DISTRIBUTION AND SITE SELECTION OF LE CONTE'S AND CRISSAL THRASHERS IN THE MOJAVE DESERT: A MULTI-MODEL APPROACH

by

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ABSTRACT

Distribution and site selection of Le Conte's and Crissal Thrashers in the Mojave Desert: a multi-model approach

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Information on the distribution and habitat requirements of a species are critical components to the development of meaningful conservation plans. Such knowledge, however, is particularly difficult to obtain for species that are elusive and occur at low densities, such as the Le Conte's (*Toxostoma lecontei*) and Crissal (*Toxostoma crissale*) thrashers. In association with a regional conservation plan, I evaluated the distribution and habitat selection of these thrashers within Clark County, Nevada in the eastern Mojave Desert. I used a call-broadcast approach to sample 432 stratified random locations, detecting Le Conte's thrashers at 45 locations and Crissal thrashers at 41 locations. To model suitable habitat and predict thrasher occurrence, I used site-specific and landscape level information to create models that represented habitat data at two spatial scales. At each of these spatial scales, I measured variables corresponding to five

environmental categories; plant assemblages, substrate, landform features, climate, and human disturbance. For analyses, I used logistic regression and assessed resulting models using an information theoretic approach. Inclusions in the best-fit model sets were determined using an Akaike Information Criterion approach. Model-averaging was used to determine the best possible parameter estimates for predicting thrasher presence from the complete sets of best-fit models. Results from the models indicated that Le Conte's thrashers occur within areas of little topographic relief such as valley bottoms near dry lake beds (playas). This pattern was strongly evidenced by the negative relationship between these thrashers and slope, in that they were never observed on slopes greater than 5 degrees, and by the disassociation with mountainous habitat and higher-elevation plant assemblages. The site-specific (ecological model) supported this broad pattern in identifying strong positive associations with playas and saltbush assemblages (specifically, *Atriplex polycarpa* and *A. canescens*). Positive associations were also determined for three other plant assemblages: wash vegetation, cholla, and Mojave mixed scrub (dominated by *Yucca schidigera)*. The landscape model confirmed the important relationship of saltbush and wash vegetation. Crissal thrashers presence showed a strong negative relationship with creosote-bursage, shadscale, and creosote-sparse Joshua tree plant assemblages and with a principal component describing climatic patterns associated with decreasing temperatures and increased precipitation at higher elevations. Two plant assemblage categories, riparian and wash vegetation, and a principal component describing latitudinal patterns in climate were positively associated with this thrasher. The landscape model for the Crissal thrasher identified the same variables and relationships as the site-specific model. Suitable habitat for both species

were predicted in ArcGIS using model average coefficients derived from best-fit landscape models. The predictive maps greatly improved on existing habitat models for these species within Clark County, and provide tools for conservation planning.

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CHAPTER 1

INTRODUCTION

The Le Conte's thrasher (*Toxostoma lecontei*) inhabits some of the most desolate environments within the Sonoran, Mojave and Peninsular deserts of North America (Merriam 1895, Sheppard 1996, Floyd et al. 2007). A closely related species, the Crissal thrasher (*Toxostoma crissale*), occurs sympatrically within the Sonoran and Mojave deserts, although this species is described as inhabiting densely vegetated patches along arroyos and riparian habitats (Cody 1999). The distribution of the Crissal thrasher also extends further to the east than the Le Conte's thrasher, covering much of the Chihuahua Desert (Cody 1999). Both of these relatively uncommon species are characterized by extreme wariness (Stephens 1884, Fisher 1893, Merriam 1895, Anthony 1897, Gilman 1904, Grinnell 1904, Engels 1940, Bent 1948), with most published information coming from anecdotal species descriptions and from early life history observations (e.g., Stephens 1884, Merriam 1895, Gilman 1909, Pemberton 1916, Grinnell 1933). The research I have conducted was designed to quantify habitat used by these species and to provide ecological models of habitat use and distribution along the northern fringe of their ranges in southern Nevada where urban expansion is causing large-scale habitat transformations.

The taxonomic classification of these species has been largely based on color variation of plumage and in some cases bill length and bill curvature, although more recently genetic data have supported the close relationship between Le Conte's and Crissal thrashers (Zink andBlackwell 1999). Historically, the Le Conte's thrasher was taxonomically separated into three subspecies, *T. l. arenicola, T. l. macmillanorum,* and *T. l. lecontei* (respectively Anthony 1897, Phillips 1964, but see Sheppard 1973, 1996). A subsequent phylogeographic analysis did not support the taxonomic split between *T. l. lecontei* and *T .l. macmillanorum,* but did find genetic divergence between these populations (collectively hereafter recognized as *T. l. lecontei*) and populations within the Peninsular Desert recognized as *T. l arenicola* (Zink and Blackwell 1997). This distinction between populations occupying the southern peninsula of Baja California and continental sister taxa is not unique to the Le Conte's thrasher and has been extensively documented across taxonomic groups (e.g. Riddle et al. 2000).

There have been as many as four subspecies recognized for the Crissal thrasher (Davis and Miller 1960) – *T. c. crissale, T. c. trinitatis, T. c. coloradense,* and *T. c. dumosum* (respectively Henry 1858, Grinnell 1927, Van Rossem 1946, Moore 1941,), but according to Cody (1999, p. 36) "The taxonomic structure below species level of the Crissal thrasher remains obscure…". Herein, I focus on regional populations of these two species within southern Nevada where LeConte's thrasher is currently recognized as *T. l. lecontei* and the Crissal thrasher is recognized as *T. c. coloradense* .

Documenting habitat preferences of these elusive thrashers is difficult because even in areas of optimal habitat, breeding numbers of both species are typically low when compared with other birds occupying the same habitat types. Most of what is known about the Le Conte's thrasher population biology comes from an intensive banding study conducted by Sheppard (1970, 1973, and 1996) within the San Joaquin Valley of

California. This species was found to be sparsely distributed throughout much of its range, with densities reaching 4.6 pairs/km^2 (one of the highest recorded for this species) and general densities appearing much lower (averaging less than 0.2 pairs/km^2; Sheppard 1996). The Crissal thrasher appears to have higher densities, although these densities can vary greatly depending on the type and heterogeneity of the habitat (Cody 1999). The highest breeding densities documented for this species were in mesquite thickets and riparian woodlands (Cody 1999). Within the mesquite thickets of southern Nevada, Crissal thrasher densities average 5.7-11.5 pairs/km^2 (different years; Austin 1970); although, densities within more open desert appear to be much lower (Cody 1999).

Although often sympatric, the Le Conte's and Crissal thrashers tend to occupy distinct habitat types (Engel 1940, Cody 1974). For both species, ground foraging is the primary mode of food acquisition and substrates tend to be sandy where these species occur (for *T. crissale* Grinnell and Miller 1944, Cody 1999 and for the *T. lecontei* Sheppard 1973, 1996). For Le Conte's thrashers, substrates are often alkaline (Merriam 1895, Grinnell and Miller 1944, Sheppard 1970, 1973) and, in general, this species inhabits areas of little topographic relief such as alluvial fans, desert flats, dunes, or the margins of river drainages or dry lakes (Sheppard 1970, 1973, 1996). Across its range, the Le Conte's thrasher tends to occur in areas with limited shrub cover and shorter vegetation (Engels 1940, Garrett and Dunn 1981, Sheppard 1996), often closely associated with cholla (*Opuntia*) and saltbush (*Atriplex*) plant species (Gilman 1904, Grinnell 1933, Sheppard 1970, Zeiner et al. 1983). Many reports state that the Le Conte's thrasher is more often found near desert washes or arroyos where larger shrubs can support nests (Grinnell 1933, Engels 1940, Sheppard 1970, 1973, 1996). In general, the species occupies desert scrub habitat types (Sheppard 1970, Zeiner et al. 1990, Small 1994, Sheppard 1996), and Mojave yucca and Joshua tree dominated woodlands (Gullion 1959, Garrett and Dunn 1981, Zeiner et al. 1990).

An essential component of Crissal thrasher habitat is thick dense vegetation with openings and runways at ground level (Mearns 1886, Engels 1940, Grinnell and Miller 1944, Cody 1999). This type of cover not only offers the bird protection and escape paths, but also provides access to leaf litter where nearly all foraging occurs (Miller and Grinnell 1944). Across its range, the Crissal thrasher tends to occur in desert riparian areas and washes (Engels 1940, Grinnell and Miller 1944, Small 1994, Cody 1999). Within these habitat types, it has been most closely associated with mesquite (*Prosopis sp*.), desert ironwood (*Olneya tesotsa*), catclaw acacia (*Acacia greggii*), cottonwoods (*Populus sp*.) and willows (*Salix sp*.) (Garrett and Dunn 1981, Laudenslayer et al. 1992, Cody 1999). Within the eastern Mojave Desert, this species can be found up to approximately 1800 m elevation, in desert washes or arroyos up into the lowest reaches of pinyon-juniper where desert almond (*prunus fasciculatum*), desert-thorn (*Lycium cooperi*), and bitterbrush (*Purshia glandulosa*) tend to dominate (Cody 1999). The Crissal thrasher also will readily use riparian habitat dominated by invasive saltcedar species (*Taxarix* spp.) (Hunter et al. 1988, Rosenberg et al. 1991, Cody 1999).

Precipitation is suspected to have an important impact on local distribution of both these species, and may define northern geographic limits (Sheppard 1973). For example, where rainfall exceeds 16.5 cm/year the density of Le Conte's thrashers decrease (Sheppard 1973), possibly because greater vegetation obstructs foraging and escape strategy, or possibly because of competition with other species. The northern distribution of Le Conte's and Crissal thrasher coincides with the northern extent of the Mojave Desert. Sheppard (1973) speculated that the occurrence and persistence of snow within the Great Basin impedes ground foraging by these thrashers.

The Le Conte's thrasher has been identified as a species of conservation concern throughout its range (Neel 1999, Clark County 2000, Rich et al. 2004) due in part to its low population density and a lack of knowledge concerning its habitat requirements. For the Crissal thrasher only populations within California and Utah are recognized as of special concern (Shufard and Gardali 2008, Utah Division of Wildlife Resources 1997). Low numbers and patchy distributions, however, could make both these species vulnerable to habitat change and localized extinctions (for *T. lecontei* Laudenslayer et al. 1992, Neel 1999 and for *T. crissale* Laudenslayer et al. 1992), particularly on fringes of distributions where conditions may be more climatically ephemeral. Populations on the peripheral edge of a species range are speculated to be more threatened than central populations because environmental conditions may be of lower quality (Lawton 1993, Lesica and Allendorf 1995). This problem may be acute in southern Nevada at the northern geographic limits for Le Conte's and Crissal thrashers, where habitat loss to urbanization in the Las Vegas Valley area has occurred at a rapid rate. From a conservation perspective, the ecology of peripheral populations may be distinct from more central populations, because the former may occur in uncharacteristic environments and knowledge of specific habitat requirements may be inadequate (Lesica and Allendorf 1995, Crampton 2004). Understanding and protecting unique peripheral populations are likely to be important components of larger plans to conserve the integrity and viability of species (Lesica and Allendorf 1995).

According to Partners in Flight (Neel 1999), an important research and monitoring need for Le Conte's thrasher in southern Nevada is to determine specific habitat preferences. Sheppard (1996) suggested that one necessary research priority would be to perform a "structural analysis of occupied/unoccupied habitat." Additionally, there is little information available on the distribution of the Crissal thrasher, specifically within southern Nevada (Species Account Manual Clark County MSHCP 2000). In direct response to these research needs, I initiated a study of the Le Conte's and Crissal thrashers within southern Nevada at the northeastern limit of the Mojave Desert. My goal was to provide quantitative information on the habitat characteristics associated with these species and to identify important environmental and ecological characteristics linked with species presence. To sample occurrence of these thrashers with reference to available habitats, I established 432 census locations and conducted call-broadcast sampling. For each location, I measured variables corresponding to five main environmental categories. These categories were chosen based on their perceived influence on thrashers (both from literature and personal observations) and included plant assemblages, substrate, physical landform features, bioclimatic influence, and human disturbance. These environmental data were then used to produce models of suitable Le Conte's and Crissal thrasher habitat, and to create detailed habitat maps for conservation planning.

CHAPTER 2

METHODS

Site Selection

I conducted detection/non-detection surveys for the Le Conte's and Crissal thrashers at the eastern edge of the Mojave Desert within Clark County, Nevada (Figure 1.). Field surveys for these thrashers were performed between March 2005 and May 2007 at 432 random locations and at an additional 86 incidental (non-random) locations where I encountered thrashers while traveling between sites. In addition, I repeated surveys at 84 sites (range 2-4 times, for 96 repeated surveys). I used these multiple visits to evaluate seasonal and yearly consistency of detection and non-detection results.

To identify sample locations, I employed stratified random sampling with strata defined by accessibility and vegetation type. To determine accessibility, survey locations were randomly generated using ArcGIS software (v9.2, ESRI Inc. Redlands, California) within a 400-meter buffer around secondary and minor roads outside of developed areas. Major highways were excluded from the roads selection because of safety concerns. In order to evaluate potential effects of roads on thrasher presence, I generated roughly 9% of survey locations (n = 37) outside of the 400 m buffers.

I targeted vegetation types with some expectation for presence of the targeted thrasher species; no surveys were conducted in areas where these species have never been documented, such as dense coniferous forest and alpine habitats. Existing vegetation data layers were used within GIS to identify survey locations within several habitat types (Table 1). Observations in the field revealed inconsistencies (i.e., areas said to be one vegetation type but were clearly a different when observed in the field)for some important vegetation types representing small areas of Clark County, specifically, Warm Desert Riparian Woodland, Warm Desert Wash, Sonora-Mojave Mixed Salt Desert Scrub and Invasive Southwest Riparian Woodland and Shrubland. In order to sample these areas effectively, I identified under-represented habitats in the field and generated survey sites within these areas using a random number table; roughly 21% (92) of the locations were generated in this fashion.

Thrasher Detection and Non-detection

I used call-broadcast to conduct surveys, which has been shown to be an effective tool to census thrashers (Sheppard 1970, England and Laudenslayer 1989). I selected this active survey approach because adequate information about the Le Conte's and Crissal thrashers in this region had not been obtained using passive point count methods (Great Basin Bird Observatory 2005). Because Le Conte's and Crissal thrashers are permanent residents, I was able to conduct surveys throughout the year.

For each survey, I recorded survey location and elevation using a Global Positioning System (GPS) receiver, as well as survey time and date. I also assessed and recorded weather (temperature, wind speed, and percent cloud cover) and surveys were conducted only under favorable conditions. The majority of surveys were performed by one researcher (DMF), although some surveys were assisted or conducted by a qualified colleague. Surveys began with a 5 to 10 minute passive point count. Afterwards, I played calls (Stokes Field Guide to Bird Songs: Western Region) of the Le Conte's, Bendire's (*T. bendirei*), and Crissal thrashers (consistently in order). Species in this genus are known to be territorial (Sheppard 1996, Cody 1999) and respond to the songs of sympatric congenerics. Each species call was played twice for approximately 30 seconds, with a one-minute observational break between call cycles.

Landscape and Site-Specific Analyses

For each survey location, I quantified habitat features and environmental variables using digital data layers, digital images, existing databases, and field observations (see below). Numerous variables were assessed, in part because I was studying two different species with unique habitat requirements, but also because this study was exploratory in that many of the critical components of suitable habitat for these thrashers were not known. I used several techniques to assess and reduce variables prior to modeling and also reduced variables that caused instability during the modeling process (see Table 2 and Variable Reduction section below).

My main analytical approach was logistic regression (Neter et al. 1996). Within the logistic regression analysis, I created models using two methods (hereafter referred to as the ecological model and landscape model). For the ecological model, I assessed site-specific as well as landscape variables (from digital data layers), whereas for the landscape model I used only data available, or that could be easily derived as digital spatial layers. Model averaging was run on both the ecological and landscape models (see data analysis) and the predictor variables from the landscape model were used to create probability maps for each species in ArcGIS for use in conservation planning.

Many studies of habitat selection appear to use either landscape-level approaches or site-specific approaches to generate models. My objective was to compare predictions from these two modeling approaches to assess the efficacy of collecting site-specific field data. If the model outputs were similar and generally provided similar conclusions for conservation planning purposes, then efforts on future projects may be reduced by limiting the gathering of site-specific data in the field.

Spatial Scales

Because call-broadcast can attract birds from distant locations where habitat features could be different from the center of the survey location, I initially quantified several variables at two spatial scales, 100m and 300m buffers around the center on each location. The larger area was appropriate because in observations of first detection, most thrashers were first detected within 300 m of the observers, although I noted a few thrashers that responded from well over 300 meters. I selected the 100-meter buffer because vegetative site descriptions were based on assessments at this scale.

Landscape Variables for Ecological Model

The landscape variables (spatial layers) I identified for use in the logistic regression analysis, included elevation, slope (degrees), latitude, longitude, and bioclimatic variables. Bioclimatic variables represent annual trends, seasonality, and extreme or limiting factors in temperature and precipitation (Hijmans et al. 2005). Bioclimatic layers with a resolution 30 arc-seconds (~1 km) were obtained from WorldClim (v1.4; http://www.worldclim.org). Elevation data was derived from a

National Elevation Data Digital (NED) at 10-meter horizontal resolution (http://ned.usgs.gov; U.S. Geological Survey 1999), and slope was generated from elevation data in ArcGIS.

Site-Specific Variables for Ecological Model

Plant Assemblage. – To assess plant species and assemblages, I identified dominant plant species in the field within visual range of the center of each survey location, documenting over 70 plant species (Appendix 1). Covariation among plant species was low such that vegetation types could not be easily classified using a principal components analysis (see below). To classify vegetation, I used an exploratory approach in which I split the overall dataset in half (hereafter referred to as the "exploratory dataset") and ran Fisher's Exact Tests to identify significant positive or negative associations (p value $\leq$ 0.05) between plant species and thrasher presence. The results from these tests as well as the list of dominant plant species identified in the field were used to assign survey locations to plant assemblages previously classified for the Mojave Desert (Sawyer and Keeler-Wolf 1995, and Clark County Multi-Species Habitat Conservation Plan Vegetation 98 data layer, Clark County Department of Conservation Planning 2000) or to plant series considered important to thrashers in the region. A total of 12 classifications were determined (Appendix 2), and these were used as categorical variables for plant assemblages in the final analysis.

Substrate. – To define the substrate at each survey location, I used a combined dataset of three contiguous Soils Survey of Clark County Clark County (Natural Resource Conservation Service, U.S. Department of Agriculture 2007). These soil surveys have map units ranging in size from just under 2 acres, up to178,000 acres. Through a process of overlays and association with descriptive variables of slope, aspect, landform, and vegetation, and after visualization using the program Google Earth (v4.0.2137.0; 2007 Digital Globe, 2007), I manually identified soil types (“components” in the soil survey database) within the 100 and 300 m buffer areas at each survey point. Evaluations of soil type on the exploratory dataset using Fisher's Exact Tests showed tantalizing associations between two soil types and thrasher presence; but, because of the large number of soils identified and low covariation among soil types I could not group soils for meaningful analysis. However, by classifying soil types I was able to identify the associated soil texture (Table 2), a variable important to ground-foraging thrashers, and these data were incorporated into the logistic regression analysis.

Physical Landform Features. – Within the soils surveys database, landforms were associated with soil type, and I was able to use the landform classifications in final analyses (Table 2). I visually determined and classified washes (included in this category were perennial water sources) within each of the 100 and 300 m buffered areas using the aerial images in Google Earth. When present within buffered areas, I measured the approximate distance from the survey location and the width of the largest wash; measurements were made using the ruler tool in Google Earth with width determined as the average of three measures at different points.

Human Influence. – I also used aerial images in Google Earth to visually determine and classify roads within each of the buffered areas, as currently available digital data layers for roads were of limited accuracy within the region. Within each of the buffered areas, I determined the number of roads, distance from the survey location to the largest road, and classification of the largest road, as follows: (1) highway, (2) secondary road, (3) major unpaved road, (4) unpaved graded (maintained) road, (5) 4x4 road, and (6) track or path associated with ATVs.

Variable Reduction

To further reduce the number of variables, I used the exploratory dataset to model covariation among the landforms and bioclimatic variables using a variety of techniques, including principal coordinate analysis (using a Jaccard index and multi-dimensional scaling). Because landforms had no axes that usefully summarize these data, I analyzed these variables separately. Bioclimatic variables, however, were inter-correlated and therefore appropriate for a principal component analysis (PCA). The initial PCA yielded potentially useful patterns in the first three PCs, but the resulting patterns appeared to be driven by elevation, latitude, and longitude; therefore, I included these additional variables in a final PCA with bioclimatic variables (total of 22 variables). The first three PCs had eigenvalues greater than 1 and explained more than 96.5% of the variation in the data, but only the first two PCs, representing 66.9% and 23.0% of the data respectively, were easily interpretable and retained for further analysis (Table 3). The loadings on PC1 represented a positive association between elevation and mean precipitation, and showed a negative relationship between elevation and mean temperature. I interpreted this as representing the general regional pattern where as elevation increases there is an increase in precipitation and a decrease in temperature. Loadings on PC2 showed that lower annual and diurnal temperature range and high seasonality of precipitation are related to latitude (independent of elevation, because most of the variation in elevation was already explained by PC1). As latitude increases there is a higher annual and diurnal temperature range and lower seasonality of precipitation. These data reflect the location of the study area at the border between the Mojave Desert and Great Basin, and the effect of summer “monsoons” on precipitation patterns at lower latitudes

As mentioned above, I measured road and wash variables at two spatial scales (100m and 300m). In several cases the larger spatial resolution added no additional information to the dataset (i.e., the data were virtually identical). In these situations, the larger spatial scale was selected for the model (Table 2). Information for the presence or absence of Crissal information in washes within 300 m of the observation point was dropped for use in final analysis, because only once was this species observed away from a wash.

As might be anticipated from the random nature of the sampling, some plant assemblages and landforms were found to be unsuitable habitat for the thrashers (Table 2). I excluded observations prior to fitting models for plant assemblages and landforms with at least 20 observations in which no thrashers were observed (Table 2). When included in model runs, these variables (containing only absence data) tended to mask information gained from the other variables in the model, and their exclusion revealed ecologically and statistically relevant patterns from the remaining variables. Removing these variables cost roughly half of my dataset for both species (n=234 and 213 for the Le Conte’s and Crissal thrashers, respectively), but I felt that this was necessary in order to identify other variables in the models that might be driving thrasher presence or absence. In the landscape models, these same plant assemblages and landform classifications were retained, but given a probability of 0 for thrasher presence.

Spatial Layers for Landscape Model

Site-specific variables used in the ecological models were not readily available as spatial data, so I used a subset of important variables that had surrogate spatial layers currently available or that could be easily created for use in the landscape models. The subset of variables included: landform, distance to nearest wash and road, slope, bioclimatic variables (PC1and PC2 described above), elevation, and plant assemblages (Appendix 3). Because no single vegetation data layer currently available represented all the plant assemblages I classified, four data layers were used to derive vegetation characteristics at the survey locations. The layers used to represent plant assemblages were as follows: (1) for creosote-bursage and wash vegetation series I used the LANDFIRE data layers of vegetation composition (www.landfire.gov 2006); (2) for black brush, pinyon- juniper, and Mojave mixed scrub (dominated by Mojave yucca *Yucca schidigera*) vegetation I used the Clark County Multi-Species Habitat Conservation Plan Vegetation 98 data layer (Clark County Department of Conservation Planning 2000), and (3) for mesquite/catclaw, I used a vegetation layer (Bureau of Land Management, Las Vegas Field Office, 2005) that was compiled specifically to represent this habitat type across Clark County. Saltbush and riparian assemblages were not represented well by available spatial layers, and I derived these assemblages from the soil surveys database and associated Ecological Site Descriptions (circa 1999, see http://esis.sc.egov.usda.gov/ESIS/About.aspx). To create these vegetation layers, I selected in ArcGIS all soil map unit polygons from polygon data associated with the soil survey database that had Ecological Survey Descriptions dominated by the plant species of interest (representing > 50% of the map unit). Identified polygons (shapefiles) were then converted to binary grids for analysis.   I used LANDFIRE data to determine if a wash was within 300 m of survey locations, and Southwest ReGAP spatial data (http://fws-nmcfwru.nmsu.edu/swregap, Utah State University 2004) to categorize landforms. Lastly, I determined distance to nearest road using a conglomerate of 2007 TIGER/ Line data (from the U.S. Census Bureau), and regional roads data from (National Park Service, Bureau of Land Management, United States Fish and Wildlife Service, United States Forest Service)

CHAPTER 3

DATA ANALYSIS

Data Analysis and Model Selection Ecological Model

For all data analyses, I used the statistical package R 2.8.1 (R Development Core Team 2008). A heterogeneity chi-square analysis indicated that there were no differences ($p>0.05$) among months and years of sampling for each thrasher species, so I combined observations from all years and months for each species in all analyses. I modeled the presence of Crissal and Le Conte’s thrashers with separate logistic regressions of the response variable, detection or non-detection of thrashers ($n=233$ and 213, respectively) and the predictor variables listed in Appendix 2.

For model development and selection, I used an information theoretic approach (Burnham and Anderson 2002) and included in logistic regression analyses all subsets of the predictor variables (12 for Le Conte’s and 10 for Crissal thrasher) as possibilities in the model selection procedure. Inclusion in the best-fit model sets were determined by AIC_C, the Akaike Information Criterion corrected for small sample size; the correction was appropriate for the datasets as the ratio of sample size to the number of parameters was less than 40 in both cases (Burnham and Anderson 2002). I calculated $\Delta_{i,}$ (difference in the AIC_C value for a model relative to the AIC_C of the best-fitting model) and Akaike weights (ωi) (the proportional likelihood of each model over the sum of likelihood of all the models) for all models. Model included in the best-fit sets were those with the highest AIC_C and $\Delta_i < 2$(Burnham and Anderson 2002). Using this criterion, no single model for either species was identified. I included multiple models in the best-fit sets for both Le Conte's and Crissal thrashers based on Δ_i and evidence ratios ($\omega i/\omega j$) of models (Burnham and Anderson 2002).

Given the large number of models with similar fit to my data, I use model-averaging (Burnham and Anderson 2002) to determine the best possible parameter estimates for predicting thrasher presence from the complete set of best-fit models with $\Delta_i < 2$. This approach allows inferences about the variables that are most important for site occupancy. I calculated the model-averaged coefficients, unconditional standard errors (SE), and lower and upper 95% confidence limits (CL) (average and variance of coefficients) to determine the magnitude and effect of each variable. According to Burnham and Anderson (2002) an effect is strong when the confidence intervals around the variance of coefficients does not include zero. Estimates of the relative importance for each predictor variable were determined by summing the Akaike weights (ωi) across all the models (in each set) in which the variable was included.

Data Analysis and Model Selection Landsacpe Model

I estimated and evaluated the landscape models using the same methods described above, with the exception that fewer predictors were included (Appendix 3). All subsets of the six Le Conte's thrasher and five Crissal thrasher predictor variables were used. Because there were several models with good fit, based on $AIC_{C,}$ for each species, I also used model averaging to make inferences about variables that were important to site occupancy of thrashers. To predict the presence of thrashers across the landscape in GIS, I used the average coefficients for each variable following the approach of Manly et al. (1993).

Model Evaluation Ecological Model

To evaluate the performance of the final models, I performed model validation (Olden et al. 2002). I chose not to use the area under the receiver operating characteristic (ROC) curve, known as AUC, a widely-used technique to evaluate predictive performance of a model, for model validation, because recent criticism of this approach reveals its limitations (Austin 2007; Lobo et al. 2008). In general AUC weights omission errors (falsely predicted negative fraction) and commission errors (falsely predicted positive fraction) equally (Lobo et al. 2008). Given that the thrasher species I studied are rare, even in optimal habitat (Sheppard 1996), I chose to minimize the false negative rate (FNR) (the probability of failing to predict a thrasher when one was present) relative to the false positive rate (FPR). Thus, I assessed model performance by the number of observations that were correctly classified. Based on visual assessment of the FNR and FPR for the ecological models, I set my classification cut-off values at 0.22 (corresponding to a correct classification rate (CCR) = 83.3%, FNR = 25.7%, and FPR =53.6%) and 0.13 (corresponding to a CCR of 70%, FNR of 2.6%, and FPR of 62.3%), for the Crissal and Le Conte's thrashers, respectively (Fig. 2 & 3). For the landscape models, I set my cut-off values at .12 (CCR = 52.4%, FNR = 12.5% and FPR = 75.2%) and .17 (CCR = 66.2% FNR = 23.1%, and FPR =67.7%) for the Crissal and Le Conte's thrasher, respectively (Fig. 4 & 5).

To determine the significance of the best-fit models, I tested the CCR, FNR, and FPR against a null distribution of expected CCR, FNR, and FPR values based on random collection data (Raes and Steege 2007). A null distribution of CCR for each species was generated by permuting the thrasher presence data 999 times, fitting the model, and then applying the cut-off values (described above) to obtain the classification rates. The calculated p-values are based on the rank of the observed value from my model relative to the 999 permuted values (randomly generated). The mean classification rate for the permuted data sets in each case are included for context.

Landscape Model Implementation in GIS

To create maps of suitable habitat for each thrasher species in ArcGIS, I used model-averaged coefficients from the landscape models. To create these maps, I clipped environmental predictor layers to the same extent and 30 m resolution as the digital elevation model (DEM) (using Raster Calculator in Spatial Analyst). For each species, the layers representing predictor variables from the logistic regression equation of the final models were used to generate a continuous grid of predictive probability distribution ranging from 0 to 1 for each cell (using Raster Calculator).

CHAPTER 4

RESULTS

Both Le Conte's and Crissal thrashers in southern Nevada appear to occur in low densities across the landscape, particularly Le Conte's thrasher. Of the 432 random locations surveyed, I detected Le Conte's thrashers at only 45 locations, and Crissal thrashers at 41 locations. For presentation of distribution maps (Fig. 6), I included an additional 24 incidental (non-random) locations for Le Conte's thrashers and 28 incidental locations for Crissal thrashers observed while in transit between sampling locations or during other activities.

Le Conte's Thrasher

As discussed in the methods section, I removed several important categories from the set of predictor variables for each species prior to model-fitting. In all these cases, the specific category was removed after an inspection of a contingency table (linking the presence of thrasher with each predictor variable or category) revealed no observations of the specific thrashers associated with the category. Four categories had a strong negative relationship with Le Conte's thrasher. Because birds were never observed at these locations, I removed these categories and corresponding observations from the data set prior to fitting the models. The variables identified in this set included: black brush (n=42), pinyon-juniper (n=29), mountains (n=38), and slopes > 4 degrees (n=153).

Ecological Model – From the best-fit model set (Table 4); twenty model-averaged coefficients were calculated for the Le Conte's thrasher (Table 5). The corresponding coefficients for the plant assemblage categories: saltbush (dominated by *A. polycarpa and A. canescens*), cholla, Mojave mixed-scrub, and wash vegetation were strongly (i.e., corresponding confidence interval did not include zero) positive, indicating that the presence of these features within the habitat had a positive effect on the thrasher. Strong positive support was also derived for the landform category, lake plains (playas). Fifteen additional coefficients that were included in the best-fit model set (Table 5) do not appear to have strong effects on thrasher presence because their confidence intervals included zero. The relative importance of individual predictor variables ($\sum\omega_i$) in determining the presence of Le Conte's thrashers in the ecological model showed that plant assemblages and landform features ranked highest (with $\sum\omega_i$ =1), closely followed by number of roads ($\sum\omega_i$ = 0.898) and presence of wash within 300 meters ($\sum\omega_i$ = 0.723). The other variables in the best-fit models had less relative importance in predicting thrashers (Table 6).

Landscape Model – From the set of best-fit landscape models (Table 7), I calculated 12 model-averaged coefficients (Table 8). Strong support was shown for positive associations between Le Conte's thrashers and saltbush and wash vegetation. A strong negative association was determined between Le Conte's thrasher presence and the presence of wash (within 300 m). These three variables ranked highest ($\sum\omega_i$ =1) for relative importance in the model determining Le Conte's thrasher presence, while the other variables from best-fit models ranked much lower in comparison (Table 9).

Model Validations – Using the established cut-off value of 0.13, the ecological model for the Le Conte's thrasher performed significantly better than a random model, improving upon the FNR, FPR, and CCR substantially over the mean from the permutations of the data (null-model distribution; Table 10). According to Raes and Steege (2007), a significant model in this assessment indicates that the relationship between species presence and the predictor variables at each location are stronger than expected from chance alone.

The landscape model improved on random appreciably less than the ecological model. Using the established cut-off value of 0.17, the landscape model for the Le Conte's thrasher did not provide an FNR that was significantly better than random permutations, although it did provide small, statistically significant improvements to the FPR and CCR (Table 10).

Predictive Habitat Mapping – Suitable habitat for Le Conte's thrasher was predicted using the model average coefficients derived from best-fit landscape models in ArcGIS, and the 0.17 cut-off value determined to minimize FNR. The predictive map of suitable habitat for the Le Conte's thrasher identified approximately 3998 km^2 (988, 000 acres) of potential suitable habitat within Clark County, Nevada, out of the approximate 5.1 million potential acres (Figure 7). From the map output, the maximum probability of observing a Le Conte's thrasher in the highest probability habitat within Clark County was 0.78, and there were only a few small, non contiguous patches (approximately 104 km^2 25946 acres) of high quality habitat (i.e. probability of 0.53 to 0.783) scattered across Clark County. The lack of a predicted habitat close to a value of 1, suggests the possibility that important habitat features (variables), or combination of variables, for this species could not be ascertained from the readily available GIS spatial layers or that the combination of variables that would predict the best habitat for a Le Conte's thrasher are not present in Clark County.

Crissal Thrasher

Ecological Model – Crissal thrashers presence was never associated with three plant assemblage categories, and these categories (and associated observations) were removed prior to fitting the models: creosote-bursage (n=77), shadscale (n=27), and creosote-sparse Joshua tree (n=33). Fourteen model-averaged coefficients were calculated from the best-fit ecological model set (Table 11). Of these, the coefficients for two plant assemblage categories, riparian and wash vegetation, and the two climatic variables (PC 1 and PC 2) showed strong effects on the presence of this thrasher (Table 12). The corresponding coefficients for the riparian and wash plant assemblages, as well as PC 2 were positive, while the coefficient for PC 1 was negative. The climatic variables PC 1 and PC2, and plant assemblages ranked highest ($\sum\omega_i = 1$) for relative importance in the model for determining Crissal thrasher presence. Other variables identified in the best-fit models ranked substantially lower (Table 13).

Landscape Model – The best-fit of landscape models for the Crissal thrasher (Table 14) included nine model-averaged coefficients (Table 15). As observed in the ecological model, riparian and wash vegetation and the climatic variable PC 1 and PC 2 exhibited strong effects on Crissal thrasher site-occupancy. The signs (positive or negative) of these coefficients were also identical to those observed in the ecological model. Plant assemblages and the climatic variables PC 1 and PC 2 were also ranked as the three most important variables ($\sum\omega_i = 1$) in the model (Table 16).

Model Validations – Validation for the ecological model for the Crissal thrashers was assessed using a cut-off value of 0.22 (see Data Analysis). The final ecological model performed significantly better than a random model (null-model distribution), improving the FNR, FPR, and CCR substantially over the mean from the permutations of the data (Table 17). Using the established cut-off value of 0.12, the landscape model did not provide an FNR significantly better than random permutations, however the model made statistically significant improvements to FPR and CCR (Table 17).

Predictive Habitat Mapping – Converting model predictions to a map of suitable habitat for the Crissal thrasher resulted in 5678 km^2 (1,403,000 acres areas with cut-off values $\geq$ to 0.12 used to minimize FNR) of potential habitat in Clark County (Figure 8). Suitable habitat for the Crissal thrasher was found mostly in the southern part of the County, with large expanses of low probability in areas north of Las Vegas. The highest probability for observing a Crissal thrasher was 0.72 in the best predicted habitats (i.e. probability of 0.37-0.72) which represented only around 108 km^2 (26687 acres) scattered in patches.

CHAPTER 5

DISCUSSION

Ecological and Landscape Models

I constructed two types of habitat suitability models for the Le Conte's and Crissal thrashers: ecologically-based models derived from site-specific data and landscape-based models generated from available (or created) geospatial data layers. Landscape models recently have gained wide usage in ecology, paleobiology, conservation biology, and natural resource management due, in part, to the availability of habitat variables in existing, electronic databases which are easier to acquire than direct measurements of variables in the field. However, the ease of acquisition of data may come at a cost as some studies suggest that predictive accuracy can be significantly improved by using site-specific data collected in the field (Wu, and Smeins 2000). In general, the ecological models I generated for each thrasher species performed better overall than the respective landscape models. This was evidenced in the False Negative Rate (FNR) for landscape models of both species showing no statistical difference from null model expectations, and while these landscape models performed significantly better than random for CCR and FPR, the models showed lower CCR and higher FPR when compared with the respective ecological models (Table 10 &17).

Accuracy of landscape-scale models depends largely on the spatial data layers available (Wu and Smeins 2000). I suspect that the weaker performance of the thrasher landscape models was in part a product of the limited availability and accuracy of spatial data layers for my study area. Several of the spatial layers I used for this study were produced at a scale no finer than 1:24,000, and the classifications within these spatial layers tend to be fewer due to the limitation of GIS data. Many of the site-specific variables included in the ecological model were not available as spatial layers, and those that were available were of limited accuracy (when compared to field observations).

In some cases, data layers may not have adequately depicted or represented the habitat feature present. One clear example from the analysis was the variable, presence of wash, which for the landscape model was determined at a much coarser resolution (i.e., from LANDFIRE data layers) than that used in the Ecological Model. In many cases, the coarser data did not detect smaller washes identified in the site-specific data, which probably resulted in this variable being identified as a negative predictor of Le Conte' s thrasher presence in the landscape model but not in the ecological model. In this case, the additional site-specific information more accurately represented the relationship between wash features and the thrasher.

In general, site-specific assessments captured variable features not readily available as spatial data layers that appear important in determining the presence of the thrashers and modeling habitat suitability. Although site-specific ecological models tend to be more accurate than landscape-scale models, site-specific models are generally more expensive to create if they include data collection in the field. My comparisons of GIS based landscape models with ecological models indicate that both models may be useful, depending on the scale of investigation and resources available.

Le Conte's Thrasher Suitable Habitat

Within the eastern Mojave Desert of southern Nevada, Le Conte's thrashers occur within areas of little topographic relief such as valley bottoms near dry lake beds (playas). This pattern was strongly evidenced by the negative relationship between these thrashers and slope, in that they were never observed on slopes greater than five degrees, and by the disassociation with mountainous habitat and higher-elevation plant assemblages (i.e., blackbrush and pinyon-juniper). The ecological model supported this broad pattern in identifying strong positive associations with playas and saltbush assemblages (*Atriplex polycarpa, A. canescens*) which often dominate these low valley areas. Wash vegetation, cholla, and Mojave yucca plant assemblages were also found to be positively associated with presence of this thrasher. The landscape model confirmed the important relationship of saltbush and wash vegetation with this species. These results are consistent with general patterns documented in early observations (Grinnell 1933, Sheppard 1970) but expand on the specifics.

Crissal Thrasher Suitable Habitat

The Crissal thrasher tends to prefer habitats dominated by riparian and wash vegetation (Engels 1940, Grinnell and Miller 1944, Small 1994, Cody 1999), patterns confirmed by both the ecological and landscape models. The landscape model for the Crissal thrasher identified the same variables and relationships as the ecological model, emphasizing the consistency and validity of the models and the importance of these variables in determining thrasher locations. Climatic (bioclimatic) variables were important in both models, and Crissal thrashers were negatively associated with increases in colder temperatures and precipitation at higher elevations (represented by PC1). Furthermore, these thrashers also showed a latitudinal pattern having a positive relationship with lower fluctuations in the range of annual and diurnal temperature and increases in seasonality of precipitation at lower latitudes (represented by PC2). The relationship with lower latitudes is visually evident in the obvious southern distribution of the species within the study area (Fig. 8).

The study area is at the northern edge of the eastern Mojave Desert in an area where many other arid-dwelling species reach their northern limits of distribution, and strong elevation and latitudinal patterns in distribution can be expected if these species reach limits of thermal tolerance (e.g., Bradford et al. 2003). Associated limits in other important habitat features, such as prey items, could also drive the pattern observed for Crissal thrashers. As noted in the introduction, Sheppard (1973) speculated that occurrence and persistence of snow impedes ground foraging by Le Conte's thrashers and excludes the species from the Great Basin. Although snow can occur across my study area, both Crissal and Le Conte's thrashers appear to reach elevation and latitudinal limits generally below areas in which snow is common, suggesting that the pattern is associated more with cold temperatures.

Importantly, I did not detect strict elevation or latitudinal patterns for the Le Conte's thrasher, although it was negatively associated with mountainous terrain and high elevation plant assemblages, and the strong negative association with slope probably overwhelmed detection of elevation limits. Clearly, a strong latitudinal pattern also exists for this species in the region, as the study area appears to be just at the northern edge of the species distribution. However, scattered patches of preferred habitat for this species occur throughout the study area which limited the detection of a strong latitudinal relationship, as was evident for the Crissal thrasher.

Habitat Suitability and Preferences in Sympatric Species

Plant assemblages were predicted as important variables for both thrasher species. Although these species tend to prefer fairly different habitats, they both appear to be selecting environments with perennial shrub or tree species with relatively dense structure. Based on the plant assemblages chosen by these birds, I hypothesize that a major portion of these thrasher's habitat selection is related to nest-site selection. Within southwestern desert and riparian habitats these thrashers are some of the largest songbirds (both species weighing about 62 grams; Sibley 2003), and their bulky nest require dense vegetation for support (Ehrlich et al. 1988). In the saltbush assemblages associated with Le Conte's thrashers, cattle saltbush is one of the most robust shrubs relative to other surrounding desert vegetation and presumably provides increased structure for nesting. The habitats where Crissal thrashers are found tend to contain shrub and tree species that are comparatively larger and dense, such as desert almond in washes, and mesquite, catclaw acacia, and tamarisk in riparian areas. For both thrasher species, choice of nest sites could be influenced by microhabitat properties that reduce energy expenditure and minimize potential stress on hatchlings (Johnston and Ratti 2002). These dense shrubs are also likely to decrease nest detection by predators. However, prey abundance associated with these plant species and understory litter may also be an important factor that cannot be ruled out by the data presented. The absence of suitable nest sites may explain the lack of association of Le Conte's and Crissal thrashers with creosote-bursage assemblages. Although creosote occurs throughout the Mojave Desert, and is extensive in my study area, thrashers do not appear to use this shrub for nesting (Sheppard 1970). My analyses indicate a strong association of both thrasher species with wash vegetation, and the increase in size and structure of plants within washes is likely driving this relationship. The possibility that this pattern was relate to loose substrates in washes that may allow effective foraging was less likely, as my measure of soil texture was not strongly associated with either thrasher.

Early species accounts assert that these thrashers are sympatric, but with unique habitat preferences (Engel 1940, Cody 1974). I only documented both species within the same survey locations six times. After reviewing my field observations, however, I could not readily identify distinct difference in the wash vegetation associated with the Le Conte's and Crissal thrashers, with the exception that Crissal thrashers tends to appear more often at sites with desert almond. One possibility is these two thrasher species are selecting for different plant assemblages occurring just outside the wash systems, but this was something I could not ascertain from my data.

Management Implications

There is an increased need to understand the habitat preferences of these thrashers as the Southwest desert regions are being transformed by rapid urban development. The Le Conte's thrasher's affinity for areas of low topographic relief and associated plant assemblages place them in areas that are disturbed by OHV enthusiasts, utility corridors, and residential and commercial developments. Crissal thrashers affinity for desert wash and riparian habitats also places them in the direct path of human activities. My measures of human disturbance were focused on the density and type of roads, but road features did not show a strong negative relationship with these thrashers. I suspect that this result was in part because most of my survey locations were stratified randomly near dirt roads (to facilitate obtaining larger sample sizes). In desert areas, roads often follow washes or traverse flatter areas, and teasing out the relationship between thrashers and roads may be difficult because of the strong associations of these thrashers with wash vegetation, and in the case of Le Conte's thrasher with areas of low slope.

Both Le Conte's and Crissal thrashers have been suggested to have weak dispersal capabilities (Laudenslayer et al. 1992), which enhances the vulnerability of these species to disturbance. Within Clark County, high-quality habitat for both species is mostly scattered in small, disconnected patches. Edge effects and disturbance could degrade habitat conditions within these patches leading to declines in the number of birds present, and the loss of habitat patches will increase isolation among remaining patches. The dynamics of low population density, patchy population structure, and stepping-stone dispersal may make the Le Conte's thrasher particularly vulnerable to disturbance.

The predictive maps of thrasher habitat I generated from landscape models can be used for conservation planning and estimation of the ecological impacts of alterations to the landscape. If called for, the surface of probability values derived from the spatial models could be used in cost-benefit analyses to compare land-use scenarios such as solar power plant site selection. Such cost-benefit analyses should take into consideration how different alternatives would impact connectivity of suitable habitat patches.

The predictive maps can also be used to provide retrospective analyses of historical habitat loss. For example within the now urbanized Las Vegas Valley, the predictive habitat maps identify scattered patches of moderate to high quality habitat for Le Conte's thrashers along the southern and western edges of the urban footprint (Fig. 7) and for the Crissal thrashers on the eastern region of the valley within areas in, or adjacent to, urban development (Fig. 8). Historical assessment of the impacts of anthropogenic disturbance on species distributions can assist in determining whether a species' decline has been substantial enough (geographically) to warrant aggressive conservation management.

In general, the habitat models identified several important environmental variables that need to be taken into account if conservation efforts for these species are to be successful. Of concern to the Le Conte's thrasher, is that residential and commercial development, along with regional federal land transfer plans, appears to focus mainly on areas with low topographic relief (and low slope). In many cases, these areas are occupied by the Le Conte's thrasher.. Preservation efforts most focus on these high quality habitats, particularly areas with dense stands of saltbush cholla, Mojave yucca and wash plant assemblages. As mentioned above, the connectivity among the habitat patches must be considered and understanding movements by these thrashers among patches should be a research priority. Models for the Crissal thrashers identify riparian and wash vegetation assemblages as key determinants of habitat suitability, and in general riparian areas have high bird diversity, specifically in arid environments, and should be protected.

Figure. 1 Study area (Clark County, Nevada) where research was conducted on environmental variables describing site-occupancy of the Le Conte's and Crissal thrashers. Study area is shown in reference to the Mojave Desert.

Table 1. List of habitat types, and data sources, sampled in GIS to stratify random survey locations.

Habitat Type	Source
Creosote-Bursage	Clark County Vegetation 98 Layer
Black brush	Clark County Vegetation 98 Layer
Mojave Mixed Scrub	Clark County Vegetation 98 Layer
Mesquite/Catclaw	Clark County Mesquite/Catclaw Layer
Pinyon-juniper	Clark County Vegetation 98 Layer
Lowland riparian	Clark County Vegetation 98 Layer
Mountain shrub	Clark County Vegetation 98 Layer
Pinyon	Clark County Vegetation 98 Layer
Salt desert scrub	Clark County Vegetation 98 Layer
N.A. Warm Desert Riparian Mesquite Bosque	Habitat type in Southwest Regional Gap Analysis
Sonora-Mojave Mixed Salt Desert Scrub	Habitat type in Southwest Regional Gap Analysis
Invasive Southwest Riparian Woodland and Shrubland	Habitat type in Southwest Regional Gap Analysis
N.A. Warm Desert Riparian Woodland	Habitat type in Southwest Regional Gap Analysis

Table 2. Variables measured and the ultimate status of these variables after data reduction prior to fitting the ecological models for each thrasher.

Variable	Le Conte's thrasher	Crissal thrasher
Slope	Final model	Final model
PC1	Final model	Final model
PC2	Final model	Final model
Distance to Dominant Road 300 m	Final model	Final model*
Distance to Wash 300 m	Final model	Final model*
Wash size 300m	Final model*	Final model
Distance to Dominant Road 100m	Dropped (data similar to 300m scale)	Dropped (data similar to 300m scale)
Distance to wash 100m	Dropped (data similar to 300m scale)	Dropped (data similar to 300m scale)
Wash size 100m	Final model	Final model
Dominant Road Class 300m	Final model	Final model
Dominant Road Class 100 m	Final model	Final model*
Number Roads 300m	Final model	Final model
Number Roads 100m	Final model	Final model
Presence/Absence Wash 100m	Dropped (data similar to 300m scale)	Final model
Presence/Absence Wash 300m	Final model	Dropped (only observation)
Plant Assemblages	Final model	Final model
– Creosote-bursage	Final model	Dropped in pre-analysis (species not observations in type)
– Joshua tree dominated woodland	Final model	Final model

Table 2 Continued:

Variable		Le Conte's thrasher	Crissal Thrasher
–	Juniper	Dropped in pre-analysis (species not observed in type)	Final Model
–	Creosote-sparse Joshua tree	Final Model	Dropped in pre-analysis (species not observed in type)
–	Pinyon-juniper	Dropped in pre-analysis (no thrasher observed in type)	Final Model
–	Mesquite series	Lumped with Riparian Habitat because of low sample size (similar numbers of thrashers observed in both types)	Lumped with Riparian Habitat because of low sample size (similar numbers of thrashers observed in both types)
–	Riparian	Lumped with Riparian Habitat because of low sample size (similar numbers of thrashers observed in both types)	Lumped with Riparian Habitat because of low sample size (similar numbers of thrashers observed in both types)
–	Mojave Mixed Scrub	Final Model	Final Model
–	Saltbush series	Final Model	Dropped in pre-analysis (species not observed in type)
–	Shadscale series	Final Model	Dropped in pre-analysis (species not observed in type)
–	Teddy-bear Cholla	Low Sample Sizes Lumped into Other category	Low Sample Sizes Lumped into Other category
–	Wash Series	Final Model	Final Model

Table 2 continued

Variable	Le Conte's thrasher	Crissal thrasher
Landforms	Final model	Final model*
– Mountains	Dropped in pre-analysis (species not observed in type)	Final model*
– Drainageways	Final model	Final model*
– Ballenas	Final model*	Final model*
– Hills	Final model*	Final model*
Texture	Final model*	Final model*
– Fine	Final model*	Final model*
– Silty	Final model*	Final model*
– Gravelly	Final model*	Final model*
– Cobbly	Final model*	Final model*
– Stony	Final model*	Final model*
– Sand	Final model*	Final model*
– Loam	Final model *	Final model*
– Clay	Dropped because of low sample size (only 4 observations)	Dropped because of low sample size (only 4 observations, but 3 had Crissal thrashers)

*These variables were included in the final analysis, but never appeared in the set of best-fit models.

Table 3. Principal components (PC) eigenvector loading for the bioclimatic variables. The eigenvalues associated with PC1 and PC2 are 14.72 and 5.07, respectively.

Variable	PC1	PC2
Elevation	-0.258	0.026
BIO6 = Min Temperature of Coldest Month	0.213	0.251
BIO11 = Mean Temperature of Coldest Quarter	0.247	0.131
BIO14 = Precipitation of Driest Month	-0.244	-0.102
BIO17 = Precipitation of Driest Quarter	-0.249	-0.066
BIO1 = Annual Mean Temperature	0.256	0.07
BIO2 = Mean Diurnal Range (Mean of monthly (max temp – min temp))	-0.021	-0.427
BIO3 = Isothermality (P2/P7) (* 100)	-0.152	-0.295
BIO4 = Temperature Seasonality (standard deviation *100)	0.222	-0.151
BIO5 = Max Temperature of Warmest Month	0.256	-0.056
BIO7 = Temperature Annual Range (P5-P6)	0.114	-0.389
BIO8 = Mean Temperature of Wettest Quarter	0.236	0.095
BIO9 = Mean Temperature of Driest Quarter	0.258	0.037
BIO10 = Mean Temperature of Warmest Quarter	0.258	0.03
BIO12 = Annual Precipitation	-0.241	0.123
BIO13 = Precipitation of Wettest Month	-0.224	0.21
BIO15 = Precipitation Seasonality (Coefficient of Variation)	0.03	0.401
BIO16 = Precipitation of Wettest Quarter	-0.233	0.14
BIO18 = Precipitation of Warmest Quarter	-0.241	0.156
BIO19 = Precipitation of Coldest Quarter	-0.236	0.142
Longitude	0.145	0.101
Latitude	-0.036	-0.383
Proportion of variance explained	66.90%	23.00%

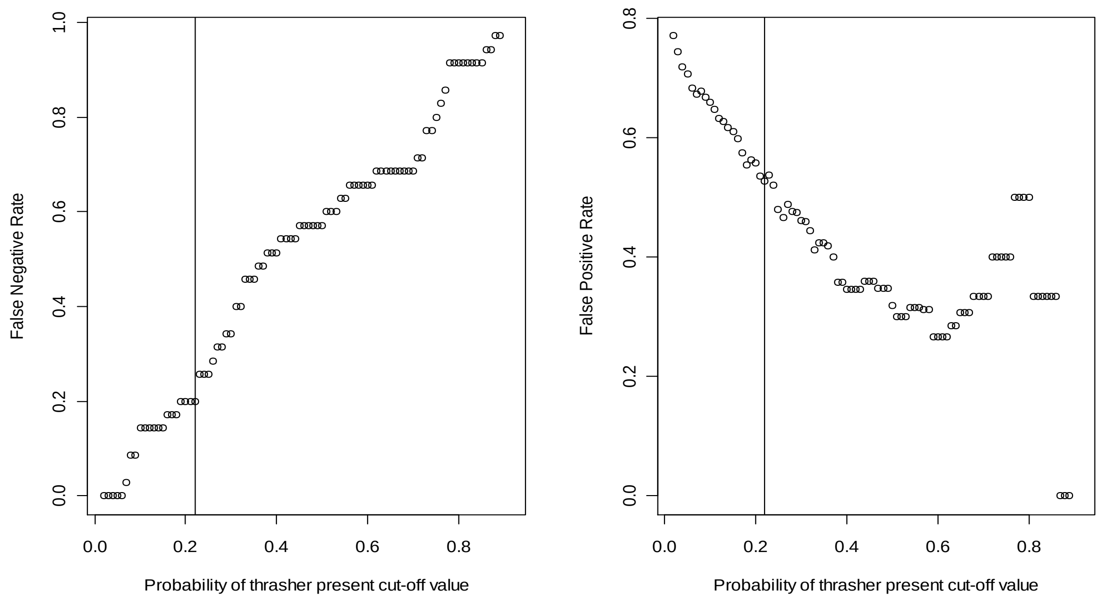

Figure 2. Plots of the probability of observing a Crissal thrasher compared to the FNR and FPR based on the ecological model. The vertical line shows the threshold cut-off value selected (0.22). This cut-off value yielded a CCR of 83.3%, an FNR of 25.7% and an FPR of 53.6%.

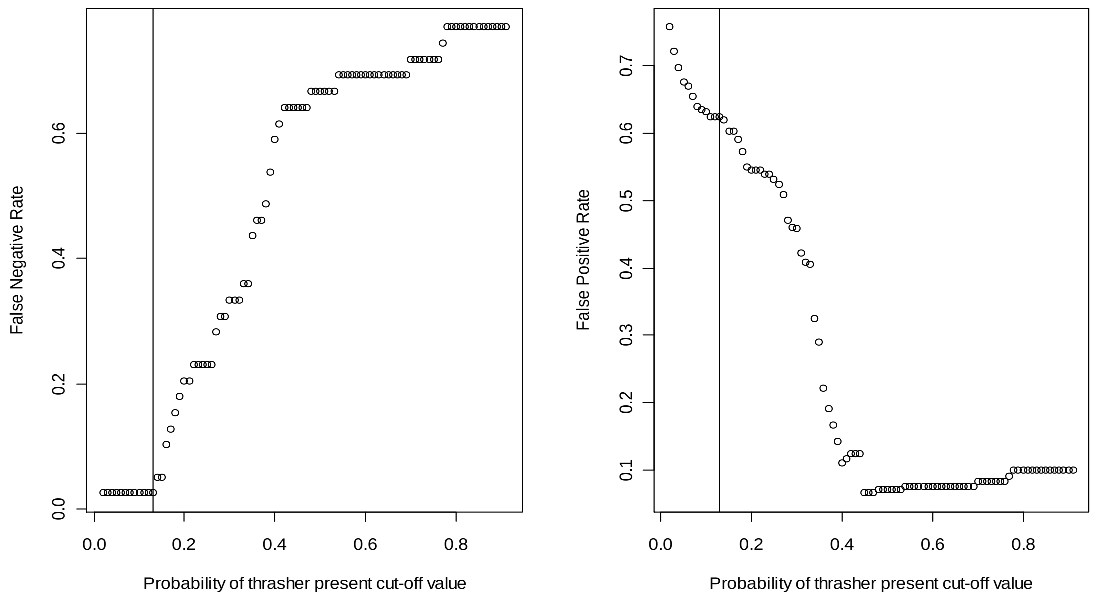

Figure 3. Plots of the probability of observing a Le Conte's thrasher compared to the FNR and FPR for the ecological model. The vertical line shows the threshold cut-off value selected (0.13). This cut-off value yielded a CCR of 70%, FNR of 2.6%, FPR 62.3%.

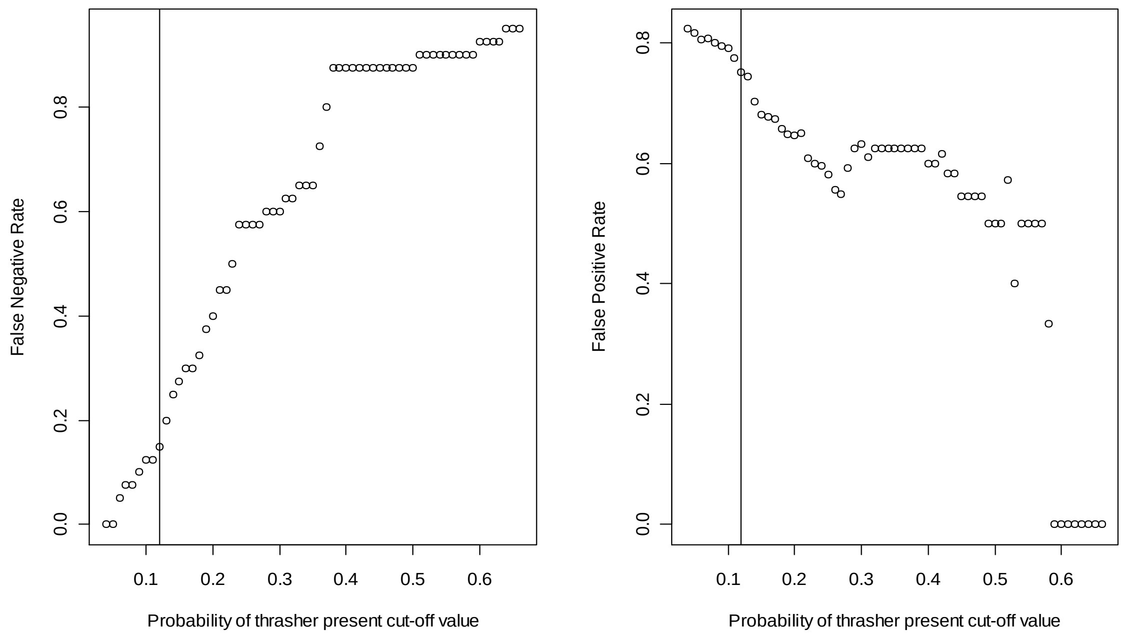

Figure 4. Plots of the probability of observing a Crissal thrasher compared to FNR and FPR for the landscape model. The vertical line shows the threshold cut-off value selected (0.12). This cut-off value yeilded CCR of 52.4%, FNR of 12.5% and an FPR of 75.2%.

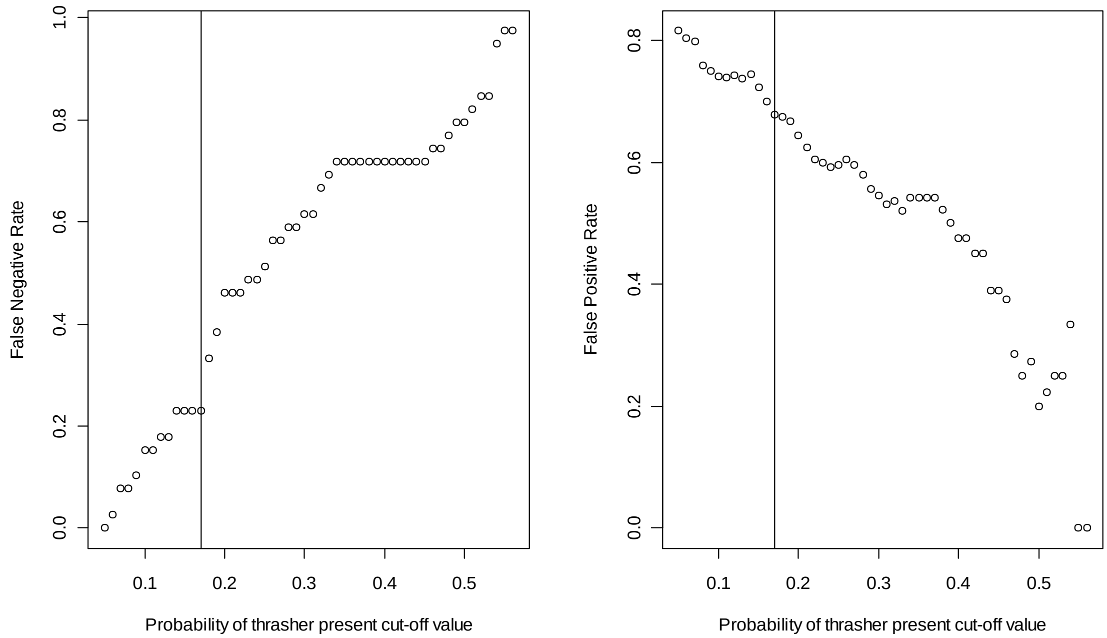

Figure 5. Plots of the probability of predicting a Le Conte's thrasher compared to FNR and FPR for the landscape model. The horizontal line shows the threshold cut-off value selected (0.17). This cut-off value yielded a CCR= 66.2%, FNR= 23.1%, and FPR = 67.7.

Table 4. Results of AICc-based model selection for the ecological model for Le Conte's thrasher. The table shows variables included in model (numbers), the calculated deviance, the corrected Akaike Information Criterion (AICc), the relative AICc between each model and the best model (top models with Δ_i), and the weight indicating the probability that the model in question is the best model for the data set (ωi).

	Deviance	AICc	Δi	ωi
5+6+7+9	129.89	157.72	0.00	0.0707
5+6+7+8+9	127.90	158.02	0.30	0.0608
4+5+6+7+9	128.01	158.13	0.41	0.0577
1+5+6+7+9	128.33	158.45	0.73	0.0491
5+6+7	132.91	158.47	0.75	0.0486
5+6+7+8	130.71	158.54	0.82	0.0469
2+5+6+7+9	128.71	158.83	1.11	0.0406
3+5+6+9	131.10	158.93	1.21	0.0386
5+6+7+9+11	128.84	158.96	1.24	0.0380
4+5+6+7	131.14	158.97	1.25	0.0379
3+4+5+6+9	128.98	159.10	1.38	0.0354
1+5+6+7	131.35	159.18	1.46	0.0341
5+6+7+9+10	129.08	159.21	1.48	0.0337
4+5+6+7+8+9	126.78	159.22	1.50	0.0334
2+5+6+7+8+9	126.80	159.24	1.52	0.0331
5+6+7+8+9+10	126.85	159.29	1.57	0.0323
5+6+7+8+9+11	126.92	159.36	1.64	0.0312
2+4+5+6+7+9	126.95	159.39	1.67	0.0307
5+6+7+9+12	129.32	159.44	1.72	0.0299
1+5+6+7+8+9	127.12	159.56	1.84	0.0282
3+5+6	134.00	159.56	1.84	0.0282
5+6+7+11	131.75	159.58	1.86	0.0279
5+6+7+8+10	129.50	159.62	1.90	0.0274
4+5+6+7+9+10	127.23	159.66	1.94	0.0268
5+6+7+8+9+12	127.26	159.70	1.98	0.0263
5+6+7+8+11	129.58	159.70	1.98	0.0262
4+5+6+7+9+11	127.28	159.71	1.99	0.0261

*Variables included in model: (1) Distance to dominant road 300 m, (2) Distance wash 300 m, (3) Dominant road class 100 m, (4) Dominant road class 300 m, (5) Landform description, (6) Plant assemblage, (7) Number roads 100 m, (8) Number of road 300 m, (9) Presence absence of wash 300 m, (10) Principal Component 1, (11) Principal Component 2, and (12) Slope.

Table 5. Results from model averaging for the ecological model involving the Le Conte's thrasher. Model-averaged coefficients, unconditional standard errors (SE), and lower and upper 95% confidence limits (CL) are reported.

Variable	Coefficient	SE	Lower 95% CL	Upper 95% CL
(Intercept)	-5.6782	2.1849	-9.9606	-1.3958
Distance to dominant road 300m	-0.0004	0.0009	-0.0021	0.0013
Distance to wash 300m	0.0003	0.0007	-0.0011	0.0018
Dominant road class 100m	-0.0237	0.0457	-0.1132	0.0657
Dominant road class 300m	0.0410	0.0753	-0.1066	0.1886
Landform: Drainage ways	-0.1977	0.8516	-1.8668	1.4713
Landform: Fan Remnants	-0.1746	0.7343	-1.6137	1.2646
Landform: Lake Plains	3.7450	1.2752	1.2456	6.2444
Plant series: Cholla	3.3712	1.3619	0.7019	6.0404
Plant series: Creosote-bursage	0.8000	1.4142	-1.9718	3.5719
Plant series: Joshua tree	2.3614	1.4365	-0.4540	5.1768
Plant series: Mojave Mixed Scrub	3.4252	1.3655	0.7489	6.1015
Plant series: Saltbush	6.2705	1.7759	2.7898	9.7513
Plant series: Shadscale	0.2884	1.4827	-2.6176	3.1943
Plant series: Wash habitat	3.3462	1.3571	0.6864	6.0060
Number roads 100m	-1.0773	0.6071	-2.2671	0.1126
Number roads 300m	0.0973	0.1589	-0.2140	0.4087
Presence/Absence wash 300m	1.6614	1.6516	-1.5758	4.8985
Principal Component 1	-0.0147	0.0330	-0.0793	0.0499
Principal Component 2	0.0192	0.0419	-0.0629	0.1013
Slope	-0.0120	0.03076	-0.0723	0.0483

Tables 6. Relative variable importance following model-averaging of the Le Conte's thrasher ecological models.

Variable	Relative Importance
Landform	1
Plant Assemblage	1
Number of Roads 100 m	0.8978
Presence/Absence of Wash 300 m	0.7228
Number of Roads 300 m	0.3459
Dominant Road Classification 300 m	0.2481
Principal Component 2	0.1495
Principal Component 1	0.1202
Distance to Dominant Road 300 m	0.1114
Distance to Wash 300 m	0.1044
Dominant Road Class 100 m	0.1022
Slope	0.0562

Table 7. Results of AICc-based model selection for the Landscape model for Le Conte's thrasher. See Table 4 for details.

Model	Deviance	AICc	Delta	Weight
5+6+7+8	179.3964	190	0	0.19342
5+7+8	181.8026	190	0.309	0.16576
3+5+6+7+8	178.3141	191	1.036	0.11525
1+5+7+8	176.4836	191	1.344	0.09879
4+5+6+7+8	178.6245	191	1.346	0.09868
1+4+5+7+8	174.4674	191	1.487	0.09196
3+5+7+8	181.0496	191	1.653	0.08463
4+5+7+8	181.2106	192	1.814	0.07808
2+5+6+7+8	174.9176	192	1.937	0.07343

* Variables included in models: (1) Landforms, (2) Plant assemblages, (3) Principal Component 1, (4) Principal Component 2, (5) Saltbush Plant Series, (6) Slope, (7)Wash habitat, and (8) Presence/Absence of Wash within 300 m.

Table 8. Results from model averaging for the landscape model involving the Le Conte's thrasher. Details follow Table 5.

Variable	Coefficient	SE	Lower 95% CI	Upper 95% CI
(Intercept)	-1.2180	0.6501	-2.4957	0.0597
Landform: fan remnants	0.0900	0.1839	-0.2711	0.4511
Landform: lake plains	0.3439	0.6213	-0.8752	1.5630
Landform: lake plains & fan remnants	0.3235	0.5652	-0.7851	1.4322
Plant series: Black brush	-0.0108	0.0730	-0.1545	0.1329
Plant series Creosote	-0.0542	0.1220	-0.2937	0.1852
Plant series Mojave mixed Scrub	0.0563	0.1177	-0.1747	0.2872
Principal Component 1	-0.0142	0.0301	-0.0733	0.0449
Principal Component 2	0.0247	0.0487	-0.0709	0.1204
Plant series: Saltbush	1.2256	0.5451	0.1519	2.2993
Slope	-0.1810	0.2409	-0.6541	0.2921
Plant series: Wash Habitat	1.5892	0.6584	0.2912	2.8873
Presence/Absence of wash 300 m	-0.9966	0.4485	-1.8807	-0.1124

Table 9. Relative variable importance following model-averaging of the Le Conte's thrasher landscape models.

Variable	Relative importance
Saltbush series	1
Wash Habitat	1
Wash within 300 m	1
Slope	0.4808
Principal Component 1	0.2687
Principal Component 2	0.1999
Landform	0.1908
Plant Assemblages	0.0734

Table 10. FNR, FPR, and CCR of the ecological and landscape models for the Le Conte's thrasher when compared to null-model distribution.

	Value Estimated from data	Mean value from permuted data	P-value
False Negative Rate (FNR)			
Ecological model	0.0256	0.1612	0.002
Landscape model	0.2308	0.2998	0.082
False Positive Rate (FPR)			
Ecological model	0.6238	0.7362	0.001
Landscape model	0.6774	0.7405	0.018
Correct Classification Rate (CCR)			
Ecological model	0.6995	0.5376	0.001
Landscape model	0.662	0.576	0.027

Table 11. Results of AICc-based model selection for the ecological models of Crissal thrasher. See Table 4 for details.

Model	Deviance	AICc	Δi	ωi
1+6+7	130.60	147.24	0.00	0.0906
1+5+6+7	128.57	147.38	0.13	0.0848
1+2+5+6+7	126.45	147.44	0.20	0.0821
1+2+6+7	128.83	147.64	0.39	0.0745
1+3+6+7	129.40	148.21	0.96	0.0560
1+3+5+6+7	127.37	148.36	1.11	0.0519
1+6+7+8	129.97	148.77	1.53	0.0422
1+3+4+6+7	127.89	148.88	1.63	0.0401
1+5+6+7+8	127.89	148.88	1.63	0.0400
1+6+7+9	130.12	148.93	1.68	0.0391
1+2+6+7+9	127.97	148.95	1.71	0.0385
1+2+4+5+6+7	125.77	148.96	1.72	0.0384
1+2+4+6+7	128.03	149.02	1.77	0.0374
1+2+5+6+7+9	125.83	149.02	1.77	0.0373
1+6+7+10	130.22	149.02	1.78	0.0373
1+2+3+5+6+7	125.91	149.10	1.86	0.0358
1+2+6+7+10	128.12	149.11	1.86	0.0357
1+2+5+6+7+10	125.92	149.11	1.87	0.0356
1+2+3+4+6+7	125.94	149.13	1.89	0.0352
1+4+6+7	130.39	149.20	1.95	0.0341
1+2+3+6+7	128.25	149.24	1.99	0.0335

* Variables included in models: (1) Plant Assemblages, (2) Dominant road class 300 m, (3) Number of roads 100 m, (4) Number of roads 300 m, (5) Presence/absence of wash 100 m, (6) Principle component 1, (7) Principle component 2, (8) Slope, (9) Wash size 100 m, and (10) Wash size 300 m.

Table 12. Results from model averaging of the ecological models involving the Crissal thrasher. Details follow Table 6.

Variable	Coefficient	SE	Lower 95% CL	Upper 95% CL
(Intercept)	-4.8416	1.1903	-7.1849	-2.4982
Black brush series	0.7464	1.1293	-1.4789	2.9718
Joshua tree	0.6210	0.9471	-1.2451	2.4872
Juniper series PJ	0.4374	1.2782	-2.0813	2.9562
Riparian-Mesquite	7.8187	1.4851	4.8924	10.745
Wash habitat	2.4933	0.8694	0.7802	4.2063
Dominant Road Class 300m	-0.0816	0.1136	-0.3048	0.1417
Number Roads 100m	-0.1149	0.2217	-0.5503	0.3205
Number Roads 300m	0.0371	0.0786	-0.1171	0.1914
Presence/Absence Wash 100m	0.5142	0.7984	-1.0538	2.0823
Principal Component 1	-0.2400	0.1017	-0.4404	-0.0395
Principal Component 2	0.6947	0.2052	0.2904	1.0991
slope	0.0031	0.0076	-0.0118	0.0181
wash_size_100m	0.0001	0.0003	-0.0005	0.0007
wash_size_300m	0.0001	0.0003	-0.0004	0.0007

Table 13. Relative variable importance following model averaging of the ecological models for the Crissal thrasher.

Variable	Relative importance
Plant assemblages	1
Principal Component 1	1
Principal Component 2	1
Dominant road class 300 m	0.3881
Presence/Absence Wash 100 m	0.3216
Number of roads 100 m	0.2216
Number of roads 300 m	0.2196
Slope	0.0953
Wash size 100 m	0.0929
Wash size 300 m	0.0875

Table 14. Results of AICc-based model selection for the Crissal thrasher landscape models. See Table 4 for details.

Model	Deviance	AICc	Delta	Weight
1+3+4	130.2408	146.88	0	0.54179
1+3+4+5	129.595	148.4	1.518	0.25357
1+2+3+4	130.0236	148.83	1.947	0.20465

* Variables includes: (1) Plant Assemblages, (2) distance to dominant road 300 m, (3) Principal Component 1, (4) Principal Component 2, and (5) Slope.

Table 15. Results from model averaging for the landscape models involving the Crissal thrasher. Details follow Table 6.

	Coefficient	SE	Lower 95% CL	Upper 95% CL
(Intercept)	-4.6329	0.9276	-6.4606	-2.8051
Plant series: Black brush	0.6467	1.1114	-1.5435	2.8369
Plant series: Joshua tree	0.5859	0.9538	-1.2935	2.4653
Plant series: Pinyon Juniper	0.3228	1.2688	-2.1774	2.8230
Plant series: Riparian-Mesquite	7.7981	1.4346	4.9712	10.6250
Plant series: Wash habitat	2.5407	0.8528	0.8603	4.2211
Distance to dominant Rd. 300 m	0.0002	0.0007	-0.0011	0.0016
Principal Component 1	-0.2347	0.0986	-0.4290	-0.0404
Principal Component 2	0.6821	0.2000	0.2880	1.0762
Slope	0.0094	0.0205	-0.0309	0.0498

Tables 16. Relative variable importance following model averaging of the landscape models for the Crissal thrasher.

Variable	Relative importance
Plant assemblage	1
Principal Component 1	1
Principal Component 2	1
Slope	0.2536
Distance to dominant road 300 m	0.2046

Table 17. Comparisons of ecological and landscape models performance for the Crissal thrasher to null-model distributions.

	Value Estimated from data	Mean value from permuted data	P-value
False Negative Rate (FNR)			
Ecological model	0.2571	0.6279	0.001
Landscape model	0.1250	0.1210	0.548
False Positive Rate (FPR)			
Ecological model	0.5357	0.7050	0.002
Landscape model	0.7518	0.7948	0.010
Correct Classification Rate (CCR)			
Ecological model	0.8326	0.7735	0.002
Landscape model	0.5236	0.3821	0.016

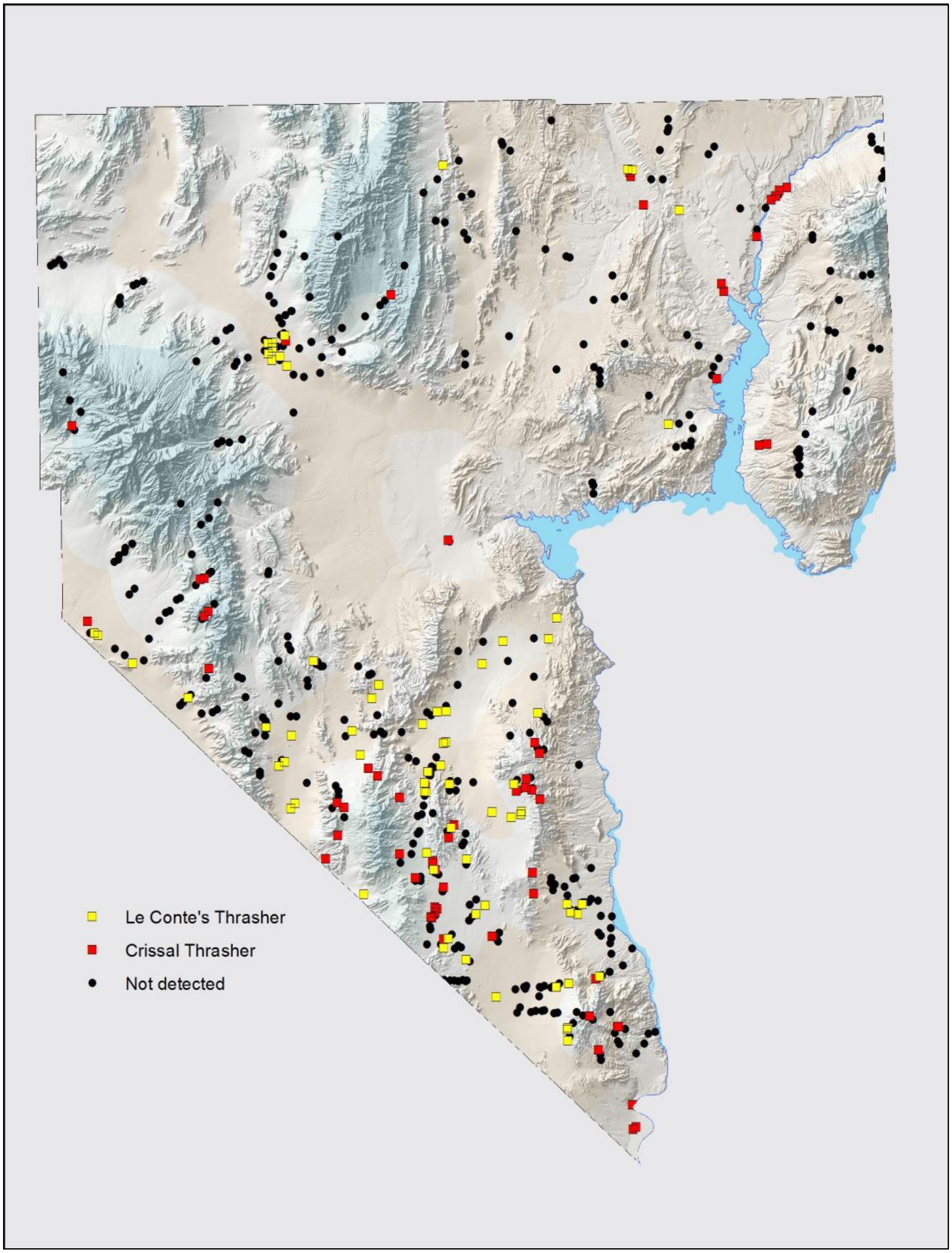

Figure 6. Map of 432 sites surveyed across Clark County, Nevada from 2005-2007. Le Conte's thrashers (shown in yellow) were detected at 45 random survey locations and at 24 non-random incidental sites The Crissal thrasher (shown in red) were detected at 41 random survey location, and 28 non-random incidental locations.

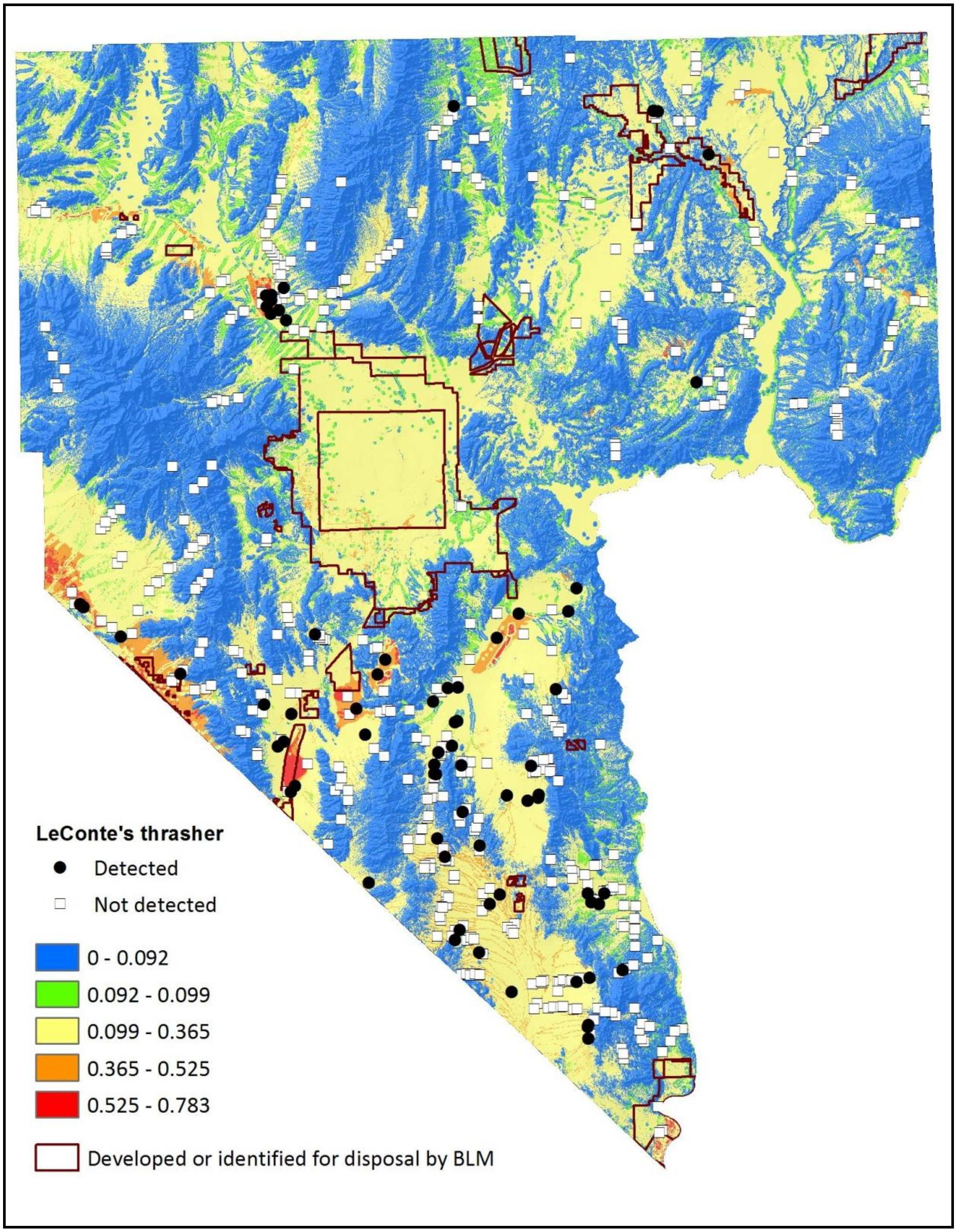

Figure 7. Map of suitable habitat for the Le Conte's thrasher in Clark County, Nevada as predicted from the landscape model (model coefficients are shown in Table 8).

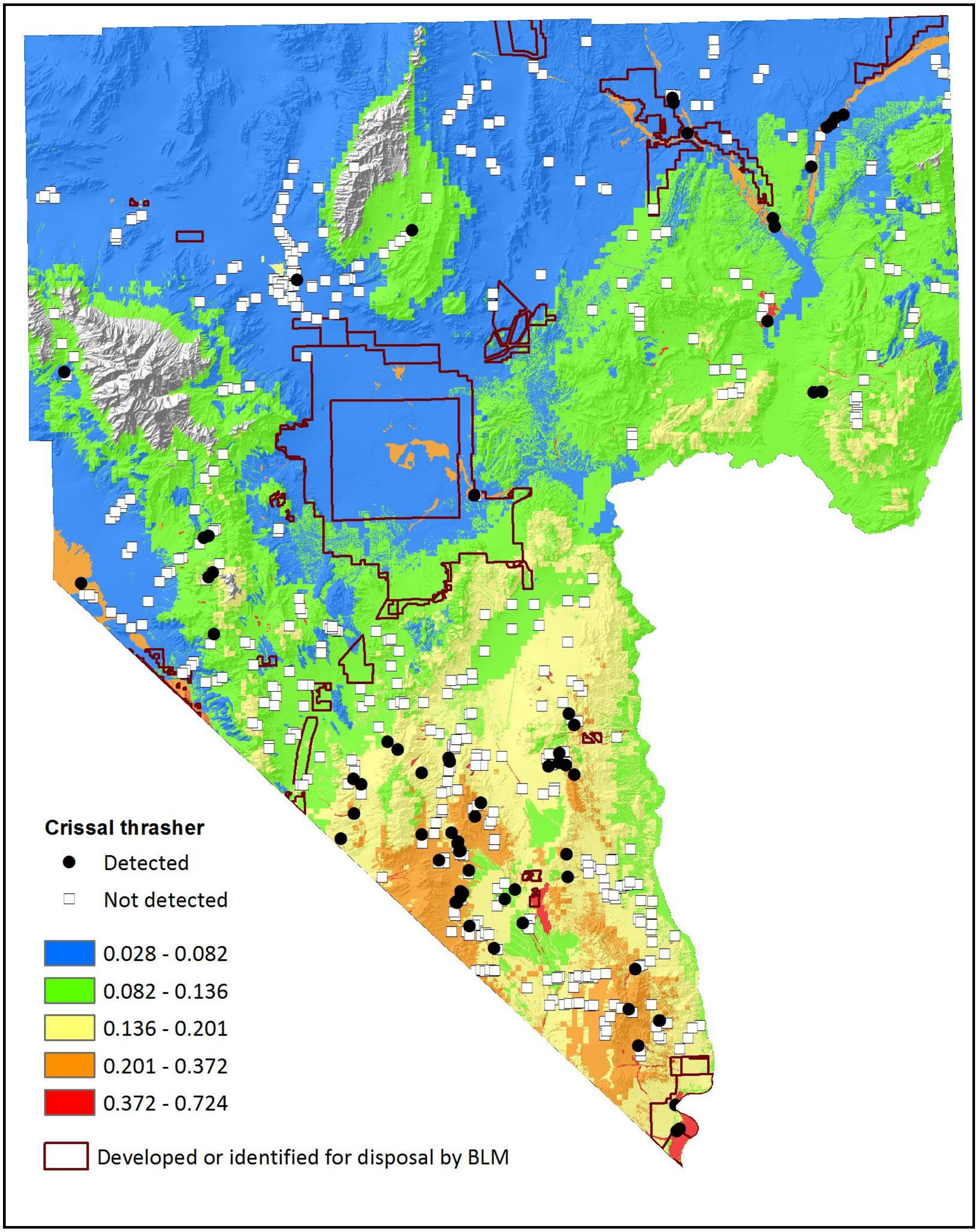

Figure 8. Map of suitable habitat for the Crissal thrasher in Clark County, Nevada as predicted from the landscape model (model coefficients are shown in Table 15). Elevations over (2158 m) were not sampled and are shown as gray on this map.

APPENDIX I

DOMINANT PLANT SPECIES MEASURED IN THE FIELD AT SURVEY LOCATIONS

1. Four-wing Saltbush (*Atriplex canescens*)
2. Rice Grass (*Achnatherum*)
3. Agave sp.
4. Bursage (*Ambrosia dumosa*)
5. Manzanita (*Arctostaphylos pungens*)
6. Sage (*Artemisia sp*.)
7. Shadscale (*Atriplex confertifolia*)
8. Catclaw (*Acacia greggii*)
9. Desert Holly (*Atriplex hymenelytra*)
10 Quailbush (*Atriplex lentiformis*)
11. Cattle Saltbush (*Atriplex polycarpa*)
12. Saltbush sp. (*Atriplex sp*.)
13. Baccharis sp.
14. Sweetbush (*Bebbia juncea*)
15. Beavertail Cactus (*Opuntia basilaris*)
16. Sedge (*Carex sp*.)
17. Chamaesyce sp.
18. Desert Willow (*Chilopsis linearis*)
19. Rabbit Brush (*Chrysothamnus nauseosus*)
20. Thistle (*Cirsium sp*.)
21. Black Brush (*Coleogyne ramosissima*)
22. Brittlebush (*Encelia farinose*)
23. Cottontop (*Echinocactus polycephalus*)
24. Ephedra sp.
25. Rock Nettle (*Eucnide urens*)
26. Apache Plume (*Fallugia paradox*)
27. Ash (*Fraxinus sp*.)
28. Silk Tassel (*Garrya flavescens*)
29. Spiny Hopsage (*Grayia spinosa*)
30. Gutierrezia sp.
31. Burrobush (*Hymenoclea salsola*)
32. Juniper (*Juniperus sp.*)
33. Littleaf Ratany (*Krameria erecta*)
34. Banana Yucca (*Yucca baccata*)
35. Creosote (*Larrea tridentate*)
36. Lycium (*Lycium sp*.)
37. African Mustard (*Malcolmia species*)
38. Parry Dalea (*Marina parryi*)
39. Spiney Monodora (*Menodora spinescens*)
40. Utah Mortonia (*Mortonia utahensis*)
41. Buckhorn Cholla (*Opuntia acanthocarpa*)
42. Bunch Grass
43. Teddy-bear Cholla (*Opuntia bigelovii*)
44 Silver Cholla.(*Opuntia echinocarpa*)
45. Pencil Cholla (*Opuntia ramosissima*)
46. Cholla sp. (*Opuntia sp.*)
47. Pygmy Cedar (*Peucephyllum schottii*)
48. Salt Cedar (*Tamarix ramosissima*)
49. Pine (*Pinus sp*.)
50. Arrowweed (*Pluchea sericea*)
51. Cottonwood (*Populus fremontii*)
52. Mesquite (*Prosopis sp*.)
53. Desert Almond (*Prunus fasciculate*)
54. Almond (*Prunus sp*.)
55. Indigo Bush (*Psorothamnus fremontii*)
56. Joshua Tree (*Yucca brevifolia*)
57. Stansbury Cliffrose (*Purshia stansburiana*)
58. Oak Tree (*Quercus sp*.)
59. Skunk Bush (*Rhus trilobata*)
60. Bladdersage (*Salazaria Mexicana*)
61. Willow (*Salix sp*.)
62. Russian Thistle (*Salsola tragus*)
63. Desert Sage (*Salvia dorrii*)
64. Senna sp."
65. Mojave Yucca (*Yucca schidigera*)

APPENDIX II

VARIABLES USED IN ECOLOGICAL MODELS

Group	Parameter Used	Descriptive statistic	Data Type/ Description	Source
Physical Landform Features	Elevation	Floating point grid	Raster GIS layer	United States Geological Survey
	Slope	Floating point grid	Raster GIS layer	Calculated from Digital Elevation Model
	Latitude	Floating point grid	Raster GIS layer	National Park Service Lake Mead GIS
	Longitude	Floating point grid	Raster GIS layer	Lake Mead GIS
	Landform – Ballenas – Fan Remnants – Flood Plains – Drainageways – Hills – Lake Plains – Mountains – Hills	Type	Raster GIS layer	Soils Survey of Clark County Clark County (Natural Resource Conservation Service, U.S. Department of Agriculture 2007)
	– Wash	Presence/Absence	Images & Hydrolines	Google Earth (Digital Globe, 2007)

Appendix II Continued:

Group	Parameter Used	Descriptive statistic	Data Type/ Description	Source
Physical Landform Features	Distance to largest wash	Minimum distance from survey point	Images	Google Earth (Digital Globe, 2007)
	Size of largest wash	Average taken from 3 points along wash	Images	
Bioclimatic Influence	BIO1 = Annual Mean Temperature BIO2 = Mean Diurnal Range Temperature BIO3 = Isothermality (P2/P7) (* 100) BIO4 = Temperature Seasonality (standard deviation *100) BIO5 = Max Temperature of Warmest Month BIO6 = Min Temperature of Coldest Month BIO7 = Temperature Annual Range (P5-P6) BIO8 = Mean Temperature of Wettest Quarter BIO9 = Mean Temperature of Driest Quarter BIO10 = Mean Temperature of Warmest Quarter BIO11 = Mean Temperature of Coldest Quarter BIO12 = Annual Precipitation BIO13 = Precipitation of Wettest Month BIO14 = Precipitation of Driest Month BIO15 = Precipitation Seasonality BIO16 = Precipitation of Wettest Quarter BIO17 = Precipitation of Driest Quarter	Floating point grid	Raster GIS layer	WorldClim data

Appendix II. Continued

Group	Parameter Used	Descriptive statistic	Data Type/ Description	Source
Bioclimatic Influence	BIO18 = Precipitation of Warmest Quarter BIO19 = Precipitation of Coldest Quarter	Floating point grid	Raster GIS layer	WorldClim data
Substrate	Texture – Sand – Clay – Loam – Fine – Silty – Gravelly – Cobbly – Stoney	Type	Vector/ inferred from GIS layers and overlays	Lake Mead National Park Service GIS; Soils Survey of Clark County Clark County (Natural Resource Conservation Service, U.S. Department of Agriculture 2007)
Plant Assemblages	Black Brush Cholla Creosote-Bursage Joshua tree Juniper Creosote/sparse Johsua tree Riparian Mesquite Series Mojave Mixed Scrub Pinyon-Juniper	Dominant plant species	Data collected in field	Field Crew

Appendix II Continued

Group	Parameter Used	Descriptive statistic	Data Type/ Description	Source
Plant Assemblage	Saltbush series (*Polycarpa* & *Atriplex canescens* dominated) Shadscale Series Teddy-Bear Cholla series Wash series	Dominant plant species	Dominant plant species	Field Crew
Human Influence	Classification of nearest dominant road (within each buffer 100 m & 300 m)	Presence/Absence	Images/Tiger lines	Google Earth (Digital Globe, 2007)
	Number of roads (within each buffer 100 m & 300 m)	Number	Images	Google Earth (Digital Globe, 2007)
	Classification of nearest dominant road (within each buffer 100 m & 300 m)	1. Highway 2. Secondary road 3. Major unpaved road 4. Unpaved graded (maintained) road 5. 4x4 road 6. track or path associated with ATVs/dirt bikes	Images	Google Earth (Digital Globe, 2007)

APPENDIX III

VARIABLES USED IN LANDSCAPE MODELS

Group	Parameter Used	Descriptive statistic	Source
Physical Landform Features	Elevation	Floating point grid	United States Geological Survey
	Slope	Floating point grid	Calculated from Digital Elevation Model
	Latitude	Floating point grid	Lake Mead GIS
	Longitude	Floating point grid	Lake Mead GIS
	Landform -Fan Remnants -Lake Plains -Mountains -Drainageways	Type	Southwest ReGAP (Utah State University)
	Wash	Presence/Absence 300 m	LANDFIRE (www.landfire.gov 2006)
Bioclimatic Influence	BIO1 = Annual Mean Temperature BIO2 = Mean Diurnal Range BIO3 = Isothermality (P2/P7) (* 100) BIO4 = Temperature Seasonality BIO5 = Max Temperature of Warmest Month BIO6 = Min Temperature of Coldest Month	Floating point grid	WorldClim data

Appendix III Continued:

Group	Parameter Used	Descriptive statistic	Source
Bioclimatic Influence	BIO7 = Temperature Annual Range (P5-P6) BIO8 = Mean Temperature of Wettest Quarter BIO9 = Mean Temperature of Driest Quarter BIO10 = Mean Temperature of Warmest Quarter BIO11 = Mean Temperature of Coldest Quarter BIO12 = Annual Precipitation BIO13 = Precipitation of Wettest Month BIO14 = Precipitation of Driest Month BIO15 = Precipitation Seasonality BIO16 = Precipitation of Wettest Quarter BIO17 = Precipitation of Driest Quarter BIO18 = Precipitation of Warmest Quarter BIO19 = Precipitation of Coldest Quarter	Floating point grid	WorldClim data
Plant Assemblages	Black Brush Creosote-Bursage Joshua Tree Mojave Mixed Scrub Pinyon Juniper Riparian-Mesquite Series Saltbush Series (*A. polycarpa & A. canescens* dominated)	Dominant plant species	LANDFIRE (www.landfire.gov 2006) Soils Survey of Clark County Clark County (Natural Resource Conservation Service, U.S. Department of Agriculture 2007) Clark County Vegetation 98 layer (Desert Conservation Program) Mesquite-Catclaw layer (Bureau of Land Management 2005)

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