BREEDING HABITAT REQUIREMENTS AND TERRITORY SIZE OF BENDIRE'S THRASHER (*Toxostoma bendirei*) IN THE SOUTHWESTERN U.S.

BY

CODY TYLER BEAR SUTTON, B. S.

A thesis submitted to the Graduate School

in partial fulfillment of the requirements

for the degree

MASTER OF SCIENCE

Major Subject: FISH, WILDLIFE, AND CONSERVATION ECOLOGY

NEW MEXICO STATE UNIVERSITY

LAS CRUCES, NEW MEXICO

DECEMBER 2020

Cody Tyler Bear Sutton

Candidate

Wildlife Science

Major

This Thesis is approved on behalf of the faculty of New Mexico State University, and it is acceptable in quality and form for publication:

Approved by the thesis Committee:

Dr. Martha J. Desmond

Chairperson

Dr. Dawn VanLeeuwen

Committee Member

Dr. Ken Boykin

Committee Member

Dr. James Cain

Committee Member

ACKNOWLEDGEMENTS

I am grateful to my advisor Dr. Martha Desmond. Her patience, support, and expertise helped me accomplish this project, while allowing me to grow and be independent while completing this work. Without her help and persistence, I would never have reached this point, and I am beyond thankful for her help.

Thank you to my technicians, Jasmine Johnson, Odd Jacobson, Daniel Horton, Fabio Tarazona, and Alison Salas for your hard work and good company during my field seasons. I also would like to extend thanks to the countless volunteers across Arizona and New Mexico who helped with data collection on this project.

This project significantly benefited from the contributions of my committee members. Thanks to Dr. Dawn VanLeeuwen for her and advice in determining analytical approaches, and Dr. Ken Boykin for his insights on MaxEnt modeling.

Special thanks to New Mexico Game and Fish for the financial support and guidance. I'd also like to recognize T&E Inc. and New Mexico Ornithological Society for their support. Margaret Darr and Chrissy Kondrat-Smith and the Desert Thrasher workgroup all provided a great amount of guidance and support in completing this project.

Thank you to my lab mates—DeeAnne Meliopoulos, Cody Bear Sutton, Fabio Tarazona, Dejeanne Doublet, and Allison Salas—who not only helped with data collection but were always there to help me along in times of need. This work is dedicated to my grandfather Lee Sutton, who was the biggest single reason I pursued a career in natural science and was always there to teach me about the natural world.

VITA

May 22, 1990	Born in Ridgecrest, CA
2012	Graduated from University of Idaho (B.S. Wildlife Science)
2012-2015	Seasonal Field Research Technician
2015-2018	Graduate Research Assistant, Department of Fish, Wildlife, and Conservation Ecology, New Mexico State University
2017-Present	Natural Resource Specialist with City of Colorado Springs

Field of Study

Major Field: Wildlife Science

ABSTRACT

BREEDING HABITAT REQUIREMENTS AND TERRITORY SIZE
OF BENDIRE'S THRASHER (Toxostoma bendirei)
IN THE SOUTHWESTERN U.S.

BY

CODY BEAR SUTTON

Master of Science

New Mexico State University

Las Cruces, New Mexico

December 2020

Dr. Martha Desmond, Chair

Bendire's Thrasher (*Toxostoma bendirei*) is an understudied and cryptic arid land obligate. Breeding bird surveys indicate that this species is experiencing one of the greatest declines of any species in North America. My research aims to answer some basic questions about Bendire's Thrasher while setting the groundwork for future conservation efforts. My objectives were to determine the most effective way to survey for Bendire's Thrasher, to improve the current understanding of Bendire's Thrasher breeding habitat requirements, and to use MaxEnt to model the current and future distribution of Bendire's Thrasher with regards to climate change. Over the two-year study, I found 69 territories. I found the use of call playback to be the most effective method for detecting thrashers. I completed vegetation surveys on all territories to compare with 70 randomly placed vegetation surveys. In addition to on the ground surveys, I completed a landscape level analysis using aerial photography and ArcGIS to develop landscape variables for my models. My models suggested that selection decreased as slope and elevation increased. Increases in obstruction, bare ground, and the presence of shrubs over 1.5m all increased selection. Average shrub height was the most influential variable with a 257% increase in the odds of Bendire's Thrasher use with each 1m increase in shrub height [Odds ratio = 3.57, 95% CI (1.82, 6.99)]. Our model of landscape variables showed that more heterogeneous landscapes having more edge and vegetation type richness were more likely to contain Bendire's Thrasher. Mean patch size was the most influential landscape variable with use being less likely as mean patch size increased [Odds ratio = 0.23, 95% CI (0.102, 0.51)]. I used breeding year precipitation, elevation, canopy cover, slope, and maximum temperature of the breeding season as variables in MaxEnt to create a map of the current distribution of Bendire's Thrasher. I used two well supported climate projections, the Community Climate System Model version 4 (CCSM4) and the Hadley Centre Global Environment Model version 2 Earth System (HadGEM2-ES) 2050, to model Bendire's Thrasher distribution for 2050. My models were all well supported with AUC values greater than 0.84. My MaxEnt models showed a decrease of around 30% for Bendire's Thrasher distribution in all climate change scenarios for 2050.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 1

CHAPTER 2

Table Page

LIST OF FIGURES

CHAPTER 1

Figure Page

CHAPTER 2

Figure Page

CHAPTER 1. BENDIRE'S THRASHER (*Toxostoma benderei*) BREEDING TERRITORY SIZE AND SELECTION IN THE SOUTHWEST

INTRODUCTION

Arid lands in the southwestern United States are experiencing habitat loss and degradation attributed to urban sprawl, energy development, overgrazing, invasive grasses and woody shrub encroachment (Eldridge et al. 2011). While urban sprawl and energy development are fairly recent (Milesi et al. 2003), these other land use changes have increased gradually over the past 100 years (Turnbull et al. 2014). Woody shrub encroachment, also known as desertification, in the southwestern United States and northern Mexico has resulted in a landscape transformation where historic desert grasslands have shifted to dense shrubland dominated by unpalatable woody plants (Peters et al. 2015). Desertification has been attributed to a variety of factors including climate change, overgrazing, fire suppression, distribution of shrub seeds by domestic livestock, and removal of native herbivores (Herbel et al. 1972, Neilson 1986, Schlesinger et al. 1990). The role of climate change in this arid region may be particularly strong, as the southwestern United States has been identified as a climate change "hotspot", with projections of increases in air temperature, aridity, and seasonal variability (Gutzler and Robbins 2011). These changes across arid lands of the southwestern United States have coincided with arid land birds becoming among the fastest declining avian guild in North America (North American Bird Conservation Initiative 2016).

Thrashers, members of the family mimidae, are among the arid land species experiencing the steepest declines (North American Bird Conservation Initiative 2016). Of the eight thrasher species in the United States, seven are arid land obligates. Three of the arid land obligates, Sage Thrasher (*Oreoscoptes montanus*), Le Conte's Thrasher (*Toxostoma lecontei*), and Bendire's

Thrasher (*Toxostoma bendirei*), are in serious decline and are considered species of greatest conservation concern by the American Bird Conservancy as well as state wildlife agencies (North American Bird Conservation Initiative 2016). Sage Thrashers are endemic to the sagebrush habitats across western North America and their declines are attributed, in part, to large-scale changes to this ecosystem (Blouin 2004). Similarly, large-scale habitat alteration has likely contributed to declines of Le Conte's and Bendire's Thrashers, However, less is known about these species requirements across the desert landscapes of the Southwest. (England and Laudenslayer 1993, Shuford and Gardali 2008).

The Bendire's Thrasher is a secretive and cryptic species that occurs throughout deserts of the southwestern United States and northern Mexico, primarily in sparse desert scrub habitats (England and Laudenslayer 1993). Because of its secretive nature and low population numbers, it may be one of the least studied avian species in the United States. When first collected, this species was originally confused with the Curve-billed Thrasher (*Toxostoma curvirostre*), and as a result, was one of the last birds to be discovered in North America, and has been little studied since its discovery in the late 1800's (England and Laudenslayer 1993). Throughout its range, Bendire's Thrashers are associated with desert scrub, grassland shrub, pinyon-juniper woodlands, and agricultural edge habitats (Brown 1901, Darling 1970, England and Laudenslayer 1993), however, their distribution is poorly understood. Within the United States this species occurs in six states with breeding populations in New Mexico, Arizona, California, and small portions of Nevada, Utah, and Colorado (Buttery 1971). In the United States, the majority of the Bendire's Thrasher population occurs in Arizona and New Mexico (England and Laudenslayer 1993). Partners in Flight (North American Bird Conservation Initiative 2016, Rosenberg et al. 2016) estimate the current global population size at approximately 70,000 to

120,000 individuals. Estimates based on breeding bird survey data indicate that 28.7% of the global population occurs in New Mexico, where breeding bird surveys indicate a 4.4% annual decline in populations over the last 10 years (North American Bird Conservation Initiative 2016). A more recent analysis estimates the population will decline range wide by 30% in the next 15 years and 50% within 20 years (North American Bird Conservation Initiative 2016, Rosenberg et al. 2016). These annual declines have led to the current listing of the Bendire's Thrasher as a species of conservation concern by state wildlife agencies in both Arizona and New Mexico. There are two main hypotheses on the cause of the Bendire's Thrashers range-wide declines. One hypothesis is related to habitat degradation and disturbance in the southwestern United States due to shrub encroachment, agriculture, and overgrazing (Ambrose 1963, Darling 1970, Remsen 1978). A second hypothesis suggests competition with the similar Curve-billed Thrasher as the cause for decline; given the similarities in diet and perceived habitat use by the two species there is assumed competition (Ambrose 1963, Darling 1970, England and Laudenslayer 1993). This is supported by data that indicates the Bendire's Thrasher decline coincides with an increase in abundance and the number of breeding bird survey routes with detections of Curve-billed Thrashers (Figure 1) (Ambrose 1963, Zink and Blackwell-Rago 2000). These two hypotheses are likely not mutually exclusive, as desertification and habitat loss would likely increase overlap and competition between these two thrasher species.

The lack of knowledge about the Bendire's Thrasher, and apparent population declines have resulted in an interest in increasing conservation efforts and basic ecological knowledge of this species. Currently most information on the breeding ecology of the Bendire's Thrasher is anecdotal (England and Laudenslayer 1993) with little rigorous study including basic information on distribution, habitat associations, and important drivers at local and landscape scales for territory establishment. My research examines vegetative and topographic characteristics of Bendire's Thrasher territories across broad vegetation community classifications and compares them with randomly selected points within the same broad vegetation community classifications at the territory and landscape scales. I hypothesized that Bendire's Thrasher territory size is influenced by major vegetation community classifications. Vegetation community will influence territory size because differences in vegetation structure and composition are important in regards to the availability of nesting locations, perches and food (Brown 1901, Ambrose 1963, England and Laudenslayer 1993). I also hypothesized that year would influence Bendire's Thrasher territory size because variability in annual precipitation amounts and patterns will influence prey availability. I hypothesized that Bendire's Thrasher breeding territories and surrounding landscape will differ in vegetation structure in comparison with randomly chosen points within similar vegetation community classifications as they will select for specific vegetation features at the local and landscape scales (Brown 1901, Ambrose 1963, England and Laudenslayer 1993). Specifically, for the territory scale I predicted shrubs will be taller on Bendire's Thrasher territories because of preference for high perches for singing, shrub density would be lower or intermediate as Bendire's Thrashers need open space for foraging, the amount of bare ground will higher in Bendire's Thrasher territories because of the need for sparsely vegetated areas for foraging, and that territories would consist of more large gaps in the canopy to also allow for this heterogeneous area of cover and bare ground for foraging (Brown 1901, Ambrose 1963, England and Laudenslayer 1993). At the landscape scale, I predicted Bendire's Thrasher would prefer heterogeneous landscape with more edge as this would provide the variation in structure and foraging space (Brown 1901, Ambrose 1963, England and Laudenslayer 1993).

METHODS

Study Area

I studied Bendire's Thrasher territory selection at two spatial scales (territory and landscape) in southwestern New Mexico and southern Arizona in 2015 and 2016 (Figure 2). In New Mexico I defined the study area using a MaxEnt model of Bendire's Thrasher distribution and optimality created in 2015 (Menke 2016). This model stratified Bendire's Thrasher habitat from low optimality to high optimality based on occurrence points from ebird.org and breeding bird surveys overlaid on climate/geographic data. I chose to focus only on areas of medium to high optimality to give myself the best chance of finding this rare species. Using ArcGIS I overlaid the LANDFIRE (2008) vegetation communities dataset generated by USGS with the identified areas of medium to high optimality (Menke 2016) to generate a list of the vegetation communities. Based on this information I then aggregated the vegetation communities into broad categories that consisted of 1.) desert scrub, 2.) desert grassland, and 3.) pinyon-juniper. A MaxEnt model of Bendire's Thrasher distribution was not available for the state of Arizona. However, for Arizona there was considerably more information on Bendire's Thrasher locations. Therefore, I used observations acquired from eBird.org that occurred during the breeding season (March – May) to generate my study area. I overlaid the eBird.org points on the LANDFIRE (2008) layer of vegetation community type in ArcGIS to determine broad vegetation community classifications. Similar to New Mexico, I used this layer to determine broad vegetation community classifications and came up with the same 3 classifications used in New Mexico and one additional vegetation community classification 4.) Sonoran paloverde. Across both study sites dominant shrubland vegetation within these classifications consisted of honey mesquite (*Prosopis glandulosa*), velvet mesquite (*Prosopis velutina*), creosote (*Larrea tridentata*), juniper sp. (*Juniperus* spp.), cholla (*Cylindropuntia* spp.), catclaw *(Acacia greggii*), whitethorn *(Vachellia constricta*), soap tree yucca (*Yucca elata*), palo verde (*Parkinsonia* spp.), and saguaro (*Carnegiea gigantea*). Across this broad study area, elevations ranged from ~200 m in Arizona to ~2400 m in New Mexico, high and low temperatures during the field season ranged from -1 °C to 50 °C, and precipitation ranged from ~10 cm to ~50 cm in some higher elevation locations.

Breeding Surveys

I searched for territorial Bendire's Thrashers during the 2015 and 2016 breeding seasons, 2015 was considered a pilot field season, and based on data collected, adjustments were made to the protocol in 2016. In 2015 searches were initiated on 15 March and in 2016 15 February. Searches each year continued until 30 May. In 2015 all searches were restricted to New Mexico and in 2016 the search area was expanded to include southern Arizona. Surveys started in the southern latitudes and moved north as breeding activity is initiated earlier in the south (England and Laudenslayer 1993). Due to the secretive nature of this species, point count surveys were supplemented with a modified area searching protocol lacking defined plots (Ralph et al. 1995). Transects were randomly plotted using ArcGIS within each of the broad vegetation community categories with the number of transects within each vegetation community type distributed according to representation. Transects were paired, with each pair being a minimum of 3 km apart. This allowed two surveyors to conduct separate surveys simultaneously. In 2015, the pilot year for this project, each transect consisted of 8 point count locations spaced 400 m apart. The 400 m spacing was based on the maximum distance it has been estimated that a thrasher would respond from, similar to the playback methods used to survey Le Conte's Thrasher (Fletcher 2009). Point counts during this field season were 13.5 min in length and were divided into two parts. The first part consisted of 3 separate 3-min intervals with no call playback (where all birds present are recorded). The second part of the survey consisted of three 90 s intervals with 30 s of Bendire's Thrasher call playback and 60 s of silence (modification of LeConte's Thrasher survey workshop protocol 2010). This was done to determine if Bendire's Thrasher could be surveyed adequately without using call playback; call playback influences movement and is not suitable for distance sampling. In 2016, the protocol was modified such that the transect length and point count length were shortened. Long transects sometimes entered inhospitable terrain or left the vegetation community the random point was targeting. I also reduced the 3 separate 3-min intervals with no playback to one as few Bendire's Thrasher were detected in 2015 using this method. In 2016, each transect consisted of three points distributed 400 m apart (800 m total transect length). Each point count lasted 7.5 min and consisted of a 3-min period of silence followed by three intervals of 30 s of playback and 60 s of silence. The shorter survey time and transect also allowed a greater allocation of time to area search around transects each day. Area searching consisted of using call playback in areas around point count transects when a survey was over, as well as other places traveled while in the field where previous Bendire's Thrashers had been identified (Ralph et al. 1993). Surveys were restricted to morning hours (30 min before sunrise to 4 hr after sunrise) and were not conducted in rainy or windy conditions (> 12 mph) (Ralph et al. 1995).

Territory Mapping

After locating a territorial male, I returned to the area to map the breeding territory. For territory mapping I used a combination of spot-mapping and the territory flush technique (Weins 1969, Gregory et al. 2004). Territory mapping consisted of 1-3 visits, with the first visit a minimum of 5 days following the initial observation to avoid mapping Bendire's Thrashers that were still migrating north in the early part of the breeding season (Phillips et al. 1964, England and Laudenslayer 1993). Once a male Bendire's Thrasher was detected on the return visit its exact location was recorded using a GPS. The male was then observed and each location he moved to was recorded with a GPS. To increase the mapped locations, the territory flush method was used in situations when the bird did not move on its own after a couple of minutes (Wiens 1969, Reed 1985). The territory flush method involved flushing the male and marking the location of each perch he landed on, instead of waiting for him to move naturally, as birds would sometimes stay on one perch for extended periods of time. Birds were not flushed when it appeared they were actively visiting their nest. Any observed territory defense and singing were noted and points where it occurred were marked by GPS. After collecting ~20 GPS points (mean: 27 range: 15-39) territory positions were mapped and total area and periphery calculated using ArcGIS software, using minimum convex polygons with Hawth's tool extension (Jones 2011).

Climate, Soil, and Topographical Measurements

I developed a GIS database to extract climate, soil, and topographical variables. Climate data was obtained from PRISM Climate Group at Oregon State University which is at an 800 m resolution (PRISM 2016). Precipitation data consisted of the bioyear, the 7-month period preceding breeding (i.e. August-February), as this period is the most influential on habitat use because of effects on local vegetation growth and food abundance (Rotenberry and Wiens 1991). Elevation, slope, and aspect data were obtained from the New Mexico Geospatial Advisory Committee and Arizona's AZGEO clearinghouse at a 10 m resolution. Slope and aspect had non-normal distributions and were square-root transformed. I obtained data on soil type using the USDA-NRCS Soil Survey Geographic Database (SSURGO) at a 10m resolution (Soil Survey Staff 2016). To obtain these variables for each territory and random point, I plotted points at the center of each territory and random location and used the value at the point.

Territory Scale Measurements

For the territory scale, vegetation data was measured at each Bendire's Thrasher territory and at an equal number of random points within each vegetation community type. Random locations were generated in GIS using a map of each vegetation community type across the entire study area. Around each random point I created a radius equal to the average size of a Bendire's Thrasher territory during the corresponding field season and state. Vegetation data was quantified within each territory and random location by randomly placing six 25 m transects using ArcGIS. The line-intercept method, at 50 cm intervals, was used to measure type and amount of cover (dead and live vegetation by species, litter, biological crust, bare ground, and rock) along each transect. Gap intercept measurements were also collected as a measure of the heterogeneity of bare ground across the territory. Any gaps >20 cm between bases and canopies of all plants were recorded. In addition to the line-intercept and gap intercept transects, I conducted belt transect surveys along each of the six transects using a belt width of 4 m to measure shrub density and shrub height (Herrick et al. 2005). Robel pole measurements were taken at 5 m intervals along each transect, with readings taken from 5 m distance in each cardinal direction using a standardized height to measure visual obstruction (Herrick et al. 2005). A photograph from one side of each transect was also collected.

Landscape Scale Measurements

At the landscape scale, I created a GIS database to extract landscape-level variables to examine vegetative heterogeneity and fragmentation. I used aerial photographs (NAIP world imagery GIS) to hand digitize the land cover types at a 1 km buffer around Bendire's Thrasher territories and random points (Figure 3). One kilometer is a commonly used buffer size in similar studies with passerines (Hagan and Meehan 2002, Askins et al. 2007, Chandler et al. 2009). Land cover types included the broad vegetation community types, as well as four new classifications, residential, agriculture, creosote bush (separated from desert scrub), and road. I separated creosote bush as it dominated habitats it grew within and typically grows shorter than what I hypothesized Bendire's Thrasher would use. These digitized vegetation communities were used to develop variables that measured the heterogeneity and degree of fragmentation of the landscape using the Patch Analyst extension in ArcGIS. Variables extracted from this database are commonly used for landscape analyses and included mean patch size, patch shape, mean fractal dimension, richness, dominance, and edge density (Askins et al. 2007, Benson et al. 2010 Chandler et al. 2009, Hagan and Meehan 2002; Table 1). Mean patch size and mean fractal dimensions' distributions were not normal and were log transformed.

DATA ANALYSIS

Differences in territory size were examined among the four broad vegetation community classifications and year using two-way ANOVAs (PROC GLM in SAS 9.3). I also examined the influence of year and vegetation community on territory size with one-way ANOVAs.

Each variable measured potentially influencing territory selection was examined among vegetation communities using two-way ANOVAs examining variability by vegetation community (PROC GLM, Benson 2009). This was done to determine if I would need to control for vegetation community type in the models. Finally, to determine which variables influenced Bendire's Thrasher territory selection I generated a set of a priori models for three separate analyses including climate, soils, and topographic models (n = 10 models), territory scale models (n = 15 models), and landscape scale models (n = 10 models). Before developing a priori models I tested all variables for correlations using Pearson correlation tests and removed any variables with greater than or equal to 0.70 correlations (Benson et al. 2009). Basal gap and canopy gap were correlated; I retained canopy gaps for further analysis as I believed gaps in the canopy were more important for Bendire's Thrasher. Foliar cover was removed as it was negatively correlated with percent bare ground, a variable known to be important for thrasher species (Ambrose 1963, Rotenberry and Wiens 1980). All temperature variables were correlated with elevation; elevation was retained for further analysis. A goodness-of-fit test was used to examine how well the global model for each scale fit the data (Shaffer 2004). Models at each scale were run using conditional logistic regression stratified for vegetation community type with PROC LOGISTIC in SAS (Benson et al. 2009). I ranked models using AIC and computed ΔAIC and model weights over all models (Burnham and Anderson 2002). Models with ΔAIC < 2 were considered to be the top models (Burnham and Anderson 2002.) Variables in the top models were model-averaged and estimates of each parameter and their scaled odds ratios were calculated. I calculated scaled odds ratios by deciding on a biologically important scale and exponentiating the product of the parameter estimate to that scale (Butler et al. 2009). As an example, I believed that a 5% increase in average obstruction is more important ecologically than a 1% increase in obstruction, so for each parameter estimate of obstruction I multiplied it by 5 before calculating the odds ratio (Butler et al. 2009).

RESULTS

Territory Size

I located 69 Bendire's Thrasher territories during the springs of 2015 and 2016 and mapped 60 of these. The average territory size was 1.67 ha (± 0.86 ha SE). Territory size did not vary among the 4 broad vegetation community types ($F_{3,52} = 2.53$, $P = 0.19$), however, it did vary between year ($F_{2,52} = 9.90$, $P = 0.0002$) in New Mexico (Table 2). Precipitation and territory size were associated ($F_{1,57} = 11.31$ $P = 0.0014$ n = 60) with areas with higher precipitation having smaller territories.

Variation Within and Among Vegetation Community Types

Variables measured differed among vegetation communities, within vegetation communities and between Bendire's Thrasher territories and random points. Among vegetation community types, nine of 14 variables measured varied significantly, slope, elevation, average obstruction, average shrub height, number of tall shrubs, % bare ground, mean patch size, richness, and edge. Within vegetation community types variation was observed in slope, elevation, average obstruction, bare ground, average shrub height, mean patch size, edge density and richness. In addition, seven variables (elevation, slope, average obstruction, shrub height, average number of tall shrubs (shrubs >1.5m tall), mean patch size, patch richness) showed significant differences between Bendire's Thrasher territories compared to random points (Figure 4).

Climate, Soil, and Topographical Models

All 10 a priori a climate, soil, and topographical models outperformed the null model. The top three models were < 2 ΔAIC and accounted for 89.7% of the Akaike weights (Table 3). These three models contained all 4 climate, soil, and topographical variables (year, slope, elevation, and bioyear precipitation). A Hosmer and Lemeshow goodness-of-fit test showed no lack of fit for the three top models ($P = 0.07$, $P = 0.19$, $P = 0.15$). Based on model averaging and odds ratios, slope and elevation had the strongest influence on territory selection (Table 4). Selection decreased by ~7% with each 5% increase in the slope (odds ratio = 0.93 95% CI = 0.919 to 0.940). With every 100 m increase in elevation the odds of a territory being established decreased by ~9% (odds ratio = 0.90 95% CI = 0.904 to 0.91).

Territory Scale Models

All but one of the 15 models out-performed the null model. There were three top models that contained 83.3% of the Akaike weights and were within 2 ΔAIC of the top model (Table 3). The top models contained the variables of average obstruction, bare ground, average shrub height, number of tall shrubs, and canopy gaps >200 cm. A goodness-of-fit test showed no lack of fit for the top three models (P = 0.58, P = 0.68, P = 0.39). Based on model averaging and odds ratios, average obstruction, bare ground, and average shrub height were the most important variables influencing territory selection (Table 4). Odds ratios indicate that the odds of Bendire's Thrasher territory selection increased by 37% with each 10% increase in average obstruction (odds ratio = 1.37 95%CI = 1.33 to 1.41). For every 10% increase in bare ground there was a ~90% increase in the odds of Bendire's Thrasher use (odds ratio = 1.90 95%CI = 1.83 to 1.96). Average shrub height was the most influential with a 257% increase in the odds of Bendire's Thrasher use with each 1m increase in shrub height (odds ratio = 3.57 95%CI = 1.820 to 6.99). Number of tall shrubs was also slightly influential on use, with a ~2% increase in Bendire's Thrasher use with each additional shrub above 1.5 meters tall (odds ratio = 1.02 95%CI = 0.989 to 1.05).

Landscape Scale Models

There was only one strongly supported landscape model (ΔAICc < 2) (Table 3). This model contained the log of mean patch size, patch richness, and edge density, indicating Bendire's Thrashers selected territories with smaller patches, a greater number of patch types and higher edge density. A goodness-of-fit test showed no lack of fit for the top model (P=0.22). Mean patch size was the most important variable based on odds ratios, with a ~77% decrease in Bendire's Thrasher use with each 1 ha increase in the mean patch size (odds ratio = 0.23 95%CI = 0.102 to 0.51) (Table 4). Patch richness increased the odds of Bendire's Thrasher use by 58% with each additional vegetation community type within 1 km of a Bendire's Thrasher territory (odds ratio = 1.58 95%CI = 1.179 to 2.12) (Table 4).

DISCUSSION

Bendire's Thrasher estimated territory size is similar to that of other desert thrasher species (Fischer 1980, Tweit and Tweit 1986, Cody 1998). For example, Curve-billed Thrasher territories averaged approximately 2 ha, and Crissal Thrasher (*Toxostoma crissale*) territories were reported to average 2.6 hectares (Fisher 1980, Cody 1998) compared to the 1.67 ha found in my study for Bendire's Thrasher. In contrast Brown Thrasher (*Toxostoma rufum*) and Sage Thrasher territories were smaller, averaging less than 1 ha (Partin 1977, Reynolds and Rich 1978). The larger territory size for the desert thrashers may be, in part, related to greater vegetation community heterogeneity and the distribution of food resources in desert environments. Studies have linked territory size in passerines to a variety of factors including density of individuals, structural vegetation variation, and food availability (Seastedt and MacLean 1979, Wiens et al. 1985, Marshall and Cooper 2004). Density of Bendire's Thrashers likely did not influence territory size as birds were widely spaced, however, it is possible that density of other mimid species did, as I often observed mimid species in close proximity to each other. It is more likely that territory size was influenced by structural characteristics of the vegetation and prey availability, and the two are likely not mutually exclusive. Marshall and Cooper (2004) found that territory size was inversely related to foliage density for Red-eyed Vireos (*Vireo olivaceus*) and foliage density was positively related to caterpillar density, suggesting vireos selected for foliage density as a cue for food availability later in the season when they were raising young. I observed a fairly wide range of territory sizes for Bendire's Thrashers, however, interestingly, territory sizes did not vary by broad vegetation community type suggesting the structure of the vegetation plays a larger role in territory size than the type of vegetative community. Smith and Shugart (1987) found that vegetation structure was the most important variable explaining variation in territory size among Ovenbirds (*Seiurus aurocapillus*). My data suggests that bioyear precipitation for Bendire's Thrasher may serve as an indicator of food availability accounting for variation in territory size. I did not, however, examine the relationship of arthropod and berry abundance on plots with bioyear precipitation. The smaller observed territory sizes in Arizona compared to New Mexico are likely due to higher annual precipitation and greater vegetation structure in the Sonoran compared to Chihuahuan Desert. A review on the effects of precipitation on invertebrates in grasslands indicates that insect abundance and vegetation growth are linked to precipitation amounts with greater insect abundance in years with more precipitation (Barnett and Facey 2016). Since insects are the primary food of Bendire's Thrasher during the breeding season, changes in the amount of precipitation and pattern are likely to influence insect abundance and subsequently, territory size. As the climate changes in the southwest and drought becomes more common (Elias et al. 2016), Bendire's Thrashers may require more space for breeding, or in some years may not have sufficient prey to raise young to fledging.

The territories that Bendire's Thrashers selected were defined by lower elevation and less slope than randomly sampled areas. Interestingly, however, two territories found during this study were over 2000 m in elevation, 200 m higher than the highest published territory (Woodbury 1939). Thrashers are likely limited more by vegetation than actual elevation. Elevation and slope influence vegetation structure and composition, so their importance as variables in my models is likely due to these effects on the height, density, and composition of the vegetative community and not actually something birds select for (Méndez-Toribio et al. 2016). In addition to elevation, Bendire's Thrasher preferred flatter areas. As elevation increases, slope also typically increases, which may contribute to Bendire's Thrasher selection for areas of lower elevation. My results are similar to those seen with LeConte's Thrasher and Crissal Thrashers where high elevation and slope over 6 percent were avoided (Fletcher 2009).

At the territory scale Bendire's Thrasher selected for vegetation community heterogeneity, they selected areas with taller shrubs, greater vegetation density (obstruction) but also more bare ground. These findings support research that links desert species to critical resources (Tomoff 1974, Mills et al. 1989, Germaine et al. 1998). For example, in Tucson Arizona, densities of territorial native birds were correlated with the volume of native vegetation (Mills et al. 1989). Bendire's Thrasher preference for taller shrubs and greater vegetation density is consistent with other desert thrashers, and previous observations on the species (Marshall 1957, Rottenberry and Wiens 1980, Sheppard 1996, Fletcher 2009). Sage Thrashers select for more shrubs and bare ground, and tall patchy scrub habitat (Rottenberry and Wiens 1980); LeConte's Thrashers also exhibit selection for taller shrubs (Sheppard 1996). Other authors have reported Bendire's Thrashers in areas with tall shrubs such as Joshua trees (*Yucca brevifolia*) and palo verde (Ambrose 1963, England and Laudenslayer 1993). Studies also suggest Bendire's Thrashers prefer open areas lacking dense vegetation structure, however, in comparison to what is often available across their range, Bendire's Thrashers appear to select areas with greater vegetation cover (Brown 1901, Ambrose 1963, England and Laudenslayer 1993). I observed a preference for a combination of tall shrubs and bare ground by Bendire's Thrasher, which supports the assumption that habitat heterogeneity, including a mix of bare ground and vegetation structure are important for this species as they often forage on the ground for invertebrates, probing into desert soils (Brown 1901, Ambrose 1963, England and Laudenslayer 1993).

At a landscape perspective, my data supports that the Bendire's Thrasher is an edge adapted species. This was illustrated by their selection of territories surrounded by smaller disconnected habitat patches and greater variation in vegetation community types surrounding territories. This is similar to the findings of England and Laudenslayer (1993), who reported that Bendire's Thrasher do not use areas with dense vegetation (for example large expanses of creosote bush or heavy mesquite encroachment) but utilize edge habitats. Some studies that include information on Bendire's Thrasher mention their use of agricultural and rural development edges (Bent 1948, Phillips et al. 1964). Phillips et al. (1964) note Bendire's Thrasher avoidance of uninterrupted brushy cover and continuous grasslands, and their preference for areas with variation in vegetation communities. Other thrasher species have also been reported to have edge associations (Fischer 1980, Marshall 1957). Curve-billed Thrashers were identified preferring to nest at woodland edges and patches of cholla within grasslands (Fischer 1980), whereas Crissal Thrashers were found using chaparral at the edges of pine-oak woodlands and edges of juniper woodlands (Marshall 1957). Bendire's Thrasher apparent preference for edge may be, in part, related to their preference for taller shrubs that often are found in fragmented areas and along roads and agricultural environments.

Chihuahuan Desert grasslands and shrublands have changed dramatically over the past 200 years due largely to an increase in the abundance of honey mesquite and creosote bush (Buffington and Herbal 1965, Gibbens et al. 1992, Schlesinger et al. 1990). However, little is known in regards to the effect of this habitat conversion on shrub-adapted birds. Augudelo et al. (2008) showed that some arid land birds are sensitive to various levels of encroachment responding negatively to invasive shrub density. My data at the territory and landscape scale suggests that these large landscape level changes in the southwest in part attributed to desertification are potentially detrimental to Bendire's Thrashers. This species prefers heterogeneous vegetation communities at both the territory and landscape scale which is not consistent with the large expanses of shrub encroachment taking place across the region. For example, between 1977 and 1995, Brown et al. (1996) observed a 3-fold increase in shrubs at their study site in southwestern New Mexico. Along with this they documented substantial changes in populations of seed eating rodents and ants illustrating how these vegetation changes were having major effects on the ecology of these areas.

My data suggests that numerous spatial scales are important for Bendire's Thrasher territory selection, and had my analysis been restricted to only the scale of the territory, important information would have been missed. Bendire's Thrasher territories were characterized by variables from each scale: flatter slopes and lower elevations at the climate, soil, and topographical level, greater vegetation density, taller shrubs, barer ground at the territory scale, and for areas surrounding the territory (landscape) smaller patch sizes, more patch types, and more edge. This is an excellent example of how evaluating selection at multiple scales can be important. The heterogeneity of the landscape surrounding Bendire's Thrasher territories appears to be important, in addition to topographical features and vegetation structure within the territory. This idea has been supported with other thrasher studies as well, LeConte's, Crissal and Sage Thrashers were all shown to be influenced by variables at the landscape and territory scales (Knick and Rotenberry 1995, Fletcher 2009). Although Bendire's Thrashers have been shown to use a wide variety of vegetation community types, the idea that structure and heterogeneity may be what is limiting the species is supported by my models. A vegetation community lacking large shrubs and bare ground would not be used by this species as highlighted by my models.

Given the unknown reasons for the continued decline of Bendire's Thrasher and how little has been published on the species, habitat loss may be the first place to look for the explanation of the decline. The majority of habitat across the current estimated range of Bendire's Thrasher likely lacks the key structural characteristics they appear to prefer. In New Mexico large expanses of short and dense creosote bush dominate the majority of the suitable elevations for Bendire's Thrasher (Raitt and Maze 1968, Peters et al 2015). In addition, much of the juniper forests are likely too dense for the species after years of grazing and fire suppression (Jacobs and Gatewood 1999). Habitats in New Mexico with tall shrubs are rare, patchy, and usually lay on the edge of roads. There is potential that these habitats are "ecological traps" given issues with vehicle strikes (Coffin 2007). In Arizona, there is likely more habitat, given the tall vegetative structure of the Sonoran Desert. Across Arizona, limitations may be from habitat loss from anthropogenic development, or from competition with a more diverse and abundant avian population. Managers should look into creative ways to work collaboratively with landowners and public land agencies to create the habitat heterogeneity that Bendire's Thrashers select. Desert grasslands in southwestern New Mexico as well as the pinyon-juniper habitats on the edge of the plains of Saint Augustine in Central New Mexico are current hot spots for the species and should be the focus for conservation efforts. In Arizona, focus should be on already protected areas for Bendire's Thrasher where they appear to have stable populations. Further investigations into the causes of decline in both states is important. Looking into nest, juvenile, and adult survival as well as competition should answer more questions. Habitat loss and competition with other thrasher species are likely confounding effects so more information will be important for conservation (Johnson 2007).

LITERATURE CITED

Askins, R. A., B. Zuckerberg, and L. Novak (2007). Do the size and landscape context of forest openings influence the abundance and breeding success of shrubland songbirds in southern New England. Forest Ecology and Management 250:137-147.

Barnett, K. L., and S. Facey (2016). Grasslands, invertebrates, and precipitation: a review of the effects of climate change. Frontiers in Plant Science, 7.

Benson, T. J., N. Anich, J. Brown, and J. Bednarz (2009). Swainson's Warbler nest-site selection in eastern Arkansas. The Condor 111:694-705.

Benson, T. J., N. Anich, J. Brown, and J. Bednarz (2010). Habitat and landscape effects on brood parasitism, nest survival, and fledgling production in Swainson's Warblers. Journal of Wildlife Management 74:81-93.

Bent, A. C. (1948). Life histories of North American nuthatches, wrens, thrashers, and their allies. U.S. National Museum Bulletin 195.

Blouin, F. (2004). Status of the Sage Thrasher *(Oreoscoptes montanus*) in Alberta. Alberta, Fish & Wildlife.

Brown, H. (1901). Bendire's Thrasher. The Auk 18:225-231.

Brown, J.H., T.J. Valone, and C.G. Curtin. 1996. Reorganization of an arid ecosystem inresponse to recent climate change. Proceeding of the National Academy of Sciences 94:9729-9733.

Buffington, L.C. and C.H. Herbel (1965). Vegetational changes on a semidesert grassland Range from 1858 to 1963. Ecological Monographs 35:139-164.

Burnham, K. P., and D. R. Anderson. (2002). Model Selection and Multimodel Inference: A Practical Information-theoretic Approach. Springer-Verlag. New York, NY.

Butler, A. B., J. Martin, W. Palmer, and J. Carroll (2009). Winter use of south Florida dry prairie by two declining grassland passerines. The Condor 111:511-522.

Buttery, R. F. (1971). Bendires Thrasher Nesting in Colorado. Colorado Field Ornithologist 9:29.

Chandler, R. B., D. King, and S. DeStefano (2009). Scrub-shrub bird habitat associations at multiple spatial scales in beaver meadows in massachusetts. The Auk 126:186-197.

Cody, M. L. (1998). California Thrasher (Toxostoma redivivum). In The birds of North America, no. 323, edited by A. Poole and F. Gill. Philadelphia, PA: The Birds of North America, Inc.

Coffin, A. W. (2007). From roadkill to road ecology: a review of the ecological effects of roads. Journal of transport Geography 15:396-406.

Darling, J. L. (1970). New breeding records of Toxostoma curvirostre and T. bendirei in New Mexico. The Condor 72:366-367.

England, A.S. and W.F. Laudenslayer. (1993). Bendire's Thrasher. The Birds of North America 71.

Eldridge, D. J., M. Bowker, F. Maestre, F., E. Roger, J. Reynolds, and W. Whitford (2011). Impacts of shrub encroachment on ecosystem structure and functioning: towards a global synthesis. Ecology Letters 14:709-722.

Elias, E., A. Rango, R. Smith, C. Maxwell, C. Steele, and K. Havstad (2016) Climate change, agriculture and water resources in the Southwestern United States. Journal of Contemporary Water Research & Education 158:46-61.

Fischer, D. H. (1980). Breeding biology of Curve-billed Thrashers and Long-billed Thrashers in southern Texas. The Condor 82:392-397.

Fletcher, D. M. (2009) Distribution and site selection of Le Conte's and Crissal Thrashers in the Mojave Desert: A multi-model approach. Master Thesis. University of Nevada, Las Vegas.

Germaine, S.. Rosenstock, S., Schweinsburg, R., and W. Richardson(1998). Relationships among Breeding Birds, Habitat, and Residential Development in Greater Tucson, Arizona. Ecological Applications 8:680-691

Gibbens, R. P., Beck, R. F., McNeely, R. P. and C. H. Herbel (1992). Recent rates of mesquite establishment on the northern Chihuahuan Desert. J. Range Manage. 4 5 , 585-588

Gregory, R. D., D. Gibbons, and P. Donald (2004). Bird census and survey techniques. Bird Ecology and Conservation: A Handbook of Techniques 17-56.

Gutzler, D. S., T. Robbins (2011). Climate variability and projected change in the western United States: regional downscaling and drought statistics. Climate Dynamics, 37:835–849.

Hagan, J. M., and A. Meehan (2002). The effectiveness of stand-level and landscape-level variables for explaining bird occurrence in an industrial forest. Forest Science 48:231-242.

Herbel, C. H., F. Ares, and R. Wright (1972). Drought effects on a semidesert grassland range. Ecology 53:1084-1093.

Herrick, J. E., J. Van Zee, K. Havstad, L. Burkett, and W. Whitford (2005). Volumes I and II, Monitoring Manual for Grassland, Shrubland, and Savanna Ecosystems. USDA-ARS Jornada Experimental Range, Las Cruces, NM.

Jacobs, B. F., and R. G. Gatewood (1999). Restoration studies in degraded pinyon-juniper woodlands of north-central New Mexico. Proceedings: ecology and management of pinyon–juniper communities within the Interior West. Ogden, UT, USA: US Department of Agriculture, Forest Service, Rocky Mountain Research Station, RMRS 9: 294-298.

Johnson, M. D. (2007). Measuring habitat quality: a review. The Condor 109:489-504.

Jones, S. L. (2011). Territory size in mixed-grass prairie songbirds. Canadian Field-Naturalist 125:12–15.

Knick, S. T and J. T. Rotenberry (1995). Landscape characteristics of fragmented shrubsteppe landscapes and breeding passerine birds. Conservation Biology 9:1059-1071

LANDFIRE (2008). Existing Vegetation Type Layer, LANDFIRE 1.1.0, U.S. Department of the Interior, Geological Survey. Accessed 28 October 2016 at http://landfire.cr.usgs.gov/viewer/.

Marshall, J. T. (1957). Birds of pine-oak woodland in southern Arizona and adjacent Mexico. Pacific Coast Avifauna 32.

Marshall, M. R. and R. J. Cooper (2004). Territory size of a migratory songbird in response to caterpillar density and foliage structure. Ecology 85:432–445.

Méndez-Toribio, M., J. A. Meave, I. Zermeño-Hernández, and G. Ibarra-Manríquez, (2016). Effects of slope aspect and topographic position on environmental variables, disturbance regime and tree community attributes in a seasonal tropical dry forest. Journal of Vegetation Science 27: 1094–1103.

Menke, K. (2016). Identifying Potential Current Distribution For Bendire's Thrasher. Unpublished manuscript.

Milesi, C., C. Elvidge, R. Nemani, and S. Running (2003). Assessing the impact of urban land development on net primary productivity in the southeastern United States. Remote Sensing of Environment 86:401-410.

Mills, G. S., J. B. Dunning, Jr., and J. M. Bates. (1989). Effects of urbanization on breeding bird community structure in southwestern desert habitats. Condor 91:416-428.

Neilson, R. P. (1986). High resolution climatic analysis and southwest biogeography. Science 232:27-33.

North American Bird Conservation Initiative (NABCI) (2016). The State of North American Birds 2016, Environment and Climate Change Canada Ottawa, Ontario.

Partin, H. (1977). Breeding biology and behavior of the Brown Thrasher (Toxostoma rufum). Phd Thesis, Ohio State University, Columbus, Ohio.

Peters, D. P., K. Havstad, S. Archer, and O. Sala (2015). Beyond desertification: new paradigms for dryland landscapes. Frontiers in Ecology and the Environment 13:4-12.

Phillips, A. C., J. Marshall, and G. Monson (1964). The birds of Arizona. Tucson: University of Arizona Press, Tucson, Arizona.

PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, accessed 4 Aug 2016.

Raitt, R. J. and R.L. Maze. (1968). Densities and Species Composition of Breeding Birds of a Creosote bush Community in Southern New Mexico. The Condor 70:205.

Ralph, C. J., G. R. Guepel, P. Pyle, T. E. Martin, and D. F. DeSante (1993). Handbook of field methods for monitoring landbirds. USDA Forest Service General Technical Report PSW-GTR-144.

Ralph, C. J., J. R. Sauer, and S. Droege (1995). Monitoring bird populations by point counts. USDA Forest Service General Technical Report.

Reed, J. M. (1985). A comparison of the" flush" and spot-map methods for estimating the size of Vesper Sparrow territories. Journal of Field Ornithology 56:131-137.

Remsen, J. V. (1978). Bird species of special concern in California. In California Department of Fish and Game, Wildlife Management Branch.

Reynolds, T. D. and T. D. Rich. (1978). Reproductive ecology of the Sage Thrasher (Oreoscoptes montanus) on the Snake River Plain in south-central Idaho. The Auk 95:580-582.

Rosenberg, K.V., J. A. Kennedy, R. Dettmers, R. P. Ford, D. Reynolds, J.D. Alexander, C. J. Beardmore, P. J. Blancher, R. E. Bogart, G. S. Butcher, A. F. Camfield, A. Couturier, D. W. Demarest, W. E. Easton, J.J. Giocomo, R.H. Keller, A. E. Mini, A. O. Panjabi, D. N. Pashley, T. D. Rich, J. M. Ruth, H. Stabins, J. Stanton, and T. Will (2016). Partners in Flight Landbird Conservation Plan: 2016 Revision for Canada and Continental United States. Partners in Flight Science Committee.

Rotenberry, J., & Wiens, J. (1980). Habitat Structure, Patchiness, and Avian Communities in North American Steppe Vegetation: A Multivariate Analysis. Ecology, 61(5), 1228-1250.

Rotenberry, J. T., and J. A. Wiens (1991). Weather and reproductive variation in shrubsteppe sparrows: a hierarchical analysis. Ecology 72:1325-1335.

Schlesinger, W. H., J. F. Reynolds, G. Cunningham, L. Huenneke, W. Jarrel, R. Virginia, and W. Whitford (1990). Biological feedback in global desertification. Science 247:1043-1048.

Seastedt, T. R., and S. F. MacLean (1979). Territory size and composition in relation to resource abundance in Lapland Longspurs breeding in arctic Alaska. The Auk 1:131-142.

Shaffer, T. L., (2004). A unified approach to analyzing nest success. Auk, 121: 526–540.

Sheppard, J. M. (1996). Le Conte's Thrasher (*Toxostoma lecontei*). In The Birds of North

America, No. 230 The Academy of Natural Sciences, Philadelphia, PA, and The American Ornithologists' Union, Washington, D.C.

Shuford, W. D., and T. Gardali (2008). California Bird Species of Special Concern: A ranked assessment of species, subspecies, and distinct populations of birds of immediate conservation concern in California. Studies of Western Birds 1. Western Field Ornithologists, Camarillo, California, and California Department of Fish and Game, Sacramento.

Smith, T. M. and H. H. Shugart (1987). Territory Size Variation in the Ovenbird: The Role of Habitat Structure. Ecology 68:695–704.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Soil Survey Geographic (SSURGO) Database. Available online at https://sdmdataaccess.sc.egov.usda.gov. Accessed 08/27/16.

Tomoff, C. S. (1974). Avian species diversity in desert scrub. Ecology 55: 396–403.

Turnbull, L., J. Wainwright, and S. Ravi (2014). Vegetation change in the southwestern USA: patterns and processes. Patterns of Land Degradation in Drylands 289-313. Springer Netherlands.

Tweit, R. C. and J. C. Tweit (1986). Urban development effects on the abundance of some common resident birds of the Tucson area of Arizona. American Birds 40:431-436.

Wiens, J. A. (1969). An approach to the study of ecological relationships among grassland birds. Ornithological Monographs, 1:93.

Wiens, J. A., J. T. Rotenberry, and B. Van Horne. (1985). Territory size variations in shrubsteppe birds. Auk 102:500-505.

Woodbury, A. M. (1939). Bird records from Utah and Arizona. The Condor 41:157-163.

Zink, R. M. and R. C. Blackwell-Rago (2000). Species limits and recent population history in the Curve-billed Thrasher. The Condor 102:881-886.

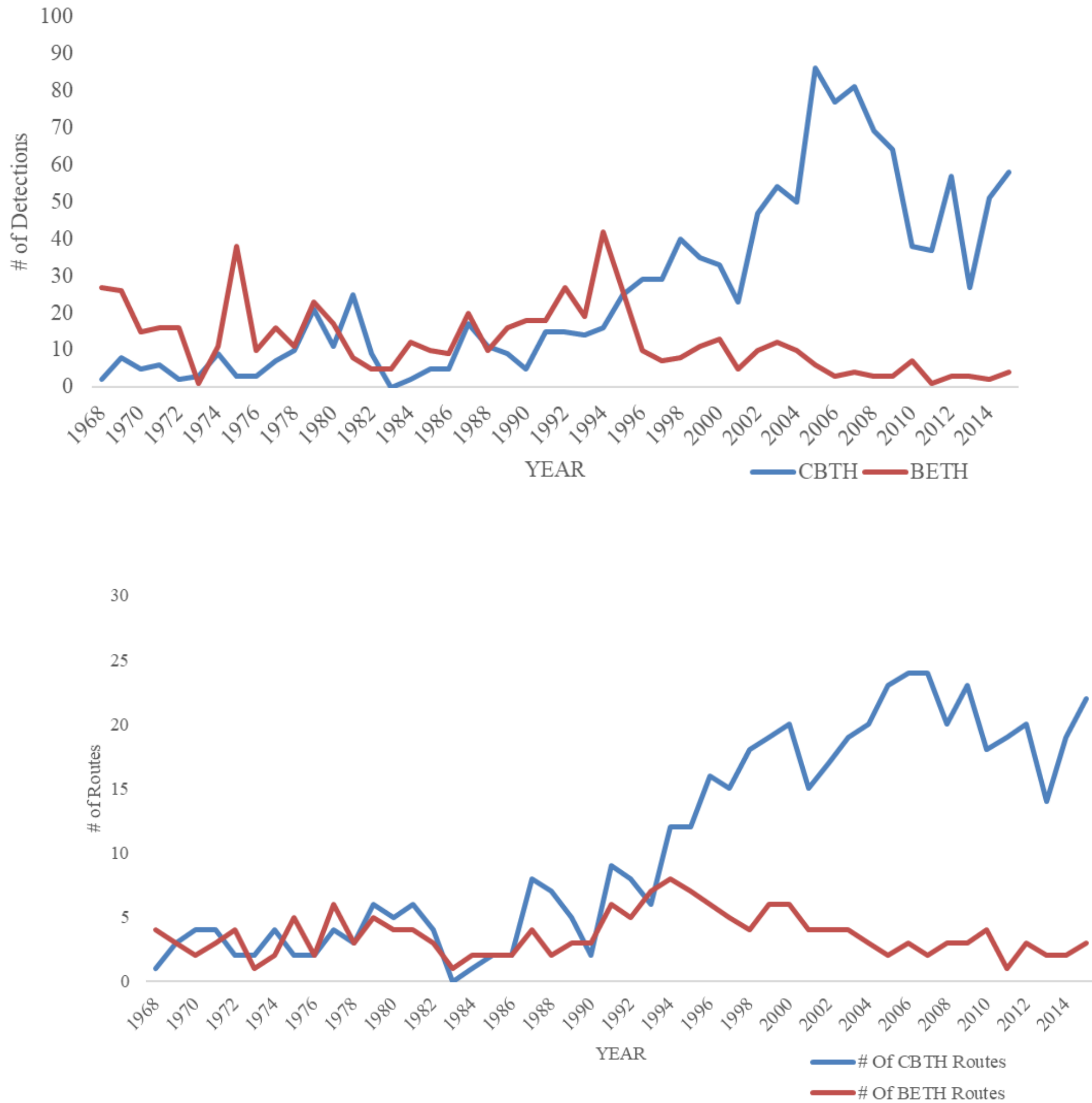

Figure 1. Graphs showing the differences in total detections (top) and the number of routes with Curve-billed Thrasher (CBTH) and Bendire's Thrasher (BETH) detections (bottom) along the same BBS routes in New Mexico from 1968-2016.

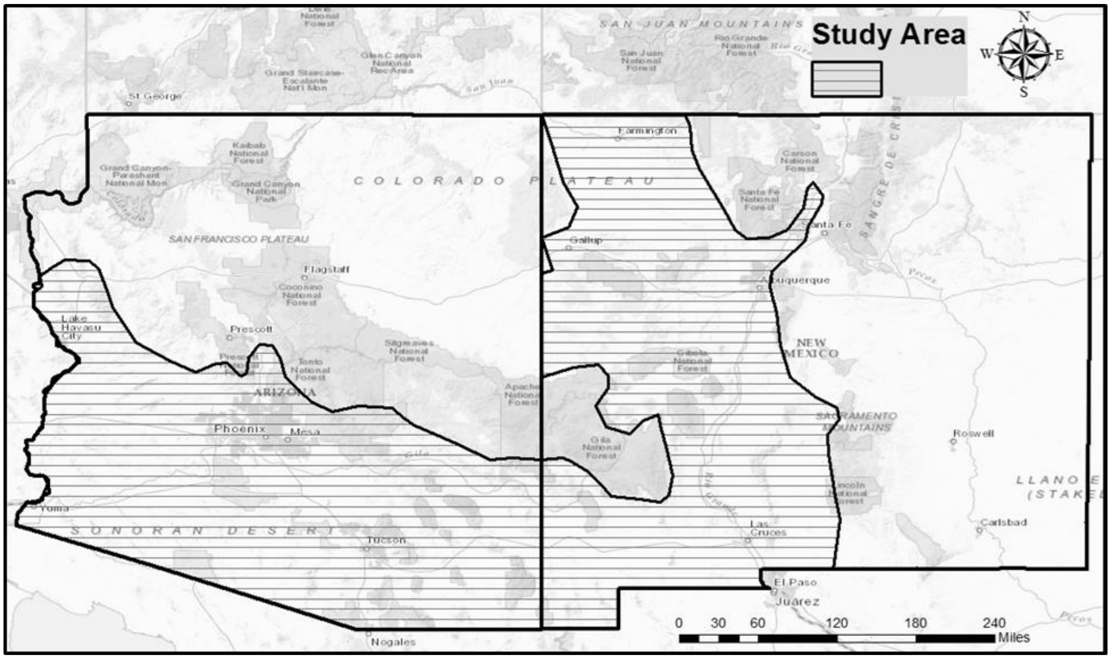

Figure 2. Study area for breeding surveys of Bendire's Thrasher across New Mexico and Arizona in 2015-2016

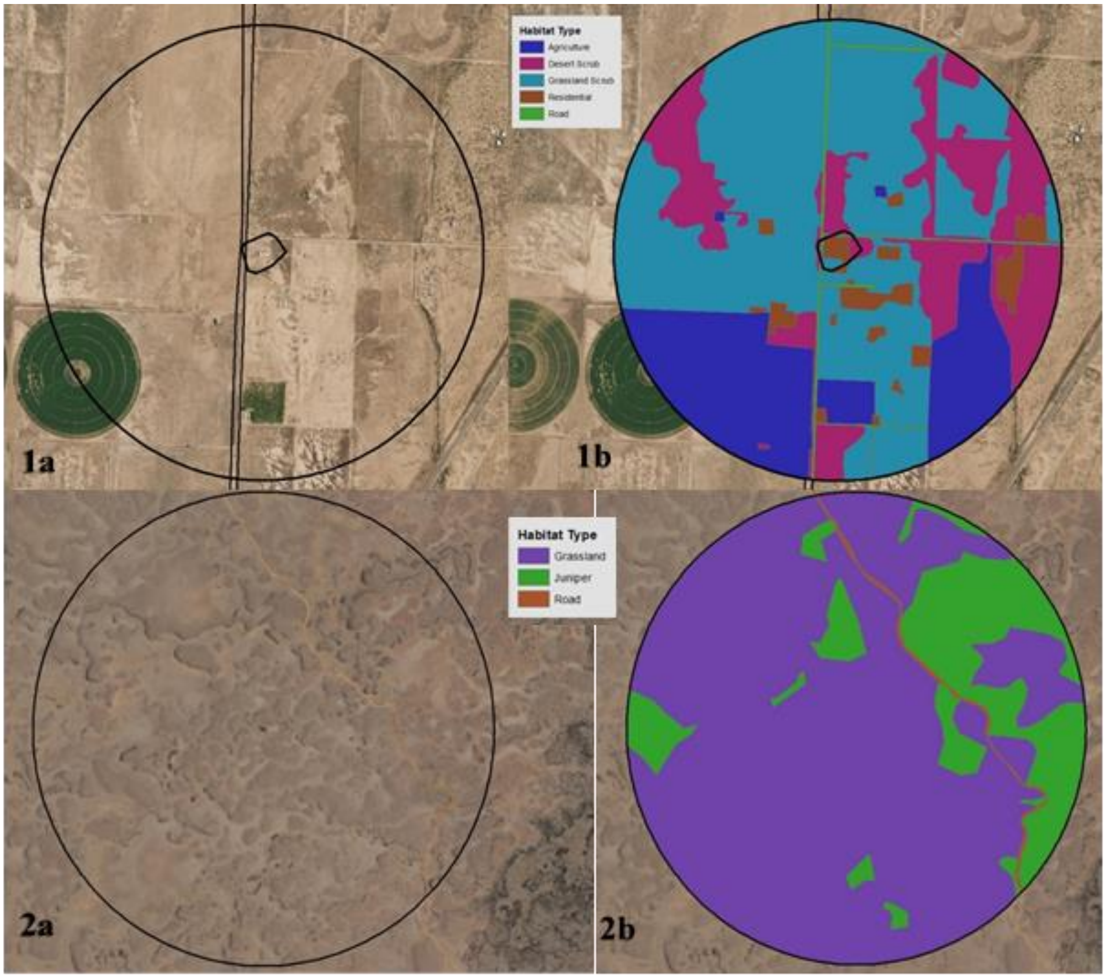

Figure 3. Example of hand digitized Bendire's Thrasher territory (before – 1a after – 1b) and random site (before – 2a after – 2b) in southwestern NM 2015-2016.

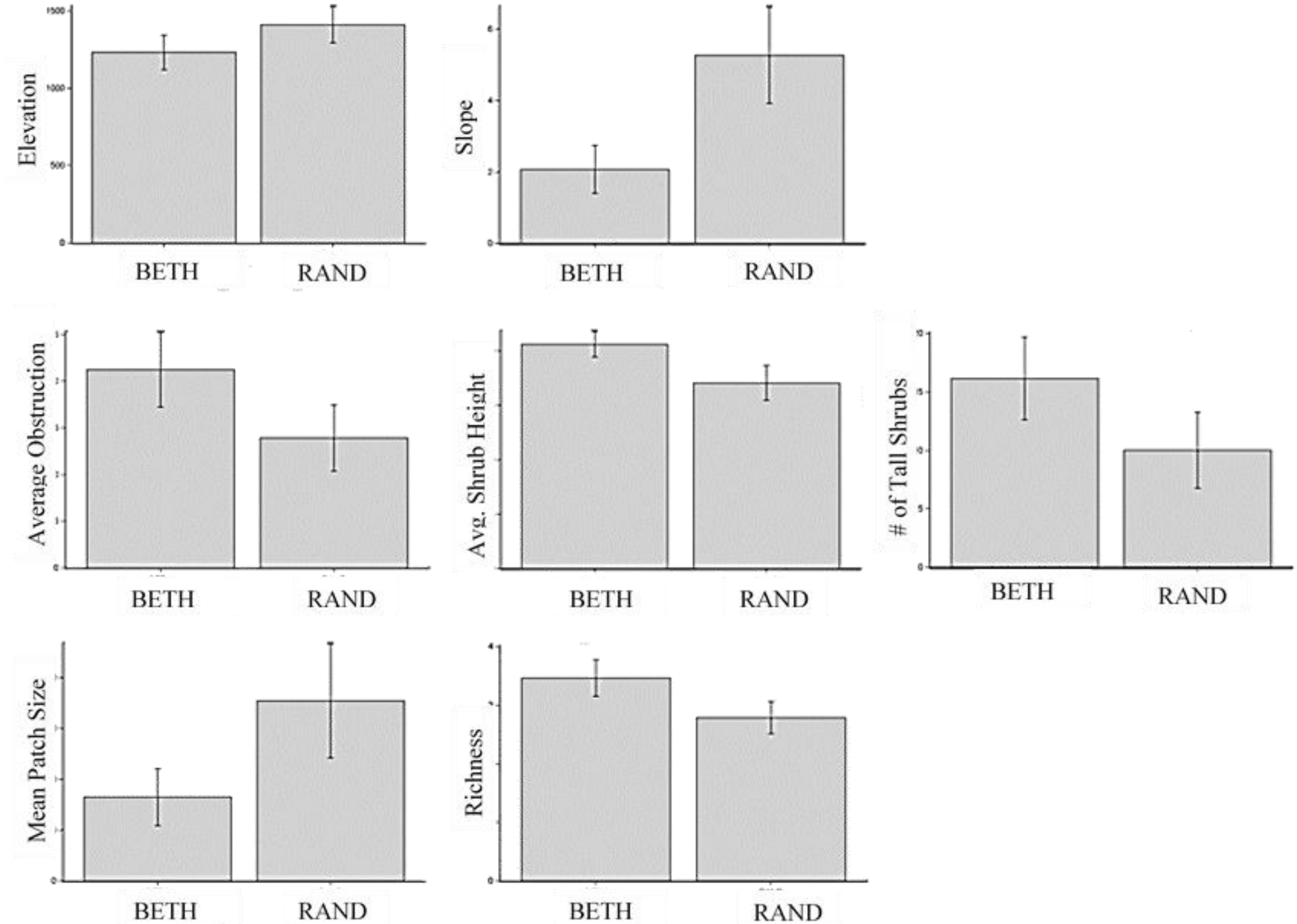

Figure 4. Mean extent ranges for the top variables of the Bendire's Thrasher habitat use models, with standard error bars in southwestern NM and south central AZ (2015-2016). BETH is Bendire's Thrasher territory and RAND is random site.

Table 1. Variables and descriptions used to examine vegetation community type associations of Bendire's Thrashers at climate, soil, topographical, territory and landscape scales.

Variable	Scale	Description
Elevation (EL)	Topographic	Elevation in meters, collected from DEMs in GIS
Slope (SL)	Topographic	Percent slope
Bioyear Precipitation (PB)	Climate	Average total precipitation from August through February (mm)
Year (YR)	Topographic	Year split into three options 2015 New Mexico, 2016 New Mexico, and 2016 Arizona
Average Obstruction (AO)	Territory	Average visual obstruction of territory, collected with Robel pole surveys (%)
Average Shrub Height (SH)	Territory	Average height of shrubs over 1.5m tall, collected with belt transect surveys
Bare Ground (BG)	Territory	Percent of territory that is bare ground, collected with line intercept surveys
Canopy Gaps >200cm (CG)	Territory	Percent of large canopy gaps that the bare ground consists of, collected with gap intercept surveys
Number of Tall Shrubs (NT)	Territory	Total number of shrubs over 1.5m, collected with belt transect surveys
Total Shrub Density (TD)	Territory	Density of all shrub sizes, collected with belt transect surveys
Mean Patch Size (PS)	Landscape	Average area (ha) of patches in the 1km buffer around territories,

Mean Fractal Dimension (FD)	Landscape	Twice the slope of log perimeter regressed on log area, measure of shape complexity of patches
Richness (RI)	Landscape	Number of different patch types
Dominance (DO)	Landscape	The measure of how much one or a few patch types dominate the landscape
Edge Density (ED)	Landscape	Amount of edge relative to the landscape area, collected with patch analyst in GIS

Table 2. Territory size estimates in hectares for all 60 mapped Bendire's Thrasher territories in New Mexico 2015-2016 and Arizona in 2016

Year	State	N	Mean (ha)	Minimum (ha)	Maximum (ha)
2015	NM	25	1.28	0.269	2.60
2016	NM	18	2.29	0.582	3.54
2016	AZ	17	1.59	0.390	3.65

Table 3. Results of conditional logistic-regression models explaining differences between Bendire's Thrasher territories and random sites across Arizona and New Mexico, 2015-2016 at the climate, soil, and topographical level and territory and landscape scale. Only the top models are reported here. YR = Year, SL = slope; EL = elevation; PB = bioyear precipitation; AO = average obstruction; BG = bare ground; SH = average shrub height; TS = number of tall shrubs; CG = canopy gaps >200cm; TD = total shrub density; PS = mean patch size; RI = richness; ED = edge density.

Scale	Model	-2 Log-likelihood	K[a]	ΔAIC	w_i
climate, soil, and topographical [b]					
	YR + SL + EL	143.01	3	0	0.46
	EL + SL	146.23	2	1.22	0.25
	YR + SL + EL + PB	142.79	4	1.78	0.19
	EL + SL + PB	146.22	3	3.21	0.09
Territory[c]					
	AO + BG + SH	145.85	3	0	0.37
	AO + BG + SH + TS	144.38	4	0.53	0.28
	AO + BG + SH + CG	145.2	4	1.36	0.19
	AO + BG + SH + CG + TS + TD	143.04	6	3.19	0.07
Landscape[d]					
	PS + RI + ED	152.88	3	0	0.6
	PS	160.05	1	3.17	0.12

[a] K is the number of parameters
[b]Minimum AIC score is 173.700
[c]Minimum AIC score is 174.3

[d]Minimum AIC score is 172.81

Table 4. Model-averaged parameter estimates for models of Bendire's Thrasher vegetation community type use in New Mexico and Arizona in 2015-2016. Parameter estimates (β) that do not bound zero and Odds ratios that do not bound 1 indicate strong support for that variable.

Scale	Variable	β	95% CI			Scaled Odds Ratio	95% CI		
Climate, soil, and topographical									
	Slope (SL)	-0.015	-0.01	to	-0.02	0.927	0.919	to	0.94
	Elevation (EL)	-0.002	-0.003	to	-0.002	0.905	0.904	to	0.91
	Bioyear Precipitation (PB)	-0.001	-0.005	to	0.002	0.99	0.993	to	1
	Year (YR)	-0.628	-0.944	to	-0.312	0.88	0.587	to	1.32
Territory									
	Average Obstruction (AO)	0.031	0.015	to	0.047	1.37	1.33	to	1.41
	Bare Ground (BG)	0.07	0.04	to	0.099	1.895	1.83	to	1.96
	Average Shrub Height (SH)	1.319	0.916	to	1.52	3.567	1.82	to	6.99
	Number of Tall Shrubs (TS)	0.061	0.032	to	0.091	1.019	0.989	to	1.05
	Canopy Gap (CG2)	-0.004	-0.013	to	0.005	0.923	0.906	to	0.94
Landscape									
	Mean Patch Size (PS)	-2.011	-2.821	to	-1.202	0.229	0.102	to	0.51
	Richness (RI)	0.342	0.088	to	0.596	1.58	1.179	to	2.12
	Edge Density (ED)	-0.016	0.007	to	5.314	0.985	0.972	to	0.998

APPENDIX A

Table 1A. Results of conditional logistic-regression models explaining abiotic/temporal differences between Bendire's Thrasher territories and random sites across Arizona and New Mexico, 2015-2016. SL = slope; EL = elevation; PB = bioyear precipitation; YR = year.

Model[a]	-2 Log-likelihood	K[b]	ΔAIC	w_i
YR SL EL	143.01	3	0	0.46
EL SL	146.23	2	1.22	0.25
Global	142.79	4	1.78	0.19
EL SL PB	146.22	3	3.21	0.09
SL	154.57	1	7.56	0.01
YR EL	158.49	2	13.48	<0.01
YR EL PB	157.39	3	14.38	<0.01
EL	164.97	1	17.96	<0.01
EL PB	164.84	2	19.83	<0.01
Null	172.81	0	23.8	<0.01
YR	171.7	0	24.69	<0.01

[a] For a list of variables present in each model see Table 1.
[b] K is the number of parameters
[c] Minimum AIC score is 173.700

Table 2A. Results of conditional logistic-regression models explaining territory scale differences between Bendire's Thrasher territories and random sites across Arizona and New Mexico, 2015-2016. AO = average obstruction; BG = bare ground; SH = average shrub height; TS = number of tall shrubs; CG = canopy gaps >200cm; TD = total shrub density.

Model[a]	-2 Log-likelihood	K^{b}	ΔAIC	w_{i}
AO BG SH	145.85	3	0	0.37
AO BG SH TS	144.38	4	0.53	0.28
AO BG SH CG	145.20	4	1.36	0.19
Global	143.04	6	3.19	0.07
SH TS TS*SH	150.48	3	4.63	0.04
SH BG	153.16	2	5.31	0.03
AO SH TS SH*TS	149.59	4	5.74	0.02
AO SH	155.75	2	7.9	0.01
SH	159.70	1	9.85	<0.01
BG TD AO	158.91	3	13.06	<0.01
TS	166.16	1	16.31	<0.01
AO	166.91	1	17.06	<0.01
CG TS	166.07	2	18.23	<0.01
TS AO CG	164.17	3	18.32	<0.01
Null	172.81	0	20.96	<0.01
BG TS BG*TS	168.35	3	22.5	<0.01

[a] For a list of variables present in each model see Table 1.
[b] K is the number of parameters
[c] Minimum AIC score is 174.35

Table 3A. Results of conditional logistic-regression models explaining landscape scale differences between Bendire's Thrasher territories and random sites across Arizona and New Mexico, 2015-2016. PS = mean patch size; RI = richness; ED = edge density; DO = dominance; FD = fractal dimension.

Model[a]	-2 Log-likelihood	*K*[b]	ΔAIC	w_i
PS RI ED	152.88	3	0	0.6
PS	160.05	1	3.17	0.12
PS RI	158.51	2	3.63	0.1
Global	152.71	5	3.83	0.09
RI	161.97	1	5.09	0.05
PS FD DO RI	157.74	4	6.85	0.02
ED RI	161.75	2	6.87	0.02
DO ED	164.92	2	10.04	<0.01
FD DO	166.04	2	11.15	<0.01
FD	168.32	1	11.44	<0.01
FD DO ED	164.56	3	11.67	<0.01
Null	172.81	0	13.93	<0.01

[a] For a list of variables present in each model see Table 1.
[b] *K* is the number of parameters
[c] Minimum AIC score is 172.81

Table 4A. Summary of the top covariates in Bendire's Thrasher multiscale habitat use models in Arizona and New Mexico separated by Bendire's Thrasher locations and random sites. SL = slope; EL = elevation; PB = bioyear precipitation; PS = mean patch size; RI = richness; ED = edge density; AO = average obstruction; BG = bare ground; SH = average shrub height; TS = number of tall shrubs; CG = canopy gaps >200cm.

Site	N	Variable	Units	Mean	Std Dev	Minimum	Maximum
BETH[a]	69						
		SL	%	2.07	2.80	0.00	10.00
		EL	m	1232.32	467.50	284.00	2172.00
		PB	mm	186.93	55.67	84.15	312.90
		PS	ha	33.02	46.67	2.78	314.12
		RI	types	3.46	1.30	1.00	6.00
		ED	m2	1343539.01	750693.97	200019.85	3469359.84
		AO	%	21.23	16.60	2.42	89.67
		BG	%	23.29	8.05	6.00	39.17
		SH	m	2.06	0.49	1.12	3.84
		TS	count	16.14	14.64	0.00	80.00
		CG	%	49.31	23.38	1.40	93.90
Random	70						
		SL	%	5.27	5.66	0.00	22.00
		EL	m	1410.79	487.87	266.00	2266.00
		PB	mm	192.21	65.32	64.15	354.36
		PS	ha	70.89	93.95	4.64	314.12
		RI	types	2.79	1.14	1.00	6.00
		ED	m2	1042724.45	604321.03	199827.69	2425813.52
		AO	%	13.93	14.86	0.25	69.42
		BG	%	19.84	11.34	0.00	44.50
		SH	m	1.71	0.67	0.50	3.45
		TS	count	10.01	13.65	0.00	81.00
		CG	%	49.94	24.77	2.00	94.70

[a] Bendire's Thrasher

CHAPTER 2. PREDICTING POTENTIAL IMPACTS OF CLIMATE CHANGE ON BENDIRE'S THRASHER (*Toxostoma benderei*) DISTRIBUTION IN THE SOUTHWESTERN U.S. USING MAXENT MODELING

INTRODUCTION

Rare and cryptic species are challenging for wildlife managers due to the lack of reliable data on distribution and habitat associations (Mckelvey et al. 2008). Species distribution models (SDM) have emerged as an important tool that can make use of available data from different sources to map species occurrences (Guisan et al. 2006, Pearson et al. 2007, Marini et al. 2010). These models can be used to identify new areas to survey, target areas to focus habitat conservation and management actions, and to identify potential threats (Guisan and Thuiller 2005, Wilson et al. 2005, Marini et al. 2009,). For example, Prieto-Torres et al. (2018) used SDMs to identify priority conservation areas for multiple species in the endangered neotropical dry forests of Peru, Ecuador, Bolivia, and Brazil.

In recent years, SDM have also been used to predict the effects of climate change on species distributions. Climate change has been identified as a major threat to wildlife species and ecosystems worldwide. Knowledge of predicted changes and trends in climate and how this may impact a species range is a pivotal element of conservation and wildlife management (Guidigan et al. 2018). This knowledge will allow managers to use these predictive models to make management decisions that will be relevant in the future. The southwestern United States is already an extreme environment and is considered to be one of the most "climate-challenged" regions in North America (Garfin et al. 2013). The predicted effects of climate change including hotter and drier conditions in the Southwest (Garfin et al. 2013) may result in reduced survival and reproduction, highlighting the importance of focusing research in this area (Garfin et al. 2013).

The Bendire's Thrasher has been identified as the fastest declining arid land bird species in the southwestern U.S. (North American Bird Conservation Initiative 2016). This species secretive nature and low population numbers have made it among the least studied avian species in the United States. Its distribution and habitat use are still poorly understood, with birds not always occurring in similar habitats (England and Laudenslayer 1993). Historical data show Bendire's Thrashers occur in desert scrub, grassland scrub, pinyon-juniper forests, and agricultural edge habitats throughout the arid lands of the southwest (Brown 1901, Darling 1970, and England and Laudenslayer 1993). Bendire's Thrasher range spans two countries (United States and Mexico) and within the United States occurs in six states with breeding pairs being observed in New Mexico, Arizona, California, and small portions of Nevada, Utah, and Colorado (Buttery 1971 and England and Laudenslayer 1993). The majority of the Bendire's Thrasher population in the U.S. occurs in Arizona and New Mexico (England and Laudenslayer 1993).

The Bendire's Thrasher is a species of conservation concern in the southwest; the influence of climate and topographic variables on its distribution is not well understood. Thus, I aimed to develop an SDM and climate projections to predict the potential range and hotspots of Bendire's Thrasher in New Mexico and Arizona, examine predicted effects of climate change on Bendire's Thrasher distribution and identify the land ownership that currently does, and with future climate projections will manage the majority of habitat for this species. This information will allow managers to identify the most suitable areas to focus long-term management actions and appropriate stakeholders to work with.

METHODS

Study area

Research was conducted in the southwestern United States in New Mexico and Arizona between February and June 2015 and 2016 (Figure 1). This area was selected because greater than 50% of the US population of Bendire's Thrasher is thought to occur within these two states (England and Laudenslayer 1993). This part of the southwestern United States is commonly referred to as the desert southwest. Dominant plants across both states consists of honey mesquite (*Prosopis glandulosa*), velvet mesquite (*Prosopis velutina*), creosote (*Larrea tridentata*), juniper sp. (*Juniperus spp.*), cholla (*Cylindropuntia spp.*), catclaw (*Acacia greggii*), whitethorn (*Vachellia constricta*), soap tree yucca (*Yucca elata*), palo verde (*Parkinsonia spp.*), and saguaro (*Carnegiea gigantea*). Woody shrub encroachment has transformed this landscape over the past 100 years from a grass to shrub dominated landscape (Peters et al. 2015). Across this broad study area, elevations ranged from ~200 m in Arizona to ~2400 m in New Mexico, temperatures during the Bendire's Thrasher breeding season (February – June 2015 and 2016) ranged from -1 °C to 50 °C, and precipitation ranged from ~10 cm to ~50 cm in some higher elevation locations (PRISM 2016).

Species occurrence locations

I compiled breeding records of Bendire's Thrasher occurrence points (February – June) throughout my study area from two main sources: 1) locations from my field surveys (2015 and 2016) in western New Mexico and south-central Arizona and 2) ebird breeding locations within the 10 years leading up to and encompassing my study period (2007-2017). I used the SDM toolbox in ArcMap to remove spatially correlated points using a 3 km threshold with preference for retaining observations from my field studies (Fourcade et al 2014). This process randomly selected one point to retain when the 3-km buffers around points overlapped. I used this larger spatial threshold to reduce the urban bias potentially created when using citizen science data like that from ebird (Perkins-Taylor and Frey 2020).

Environmental datasets

To address environmental influences on Bendire's Thrasher occurrence, I downloaded climatic data from WorldClim (Fick 2017) and the Parameter-elevation Regressions on Independent Slopes Model (PRISM) database (PRISM 2016) from Oregon State University. Additionally, topographic and vegetative cover data was obtained from USGS National Map database (Archuleta 2017). I initially examined 19 bioclimatic variables from WorldClim, and I created three additional variables using data from PRISIM (Table1). The three variables created using PRISIM data focused on temperature and precipitation data relevant to the Bendire's Thrasher breeding season. Average maximum and minimum temperatures of the breeding season consisted of taking the max/min temperature rasters (PRISM 2016) from February thru May (documented months of active breeding for the Bendire's Thrasher) and averaging them in GIS. Bioyear precipitation consisted of the total precipitation raster from the seven months leading up to breeding which is hypothesized to be the precipitation that most influences breeding success (Rotenberry and Wiens 1991); this is August – February for the Bendire's Thrasher (Table 1). All climatic data were at an 800m resolution. To address topographic influences on Bendire's Thrasher occurrence I extracted rasters of elevation and slope from the USGS National Map database. These topographic data were at a 10m resolution. Lastly to address habitat influences on Bendire's Thrasher occurrence I downloaded maps of percent vegetation cover from the USGS National Land Cover Database (NLCD) (Dewitz 2019). These habitat data were at a 30m resolution. Running models with MaxEnt requires all data to be scaled to the same resolution, since my data ranged from 10-800m resolution I changed the resolution of all data to 800m (Guisan et al. 2007 and Phillips et al. 2008). I tested all variables for correlations and removed any layers with a Pearson Correlation greater than or equal to 0.7 (Dormann 2013). All 19 WorldClim variables (temperature and precipitation variables) were correlated with elevation; elevation was retained for further analysis as I believe it better explained selection ecologically. Average maximum and minimum temperature of the breeding season were correlated, so I chose to retain maximum temperature as I believe that the high temperatures in the southwest from February thru May have the greater impact on Bendire's Thrasher breeding success. Bioyear precipitation, slope, and percent cover were not correlated with elevation or average maximum temperature of the breeding season, so they were also retained for modeling. The final variable set included average maximum temperature of the breeding season, bioyear precipitation, elevation, slope, and percent cover (Table 1).

Climate projection models

To examine climate projections, I obtained data from WorldClim. I used the Community Climate System Model version 4 (CCSM4) and 2) Hadley Centre Global Environment Model version 2 Earth System (HadGEM2-ES) 2050. These two models are commonly used for MaxEnt climate projections in North America and were recently identified as good models for projecting Southwestern bird species potential distribution (Salas et al. 2017). I ran these models using two greenhouse gas Representative Concentration Pathways (RCPs 2.6 and 8.5) as these have been found to represent the best-case and worst-case scenarios for emissions, with RCP 2.6 representing the most aggressive scenario for reducing emissions while RCP 8.5 is the scenario that projects the highest concentrations of multiple greenhouse gas emissions. (Roeckner et al. 2010). The two models each with the two greenhouse gas projections resulted in four climate scenarios. I used the projected changes in precipitation and temperature under the two climate projection models to create variables of bioyear precipitation and maximum breeding season temperature for each of the 4 climate scenarios. The final variables used in the four climate projections were bioyear precipitation, maximum temperature of the breeding season, elevation, and slope, cover was left out of the climate projections as it could not be projected into the future and was found to be unimportant in the SDM.

Modeling methods

Given the presence-only nature of my data I used program MaxEnt (version 3.3.1; Phillips et al. 2008) to assess Bendire's Thrasher distribution. MaxEnt uses presence only data to estimate the likelihood of a species distribution using the concept of maximum entropy. I ran models in MaxEnt under default setting and retained 20% of both the survey and ebird occurrence points to test the accuracy of the model (Phillips et al. 2008). I ran 20 replications with 1000 iterations for each model and used the Jackknife procedure built into MaxEnt to test the importance of each variable. The receiver operating characteristic (ROC) analysis was used to evaluate the fit of the model and model performance. The area under ROC curve (AUC) was used as an index to provide overall accuracy. AUC ranges between 0 and 1 and I employed the scaling system used by Salas et al. (2017) to rank the models: > 0.9 indicated high accuracy, 0.7

to 0.9 indicated good accuracy, and those < 0.7 indicated low accuracy. In addition to AUC, I also looked at kappa (k) which measures the overall accuracy of the model predictions by the accuracy expected to occur by chance. The kappa value ranges from −1 to 1 with poor accuracy being a $k < 0.4$; good accuracy, $0.4 < k < 0.75$; and excellent accuracy, $k > 0.75$ (Landis and Koch 1977). Kappa values can be low when using only presence data, so I also calculated a threshold-dependent statistical matrix called true skill statistics (TSS) (Allouche et al. 2006). I used the threshold value of 0.5 (Pearson et al. 2002). The TSS ranges from −1 to +1, where +1 indicates perfect agreement, and 0 represents a random fit (Allouche et al. 2006).

Land Owner Responsibility

To examine land ownership (land management agencies and private ownership) with responsibility for the largest percentage of current and future potential Bendire's Thrasher habitat I used ArcMap and the results of my current species distribution model (SDM) and the HAD 2.6 climate projection, as this was the best performing best case scenario model. I converted the MaxEnt results to a polygon file using areas of 0.50 or greater suitability as anything below that threshold may not represent habitat. Maps of surface ownership were obtained from the BLM (data.gov), these data were imported into GIS and overlaid with the results of the SDM polygon. I then used the spatial analyst union tool to generate total area of Bendire's Thrasher suitable habitat under each management agency, I then used these total areas to calculate percentages of suitable habitat managed.

RESULTS

Occurrence Points

I documented 92 Bendire's Thrasher breeding locations in Arizona and New Mexico in 2015 and 2016. I used an additional 439 observations during the breeding season from ebird.org (2007-2017) for a final vector layer of 531 locations across Arizona and New Mexico. After removing spatially correlated points my sample size was reduced to 388 locations (Figure 1).

Species Distribution Model

The Bendire's Thrasher SDM model of five uncorrelated climatic, biogeographic and vegetation variables performed better than random with an AUC of 0.846 (SD = 0.036) with 20 replications. The average AUC of the test data was 0.848 (SD = 0.035). No clear change in AUC was observed with additional replications. The TSS was 0.556 and the kappa was 0.361. The top two variables contributing substantially to the overall model were maximum temperature during the breeding season and bioyear precipitation (Table 2). Percent cover, slope and elevation all had less than 10% contribution (Table 2). The Jackknife test indicating the relative importance of individual variables showed maximum temperature of the breeding season, elevation and bioyear precipitation had the highest predictive power (Figure 2). Based on these results, the most suitable areas in New Mexico and Arizona for breeding Bendire's Thrashers were identified as extreme southwestern New Mexico and southcentral New Mexico and broadly in southcentral Arizona as well as extreme south eastern AZ and the central portion of western AZ. (Figure 3). Compared to other areas in both states, Bendire's Thrashers are associated with areas of low elevation and rainfall and warm temperatures.

Climate Projections

The four climate projections that I tested to examine the influence of climate change on Bendire's Thrasher distribution by 2050 had AUC values above 0.84 (Standard deviations ranged from 0.02 to 0.04) (Table 3); each model was based on projected changes in maximum temperature and bioyear precipitation. Each of these climate scenarios demonstrated a substantial reduction in the suitable range of Bendire's Thrasher by 2050 (Figure 4). The more extreme emission scenarios showed a slightly larger reduction in suitable range (Figure 4). The Hadley Centre Global Environment Model version 2 Earth System (HadGEM2-ES) RCP pathway 2.6 appeared to be the least extreme scenario based on my 4 models retaining the largest area of potential habitat and the HadGEM2-ES RCP pathway 8.5 was the worst-case scenario with the largest reduction in potential habitat for Bendire's Thrasher (Figure 4).

Land Owner Responsibility

The land ownership layer was added to the current Bendire's Thrasher distribution; areas that had a 50% or higher probability of Bendire's Thrasher presence were used to evaluate land management responsibility. I repeated this process for the future projections of Bendire's Thrasher distribution from the HadGEM2-ES 2.6 model (Table 4). In New Mexico, the majority of potential Bendire's Thrasher habitat is managed by private landowners, Bureau of Land Management, the State of New Mexico and the Department of Defense. In Arizona, important land managers include private landowners, tribal lands, Bureau of Land Management, and Arizona state land (Table 4). Future projections show Bendire's Thrasher becoming extirpated in New Mexico. Bendire's Thrashers are projected to persist in Arizona and important landowners still include private landowners, tribal lands, Bureau of Land Management, and Arizona state land; the order of importance remains the same however there is a reduction in acreage (Table 4).

DISCUSSION

Distribution of breeding Bendire's Thrasher in New Mexico and Arizona appears to be most strongly influenced by climatic variables including maximum temperature and a measure of precipitation that accounts for accumulation over the seven months preceding breeding (bioyear precipitation). This declining species is found in some of the warmest and driest habitats of the southwest. I also detected some support for elevation with breeding Bendire's Thrashers not found above 2100m. The LeConte's and Crissal Thrashers, two other desert-adapted thrashers, have also been associated with hot, dry conditions in the southwest; while Crissal Thrashers have a broader distribution that overlaps that of Bendire's Thrashers, LeConte's Thrashers are mainly west of the Bendire's Thrasher breeding range (Fletcher 2009, Sheppard 2018). Within New Mexico and Arizona, I found the most suitable conditions for Bendire's Thrasher current breeding distribution to occur in extreme southwest New Mexico into parts of southcentral New Mexico and broadly in southcentral Arizona, as well as parts of southeast and west central Arizona. Distribution of this species was not strongly influenced by slope or vegetation cover. Bendire's Thrasher distribution encompasses some of the warmest and driest portions of the southwest, however, this does not imply strict avoidance of areas with higher precipitation or cooler temperatures. Scale is important. At a landscape scale this species does avoid areas with cooler temperatures and higher precipitation which would also influence and be influenced by vegetation and elevation. Plant communities including vegetation type, height and density are likely important (see chapter 1) but the data I included in my model on canopy cover was probably too coarse (800 m) to be accurate enough to affect the model. LeConte's Thrashers avoid areas where consistently higher precipitation has resulted in taller and denser shrub communities (Sheppard 2018). Within their range, Bendire's Thrashers are found to select territories that recently had higher precipitation. This is likely related to increased prey availability as arthropod abundance is closely linked to precipitation (Tanaka and Tanaka 1982, Bolger et al. 2005). Additionally, territory size is inversely related to precipitation, again likely a result of prey availability (see chapter 1). While temperature and precipitation were found to be most important influencing the boundaries of their distribution (see chapter 1), Bendire's Thrasher may respond differently to these variables at a finer scale.

The species distribution model does show a large area across New Mexico and Arizona that is currently suitable for Bendire's Thrasher populations. However, much of this region may lack the key structural characteristics this species appears to prefer. In southern New Mexico, honey mesquite and creosote bush, dominant components of the desert scrub system have expanded into former areas of open grassland. This desertification process has resulted in large scale habitat change where areas formally dominated by grasslands with scattered shrubs are now heavily shrub encroached, dominated by honey mesquite or large expanses of short and dense creosote bush (Raitt and Maze 1968, Nielson 1986, Schlesinger et al. 1990). Much of this large-scale habitat change has taken place at suitable elevations for Bendire's Thrasher. In addition, much of the juniper forests across the southwest may now be too dense for the species after years of grazing and fire suppression (Jacobs and Gatewood 1999). In Arizona, where suitable habitat is more common, population declines may stem from human development, or competition with a more diverse and abundant avian population (Shochat et al. 2004, Shochat et a. 2010).

Future climate change projections show a substantial decline in distribution for this species with severe range contraction in Arizona and extirpation from New Mexico. This result is in sharp contrast with other models that show this desert adapted species will increase in distribution with increasing temperature and decreasing precipitation (Audubon 2014, Menke 2016). The observed differences are likely related to the choice of datasets and variables for the models. The New Mexico model created by Menke in 2015, suggesting the distribution of this species will substantially expand across southern and southeastern New Mexico by 2050 with higher temperatures and lower precipitation used coarser scale data averaged across the entire year while I restricted my data set to the breeding season for temperature and months leading up to the breeding season for precipitation (variables most likely to influence nest survival). Variables used in my model should more accurately depict influences of climate on the breeding distribution of this species. Other studies have used these models to project effects of climate change on similar species of concern. Salas et al. (2017) used similar methods to model the impacts of climate change on nine species of birds in the south-central U.S and reported similar predictions of future range contractions for these species.

Land management practices can influence the suitability of a site for occupancy by Bendire's Thrasher and my results suggest important managers include private landowners, Bureau of Land Management, tribal lands, state lands and the Department of Defense. In particular state and federal agencies and tribes can play an important role in maintaining or improving habitat for this declining species. Recent studies show a strong affiliation with desert washes, similar to the LeConte's Thrasher (Sheppard 2018, Salas per comm.). Modeling across the breeding range of this species could be used to identify potentially suitable areas for occupancy. Working with land managers to restrict development and human activity and maintain the integrity of the shrub and grassland communities in areas considered to have high suitability for this species is important. While management should target the entire range of this species, it is important to focus a large effort in areas identified to serve as refuge from future climate change.

LITERATURE CITED

Allouche, O., Tsoar, A., Kadmon, R. (2006). Assessing the accuracy of species distribution models: prevalence, kappa and the true skill statistic (TSS). J. Appl. Ecol. 43 (6), 1223–1232.

Archuleta, C.M., Constance, E.W., Arundel, S.T., Lowe, A.J., Mantey, K.S., and Phillips, L.A., (2017), The National Map seamless digital elevation model specifications: U.S. Geological Survey Techniques and Methods, book 11, chap. B9, 39 p

Barnett, K. L., and S. Facey (2016). Grasslands, invertebrates, and precipitation: a review of the effects of climate change. Frontiers in Plant Science, 7.

Bolger, D. T.., Pattern, M.A. Bockstrock D.C. 2005. Avian reproductive failure in response to an extreme climatic event. Oecologia 142:398-406.

Borgman, C. C., & Wolf, B. O. (2016). The indirect effects of climate variability on the reproductive dynamics and productivity of an avian predator in the arid Southwest. Oecologia, 180(1), 279-291.

Brown, H. (1901). Bendire's Thrasher. The Auk 18:225-231.

Buttery, R. F. (1971). Bendires Thrasher Nesting in Colorado. Colorado Field Ornithologist 9:29.

Cabeza, M., Arponen, A., Jäättelä, L., Kujala, H., Van Teeffelen, A., & Hanski, I. (2010). Conservation planning with insects at three different spatial scales. Ecography, 33:54-63.

Darling, J. L. (1970). New breeding records of Toxostoma curvirostre and T. bendirei in New Mexico. The Condor 72:366-367.

Dewitz, J. (2019). National Land Cover Database (NLCD) 2016 Products: U.S. Geological Survey data release, https://doi.org/10.5066/P96HHBIE.

Dormann, C.F., Elith, J., Bacher, S., Buchmann, C., Carl, G., Carré, G., Marquéz, J.R.G., Gruber, B., Lafourcade, B., Leitão, P.J., Münkemüller, T., McClean, C., Osborne, P.E., Reineking, B., Schröder, B., Skidmore, A.K., Zurell, D. and Lautenbach, S. (2013), Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. Ecography, 36: 27-46.

England, A.S. and W.F. Laudenslayer. (1993). Bendire's Thrasher. The Birds of North America 71.

Fick, S.E. and R.J. Hijmans, 2017. Worldclim 2: New 1-km spatial resolution climate surfaces for global land areas. International Journal of Climatology

Fletcher, D. M. (2009) Distribution and site selection of Le Conte's and Crissal Thrashers in the Mojave Desert: A multi-model approach. Master Thesis. University of Nevada, Las Vegas.

Fourcade, Y., Engler, J. O., Rödder, D., & Secondi, J. (2014). Mapping species distributions with MaxEnt using a geographically biased sample of presence data: a performance assessment of methods for correcting sampling bias. PloS one, 9(5), e97122.

Perkins-Taylor, I. E., & Frey, J. K. (2020). Predicting the distribution of a rare chipmunk (Neotamias quadrivittatus oscuraensis): comparing MaxEnt and occupancy models. Journal of mammalogy, 101(4), 1035-1048.

Garfin, G., A. Jardine, R. Merideth, M. Black, and S. LeRoy, eds. 2013. Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment. A report by the Southwest Climate Alliance. Washington, DC: Island Press.

Guidigan, M. L. G., Azihou, F., Idohou, R., Okhimamhe, A. A., Fandohan, A. B., Sinsin, B., & Adet, L. (2018). Modelling the current and future distribution of Kigelia africana under climate change in Benin, West Africa. Modeling Earth Systems and Environment, 4(3), 1225-1238.

Guisan, A., Lehmann, A., Ferrier, S., Austin, M., OVERTON, J., Aspinall, R., & Hastie, T.(2006). Making better biogeographical predictions of species’ distributions. Journal of Applied Ecology, 43(3), 386-392.

Guisan, A., & Thuiller, W. (2005). Predicting species distribution: offering more than simple habitat models. Ecology letters, 8(9), 993-1009.

Guisan, A., Graham, C. H., Elith, J., & Huettmann, F. (2007). Sensitivity of predictive species distribution models to change in grain size. Diversity and Distributions, 13(3), 332-340.

Kunkel, K. E., L. E. Stevens, S. E. Stevens, L. Sun, E. Janssen, D. Wuebbles, K. T. Redmond, and J. G. Dobson, 2013: Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 5. Climate of the Southwest U.S. NOAA Technical Report NESDIS 142-5

Landis, J.R., & Koch, G.G. (1977). An application of hierarchical kappa-type statistics in the assessment of majority agreement among multiple observers. Biometrics 363–374.

Marini, M. Â., Barbet-Massin, M., Lopes, L. E., & Jiguet, F. (2009). Predicted

Climate-Driven Bird Distribution Changes and Forecasted Conservation Conflicts in a Neotropical Savanna. Conservation Biology, 23(6), 1558-1567.

Marini, M. Â., Barbet-Massin, M., Lopes, L. E., & Jiguet, F. (2010). Predicting the occurrence of rare Brazilian birds with species distribution models. Journal of Ornithology, 151(4), 857-866.

McKechnie, A. E., Hockey P. & Wolf B. (2012) Feeling the heat: Australian landbirds and climate change, Emu Austral Ornithology, 112:2.

McKelvey, K. S., Aubry, K. B., & Schwartz, M. K. (2008). Using anecdotal occurrence data for rare or elusive species: the illusion of reality and a call for evidentiary standards. BioScience, 58(6), 549-555.

Menke, K. (2016). Identifying Potential Current Distribution For Bendire's Thrasher. Unpublished manuscript.

National Audubon Society. 2014. Audubon's Birds and Climate Change Report: A Primer for Practitioners. National Audubon Society, New York. Version 1.2
Neilson, R. P. 1986. High resolution climatic analysis and southwest biogeography. Science 232:27-33.

North Amercian Bird Conservation Initiative (NABCI) (2016). The State of North American Birds 2016, Environment and Climate Change Canada Ottawa, Ontario.

Pearson, T. A., Blair, S. N., Daniels, S. R., Eckel, R. H., Fair, J. M., Fortmann, S. P., & Taubert, K. A. (2002). AHA guidelines for primary prevention of cardiovascular disease and stroke: 2002 update - Consensus panel guide to comprehensive risk reduction for adult patients without coronary or other atherosclerotic vascular diseases. Circulation, 106(3), 388-391.

Pearson, R. G., Raxworthy, C. J., Nakamura, M., & Townsend Peterson, A. (2007). Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. Journal of biogeography, 34(1), 102-117.

Peters, D. P., K. Havstad, S. Archer, and O. Sala (2015). Beyond desertification: new paradigms for dryland landscapes. Frontiers in Ecology and the Environment 13:4-12

Phillips, S. J., & Dudík, M. (2008). Modeling of species distributions with MaxEnt: new extensions and a comprehensive evaluation. Ecography, 31(2), 161-175.

Prieto-Torres, D. A., Nori, J., & Rojas-Soto, O. R. (2018). Identifying priority conservation areas for birds associated to endangered Neotropical dry forests. Biological Conservation, 228, 205-214.

PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, created 4 Feb 2004.

Shochat, E., Lerman, S. B., Katti, M., & Lewis, D. B. (2004). Linking optimal foraging behavior to bird community structure in an urban-desert landscape: field experiments with artificial food patches. The American Naturalist, 164(2), 232-243.

Shochat, E., Lerman, S., & Fernández-Juricic, E. (2010). Birds in urban ecosystems: population dynamics, community structure, biodiversity, and conservation. Urban ecosystem ecology, 55, 75-86.

Salas, E. A. L., Seamster, V. A., Boykin, K. G., Harings, N. M., & Dixon, K. W. (2017). Modeling the impacts of climate change on Species of Concern (birds) in South Central USA based on bioclimatic variables. AIMS Environmental Science, 4(2), 358.

Schlesinger, W. H., Reynolds, J. F. Cunningham, G. L., Huenneke,, L. F., Jarrell, W. M., Virginia, R.A. and Whitford, W. G.. 1990. Biological feedbacks in global desertification.   Science 247:1043-1048.

Sheppard, J. M. 2018. The biology of a desert apparition: LeConte's Thrasher (Toxostoma lecontei). Studies of Western Birds 2. Western Field Ornithologists, Camarillo, California.

Skagen, S. K., & Adams, A. A. Y. (2012). Weather effects on avian breeding performance and implications of climate change. Ecological Applications, 22(4), 1131-1145

Tanka, L.K. and Tanaka, S.K. 1982. Rainfall and seasonal-changes in arthropod abundance on a tropical oceanic island. Biotropica 14:114-123.

Zuckerberg, B., Ribic, C. A., & McCauley, L. A. (2018). Effects of temperature and precipitation on grassland bird nesting success as mediated by patch size. Conservation Biology

Table 1. The variable names, definitions, source for all the variables considered in the species distribution model for Bendire's Thrasher in New Mexico and Arizona.

Variable	Definition	Source
Annual Mean Temperature	The annual mean temperature.	WorldClim
Mean Diurnal Range	The mean of the monthly temperature ranges.	WorldClim
Isothermality	How large the day to night temperatures oscillate relative to the summer to winter oscillations.	WorldClim
Temperature Seasonality	The amount of temperature variation over a given year.	WorldClim
Max Temperature of Warmest Month	The maximum monthly temperature occurrence over a given year.	WorldClim
Min Temperature of Coldest Month	The minimum monthly temperature occurrence over a given year.	WorldClim
Temperature Annual Range	Measure of temperature variation over a given period.	WorldClim
Mean Temperature of Wettest Quarter	Quarterly index approximates mean temperatures that prevail during the wettest season.	WorldClim
Mean Temperature of Driest Quarter	Quarterly index approximates mean temperatures that prevail during the driest quarter.	WorldClim
Mean Temperature of Warmest Quarter	Quarterly index approximates mean temperatures that prevail during the warmest quarter.	WorldClim
Mean Temperature of Coldest Quarter	Quarterly index approximates mean temperatures that prevail during the coldest quarter.	WorldClim
Annual Precipitation	The sum of all total monthly precipitation values.	WorldClim
Precipitation of Wettest Month	Index of the total precipitation that prevails during the wettest month.	WorldClim

Precipitation of Driest Month	Index of the total precipitation that prevails during the driest month.	WorldClim
Precipitation Seasonality	Measure of the variation in monthly precipitation totals over the course of the year.	WorldClim
Precipitation of Wettest Quarter	Index of the total precipitation that prevails during the wettest quarter.	WorldClim
Precipitation of Driest Quarter	Index of the total precipitation that prevails during the driest quarter	WorldClim
Precipitation of Warmest Quarter	Index of the total precipitation that prevails during the warmest quarter.	WorldClim
Precipitation of Coldest Quarter	Index of the total precipitation that prevails during the coldest quarter.	WorldClim
Maximum Temperature of the Breeding Season	Average of the maximum monthly temperatures from Feb-May for years 2007-2017.	PRISM
Minimum Temperature of the Breeding Season	Average of the minimum monthly temperatures from Feb-May for years 2007-2017.	PRISM
Bioyear Precipiation	The cumulative precipitation of the 7-month period prior to the breeding season for years 2007-2017.	PRISM
Elevation	The elevation of a location in meters.	USGS
Slope	The average slop of a location in percent.	USGS
Cover	The estimate of percent vegetative cover.	USGS

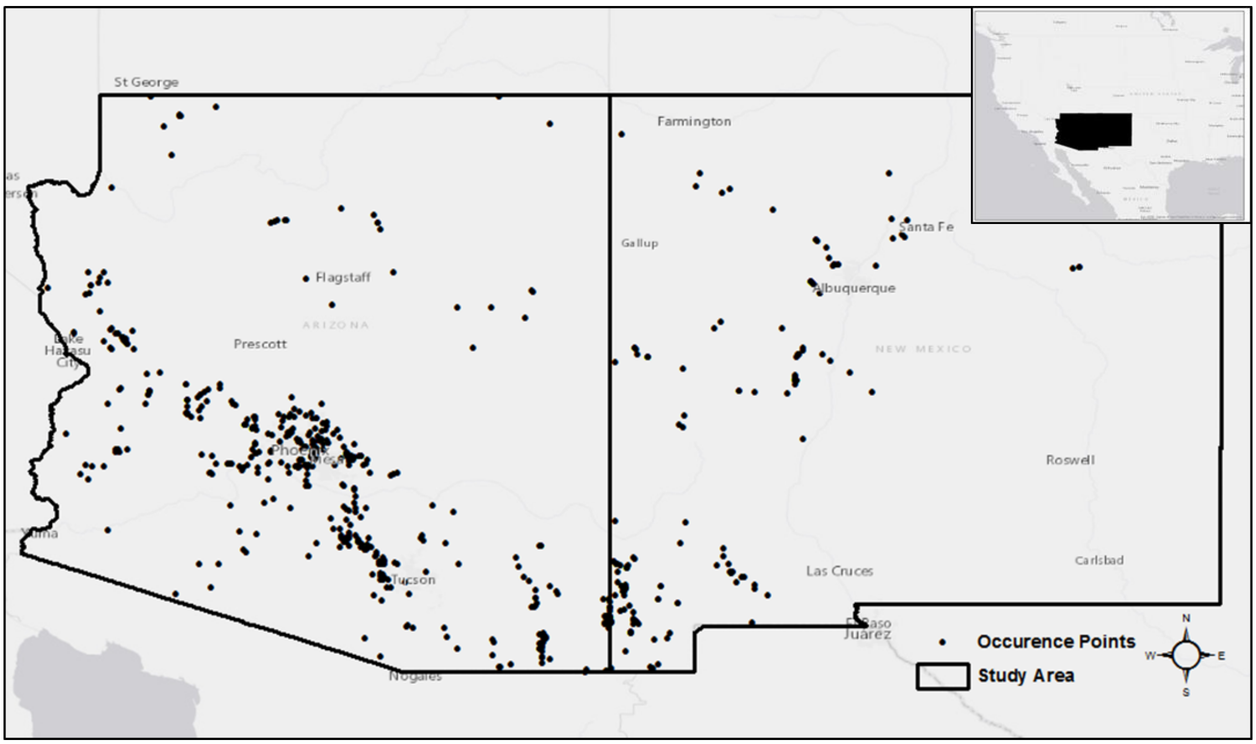

Figure 1. Bendire's Thrasher occurrence points attained from field studies in 2015 and 2016 and from ebird.org from 2007-2017.

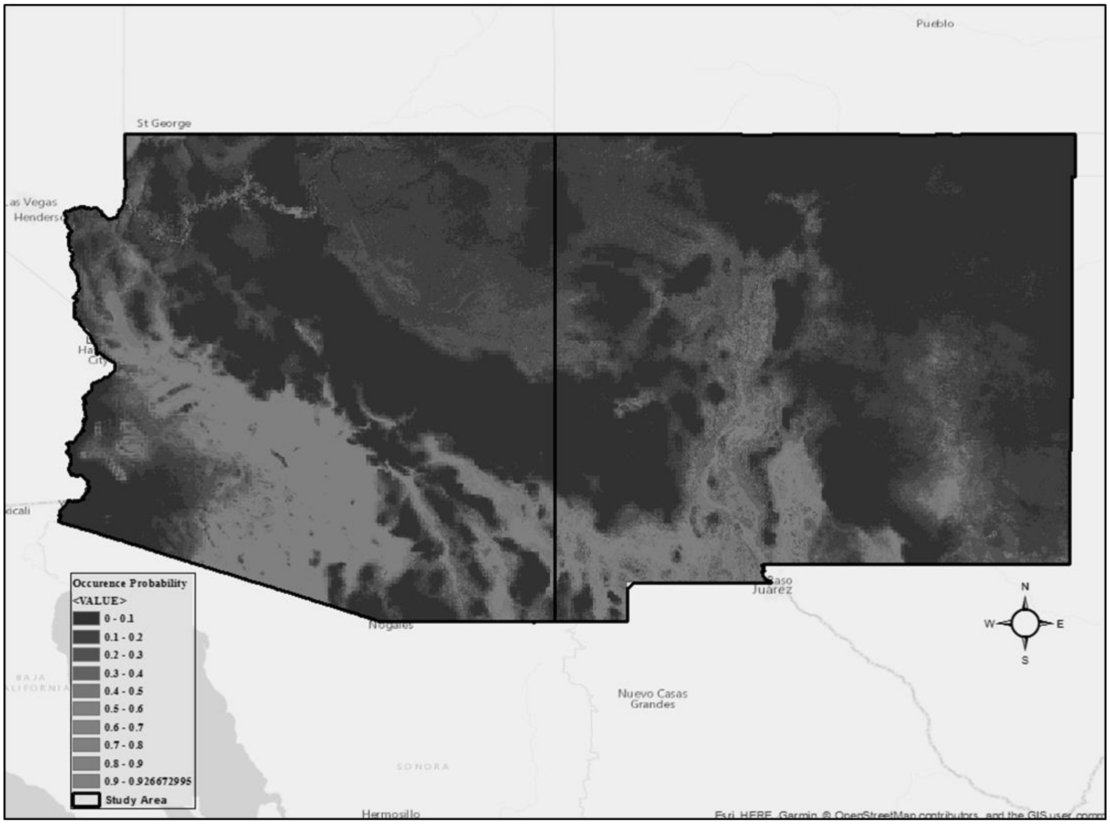

Figure 2. Results of a current Species distribution model for Bendire's Thrasher in Arizona and New Mexico created using occurrence points collected from the field and Ebird and analyzed in MaxEnt.

Table 2. Percent contribution and importance provided by MaxEnt for the 5 variables used in the species distribution model for Bendire's Thrasher in Arizona and New Mexico.

Variable	Percent Contribution	Permutation Importance
Maximum Temperature of the Breeding Season	54.4	44.6
Bioyear Precipitation	32.2	36.6
Percent Canopy Cover	8.3	2.8
Slope	3.7	3
Elevation	1.4	13

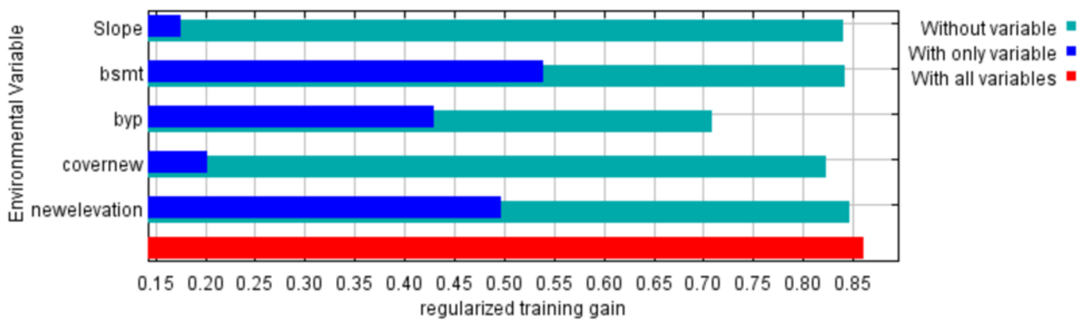

Figure 3. MaxEnt results of the jackknife test of 5 variables contribution to the species distribution model for Bendire's Thrasher in Arizona and New Mexico. Bsmt is the maximum temperature of the breeding season. Byp is bioyear precipitation. Cover is percent canopy cover.

Table 3. Breakdown of total acreage and percentage that each landowner controls of potential Bendire's Thrasher habitat (>50%) currently and in the future under the Hadley Centre Global Environment Model version 2 Earth System at greenhouse gas representative concentration pathway 2.6 from a species distribution model for Arizona and New Mexico completed in MaxEnt.

Landowners of Suitable Bendire's Thrasher Habitat					
Current Arizona			Current New Mexico		
Owner	Acreage	Percentage	Owner	Acreage	Percentage
Private Land	3352533	29	Private Land	1274055	34
Tribal Land	2942321	26	Bureau of Land Management	954284	26
Bureau of Land Management	2187597	19	NM State Land	701160	19
AZ State Land	1980728	17	Department of Defense	649142	18
National Park Service	306975	3	National Park Service	95100	3
Department of Defense	279399	2	Bureau of Reclamation	3720	0
U.S. Fish and Wildlife Service	171319	1	U.S. Fish and Wildlife Service	17910	0
United States Forest Service	165460	1	United States Forest Service	8782	0
Bureau of Reclamation	54115	0	Tribal Land	2098	0
Local Government	7818	0			
Total Acres	11448264	100	Total Acres	3706251	100
Future Arizona			Future New Mexico		
Owner	Acreage	Percent	Owner	Acreage	Percent
Private Land	2754693	27	Private Land	0	0
Tribal Land	2938922	29	Bureau of Land Management	0	0
Bureau of Land Management	1925761	19	NM State Land	0	0
AZ State Land	1692651	16	Department of Defense	0	0
National Park Service	306504	3	National Park Service	0	0
Department of Defense	269117	3	Bureau of Reclamation	0	0
U.S. Fish and Wildlife Service	157251	2	U.S. Fish and Wildlife Service	0	0
United States Forest Service	164673	2	United States Forest Service	0	0
Bureau of Reclamation	52262	1	Tribal Land	0	0
Local Government	5100	0			

Total Acres	10266935	100	Total Acres	0	0

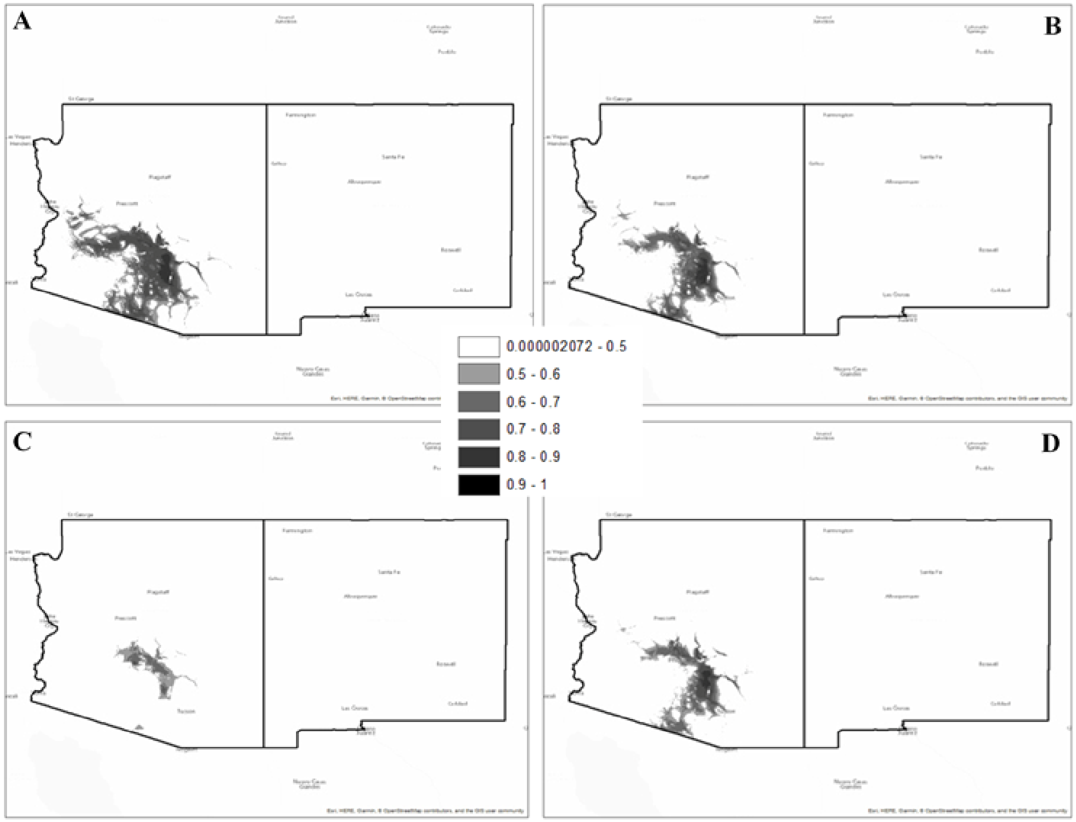

Figure 4. The distribution model for Bendire's Thrasher with the 4 various climate projections completed in MaxEnt. A: Hadley Centre Global Environment Model version 2 Earth System at greenhouse gas representative concentration pathway 2.6. B: Community Climate System Model version 4 at greenhouse gas representative concentration pathway 2.6. C: Hadley Centre Global Environment Model version 2 Earth System at greenhouse gas representative concentration pathway 8.5. D: Community Climate System Model version 4 at greenhouse gas representative concentration pathways.