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Research Paper

Habitat use of conifer forests for Interior Band-tailed Pigeons is mediated by precipitation

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ABSTRACT. Although managing habitats in the context of climate change is increasingly important in Western North America, management recommendations are often lacking at fine scales relevant for management. Identifying management actions for climate adaptation requires an understanding of how wildlife (i) might vary in their response to habitat conditions across their range and (ii) the spatial scale of environmental effects. We quantified breeding habitat use of the Interior population of Band-tailed Pigeons (*Patagioenas fasciata*) in the Southwestern U.S. by analyzing data from satellite-tagged birds with a resource selection function. We used Reversible-jump Markov chain Monte Carlo (RJMCMC) to quantify habitat use of Band-tailed Pigeons across vegetation, topography, and precipitation, examining the possibility for differences in habitat selection and estimated the most ecologically relevant spatio-temporal scale for these habitat features (i.e., the optimal “scale of effect”). Our RJMCMC results indicated that Band-tailed Pigeon intensity of use was characterized by precipitation × conifer cover and precipitation × basal area interactions. In drier areas, Band-tailed Pigeons were more likely to use areas with more conifer cover; as precipitation increased, Band-tailed Pigeons were more likely to use areas with less conifer cover. Increased precipitation facilitated greater use of forests with higher basal area, and drier areas were associated with use of forests with lower basal area. Conifer cover was primarily selected at the 1 km scale, and basal area was selected at the 2 km scale in response to precipitation during the winter preceding the breeding season. Although Band-tailed Pigeons have long been known to associate with conifer forests, we found that their use of conifer forest varied across a gradient of precipitation. Using our approach to select the scale of effect for forest habitat and basal area in response to changes in precipitation can provide more precise, spatially relevant habitat management recommendations than approaches using model selection such as Akaike’s Information Criterion.

Les précipitations ont un effet sur l’utilisation des forêts de conifères par le Pigeon à queue barrée de l’intérieur

RÉSUMÉ. Bien que la gestion des habitats en contexte de changements climatiques soit de plus en plus importante dans l’ouest de l’Amérique du Nord, les recommandations de gestion font souvent défaut aux échelles fines pertinentes. La sélection de mesures de gestion destinées à l’adaptation au climat nécessite une compréhension de la façon dont la faune (i) pourrait varier dans sa réponse aux conditions de l’habitat dans son aire de répartition et (ii) l’échelle spatiale des effets environnementaux. Nous avons quantifié l’utilisation de l’habitat de reproduction de la population intérieure de Pigeons à queue barrée (*Patagioenas fasciata*) dans le sud-ouest des États-Unis en analysant les données d’oiseaux munis d’émetteurs satellitaires avec une fonction de sélection des ressources. Nous avons utilisé la méthode de Monte-Carlo par chaînes de Markov à saut réversible (MCCMSR) pour quantifier l’utilisation de l’habitat des Pigeons à queue barrée en fonction de la végétation, de la topographie et des précipitations, en examinant la possibilité de différences dans la sélection de l’habitat et en estimant l’échelle spatio-temporelle la plus pertinente sur le plan écologique pour ces caractéristiques d’habitat (c’est-à-dire « l’échelle d’effet » optimale). Les résultats de MCCMSR ont indiqué que l’intensité d’utilisation du Pigeon à queue barrée était caractérisée par des interactions précipitations × couverture de conifères et précipitations × surface terrière. Dans les zones plus sèches, le Pigeon à queue barrée était plus susceptible d’utiliser des zones avec une couverture de conifères plus importante; à mesure que les précipitations augmentaient, le Pigeon à queue barrée était plus susceptible d’utiliser des zones avec une couverture de conifères moins importante. L’augmentation des précipitations a permis une plus grande utilisation de forêts à surface terrière plus élevée, et les zones plus sèches ont été associées à l’utilisation de forêts à surface terrière plus faible. La couverture de conifères a été principalement sélectionnée à l’échelle de 1 km, et la surface terrière a été sélectionnée à l’échelle de 2 km en réponse aux précipitations durant l’hiver précédant la saison de reproduction. Bien que nous sachions depuis longtemps que les Pigeons à queue barrée fréquentent les forêts de conifères, nous avons constaté que leur utilisation de ces forêts variait en fonction d’un gradient de précipitations. L’utilisation de notre approche pour sélectionner l’échelle d’effet de l’habitat forestier et de la surface terrière en réponse aux changements de précipitations permet d’obtenir des recommandations de gestion de l’habitat plus précises et plus pertinentes sur le plan spatial que les approches utilisant la sélection de modèles, comme le critère d’information d’Akaike.

Key Words: *Columbidae*, *forest management*, *RJMCMC*, *spatial scale*

INTRODUCTION

Effective solutions for managing habitat under climate change may require implementing actions in coordinated ways across large land areas (Hannah et al. 2007, Hannah 2008). The large amount of federal land holdings in Western North America (46% of the 11 conterminous Western U.S.; Vincent et al. 2020) provides an opportunity to coordinate and implement habitat management for species of concern (e.g., birds of conservation concern; U.S. Fish and Wildlife Service 2021) across broad extents and multiple spatial scales, providing the opportunity to downscale future climate change scenarios to inform fine scale, local management recommendations. However, management recommendations to address climate adaptation for wildlife are generally developed at broad scales that have limited application at fine scales relevant for management action (LeDee et al. 2020).

Identifying local habitat management actions for climate adaptation requires an understanding of how wildlife (i) might vary in their response to habitat conditions across their range and (ii) the scale of effect. First, species may respond to environmental gradients in subtly different or entirely distinct ways across their range (Fortin et al. 2008, Boves et al. 2013, Crosby et al. 2019). Identifying these differences can allow management actions to be customized to maximize their local relevance (e.g., Crosby et al. 2019). Alternatively, failing to consider these differences can result in biased estimates or weak statistical power to predict responses to environmental changes that may vary across space (Crosby et al. 2019). Second, identifying the appropriate “scale of effect” of habitat conditions is essential to informing effective management (Jackson and Fahrig 2015). New statistical methods can be used to test multiple spatial scales, identify the relevant scale of response, and better predict species’ use of habitat (Stuber et al. 2017, Monroe et al. 2021, Monroe et al. 2022). Information gained from multi-scale studies can be used to manage habitat at an optimal spatial scale that benefits species of interest (e.g., grassland bird management at the pasture scale; Monroe et al. 2021).

Although relatively understudied, the Band-tailed Pigeon (*Patagioenas fasciata*) responds to environmental conditions differently across an environmental gradient and at multiple spatial scales in the Pacific population of the northwestern United States (Overton et al. 2010). However, the Interior population in the southwestern United States is less studied and their range includes a diverse ecological gradient providing an opportunity to better understand how a species might respond to management across multiple spatial scales. The Interior population has also decreased by an average of 2.5% per year from 1968 to 2019; however, no significant trends were identified from 2009 to 2019 or 2014 to 2019, and the population status is uncertain given a lack of standardized monitoring for the species (Seamans 2020). Decreases in population abundance have likely been due to alteration of the species’ preferred habitat, especially coniferous forests (Seamans 2020). Climate change is predicted to reduce suitable range for the Interior population by 45% by 2070 under current CO₂ emissions scenarios (Coxen et al. 2017) and major shifts in habitat may occur because of high probability of wildfires and drought in this region (Liu et al. 2013, McDowell et al. 2015, Cattau et al. 2020). Additional habitat may become unsuitable because of climate-change related mortality of conifer forests in the Southwest United States (McDowell et al. 2015), particularly

in the southern portion of the Band-tailed Pigeon’s range (Coxen et al. 2017).

Although climate change may reduce the extent of habitat for the Band-tailed Pigeon, forest management practices (e.g., thinning or burning) could create new habitat for the species. The Interior population of Band-tailed Pigeons in New Mexico has shown preference for riparian areas, areas with conifer forest, and habitat with 60–70% canopy cover (Coxen et al. 2017), yet relevant spatial scales for management of the population remain unknown. Although Band-tailed Pigeons along the Pacific Coast of North America increase in response to increasing deciduous forest cover at a local spatial scale (3.14 ha; Overton et al. 2010), habitat available for the Interior population is considerably different than the Pacific population. Habitat in the southern portion of the Interior range differs in dominant vegetation types and the amount and timing of precipitation (200 to 1000 mm/y; Halbritter and Bender 2015), that varies considerably from the Pacific Coast (> 1200 mm/y; Overton et al. 2010).

We quantified summer habitat use of the Interior population of Band-tailed Pigeons in the Southwestern U.S. by analyzing data from satellite-tagged birds with a resource selection function. Our goals were to (1) quantify habitat use of Band-tailed Pigeons across vegetation, topography, and precipitation, examining the possibility for differences in habitat selection, and (2) estimate the most ecologically relevant spatio-temporal scale for these habitat features (i.e., the optimal “scale of effect”). Better understanding differences in habitat selection across the Interior population’s range, as well as the most important spatial scales for habitat, has the potential to inform local, fine-scale forest and habitat management for the species in the context of climate change.

METHODS

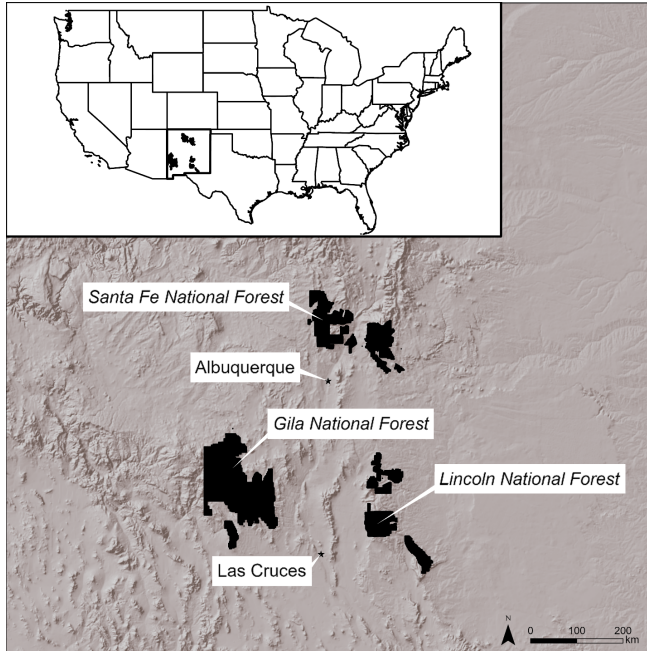
Survey sites

We captured Band-tailed Pigeons on three private properties in Silver City, Weed, and Los Alamos, New Mexico that were either adjacent to or an inholding within the Gila, Lincoln, and Santa Fe National Forests, respectively (Fig. 1). Sites were chosen based on regular visitation of Band-tailed Pigeons to private landowner bird feeders over the previous 5–10 years (Coxen et al. 2017). New Mexico is primarily defined as having a cold steppe (BSk) Köppen climate; however, our Silver City and Weed study areas are also characterized by Mediterranean warm temperature climates with hot dry summers (Csa), whereas Los Alamos has a continental warm temperature, fully humid climate (Cfb; Kottek et al. 2006), and in general have elevation ranges of 1300 m to 3000 m that influence localized climates. New Mexico, as part of the Southwest, has a distinct monsoon season involving a change in predominant wind direction and storm track (Sheppard et al. 2002). Monsoon season typically begins in early July; New Mexico receives between 30 and 40 percent of its total annual precipitation during the summer months of June through August and annual precipitation ranging from 200 mm to 1000 mm (Keane et al. 2000, Reif 2006, Halbritter and Bender 2015).

Data sources

We used Argos satellite platform transmitting terminal devices and attached them with backpack harnesses to individuals ≥ 315 g. Five Band-tailed Pigeons were captured at each of our three sites for 15

Fig. 1. The location of the study area in New Mexico, USA with U.S. Department of Agriculture National Forests that were included in the study highlighted in black.



total tagged birds. Eight of these devices weighed 5 g (< 2% body weight; Microwave Telemetry, Inc., Columbia, Maryland, USA) and seven weighed 9 g (< 3% body weight; North Star Science and Technology, LLC, King George, Virginia, USA), and the fix rate was set at eight locations per day. We tagged birds from mid-June through early July 2015. One transmitter failed at the Silver City site resulting in a total of 14 tagged birds for analysis. We only used locations of Argos location class 2 (error < 500 m) and 3 (error < 250 m) in our analysis. Data were additionally filtered to only contain locations during the breeding season (1 April–19 Aug; Collins et al. 2019).

We used a grid-based approach to quantify habitat selection, where the number of locations in each grid cell was the response variable, equivalent to an intensity of use (Nielson and Sawyer 2013). A grid-based approach provides a conceptually simple approach that produces unbiased estimates of intensity of use when locations are temporally correlated (Nielson and Sawyer 2013). To create the spatial grid for our population, we buffered around each location by 500 m, then created a grid of 500 m over the perimeter of the buffered area with a randomly selected starting location. The additional buffer accounted for error related to locations from Argos fixes.

To quantify the response of Band-tailed Pigeons to potential variability in habitat, we developed a suite of covariates related to vegetation, topography, and climate. We selected covariates based on a previous species distribution model (Coxen et al. 2017) and other information about the species (Kirkpatrick et al. 2007, Blackman 2013). Our landscape variables were latitude, land cover class data (proportion of conifer forest or shrub cover; data from 2016 National Land Cover Dataset, obtained through R [v. 4.0.3, R Core Team 2021] using package FedData [Bocinsky

2016]), digital elevation model (DEM; data from U.S. Geological Survey's National Elevation Dataset [Gesch et al. 2002]). We used the terra package in R (Hijmans 2021) to calculate slope, flow direction of water, topographic position index (TPI), topographic ruggedness index (TRI), and aspect. We used ArcGIS Pro (ESRI 2021) to calculate topographic wetness index (TWI; Beven and Kirkby 1979). We also included basal area (BA, total tree basal area per acre in square feet for trees > 2.5 cm in diameter) and standard deviation of basal area (BA SD), age of stand, and canopy cover as covariates to account for forest structure and composition in each National Forest (INREV [OSU INREV 2020]). Our climate variables were average precipitation accumulation and Palmer Drought Severity Index (PDSI) estimated from GridMET (Abatzoglou 2013) and the climateR package in R (Johnson and Clark 2020). We evaluated correlation between covariates and removed covariates with $|r| > 0.6$.

To relate spatial covariates to our grid cells, we created buffers at different spatial scales around each grid cell based on daily movements of Band-tailed Pigeons (< 3 km per day; Collins et al. 2019) and computed the corresponding covariate value for each spatial scale. This resulted in three spatial scales, sc , of interest: 500 m² (average covariate value within the grid cell), 1 km² (250 m buffer around each side of the grid cell), and 2 km² (750 m buffer). For temporally varying climatic covariates, we calculated the mean covariate value for each grid cell and then selected from different temporal scales reflecting the effect of precipitation from the fall and winter preceding the breeding season (1 Oct–31 Mar), just before the breeding season (31 Mar–1 June), or the monsoon season during the previous year (1 June–31 Aug), which also included the breeding season.

Statistical model

We used a hierarchical model (Reversible-jump Markov chain Monte Carlo, RJMCMC; O'Hara and Sillanpää 2009) and variable selection (Bayesian Latent Indicator Scale Selection [BLISS]; Stuber et al. 2017) to identify spatial and temporal covariates for habitat use across multiple scales. In general, both of these selection procedures are related (O'Hara and Sillanpää 2009, Hooten and Hobbs 2015) and identify relevant covariates (RJMCMC) and spatial scales (BLISS) of importance through either moving the model between multiple dimensions by switching on and off model components (RJMCMC), or by identifying which spatial scales are important for those covariates included in the model (BLISS). In our application, we used RJMCMC to estimate the probability a covariate was relevant for Band-tailed Pigeon habitat use. If RJMCMC included a covariate in the final model, we used BLISS to determine which spatial or temporal scale was best supported by the data.

More specifically, our model for counts of locations per cell i , y_i , was

$$y_i \sim \text{NegBinom}(\mu_i, \rho) \quad (1)$$

$$\log(\mu_i) = \beta_0 + \beta_1 x_{i,s,1}(SC_1) + \dots + \beta_m x_{i,s,m}(SC_m) \quad (2)$$

where β_0 was an intercept, $\beta_{1:m}$ were slopes for environmental covariates, $x_{i,s}$ at each spatial or temporal scale s , and ρ was an overdispersion parameter. Our spatial and temporal scales, sc ,

were defined with a categorical prior, $sc_m \sim \text{cat}(w_1, w_2, w_3)$, where all w_s are equal ($w_s = 1/3$). We included a quadratic term for each covariate and constrained quadratic terms to have the same spatial or temporal scale as their corresponding linear term. Because our analyses used RJMCMC for linear, quadratic, and interaction terms, we constrained the model to incorporate linear terms along with quadratic and interaction terms (e.g., the quadratic term for basal area was only included in the model if the linear term for basal area was included). We specified hyperparameters as $\beta_0 \sim \text{Normal}(0,2)$, $\beta_{1,m} \sim \text{Normal}(0,2)$, and $\rho \sim \text{Gamma}(0.01,0.01)$.

We used the Freeman-Tukey statistic to compute Bayesian p-values to assess model fit (Kéry and Royle 2016). We implemented our model in NIMBLE (v. 0.11.1; de Valpine et al. 2022) via R (v. 4.0.3; R Core Team 2021). We collected 10,000 samples each from three MCMC chains after a burn-in of 100,000 and assessed model convergence visually from traceplots and with a Gelman-Rubin statistic (Gelman and Rubin 1992) using stable variance estimators (< 1.1 ; Vats and Knudson 2018).

RESULTS

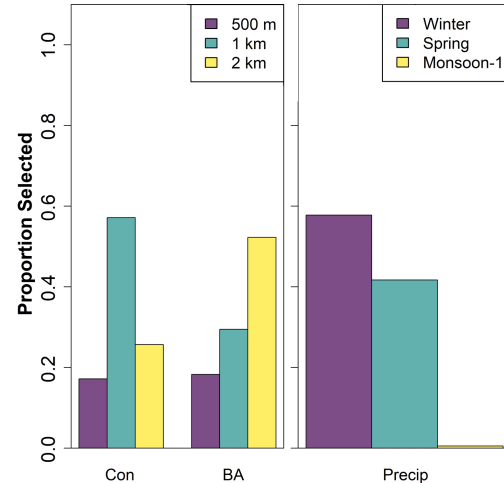
We obtained 836 usable location fixes for 14 tagged birds (Argos class 3 = 315, Argos class 2 = 521) from 11 June to 31 Aug 2015. Our grid covering the study sites resulted in 1637 500 m² grid cells with the number of locations in each grid cell ranging from 0 to 13 (mean = 0.43, SD = 1.1) with 491 grid cells (30%) having > 1 location. Of those grid cells, 719 were in the Santa Fe National Forest, 390 in the Gila National Forest, 515 in the Lincoln National Forest, and 13 in the northern portion of Cibola National Forest just west of the Santa Fe National Forest. There were strong correlations between precipitation and latitude, precipitation and PDSI, slope and TPI, flow and TPI, TRI and TPI, and elevation and precipitation so we removed latitude, PDSI, slope, flow, TRI, and elevation from the model, retaining precipitation and TPI.

Our goodness-of-fit test did not indicate a lack of fit (Bayesian p-value = 0.6) and all parameters in our model were below our convergence requirement and appeared to converge based on visual inspection. Our RJMCMC results indicated that Band-tailed Pigeon intensity of use was characterized by precipitation $\times$ conifer cover and precipitation $\times$ basal area interactions (Table 1). In drier areas, Band-tailed Pigeons were more likely to use areas with more conifer cover; as precipitation increased, Band-tailed Pigeons were more likely to use areas with less conifer cover (probability of inclusion = 0.91; $\beta = -0.30$, 95% CrI = -0.52 – 0.0). Santa Fe National Forest had greater winter precipitation and less conifer cover than Lincoln and Gila National Forests (Figs. A1.1 and A1.2). Increased precipitation facilitated greater use of forests with higher basal area, whereas drier areas were associated with use of forests with lower basal area (probability of inclusion = 0.55; $\beta = 0.19$, 95% CrI = 0.00 – 0.45 ; Figs. 2 and 3). Conifer cover was primarily selected at the 1-km² scale and basal area was selected at the 2-km² scale (Fig. 2a) in response to precipitation during the winter preceding the breeding season (Fig. 2b). Other covariates were not selected for inclusion in the model (probability of inclusion < 0.50 ; Fig. A1.3). Gila National Forest had the highest predicted relative use overall compared to Lincoln and Santa Fe National Forests (Fig. 4).

Table 1. Quantiles for the posterior distributions of parameter estimates from a model for intensity of habitat use of Band-tailed Pigeons (*Patagioenas fasciata*) in New Mexico. After Reversible-jump Markov chain Monte Carlo (RJMCMC) selection, the model contained a parameter for an intercept (β_0), percentage of conifer cover, winter precipitation, basal area, an interaction of precipitation and basal area, an interaction of precipitation and percentage conifer cover, and the size parameter associated with the Negative Binomial distribution (ρ).

Parameter	Quantile of Posterior Distribution		
	0.025	0.50	0.975
β_0	-1.54	-1.19	-0.92
$\beta_{conifer}$	0.12	0.30	0.62
β_{precip}	-0.21	-0.03	0.15
$\beta_{basal\ area}$	-0.18	0.00	0.34
$\beta_{precip \times basal\ area}$	0.00	0.30	0.53
$\beta_{precip \times conifer}$	-0.51	-0.32	0.00
ρ	0.33	0.40	0.50

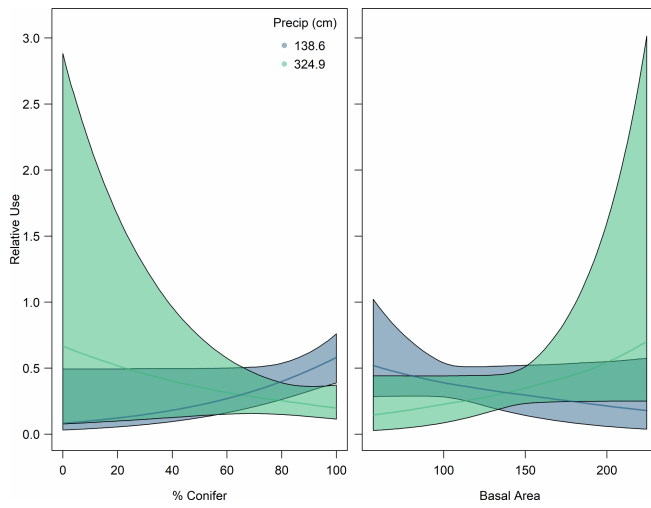
Fig. 2. Proportion of Markov chain Monte Carlo (MCMC) samples selected at each spatial and temporal scale for percent conifer cover (Con) and basal area (BA; left) and precipitation (right) for relative intensity of use of Band-tailed Pigeons (*Patagioenas fasciata*) in New Mexico.



DISCUSSION

We found that Band-tailed Pigeon habitat selection was driven primarily by conifer cover, basal area, and precipitation, although covariates related to local topography and vegetation structure were less important than expected. Although Band-tailed Pigeons have long been known to associate with conifer forests, we found that their use of conifer forest varied across a gradient of precipitation. Birds shifted from preferentially using areas of predominantly conifer cover in drier sites to less conifer cover in wetter sites. Additionally, Band-tailed Pigeons selected sites with higher basal area in wetter sites and lower basal area at drier sites.

Fig. 3. Relative intensity of use (number of locations per 500-m² grid cell) of Band-tailed Pigeons (*Patagioenas fasciata*) during breeding season in New Mexico in response to percent of conifer cover (at 1 km²; left) and basal area (at 2 km²; right) at high and low precipitation values during winter.



Selection for conifer cover was most pronounced at a 1-km² scale and basal area at a 2-km² scale (the largest we tested), suggesting selection of conifer forests at landscapes greater than 500 m².

Our results indicate that Band-tailed Pigeons use conifer forest differently across gradients in precipitation. The Southwest United States is predicted to experience increased drought and temperatures with climate change, thus causing increased mortality of coniferous trees (McDowell et al. 2015). These forecasts suggest the northern portion of the species' range in New Mexico may face future climatic conditions that are more like the current conditions (hotter and drier) in the southern range. Thus, if selection of conifer forest is stronger in drier areas, contiguous conifer forest cover could become more important to Band-tailed Pigeons in the northern part of the range in the future. Meanwhile, climate changes in the southern portion of the Band-tailed Pigeon's range will likely cause a reduction in habitat for the species (Coxen et al. 2017). Management to maximize the survival of contiguous conifer forests may therefore be essential to Band-tailed Pigeon persistence in the southern part of the range. If sufficient conifer forest habitat cannot be maintained there, management of the northern part of the range may need to shift with changing climatic conditions to support the species. For example, management could implement fine-scale, more intensive stand-level management practices such as selective thinning to reduce water stress and competition, slow overland flow to increase infiltration and enhance soil water availability, vegetation and pest management, mulching residual thinning debris, and fire management to reduce fuel loads (Cobb et al. 2017, Field et al. 2020).

Band-tailed Pigeons forage in both oak woodlands and mixed conifer forest but primarily nest in mixed-conifer forest (Neff 1947, Kirkpatrick et al. 2005, Hughes 2007). Although the species

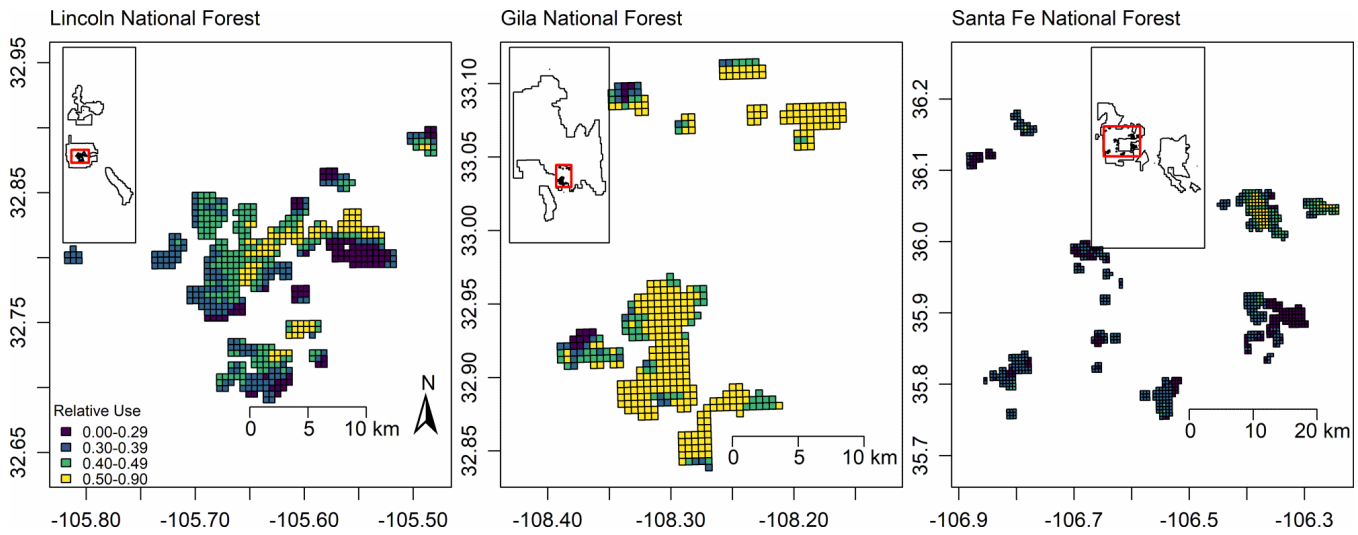
exhibits nomadism in response to shortages in food and an unpredictable food supply (Gutierrez et al. 1975), pigeons near agricultural areas (e.g., small grains, orchards), where food supplies are more consistent have high site fidelity (Braun 1972). Given our birds were not captured near constant food supplies such as agricultural products, our results may indicate selection of foraging habitats that were available over a larger spatial and temporal scale because of local forage eruptions and shortages driven by climatic events (i.e., previous year's precipitation or monsoonal rains driving mast and berry production).

As winter precipitation and latitude were strongly correlated, the interaction we found between precipitation and conifer forest cover may also indicate changes in forest associations with latitude. Variation in habitat associations across a latitudinal gradient have also been found in the Pacific population of Band-tailed Pigeons, though differences in habitat selection across this gradient were not specifically tested (Overton et al. 2010). The shift in habitat selection across the range of the Interior population of Band-tailed Pigeons suggests that appropriate habitat management in one area may not be more optimal in another. Instead, reducing conifer cover might be more effective in Northern New Mexico, although improved availability of conifer forest cover may benefit populations at more southern latitudes.

In addition to different use of conifer forest with changes in precipitation, Band-tailed Pigeons also used stands with different basal areas with changes in precipitation. Band-tailed Pigeons used stands with higher basal area in areas with high precipitation during winter and stands with lower basal area in drier sites. Given Band-tailed Pigeons are still using sites with higher basal area in wetter areas, it is likely they are shifting use to either mixed or deciduous forest stands as wetter conditions produce desirable foraging areas (Gottfried 1992). During the summer period, Band-tailed Pigeons will forage in cultivated fields and livestock feeding areas, as well as consume buds, flowers, and fruits of wild trees and shrubs including oaks (*Quercus*) and pines (*Pinus*; Kautz 1977, Blackman et al. 2013). Available forage greatly impacts the habits, range, distribution, during the summer period of Band-tailed Pigeons (Gutiérrez et al. 1975, Jarvis and Passmore 1992). Long distance movements to foraging areas, flock foraging behavior, and high-foraging area fidelity are all characteristic of the species. Although Band-tailed Pigeons are likely using other forested areas in the study sites, we were unable to test for relationships with habitat use of deciduous or mixed forest cover types as these were correlated with conifer forest (Cade 2015).

Although conifer forest cover was expected to be important for determining Band-tailed Pigeon habitat use, we anticipated that covariates related to forest stand characteristics (e.g., age of stand) would be more important than our model indicated. Previous research using these data on Band-tailed Pigeon habitat use found responses to both canopy cover and elevation (Coxen et al. 2017), though statistical approaches differed from this study in the methodology, as well as the spatial scales of inference. Moreover, Coxen et al. (2017) did not evaluate differences in habitat selection across the range of locations which can lead to biased inference (Crosby et al. 2019). Our statistical approach also estimated the relative importance of environmental covariates across a range of

Fig. 4. Predicted relative use of Band-tailed Pigeons (*Patagioenas fasciata*) in three study sites (Lincoln, Gila, and Santa Fe National Forests) in New Mexico. The main portion of the figure is the study site; the inset in each panel is the entire Forest Service unit with the location of the study area shown in red.



spatial scales, although Coxen et al. (2017) used a 1-km² grid cell for all covariates. Including a range of spatial scales for evaluation in our analysis indicated that Band-tailed Pigeons select habitats at broader spatial scales (1–2 km²).

Differences between our results and inference and those of Coxen et al. (2017) highlight the need for including changes in responses to vegetation use by species over broad spatial scales. For example, Cerulean Warblers (*Setophaga cerulea*) exhibit spatial heterogeneity in local habitat-selection across the Appalachian Mountains (Boves et al. 2013), and boreal songbirds differ in habitat selection across the Canadian boreal forest (Crosby et al. 2019). Because climate change is forecast to occur across latitudinal gradients, evaluating differences in habitat selection when predicting the effects of climate change on species' habitat use is critical (Crosby et al. 2019). Although it is important to evaluate species' responses across broad, regional spatial scales, habitat management guidance is needed at local scales to mitigate climate change (LeDee et al. 2020). Using our approach to select the scale of effect for forest habitat and basal area in response to changes in precipitation can provide more precise, spatially relevant habitat management recommendations within the current environment, and within the context of future environmental change.

Responses to this article can be read online at:
<https://www.ace-eco.org/issues/responses.php/2315>

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APPENDIX

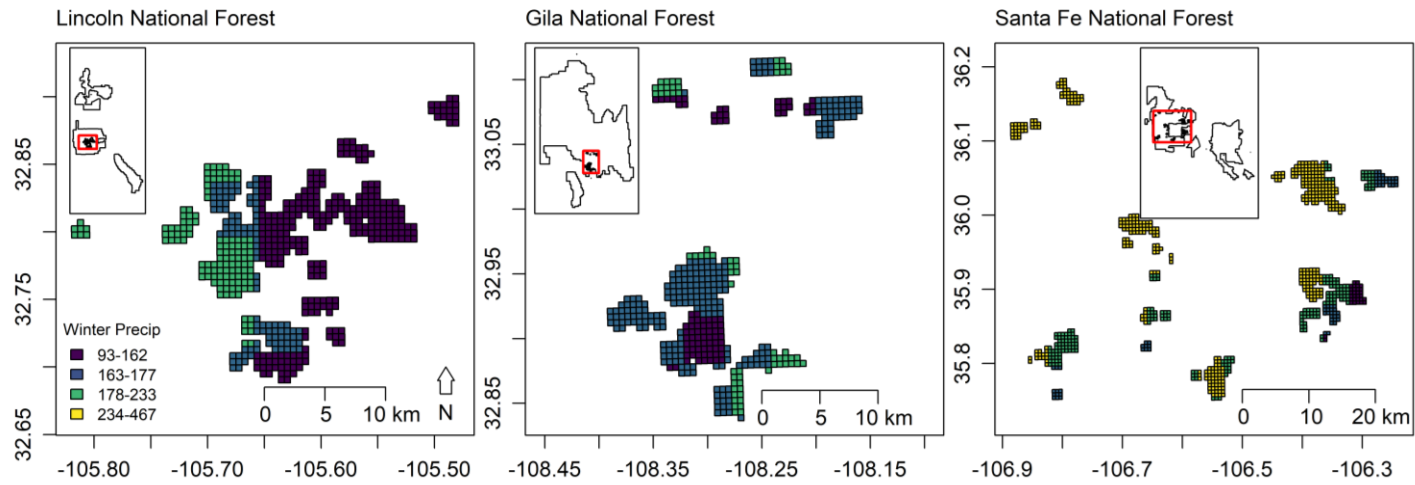


Figure A1.1: Winter precipitation (1 Oct – 31 Mar) in the study areas within Lincoln, Gila, and Santa Fe National Forests. The main figure shows the spatial grid of locations for Band-tailed Pigeons with the inset showing the National Forest with the study site in red.

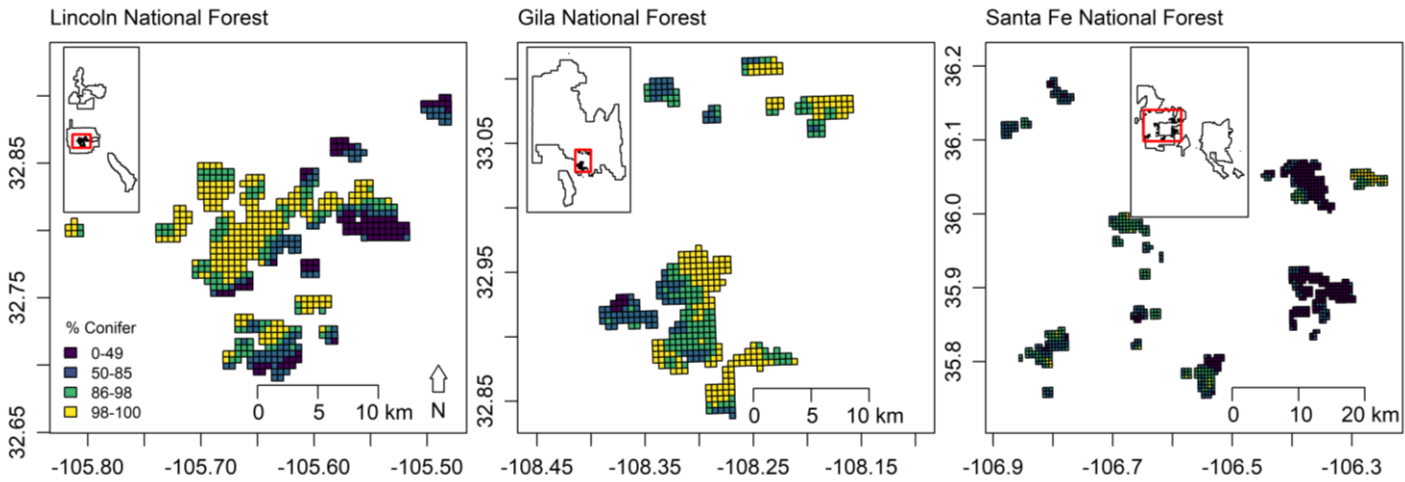


Figure A1.2: Percent conifer cover in the study areas within Lincoln, Gila, and Santa Fe National Forests. The main figure shows the spatial grid of locations for Band-tailed Pigeons with the inset showing the National Forest with the study site in red.

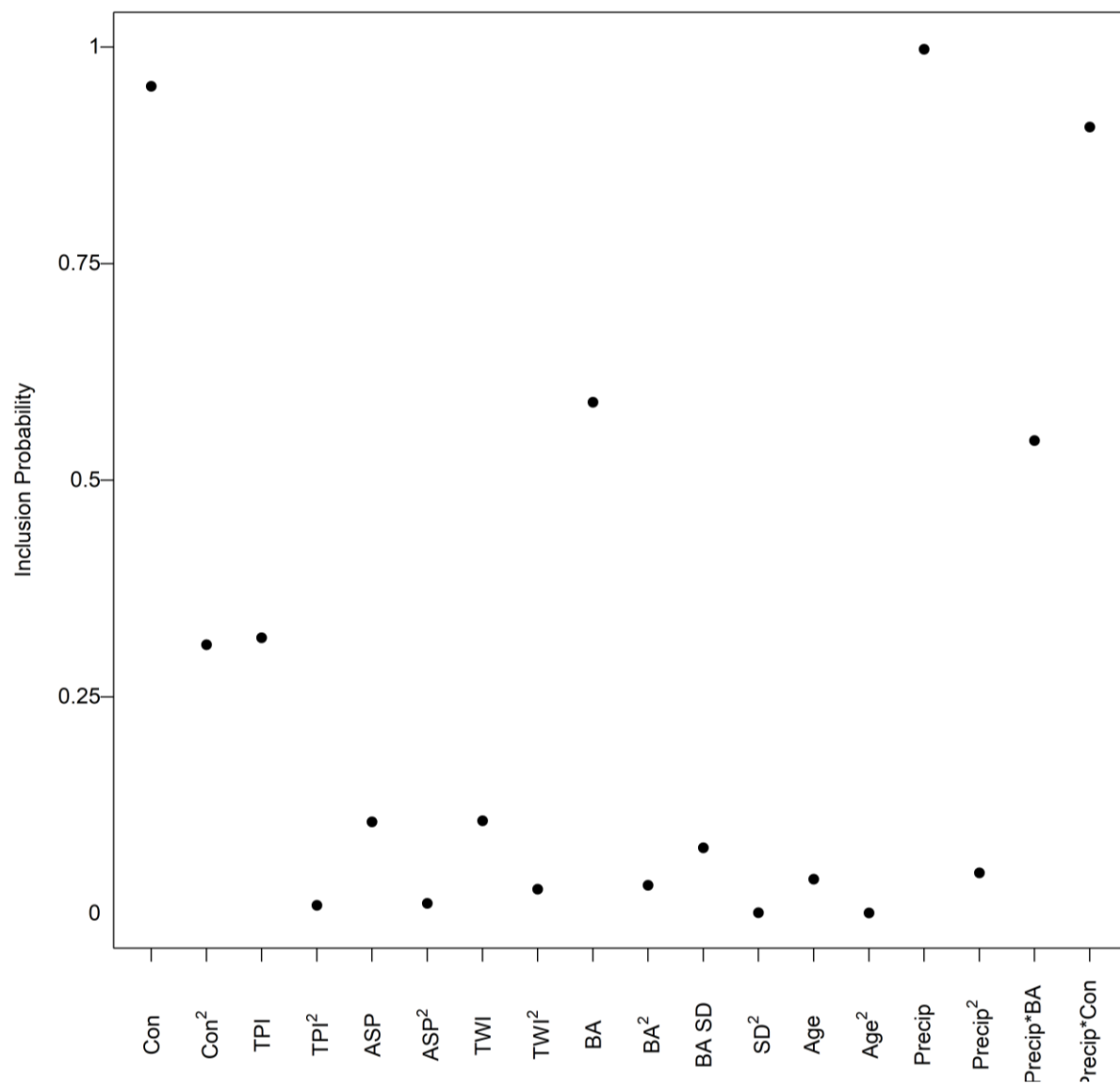


Figure A1.3: Proportion of times each covariate and its associated quadratic form was selected to include in the model. Covariates were proportion of conifer forest cover (Con), topographic position index (TPI), aspect (ASP), topographic wetness index (TWI), precipitation (Precip), basal area (BA), standard deviation of basal area (BA SD and SD²), stand age (Age), percent canopy cover (Canopy), and percent shrub cover (Shrub).