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IDENTIFYING POTENTIAL CURRENT DISTRIBUTION FOR BENDIRE'S THRASHER *(Toxostoma bendirei)*

Final Report

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Project Overview

The main goal of this project was to produce a robust, defensible, and predictive model that illustrates the potential current distribution of Bendire's Thrasher *(Toxostoma bendirei)* and potential future range shift. Due to the important relationship with the Curve-billed Thrasher *(Toxostoma curvirostre)*, the current distribution for this species was also modeled. The resulting datasets provide insight into the current range of each species, potential current habitat quality, and the relationship between the two species on a landscape scale. Each model was projected onto future climate change data identifying potential range shifts.

According to Breeding Bird Survey (BBS) data and Appendix I of the New Mexico Comprehensive Wildlife Conservation Strategy (CWCS), the range of Bendire's Thrasher has been declining rapidly in recent years. Wayne Thogmartin (USGS) has calculated individual species extinction rates based on BBS data. His results show that in New Mexico Bendire's Thrasher will no longer be identified via BBS by 2025-2030 (Krueper 2013). Furthermore it has been estimated that New Mexico holds 40.7% of the global population of the species, and the rate of decline in New Mexico is higher than any other state (Sauer 2011).

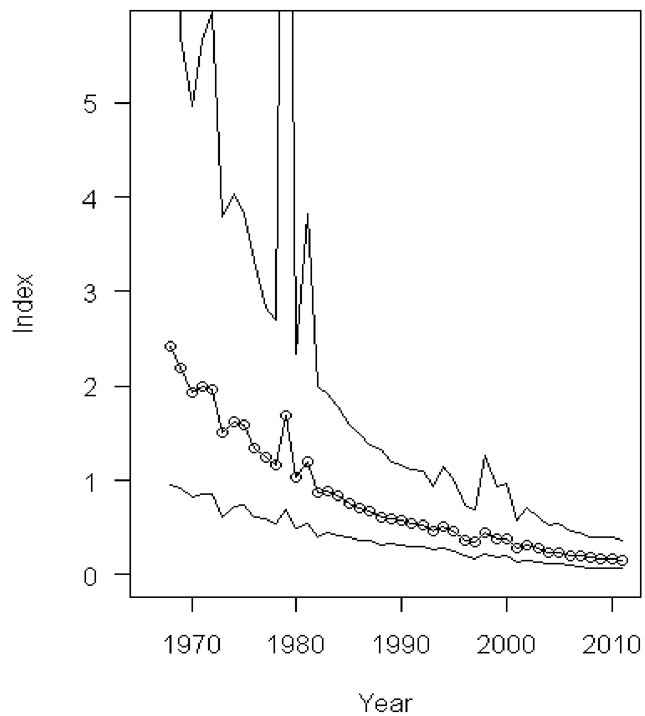

Figure 1. New Mexico BBS Trend for Bendire's Thrasher (Sauer 2011)

Bendire’s and Curve-billed Thrasher Occurrence Data

Occurrence data was used to drive the inductive models for each species, and to evaluate model outputs from each. A search was conducted to obtain all known spatial data occurrence points for both Bendire's and Curve-billed Thrasher since the year 2000. Numerous sources were investigated including: Matt Baumann (NMDGF), the New Mexico Ornithological Society database, New Mexico Natural Heritage occurrence data, Breeding Bird Survey (BBS), and eBird.

New Mexico Natural Heritage does not track either species. The New Mexico Ornithological Society database records were too spatially coarse to be useful for model training, and contained overlap with the BBS data. In many cases they just listed the county of occurrence.

The two sources used were the Breeding Bird Survey (BBS) and eBird. Mining the eBird data was straightforward via the online resource: http://ebird.org/content/ebird/. In contrast, mapping the data from BBS was perhaps the most labor intensive piece of this project. BBS data are collected along 24.5 mile long routes which are divided into stops at each half mile. Routes are surveyed annually in June. At each stop birders take a 3 minute count of all birds observed in a ¼ mile radius. The observations are spatially organized in a database by route and stop IDs. New Mexico has 86 BBS Routes (Figure 2), of which 46 had occurrences of one or both species. Unfortunately the GIS data representing these routes and stops was either missing or incomplete. We did obtain GIS data for the routes. These were vetted with individual Route Observers. Some routes were found to be out of date or wrong and were corrected with the Observer feedback. There were also GIS data identifying the start and end of each route, however, the individual stops had never been mapped. To create the route stops, each of the 46 routes was segmented into 48 equal length segments with the ArcGIS *Construct points* tool. The vertices of those routes were then converted to points and attributed with route and route stop IDs. The occurrence data was joined to the stops.

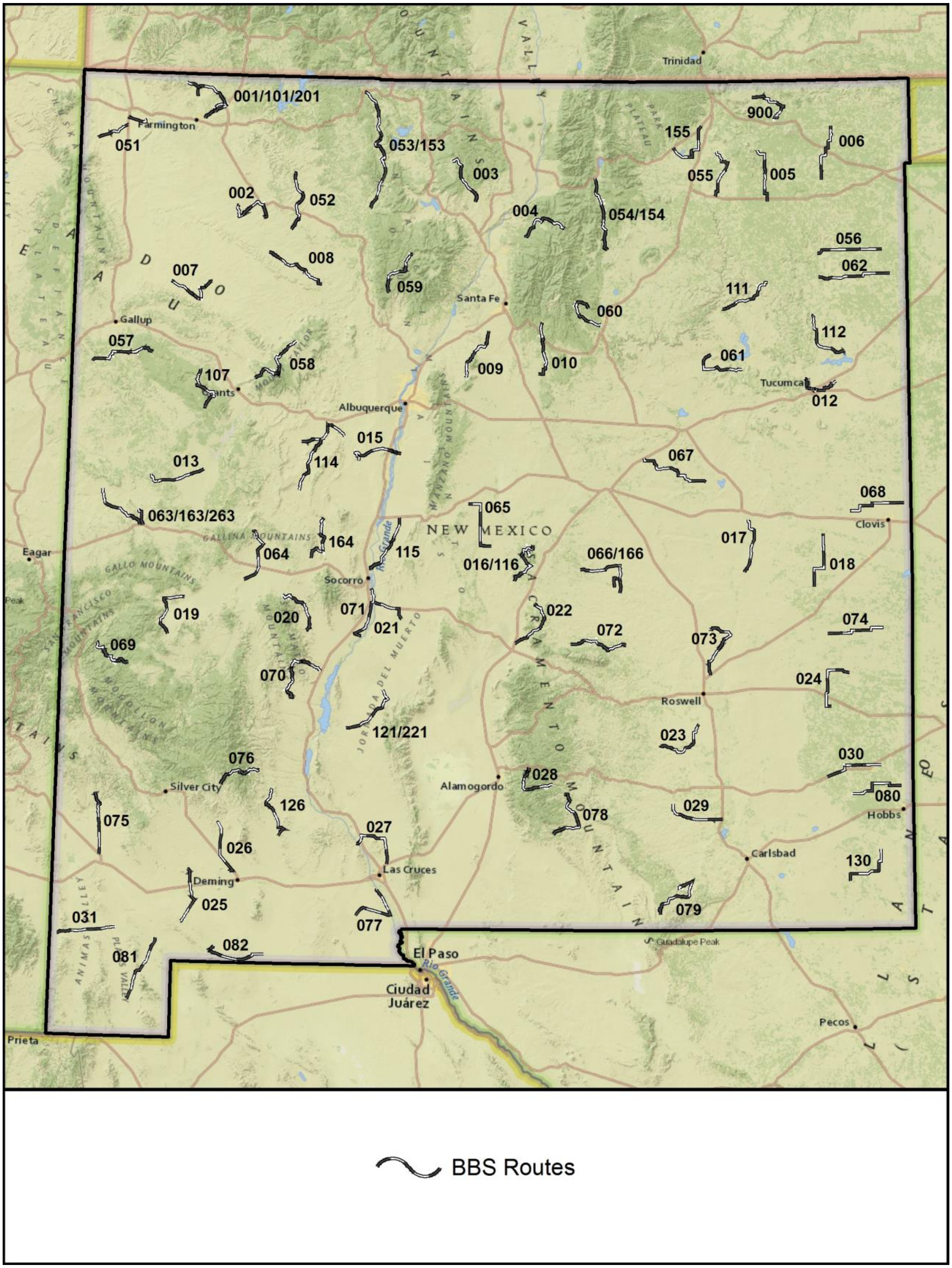

Figure 2. New Mexico Breeding Bird Survey Routes

There were observations that were repeated between the eBird and BBS data. Those redundant points were eliminated from the model training data for each species. With both sources we ended up with 292 model training points for Bendire's Thrasher (Figure 3) and 9,114 for Curve-billed Thrasher (Figure 4).

The occurrence data used was the best available. It should be noted however that there is bias in the BBS observations since they are necessarily located along roads. The consistent observation points from year to year along BBS routes, while being useful for monitoring population trends over time, limit the spatial variation of the collected data. There is a sampling bias in the eBird data with numerous sightings in the areas around Albuquerque and Santa Fe. This is likely due to the fact that this is the part of the state with the largest human population and there are many more birders looking in these areas.

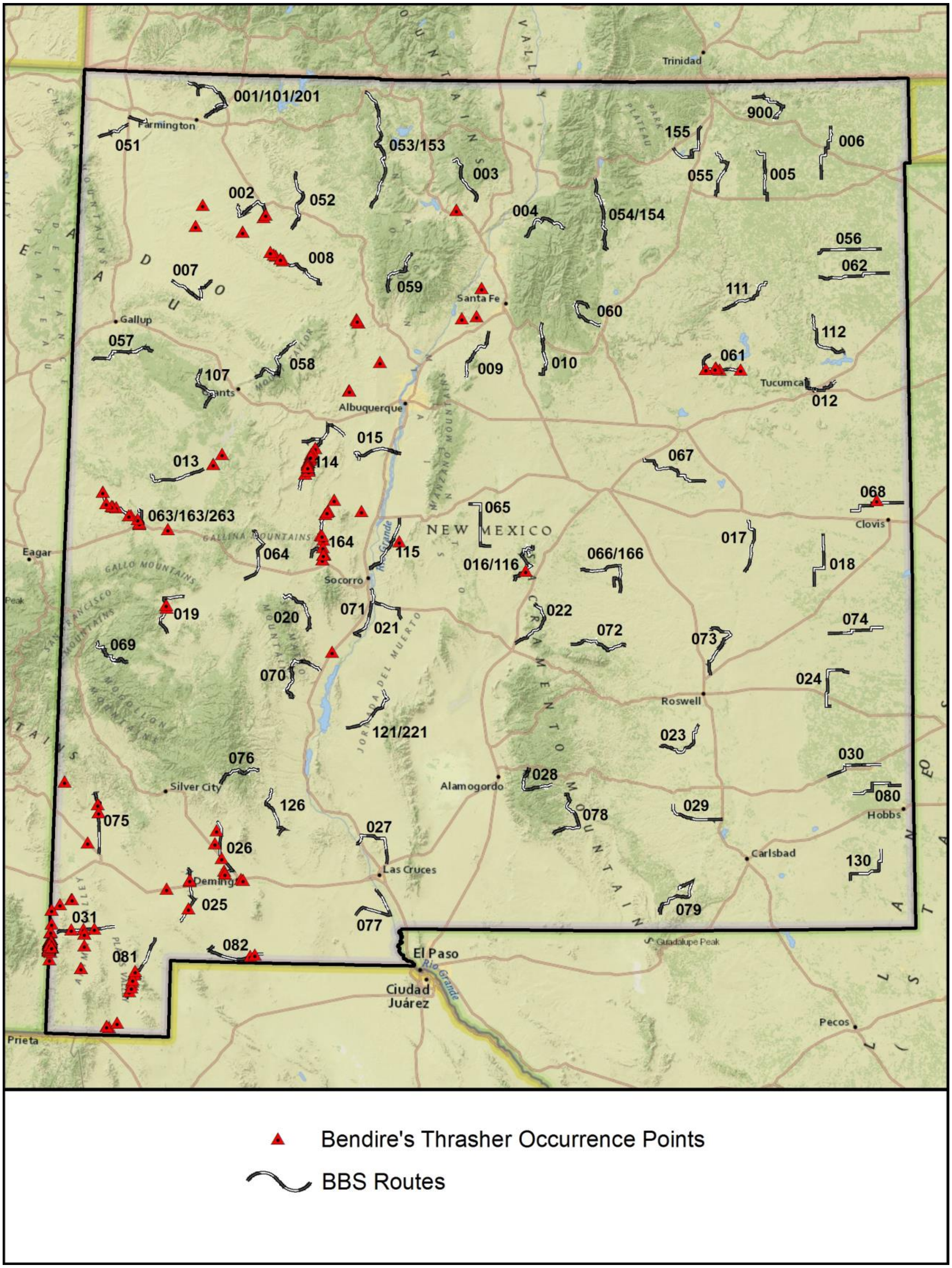

Figure 3. Bendire's Thrasher Model Training Points

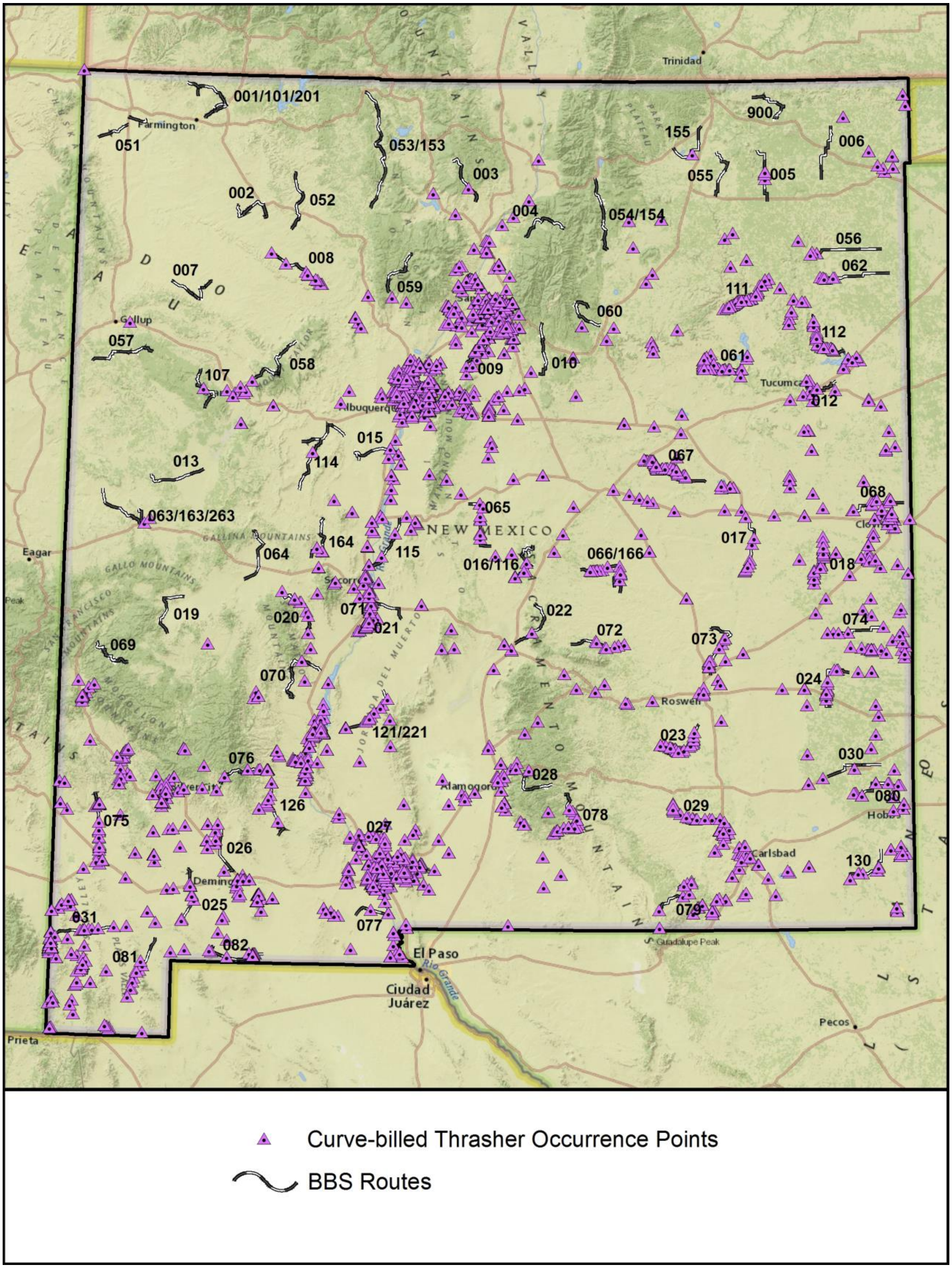

Figure 4. Curve-billed Thrasher Model Training Points

Environmental Data

The model incorporated environmental data. The inductive modeling approach involved taking measurements of environmental characteristics important to each species from locations where each species' presence has been recorded. It is assumed that vegetation type, stand height, canopy cover, elevation, and climactic data will be important to determining the habitat of each species.

Bendire's Thrasher prefer sparse desert shrubland, degraded grasslands with scattered shrubs and open woodlands with scattered shrubs. To represent this vegetation data were obtained from LandFire. Specifically, Bird's Eye View (BEV) obtained LandFire Improved data for Existing Vegetation Type. They also avoid riparian areas and areas with dense vegetation (NMPIF 2005). To represent that variable LandFire Improved Canopy Cover and Canopy Height were used. Each raster dataset was clipped to New Mexico. These data have a 30 meter resolution.

Climate data was obtained from the PRISM Climate Group at Oregon State University. Data representing U.S. average annual precipitation from (1971-2000), U.S. average annual minimum temperature (1971-2000) and U.S. average annual maximum temperature (1971-2000) were obtained. To represent spring temperatures the average minimum temperature for the months of March and April (1971 - 2000) were also acquired. These two datasets were averaged to generate an average minimum spring temperature raster. The climate data were converted to American Standard Code for Information Interchange (ASCII) grids. The temperatures were then converted from Celsius to Fahrenheit and the data clipped to New Mexico. These data have one 800 meter resolution.

Bendire's Thrasher has been documented to prefer elevations between less than 6,000 feet and inhabits valley flats, gently sloping ridges and nearly level plateaus or terraces (SWReGAP). Elevation data will be used to model these parameters. The New Mexico Geospatial Advisory Committee supported 10 meter digital elevation model was obtained from the Resource Geographic Information System. This is the most precise DEM available and has 10 meter resolution. Both a topographic position index (TPI) and a slope dataset were produced from the DEM. TPI is a measure of the difference in elevation between a pixel and the mean of its surrounding cells. It allows the model to distinguish between topographic landscape features such as slopes, canyon bottoms, ridges etc. These latter two datasets were used to represent the flatter terrain the Bendire's Thrasher prefers.

MaxEnt Modeling

This modeling was done with MaxEnt (v3.3.3a), a software product developed and maintained by Princeton University (Phillips 2004). It is based on the maximum entropy approach for species habitat modeling whereby it takes as input a set of layers or environmental variables (such as elevation, precipitation, etc.), as well as a set of georeferenced occurrence locations, and produces a model of the range of the given species (Phillips 2006). MaxEnt was chosen for several reasons. First it does not require species absence data. Second, it has been shown to perform well with species that have restricted ranges and when there is a limited number of model training points. The 2011 Share With Wildlife project to model suitable nesting habitat for

Common Black-hawk, demonstrated how well suited Maxent is to modeling distributions of poorly understood species (Menke, 2011). Third it allows for environmental data be both continuous and categorical.

MaxEnt requires both model training data be in a specific format. All the occurrence points were converted to the following format:

```
"SName","Long","Lat"
Toxostoma bendirei,-104.68195,34.93861
Toxostoma curvirostre,-104.404761,35.694374
```

Environmental data need to be in ascii grids with identical spatial resolution, pixel alignment and horizontal and vertical pixel dimensions. As stated earlier, the input environmental data had spatial resolutions ranging from 30 to 800 meters. Having the model developed at the resolution of the coarsest input was not practical for a species with such local scale habitat requirements. It also wasn't sound to resample the coarse data down to 30 meter resolution. Therefore an intermediate resolution of 200 meters was chosen. The Export to Circuitscape Tool for ArcGIS was used to process all raster inputs for use in MaxEnt (Jenness 2011). This involved increasing the resolution of the climate data from 800m to 200m, and decreasing the resolution of the elevation related and LandFire data from 30m to 200m. It is understood that this technique does not create better data. It simply puts all the data in same spatial resolution.

Several model runs were tried before the most robust model was developed. The runs employed different combinations of environmental layers and different MaxEnt settings. Initial runs for each species were done using the MaxEnt Random Test Percentage feature. This setting allows you to specify a percentage of the training points that can be set aside for evaluation. The percentage was set to 25%. Once it was determined that each model was predicting the presence of the evaluation points the final runs for each species were trained on all the occurrence points to generate the most robust model possible.

Model Performance

MaxEnt is very strong at providing metrics one can use to measure the predictive power of a given model. One way to measure how well the model is performing is to have one set of occurrence points for model training and one for model evaluation. MaxEnt can measure how well the model predicts the presence of the evaluation points. In Figure 5 we see the predicted omission rate which is a straight black line. The *omission on test samples* is a very good match to the *predicted omission* rate which is a good indication of a model with good predictive power. Figure 6 shows the same figure for Curve-billed Thrasher which shows an even stronger match between the *omission on test samples* and the *predicted omission* rate. This isn’t surprising since there were so many training points for Curve-billed thrasher.

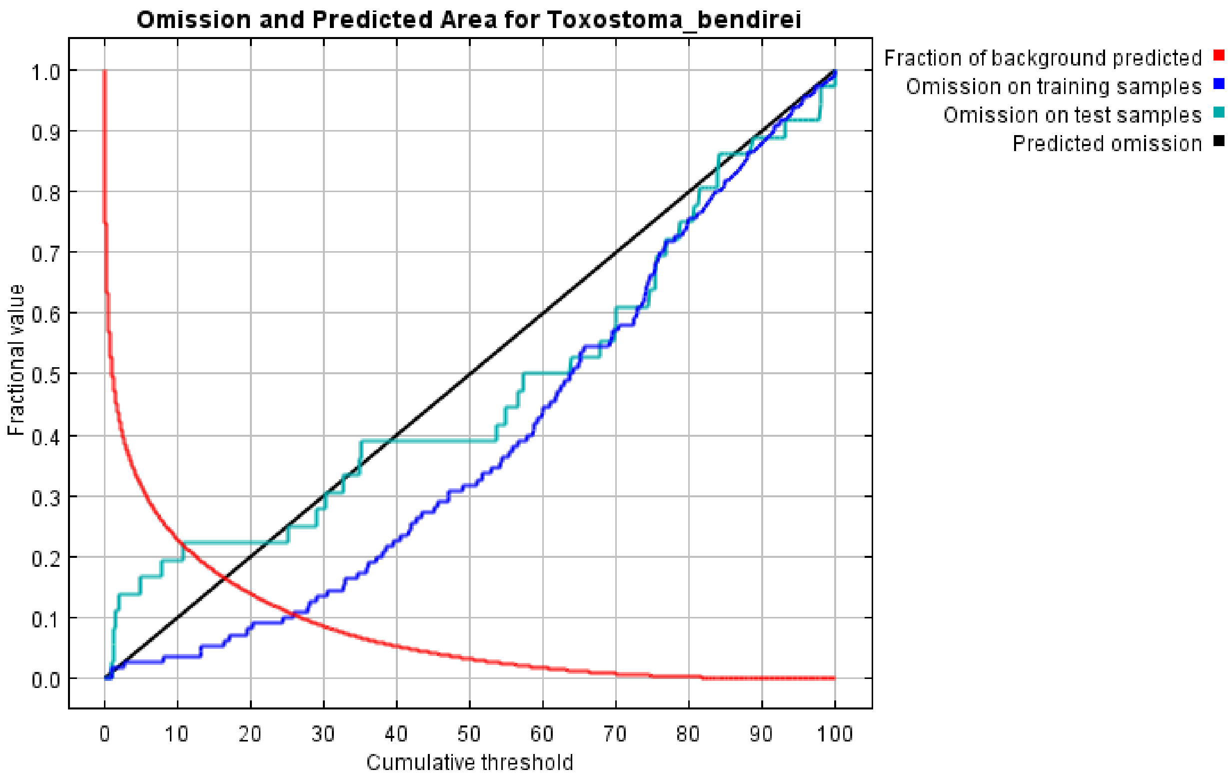

Figure 5. Omission vs. Predicted Area for Bendire's Thrasher

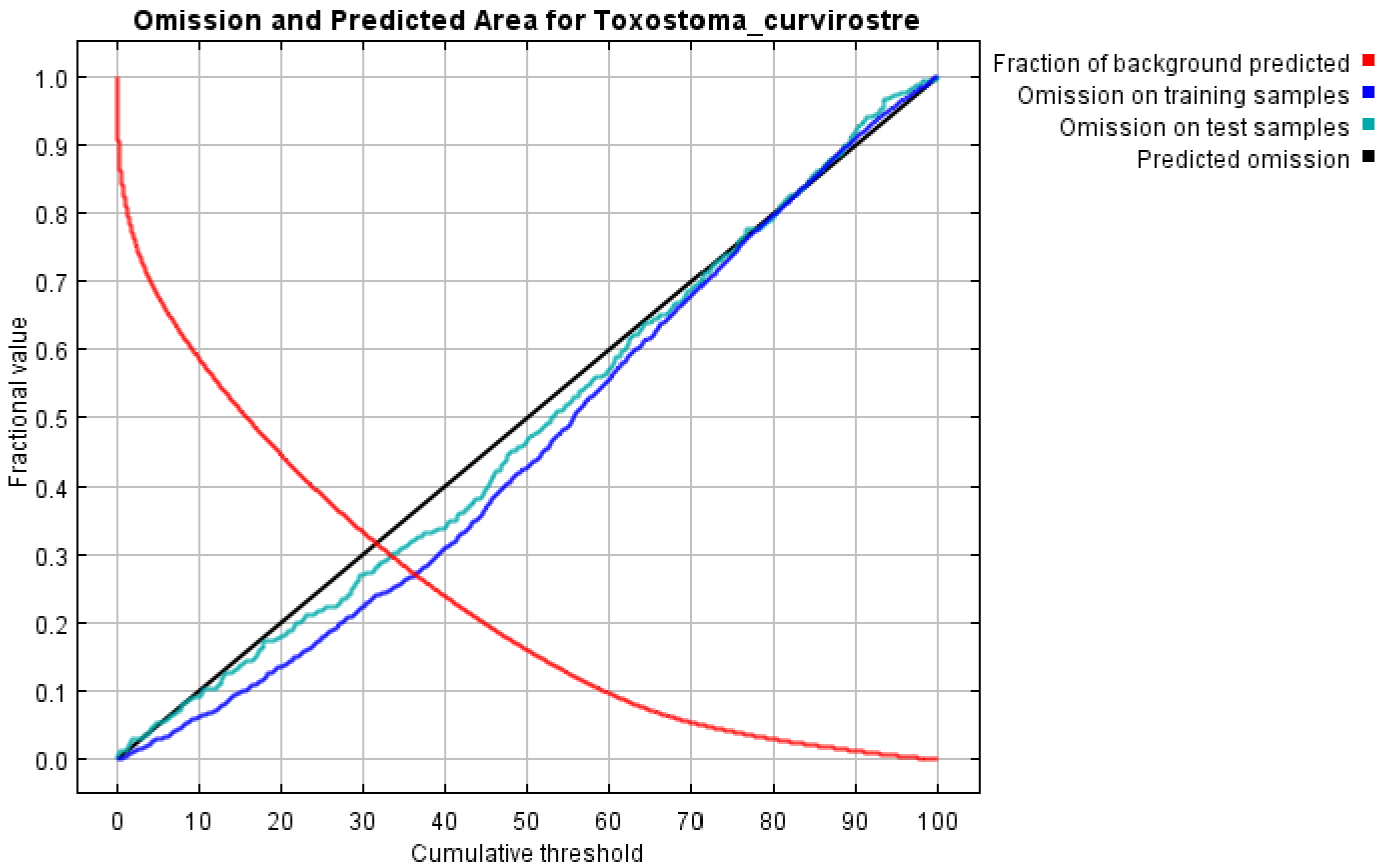

Figure 6. Omission vs. Predicted Area for Curve-billed Thrasher

Figure 7 shows the receiver operating curve for both training and evaluation points for Bendire's Thrasher. A random prediction is shown by the straight black line. A model should obviously predict quite a bit better than a random prediction. The red line shows the fit of the model to the training data. The blue line shows the fit of the model to the evaluation data, and is the real test of the models predictive power. MaxEnt reports the area under each curve (AUC) as a value between zero and one. A random prediction has an AUC of 0.5. It is normal for the training (red) line to show a higher AUC than the evaluation (blue) line. For the final model the AUC was 0.955 for the training data and 0.892 for the evaluation data. This shows that the model is performing very well against the training data and most importantly has strong predictive power against the 25% of the occurrence points held out for evaluation.

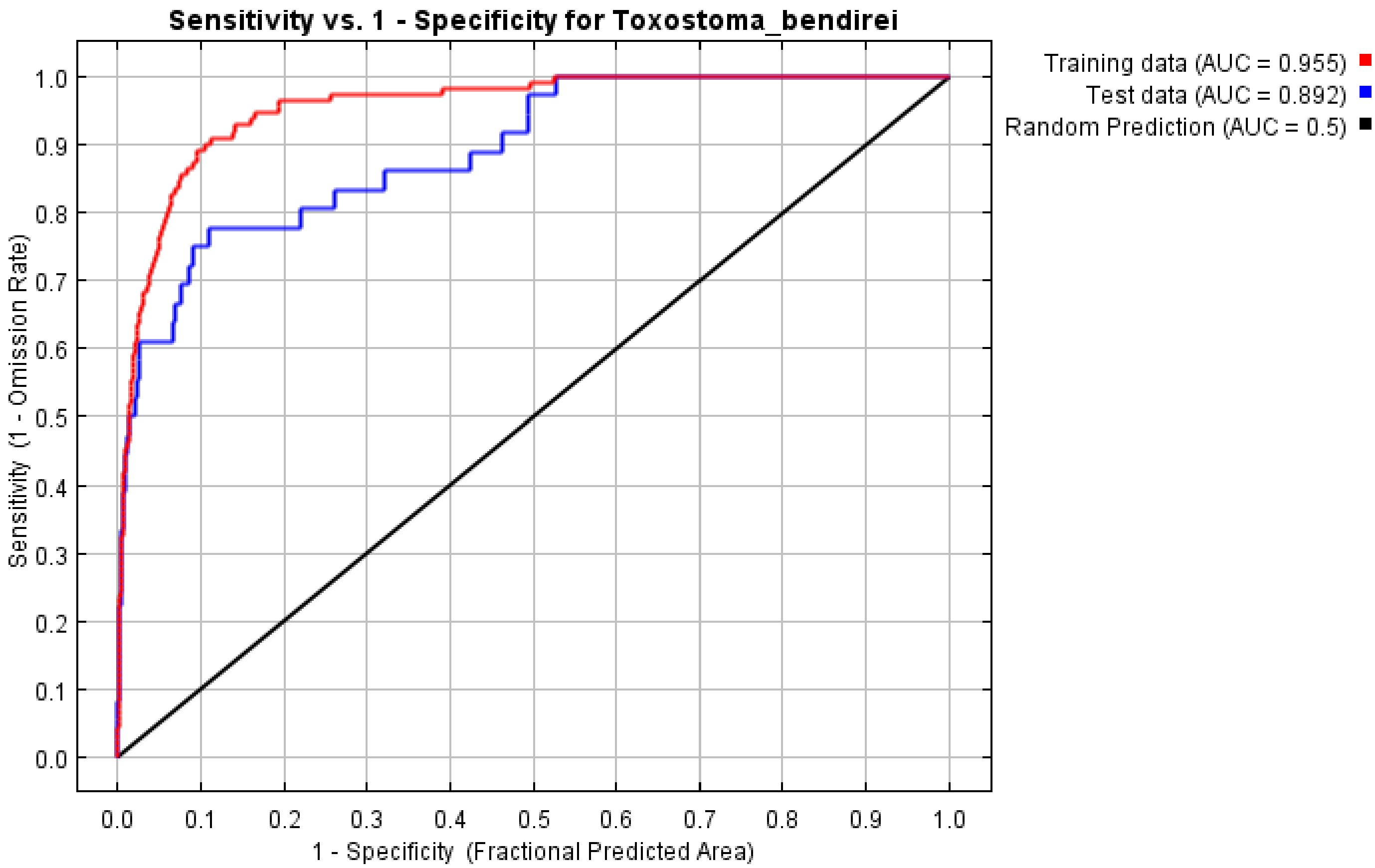

Figure 7. AUC curves for Bendire's Thrasher Training and Evaluation Sites

Figure 8 shows the receiver operating curve for both Curve-billed Thrasher training and evaluation points. For the initial model the AUC was 0.805 for the training data and 0.779 for the evaluation data. This shows that the model is performing well against the training data, albeit not as strong as the model for Bendire's Thrasher. However, it performs almost equally as well against the evaluation points showing that is predicts those training points well. It is important to note that the AUC values tend to be higher for species with narrower ecological niches or species with smaller ranges. Therefore, it is not surprising that the AUC values are higher for Bendire's Thrasher than Curve-billed, which inhabit much of the southern two-thirds of New Mexico.

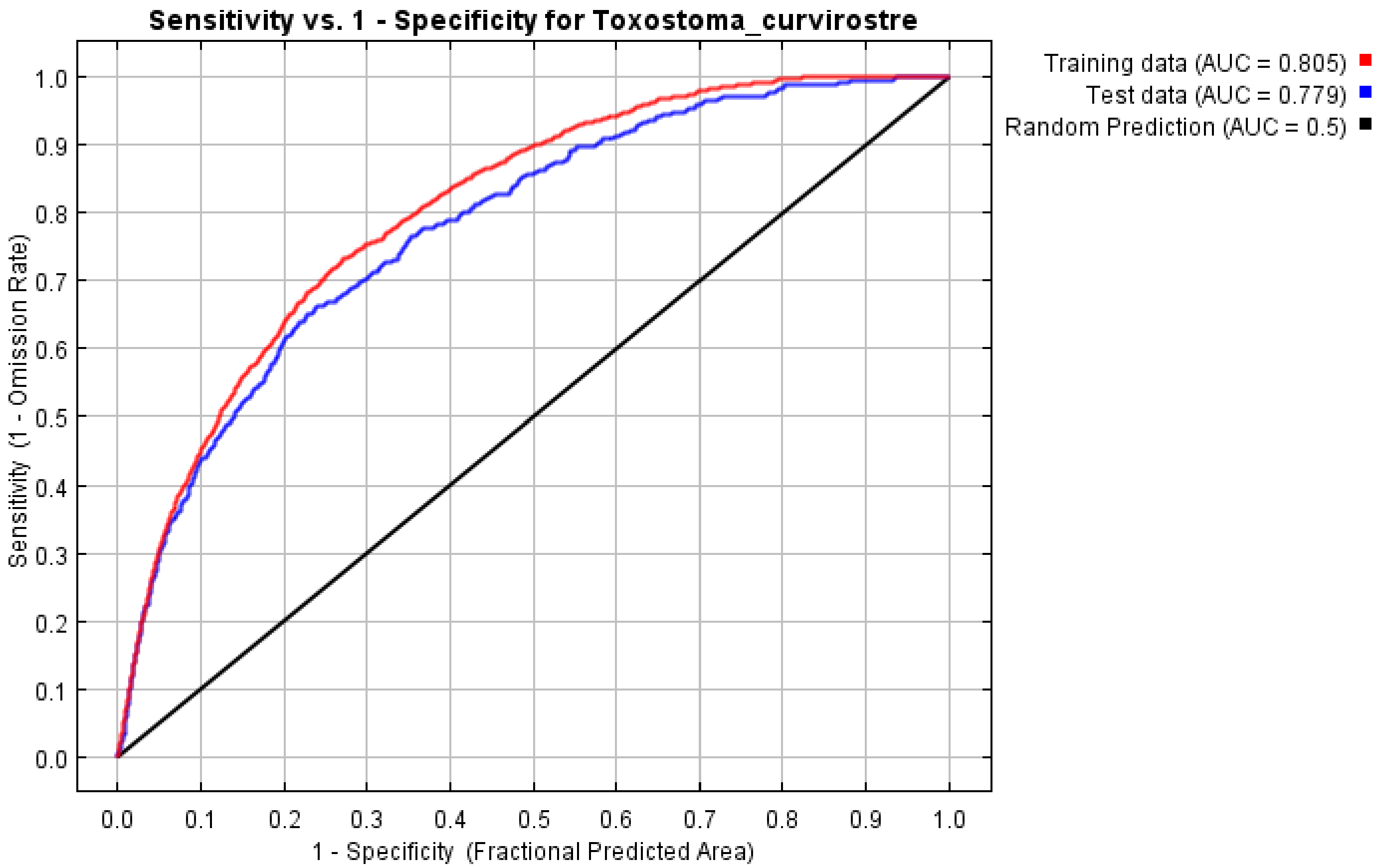

Figure 8. AUC curves for Curve-billed Thrasher Training and Evaluation Sites

Variable Contribution to the Models

The variables used in the final run for Bendire's Thrasher are shown in Table 1. Average annual precipitation was the most important variable in predicting habitat followed by average annual maximum temperature. Here two climactic variables were the most important. Vegetation type and elevation were also very important in predicting habitat. Average annual minimum temperature, average spring minimum temperature, TPI, slope, canopy height, and canopy cover also contributed slightly.

Bendire's Thrasher	
Variable	**Percent contribution**
Average Annual Precipitation	36.5
Average Annual Maximum Temperature	21.8
Vegetation Type	18.4
Elevation	10.6
Average Annual Minimum Temperature	4.2
Average Spring Minimum Temperature	2.8

Topographic Position Index	2.8
Slope	1.6
Canopy Height	0.7
Canopy Cover	0.5

Table 1: Variables used in the final run shown by their percent contribution to the model

A jackknife test is an alternative way to look at which variables are most important to the model. This test ran ten iterations as there are ten environmental variables. Each run excludes one of the environmental layers and the model is created with the remaining layers. Ten additional runs were then processed whereby each variable is used in isolation. Finally the model is run with all the variables. The result for Bendire's Thrasher can be seen in Figure 9. The red bar shows the model gain when run with all variables. The dark blue bars show how well the model performs relative to that, when run it with just that one variable. We can see that the model does not gain much by being run against canopy cover, canopy height, TPI or slope alone. The teal bars show how well the model performs leaving that one variable out. Here we see that the model does not perform as well when the vegetation type is left out, although it was only the third most important variable in percent contribution to the model. The other top contributing variables are also shown to be important by this test.

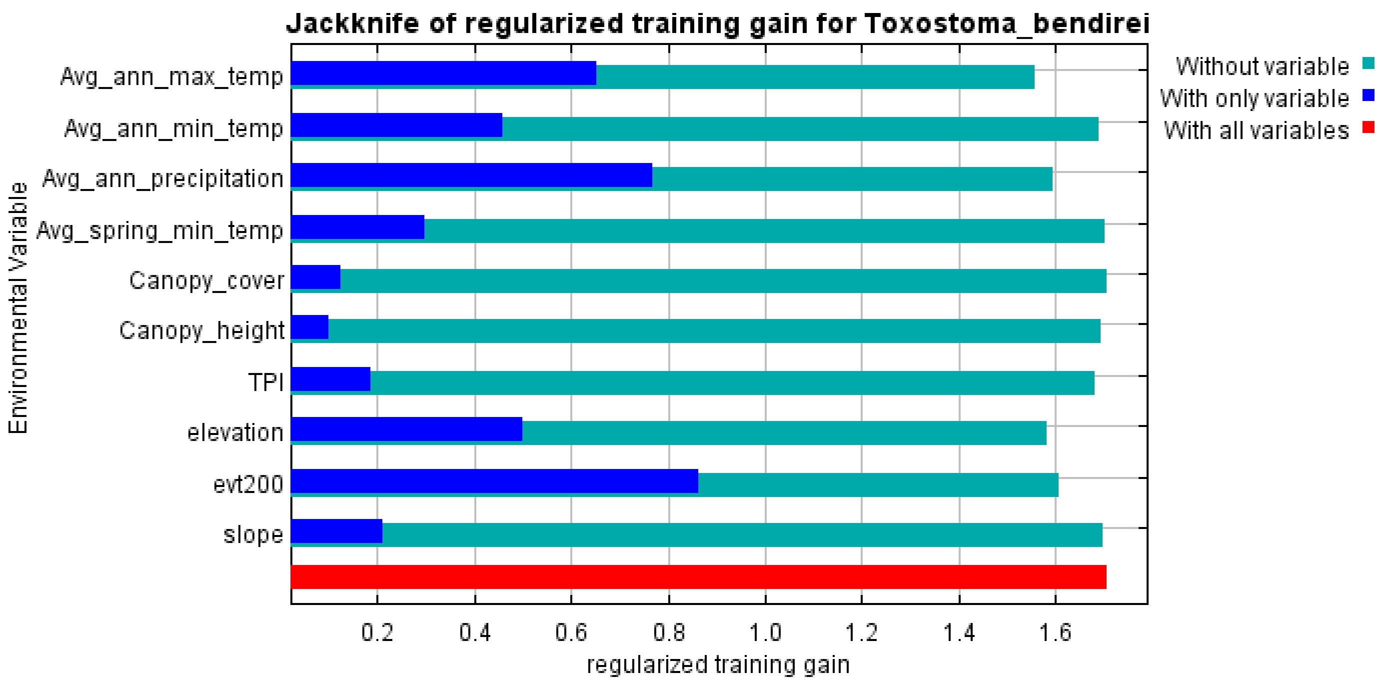

Figure 9. Jackknife test of individual variable importance (Bendire's Thrasher)

The variables used in the final run for Curve-billed Thrasher are shown in Table 2. Here vegetation type is easily the most important variable. This is quite different from the Bendire's Thrasher model, where the top two most important variables were climactic, and overall the variables were more evenly weighted. Average annual minimum temperature and average spring minimum temperature were also very important to the model. Elevation was fairly important and the remaining variables contributed very little.

Curve-billed Thrasher	
Variable	**Percent contribution**
Vegetation Type	54.2
Average Annual Minimum Temperature	21.6
Average Spring Minimum Temperature	10.8
Elevation	7.3
Average Annual Precipitation	2.3
Topographic Position Index	2.1
Average Annual Maximum Temperature	1.4
Slope	0.1
Canopy Height	0.1
Canopy Cover	0.1

Table 2: Variables used in the final run shown by their percent contribution to the model

The jackknife test backup the percent contribution very closely with the exception of average annual maximum temperature which is shown to be more important in the jackknife test (Figure 10).

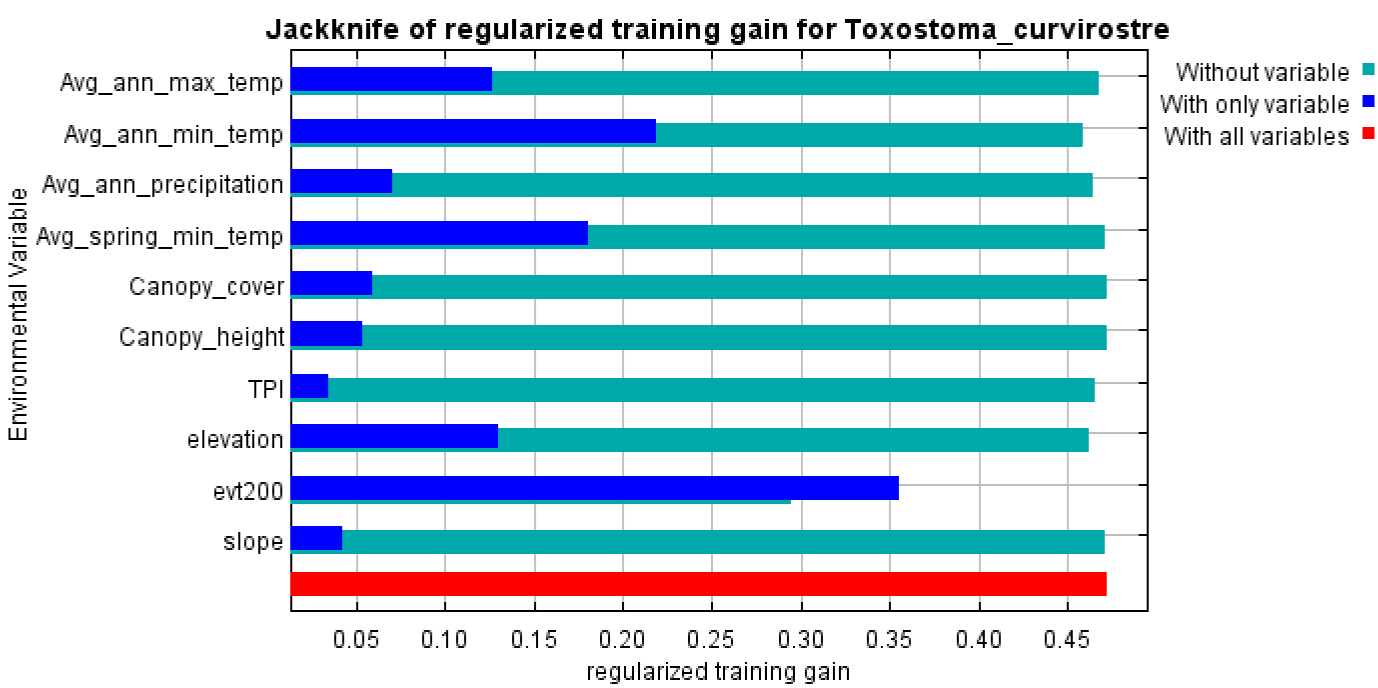

Figure 10. Jackknife test of individual variable importance (Curve-billed Thrasher)

Current Habitat Results

Figures 11 shows the current habitat identified for Bendire's Thrasher, with the BBS Routes included for context. The most optimum habitat for Bendire's Thrasher is confined to the lower elevation and flatter terrain along I-10, the valleys in the boot heel of New Mexico, the Plains of San Augustin, and the Red Hill region west of Quemado. There is other good habitat identified west of the Rio Grande in the Rio Puerco drainages and the lower lands southwest of Santa Fe. That these latter areas were identified as good habitat may be in part due to the bias in the occurrence points.

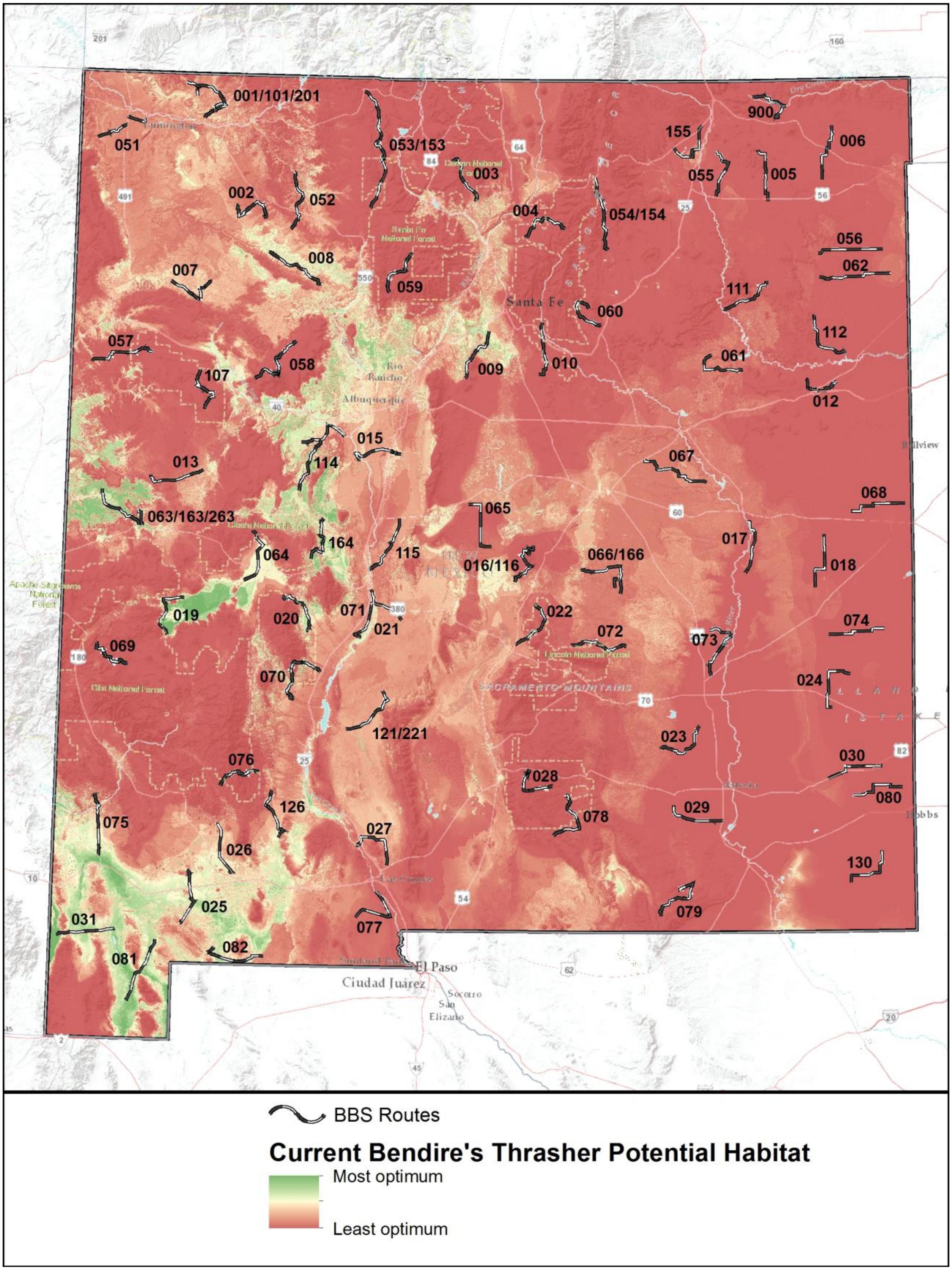

Figure 11. Current Bendire's Thrasher Potential Habitat

Figures 12 shows the current habitat identified for Curve-billed Thrasher, again with the BBS Routes included for context. Nearly two thirds of the state is identified as good habitat. The most optimum areas are the low lying areas surrounding the Mesilla Valley, Clovis, Carlsbad, the region on the NM/TX border south of the Kiowa Grasslands, and the middle Rio Grande Valley. There are also some small pockets identified along the San Juan River in northwest New Mexico.

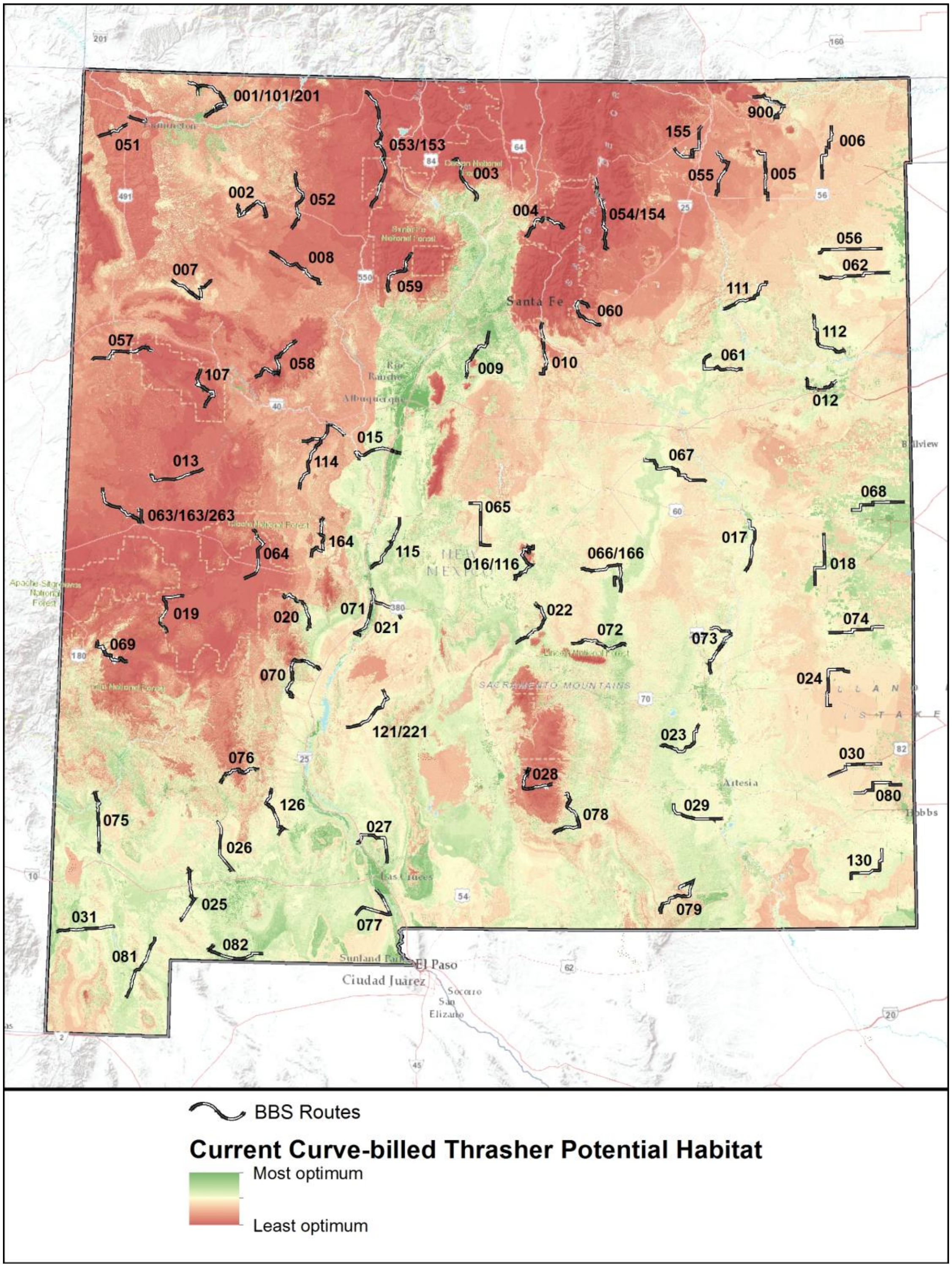

Figure 12. Current Curve-billed Thrasher Potential Habitat

Potential Future Habitat

One of the goals of this project was to identify future range shifts for each species to help inform management and field surveys. Once a model has been developed in MaxEnt against a current set of training data and environmental variables, it can be projected onto an equivalent set of future data.

The projected environmental included the same LandFire vegetation and elevation based datasets used for the current models. What changed was the climactic data. This was especially interesting for Bendire's Thrasher since the top two contributing factors were Average Annual Precipitation and Average Annual Maximum Temperature.

We obtained future climate projections from the most recent global climate models (GCMs) in the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report. Each projection has four representative concentration pathways (RCPs), or greenhouse gas concentration trajectories. These model outputs, often of coarse resolution from 2 to 3 degrees, are downscaled and calibrated using the WorldClim 1.4 model as a baseline "current" climate. The data are available in a range of spatial resolutions: 10 minutes, 5 minutes, 2.5 minutes, and 30 seconds. The HadGEM2-ES (Hadley Global Environmental Model 2 Earth System) global circulation model, developed by the Hadley Center in the United Kingdom was selected for its comprehensive features, including the vegetative cover component. The relatively small region of interest (ROT) of New Mexico required a highest available spatial resolution of 30 seconds. The datasets, available as monthly climate surfaces, include projections of minimum and maximum temperatures and precipitation for the years 2050 and 2070. The bioclimate variable datasets were not used. For the purposes of conservation planning, the closer projection of 2050 was considered more appropriate. The emissions scenario chosen was RCP 8.5, which at the current time seems the most likely trajectory, where greenhouse emissions continue to rise throughout the 21st century with no stabilization.

The monthly temperature and precipitation data were combined to create:

- Average Annual Minimum Temperature 2050
- Average Annual Maximum Temperature 2050
- Average Spring Minimum Temperature 2050
- Average Annual Precipitation 2050

The temperature data were converted to degrees Fahrenheit and the precipitation data to inches to match the PRISM data. The data were downscaled to the projects spatial resolution of 200 meters.

Figure 13 shows the habitat for Bendire's Thrasher projected to the year 2050. For the current potential habitat model Average Annual Precipitation and Average Annual Maximum Temperature were restricting the range to the southwestern portion of New Mexico. With the warming and drying predicted by the 2050 climate data the optimum range expands dramatically across southern and southeastern New Mexico.

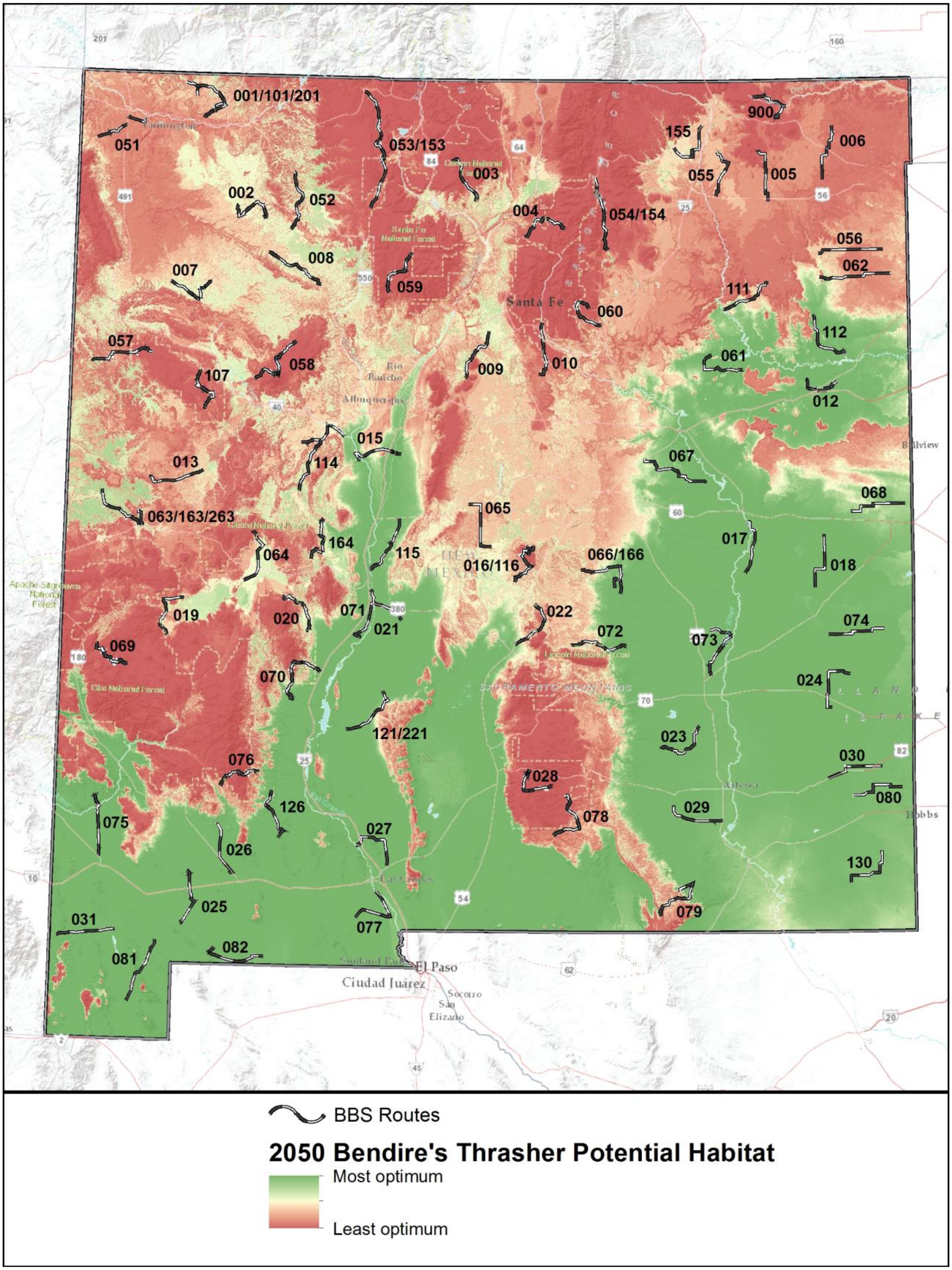

Figure 13. Future (2050) Bendire's Thrasher Potential Habitat

Figure 14 shows the habitat for Curve-billed Thrasher projected to the year 2050. Here the range shifts north away from the Mesilla Valley. The most optimum habitat is predicted to be in central and northeastern New Mexico.

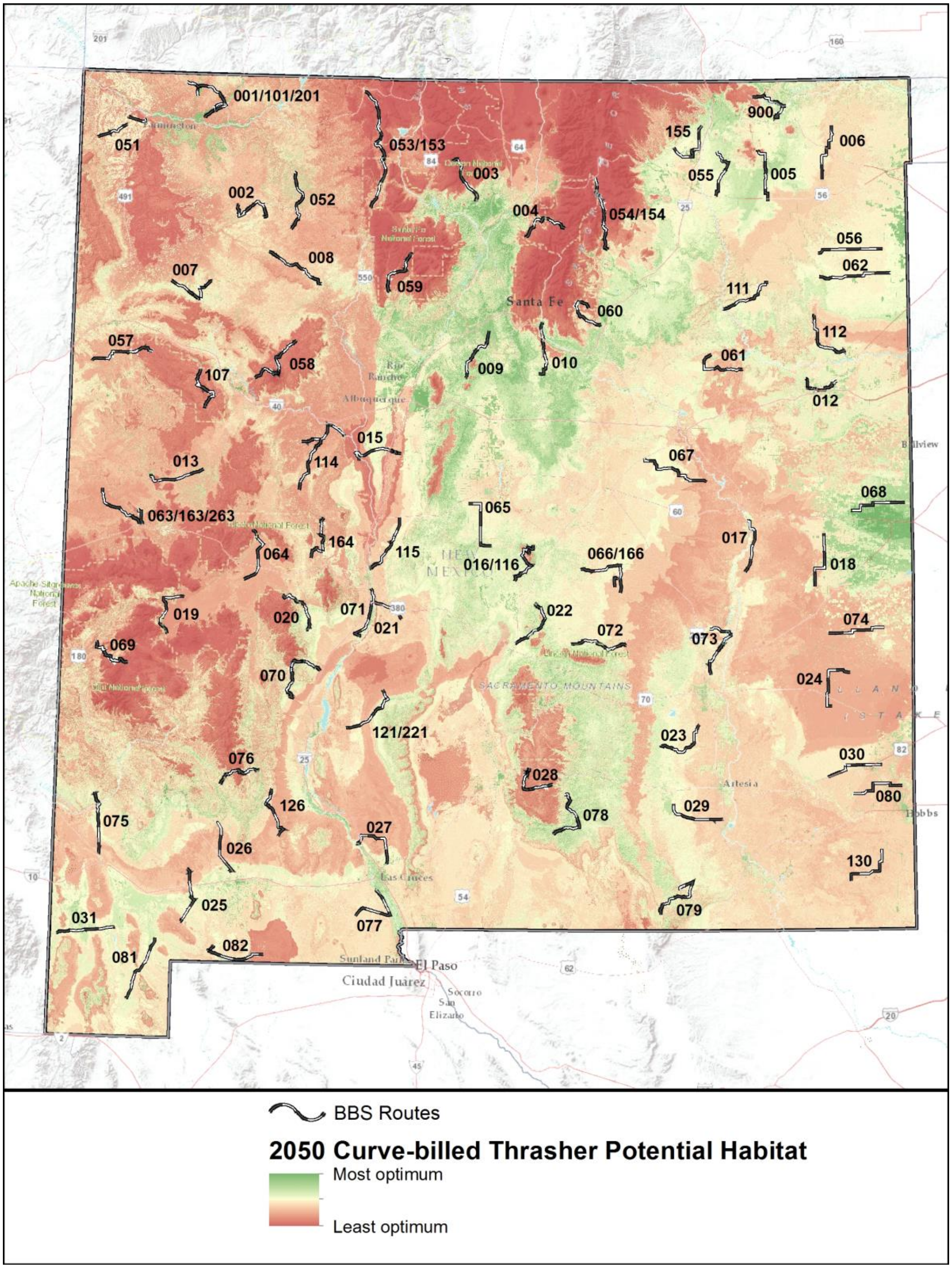

Figure 14. Future (2050) Curve-billed Thrasher Potential Habitat

Conclusion

The overall current range identified for each species correlates well with other maps of each species range found in bird guides and modeled by the Southwest Regional GAP Analysis Project. The two models are strong predictors of evaluation sample points and provide a much more detailed picture of relative habitat quality across both species ranges than previously existed.

Thrasher researchers suspect that part of the decline may be due to habitat fragmentation by anthropogenic forces. The Breeding Bird Survey was one of the main sources of occurrence points. These points are all located along roadways. The first run of each model included a human footprint dataset. Including the human footprint data when a majority of the points are along roads caused to model to identify roaded areas as optimum habitat. Therefore the decision was made to include only natural landscape features as environmental variables. This made it impossible to create a model that incorporated habitat fragmentation. Occurrence points with less spatial bias would likely help inform this hypothesized issue. However, we assume that increased development in the range of Bendire's Thrasher is likely a negative habitat factor. This could also be addressed by overlaying human development data (roads, energy development etc.) over the current habitat raster.

The amount of habitat predicted in 2050 for Bendire's Thrasher was surprising given its current decline. While we are confident in the current Bendire's Thrasher potential habitat model, the future range shift result indicates that there are factors affecting its decline not represented in the model. The most consistent Bendire's Thrasher sightings are in the boot heel of New Mexico which is also identified as good Curve-billed Thrasher habitat. In this area Bendire's habitat may be impacted by competition with Curve-billed.

A unique stronghold for Bendire's appears to be the region in west central New Mexico around Quemado and the Plains of San Augustin, extending north through Cerro Verde, then east of Mt. Taylor to Chaco Mesa. BBS Routes 019, 063/163/263, 164, 114, 008 & 002 consistently observe Bendire's Thrasher but not Curve-billed. This area is also predicted to be Bendire's habitat in 2050 but not Curve-billed. This seems like an important area for field surveys and research on the decline of the species.

The 2050 Curve-billed potential habitat model predicts range for this species to shift north and become slightly smaller. This also contradicts current population trends for the species. While the current model is a very strong predictor of current habitat, as with Bendire's there is obviously more to the expansion of this species than the model can predict. The northward shift in habitat does follow the range shift trend for many species.

Collectively the occurrence points, environmental data, and the models of current and future potential habitat for each species, constitute a robust new resource which can be used to better understand these two species. These data should also serve useful for identifying new study sites for Bendire's Thrasher. As new localities are observed the models can be re-run to refine potential current and future habitat data.

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