data from the physical datasheets onto digital maps in the program ArcMap. We then calculated the distance of each bird detection to the surveyor for each survey.

Lidar Data Collection

We collected lidar (Light Detection and Ranging) data at each bird survey point (Figure 2). During the 2-minute buffer period between exiting the vehicle and beginning the bird survey, we picked a random direction between 1º and 360º N and traveled ~15 m (25 paces) in that direction. We set up the lidar camera (Leica BLK360 Imaging Laser Scanner) at that location, began a scan, and returned to the center of the survey circle to conduct the bird survey. We conducted a lidar scan each time we visited a survey point, so points with repeat visits also had multiple lidar scans at a unique random location each time. Raw output from lidar scans was converted into metrics following methods from Loudermilk et al. (2023). Metrics from different lidar scans at the same point were averaged for our analysis.

We used three metrics from the lidar data to represent habitat characteristics associated with bobwhite management in our model: percent ground, mean height, and mean basal area. Percent ground described the percentage of points classified as ground and reflected the proportion of the scan area not covered by upright vegetation. Mean height described the mean height (meters) of points in the entire scan and reflected the mean height of vegetation, including trees and understory, in the scan area. Mean basal area was a measurement of the cross-sectional area of trees at breast height (m^2/ha) and reflected the amount of tree coverage in the scan area.

Fire Data

We compiled data on fire frequency across our study area from the Tall Timbers Geospatial Center Southeast Fire History Dataset (Tall Timbers 2021). The dataset contains rasters of different fire history metrics, derived from the USGS Burned Area (v2) Products (Hawbaker et al. 2020), that indicate burn presence (with 90-100% probability) for groups of pixels greater than approximately 2.24 acres from the years 1994-2021. For our analysis, we used the “Frequency” metric, which indicates the number of times a pixel was burned across the time series. Using the Zonal Statistics tool in the program ArcGIS Pro, we calculated the maximum raster value for each 250m-radius survey area, representing the maximum number of burns within the survey area. We incorporated these values as covariates in our models to represent fire frequency at each survey point.

Landcover Data

We gathered landcover data from the LANDFIRE database (U.S. Department of Interior et al. 2022) to generate covariates for our bird abundance model. We created a vegetation class called “Deciduous,” which included the classes “Eastern Warm Temperate Urban Deciduous Forest,” “Eastern Warm Temperate Developed Ruderal Deciduous Forest,” “Eastern Warm Temperate Orchard,” “Southeastern Exotic Ruderal Forest,” and “Southeastern North American Temperate Forest Plantation.” We then calculated the percent cover of this combined deciduous class for each 250m-radius survey area.

Guild and Trait Characterization

We grouped bird species into guilds according to diet to better model effects that may be similar within guilds but different across guilds (Appendix A). Previous studies have shown differences in responses to habitat management actions in pine savanna systems from birds with different diets and feeding strategies (Davis et al. 2000). We used diet and feeding strategy classifications from González-Salazar et al. (2014).

To characterize functional diversity, we compiled traits for each species known to be functionally important (Flynn et al. 2009, Mendez et al. 2012, Luck et al. 2013, Lee and Martin 2017). We used 5 trait categories: diet, feeding strategy, body mass, migratory status, and habitat preference (Table 1). Data on body mass, migratory status, and habitat preference came from

The Cornell Lab of Ornithology All About Birds webpage (Cornell Lab of Ornithology 2022). When body mass was given as a range, the mean of the range was used. Body mass values not found on All About Birds were gathered from Sibly et al. (2012).

Abundance Model

We created a Bayesian hierarchical model to analyze the effects of habitat characteristics and fire history on the densities of bird species and bird diversity at each property using point count data with imperfect detection and availability. Detections labeled "call" were only included for bird species with no recognized song, and detections labeled "visual" were not included. Density estimates therefore represent densities of singing males for bird species with recognized songs and densities of all birds for species with no recognized songs. For our abundance model, we only included species with at least 50 detections from the 2 observers to increase model convergence likelihood.

We modeled whether birds present in the survey area were available to be sampled. We split the 10-minute sampling occasions into 5 equally spaced 2-minute time bins. We allowed the availability probability (i.e., vocalization likelihood) p'_a of an individual of guild g and species s at point i and visit v to vary with date, date squared, time after sunrise, temperature, wind:

$$\text{logit}\left(\mathrm{p}'_{\mathrm{a}_{\mathrm{gsiv}}}\right) = \phi_{0_{gs}} + \phi_{1_g} * \mathrm{DATE}_{\mathrm{iv}} + \phi_{2_g} * \mathrm{DATE}_{\mathrm{iv}}^2 + \phi_{3_\mathrm{g}} * \mathrm{TIME}_{\mathrm{iv}} + \phi_{4_\mathrm{g}} * \mathrm{TEMP}_{\mathrm{iv}} + \phi_{5_\mathrm{g}} * \mathrm{WIND}_{\mathrm{iv}}$$

The probability π_{gsivt} that a bird was available in time bin t was conditional on the bird not being detected before and was given as:

$$\pi_{gsivt} = p'_{a_{gsiv}} * \left(1 - p'_{a_{gsiv}}\right)^{t-1}$$

Finally, the probability p_a that a bird was ever available was given as:

$$p_{a_{gsiv}} = \sum_{t=1}^{ntimebins} \pi_{gsivt}$$

To model detection, we first modelled σ_{gsivo} as a linear function of an intercept and noise covariate, with a unique intercept for each observer, *o*:

$$\log(\sigma_{gsivo}) = \beta_{0_{gos}} + \beta_{1_g} * \mathrm{NOISE}_{iv}$$

Detection $pbin_{d_{gsivbo}}$ for each distance bin *b* was given as:

$$pbin_{d_{gsivbo}} = \left(\sigma^2_{gsivo} * \left(1 - e^{-db^2_{b+1}/\left(2*\sigma^2_{gsivo}\right)}\right) - \sigma^2_{gsivo} * \left(1 - e^{-db^2_{b}/\left(2*\sigma^2_{gsivo}\right)}\right) * 2\pi/(area * pix_b)\right) * \mathrm{pix}_b$$

Where db_b was the length of distance bin *b* and pix_b was the proportion of the total point count area of distance bin *b*.

The overall detection $p_{d_{gsivo}}$ for each bird species on each survey was given as:

$$p_{d_{gsivo}} = \sum_{b=1}^{ndistancebins} pbin_{d_{gsivbo}}$$

We modeled abundance of birds at a point N_{gsi} as a Poisson distribution from some expected abundance:

$$N_{gsi} \sim \mathrm{Poisson}(\lambda_{gsi})$$

$$\log(\lambda_{gsi}) = \alpha_{0_{gs}} + \alpha_{1_{gs}} * \mathrm{FIREFREQ}_i + \alpha_{2_{gs}} * \mathrm{FIREFREQ}_i^2 + \alpha_{3_{gs}} * \mathrm{GROUND}_i + \alpha_{4_{gs}} * \mathrm{GROUND}_i^2 + \alpha_{5_{gs}} * \mathrm{HEIGHT}_i + \alpha_{6_{gs}} * \mathrm{HEIGHT}_i^2 + \alpha_{7_{gs}} * \mathrm{TBA}_i + \alpha_{8_{gs}} * \mathrm{TBA}_i^2 + \alpha_{9_{gs}} * \mathrm{DECID}_i + \alpha_{9_{gs}} * \mathrm{DECID}_i^2 + \epsilon_{gsi}$$

The value ϵ_i represented a random site effect:

$$\epsilon_{gsi} \sim Normal(0, \sigma_{gs})$$

$$\sigma_{gs} \sim \text{Uniform}(0{,}5)$$

In this equation, FIREFREQ represents maximum fire frequency across the survey area from 1994-2021, GROUND represents the % of lidar points classified as “ground,” HEIGHT represents mean vegetation height determined from lidar data, TBA represents total basal area determined from lidar data, and DECID represents the percent cover of deciduous forest. All covariates were scaled by dividing their centered values by their standard deviations.

We analyzed data using Markov chain Monte Carlo simulations in a Bayesian framework. We performed analyses in R and JAGS using the R package jagsUI (Kellner and Meredith 2021, R Core Team 2022). We sampled from posterior distributions using 3 Markov chains each a maximum of 200,000 iterations in length, and discarded all iterations except the last 1,000 as burn-in.

We used a version of this abundance model to analyze relationships between bobwhite abundance and abundance of other bird species. Habitat variable effects were not needed to characterize these relationships, so this version of the model estimated abundance of each bird species at each site simply as a function of mean abundance and a random point effect. We fit the following linear model to each posterior sample:

$$\text{species}_i abundance = \beta_0 + \beta_1 * N\text{OBO. abundance} + \beta_2 * N\text{OBO. abundanc}e^2$$

We then calculated the median and 95% credible interval values for β_1 and β_2.

For all relevant parameters estimated in the abundance and other models, we summarized the median values, 95% credible intervals, and f values. The 95% credible intervals were the range of posterior samples within the 0.025 and 0.975 quantiles of all samples that remained after burn-in for each parameter. The f value represented the proportion of samples that shared the same sign as the median estimate. We made notes of parameter effects with f values greater than 0.9. We characterized responses to bobwhite management indicators as synergistic if bird communities responded positively to increasing fire frequency and ground cover, or as having trade-offs if they responded positively to increasing vegetation height, basal area, or deciduous cover.

For the abundance model and all other models, we monitored R-hat values to assess model convergence. The R-hat convergence diagnostic compares the between- and within-chain estimates for model parameters and indicates convergence when values are close to 1. We noted when R-hat values were above 1.1 as a lack of convergence.

Occupancy Model

In addition to modeling the effects of habitat variables associated with bobwhite management on bird density, we modeled the effects of these variables on site occupancy probability. For our occupancy model, we included song and call detections, but not detections labeled "visual," because we believe visual and auditory detections carry different detection probabilities and thus would need to be modeled differently. Unlike the abundance model, we did not subset bird species for the occupancy model based on the number of detections. We created a Bayesian hierarchical model using the program jagsUI. We included only observations from the first visit to each point in the occupancy model. Occupancy by bird species s in guild g of site i was modeled as a Bernoulli distribution from some occupancy probability ψ_{gsi}:

$$z_{gsi} \sim \mathrm{Bernoulli}(\psi_{gsi})$$

The logit of ψ_{gsi} was modeled as a linear function of the habitat variables:

$$\begin{aligned}\mathrm{logit}\left(\psi_{gsi}\right) = {} & \alpha_{0_{gs}} + \alpha_{1_{gs}} * \mathrm{FIREFREQ}_i + \alpha_{2_{gs}} * \mathrm{FIREFREQ}_i^2 + \alpha_{3_{gs}} * \mathrm{GROUND}_i + \alpha_{4_{gs}} \\ & * \mathrm{GROUND}_i^2 + \alpha_{5_{gs}} * \mathrm{HEIGHT}_i + \alpha_{6_{gs}} * \mathrm{HEIGHT}_i^2 + \alpha_{7_{gs}} * \mathrm{TBA}_i + \alpha_{8_{gs}} * \mathrm{TBA}_i^2 \\ & + \alpha_{9_{gs}} * \mathrm{DECID}_i \ + \alpha_{9_{gs}} * \mathrm{DECID}_i^2 \ + \epsilon_{gsi}\end{aligned}$$

The value ϵ_{gsi} represents a random site effect:

$$\epsilon_{gsi} \sim \mathrm{Normal}\left(0, \sigma_{gs}\right)$$

$$\sigma_{gs} \sim Exp(1)$$

Observation *y* by observer *o* in each time bin *t* was modeled as a Bernoulli distribution of detection probability *p*, conditional on site occupancy:

$$y_{gsito} \sim \mathrm{Bernoulli}\left(z_{gsi} * p_{gsio}\right)$$

Detection probability was modeled as a function of date, date squared, time after sunrise, temperature, wind, and a random point effect:

$$\begin{aligned}\mathrm{logit}\left(\mathrm{p}_{gsio}\right) = {} & \phi_{0_{gos}} + \phi_{1_g} * \mathrm{DATE}_i + \phi_{2_g} * \mathrm{DATE}_\mathrm{i}^2 + \phi_{3_g} * \mathrm{TIME}_\mathrm{i} + \phi_{4_g} * \mathrm{TEMP}_\mathrm{i} + \phi_{5_g} \\ & * \mathrm{WIND}_i + \epsilon_{gi}\end{aligned}$$

$$\epsilon_{gi} \sim \mathrm{Normal}\left(0, \sigma_g\right)$$

$$\sigma_g \sim Exp(1)$$

Functional Diversity

We used the R package “mFD” to compute functional evenness, functional dispersion, functional divergence, and functional richness (Magneville et al. 2022). First, we used the mFD::funct.dist() function to estimate functional traits-based Gower distances between species. To generate a multidimensional space in which to compute functional diversity indices, we performed a Principal Coordinate Analysis using these trait-based distances. We computed the mean absolute deviation between species pairwise distances in each functional space and trait-based distances and selected the functional space that had the lowest mean absolute deviation value. To compute functional diversity indices for each point, we needed species abundances, so we ran a version of the abundance model that estimated the abundance of all bird species detected aurally at each point. We ran 3 chains of this model for 200,000 iterations each, discarding the first 199,999 iterations as burn-in, yielding 3,000 posterior samples. We then created a matrix summarizing species assemblages at each point for each posterior sample iteration. We applied the mFD::alpha.fd.multidim() function to each of these matrices to generate 3,000 estimates of functional richness, functional divergence, functional dispersion, and functional evenness at each point (1 estimate of each index for each posterior sample).

We then characterized the relationship between bobwhite abundance and each functional diversity index. We fit the following linear model to each posterior sample:

$$f.div.index_i = \beta_0 + \beta_1 * NOBO.abundance + \beta_2 * NOBO.abundance^2$$

We calculated the median and 95% credible intervals for β_1 and β_2.

RESULTS

We detected a total of 66 bird species across all sites during our point count surveys. Of these 66 species detected, 55 were detected aurally and were included in our analysis (Appendix A). A total of 5,623 detections were included in our analysis. All models ran for their maximum number of allowed iterations. R-hat values indicated convergence failure for some variables (Appendix B). Several covariates had significant impacts on bird detection (Appendix C).

Fire frequency values ranged from 0-14 burns, percent ground cover ranged from 3.33% to 96.0%, average vegetation height ranged from 0.0581 m to 11.0 m, basal area ranged from 0.00 m^2/ha to 27.9 m^2/ha, and percent deciduous cover ranged from 0.00% to 91.3%.

Bird density and occupancy

Granivores had the highest median estimate for mean density at 0.20 birds/ha (95% CI: [0.09, 2.12]). Insectivores had the second highest estimate at 0.13 birds/ha (95% CI: [0.09, 1.31]). Omnivores had the lowest estimated density at 0.04 birds/ha (95% CI: [0.00, 2.77]). The bird with the highest mean density was eastern towhee (*Pipilo erythrophthalmus*) at 0.55 birds/ha (95% CI: [0.42, 0.70]), followed by indigo bunting (*Passerina cyanea*) at 0.55 birds/ha (95% CI: [0.42, 0.69]), northern cardinal (*Cardinalis cardinalis*) at 0.46 birds/ha (95% CI: [0.37, 0.58]), Carolina wren (*Thryothorus ludovicianus*) at 0.42 birds/ha (95% CI: [0.32, 0.57]), and northern bobwhite at 0.38 birds/ha (95% CI: [0.32, 0.46]; Figure 3).

Red-bellied woodpecker (*Melanerpes carolinus*) occupied the greatest proportion of sites (Median = 95%, 95% CI: [85%, 99%]), followed by northern bobwhite (Median = 93%, 95% CI: [90%, 96%]), eastern towhee (Median = 92%, 95% CI: [86%, 98%]), Carolina wren (Median = 87%, 95% CI: [80%, 93%]), and northern cardinal (Median = 87%, 95% CI: [82%, 92%]; Figure 4).

Relationships between bobwhite abundance and avian community

Estimated northern bobwhite abundance showed weak correlations with estimated abundances of other bird species (Table 2; Figure 5). The 95% credible intervals for the coefficients of effects of bobwhite abundance on abundances of other bird species all overlapped with 0. However, over 90% of the posterior distributions of these effects shared the same sign as the median estimates for those variables for 4 bird species, suggesting some confidence in the direction of those effects. Those effects were a negative correlation between bobwhite abundance and American crow (*Corvus brachyrhynchos*), Carolina chickadee (*Poecile carolinensis*), and northern parula (*Setophaga americana*) and a concave up relationship between bobwhite abundance and abundance of white-eyed vireo (*Vireo griseus*). We found no significant relationship between bobwhite abundance and our 4 indices of functional diversity: functional dispersion, functional divergence, functional evenness, and functional richness (Table 3). Out of these 4 functional diversity indices, functional richness had the lowest values and functional divergence had the highest values (Figure 6).

Relationships between bobwhite management indicators and avian community

The 95% credible intervals for the mean effects of every habitat covariate on log abundance for each guild overlapped with 0, suggesting uncertainty over the true direction of each effect. However, over 90% of the posterior distributions for 3 variables shared the same sign as the median estimate for those variables, suggesting some confidence in the direction of those effects (Table 4). Those variable effect estimates were: non-linear concave down effects of fire frequency on granivores, nonlinear concave down effects of mean basal area on granivores, and nonlinear concave down effects of mean basal area on insectivores (Figure 3). These guild responses were similar to responses from northern bobwhite to the respective habitat variables, indicating some synergisms between fire and basal area as bobwhite management indicators and granivores and insectivores, although this synergy decreases as the management intensity increases. No other synergies or trade-offs were detected between bobwhite management indicators and avian guild abundance responses.

There was substantial variation in the effects of each covariate on the log abundance of species within each guild (Appendix D). At the species level, several effects of habitat covariates on density were significant. In the granivore guild, fire frequency had a positive effect on the abundance of field sparrow (*Spizella pusilla*), mourning dove (*Zenaida macroura*), and bobwhite, and a negative effect on abundance of indigo bunting (*Passerina cyanea*) and northern cardinal (*Cardinalis cardinalis*). In the insectivore guild, fire frequency had a positive effect on the abundance of common yellowthroat (*Geothlypis trichas*) and a negative effect on the abundance of white-eyed vireo. Basal area had a positive effect on the abundance of eastern wood-pewee (*Contopus virens*) and white-eyed vireo and a negative effect on the abundance of northern mockingbird (*Mimus polyglottos*). In the omnivore guild, ground cover and vegetation height both had nonlinear concave up effects on the abundance of blue jay (*Cyanocitta cristata*).

The nonlinear concave down effect of vegetation height on carnivore occupancy probability had the greatest magnitude of any effect on guild occupancy (Table 7). The only bobwhite management indicator effect on guild occupancy for which the 95% credible interval did not overlap zero was a positive effect of vegetation height on insectivore occupancy probability. However, several additional parameters had f values over 0.90, indicating confidence in the direction of the effect. These effects were: a nonlinear concave down effect of mean basal area on carnivore occupancy probability, a nonlinear concave up effect of ground cover on granivore occupancy, a nonlinear concave up effect of vegetation height on granivore occupancy, a nonlinear concave down effect of mean basal area on granivore occupancy, a nonlinear concave down effect of vegetation height on insectivore occupancy, and a nonlinear concave up effect of mean basal area on insectivore occupancy (Figure 8). We can characterize the effects of bobwhite management on basal area and vegetation height as mildly synergistic with carnivore occupancy, although this relationship diminishes at high levels of management intensity. We characterize the relationships between granivore occupancy and bobwhite management impacts on ground cover and basal area as synergistic, although this effect diminishes with increasing management intensity on basal area. There appear to be trade-offs between the impact of bobwhite management on vegetation height and granivore occupancy. For insectivore occupancy, we detected trade-offs with bobwhite management effects on vegetation height at the extremes of management intensity, and with bobwhite management effects on basal areas at intermediate levels of management intensity. We detected no synergy or antagonism between bobwhite management intensity and omnivore occupancy.

Several effects of habitat covariates on species occupancy were significant (Appendix E). Among granivores, fire had a positive effect on mourning dove occupancy, ground cover had a negative effect on indigo bunting occupancy, ground cover had nonlinear concave up effects on brown-headed cowbird (*Molothrus ater*), eastern towhee, and field sparrow occupancy, vegetation height had nonlinear concave up effects on indigo bunting, northern bobwhite, and northern cardinal occupancy, and mean basal area had a nonlinear concave down effect on common ground dove (*Columbina passerina*) occupancy. Among insectivores, vegetation height had a positive effect on Carolina chickadee, eastern wood-pewee, great-crested flycatcher (*Myiarchus crinitus*), red-headed woodpecker (*Melanerpes erythrocephalus*), summer tanager (*Piranga rubra*), and white-breasted nuthatch (*Sitta carolinensis*) occupancy, vegetation height had a nonlinear concave down effect on common yellowthroat occupancy, and mean basal area had a negative effect on eastern kingbird, northern mockingbird, and red-winged blackbird occupancy. Among carnivores, vegetation height had nonlinear concave down effects on barred owl (*Strix varia*) and red-shouldered hawk (*Buteo lineatus*) occupancy.

DISCUSSION

Managers of quail properties in the Red Hills promote bobwhite populations by creating conditions characterized by low basal area, diverse grass and forb understory cover with patches of bare ground, and a low proportion of hardwoods relative to pine cover. The only relationships we detected between bobwhite abundance and abundance of other species were subtle trade-offs between bobwhite abundance and abundances of American crow, Carolina chickadee, and northern parula, and trade-offs that leveled off for abundance of white-eyed vireo as bobwhite abundance increased. We found no relationships between bobwhite abundance and functional diversity indices across sites managed for bobwhite. Additionally, bobwhite management intensity on sites managed for bobwhite generally had little noticeable effect on the avian community as a whole, although we did detect some synergistic and antagonistic relationships between bobwhite management indicators and bird abundance and occupancy at the guild level. We detected more significant bird responses to bobwhite management indicators at the species level. Generally, granivorous birds showed the most synergistic response to bobwhite management intensity, while insectivorous and carnivorous birds showed moderate or mixed responses, and omnivorous birds showed little to no response.

The generally synergistic effects of bobwhite management on granivorous birds could be due in part to the application of frequent fire, which promotes plants with high seed yield and conditions that facilitate foraging of grain on the ground. Granivore density showed a nonlinear concave down response to fire frequency, suggesting that granivore density increases with fire frequency, but this positive effect decreases as fire frequency increases. Biennial and annual fire intervals are common on pine savanna sites in the Red Hills region (Rother et al. 2020). In pine ecosystems, frequent fire promotes landscapes dominated by grasses and forbs (Streng et al. 1996, Glitzenstein et al. 2012), providing important food resources in the form of seeds and brood and nesting cover for the many ground-nesting species of granivorous birds. Many other studies have shown positive responses of grassland and shrubland birds to frequent fire (Tucker et al. 2004, Weber et al. 2022). All the granivorous birds in our study had a feeding strategy of gleaning food from the ground and undergrowth. Frequent fire removes overly dense, woody undergrowth and may facilitate foraging and mobility on the ground (Carver et al. 2000, Cram et al. 2002). Our results suggest synergy between fire as a bobwhite management strategy and the granivore guild, although this synergy weakens as maximum fire frequency increases. This relationship is consistent with research findings that fire frequency can reach thresholds after which further increases have little additional impact on species richness or understory vegetation composition (Grant et al. 2010, Glitzenstein et al. 2012).

Our findings that granivorous birds responded positively to fire frequency while insectivorous birds did not are supported by previous studies, which have documented declines in predominantly insectivorous species and general increases in species that feed on the ground and in the lower canopy in response to frequent fire in savanna ecosystems (Davis et al. 2000, Valentine et al. 2012). Frequent fire can alter the composition of arthropod assemblages and reduce abundances of certain taxa, potentially to the detriment of some insectivorous birds (Andersen and Müller 2000, Parr et al. 2004). On the other hand, frequent fire is known to increase population densities and biomass of certain groups of insects, such as herbivorous insects on old-field type habitats (Hurst 1972) and native bee communities in longleaf pine savannas (Moylett et al. 2020). The one insectivorous species for which we did detect a positive effect of fire, common yellowthroat, has also shown the highest abundances in burned areas in other studies in longleaf pine systems (Fitzgerald and Tanner 1992, Allen et al. 2006). Meanwhile, the one negative response of an insectivorous bird, white-eyed vireo, to fire may have been due to secondary habitat effects such as decreases in basal area rather than effects on insect food resources. Importantly, we analyzed the effects of a range of fire frequencies on birds in the context of a landscape that undergoes consistent and frequent burning. We expect we would find different relationships to fire frequency if comparing lands managed for bobwhite to landscapes that are never burned, such as planted pine stands or mixed pine and hardwood stands, and this is an opportunity for future research.

Bare ground is important for some ground-foraging birds, because it allows for unimpeded movement, easy location of seeds and insect prey (Taylor et al. 1999), and decreased visual obstruction, which can reduce predation risk for some species (Whittingham and Evans 2004, Devereux et al. 2006). We found a nonlinear concave up effect of bare ground on granivore occupancy, suggesting the effect of bare ground gradually becomes synergistic with granivores as bobwhite management intensity increases. We did not detect trade-offs or synergies between increasing bare ground and occupancy or abundance of any other guild. However, other studies suggest that there are likely threshold effects where too much bare ground results in a lack of cover; for example, Lusk et al. (2006) found that sites became suitable for bobwhite when bare-ground exposure fell below 30%.

Previous studies have shown mixed effects of vegetation height on grassland and shrubland bird densities, with some species, such as bobolink and chestnut-sided warbler, demonstrating increased density with higher vegetation (Winter et al. 2005, Askins et al. 2012), and others, such as blue-winged warbler and indigo bunting, decreasing with vegetation height (Askins et al. 2007, 2012). We observed some potential trade-offs between vegetation height as a bobwhite management indicator and avian community responses. Carnivores and insectivores showed the highest occupancy probability at intermediate levels of mean vegetation height, whereas granivores showed the lowest occupancy probability at intermediate levels of mean vegetation height. Increasing intensity of bobwhite management would be expected to result in lower mean vegetation height, which could lead to a decrease in granivore occupancy at moderate levels of intensity and a decrease in carnivore and insectivore occupancy at high levels of intensity. A moderate degree of vegetation height is considered important for some birds, as it provides escape cover and nest cover (Lusk et al. 2006, Kullberg and Lafrenz 2007). Because managers at our study sites employ frequent fire to limit plant succession, the range of vegetation height we observed is likely lower than for nearby sites not managed for bobwhite, where vegetation is not limited by fire and can grow taller. While many birds in our study responded positively to taller vegetation, it is unclear if those effects would hold in areas with a greater range of vegetation height.

Basal area is known to have a positive effect on density for some insectivorous birds, particularly those that glean insects from the canopy (Brennan et al. 1999, Narango et al. 2017). Similarly, we found that the two species for which we detected positive responses to basal area, eastern wood-pewee and white-eyed vireo, were insectivorous canopy-gleaners. On the other hand, some insectivorous species that glean off the ground or bark or hawk under the canopy have been shown to respond positively to hardwood removal (Steen et al. 2013). In fact, all of the insectivore species that showed a significant negative response to mean basal area (northern mockingbird, eastern kingbird, and red-winged blackbird) were either ground-gleaners or under-canopy air hawkers. Overall, our results suggest that basal area as an indicator of bobwhite management had synergistic effects on granivores and carnivores and mixed effects on insectivores. However, the positive effects of decreasing basal area on granivore and carnivore abundance and occupancy appear to diminish with increasing management intensity.

We did not detect trade-offs or synergies between percent deciduous cover as an indicator of bobwhite management and avian occupancy or abundance at the guild or species level. Previous studies have shown that fewer granivorous bird species occupy forested systems than open agricultural systems (Macgregor-Fors and Schondube 2011), and ground-dwelling species like bobwhite have been shown to prefer lower proportions of deciduous cover (Schairer et al. 1999). Other studies have shown that hardwood reduction may not benefit adult bobwhite survival or productivity within 2-3 years of hardwood removal on sites intensively managed for bobwhite (Malone et al. 2022). We did not detect a relationship between bobwhite abundance or occupancy and deciduous cover. Important to note is that hardwoods have already been significantly reduced across the region decades before this study (Welch et al. 2004). The variation in hardwood density that remains may not have been substantial enough to detect significant relationships between deciduous cover and bird density. Our results suggest that managers can reduce deciduous cover without significant repercussions to other aspects of the bird community, although this may have only modest impacts on bobwhite populations.

We found some trade-offs between increases in bobwhite abundance and abundances of bird species with habitat requirements that differ from those of bobwhite. This is in contrast to findings from Crosby et al. (2015) that bobwhite presence was a positive predictor for 9 other bird species. Of those 9 species, field sparrow, eastern bluebird, and northern mockingbird were also detected in our study. We did observe a positive relationship between bobwhite abundance and field sparrow and northern mockingbird abundance, but this effect was not significant. Eastern bluebird had too few detections to be included in our analysis of relationships between the abundances of bobwhite and other species. Importantly, Crosby et al. (2015) surveyed birds across a much broader range of cover types representing a gradient of closed-canopy forest, woodland, savannah, and open prairie, with ranching and row-crop agriculture being the dominant land uses. Because our study focused on lands managed intensively for bobwhite with more similar habitat characteristics, we may not have been able to detect abundance relationships that are only present or are more pronounced on landscapes less suitable for bobwhite.

The only species for which we did detect abundance relationships to bobwhite abundance were American crow, Carolina chickadee, northern parula, and white-eyed vireo. The abundances of American crow, Carolina chickadee, and northern parula showed negative responses to bobwhite abundance, which is not surprising considering these species are associated with forest interiors or forest edges, as opposed to the bobwhite association with early successional habitat (Cornell Lab of Ornithology 2022). White-eyed vireo abundance decreased and then leveled out as bobwhite abundance increased. This is consistent with findings that the removal of the understory in pine grassland using fire or herbicide treatment significantly lowers white-eyed vireo numbers (Singleton et al. 2013).

Our estimates of bobwhite density were lower overall than estimates from other studies in the same region on intensively managed properties. Palmer et al. (2022) estimated pre-breeding bobwhite density ranged from 1.5-8.6 birds/ha on an intensively managed property in Leon County, Florida from 2002-2006. We would expect our density estimates to be lower than those reported by Palmer et al. because we estimated densities of singing males for species that sing, like bobwhite, rather than densities of all individuals of each species. However, even doubling our density estimates for bobwhite results in significantly lower densities than what has been reported in the literature at similar sites. Our low density estimates could be due in part to our exclusion of call detections for species that sing in our density analysis. If an individual called before it sang, the detection was marked as a call and would not have been included in our density analysis, potentially resulting in underestimation of density for birds that sing. We plan to investigate this potential source of bias further in future research by assessing the impact of including call detections in analyses.

We estimated relatively high occupancy rates for some rare or declining open-forest-associated bird species such as Bachman’s sparrow, field sparrow, and red-headed woodpecker, with median occupancy estimates of over 40% for each of these species. Estimates of density for Bachman’s sparrow were similar to density estimates from the literature in comparable habitat types. Our median estimate of singing male Bachman’s sparrow density was 0.10 birds/ha (95% CI: [0.07, 0.16]). Perkins et al. (2003) documented between 0.11 and 0.26 Bachman’s sparrow territories per hectare on native dry prairie sites in central Florida from 1994-1998. We estimated lower occupancy rates for brown-headed nuthatch (*Sitta pusilla*), a conservation priority species dependent on southern pine forests (Schneider and Keyes 2016), compared to what has been reported from Ouchita National Forest, but higher compared to Ozark-St. Francis National Forest, which is considered a range-extension zone, where predicted occupancy at the limits was 0.01 and near 0 for stands with high levels of tree stocking (Stanton et al. 2015). Our findings suggest bobwhite management in the Red Hills creates suitable habitat for several rare or declining bird species dependent on open pine woodlands.

To the best of our knowledge, this is the first study to apply Bayesian methods to functional diversity analysis. This approach allowed us to create hierarchical models to estimate functional diversity indices with uncertainty intervals for bird communities with imperfect detection and availability. Just as failing to account for imperfect detection and availability can bias abundance estimates (Williams et al. 2002, Kéry and Schaub 2011), so can it bias estimates of functional diversity indices, which rely on estimates of abundance. We predicted that sites with intermediate bobwhite densities would have higher functional diversity because we expected intermediate levels of disturbance to allow species to occupy a broader functional space. However, we found no evidence of any relationships between bobwhite abundance and functional diversity. While we did not find that functional divergence was related to bobwhite abundance, functional divergence values were generally high. Our findings on functional richness suggest that bobwhite density has no relationship to the range of functional traits present in the bird community. Mason et al. (2005) posits that low functional richness indicates that some of the resources potentially available to the community are unused. While most of our sites generally exhibited low functional richness values, this could be due to the way we structured our functional traits. We used the diet and feeding strategy classifications from Gonzáles-Salazar (2014), in which each diet has its own class of feeding strategies. Under this classification, it is impossible for a bird to have a feeding strategy from a diet guild not its own, so many functional trait combinations will always go unrealized. This same logic may explain the generally high values of functional divergence. We found no relationship between bobwhite abundance and functional evenness, suggesting that bobwhite density is not a good predictor of how evenly birds utilize the niche space in a given assemblage. Finally, contrary to our expectation, we found no relationship between bobwhite density and the dispersion of bird species within the trait space. We expected that bobwhite densities would reflect disturbance intensities and that areas with intermediate levels of disturbance would allow for the greatest spread of species disturbance adaptations, including species not adapted for disturbance and species well-adapted for disturbance. Other studies have found a reduction in functional evenness and dispersion with higher disturbance intensity (Mouillot et al. 2013). Perhaps the functional traits we chose to characterize species by did not reflect disturbance adaptations enough for this relationship to be apparent, or perhaps bobwhite density did not track with disturbance intensity as closely as we expected it to on sites that are all intensively managed for bobwhite. Unlike other sources of disturbance, bobwhite management strategies may have little influence on the structure of the functional assemblages in pine savanna systems because assemblages are already well-adapted to the natural disturbance regimes that the management strategies simulate.

Overall, our results suggest that habitat characteristics associated with bobwhite management on properties intensively managed for bobwhite have limited effects on avian abundance and occupancy at the diet guild level, although these characteristics more noticeably affect abundance and occupancy at the individual species level. Importantly, these results should be considered within the context of lands managed intensively for bobwhite, and we would expect to see different relationships on lands not managed for bobwhite. Through management that prevents plant succession to hardwood forest, particularly frequent fire application, managers of quail properties create habitat that more closely resembles the landscape prior to European settlement. These conditions are favorable to some native bird species, particularly those that depend on open-canopy conditions. However, bird species that depend on greater tree density may be negatively impacted by bobwhite management. Furthermore, while limiting vegetation height through prescribed fire or other disturbance may benefit some bird species, overly limiting vegetation height may be detrimental to the bird community.

Managing land for a single species should not be expected to benefit all species or maximize functional diversity. However, our results indicate that bobwhite management strategies, such as burning frequently and limiting basal area, could serve as an important component of management plans that seek to maintain populations of open-canopy specialists, including several rare or declining species, and contribute to the function of the pine savanna ecosystem. The lack of evidence for relationships between bobwhite density and densities of other birds or functional diversity indices on properties intensively managed for bobwhite indicates that where levels of management are already high, the known benefits derived from further promoting bobwhite habitat, such as recreational, aesthetic, and economic value, may come at little cost or benefit to supporting ecosystem services.

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TABLES AND FIGURES

Table 1. Summary of traits used in functional diversity analysis.

Trait	Type	Values	Units/categories
Diet	Categorical	4 categories	Insectivore, Omnivore, Granivore, Carnivore
Feeding strategy	Categorical	12 categories	Air hawker under canopy, Ground forager, Ground to undergrowth gleaner, Nocturnal, Lower canopy foliage cleaner, Bark gleaner, Ground gleaner, Air hawker above canopy, Air-hawker, Bark excavator, Upper canopy foliage gleaner, Ground hawker
Body mass	Continuous	Mean	Gram
Migratory status	Binary	2 categories	Migratory, non-migratory
Habitat preference	Categorical	7 categories	Ear (early successional), Fed (forest edge), Fin (forest interior), Ope (open), Shr (shrub), Wet (water associated), Oth (other)

Table 2. Relationships between estimated bobwhite abundance and estimated abundances of other species. β1 represents the parameter on the unsquared term, β2 represents the parameter on the squared term, and f represents the proportion of the posterior distribution that has the same sign as the median estimate.

Species	β1 median	β1 2.5% CI	β1 97.5% CI	β1 f	β2 median	β2 2.5% CI	β2 97.5% CI	β2 f
AMCR	-0.153	-0.712	0.079	0.912	0.006	-0.009	0.035	0.808
BACS	-0.078	-0.761	0.487	0.608	0.000	-0.035	0.040	0.510
BHCO	-0.023	-1.645	1.131	0.524	0.001	-0.071	0.098	0.510
BLGR	0.089	-0.558	0.714	0.622	-0.008	-0.048	0.030	0.686
BLJA	0.006	-0.472	0.440	0.514	-0.002	-0.029	0.027	0.567
CACH	-0.309	-1.417	0.123	0.914	0.014	-0.012	0.073	0.853
CARW	-0.074	-0.630	0.470	0.613	0.000	-0.034	0.034	0.512
COGD	0.126	-0.136	0.365	0.844	-0.006	-0.021	0.011	0.786
COYE	0.058	-0.477	0.569	0.595	0.000	-0.032	0.034	0.507
EAKI	0.267	-0.631	1.314	0.768	-0.012	-0.074	0.048	0.707
EATO	0.236	-0.662	1.137	0.712	-0.005	-0.060	0.054	0.578
EAWP	-0.047	-0.284	0.163	0.678	0.001	-0.012	0.016	0.587
FISP	0.038	-0.531	0.520	0.562	0.008	-0.022	0.049	0.696
GCFL	-0.326	-1.469	0.263	0.858	0.015	-0.021	0.080	0.795
INBU	-0.042	-0.715	0.595	0.553	-0.002	-0.042	0.039	0.534
MODO	0.110	-0.178	0.394	0.780	-0.005	-0.023	0.014	0.705
NOBO	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.504
NOCA	-0.078	-0.677	0.497	0.606	0.000	-0.037	0.037	0.501
NOMO	0.087	-0.277	0.429	0.708	-0.002	-0.023	0.023	0.587
NOPA	-0.533	-2.022	0.143	0.940	0.021	-0.018	0.101	0.862
OROR	0.093	-0.365	0.622	0.682	-0.004	-0.035	0.027	0.623
PIWA	-0.170	-0.787	0.249	0.798	0.005	-0.022	0.039	0.657
RBWO	-0.011	-0.459	0.422	0.522	0.000	-0.027	0.028	0.505
RHWO	0.144	-0.388	0.710	0.727	-0.009	-0.045	0.023	0.737
RWBL	0.255	-0.721	1.052	0.727	0.000	-0.050	0.069	0.504
TUTI	-0.076	-0.499	0.285	0.673	0.002	-0.021	0.027	0.573
WBNU	-0.007	-0.715	0.527	0.511	-0.002	-0.036	0.039	0.554
WEVI	-0.556	-1.719	0.008	0.973	0.025	-0.007	0.092	0.937

Table 3. Parameter estimates for effects of bobwhite abundance on four functional diversity indices. "f.dis" stands for functional dispersion, "f.div" stands for functional divergence, "f.eve" stands for functional evenness, and "f.ric" stands for functional richness. The linear model was expressed as:

$$f.div.index_i = \beta_0 + \beta_1 * NOBO.abundance + \beta_2 * NOBO.abundance^2$$

Index	β1 median	β1 2.5% CI	β1 97.5% CI	β1 f	β2 median	β2 2.5% CI	β2 97.5% CI	β2 f
f.dis	0	-0.004	0.004	0.507	0	0.000	0.000	0.509
f.div	0	-0.004	0.004	0.509	0	0.000	0.000	0.506
f.eve	0	-0.007	0.007	0.504	0	0.000	0.000	0.503
f.ric	0	-0.016	0.015	0.509	0	-0.001	0.001	0.515

Table 4. Effects of habitat covariates on log of mean abundance for birds with at least 50 detections in each guild. β1 represents the parameter on the unsquared term, β2 represents the parameter on the squared term, and f represents the proportion of the posterior distribution that has the same sign as the median estimate.

Variable	Unit	β1 median	β1 2.5% CI	β1 97.5% CI	β1 f	β2 median	β2 2.5% CI	β2 97.5% CI	β2 f
Granivore									
Fire	frequency (1994-2021)	0.064	-0.071	0.209	0.831	-0.033	-0.075	0.006	0.943
Ground	percent cover	-0.035	-0.133	0.055	0.801	-0.001	-0.030	0.030	0.528
Vegetation height	m	-0.026	-0.150	0.116	0.649	0.003	-0.056	0.080	0.532
Mean basal area	m^2/ha	-0.005	-0.125	0.109	0.535	-0.039	-0.123	0.022	0.906
Deciduous	percent cover	-0.027	-0.133	0.098	0.758	0.002	-0.072	0.080	0.529
Insectivore									
Fire	frequency (1994-2021)	-0.025	-0.160	0.101	0.670	-0.020	-0.076	0.033	0.738
Ground	percent cover	-0.002	-0.088	0.090	0.471	-0.015	-0.058	0.019	0.773
Vegetation height	m	0.043	-0.080	0.160	0.758	-0.012	-0.121	0.095	0.583
Mean basal area	m^2/ha	-0.014	-0.188	0.168	0.563	-0.036	-0.093	0.013	0.917
Deciduous	percent cover	0.023	-0.045	0.109	0.752	0.017	-0.069	0.094	0.685
Omnivore									
Fire	frequency (1994-2021)	-0.148	-2.130	1.897	0.652	-0.072	-1.999	2.184	0.592
Ground	percent cover	-0.095	-2.056	2.271	0.562	0.016	-1.656	1.752	0.476
Vegetation height	m	-0.038	-2.098	2.020	0.535	0.207	-1.762	1.843	0.686
Mean basal area	m^2/ha	0.073	-2.004	2.129	0.562	-0.055	-1.704	1.625	0.570
Deciduous	percent cover	-0.224	-2.323	1.907	0.678	0.120	-1.825	2.278	0.630

Table 5. Effects of habitat covariates on logit of mean occupancy probabilities for birds in each guild. β1 represents the parameter on the unsquared term, β2 represents the parameter on the squared term, and f represents the proportion of the posterior distribution that has the same sign as the median estimate.

Variable	Unit	β1 median	β1 2.5% CI	β1 97.5% CI	β1 f	β2 median	β2 2.5% CI	β2 97.5% CI	β2 f
Carnivore									
Fire	frequency (1994-2021)	-0.289	-1.550	0.777	0.723	-0.036	-1.192	1.024	0.530
Ground	percent cover	0.001	-1.292	1.311	0.501	-0.104	-1.489	0.647	0.600
Vegetation height	m	-0.187	-1.665	1.175	0.625	-1.371	-2.678	0.054	0.973
Mean basal area	m^2/ha	0.086	-1.561	1.530	0.546	-0.673	-1.894	0.354	0.936
Deciduous	percent cover	-0.610	-2.120	0.627	0.848	0.360	-1.068	1.470	0.705
Granivore									
Fire	frequency (1994-2021)	0.142	-0.418	0.733	0.703	-0.007	-0.262	0.265	0.529
Ground	percent cover	-0.420	-0.906	0.050	0.961	0.207	-0.028	0.593	0.964
Vegetation height	m	0.160	-0.286	0.767	0.732	0.341	-0.124	0.863	0.936
Mean basal area	m^2/ha	-0.209	-0.940	0.216	0.800	-0.209	-0.496	0.088	0.942
Deciduous	percent cover	-0.108	-0.574	0.339	0.698	0.093	-0.255	0.493	0.677
Insectivore									
Fire	frequency (1994-2021)	-0.084	-0.238	0.069	0.857	-0.029	-0.134	0.087	0.726
Ground	percent cover	-0.102	-0.288	0.077	0.866	-0.020	-0.113	0.050	0.683
Vegetation height	m	0.293	0.109	0.497	0.997	-0.117	-0.259	0.011	0.965
Mean basal area	m^2/ha	-0.182	-0.417	0.036	0.949	0.065	-0.016	0.147	0.952
Deciduous	percent cover	0.054	-0.079	0.181	0.800	0.026	-0.094	0.109	0.664
Omnivore									
Fire	frequency (1994-2021)	-0.249	-1.441	0.934	0.655	-0.202	-1.514	1.023	0.613
Ground	percent cover	-0.280	-2.298	0.935	0.665	0.298	-1.100	1.888	0.652
Vegetation height	m	0.430	-1.110	2.276	0.700	-0.319	-2.048	1.383	0.631
Mean basal area	m^2/ha	0.104	-1.148	1.513	0.563	-0.231	-1.680	1.132	0.633
Deciduous	percent cover	-0.806	-2.248	0.562	0.887	0.288	-1.311	2.047	0.645

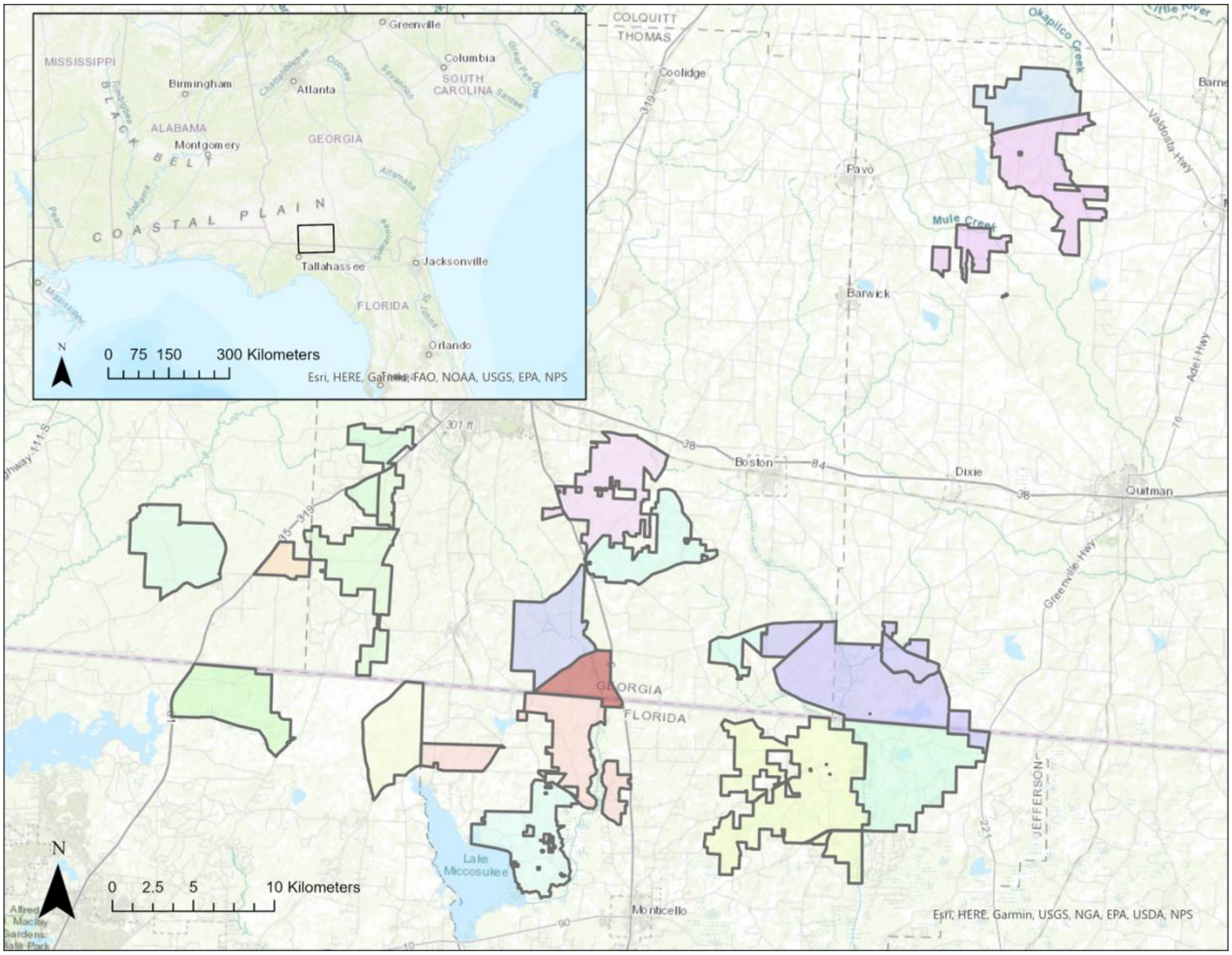


Figure 1. Map of properties where bird surveys were conducted. Properties are shown with grey outline and translucent colored fill.

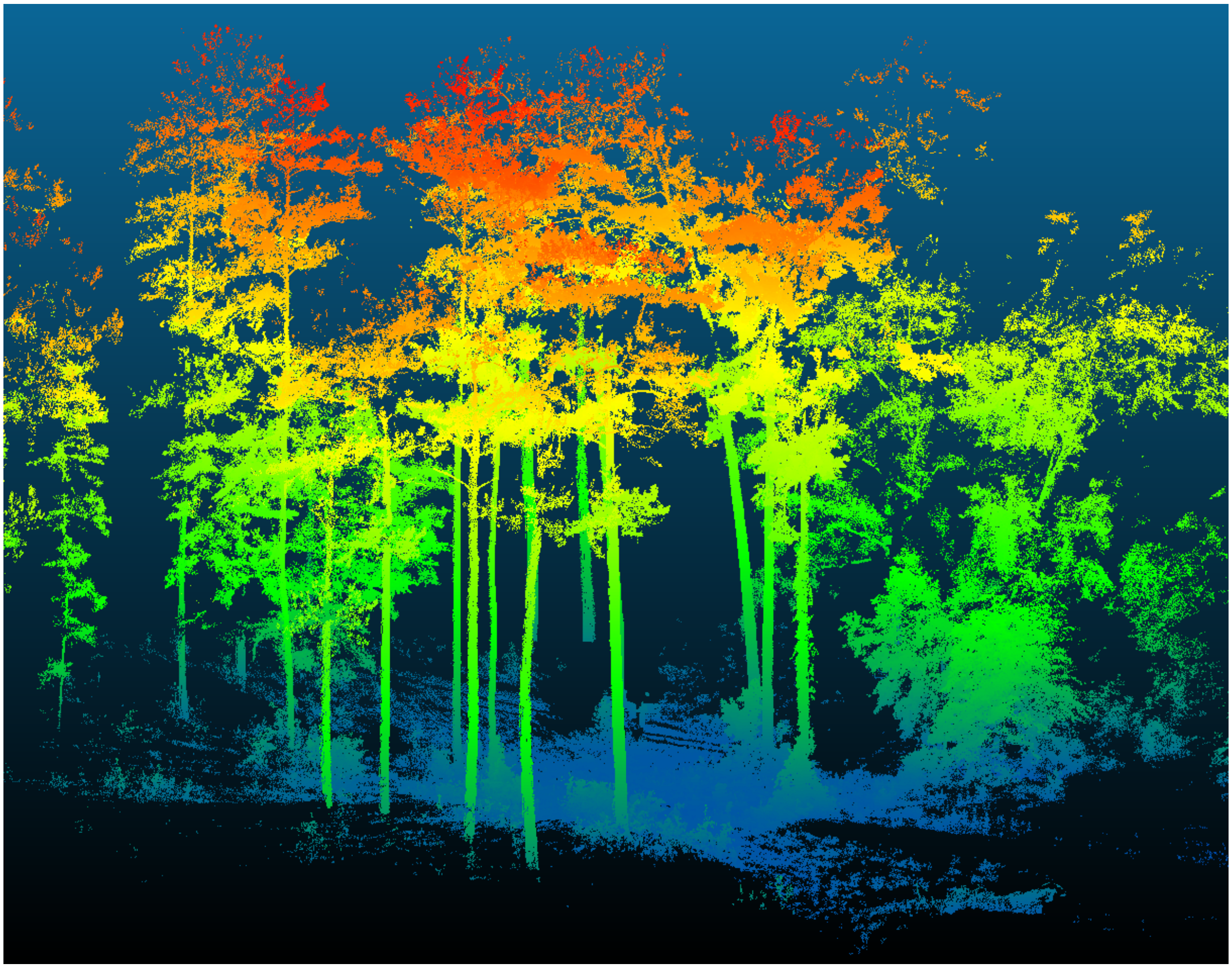


Figure 2. Example of image taken by LIDAR scanner at a survey point. Color gradient corresponds to height of point, with cooler colors lower and warmer colors higher.

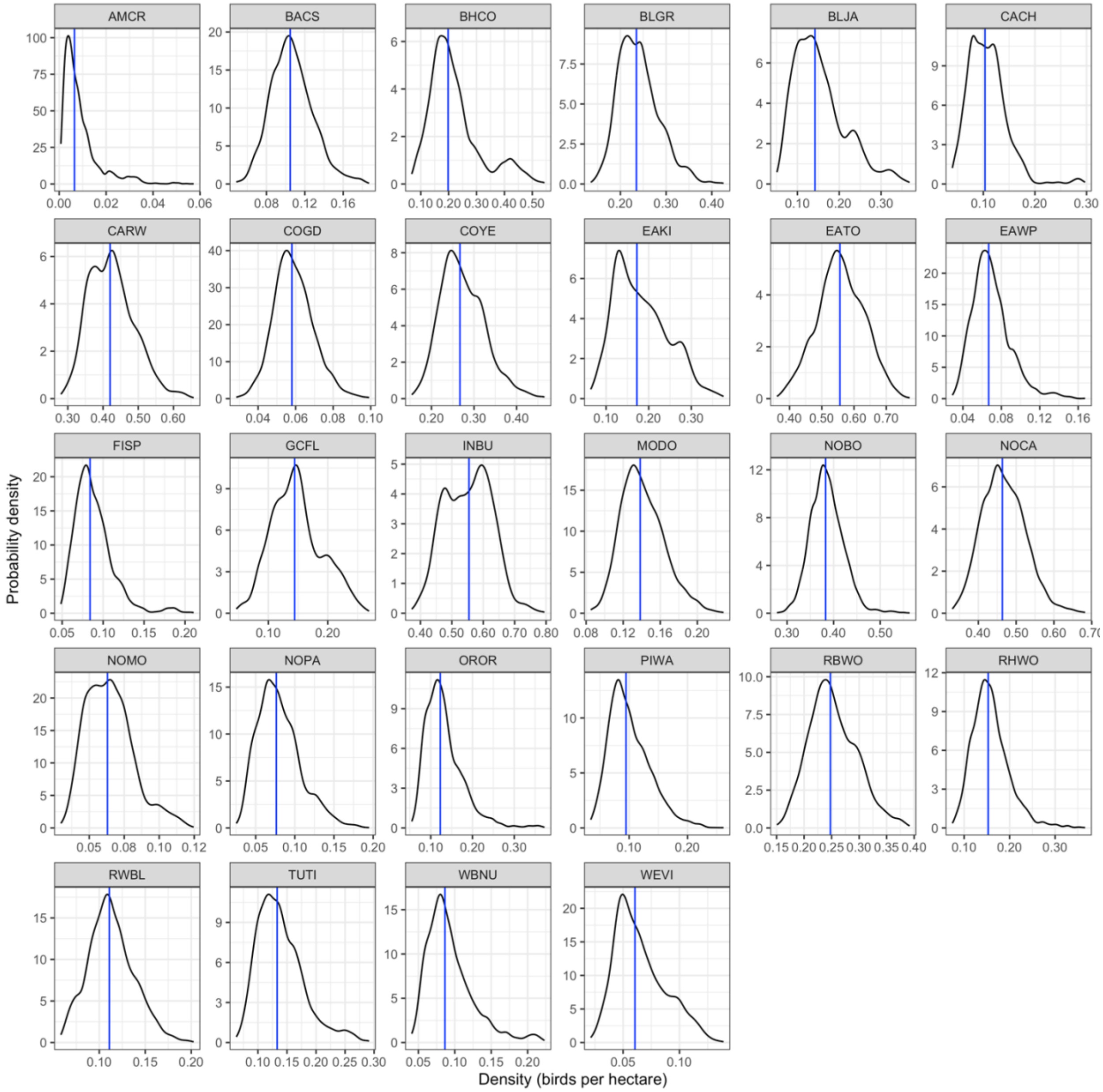


Figure 3. Probability density of bird species density. Blue lines represent median density estimates for each species.

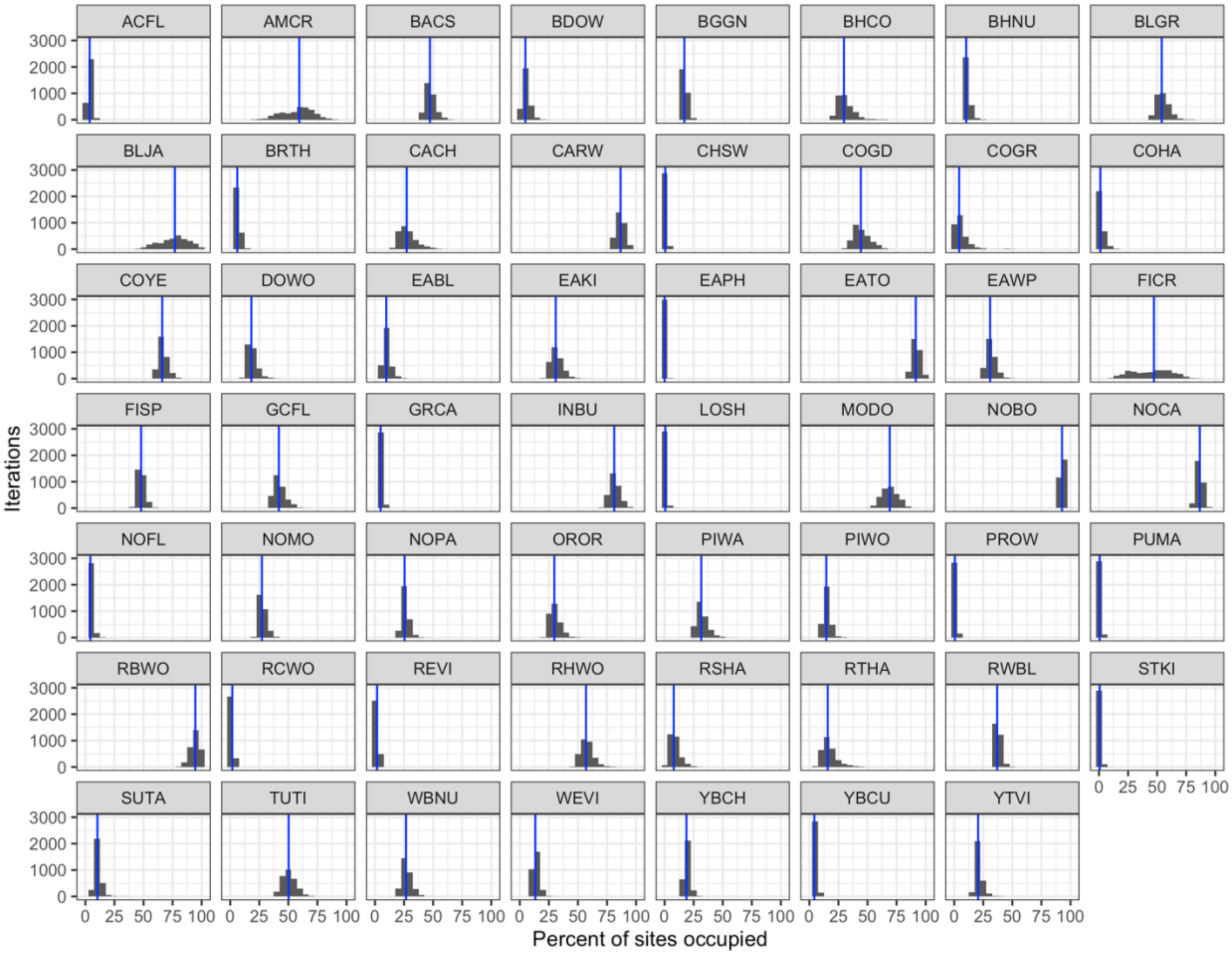


Figure 4. Occupancy model estimates of number of sites occupied by each bird species. Vertical blue lines represent median estimates.

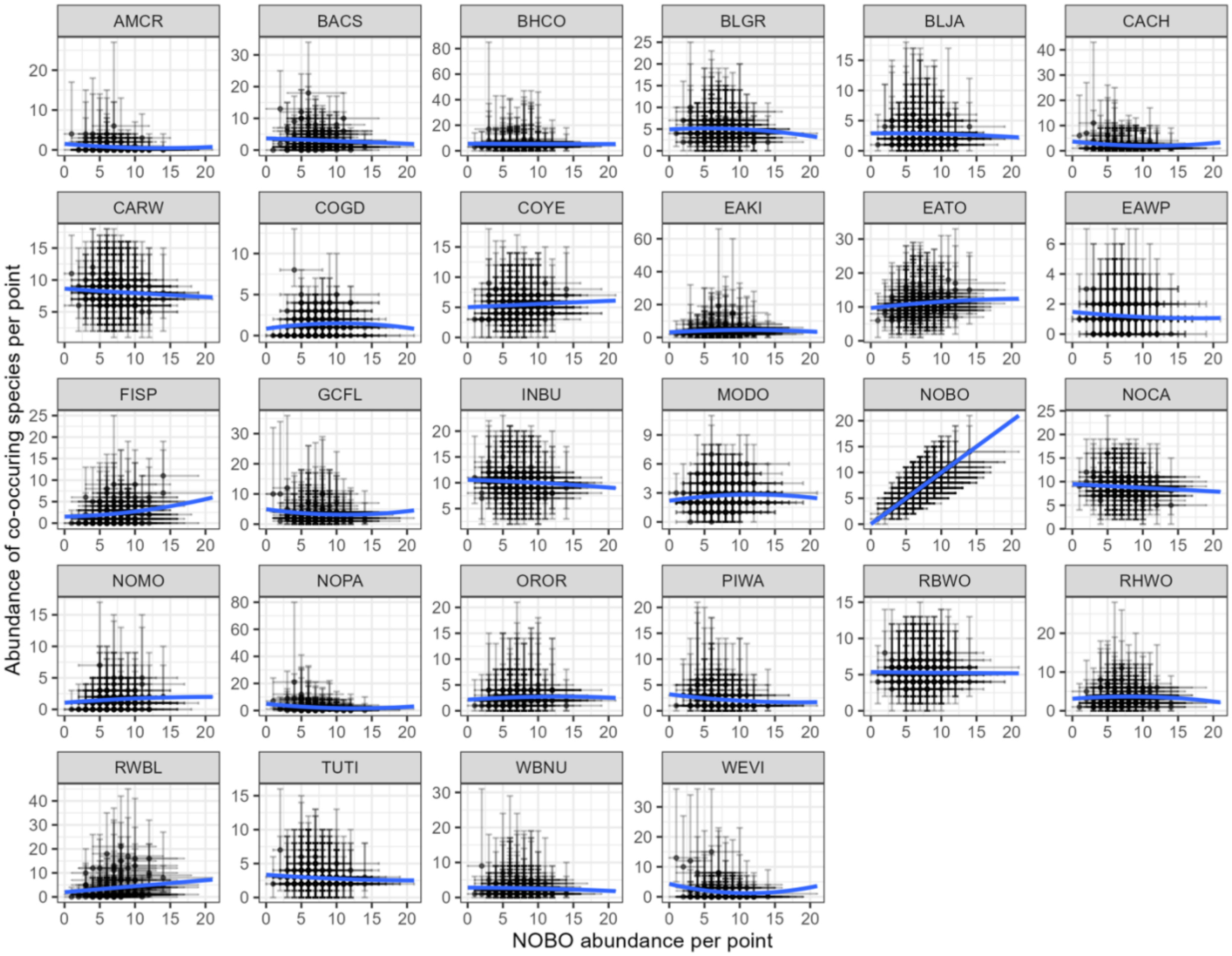


Figure 5. Correlations between estimated northern bobwhite abundances and estimated abundances of other bird species (with at least 50 total detections) at each point. Black dots represent median abundance estimates at each point. Horizontal bars represent 95% credible intervals on northern bobwhite abundances and vertical bars represent 95% credible intervals on abundances of co-occurring species. The blue lines represent linear regressions run on median abundance estimates of each bird species as a function of median bobwhite abundance estimates.

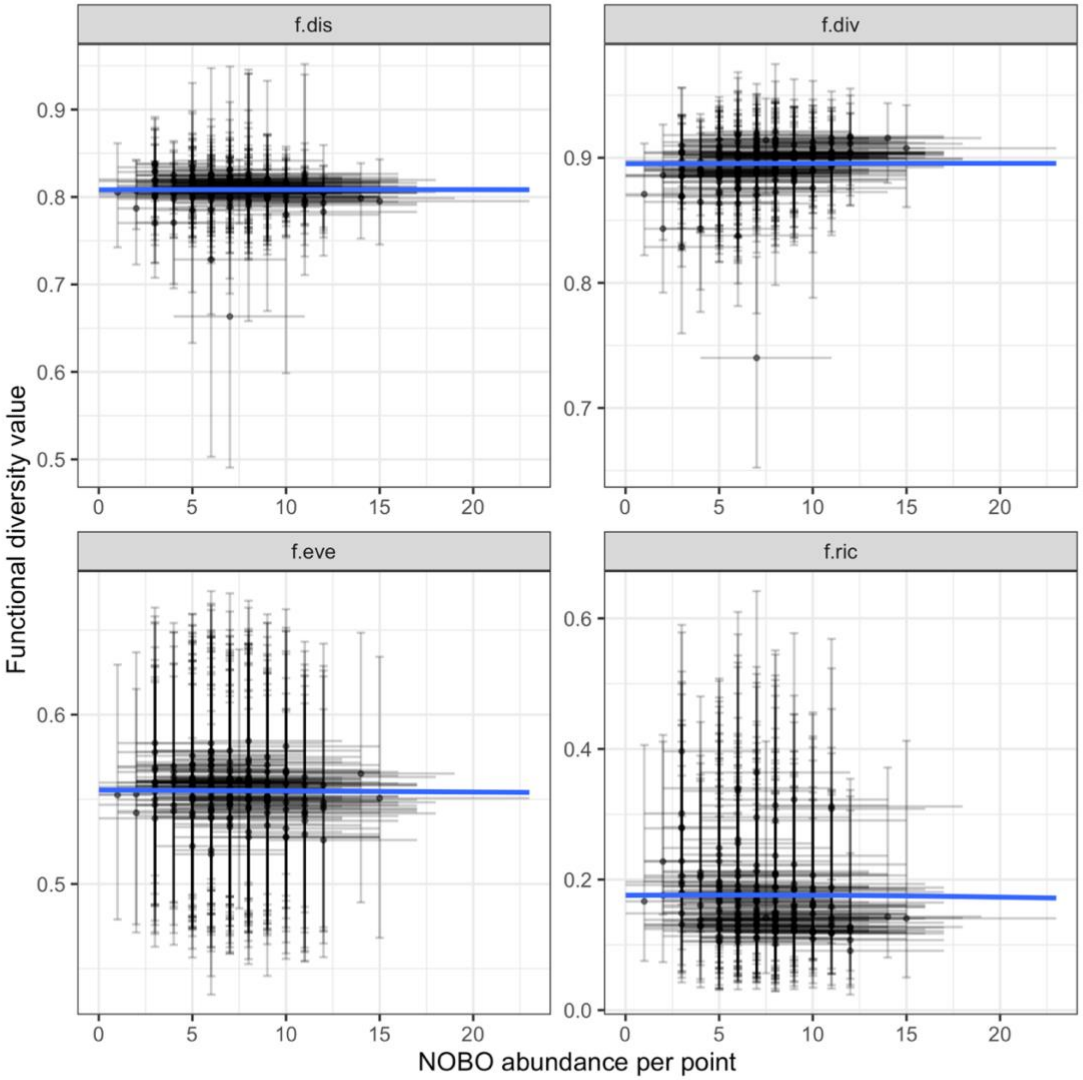


Figure 6. Correlations between northern bobwhite abundance and 4 functional diversity indices. "f.dis" stands for functional dispersion, "f.div" stands for functional divergence, "f.eve" stands for functional evenness, and "f.ric" stands for functional richness. Black dots represent median bobwhite abundance estimates and median functional diversity index values at each point. Horizontal bars represent 95% credible intervals on northern bobwhite abundances and vertical bars represent 95% credible intervals on functional diversity index values. The blue lines represent linear regressions run on median functional diversity index value estimates as a function of median bobwhite abundance estimates.

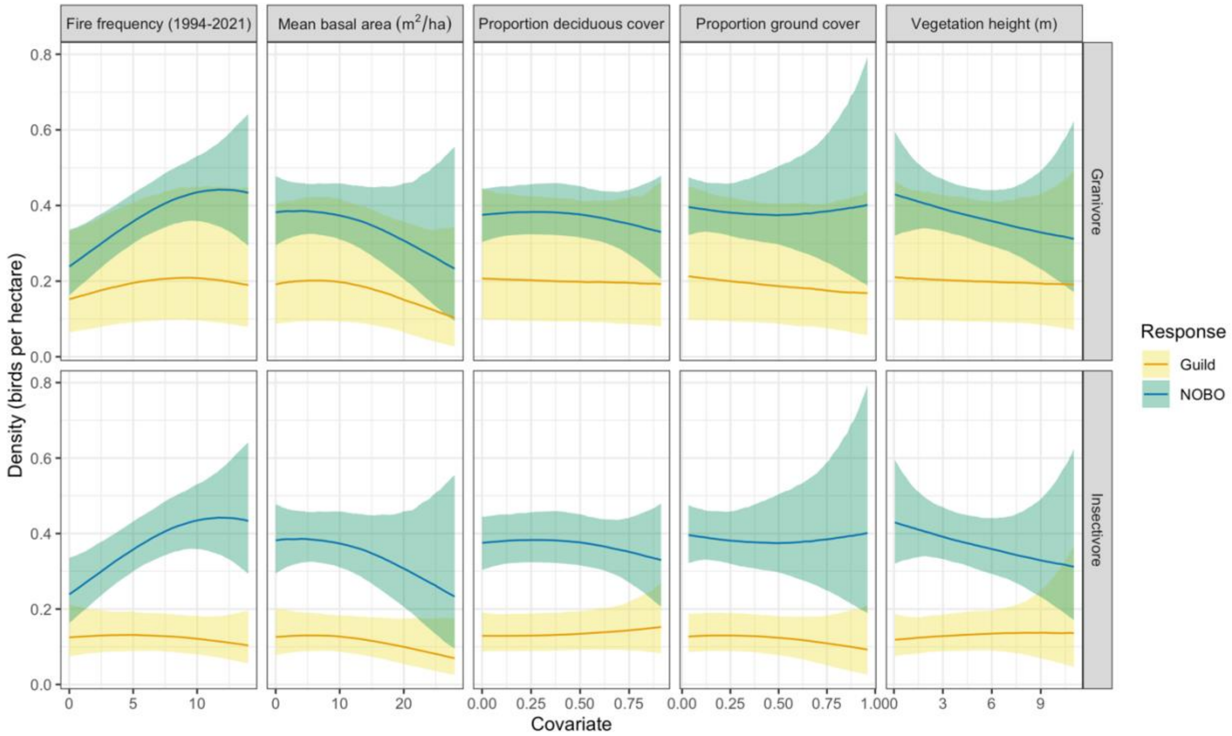


Figure 7. Effects of habitat covariates on mean densities of birds in granivore and insectivore guild and bobwhite. Solid lines represent median estimates and colored ribbons represent 95% credible intervals.

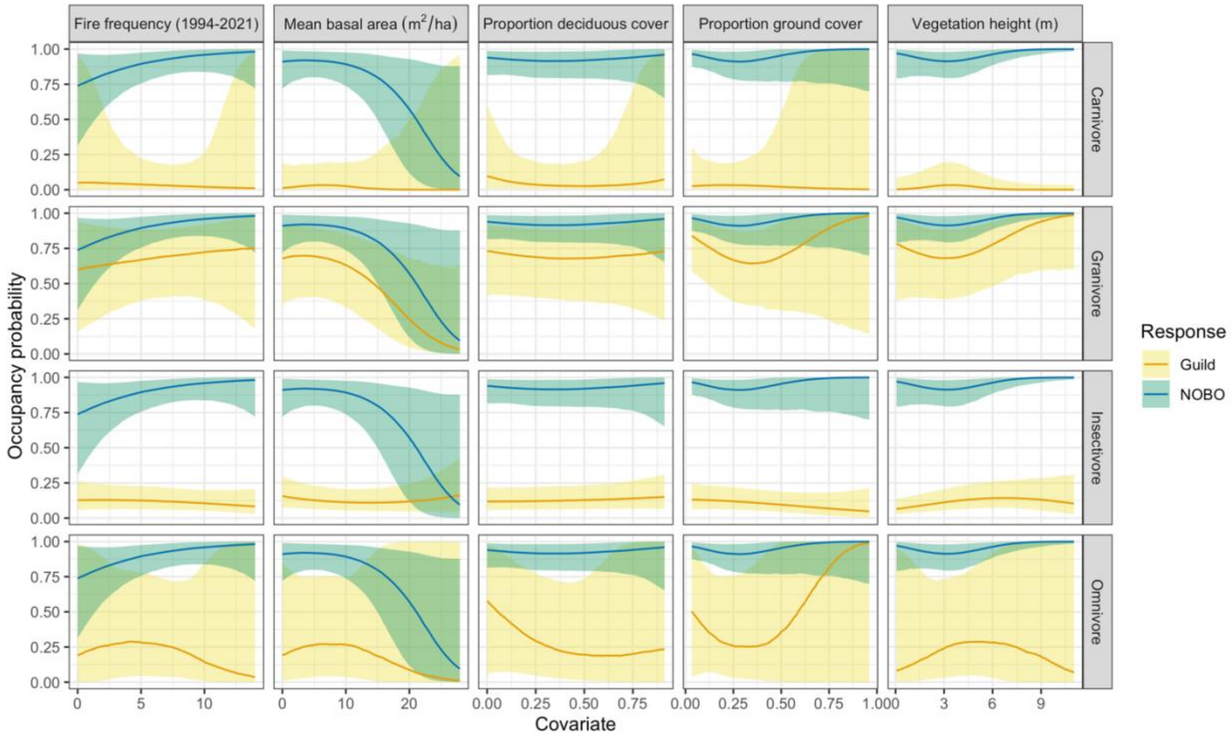


Figure 8. Effects of habitat covariates on mean occupancy probabilities of birds in each guild and bobwhite. Solid lines represent median estimates and colored ribbons represent 95% credible intervals.

CHAPTER THREE

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Open-canopy ecosystems are imperiled due to intensive agriculture, development, and changes in disturbance regimes, particularly loss of fire, which has led to ecological succession. Land managers seeking to promote populations of northern bobwhite employ management strategies such as frequent prescribed burning and hardwood removal to maintain open-canopy systems. We used a Bayesian hierarchical modeling framework to investigate how 5 habitat variables associated with bobwhite management, fire frequency, ground cover, vegetation height, basal area, and deciduous cover, affected bird community structure and functional diversity on private properties managed intensively for bobwhite. We also analyzed the relationships between bobwhite abundance, other bird species' abundances, and functional diversity indices.

We found minimal impacts of habitat characteristics associated with bobwhite management on the abundance and occupancy of birds at the diet guild level. However, we found positive effects of some habitat variables disfavored by bobwhite management on certain bird guilds, namely a positive effect of vegetation height on insectivorous birds. At the species level, we detected significant relationships between habitat covariates and avian abundance and occupancy. Managers should utilize different strategies depending on their objectives, and managing habitat for bobwhite alone should not be expected to benefit all birds in the community. For example, managers wishing to promote recreational hunting opportunities may opt for the frequent fire return intervals common on quail properties, as fire frequency had a positive effect on the abundance of bobwhite and mourning dove, both popular game birds. On the other hand, managers seeking to promote avian insectivores may opt to allow vegetation to grow higher than what is optimal for bobwhite, as vegetation height had a positive effect on the occupancy of several insectivores in our study.

Our use of Bayesian methods allowed us to account for imperfect bird availability and detection when estimating avian abundances and functional diversity indices. We recommend similar approaches for future studies that seek to estimate functional diversity metrics from avian point count data to help reduce bias from variable detection rates. We did not detect any significant relationships between bobwhite abundance and the abundances of other bird species or functional diversity indices within properties intensively managed for bobwhite. This suggests that the benefits to cultural ecosystem services derived from the highest levels of bobwhite management, such as recreational, aesthetic, and economic value, may operate largely independently of other supporting or regulating ecosystem services, within the context of lands managed intensively for bobwhite.

APPENDIX A. List of bird species codes and functional traits.

Habitat preference abbreviations: Fin, forest interior; Fed, forest edge; Shr, shrub; Open, open-forest; Ear, early successional/grassland; Wet, water-associated; Oth, others (mostly artificial structures such as houses).

Species AOU code	Common name	Scientific name	Diet	Feeding strategy	Mean weight (g)	Migrant	Habitat preference
ACFL	Acadian Flycatcher	*Empidonax virescens*	Insectivore	Air hawker under canopy	12	1	Fin
AMCR	American Crow	*Corvus brachyrhynchos*	Omnivore	Ground forager	468	0	Fed
BACS	Bachman's Sparrow	*Peucaea aestivalis*	Granivore	Ground to undergrowth gleaner	20	0	Ope
BDOW	Barred Owl	*Strix varia*	Carnivore	Nocturnal	760	0	Fin
BGGN	Blue-gray Gnatcatcher	*Polioptila caerulea*	Insectivore	Lower canopy foliage cleaner	7	0	Fed
BHCO	Brown-headed Cowbird	*Molothrus ater*	Granivore	Ground to undergrowth gleaner	42	0	Fed
BHNU	Brown-headed Nuthatch	*Sitta pusilla*	Insectivore	Bark gleaner	10	0	Ope
BLGR	Blue Grosbeak	*Passerina caerulea*	Insectivore	Ground gleaner	28	1	Ope
BLJA	Blue Jay	*Cyanocitta cristata*	Omnivore	Ground forager	85	0	Fed
BRTH	Brown Thrasher	*Toxostoma rufum*	Insectivore	Ground gleaner	75	0	Shr
CACH	Carolina Chickadee	*Poecile carolinensis*	Insectivore	Lower canopy foliage cleaner	10	0	Fin
CARW	Carolina Wren	*Thryothorus ludovicianus*	Insectivore	Lower canopy foliage cleaner	20	0	Fed
CHSW	Chimney Swift	*Chaetura pelagica*	Insectivore	Air hawker above canopy	24	1	Oth
COGD	Common Ground-Dove	*Columbina passerina*	Granivore	Ground to undergrowth gleaner	35	0	Fed
COGR	Common Grackle	*Quiscalus quiscula*	Omnivore	Ground forager	108	0	Fed
COHA	Cooper's Hawk	*Accipiter cooperii*	Carnivore	Air-hawker	505	0	Fin
COYE	Common Yellowthroat	*Geothlypis trichas*	Insectivore	Lower canopy foliage cleaner	10	1	Shr
DOWO	Downy Woodpecker	*Dryobates pubescens*	Insectivore	Bark excavator	24	0	Fin

Species AOU code	Common name	Scientific name	Diet	Feeding strategy	Mean weight (g)	Migrant	Habitat preference
EABL	Eastern Bluebird	*Sialia sialis*	Insectivore	Ground gleaner	30	0	Fed
EAKI	Eastern Kingbird	*Tyrannus tyrannus*	Insectivore	Air hawker under canopy	44	1	Fed
EAPH	Eastern Phoebe	*Sayornis phoebe*	Insectivore	Air hawker under canopy	18	1	Ope
EATO	Eastern Towhee	*Pipilo erythrophthalmus*	Granivore	Ground to undergrowth gleaner	42	0	Shr
EAWP	Eastern Wood-Pewee	*Contopus virens*	Insectivore	Air hawker under canopy	14	1	Ope
FICR	Fish Crow	*Corvus ossifragus*	Omnivore	Ground forager	262	0	Wet
FISP	Field Sparrow	*Spizella pusilla*	Granivore	Ground to undergrowth gleaner	13	0	Ear
GCFL	Great Crested Flycatcher	*Myiarchus crinitus*	Insectivore	Air hawker under canopy	34	1	Ope
GRCA	Gray Catbird	*Dumetella carolinensis*	Insectivore	Ground gleaner	40	1	Fed
INBU	Indigo Bunting	*Passerina cyanea*	Granivore	Ground to undergrowth gleaner	15	1	Ope
LOSH	Loggerhead Shrike	*Lanius ludovicianus*	Insectivore	Ground gleaner	42	0	Ope
MODO	Mourning Dove	*Zenaida macroura*	Granivore	Ground to undergrowth gleaner	133	0	Fed
NOBO	Northern Bobwhite	*Colinus virginianus*	Granivore	Ground to undergrowth gleaner	172	0	Ear
NOCA	Northern Cardinal	*Cardinalis cardinalis*	Granivore	Ground to undergrowth gleaner	45	0	Fed
NOFL	Northern Flicker	*Colaptes auratus*	Insectivore	Ground gleaner	135	0	Fed
NOMO	Northern Mockingbird	*Mimus polyglottos*	Insectivore	Ground gleaner	52	0	Oth
NOPA	Northern Parula	*Setophaga americana*	Insectivore	Air hawker under canopy	8	1	Fin
OROR	Orchard Oriole	*Icterus spurius*	Insectivore	Upper canopy foliage gleaner	22	1	Ope
PIWA	Pine Warbler	*Setophaga pinus*	Insectivore	Air hawker under canopy	12	0	Fin

Species AOU code	Common name	Scientific name	Diet	Feeding strategy	Mean weight (g)	Migrant	Habitat preference
PIWO	Pileated Woodpecker	*Dryocopus pileatus*	Insectivore	Bark excavator	300	0	Fin
PROW	Prothonotary Warbler	*Protonotaria citrea*	Insectivore	Lower canopy foliage cleaner	14	1	Fin
PUMA	Purple Martin	*Progne subis*	Insectivore	Air hawker above canopy	52	1	Wet
RBWO	Red-bellied Woodpecker	*Melanerpes carolinus*	Insectivore	Bark excavator	74	0	Fin
RCWO	Red-cockaded Woodpecker	*Dryobates borealis*	Insectivore	Bark excavator	47	0	Ope
REVI	Red-eyed Vireo	*Vireo olivaceus*	Insectivore	Lower canopy foliage cleaner	19	1	Fin
RHWO	Red-headed Woodpecker	*Melanerpes erythrocephalus*	Insectivore	Air hawker under canopy	74	1	Ope
RSHA	Red-shouldered Hawk	*Buteo lineatus*	Carnivore	Ground hawker	630	0	Fin
RTHA	Red-tailed Hawk	*Buteo jamaicensis*	Carnivore	Ground hawker	1180	0	Ope
RWBL	Red-winged Blackbird	*Agelaius phoeniceus*	Insectivore	Ground gleaner	54	0	Wet
STKI	Swallow-tailed Kite	*Elanoides forficatus*	Insectivore	Air hawker above canopy	485	1	Fed
SUTA	Summer Tanager	*Piranga rubra*	Insectivore	Upper canopy foliage gleaner	29	1	Fin
TUTI	Tufted Titmouse	*Baeolophus bicolor*	Insectivore	Lower canopy foliage cleaner	22	0	Fin
WBNU	White-breasted Nuthatch	*Sitta carolinensis*	Insectivore	Bark gleaner	24	0	Fin
WEVI	White-eyed Vireo	*Vireo griseus*	Insectivore	Lower canopy foliage cleaner	12	1	Shr
YBCH	Yellow-breasted Chat	*Icteria virens*	Insectivore	Lower canopy foliage cleaner	27	1	Shr
YBCU	Yellow-billed Cuckoo	*Coccyzus americanus*	Insectivore	Upper canopy foliage gleaner	60	1	Ope
YTVI	Yellow-throated Vireo	*Vireo flavifrons*	Insectivore	Lower canopy foliage cleaner	18	1	Fed

APPENDIX B. Model diagnostics.

The abundance model ran for the maximum allowed 200,000 iterations for each of 3 chains, with 199,000 of those iterations discarded as burn-in, yielding 3,000 total samples from the joint posterior. However, Rhat values indicated convergence failure. Out of 459 variables monitored, 91 had Rhat values greater than 1.1, with a maximum value of 2.13. All Rhat values for mean effects of bobwhite management indicators on guild abundance were less than 1.16. The occupancy model ran for its maximum 500,000 iterations and indicated convergence failure for some variables. Out of 753 variables monitored, 188 had Rhat values greater than 1.1, with a maximum value of 2.65. The maximum Rhat value for mean effects of bobwhite management indicators on guild occupancy was 1.41. To characterize functional diversity, we analyzed the quality of functional spaces with up to 10 principal coordinate analysis axes. The functional space with the lowest mean absolute deviation between species pairwise distances in each functional space and trait-based distances had 7 principal coordinate analysis axes (mad = 0.052; Figure 6). Rhat values indicated that the model used to generate abundance estimates for our functional diversity analysis did not converge fully for some variables monitored. Out of 9,512 variables monitored, 2,381 had Rhat values greater than 1.1. The maximum Rhat value was 5.75 and the median was 1.03.

APPENDIX C.1 Effects of covariates on availability in abundance model.

Day of year had a nonlinear concave down effect on granivore availability, time of day had a positive effect on insectivore availability, wind had a negative effect on insectivore availability, and day of year had a positive effect on omnivore availability.

Variable	Median	2.5% CI	97.5% CI	f
Granivore				
Day	0.341	0.263	0.424	1.000
Day squared	-0.091	-0.174	-0.007	0.983
Time of day	-0.021	-0.126	0.075	0.652
Temperature	-0.018	-0.093	0.048	0.701
Wind	0.055	-0.034	0.153	0.882
Insectivore				
Day	0.033	-0.055	0.115	0.785
Day squared	-0.015	-0.090	0.061	0.667
Time of day	0.133	0.017	0.251	0.988
Temperature	0.061	-0.010	0.135	0.956
Wind	-0.165	-0.265	-0.059	1.000
Omnivore				
Day	0.244	0.032	0.461	0.987
Day squared	-0.056	-0.245	0.143	0.718
Time of day	0.137	-0.147	0.427	0.832
Temperature	-0.068	-0.245	0.116	0.778
Wind	-0.089	-0.382	0.175	0.751

APPENDIX C.2 Effects of covariates on logit of availability in occupancy model. Three covariates on detection probability in the occupancy model were statistically significant. Day of year had a nonlinear concave down effect on carnivore detection probability, day of year positively affected granivore detection probability, and wind negatively affected insectivore detection probability.

Variable	Median	2.5% CI	97.5% CI	f
Carnivore				
Day	0.106	-1.897	2.370	0.545
Day squared	-4.410	-6.935	-2.148	1.000
Time of day	0.308	-1.226	1.978	0.647
Temperature	0.340	-1.931	2.566	0.634
Wind	0.562	-0.405	1.523	0.871
Granivore				
Day	0.313	0.100	0.518	0.998
Day squared	-0.111	-0.261	0.033	0.941
Time of day	0.085	-0.113	0.296	0.786
Temperature	-0.130	-0.420	0.159	0.806
Wind	0.056	-0.115	0.226	0.757
Insectivore				
Day	0.033	-0.113	0.181	0.668
Day squared	-0.086	-0.190	0.017	0.945
Time of day	0.072	-0.111	0.232	0.793
Temperature	0.093	-0.117	0.349	0.810
Wind	-0.157	-0.276	-0.041	0.996
Omnivore				
Day	0.341	-0.171	0.831	0.907
Day squared	0.046	-0.331	0.429	0.600
Time of day	0.154	-0.455	0.708	0.709
Temperature	-0.354	-1.147	0.421	0.810
Wind	0.033	-0.395	0.498	0.552

APPENDIX D.1 Effects of fire frequency on log abundance of birds.

Species	β1 median	β1 2.5% CI	β1 97.5% CI	β1 f	β2 median	β2 2.5% CI	β2 97.5% CI	β2 f
BACS	0.087	-0.118	0.294	0.812	-0.027	-0.077	0.063	0.813
BHCO	0.019	-0.278	0.265	0.562	-0.037	-0.128	0.027	0.889
COGD	0.026	-0.160	0.207	0.613	-0.034	-0.101	0.037	0.891
EATO	0.071	-0.043	0.189	0.890	-0.029	-0.085	0.025	0.868
FISP	0.215	0.021	0.461	0.986	-0.033	-0.096	0.031	0.883
INBU	-0.120	-0.238	-0.012	0.983	-0.036	-0.096	0.012	0.927
MODO	0.240	0.101	0.398	1.000	-0.031	-0.088	0.031	0.865
NOBO	0.142	0.059	0.227	0.999	-0.036	-0.085	0.008	0.944
NOCA	-0.122	-0.239	-0.017	0.988	-0.040	-0.100	0.007	0.943
BLGR	0.068	-0.101	0.241	0.787	-0.011	-0.091	0.085	0.591
CACH	-0.108	-0.365	0.158	0.806	-0.008	-0.120	0.103	0.561
CARW	-0.016	-0.146	0.108	0.609	-0.030	-0.122	0.035	0.777
COYE	0.172	0.032	0.336	0.993	-0.030	-0.129	0.044	0.762
EAKI	-0.017	-0.230	0.232	0.558	-0.042	-0.208	0.046	0.794
EAWP	0.029	-0.203	0.278	0.603	-0.015	-0.141	0.089	0.631
GCFL	-0.152	-0.366	0.048	0.933	-0.024	-0.139	0.076	0.687
NOMO	0.236	-0.005	0.516	0.971	-0.024	-0.152	0.071	0.696
NOPA	-0.240	-0.560	0.041	0.948	-0.030	-0.159	0.077	0.715
OROR	0.011	-0.211	0.252	0.538	-0.039	-0.192	0.048	0.788
PIWA	-0.057	-0.277	0.164	0.700	-0.015	-0.122	0.103	0.632
RBWO	-0.033	-0.152	0.089	0.709	0.016	-0.049	0.116	0.683
RHWO	0.105	-0.083	0.284	0.867	-0.013	-0.099	0.073	0.632
RWBL	0.043	-0.186	0.283	0.646	-0.050	-0.236	0.034	0.834
TUTI	-0.130	-0.340	0.060	0.907	0.001	-0.085	0.135	0.510
WBNU	0.113	-0.139	0.372	0.813	-0.011	-0.108	0.096	0.577
WEVI	-0.510	-0.853	-0.144	1.000	0.013	-0.077	0.206	0.608
AMCR	-0.319	-0.997	0.128	0.920	0.000	-0.428	0.608	0.500
BLJA	-0.033	-0.250	0.177	0.610	-0.147	-0.318	0.018	0.952

APPENDIX D.2 Effects of ground cover on log abundance of birds.

Species	β1 median	β1 2.5% CI	β1 97.5% CI	β1 f	β2 median	β2 2.5% CI	β2 97.5% CI	β2 f
BACS	-0.018	-0.128	0.172	0.597	-0.003	-0.065	0.037	0.560
BHCO	-0.050	-0.258	0.076	0.829	0.004	-0.041	0.050	0.575
COGD	-0.038	-0.185	0.097	0.760	-0.002	-0.057	0.039	0.532
EATO	-0.018	-0.116	0.110	0.633	0.006	-0.027	0.047	0.623
FISP	-0.032	-0.173	0.123	0.701	0.006	-0.037	0.048	0.624
INBU	-0.064	-0.207	0.040	0.904	-0.006	-0.059	0.029	0.625
MODO	-0.020	-0.131	0.122	0.625	-0.005	-0.076	0.033	0.605
NOBO	-0.021	-0.110	0.086	0.676	0.004	-0.026	0.035	0.616
NOCA	-0.063	-0.203	0.038	0.899	0.000	-0.037	0.034	0.508
BLGR	0.013	-0.086	0.184	0.587	-0.013	-0.073	0.034	0.702
CACH	0.003	-0.147	0.232	0.526	-0.021	-0.177	0.035	0.748
CARW	-0.016	-0.161	0.090	0.674	-0.011	-0.072	0.035	0.704
COYE	-0.003	-0.147	0.120	0.537	-0.006	-0.052	0.040	0.603
EAKI	0.033	-0.066	0.318	0.694	0.000	-0.044	0.081	0.495
EAWP	-0.008	-0.190	0.147	0.577	-0.020	-0.150	0.029	0.757
GCFL	-0.009	-0.178	0.138	0.594	-0.010	-0.073	0.054	0.649
NOMO	0.015	-0.082	0.246	0.604	-0.008	-0.063	0.037	0.644
NOPA	-0.010	-0.202	0.124	0.617	-0.016	-0.114	0.050	0.721
OROR	-0.005	-0.198	0.144	0.553	-0.009	-0.082	0.056	0.632
PIWA	0.000	-0.151	0.172	0.498	-0.017	-0.113	0.043	0.728
RBWO	-0.004	-0.116	0.112	0.553	-0.011	-0.062	0.029	0.716
RHWO	-0.009	-0.187	0.108	0.609	-0.010	-0.068	0.060	0.651
RWBL	0.001	-0.168	0.168	0.512	-0.022	-0.107	0.029	0.789
TUTI	0.001	-0.127	0.150	0.511	0.003	-0.043	0.081	0.551
WBNU	-0.008	-0.226	0.129	0.587	-0.022	-0.153	0.023	0.807
WEVI	-0.020	-0.382	0.089	0.708	-0.018	-0.113	0.034	0.737
AMCR	0.125	-0.569	1.463	0.596	-0.136	-0.767	0.143	0.747
BLJA	-0.246	-0.571	0.036	0.954	0.091	0.000	0.175	0.975

APPENDIX D.3 Effects of vegetation height on log abundance of birds.

Species	β1 median	β1 2.5% CI	β1 97.5% CI	β1 f	β2 median	β2 2.5% CI	β2 97.5% CI	β2 f
BACS	0.108	-0.088	0.383	0.798	0.017	-0.058	0.177	0.634
BHCO	0.001	-0.209	0.279	0.503	-0.017	-0.117	0.082	0.628
COGD	-0.041	-0.233	0.137	0.675	0.001	-0.074	0.105	0.511
EATO	-0.068	-0.217	0.056	0.855	-0.006	-0.079	0.077	0.560
FISP	-0.097	-0.332	0.055	0.873	-0.010	-0.115	0.083	0.585
INBU	0.034	-0.093	0.200	0.670	0.009	-0.054	0.096	0.573
MODO	-0.014	-0.151	0.136	0.572	0.006	-0.073	0.132	0.545
NOBO	-0.071	-0.198	0.037	0.886	0.002	-0.064	0.081	0.524
NOCA	-0.073	-0.217	0.058	0.860	0.004	-0.069	0.081	0.533
BLGR	0.064	-0.112	0.303	0.773	0.022	-0.120	0.154	0.606
CACH	0.110	-0.122	0.501	0.835	-0.019	-0.288	0.184	0.575
CARW	0.136	-0.033	0.323	0.928	-0.072	-0.193	0.039	0.895
COYE	-0.063	-0.325	0.123	0.698	-0.032	-0.197	0.122	0.660
EAKI	-0.009	-0.336	0.204	0.535	0.130	-0.096	0.333	0.871
EAWP	0.130	-0.071	0.435	0.879	-0.063	-0.264	0.088	0.793
GCFL	0.147	-0.050	0.487	0.914	0.067	-0.075	0.219	0.780
NOMO	0.023	-0.232	0.246	0.588	0.137	-0.063	0.357	0.902
NOPA	-0.010	-0.304	0.237	0.534	-0.192	-0.525	0.035	0.939
OROR	-0.041	-0.444	0.160	0.638	-0.069	-0.397	0.151	0.757
PIWA	0.052	-0.188	0.315	0.699	-0.136	-0.395	0.058	0.897
RBWO	-0.016	-0.199	0.119	0.576	0.020	-0.108	0.134	0.624
RHWO	0.070	-0.093	0.278	0.800	0.123	-0.034	0.293	0.937
RWBL	-0.029	-0.411	0.164	0.598	0.008	-0.180	0.197	0.533
TUTI	0.103	-0.135	0.378	0.849	-0.020	-0.189	0.118	0.598
WBNU	0.090	-0.097	0.395	0.823	0.223	-0.022	0.411	0.963
WEVI	0.002	-0.331	0.234	0.490	-0.215	-0.607	0.024	0.957
AMCR	-0.060	-0.789	0.596	0.579	0.130	-0.480	0.542	0.672
BLJA	-0.010	-0.385	0.296	0.529	0.249	0.003	0.437	0.977

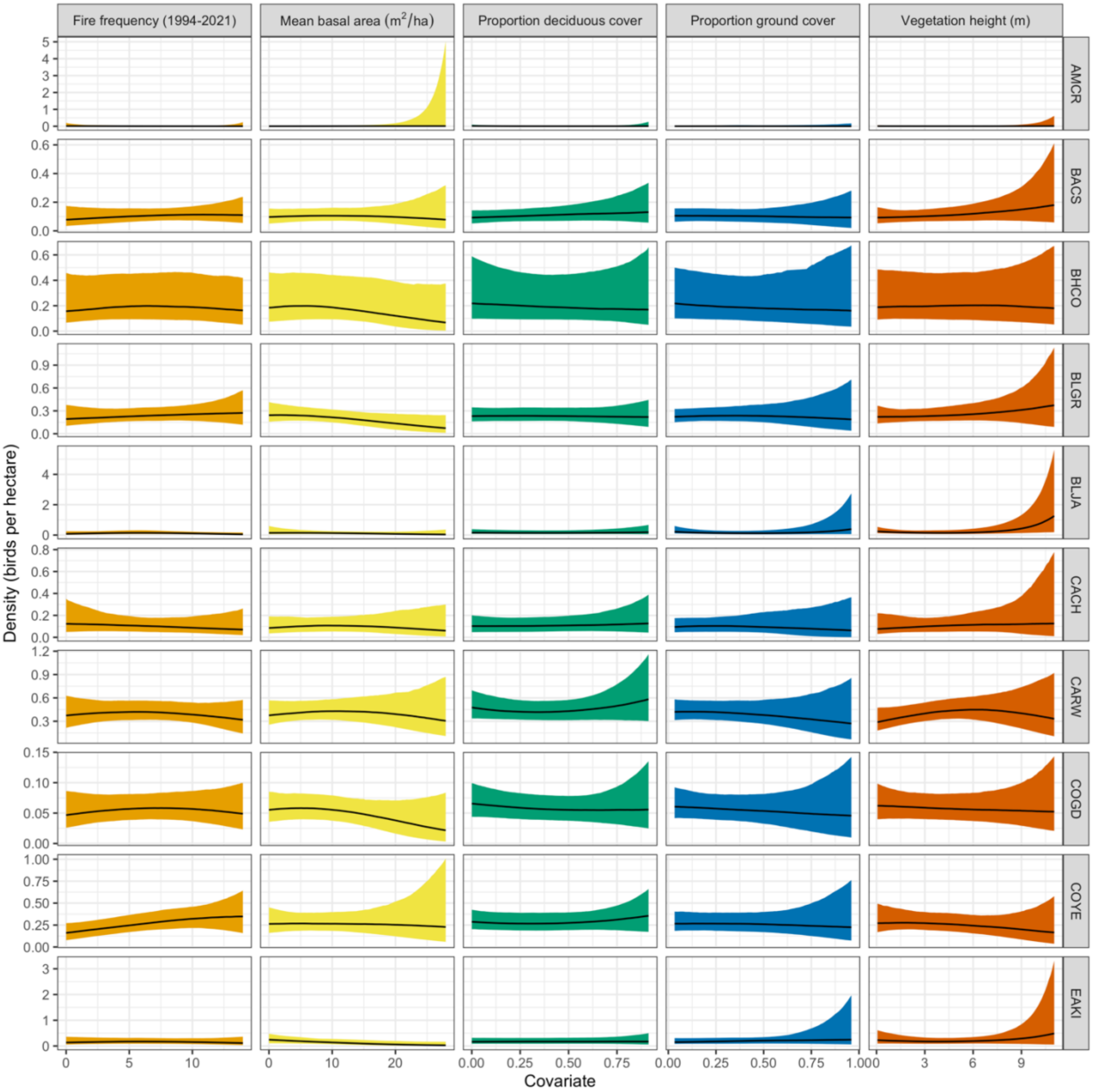
APPENDIX D.4 Effects of mean basal area on log abundance of birds.

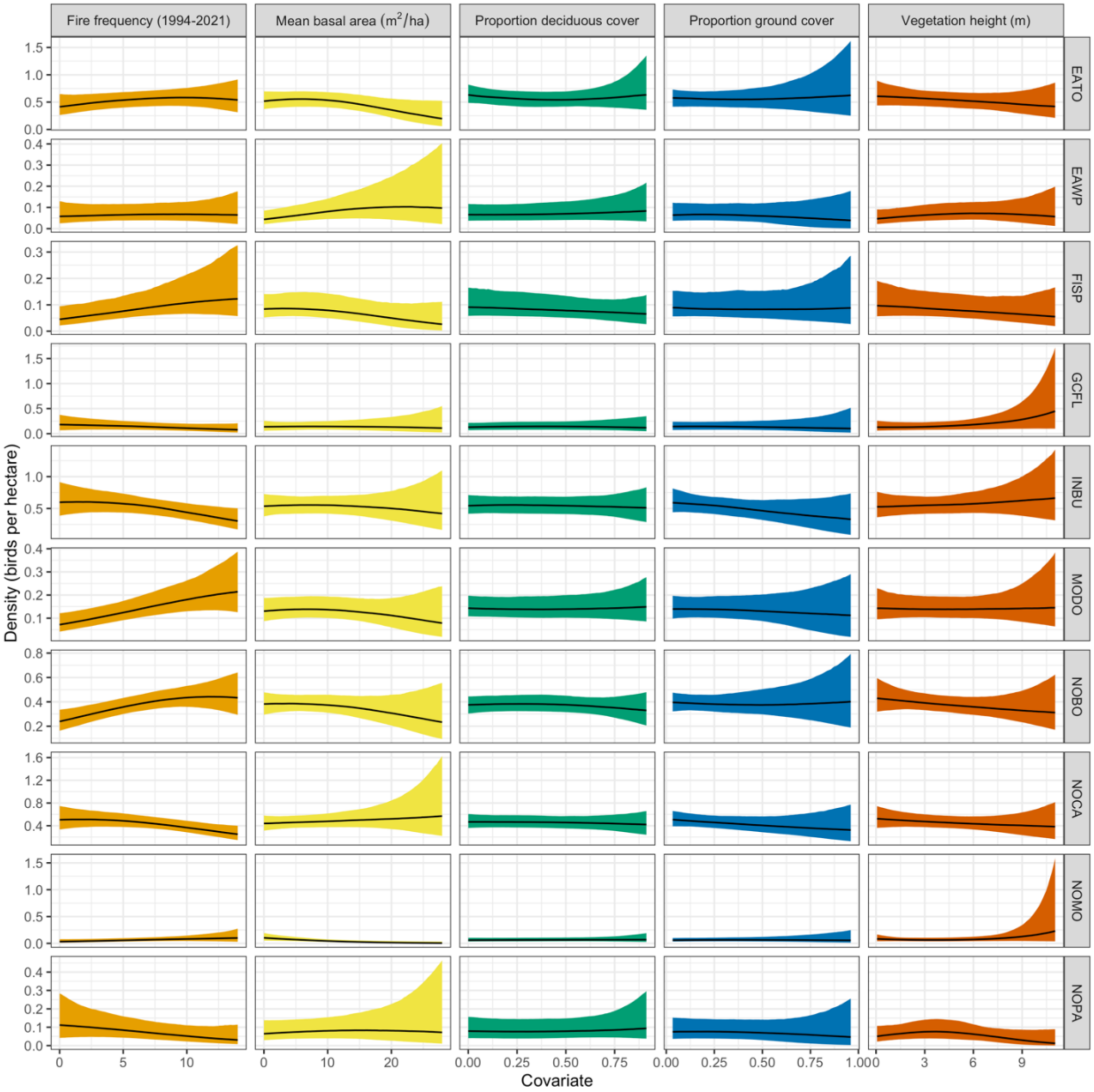
Species	β1 median	β1 2.5% CI	β1 97.5% CI	β1 f	β2 median	β2 2.5% CI	β2 97.5% CI	β2 f
BACS	0.028	-0.120	0.312	0.650	-0.029	-0.146	0.064	0.764
BHCO	-0.017	-0.261	0.146	0.581	-0.061	-0.268	0.050	0.899
COGD	-0.023	-0.246	0.142	0.628	-0.054	-0.200	0.034	0.890
EATO	-0.016	-0.153	0.127	0.586	-0.063	-0.156	0.006	0.963
FISP	-0.044	-0.325	0.090	0.717	-0.058	-0.226	0.035	0.905
INBU	0.003	-0.124	0.144	0.515	-0.018	-0.087	0.055	0.708
MODO	0.008	-0.121	0.160	0.552	-0.040	-0.139	0.037	0.845
NOBO	-0.023	-0.152	0.100	0.634	-0.026	-0.102	0.038	0.793
NOCA	0.045	-0.072	0.210	0.745	-0.001	-0.075	0.078	0.494
BLGR	-0.090	-0.358	0.128	0.782	-0.052	-0.165	0.029	0.916
CACH	0.104	-0.272	0.398	0.723	-0.056	-0.207	0.036	0.898
CARW	0.053	-0.131	0.243	0.692	-0.036	-0.107	0.039	0.824
COYE	0.001	-0.239	0.217	0.495	-0.015	-0.080	0.102	0.626
EAKI	-0.325	-0.695	0.002	0.975	-0.042	-0.164	0.064	0.818
EAWP	0.317	0.046	0.640	0.993	-0.054	-0.174	0.027	0.910
GCFL	0.021	-0.283	0.354	0.563	-0.025	-0.110	0.083	0.691
NOMO	-0.491	-0.820	-0.133	0.999	-0.043	-0.184	0.065	0.827
NOPA	0.093	-0.199	0.416	0.757	-0.032	-0.156	0.086	0.709
OROR	-0.281	-0.661	0.084	0.936	-0.027	-0.112	0.098	0.691
PIWA	0.227	-0.053	0.510	0.944	-0.047	-0.168	0.048	0.861
RBWO	0.049	-0.134	0.262	0.697	-0.065	-0.175	0.006	0.963
RHWO	-0.057	-0.300	0.170	0.666	-0.040	-0.140	0.057	0.829
RWBL	-0.258	-0.630	0.112	0.911	-0.033	-0.127	0.079	0.758
TUTI	0.127	-0.177	0.394	0.793	-0.032	-0.118	0.071	0.762
WBNU	-0.049	-0.380	0.263	0.637	-0.029	-0.121	0.077	0.725
WEVI	0.334	0.025	0.735	0.983	-0.029	-0.120	0.086	0.718
AMCR	0.358	-0.421	1.175	0.782	-0.048	-0.395	0.375	0.591
BLJA	-0.107	-0.609	0.245	0.722	-0.068	-0.233	0.128	0.780

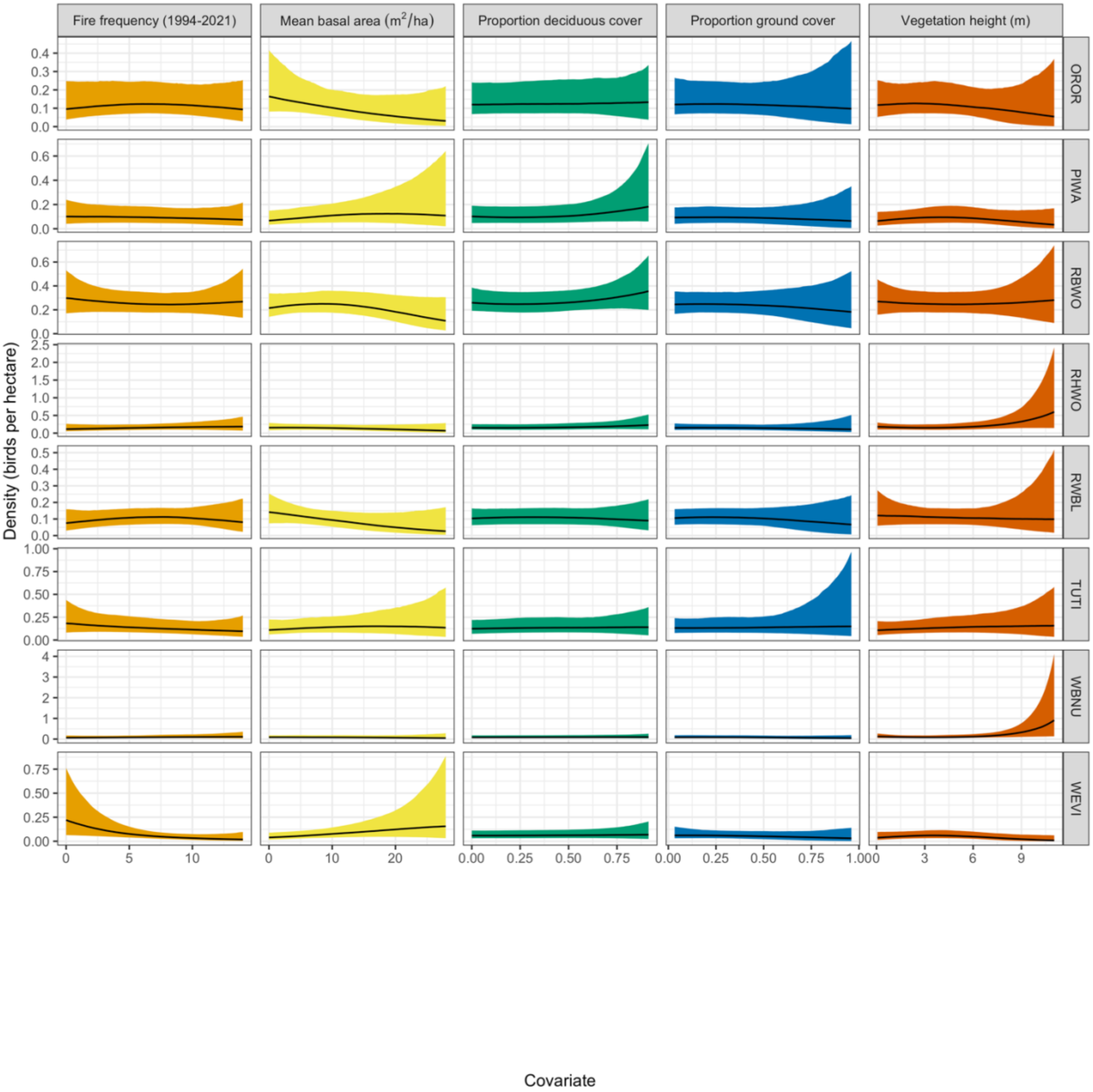
APPENDIX D.5 Effects of deciduous cover on log abundance of birds.

Species	β1 median	β1 2.5% CI	β1 97.5% CI	β1 f	β2 median	β2 2.5% CI	β2 97.5% CI	β2 f
BACS	0.101	-0.057	0.420	0.647	-0.002	-0.159	0.124	0.521
BHCO	-0.045	-0.339	0.099	0.847	-0.001	-0.126	0.143	0.486
COGD	-0.050	-0.280	0.063	0.907	0.019	-0.082	0.176	0.646
EATO	-0.048	-0.200	0.047	0.909	0.041	-0.042	0.203	0.778
FISP	-0.052	-0.309	0.063	0.902	-0.010	-0.165	0.111	0.580
INBU	-0.019	-0.101	0.116	0.621	-0.008	-0.120	0.081	0.571
MODO	-0.022	-0.116	0.125	0.673	0.011	-0.068	0.123	0.589
NOBO	-0.017	-0.080	0.096	0.599	-0.022	-0.119	0.051	0.718
NOCA	-0.022	-0.112	0.096	0.681	-0.009	-0.106	0.065	0.608
BLGR	0.006	-0.142	0.110	0.452	-0.010	-0.154	0.104	0.562
CACH	0.026	-0.100	0.221	0.739	0.025	-0.136	0.198	0.647
CARW	-0.025	-0.172	0.037	0.667	0.069	-0.029	0.173	0.917
COYE	-0.002	-0.145	0.076	0.512	0.048	-0.060	0.162	0.810
EAKI	0.020	-0.129	0.155	0.672	-0.003	-0.196	0.186	0.510
EAWP	0.026	-0.077	0.220	0.742	0.021	-0.116	0.166	0.642
GCFL	0.026	-0.081	0.206	0.783	-0.035	-0.217	0.095	0.682
NOMO	0.026	-0.061	0.213	0.796	0.004	-0.146	0.157	0.524
NOPA	0.019	-0.146	0.165	0.639	0.028	-0.115	0.204	0.674
OROR	0.019	-0.139	0.175	0.629	0.003	-0.213	0.167	0.484
PIWA	0.030	-0.062	0.273	0.808	0.074	-0.066	0.321	0.862
RBWO	0.020	-0.089	0.115	0.668	0.051	-0.051	0.170	0.841
RHWO	0.027	-0.059	0.232	0.798	0.044	-0.084	0.187	0.774
RWBL	0.020	-0.128	0.154	0.653	-0.028	-0.219	0.100	0.659
TUTI	0.027	-0.061	0.212	0.810	-0.005	-0.196	0.121	0.530
WBNU	0.027	-0.077	0.230	0.733	0.000	-0.159	0.145	0.499
WEVI	0.026	-0.089	0.179	0.729	0.009	-0.160	0.172	0.548
AMCR	-0.607	-1.260	0.017	0.963	0.274	-0.365	0.908	0.852
BLJA	-0.036	-0.284	0.192	0.641	0.057	-0.166	0.291	0.702

APPENDIX D.6 Effects of habitat covariates on densities of birds.




Fire frequency (1994-2021)
Mean basal area (m^2/ha)
Proportion deciduous cover
Proportion ground cover
Vegetation height (m)
EATO
EAWP
FISP
GCFL
INBU
MODO
NOBO
NOCA
NOMO
NOPA
Density (birds per hectare)
Covariate
0
5
10
20
0.00
0.25
0.50
0.75
1.000
3
6
9
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.8
1.0
1.2
1.5
1.6


Fire frequency (1994-2021)
Mean basal area (m^2/ha)
Proportion deciduous cover
Proportion ground cover
Vegetation height (m)
OROR
PIWA
RBWO
RHWO
RWBL
TUTI
WBNU
WEVI
Density (birds per hectare)
0.0
0.1
0.2
0.3
0.4
0.0
0.2
0.4
0.6
0.0
0.2
0.4
0.6
0.0
0.5
1.0
1.5
2.0
2.5
0.0
0.1
0.2
0.3
0.4
0.5
0.00
0.25
0.50
0.75
1.00
0
1
2
3
4
0.00
0.25
0.50
0.75
0
5
10
0
10
20
0.00
0.25
0.50
0.75
0.00
0.25
0.50
0.75
1.00
0
3
6
9
Covariate

APPENDIX E.1 Effects of fire frequency on mean logit of bird occupancy probability.

Species	β1 median	β1 2.5% CI	β1 97.5% CI	β1 f	β2 median	β2 2.5% CI	β2 97.5% CI	β2 f
BDOW	-0.746	-2.669	0.455	0.876	0.298	-0.842	2.112	0.689
COHA	-0.272	-1.974	1.444	0.669	-0.295	-3.921	0.932	0.673
RSHA	-0.007	-1.323	1.833	0.497	0.049	-1.012	1.235	0.538
RTHA	-0.314	-1.826	0.883	0.720	-0.262	-1.828	0.900	0.658
BACS	0.095	-0.713	1.023	0.600	-0.007	-0.349	0.346	0.522
BHCO	-0.074	-0.796	0.633	0.590	-0.074	-0.590	0.204	0.673
COGD	-0.020	-0.651	0.662	0.526	0.009	-0.317	0.368	0.529
EATO	0.307	-0.530	1.186	0.772	0.023	-0.302	0.560	0.566
FISP	0.376	-0.102	1.066	0.932	0.035	-0.250	0.377	0.620
INBU	-0.404	-1.306	0.275	0.873	0.008	-0.313	0.434	0.529
MODO	1.126	0.348	2.058	0.999	-0.002	-0.348	0.431	0.492
NOBO	0.581	-0.122	1.537	0.944	-0.001	-0.333	0.410	0.494
NOCA	-0.689	-1.700	0.061	0.964	-0.054	-0.464	0.225	0.643
ACFL	-0.148	-0.698	0.322	0.742	-0.026	-0.321	0.247	0.611
BGGN	-0.168	-0.569	0.185	0.828	-0.013	-0.231	0.260	0.454
BHNU	-0.116	-0.559	0.293	0.712	-0.036	-0.311	0.215	0.660
BLGR	-0.066	-0.516	0.346	0.636	-0.008	-0.229	0.310	0.469
BRTH	-0.111	-0.560	0.310	0.707	-0.039	-0.403	0.169	0.686
CACH	-0.075	-0.459	0.316	0.666	-0.021	-0.253	0.259	0.583
CARW	-0.110	-0.542	0.324	0.709	-0.047	-0.398	0.184	0.718
CHSW	-0.133	-0.743	0.394	0.710	-0.028	-0.347	0.228	0.624
COYE	0.292	-0.064	0.690	0.932	-0.055	-0.336	0.122	0.771
DOWO	-0.220	-0.712	0.183	0.864	-0.041	-0.350	0.182	0.707
EABL	-0.383	-0.919	0.023	0.966	0.024	-0.170	0.371	0.586
EAKI	0.021	-0.344	0.417	0.552	-0.041	-0.324	0.176	0.706
EAPH	-0.065	-0.588	0.476	0.618	-0.037	-0.372	0.218	0.671
EAWP	-0.019	-0.388	0.386	0.536	-0.021	-0.252	0.231	0.589
GCFL	-0.172	-0.581	0.197	0.814	-0.029	-0.263	0.212	0.640
GRCA	-0.002	-0.430	0.482	0.496	-0.048	-0.443	0.164	0.737
LOSH	-0.142	-0.732	0.334	0.726	-0.029	-0.373	0.253	0.622
NOFL	-0.087	-0.571	0.402	0.646	-0.030	-0.327	0.204	0.629
NOMO	0.321	-0.049	0.786	0.947	-0.022	-0.238	0.214	0.597
NOPA	-0.212	-0.610	0.136	0.890	-0.057	-0.388	0.123	0.783
OROR	-0.006	-0.396	0.372	0.509	-0.048	-0.362	0.161	0.746
PIWA	-0.107	-0.490	0.217	0.739	0.001	-0.171	0.287	0.503
PIWO	-0.226	-0.679	0.175	0.873	-0.048	-0.383	0.143	0.727
PROW	-0.147	-0.762	0.339	0.739	-0.024	-0.320	0.258	0.598
PUMA	-0.026	-0.540	0.587	0.540	-0.030	-0.346	0.269	0.636
RBWO	-0.138	-0.662	0.325	0.735	0.010	-0.200	0.412	0.538

Species	β1 median	β1 2.5% CI	β1 97.5% CI	β1 f	β2 median	β2 2.5% CI	β2 97.5% CI	β2 f
RCWO	0.052	-0.438	0.633	0.594	-0.020	-0.269	0.278	0.578
REVI	-0.062	-0.563	0.439	0.594	0.013	-0.203	0.412	0.540
RHWO	-0.043	-0.404	0.294	0.599	-0.025	-0.226	0.219	0.616
RWBL	0.105	-0.255	0.517	0.717	-0.094	-0.504	0.087	0.844
STKI	-0.141	-0.749	0.323	0.724	-0.029	-0.312	0.228	0.640
SUTA	-0.013	-0.430	0.414	0.526	-0.032	-0.299	0.207	0.661
TUTI	-0.173	-0.572	0.169	0.839	0.024	-0.153	0.412	0.585
WBNU	0.145	-0.207	0.624	0.771	-0.031	-0.288	0.189	0.653
WEVI	-0.324	-0.811	0.047	0.957	0.052	-0.140	0.387	0.666
YBCH	-0.074	-0.418	0.295	0.685	-0.029	-0.272	0.181	0.628
YBCU	-0.161	-0.650	0.281	0.765	-0.028	-0.293	0.252	0.613
YTVI	-0.137	-0.591	0.288	0.750	-0.050	-0.382	0.151	0.749
AMCR	-0.536	-3.375	0.966	0.791	0.025	-1.413	2.015	0.516
BLJA	-0.140	-1.395	1.620	0.588	0.051	-1.262	2.962	0.527
COGR	-0.223	-1.543	1.555	0.621	-0.659	-3.489	0.822	0.770
FICR	-0.250	-2.842	1.280	0.627	-0.565	-2.504	1.103	0.723

APPENDIX E.2 Effects of ground cover on mean logit of bird occupancy probability.

Species	β1 median	β1 2.5% CI	β1 97.5% CI	β1 f	β2 median	β2 2.5% CI	β2 97.5% CI	β2 f
BDOW	0.248	-1.276	2.298	0.635	-0.248	-2.443	0.511	0.695
COHA	0.002	-2.444	2.075	0.499	-0.308	-3.445	0.540	0.719
RSHA	-0.652	-4.540	0.910	0.771	-0.136	-2.239	0.641	0.615
RTHA	0.432	-0.840	3.058	0.733	0.284	-0.230	1.645	0.837
BACS	-0.273	-0.887	0.685	0.765	-0.019	-0.582	0.434	0.528
BHCO	-0.552	-1.543	-0.059	0.986	0.235	0.017	0.630	0.982
COGD	-0.467	-1.288	0.125	0.942	0.218	-0.035	0.859	0.954
EATO	-0.402	-1.130	0.459	0.875	0.309	0.002	1.138	0.976
FISP	-0.381	-0.967	0.113	0.943	0.349	0.084	0.865	0.997
INBU	-0.548	-1.519	-0.048	0.984	0.053	-0.279	0.658	0.605
MODO	-0.382	-1.008	0.293	0.881	0.178	-0.150	0.763	0.847
NOBO	-0.310	-0.883	0.598	0.820	0.290	-0.012	1.058	0.970
NOCA	-0.398	-1.080	0.222	0.908	0.175	-0.118	0.723	0.870
ACFL	-0.120	-0.647	0.299	0.747	-0.024	-0.253	0.135	0.628
BGGN	-0.081	-0.441	0.351	0.681	-0.039	-0.251	0.101	0.716
BHNU	-0.007	-0.356	0.491	0.486	0.027	-0.101	0.198	0.675
BLGR	-0.056	-0.451	0.412	0.607	-0.005	-0.148	0.151	0.535
BRTH	-0.114	-0.565	0.304	0.760	-0.033	-0.273	0.098	0.678
CACH	-0.083	-0.488	0.368	0.665	-0.041	-0.319	0.103	0.700
CARW	-0.209	-0.744	0.139	0.889	0.000	-0.135	0.163	0.502
CHSW	-0.113	-0.664	0.352	0.737	-0.023	-0.281	0.138	0.618
COYE	-0.098	-0.446	0.265	0.718	0.030	-0.086	0.266	0.681
DOWO	-0.113	-0.561	0.297	0.758	-0.018	-0.226	0.128	0.615
EABL	-0.078	-0.518	0.366	0.680	-0.043	-0.288	0.096	0.691
EAKI	0.086	-0.263	0.699	0.650	0.056	-0.076	0.316	0.795
EAPH	-0.107	-0.593	0.420	0.725	-0.020	-0.280	0.149	0.603
EAWP	-0.183	-0.706	0.139	0.878	-0.037	-0.272	0.093	0.692
GCFL	-0.092	-0.450	0.326	0.705	0.009	-0.129	0.183	0.560
GRCA	-0.100	-0.528	0.331	0.710	-0.024	-0.276	0.115	0.630
LOSH	-0.102	-0.628	0.371	0.709	-0.026	-0.296	0.117	0.631
NOFL	-0.107	-0.615	0.362	0.729	-0.029	-0.285	0.119	0.648
NOMO	0.043	-0.293	0.560	0.587	0.003	-0.127	0.149	0.520
NOPA	-0.218	-0.705	0.108	0.904	-0.025	-0.222	0.094	0.641
OROR	-0.088	-0.426	0.301	0.699	0.007	-0.129	0.180	0.545
PIWA	-0.044	-0.369	0.376	0.602	-0.037	-0.238	0.099	0.688
PIWO	-0.147	-0.616	0.208	0.828	-0.034	-0.292	0.112	0.670
PROW	-0.110	-0.596	0.342	0.731	-0.021	-0.267	0.133	0.606
PUMA	-0.121	-0.690	0.327	0.758	-0.017	-0.231	0.147	0.598
RBWO	-0.074	-0.520	0.394	0.660	-0.015	-0.199	0.167	0.579

Species	β1 median	β1 2.5% CI	β1 97.5% CI	β1 f	β2 median	β2 2.5% CI	β2 97.5% CI	β2 f
RCWO	-0.106	-0.595	0.369	0.722	-0.028	-0.273	0.130	0.638
REVI	-0.138	-0.705	0.251	0.790	-0.019	-0.262	0.134	0.601
RHWO	-0.053	-0.407	0.396	0.613	0.021	-0.094	0.193	0.635
RWBL	-0.055	-0.428	0.374	0.622	-0.022	-0.184	0.105	0.637
STKI	-0.106	-0.618	0.388	0.715	-0.025	-0.275	0.125	0.626
SUTA	-0.019	-0.411	0.549	0.463	-0.027	-0.259	0.100	0.650
TUTI	-0.107	-0.496	0.256	0.754	0.043	-0.076	0.282	0.761
WBNU	-0.118	-0.517	0.256	0.777	-0.061	-0.349	0.065	0.782
WEVI	-0.240	-0.912	0.127	0.904	-0.018	-0.254	0.120	0.608
YBCH	-0.330	-0.918	0.008	0.972	-0.023	-0.244	0.119	0.628
YBCU	-0.008	-0.381	0.620	0.488	-0.017	-0.235	0.140	0.595
YTVI	-0.131	-0.622	0.256	0.791	-0.036	-0.268	0.097	0.693
AMCR	-0.187	-2.369	1.416	0.609	0.158	-1.388	2.392	0.578
BLJA	-0.397	-2.417	1.021	0.697	1.298	-0.101	5.023	0.952
COGR	-0.470	-2.441	1.072	0.713	0.033	-2.205	2.051	0.517
FICR	-0.314	-2.429	1.494	0.643	-0.160	-2.351	2.238	0.557

APPENDIX E.3 Effects of vegetation height on mean logit of bird occupancy probability.

Species	β1 median	β1 2.5% CI	β1 97.5% CI	β1 f	β2 median	β2 2.5% CI	β2 97.5% CI	β2 f
BDOW	-0.052	-2.117	2.294	0.535	-1.803	-7.458	-0.486	0.994
COHA	-0.140	-2.293	2.206	0.586	-1.651	-5.481	0.048	0.971
RSHA	-0.026	-2.055	2.872	0.488	-1.750	-5.483	-0.230	0.985
RTHA	-0.955	-4.081	0.814	0.804	-1.308	-2.811	0.296	0.946
BACS	0.305	-0.191	1.424	0.824	0.169	-0.512	0.849	0.726
BHCO	0.316	-0.176	1.218	0.827	-0.159	-0.922	0.460	0.676
COGD	0.088	-0.548	0.880	0.616	0.187	-0.508	0.751	0.746
EATO	0.092	-0.674	0.941	0.612	0.527	-0.056	1.499	0.961
FISP	-0.032	-0.644	0.598	0.546	-0.035	-0.618	0.450	0.556
INBU	0.254	-0.358	1.288	0.774	0.656	0.077	1.563	0.985
MODO	0.082	-0.740	0.905	0.613	0.425	-0.104	1.182	0.929
NOBO	0.251	-0.316	1.273	0.770	0.636	0.067	1.480	0.987
NOCA	0.004	-0.932	0.744	0.496	0.730	0.100	1.843	0.990
ACFL	0.233	-0.435	0.797	0.816	-0.274	-0.923	0.120	0.898
BGGN	0.381	-0.030	0.896	0.967	-0.076	-0.367	0.293	0.679
BHNU	0.230	-0.296	0.718	0.838	-0.178	-0.576	0.161	0.838
BLGR	0.389	-0.093	0.937	0.947	0.000	-0.339	0.428	0.501
BRTH	0.325	-0.131	0.827	0.924	-0.031	-0.418	0.340	0.568
CACH	0.519	0.102	1.167	0.993	-0.039	-0.409	0.387	0.584
CARW	0.405	-0.022	0.990	0.968	-0.137	-0.537	0.310	0.744
CHSW	0.209	-0.503	0.797	0.769	-0.152	-0.637	0.306	0.758
COYE	0.176	-0.313	0.608	0.785	-0.315	-0.634	-0.042	0.986
DOWO	0.206	-0.363	0.678	0.800	-0.233	-0.690	0.120	0.892
EABL	0.238	-0.294	0.691	0.830	0.052	-0.299	0.507	0.607
EAKI	0.270	-0.131	0.735	0.911	-0.004	-0.332	0.439	0.491
EAPH	0.273	-0.331	0.899	0.841	-0.168	-0.737	0.269	0.778
EAWP	0.509	0.088	1.076	0.993	-0.192	-0.566	0.185	0.870
GCFL	0.588	0.158	1.191	0.998	-0.034	-0.338	0.335	0.584
GRCA	0.236	-0.289	0.750	0.820	-0.219	-0.730	0.154	0.876
LOSH	0.198	-0.469	0.727	0.763	-0.109	-0.635	0.348	0.690
NOFL	0.247	-0.325	0.793	0.834	-0.101	-0.506	0.317	0.702
NOMO	0.192	-0.310	0.607	0.800	0.198	-0.127	0.571	0.870
NOPA	0.114	-0.452	0.519	0.669	-0.266	-0.674	0.064	0.945
OROR	0.060	-0.499	0.467	0.605	-0.139	-0.499	0.197	0.807
PIWA	0.315	-0.142	0.753	0.929	-0.260	-0.613	0.043	0.959
PIWO	0.286	-0.186	0.761	0.896	-0.172	-0.551	0.168	0.850
PROW	0.362	-0.121	1.026	0.933	-0.123	-0.575	0.295	0.727
PUMA	0.298	-0.324	0.935	0.862	-0.191	-0.718	0.259	0.813
RBWO	0.262	-0.321	0.844	0.853	-0.041	-0.485	0.487	0.582

Species	β1 median	β1 2.5% CI	β1 97.5% CI	β1 f	β2 median	β2 2.5% CI	β2 97.5% CI	β2 f
RCWO	0.367	-0.166	1.093	0.927	-0.070	-0.504	0.366	0.644
REVI	0.268	-0.330	0.857	0.825	-0.232	-0.783	0.178	0.866
RHWO	0.565	0.146	1.145	0.998	0.179	-0.179	0.686	0.811
RWBL	0.043	-0.577	0.471	0.575	-0.078	-0.445	0.333	0.679
STKI	0.189	-0.431	0.731	0.759	-0.110	-0.581	0.312	0.706
SUTA	0.523	0.098	1.216	0.992	-0.258	-0.727	0.076	0.929
TUTI	0.372	-0.052	0.841	0.963	-0.067	-0.378	0.301	0.663
WBNU	0.393	0.020	0.952	0.979	0.150	-0.194	0.608	0.775
WEVI	0.115	-0.530	0.584	0.660	-0.277	-0.723	0.078	0.934
YBCH	0.182	-0.345	0.603	0.779	-0.296	-0.758	0.037	0.959
YBCU	0.248	-0.325	0.766	0.829	0.050	-0.317	0.429	0.608
YTVI	0.324	-0.193	0.926	0.908	-0.138	-0.573	0.243	0.768
AMCR	0.669	-1.232	3.006	0.746	-0.387	-2.846	3.666	0.604
BLJA	0.549	-1.445	2.490	0.771	0.712	-1.835	8.999	0.674
COGR	0.491	-1.410	2.580	0.701	-1.023	-5.297	0.805	0.834
FICR	0.294	-1.990	2.384	0.588	-0.631	-2.729	1.358	0.729

APPENDIX E.4 Effects of mean basal area on mean logit of bird occupancy probability.

Species	β1 median	β1 2.5% CI	β1 97.5% CI	β1 f	β2 median	β2 2.5% CI	β2 97.5% CI	β2 f
BDOW	-0.124	-2.988	2.326	0.547	-0.821	-3.161	0.245	0.946
COHA	0.145	-2.776	2.871	0.544	-0.614	-3.230	0.503	0.793
RSHA	1.913	-0.377	4.860	0.936	-1.044	-2.056	0.489	0.932
RTHA	-1.411	-4.540	0.920	0.843	-0.535	-2.058	1.285	0.881
BACS	-0.090	-0.869	0.655	0.609	-0.222	-0.619	0.128	0.937
BHCO	-0.237	-1.112	0.281	0.798	-0.231	-0.728	0.035	0.962
COGD	-0.298	-1.234	0.223	0.839	-0.264	-0.767	-0.001	0.975
EATO	-0.219	-1.140	0.393	0.751	-0.203	-0.516	0.280	0.895
FISP	-0.365	-1.308	0.156	0.882	-0.205	-0.619	0.151	0.916
INBU	-0.185	-1.066	0.429	0.724	-0.190	-0.494	0.540	0.841
MODO	-0.203	-1.089	0.376	0.745	-0.209	-0.568	0.157	0.909
NOBO	-0.239	-1.115	0.318	0.779	-0.229	-0.636	0.070	0.952
NOCA	-0.080	-0.925	0.659	0.587	-0.164	-0.444	0.533	0.785
ACFL	0.090	-0.543	0.866	0.618	0.075	-0.049	0.299	0.939
BGGN	-0.015	-0.525	0.525	0.520	0.069	-0.086	0.212	0.907
BHNU	-0.161	-0.732	0.412	0.712	0.063	-0.158	0.180	0.854
BLGR	-0.375	-1.035	0.254	0.884	0.063	-0.180	0.173	0.850
BRTH	-0.439	-1.168	0.120	0.938	0.064	-0.216	0.188	0.847
CACH	-0.187	-0.822	0.392	0.731	0.060	-0.280	0.149	0.793
CARW	0.101	-0.520	0.921	0.625	0.066	-0.113	0.241	0.879
CHSW	-0.347	-1.208	0.369	0.843	0.068	-0.130	0.234	0.887
COYE	-0.277	-0.746	0.194	0.886	0.071	-0.059	0.220	0.928
DOWO	-0.120	-0.726	0.480	0.657	0.063	-0.192	0.176	0.838
EABL	-0.238	-0.840	0.328	0.805	0.066	-0.102	0.223	0.901
EAKI	-0.719	-1.375	-0.165	0.994	0.068	-0.141	0.207	0.887
EAPH	-0.196	-1.053	0.640	0.697	0.067	-0.165	0.204	0.873
EAWP	0.214	-0.312	0.851	0.777	0.063	-0.155	0.176	0.847
GCFL	-0.163	-0.675	0.396	0.730	0.068	-0.081	0.233	0.898
GRCA	-0.409	-1.186	0.194	0.901	0.064	-0.163	0.189	0.866
LOSH	-0.337	-1.213	0.351	0.834	0.065	-0.158	0.202	0.874
NOFL	-0.006	-0.623	0.616	0.506	0.086	-0.002	0.423	0.973
NOMO	-0.792	-1.437	-0.222	0.998	0.068	-0.086	0.231	0.917
NOPA	-0.134	-0.656	0.347	0.709	0.065	-0.096	0.197	0.891
OROR	-0.453	-1.005	0.051	0.964	0.076	-0.048	0.292	0.946
PIWA	-0.159	-0.626	0.335	0.742	0.062	-0.125	0.169	0.858
PIWO	0.069	-0.418	0.553	0.609	0.082	-0.008	0.375	0.968
PROW	-0.073	-0.773	0.756	0.581	0.066	-0.142	0.228	0.882
PUMA	-0.231	-1.016	0.487	0.752	0.066	-0.146	0.213	0.871
RBWO	-0.195	-0.915	0.558	0.714	0.071	-0.076	0.278	0.917

Species	β1 median	β1 2.5% CI	β1 97.5% CI	β1 f	β2 median	β2 2.5% CI	β2 97.5% CI	β2 f
RCWO	0.040	-0.628	0.842	0.547	0.071	-0.086	0.270	0.917
REVI	0.187	-0.461	1.026	0.704	0.078	-0.039	0.319	0.946
RHWO	-0.168	-0.681	0.417	0.738	0.067	-0.120	0.227	0.883
RWBL	-0.576	-1.218	-0.050	0.983	0.064	-0.172	0.184	0.855
STKI	-0.343	-1.234	0.389	0.830	0.068	-0.145	0.223	0.888
SUTA	0.021	-0.546	0.603	0.525	0.062	-0.181	0.166	0.833
TUTI	0.045	-0.407	0.600	0.571	0.072	-0.056	0.256	0.933
WBNU	-0.282	-0.796	0.206	0.873	0.064	-0.123	0.202	0.867
WEVI	0.267	-0.294	0.885	0.820	0.077	-0.048	0.312	0.943
YBCH	-0.519	-1.079	0.000	0.975	0.058	-0.217	0.142	0.792
YBCU	-0.158	-0.760	0.410	0.700	0.082	-0.026	0.327	0.958
YTVI	0.008	-0.563	0.672	0.511	0.068	-0.132	0.232	0.896
AMCR	0.244	-0.909	4.265	0.656	0.366	-1.603	2.117	0.651
BLJA	0.084	-1.504	1.924	0.541	-0.092	-2.046	3.909	0.465
COGR	0.171	-1.292	2.658	0.597	-0.673	-3.049	0.847	0.796
FICR	-0.147	-3.441	1.505	0.564	-0.782	-3.979	1.022	0.792

APPENDIX E.5 Effects of deciduous cover on mean logit of bird occupancy probability.

Species	β1 median	β1 2.5% CI	β1 97.5% CI	β1 f	β2 median	β2 2.5% CI	β2 97.5% CI	β2 f
BDOW	-0.892	-2.996	0.469	0.903	0.238	-2.422	1.493	0.621
COHA	-0.598	-2.304	1.440	0.765	0.122	-3.229	1.566	0.429
RSHA	-0.599	-2.184	0.827	0.813	0.617	-0.901	2.149	0.792
RTHA	-0.635	-2.199	0.674	0.836	0.780	-0.538	2.227	0.867
BACS	0.438	-0.414	1.609	0.833	0.032	-0.527	0.493	0.548
BHCO	-0.178	-0.788	0.344	0.737	0.056	-0.428	0.522	0.597
COGD	-0.095	-0.665	0.491	0.637	0.235	-0.195	0.968	0.840
EATO	-0.150	-0.885	0.574	0.680	0.096	-0.465	0.691	0.639
FISP	-0.351	-1.010	0.217	0.913	-0.072	-0.592	0.336	0.622
INBU	-0.064	-0.728	0.579	0.582	0.141	-0.299	0.803	0.715
MODO	-0.195	-0.866	0.395	0.735	0.072	-0.515	0.649	0.606
NOBO	-0.097	-0.745	0.612	0.625	0.167	-0.252	0.822	0.770
NOCA	-0.283	-1.052	0.267	0.839	0.044	-0.505	0.574	0.563
ACFL	0.072	-0.283	0.431	0.685	0.034	-0.191	0.179	0.678
BGGN	0.036	-0.264	0.306	0.608	0.029	-0.194	0.151	0.638
BHNU	0.013	-0.365	0.306	0.473	0.022	-0.241	0.133	0.393
BLGR	0.028	-0.327	0.329	0.585	0.032	-0.188	0.176	0.641
BRTH	0.143	-0.115	0.633	0.851	0.046	-0.139	0.234	0.728
CACH	0.102	-0.166	0.479	0.780	0.049	-0.124	0.242	0.736
CARW	0.001	-0.407	0.310	0.498	0.048	-0.115	0.245	0.753
CHSW	0.033	-0.349	0.369	0.588	0.031	-0.197	0.183	0.654
COYE	0.045	-0.206	0.328	0.647	0.049	-0.100	0.221	0.752
DOWO	0.046	-0.291	0.359	0.630	0.029	-0.214	0.169	0.652
EABL	0.027	-0.325	0.325	0.575	0.035	-0.173	0.171	0.676
EAKI	0.031	-0.290	0.319	0.586	0.032	-0.185	0.161	0.655
EAPH	0.054	-0.300	0.421	0.644	0.032	-0.202	0.177	0.660
EAWP	0.051	-0.238	0.369	0.671	0.027	-0.198	0.157	0.620
GCFL	0.024	-0.303	0.348	0.566	0.025	-0.222	0.147	0.623
GRCA	0.109	-0.168	0.528	0.793	0.038	-0.186	0.204	0.684
LOSH	0.030	-0.372	0.376	0.583	0.030	-0.200	0.161	0.656
NOFL	0.046	-0.295	0.380	0.636	0.024	-0.245	0.145	0.608
NOMO	0.105	-0.151	0.456	0.799	0.027	-0.198	0.140	0.634
NOPA	0.025	-0.296	0.293	0.570	0.036	-0.159	0.175	0.685
OROR	0.023	-0.278	0.306	0.566	0.030	-0.192	0.169	0.652
PIWA	0.164	-0.072	0.573	0.922	0.056	-0.094	0.263	0.798
PIWO	0.048	-0.262	0.341	0.639	0.033	-0.186	0.166	0.661
PROW	0.064	-0.278	0.454	0.680	0.032	-0.186	0.168	0.661
PUMA	0.057	-0.358	0.420	0.654	0.030	-0.208	0.165	0.643
RBWO	0.047	-0.341	0.407	0.627	0.047	-0.140	0.248	0.730

Species	β1 median	β1 2.5% CI	β1 97.5% CI	β1 f	β2 median	β2 2.5% CI	β2 97.5% CI	β2 f
RCWO	0.076	-0.239	0.503	0.711	0.031	-0.199	0.178	0.652
REVI	0.064	-0.277	0.462	0.673	0.039	-0.170	0.215	0.702
RHWO	0.108	-0.144	0.454	0.816	0.032	-0.173	0.174	0.656
RWBL	0.042	-0.257	0.307	0.631	0.018	-0.245	0.114	0.427
STKI	0.032	-0.371	0.395	0.597	0.033	-0.186	0.189	0.662
SUTA	0.055	-0.259	0.367	0.645	0.042	-0.152	0.210	0.712
TUTI	0.095	-0.173	0.439	0.779	0.021	-0.247	0.133	0.596
WBNU	0.121	-0.139	0.508	0.836	0.028	-0.190	0.150	0.627
WEVI	0.045	-0.294	0.354	0.628	0.033	-0.178	0.180	0.668
YBCH	-0.118	-0.598	0.140	0.757	0.031	-0.177	0.155	0.658
YBCU	0.018	-0.369	0.320	0.549	0.038	-0.167	0.190	0.674
YTVI	0.038	-0.299	0.356	0.619	0.046	-0.128	0.226	0.724
AMCR	-1.300	-5.080	0.197	0.949	2.306	-0.794	8.342	0.881
BLJA	-0.692	-3.038	1.285	0.775	0.490	-1.264	7.058	0.701
COGR	-0.744	-2.912	1.738	0.802	-2.171	-13.110	0.879	0.871
FICR	-1.205	-3.623	0.209	0.947	2.539	-0.624	10.171	0.877