BREEDING HABITAT REQUIREMENTS AND TERRITORY SIZE OF BENDIRE'S THRASHER (*Toxostoma bendirei*)

Photo taken by Cody Bear Sutton
Hildago Co, New Mexico

Final Report to New Mexico Department of Game & Fish

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TABLE OF CONTENTS

INTRODUCTION

Arid lands in the southwestern United States are experiencing habitat loss and degradation attributed to urban sprawl, energy development, long-term unsustainable land use, invasive grasses and woody shrub encroachment (Eldrige 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 from historic desert grasslands 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 aridland species experiencing the steepest declines (North American Bird Conservation Initiative 2016). Of the eight thrasher species in the United States, seven are aridland 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 Thrasher, however, less is known about these species requirements across desert landscapes of the southwest. (Shuford and Gardali 2008, England and Laudenslayer 1993).

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 U.S. When first collected, this species was originally confused with the Curved-billed Thrasher (*Toxostoma curvirostre*). As a result, the Bendire's Thrasher 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, desert grassland, pinyon-juniper woodlands, and agricultural edge habitats (Brown 1901, Darling 1970, England and Laudenslayer 1993). 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). The current global population size is estimated to be between 70,000 to 120,000 individuals (North American Bird Conservation Initiative 2016, Rosenberg et al 2016). It is estimated 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 Sauer et al. 2014), and 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 the habitat degradation and disturbance in southwestern U.S. 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 (Ambrose 1963, Darling 1970, England and Laudenslayer 1993). This hypothesis is supported by Breeding Bird Survey data (Saurer et al. 2014) that shows Bendire's Thrasher decline coinciding with the range expansion 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. This research examines habitat characteristics of Bendire's Thrasher territories across broad habitat classifications and compares them with randomly selected points within habitat classifications at the territory and landscape scales. We hypothesized that Bendire's Thrasher territory size is influenced by broad-scale habitat classifications because differences in vegetation structure and composition are important for nest sites and food availability, and will differ across years because variability in annual precipitation totals and patterns will influence prey availability. We also hypothesize that Bendire's Thrasher breeding territories and surrounding landscape will differ in vegetation structure in comparison with randomly chosen points within similar habitat classifications as they will select for a specific structure. Specifically, at the territory scale we predicted shrub height would be important because of preference for higher perches for singing, shrub density would be lower or intermediate as Bendire's Thrashers need open space for foraging, percent bare ground would be important because the need for bare ground for foraging, and territories would have more large gaps in the canopy that also allow for heterogeneous cover and bare ground for foraging. At the landscape scale, we predicted Bendire's Thrasher would prefer heterogeneous landscape with more edge as this would provide the variation in structure and foraging space that has been observed to be important for other thrasher speceis.

STUDY AREA AND METHODS

Study Area

We studied Bendire's Thrasher territory selection at two spatial scales in southwestern New Mexico and southern Arizona in 2015 and 2016 (Figure 2). In New Mexico we defined the study area using a MaxEnt model of Bendire's Thrasher distribution and optimality created in 2015 (Menke and Bushway 2015). This model stratified Bendire's Thrasher habitat from low optimality to high optimality based on occurrence points from ebird.org and breeding bird surveys and climate/geographic data. We selected to focus only on areas of medium to high optimality. Using ArcGIS we overlaid the LANDFIRE of habitat types generated by USGS with the areas of medium to high optimality to generate a list of habitats this area consisted of (LANDFIRE 2008). Based on this information, we sorted the habitat into broad categories that consisted of 1.) desert scrub, 2.) desert grasslands, 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, we used observations acquired from eBird.org to generate the study area. We overlaid the eBird.org points on the LANDFIRE layer of habitat type in ArcGIS. Similar to New Mexico, we used this layer to determine broad habitat classifications and arrived at the same 3 classifications used in New Mexico and one additional habitat classification 4.) Sonoran paloverde. Across both study areas dominant shrubland vegetation within these classifications consisted of honey mesquite (*Prosopis glandulosa*), velvet mesquite (*Prosopis velutina*), creosote (*Larrea tridentate*), juniper sp. (*Juniperus sp.*), cholla (*Opuntia sp.*), catclaw (*Acacia sp.*), soap tree yucca (*Yucca elata*), palo verde sp. (*Parkinsonia sp.*), and saguaro (*Carnegiea gigantean*). Across this broad study area, elevations ranged from ~200 m in Arizona to ~2400 m in New Mexico, 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

We searched for territorial Bendire's Thrasher 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 begins earlier in the south (England and Laudenslayer 1993). Due to the secretive nature of this species, point count surveys were supplemented with area searching without defined plots (Ralph et al. 1993, Ralph et al. 1995). Transects were randomly plotted using ArcGIS within each of the broad habitat categories with number of transects within each habitat type distributed according to representation. Transects were paired, with each pair being approximately 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 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-second intervals with 30 seconds of Bendire's Thrasher call playback and 60 seconds 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. The transect length and point count length were shortened. Long transects sometimes entered inhospitable terrain and lower quality Bendire's Thrasher habitat. We 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 (See Appendix A for all point count data). In this field season, 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 sec of playback and 60 sec 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 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 hours after sunrise, and were not conducted in rainy or windy conditions (> 12 mph) (Ralph et al.1995).

Territory Mapping

After locating a territorial male, we returned to the area to map the breeding territory. For territory mapping we used a combination of spot-mapping and the territory flush technique (Wiens 1969, Gregory et al. 2004). Territory mapping consisted of 1-3 visits, the first visit was a minimum of 5 days following the initial observation to avoid mapping Bendire's Thrasher that were still migrating north in the early part of the breeding season (Phillips et al 1964, England and Laudenslayer 1989). Once the 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 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

SE: ±12) a territory polygon was created by connecting the outermost points by straight lines (Wiens 1969, Jones 2011). Territory positions were mapped and total area and periphery calculated using ArcGIS software, using minimum convex polygons with Hawth's tool extension (Jones 2011).

Abiotic/temporal Measurements

We developed a GIS database to extract abiotic variables. Climate data was obtained from PRISM Climate Group at Oregon State University which is at an 800 m resolution (PRISM 2004). Precipitation data consisted of the bioyear, this is 7-months preceding breeding; this period is the most influential on habitat use because of the effects of precipitation 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. We obtained data on soil type using the USDA-NRCS Soil Survey Geographic Database (SSURGO) at a 10 m resolution (USDA NRCS 2016). To obtain these variables for each territory and random point, we 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 habitat type. Random locations were generated in GIS and stratified by habitat types (desert scrub, desert grassland, pinyon-juniper, and Sonoran paloverde). Around each random point we 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 habitat. Gaps >20 cm between bases and canopies of all plants were recorded. In addition to the line-intercept and gap intercept transects, we 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 on each side of the pole to measure visual obstruction (Herrick et al 2005). A photograph from the 0 m side of each transect was also collected.

Landscape Scale Measurements

At the landscape scale, we created a GIS database to extract landscape-level variables to examine habitat heterogeneity and fragmentation. We 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. One kilometer is a commonly used buffer size in similar studies with avian species (Knick and Rotenberry 1995, Askins et al 2007, Chandler et al 2009, Hagan and Meehan 2002). Land cover types included the previously defined broad cover types (desert scrub, desert grassland, pinjon juniper and Sonoran paloverde) as well as four new classifications, residential, agriculture, creosote bush (separated from desert scrub), and road (Figure 3). These digitized habitats 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, mean shape index, mean fractal dimension, richness, dominance, and edge density (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 habitat classifications, between years, and between states using two-way ANOVA to examine variability in territory size by habitat type and site (PROC GLM in SAS 9.3). We also examined the influence of bioyear precipitation, year, and habitat type on territory size with one-way ANOVAs.

Each individual variable measured potentially influencing territory selection was examined among habitats using two-way ANOVAs looking at variability by habitat type and year (PROC GLM, Benson 2009). This was done to determine if we would need to control for habitat type in the models. Finally, to determine which variables influenced Bendire's Thrasher territory selection we generated a set of a priori models for three separate analyses including temporal/abiotic models (n = 10 models), territory scale models (n = 15 models), and landscape scale models (n = 10 models). Before developing a priori models we tested all variables for correlations using Pearson correlation tests and removed any variables with greater than or equal to 0.70 correlations (Benson 2009). We ran these models using conditional logistic regression stratified for habitat type with PROC LOGISTIC in SAS (Benson 2009). We ranked the 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. We 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, we 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 we multiplied it by this value before calculating the odds ratio (Butler et al. 2009).

RESULTS

Territory Size

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

Variation within and among Habitat Types

Characteristics of Bendire's Thrasher territories varied among the four habitat types and between territory and random points within habitat types. Seven of 14 variables measured varied significantly among habitat types: canopy gaps, average obstruction, average shrub height, bare ground, elevation, slope, and richness (Table 5). The seven variables that did not vary among habitat types were total shrub density, number of tall shrubs, bioyear precipitation, mean patch size, mean fractal dimension, dominance, and edge density (Table 5). In addition to the variation within and among habitat types our analysis showed substantial differences between random location and Bendire's Thrasher territories (Figure 4).

Abiotic/Temporal Models

All 10 a priori abiotic models outperformed the null model. The top three models had $\Delta AIC \leq 2$ and accounted for 89.7% of the Akaike weights. (Table 3). These three models contained all 4 temporal/abiotic variables (year, slope^2, elevation, and bioyear precipitation). A goodness-of-fit test showed all three top models fit the data (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). Habitat selection decreased by ~7% with each 5% increase in the slope (odds ratio = 0.93). With every 100 m increase in elevation the odds of a territory being established decreased by ~9% (odds ratio = 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 weight 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 the top three models fit the data (P=0.5838, P=0.6819, P=0.3936). 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). The odds of Bendire's Thrasher territory selection increased by 37% with each 10% increase in average obstruction (odds ratio = 1.37). For every 10% increase in bare ground there was an approximate 90% increase in the odds of

Bendire's Thrasher use (odds ratio = 1.90). Average shrub height was the most influential with a 257% increase in the odds of Bendire's Thrasher use with each 1 m increase in shrub height (odds ratio = 3.57). Number of tall shrubs also had an influence on use, with a ~2% increase in Bendire's Thrasher use with each additional shrub (odds ratio = 1.019).

Landscape Scale Models

There was only one strongly support landscape model ($\Delta AIC_c \leq 2$) (Table 3). This model contained the log of mean patch size, richness, and edge density, indicating Bendire's Thrashers selected territories with smaller patches, a higher number of patch types and higher edge density. A goodness-of-fit test showed the top model fit the data (P = 0.2241) (Table 4). Mean patch size was the most important variable based on odds ratios, with a ~77% decrease in Bendire's use with each 1 ha increase in the mean patch size (odds ratio = 0.23). Richness increased the odds of Bendire's Thrasher use by 58% with each additional habitat type within 1 km of a Bendire's Thrasher territory (odds ratio = 1.58).

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 our study for Bendire's Thrasher. In contrast Brown Thrasher (*Toxostoma rufum*) and Sage

Thrasher (*Oreoscoptes montanus*) territories were smaller, averaging less than 1 ha (Partin 1977, Reynolds and Rich 1978). The larger territory size for the desert thrashers may, in part, be related to greater habitat 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 habitat variation, and food availability (Seastedt amd 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 other thrasher species did. It would be interesting to map territories of other thrasher species in relation to Bendire's Thrashers. 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. We observed a fairly wide range of territory sizes for Bendire's Thrahers. Our data suggests that bioyear precipitation for Bendire's Thrasher may serve as an indicator of food availability and this accounted for variation in territory size, however, we did not quantify arthropod and berry abundance on plots to relate to bioyear precipitation. A review on the effects of precipitation on invertebrates and grasslands indicates that insect abundance and vegetation growth are linked to precipitation amounts with greater 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 precipitation amounts and patterns 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), 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 elevations and less slope than randomly sampled. Two territories found during this study were over 2000 m, 200 m higher than the highest published territory (Woodbury 1939). Thrashers are likely limited more by vegetation than actual elevation. 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 lower elevations. Our results are similar to those seen with LeConte's and Crissal Thrashers where high elevations and slopes over 6 percent were avoided (Fletcher 2009).

At the territory scale Bendire's Thrasher selected for habitat heterogeneity, they preferred areas with taller shrubs, greater vegetation density (obstruction) and barer 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. 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 and England and Laudenslayer 1989). Studies also suggest Bendire's Thrashers prefer open habitats, however, in comparison to surrounding areas, Bendire's Thrashers appear to select patches with greater cover (Ambrose 1963, Brown 1901, and England and Laudenslayer 1989). Our findings also support the assumption that habitat heterogeneity, that includes expanses bare ground, is important for Bendire's Thrashers, as they often forage on the ground for invertebrates, probing into the desert soil (Brown 1901, Ambrose 1963, and England and Laudenslayer 1989).

At a landscape perspective, our 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 habitat types surrounding territories. This is similar to 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 (Phillips et al 1964 and Bent 1948). Phillips et al. (1964) note Bendire's Thrasher avoidance of uninterrupted brushy cover and continuous grasslands and their preference for areas with variation in habitat. Other thrasher species have also been reported to have edge associations (Fischer 1980 and Marshall 1957). Curve-billed Thrashers were identified preferring to nest at woodland edges and patches of cholla within grasslands (Fischer 1980) whereas Crissal Thrasher were found using chaparral at the edges of pin-oak woodlands and edges of juniper woodlands (Marshall 1957). Bendire's Thrasher apparent preference for edge may, in part, be 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 (*Prosopis glandulosa*) and creosote bush (*Larrea tridentata*) (Buffington and Herbal 1965, Gibbens and Beck 1988, Schlesinger et al. 1990). However, little is known related to the effect of this habitat conversion on shrub-adapted birds. Our data at the territory and landscape scale strongly suggests that these large landscape level changes in the southwest due to desertification are detrimental to Bendire's Thrashers. This species prefers heterogeneous habitats at both the territory and landscape scale which is not consistent with the large expanses of shrub encroachment that has been 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.

Our data suggests that numerous spatial scales are important for Bendire's Thrasher territory selection and had our 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 abiotic 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 a good example of how evaluating habitats 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 Thrasher both showed 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 habitat types, the idea that structure may be what is limiting the species is supported by our models. A habitat lacking large shrubs and bare ground would not be used by this species as highlighted by our 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 lack 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. In addition, much of the juniper forests are likely too dense for the species. 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 an "ecological trap" given issues with vehicle strikes (Coffin 2007). In Arizona, there is likely more suitable 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 southern 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 survival, juvenile survival, adult survival and competition should answer more questions. Habitat loss and competition are likely confounding effects so more information will be important for conservation (Johnson 2007). The effects of land management may also decrease the suitability of habitats and are worthy of future investigation. There is still much unknown about this species and this study is just the foundation to base future research.

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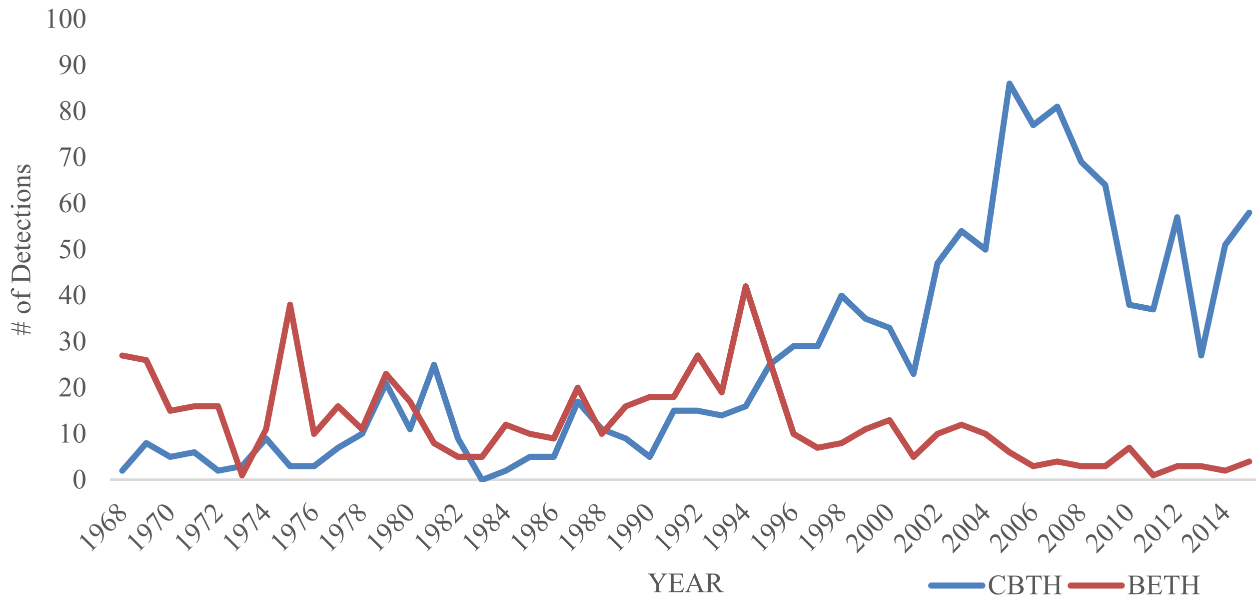
Tables and Figures



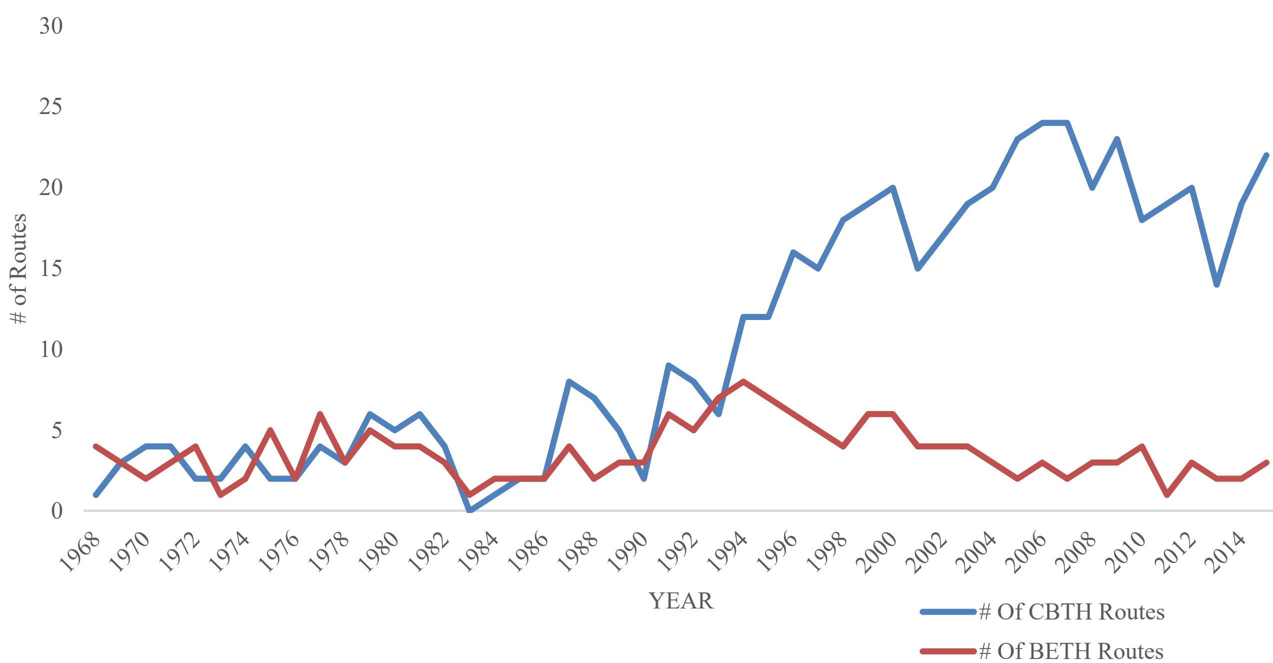


Figure 1. Graphs showing the differences in total detections (top) and the number of routes with Curve-billed Thrasher and Bendire’s Thrasher detections (bottom) along BBS routes in New Mexico from 1968-2016.

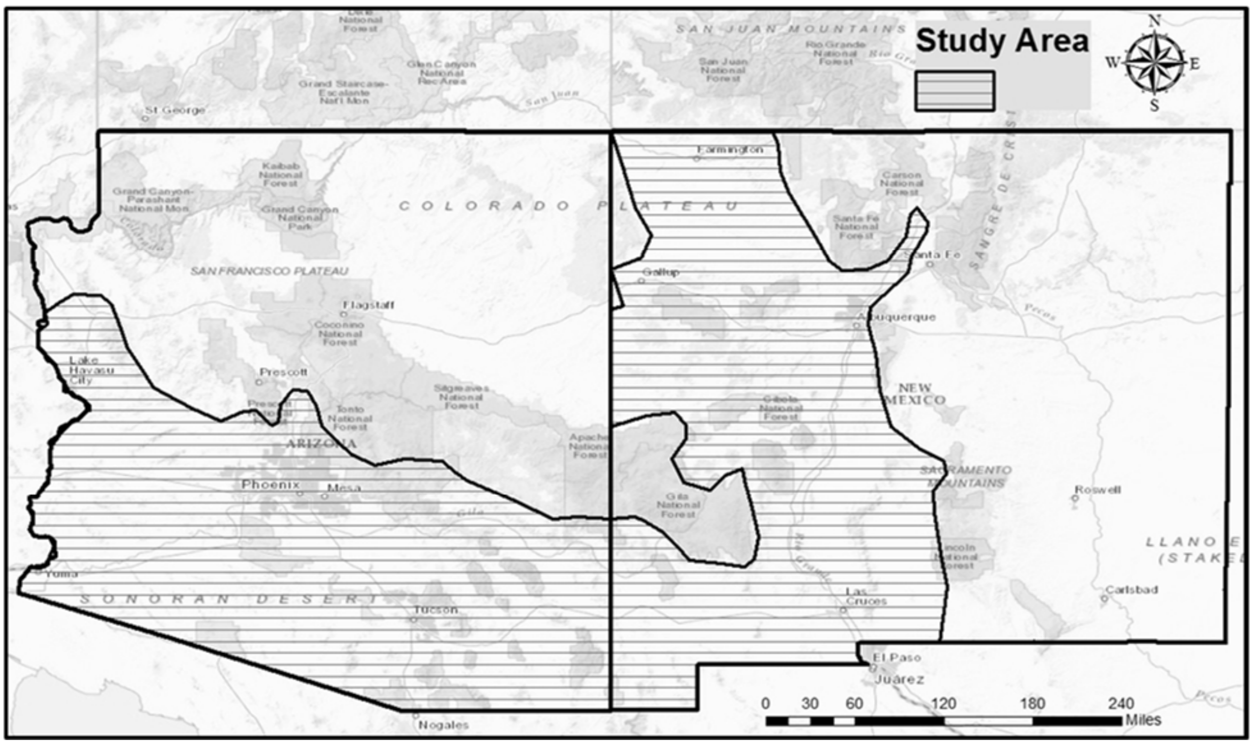


Figure 2. Study area for breeding surveys of Bendire's Thrasher across New Mexico and Arizona in 2015-2016.

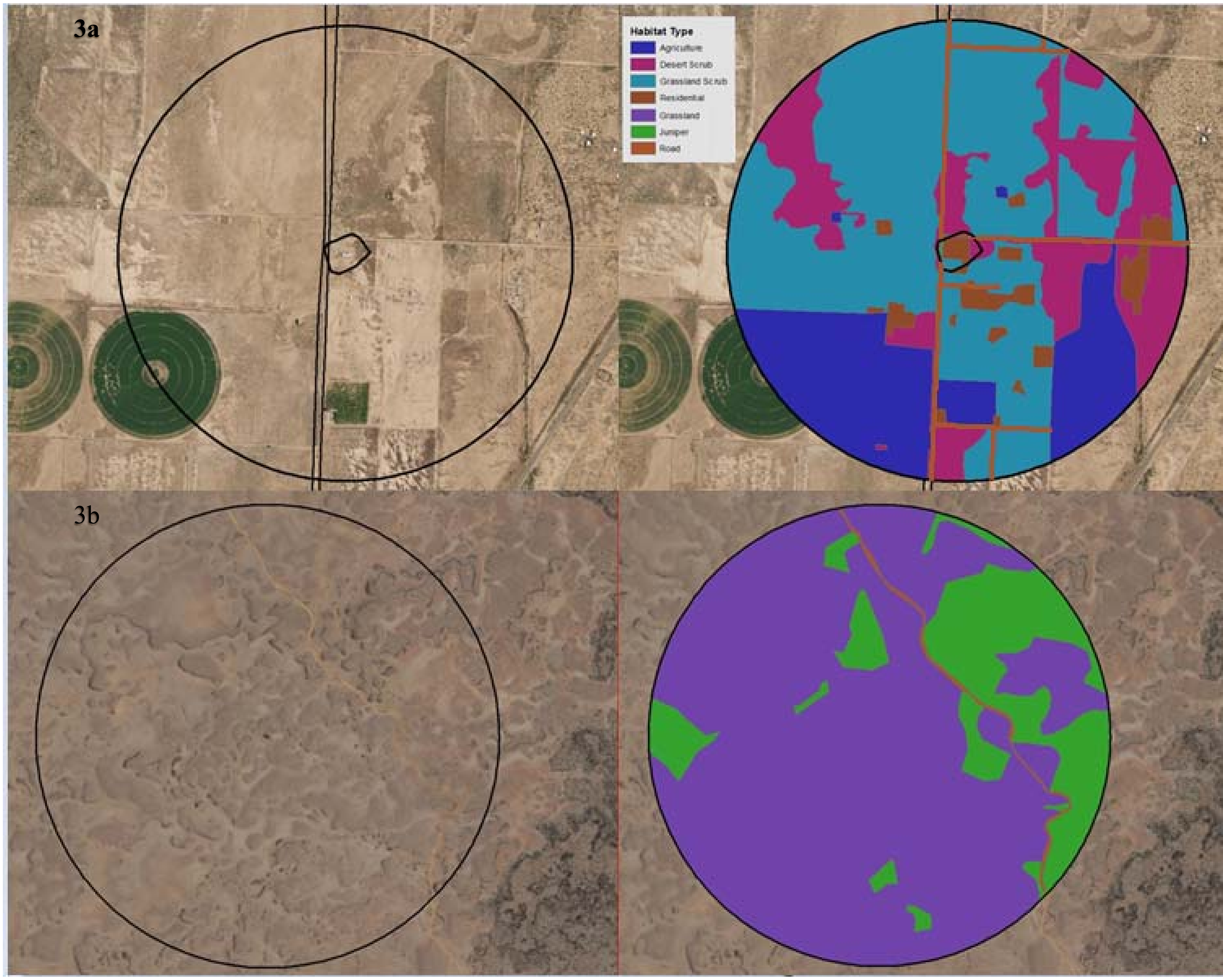


Figure 3. Example of hand digitized Bendire's Thrasher territory (3a) and random site (3b) in desert shrublands of southwestern NM 2015.

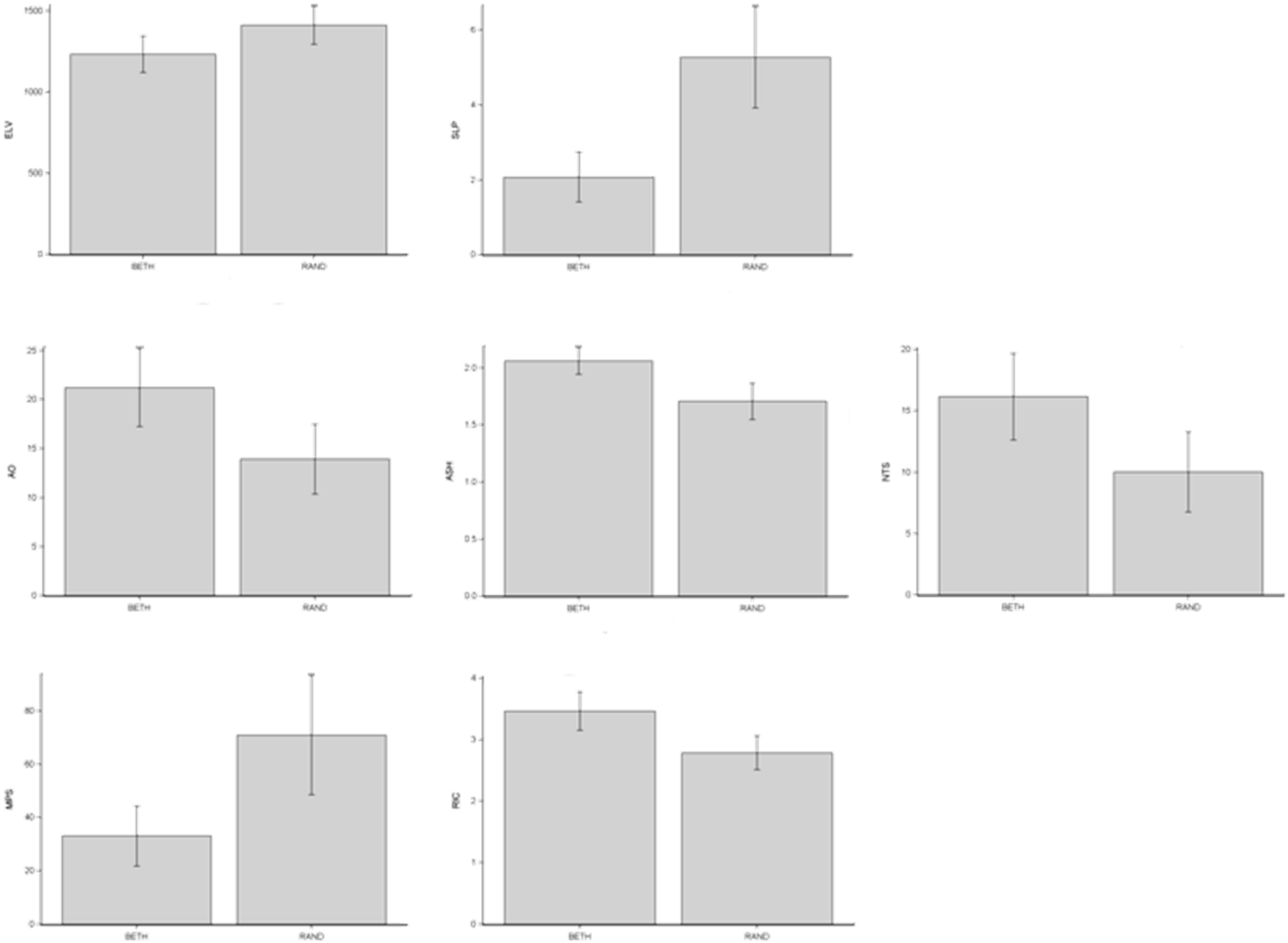


Figure 4. Mean extent ranges for the top variables of the Bendire's Thrasher habitat use models, with standard error bars.

Table 1. Description of variables used to create models in my habitat use analysis of Bendire's Thrasher in Arizona and New Mexico 2015-2016.

Variable	Type	Description
Elevation (EL)	Abiotic	Elevation in meters, collected from DEMs in GIS
Slope (SL)	Abiotic	Percent slope
Bioyear Precipitation (PB)	Abiotic	average precipitation from August through February
Year (YR)	Abiotic	Year split into 3 options 2015 New Mexico, 2016 New Mexico, 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 (ha) for mapped Bendire's Thrasher territories ($n = 60$) 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 abiotic level and territory and landscape scale. Only the top models are reported here. SL = slope; EL = elevation; 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; YR = year.

Scale	Model	-2 Log-likelihood	*K*[a]	ΔAIC	w_i
Abiotic[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 174.35
[d]Minimum AIC score is 172.81

Table 4. Model-averaged parameter estimates for models of Bendire's Thrasher habitat use in New Mexico and Arizona in 2015-2016.

Scale	Variable	β	95% CI			Scaled Odds Ratio
Abiotic						
	Slope (SL)	-0.016	-0.022	to	-0.045	0.927
	Elevation (EL)	-0.002	-0.003	to	-0.002	0.905
	Bioyear Precipitation (PB)	-0.001	-0.005	to	0.002	0.990
	Year (YR)	-0.628	-0.944	to	-0.312	0.880
Territory						
	Average Obstruction (AO)	0.031	0.015	to	0.047	1.370
	Bare Ground (BG)	0.070	0.040	to	0.099	1.895
	Average Shrub Height (SH)	1.319	0.916	to	1.520	3.567
	Number of Tall Shrubs (TS)	0.061	0.032	to	0.091	1.019
	Canopy Gap (CG2)	-0.004	-0.013	to	0.005	0.923
Landscape						
	Mean Patch Size (PS)	-2.011	-2.821	to	-1.202	0.229
	Richness (RI)	0.342	0.088	to	0.596	1.580
	Edge Density (ED)	-3.11E-07	-7.56E-07	to	1.33E-07	1.000

Parameter estimates (β) that do not bound zero and Odds ratios that do not bound 1 indicate strong support for that variable.

Table 5. Abiotic, territory, and landscape measurements and results for ANOVAS testing the differences between the broad habitat categories and year in New Mexico and Arizona in 2015-2016.

	Territory		Random		HT[a]	
Variable	$\bar{X}$	SE	$\bar{X}$	SE	*F*	*P*
Slope (%)	2.07	0.34	5.27	0.68	7.55	0.00
Elevation (m)	1232.32	56.28	1410.79	58.31	51.23	<0.001
Bioyear Precipitation (mm)	186.93	6.70	192.21	7.81	2.23	0.09
Mean Patch Size (ha)	33.02	5.62	70.89	11.23	1.31	0.28
Richness (types)	3.46	0.16	2.79	0.14	2.42	0.07
Edge Density (m2)	1343539.01	90372.93	1042724.45	72230.18	3.20	0.03
Average Obstruction (%)	21.23	2.00	13.93	1.78	5.08	0.00
Bare Ground (%)	23.29	0.97	19.84	1.36	1.35	0.26
Average Shrub Height (m)	2.06	0.06	1.71	0.08	7.75	<0.001
Number of Tall Shrubs (count)	16.14	1.76	10.01	1.63	1.30	0.28
Canopy gaps >200cm (%)	49.31	2.81	49.94	2.96	7.71	<0.001

[a] We tested for effects of habitat types (HT; desert scrub, grassland scrub, pinyon-juniper; Sonoran paloverde) using proc ANOVA