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Executive summary

We present here the largest and most comprehensive study of the black-capped vireo (*Vireo atricapilla*) in Texas using an appropriate study design. The goals of our research were to (1) gather data to determine the distribution of black-capped vireos throughout their range in Texas, (2) evaluate topographic, climatic, and vegetative factors driving the distribution of vireos, (3) determine how vireos distribute themselves locally and whether they are clustering on the landscape, (4) determine what habitat characteristics describe local population abundance, (5) use those data to develop a distribution model that estimates probability of vireo occurrence based on landscape and vegetative characteristics and (6) validate this distribution model using an independent dataset. From this research, we have developed a decision-support tool that allows a user to quickly determine the occupancy probability of an area based on several user-defined metrics, providing a user-friendly interface to our predictive occupancy models.

The black-capped vireo is an endangered migratory songbird with a known breeding range throughout portions of central and west Texas, isolated areas in Oklahoma, and the states of Coahuila, Tamaulipas, and Nuevo Leon in Mexico. The species was listed as Endangered under the Endangered Species Act (ESA) of 1973, as amended, in November of 1987, citing habitat loss from development, habitat destruction from the grazing of sheep, goats, and exotic livestock, and nest predation by the brown-headed cowbird (*Molothrus ater*). Breeding habitat is composed of patches of low, scrubby, mostly deciduous woody shrubs and trees of irregular height. No habitat model currently exists for the vireo, and the ability to model and predict the species' habitat on a broad spatial scale would be a valuable tool for conservation and management.

We used a combination of randomly-distributed and area-focused surveys to obtain data on vireo occupancy across the range. Across our two years of data, we surveyed for vireo at over 10,700 points in 57 counties in Texas, greatly adding to the knowledge of vireo distribution within their breeding grounds in the state. We detected vireo at approximately 13.1% (1402) of points across both years. In general, the percent of points with detections was higher in the western portion of the range. We found evidence that vireo are clustering on the landscape at all of our study areas except the Devil's Sinkhole and Devil's River study areas, two of the furthest west study areas, where the distribution of detections was not different from random. Also, we determined that there are strong correlations between vireo occupancy and several metrics from remote-sensing, including profile curvature (the rate of change of the slope gradient) and the ecosite type (from the NRCS Ecological Site Description database). We found that aridity helped explain the variation in vireo habitat from the western part of the range to the east by incorporating an interaction of aridity into our range-wide model. We found evidence that abundance is influenced by the proportion of Low Stony Hill in the eastern part of its range where the aridity index is high (i.e., our Balcones and Fort Hood study sites). We used our area-focused surveys to create models of species' distribution relative to (1) vegetation measurements taken at survey points and (2) broad-scale environmental variables obtained from remote-sensing technology. We used our randomly-distributed survey data to validate these models.

We developed a theoretical network suggesting that there are multiple levels of habitat requirements that influence occupancy probability. This network, or Bayesian Belief Network, provides a flow chart of the various metrics that influence vireo habitat and the occurrence of vireos. We used the relationships developed in our regression models to inform some of the relationships in this network. First, the correct topographic, geologic, and climatic features

must exist to support vireo habitat, specifically, the types of vegetation required by vireo. Second, the vegetation growing in these areas must be in the correct successional state or managed in such a way that it is useable and attractive to vireo. While a region might exist that can support vireo habitat, if the understory vegetation becomes over-browsed or the canopy cover becomes fully closed, then these types of areas are less likely to be occupied by vireo. And finally, if an area has all the necessary features of potential vireo habitat, the probability that a vireo will settle there is influenced by the presence of nearby vireos (emigration, immigration) as well as by the presence of predators and nest parasites such as the brown-headed cowbird. In regions where predator and cowbird trapping is taking place, the probability of vireo presence increases. This network creates a hands-on tool for use in habitat assessment and management to evaluate the probability that an area will be occupied by vireos by creating a user-friendly interface for our regression models.

Introduction

As the human population grows and new developments and infrastructure expand out around urban areas, habitat conservation for threatened and endangered species becomes more challenging. Development and implementation of successful management practices require knowledge of animal distribution relative to environmental conditions (Kantrud and Stewart 1984, Wiens and Rotenberry 1985, Debinski and Brussard 1994, Colwell and Dodd 1995). Thus, the first step in understanding the status of a population is to quantify the distribution, abundance, and use of habitat across the area of interest.

The vireo is a migratory songbird with a known breeding range throughout portions of central Texas, isolated areas in Oklahoma (Grzybowski 1986, Wilkins et al. 2006), and the states of Coahuila, Tamaulipas, and Nuevo Leon in Mexico (Farquhar and Gonzalez 2005). In November 1987, the U.S. Fish and Wildlife Service (USFWS) listed the species as Endangered under the Endangered Species Act (ESA) of 1973, as amended, citing habitat loss from development, habitat destruction from the grazing of sheep, goats, and exotic livestock, and nest predation by the brown-headed cowbird (*Molothrus ater*; Ratzlaff 1987). This is the final report of a study designed to evaluate the current range-wide status (distribution and abundance) of the black-capped vireo (*Vireo atricapilla*; hereafter “vireo”) in Texas.

Our goals were to determine the range-wide distribution, abundance, and habitat use of the vireo in Texas, and then develop predictive habitat models from these surveys on public and private properties across the range. Breeding habitat for the vireo in the U.S. is composed of patches of low, scrubby shrubs and trees that are primarily deciduous and of irregular height (Graber 1961). However, vireo habitat varies greatly in vegetation composition and other characteristics across the range. For example, vireos are associated with an early successional stage in the eastern part of the range, where recent fires and other disturbance can maintain habitat or create new habitat by suppressing the invasion of Ashe juniper (*Juniperus asheii*; Graber 1957, Marshall et al. 1985, Grzybowski et al. 1994, Cimprich 2002); however, vireos can be found within climax communities in the western Chihuahuan desert region, where a lack of rainfall limits vegetation development (Keddy-Hector 1992, Farquhar and Gonzalez 2005, Smith 2011). Additionally, vireo habitat is difficult to map because it is often not discrete; that is, the boundaries of potential habitat are hard to define due to the clumpy and often transitional nature of the vegetation, unlike more distinguishable patches of vegetation (e.g., forest, marsh, riparian) used by many bird species. In Texas, for example, the mature woodland habitat occupied by the endangered golden-cheeked warbler (*Dendroica chrysoparia)* can usually be readily identified using remote sensing techniques (Morrison et al. 2010; Collier et al. in review).

Prior to this report, only one range-wide estimate of habitat availability for the vireo existed (Maresh et al. 1999, Maresh and Rowell 2000) in which researchers used two 30-mile (48 km) road-surveys in each of 53 counties in Texas to survey for vireos and estimate habitat suitability. These estimates were then extrapolated across the rest of each county and into neighboring counties based on topographic maps, yielding an estimate of approximately 1.45 million acres (586,795 ha) of potential habitat in Texas (Maresh et al. 1999, Maresh and Rowell 2000). All other work on vireo occupancy and habitat—regardless of the duration and nature of the work—has been highly localized. Studies of vireo habitat have been conducted on either small private properties or on a few large, managed properties such as the Wichita Mountains National Wildlife Refuge (23,885 ha) in Oklahoma, and Fort Hood Military Reservation (87,890 ha) and Kerr Wildlife Management Area (2,628 ha) in Texas (Grzybowski et al. 1994, Juarez

2004, Leyva et al. 2004). Studies on vireo demography have occurred mostly on Fort Hood Military Reservation or other smaller public properties (e.g., Noa 2005, Cimprich and Kostecke 2006, Comolli 2009, Smith 2011, Pope 2011). Most data on the vireo have been generated from locations with large population sizes so that adequate samples could be gathered, and/or from locations that are highly managed for the species (e.g., cowbird trapping, vegetation management). Although data from many of these studies are informative, the findings may not be applicable across the range of the species. Thus, we developed this study as the first to implement a range-wide survey for vireos and vireo habitat in Texas using an appropriate study design.

For species such as the vireo whose habitat varies greatly across the range, the ability to create a habitat map that does not over- or underestimate habitat is dependent upon accurately accounting for variation in local vegetative conditions. Creating a distribution map is further complicated by limited access for sampling on private properties, which account for the majority of the vireo's range in Texas. Predicting the distribution and habitat occupancy for the vireo must also consider the tendency of the vireos to form groups or clusters of individuals. In general, the distribution and abundance of a species within potential habitat is a result from the organism's behavioral processes of habitat selection (Hilden 1965, Block and Brennan 1993, Jones 2001, Dall et al. 2005). Animals can use a variety of information to make habitat selection decisions, and the presence of conspecifics can act as an indicator of local habitat quality (Valone 1989, Danchin and Doligez 2001). Conspecific attraction is displayed in many species of songbird, including the black-capped vireo (Ward and Schlossberg 2004). Conspecific attraction could drive the birds to cluster on the landscape, thus reducing distributional uniformity and potentially providing an explanation for lack of differences in selection of available habitat. As a further complication, birds may also cluster together temporally, thus as local populations grow, emigration supports additional nearby clusters (Grzybowski, unpublished data).

Here we present the results of a 2-year study across the range of the vireo in Texas. Our objectives were to (1) gather data to determine the distribution of black-capped vireos throughout their range in Texas, (2) evaluate topographic, climatic, and vegetative factors driving the distribution of vireos, (3) determine how vireos distribute themselves locally and whether they are clustering on the landscape, (4) estimate number of individuals detected in each survey location and determine what habitat characteristics describe local population abundance, (5) use those data to develop a distribution model that estimates probability of vireo occurrence based on landscape and vegetative characteristics, and (6) validate this distribution model using an independent dataset. Using survey data collected across the range in Texas, our results greatly improve upon current descriptions and estimates of vireo habitat in Texas. The results of our project provide information on the baseline status of the vireo and may offer a tool useful for recovery planning.

Methods

We used a combination of randomly-distributed and area-focused surveys to develop and validate a model for predicting vireo occurrence in the species' range in Texas. This model resulted in a decision-support tool that allows a user to quickly calculate the predicted occupancy of an area based on several user-defined metrics. We used randomly-distributed survey data to gain an initial distribution of vireo within their range in Texas. We then used area-focused data to look at vireo distribution within more localized areas. Models developed from these area-focused data were then validated with data from our randomly-distributed surveys.

Randomly-distributed surveys

We surveyed across the range of the vireo on randomly-distributed properties between the months of April and June 2009. We developed a design to identify areas to survey for vireos, (detailed in Appendix A), along with a standardized survey protocol for detecting vireos in our survey locations (Appendix B). Initial analyses of the randomly-distributed data between detection and non-detection points (defined in Appendix A) yielded no biologically significant differences in several remotely-sensed metrics and vegetation metrics taken on site (e.g., slope, aspect, distance to water, canopy cover, tree height, height of the understory, vegetative species diversity) between detection and non-detection points (both at the point and by looking at the mean and SD of each metric within a 120-m radius (i.e., about 4.5 ha which is the approximate size of a vireo territory based on previous Texas A&M University research [Morrison unpublished data]). These findings, presented in the Phase III report of this study (Groce et al. 2009), prompted us to change our sampling strategy for the second year from randomly-distributed to area-focused surveys. The randomly-distributed survey data were used to validate our findings of the area-focused data.

Area-focused surveys

In 2010, we focused our study on localized areas (hereafter “study areas”) to better determine (1) whether vireo are clustered on the landscape and (2) which remotely-sensed and ground vegetation measurements predicted vireo occurrence. We selected 8 study areas that were scattered across the breeding range of the vireo in Texas (Fig. 1), including Devil’s River State Park and surrounding area, Kickapoo Caverns State Park and surrounding area, Devil’s Sinkhole State Park and surrounding area, Kerr Wildlife Management Area and surrounding area, Mason County area, Balcones Canyonlands National Wildlife Refuge and surrounding area, Fort Hood Military Reservation and surrounding area, and Taylor County area. We chose 7 of these locations based on their known vireo populations, determined from either our surveys in 2009 or concurrent research in these areas. We included an additional location, Taylor County, to expand our sampling frame to the north-central portion of the range (Fig. 1). Within each of the 8 study areas, we focused on a central location and attempted to gain as much contiguous property access around that location as possible. Unlike the 2009 surveys that occurred on relatively small but widely distributed properties, the primary goal of our 2010 sampling was to enhance our ability to model vireo habitat by focusing on large contiguous areas. The study areas are detailed in Appendix C.

Area-focused sampling methods

Field surveys

To ensure the surveys covered all accessible areas of a property, we selected a random point from which we created a grid of survey points (300 m x 300 m) that covered each of our 8 study areas. We sampled from late March to late June in 2010, between sunrise and 13:00. For each property, one surveyor moved slowly from grid point to grid point (hereafter survey point), conducting a 5-minute auditory and visual count at each survey point. This survey method differed from that which we used in 2009 (randomly-distributed surveys) because surveyors had predetermined locations to conduct point counts (i.e., survey points) instead of recording vireo detections along survey routes (see *Appendix A*). We did not conduct counts at survey points that occurred in areas of open pasture or in the middle of dense woodlands. We recorded distance and direction from the survey point to each vireo detected from that point, estimating distance to the nearest 10 m. In addition to vireo detections acquired during 5-min counts at survey points, we recorded vireos detected while moving between survey points and outside of the 5-min count time limit. These detections were given a distance and direction associated with a new GPS point at the location of the surveyor when the vireo was detected. We recorded all new detections at the time of detection, regardless of whether the bird was detected during the formal count time or not. However, if during a point count we detected a previously-detected bird, we recorded the bird a second time in order to accurately reflect detections during point counts. Observers did not survey during inclement weather (e.g., excessive rain or wind >~20 km/hr), or any conditions that would inhibit their ability to detect the birds. We did not revisit survey points. For additional information on vireo surveys in 2010, see Appendix D. For data analysis purposes, we combined detections of vireos recorded during the timed point count with detections acquired outside of the 5-min count (see *Analyses* below). However, for analyses concerning abundance, we used only the counts of birds detected during our 5-minute point counts.

Vegetation measurements

We measured certain vegetation characteristics at each survey point. We selected vegetation metrics that provide an index of vertical structure of woody vegetation (including species), and an index of woody vegetation dispersion (density of patches). These metrics quantify vegetative indices that are thought to influence vireo occurrence (e.g., presence of a browse-line). Surveyors visualized 2 perpendicular transects centered on the grid point (thus, 4 transects stemming from the point), with one transect oriented in the direction of the closest woody vegetation and subsequent transects at 90, 180, and 270° from the first transect.

Our vegetation measurements yielded the following metrics:

- Average distance to vegetation (DistToVeg): standing at a survey point, the average distance to the closest woody vegetation across the four transects.
- Vegetation height – top (htTop): the average height of the woody vegetation across the four transects, estimated to the nearest meter.
- Vegetation height – bottom (htBottom): the average height of the lowest cover of the woody vegetation across the four transects, estimated to the nearest 0.1 meters.
- Oak Index (Oak): the number of transects in which an oak species was the closest dominant woody vegetation.
- Juniper Index (Juniper): the number of transects in which a juniper species was the closest dominant woody vegetation.

Additional information regarding the 2010 vegetation surveys can be found in Appendix D.

GIS and remote sensing

Using a suite of geospatial analysis tools in ESRI ArcGIS 10, we calculated a compilation of remotely-sensed attributes and assigned these attributes to each survey point based on their position in the landscape. These attributes were averaged within a 100-m buffer around each point to approximate the mean territory size of a vireo (3 ha; range of mean territory sizes = 1.5 to 3.6 ha; Graber 1961, Tazik 1991). We reduced this buffer from the 120-m we used in our 2009 randomly-distributed survey pre-analysis to better reflect the territory sizes in the literature. Remotely-sensed attributes included:

- The USGS 2001 National Landcover Dataset (NLCD) tree canopy density layer (Huang et al. 2001) was used to determine the percent canopy cover for each survey point and the mean canopy cover within the 100-m buffer around each survey point.
- The US EPA Level III Ecoregions of the Conterminous United States (based on Omernik 2004) were used to assign each survey point its corresponding ecoregion (Fig. 2).
- The Natural Resources Conservation Service (NRCS) Ecological Site Description (ESD) database was used to assign an ecosite category to each survey point. For locations where the ecosite was undefined in the ESD database, we referred to the NRCS soil surveys for the ecosite description. In addition, we calculated the proportion of the landscape within the 100-m buffer of each survey point that was comprised of a particular ecosite. We grouped ecosites into ecosite families based upon similar physiographic features, position in the landscape, climax plant community, and Major Land Resource Area (MLRA; Table 1).
- USGS National Elevation Dataset (NED) 1/3 arc second digital elevation models (DEM; 10-m resolution) were used to derive slope (degrees), planimetric curvature (degrees/100 m), and profile curvature (degrees/100 m) for each survey point.

Profile curvature is the rate of change of slope gradient in the direction of greatest change, where positive values are vertically concave and negative values are vertically convex (Carson and Kirkby 1972, Schmidt et al. 2003). A profile curvature value of zero means the slope is flat (Fig. 3). From a hydrological standpoint, profile curvature affects the acceleration or deceleration of flow across the surface. Planimetric curvature is defined as the rate of change of direction of a contour line, or horizontal convexity (Carson and Kirkby 1972, Schmidt et al. 2003) and, from a hydrological perspective, affects the dispersion of water as it flows downhill. Positive values for planimetric curvature are horizontally convex (water-diverging slopes) and negative values are horizontally concave (water-collecting slopes; Fig. 3).

Additionally, we used an aridity index from the Cosultative Group on International Agricultural Research (CGIAR; Zomer et al. 2008) where higher values correspond to wetter and cooler environments. In Texas, aridity values generally decrease from east to west and with an increase in elevation (Fig. 4). The aridity index is a ratio calculated as the mean annual precipitation over the mean annual potential evapotranspiration, multiplied by 10,000 (Zomer et al. 2008).

The same metrics (listed above) were calculated at the same 100-m radius and assigned to each detection and non-detection point from our 2009 randomly-distributed survey data. Therefore, for these survey data, these buffers were centered on bird location or point of non-detection. However, for our area-focused surveys, these buffers were centered on the 300-m grid points.

Additionally, because there were 2 observers surveying an area simultaneously but independently during the randomly-distributed surveys in 2009, we likely counted some birds twice (i.e., once by each observer). Therefore, in our analyses, we only used detections that were ≥200 m apart. If several detections occurred in the same area, we took a subsample so that the selected points did not fall within 200 m of another. Additionally, we subsampled our stop points so that none of our 2009 points, detections or non-detections, were within 200 m of each other. This way, when buffered by 100 m, none of the buffer areas overlapped and therefore attributes associated with a point were not pseudo-replicated. We summarized the above metrics for detection versus non-detection points across the study range as well as by study site.

Table 1. List of ecosites and ecosite families (in bold) used in this study.

Ecosite Families Ecosites	
Adobe	**Ramadero**
Adobe	**Red Sandy Loam**
Steep Adobe	**Red Savannah**
Blackland	**Redland**
Chalky Ridge	Redland
Clay Flat	Deep Redland
Clay Loam	Gravelly Redland
Clayey Bottomland	**Rocky Hill**
Clayey Upland	**Saline Clay Loam**
Claypan Prairie	**Sandstone Hill**
Claypan Savannah	**Sandy**
Deep Sand	**Sandy Loam**
Draw	**Sandy Loam Prairie**
Eroded Blackland	**Shallow**
Granite Gravel	Shallow
Granite Hill	Very Shallow
Gravelly	Shallow Ridge
Gravelly Sandy Loam	**Shallow Clay**
High Lime	**Shallow Granite**
Igneous Hill	**Shallow Sandy Loam**
Lakebed	**Steep Rocky**
Limestone Hill	**Stony Clay Loam**
Loamy Bottomland	**Stony Loam**
Loamy Sand	**Tight Sandy Loam**
Loamy Sand Prairie	**Very Shallow Clay**
Low Stony Hill	

Analyses

To classify each survey point as either a detection or non-detection point for the area-focused 2010 survey data, we first mapped the spatial locations of bird detections in ArcMap using the recorded distance and direction from a given survey point or from the additional locations between survey points (see *Area-focused sampling methods, Field Surveys* above). We considered a survey point a detection point if a projected location of a vireo was located within 100-m of the survey point. We defined a survey point as a non-detection point if no projected vireo locations were located within 100 m of the point. This allowed us to use birds detected as we approached or left a point even if the bird was not detected during the formal point count period, and we could therefore better define areas of use by vireos.

Descriptive statistics

We report our 2010 area-focused survey data by study area. We used a 2-sample *t*-statistic to test for differences in mean percent occurrence for each remotely-sensed or vegetation metric. We considered $\alpha \leq 0.05$ as significant. We report the mean, standard deviation, and results of significant *t*-tests. Since we used the randomly-distributed 2009 survey data as an independent data set to evaluate models developed from the 2010 area-focused survey data, we used the same analyses for the 2009 data set, reported by Level III Ecoregion.

Spatial distribution

To determine whether vireos were randomly clustered within our 2010 study areas, we used the detection and non-detection assignments of our 300-m spaced survey points. We assigned detections a value of 1 and non-detections a value of 0. For each of the 8 study areas, we ran a cluster analysis in ArcMap Spatial Statistics (ESRI) using the High/Low Clustering tool (Getis-ord general G function; Getis and Ord 1992), which determines whether the high values (1s, detections) or the low values (0s, non-detections) are clustering, but if both are clustering, the Getis-Ord test would not predict a distribution statistically different than random. If the test did not predict detections (i.e., vireos) to be clustered, we then ran an additional spatial autocorrelation test, the Global Moran's I statistic (Moran 1950; Cliff and Ord 1972; Anselin 1995). The Moran's I statistic tests if the clustering is occurring in both detections and non-detections at the same time, which would not be detected in the Getis-ord general G test. For both tests, we used row standardization where spatial weights are divided by the sum of the weights of all neighboring survey points.

Predictive occurrence models

Model analysis and selection

We used logistic regression to model variation in vireo occurrence relative to local and regional environmental variables for each of our study areas (see *Model Construction* below). We reduced multicollinearity among variables by examining the variance inflation factor for each pair of variables and we considered any pairs with a variance inflation factor ≥ 2 as collinear (Graham 2002). A variance inflation factor of ≥ 2 is equivalent to an $r \geq 0.7$. Variables with high variance inflation factor are collinear and if the variables are included in the same model the collinearity would influence the estimated coefficients of the effects. If variables were collinear, we compared their effect on occurrence in main effects models and in separate additive and interactive models.

Model selection

Our goal was to determine which models best fit the data and to use these models to predict vireo occurrence within each study area (see *Model Prediction* below). We used Akaike Information Criterion (AIC), which calculates criteria for evaluating model selection, to determine which combination of variables provided the best approximating fit of the data. This approach evaluates models relative to the set of models provided; the selection of a best model is contingent on the other models in the set. In other words, it is possible that a model might be the best approximating model but that in an absolute sense it might not be the optimal model or have much predictive ability. Thus, we used model selection criteria to assist with the overall determination of the best variable combinations to consider for predicting across the study area. For this reason, our approach included several exploratory steps.

First, we examined single effects and all possible additive combinations of the explanatory variables. For the combination of additive models, we used model-averaging to assess uncertainty in model selection, because it is likely that no single model would clearly support the data over another model. Uncertainty arises because the selection process is contingent upon the selected variables, the set of candidate models, and the single data set (Burnham and Anderson 2002, pages 149–167). Model averaging provides coefficients and unconditional standard errors, and by considering only additive combinations, we ensured that the coefficients derived from model averaging were not inflated because of unequal representation in the candidate models. We used the results from the evaluation of single-model effects and model averaging to support our selection of the model to use for further prediction of occurrence (see *Bayesian network analysis* below).

Second, we examined the interactive effect of each paired variable. If any interactive effect was considered competitive, we combined the interaction with all additive combinations of the predictor variables. We considered models to be competitive if $\Delta AIC<2$ because this suggests a "substantial" level of empirical support for these models (Burnham and Anderson, page 70). For these top models, we considered the effect of a variable to be significant after examining coefficients and 95% confidence intervals from single models and from model-averaging evaluation.

Model construction

Regional vegetation models

Within each study area, we examined relationships between points with vireo detections and each of our vegetation metrics. These metrics are described in detail in *Vegetation Measurements* above). We did not include Mason Co. or Taylor Co. study areas in the vegetation analysis because of small sample sizes; however, we provide descriptive statistics for these two study areas.

Regional remote-sensing models

For each study area, we also evaluated competitive models based on metrics obtained from remote-sensing (see *GIS and Remote Sensing* above). Again, we did not include Mason Co. or Taylor Co. study areas because of small sample sizes but provide descriptive statistics for these two study areas. For each of the 6 study areas, we determined which ecosites to include in our model selection procedure based on the representation of that ecosite in our sample from that study area. We used only those ecosites that were represented (i.e., proportion > 0) in >10% of the survey points for a region. For example, in the Kickapoo study area, Low Stony Hill was represented (proportion >0) at 464 survey points of 1,009 total points (54% of the sampling locations). We selected >10% representation as the minimum amount because it allowed for inclusion of at least 3 ecosites into candidate models. The ecosites included for each study area were:

- Devil's River: Low Stony Hill, Steep Rocky, Loamy Bottomlands, and Shallow Ridge ecosites
- Kickapoo: Low Stony Hill, Shallow, and Steep Rocky ecosites
- Devil's Sinkhole: Low Stony Hill, Steep Rocky, and Shallow ecosites.
- Kerr: Low Stony Hill, Redland, Shallow, Steep rocky ecosites.
- Balcones: Low Stony Hill, Adobe, and Steep adobe ecosites
- Fort Hood: Low Stony Hill, Adobe, Clay Loam, and Shallow ecosites

Range-wide model

We followed the same approach used for the predictive models of the study areas to determine what combination of remotely-sensed variables best describes vireo occurrence across the range in Texas. We decided which metrics to include in the range-wide model based on the results of the study area models. We used our 2010 area-focused survey data from our 6 study areas with suitable sample sizes to create the range-wide model, and we included an index of aridity to represent the variation in aridity across the study area (see *GIS and Remote Sensing* above). We could not model range-wide vireo occurrence using measurements from our vegetation survey as we do not have vegetation data for the entire range.

Model evaluation and regional projections

Model projection

We projected the best approximating model across each of the 6 study areas to represent the potential distribution of vireos within each area. Using the values of the predictor variables (i.e., variables selected from logistic regression model selection) calculated for a set of 200-m pixels across each study area, we ran the logistic regression to obtain a predicted occupancy value for each pixel. We then used these predicted occupancy values to create maps displaying the predicted occupancy probabilities across each of the 6 study areas. We report descriptive statistics for the probability of vireo occurrence within each of the 6 study areas and for the range-wide projection.

Model evaluation

We evaluated our predictive models for each study area and for range-wide predicted occurrence using the 2010 area-focused data set (i.e., training data set used to develop the logistic regression models) and an independent data set from the randomly-distributed surveys conducted in 2009. Comparing the 2009 data against the 2010 training data set from 2010 provides a measure of recognition, defined as the percent of vireo detections that are correctly classified by the selected model (sensu Fielding and Bell 1997). We examined whether the mean and 95% CI from predicted occurrence values was higher for points classified as predicted than for points classified as non-detected from field surveys.

We constructed classification tables to examine different metrics for our range-wide model evaluation. A classification table (i.e., confusion matrix *per* Fielding and Bell 1997) is a 2 x 2 table that compares the number of actual vireo detections and non-detections obtained from field-based surveys, against whether the predictive classification described that point location as potential vireo habitat. This method requires that the predictive classification estimate of probability of occurrence be categorized into 2 categories, habitat or non-habitat, based on a threshold value. Often this threshold is arbitrarily selected at the 0.5 mid-point between the range of occurrence probabilities, 0 to 1. But for our study, the range of probability of occurrence rarely exceeded 0.8 and based on frequency distributions the median (mid-point) values were ~0.2 to ~0.3. Specific threshold values for each study area and our range-wide model are provided below in *Results*. We calculated several model evaluation metrics from the classification table. Because these metrics are sensitive to samples sizes of detections and non-detections, we estimated the prevalence of positive detections in our point count data (Table 2).

Evaluation metrics are defined below (Fielding and Bell 1997, Anderson et al. 2003; see also Table 2):

Prevalence: a measure of the proportion of detections relative to the total number of surveys.

Correct classification rate: overall accuracy of predicted map to correctly classify locations with vireo detections and those without detections as habitat or non-habitat, respectively.

Omission (false negative rate): locations with vireo detections that are falsely classified by the predicted habitat map as non-habitat.

Commission index (false positive rate): non-detection locations that are falsely classified by the predicted map as vireo habitat.

Sensitivity: the percent of true presences correctly identified

Specificity: the percent of true absences correctly identified

Positive predictive power: assesses the probability that a location is habitat (i.e., vireo was detected) in all areas predicted as habitat by the model

Negative predictive power: assesses the probability that a location is classified as non-habitat (i.e., did not detect a vireo) in all areas predicted as non-habitat by the model

Commission index includes true commission error (overprediction) and apparent commission error (correctly predicted but not verifiable). Apparent commission error arises from the prediction of an area as suitable habitat, but survey data do not classify the area as occupied. This error derives from several biotic or sampling factors: (1) the sampling of the area might have been inadequate because of incomplete but extensive surveys, (2) failure of species to disperse to an area (e.g., restrictions over evolutionary time or conspecific behavior reduces dispersion), (3) competition, and (4) predation. Thus areas that are suitable habitat are not occupied (Anderson et al. 2003).

Table 2. Example of a classification table and calculations for model evaluation metrics reproduced from Fielding and Bell 1997, Anderson et al. 2003.

	Actual	
Predicted	Y	N
Y	a	b
N	c	d

Measure	**Calculation**
Prevalence	(a + c)/N
Correct classification rate	(a + d)/N
False negative rate (omission)	c/(a + c)
False positive rate (commission)	b/(b + d)
Sensitivity	a/(a+c)
Specificity	d/(b+d)
Positive predictive power (PPP)	a/(a + b)
Negative predictive power (NPP)	d/(c + d)

Bayesian network analysis

Several key variables influencing vireo distribution cannot be readily measured using remote sensing data. Additionally, because of the propensity for vireos to cluster in an area, they will not always occupy all apparently suitable habitat. Thus, we needed to develop a framework for enhancing the identification of suitable vireo habitat across the breeding range. We chose to use a procedure termed Bayesian belief network (BBN; Marcot et al. 2006), which is a tool based on interacting factors (i.e., key factors) that allows for accurate prediction of local conditions while addressing uncertainty in exact quantification of the biological processes which created that pattern (Marcot et al. 2006, McCann et al. 2006). This tool will assist managers in Texas to evaluate effects of local and regional ecological conditions on predictions of vireo occurrence

In the simplest sense, the BBNs we present here represent a biological system in which causality plays a role, but the ability to fully describe the mechanism which links these biological factors together is limited by uncertainty. In contrast to most modeling approaches, BBNs use probabilistic expression to describe the relationships between variables. Thus, belief in the state of a system is shown by the belief vector structure (graphically depicted as a histogram in each node). Because true system state is unknown, uncertainty within each variable (node) is indicated by the distribution of belief allocated within each node.

We developed BBNs which depict the impacts of local and regional environmental and geographical factors on the predicted occurrence of vireos within 6 of our study areas, as well as across the entire breeding range, in Texas. Our BBN synthesizes the data collected on vireo locations based on both remotely-sensed metrics as well as on site vegetation conditions into a tool for use in conservation planning and management. We developed the Bayesian belief network in Netica (Norsys Software Corp.)

Our hypothesized BBN for vireo occurrence within the breeding range in Texas is composed of two different levels (Fig. 5). The first, or remote-sensing (broad) scale, incorporates those metrics that can be measured remotely and applied to the entire range. This level answers the question "Could it be habitat?" which we termed Vireo Susceptibility. While ground-truthing is necessary to ensure that the calculations for slope, canopy cover, curvature values, and ecosite are correct, this first level allows us to gain an initial estimate of probability of habitat without needing additional information of the vegetation or landscape collected in the field (Fig. 5). At this level, we can think of the question as, "do all the necessary landscape ingredients exist that make vireo habitat?"

At the second level, the local scale, we incorporate those metrics that can only be measured once a person has been to the location and has knowledge concerning the vegetation management and what the finer details of the vegetation is like (e.g., existence of browse line). This level first answers the question, "Is it habitat?" Given that an area would be susceptible to vireo settling if the local conditions were right, we can then incorporate information about the management practices on that property which may influence the local vegetation and the vegetative structure (e.g., Has it been burned? Are there goats or cattle?). Incorporating this information will help to determine the probability that, if given the opportunity, a vireo would settle there. Continuing with our "ingredient" metaphor, this level can be thought of as the necessary procedures (management, vegetation state) that yield vireo habitat—i.e., given all the necessary ingredients are there, has the area been managed or does it naturally have the correct vegetative conditions to be habitat?

The third level, still at the local scale, deals with the actual presence or absence of vireos at the location. Given a probability that the area is vireo habitat, our third question is, "Do vireos currently occur in the area or nearby?" (i.e., the likelihood of vireo presence). Once we predict an area is habitat for a vireo, the additional factors influencing vireo presence would be first, whether there are other vireos or clusters of vireos nearby, which would aid in dispersal to the area and access to mates, and second, whether or not cowbird trapping is being done in the vicinity, which would influence the parasitism and predation rates by cowbirds and thus, the reproductive success of vireos (Fig. 5). Availability of food resources is another factor that might influence whether or not birds settle in an area.

The data we collected during this study inform several of these causal relationships (node to node); however, we do not have adequate data to inform all the relationships. The results of our regional logistic regression models were used to inform relationships at the remote-sensing scale (Fig. 5; red box), and similarly, the results of our vegetation model regressions were used to inform some of the relationships at the local scale (Fig. 5; green box). Relationships for which we lack data are the focus of future study.

Abundance

We estimated the minimum number of vireos detected (individuals) for each year within the approximate area surveyed (ha). For 2009, we used the subset of detections (>200 m apart) so as to not double-count individuals. For 2010, we used a combination of the number of birds detected during the 5-minute point counts plus the number of survey points where no birds were detected during the point count but had one or more detections within 100 m. We report the actual number of individuals detected as a range between this minimum and the total number of detections. To estimate actual area surveyed in 2009, we used the "Aggregate points" tool in ArcMap to create minimum convex polygons of all points within 800 m, to approximate the maximum distance potentially traveled in 20 minutes if moving slowly (see Appendix A). In 2010, we estimated actual area surveyed by buffering each gridpoint surveyed by 100 m. Each of these estimates should be low, considering in 2009, there were likely areas surveyed where no points were taken that would fall outside of these polygons. Similarly, in 2010, researchers traveled between points where these buffers do not cover.

To examine variation in the number of vireos at a survey point relative to remotely-sensed habitat variables, we used only the number of vireos detected at survey points during the 5-min point count surveys within the study areas in 2010. We used the habitat variables that best predicted vireo occurrence because for many species occupancy is often correlated with abundance (Pollock 2006). To determine if a habitat variable described vireo abundance, we examined the mean and 95% CI of each variable relative to the number of vireos detected during surveys. We determined that a variable potentially described vireo abundance if the 95% CI did not overlap.

Results

Randomly-distributed survey results

In 2009, we surveyed for black-capped vireos on randomly-distributed properties in 57 counties and 8 ecoregions in central and west Texas between April and June (Table 3). We detected vireos in 25 (43.9%, n = 57) of the surveyed counties.

We conducted 5-min surveys at 4,056 stop points (defined in Appendix A) along the survey routes, and we recorded location data for 460 vireo detections (Table 3; Fig. 6). Because there were 2 observers surveying an area simultaneously but independently, the 460 vireo locations cannot be considered unique individuals. For analysis purposes, we used a subsample of locations that were ≥200 m from each other. This subsample yielded 2,322 stop points and 251 detections (Table 3).

Table 3. Number of points visited and number of black-capped vireo detections by Level III ecoregion (based on Omernik 2004), during surveys in 2009. We used a subset of all points visited and detections where all points were ≥ 200 m from each other.

	Total		Subset (>200m)	
	Points Visited	**Vireo Detections**	**Points Visited**	**Vireo Detections**
Edwards Plateau	1932	343	1131	189
Cross Timbers	976	51	451	27
Chihuahuan Deserts	688	35	493	24
Central Great Plains	288	19	156	3
Arizona/New Mexico Mountains	115	0	57	0
Texas Blackland Prairies	31	0	18	0
Southern Texas Plains	13	12	8	8
Southwestern Tablelands	13	0	8	0
Total	4056	460	2322	251

Randomly-distributed survey summary data

Ecosites have not been mapped for Culberson and Presidio counties nor the Big Bend area of Brewster County; thus, the Arizona/New Mexico Mountains ecoregion and much of the Chihuahuan Desert ecoregion are not included in the ecosite analyses, which accounts for the smaller sample size in the Chihuahuan Desert ecoregion for these analyses. Sample size, means, and standard deviations are reported in Appendix E and discussed below by ecoregion, presented from west to east. Significant t-tests ($P < 0.05$) are reported in Tables 4 and 5; for t-test details, see Appendix E. For all metrics, we did not report data that was not statistically significant unless we noted an obvious pattern (i.e., potentially biologically significant). Ecosites that were represented in ≥10% of the total survey points for a region were included in the t-tests. Although results are presented for each ecoregion, we note that survey site selection was determined by recovery region (as suggested by USFWS 1996) and were not intended to be evenly distributed among ecoregions. For percent canopy cover and the proportion of ecosites surrounding our survey points, differences (change in %) reported are absolute.

Arizona/New Mexico Mountains

We did not detect any vireo in the Texas portion of this ecoregion (115 points surveyed). Average canopy cover was relatively high in this region (36%), and it was the only ecoregion with a negative (sidewardly concave) average planimetric curvature (Appendix E). Profile curvature and slope were comparable to other ecoregions. No ecosite information exists for survey points in this area.

Chihuahuan Deserts

Ecosites have not been mapped in the western portion of this ecoregion, thus our ecosite analyses include 124 fewer survey points (109 non-detections and 15 detections) than what was actually surveyed. Gravelly and Steep Rocky were the two most represented ecosites (32.1 and 27.5%, respectively). Although Draw was represented in only 19.8% of the points, it was represented in 88.9% of the detections (Appendix E) and differed between detections and non-detections by 58.1% (Table 5). We found no differences between points of non-detection and detection for our remote sensing metrics in this ecoregion although the number of vireo detections was small (Appendix E).

Edwards Plateau

The Edwards Plateau contained the highest number of points surveyed (1320) and the highest number of ecosites (28) compared to other ecoregions. Steep Rocky and Low Stony were the most common ecosite across all survey points (34.7% and 32.4% of points, respectively) and at vireo locations (56.1% and 50.3%, respectively; Appendix E). The proportion of Steep Rocky was 18.9% higher at detections than non-detections while the proportion of Low Stony Hill was 13.7% higher at detections than non-detections (Table 5). Clay Loam, Shallow, Sandy Loam, Limestone Hill, Redland, and Loamy Bottomland were also significantly different between detections and non-detections, but the mean differences were small (Table 5). Detections in the Edwards Plateau ecoregion occurred on slopes that averaged 10.8° lower than non-detections (Table 4). Profile curvature was 0.04°/100 m higher at detection points, and canopy cover was 5.0% lower at detections than non-detections (Table 4).

Southwestern Tablelands

Only 8 survey points occurred within the Southwestern Tablelands ecoregion and we did not detect vireos at any point. The ecosites most represented at survey points were Shallow (75% of points) and Clay Loam (62.5%). The average slope (1.4°) was the lowest of all the ecoregions (Appendix E).

Southern Texas Plains

We surveyed 16 points in the Southern Texas Plains. The Steep Rocky ecosite was represented at 81.3% of all survey points and 100% of the 8 detections. Low Stony Hill was represented at 50% of the survey points and 12.5% of the detections (Appendix E). Both ecosites had proportions that were significantly different between detections and non-detections; Steep Rocky had a difference of 59.5% and was higher at detections, and Low Stony Hill had a difference of 49.7% and was higher at non-detections (Table 5). Average canopy cover (1.7%) was the lowest in this ecoregion than other ecoregions (Appendix E). Profile curvature was 0.3°/100 m higher at detection points than non-detection points (Table 4).

Central Great Plains

The most represented ecosite in the Central Great Plains was Loamy Bottomland, occurring at 27% of the survey points (n = 159), closely followed by Clay Loam, which occurred at 26.4% of the survey points (Appendix E). The sample size of detections was low (n = 3), but Low Stony Hill was represented at all three vireo detection points. The proportion of Low Stony Hill was 66.4% higher at detections than non-detections, and the difference was significant, despite the low sample size of detections (Table 5). Clay Loam and Adobe were also represented at detections (Appendix E). Profile curvature was 0.05°/100 m lower at detections than non-detections, and canopy cover was 28.9% higher at detections than non-detections (Table 4).

Cross Timbers

Low Stony Hill, Clay Loam, and Adobe were represented most often at survey points (26.2%, 24.3%, and 22.6% of points, respectively; n = 478; Appendix E). Of the 27 vireo detections, Low Stony Hill was represented at 77.8%, and the proportion of Low Stony Hill was 29.7% higher at detections than non-detections by (Table 5). Adobe was represented at 59.3% of detections (Appendix E). Sandy Loam also showed a significant difference between detections and non-detections, but the difference was slight (5.3%; Table 5). Both profile curvature and planimetric curvature were lower at detection points than non-detection points (0.04 and 0.03°/100 m, respectively; Appendix E).

Texas Blackland Prairies

We surveyed 18 points in the Texas Blackland Prairies and did not detect vireos. Eroded Blackland was represented at 72.2% of the survey points, and Low Stony Hill was represented at 27.8% (Appendix E). Average canopy cover was highest in this ecoregion (42.7%) compared to other ecoregions (Appendix E).

All regions

Profile curvature and canopy cover showed statistically significant differences between detections and non-detections across all ecoregions (Table 4). Profile curvature was 0.27°/100 m lower at detections than non-detections, and canopy cover was 6.6% lower at detections (Table 4). Many ecosites showed statistically significant differences between detections and non-detections, but only Steep Rocky and Low Stony Hill had differences that were substantial. The proportions of Steep Rocky and Low Stony Hill were 19.6% and 17.9% higher, respectively, at detections versus non-detections (Table 5).

Table 4. Results of significant ($P < 0.05$) t-tests between detection and non-detection points (including means and standard errors) during our 2009 randomly-distributed surveys for remote sensing metrics averaged over a 100-m radius. Details of t-tests are reported in Appendix E.

		Detection				Non-detection			
		n	mean	SE		n	mean	SE	p
Edwards Plateau									
	Slope	189	10.473	1.487		1131	21.240	2.125	0.040
	Profile Curvature	189	0.067	0.013		1131	0.027	0.003	<0.001
	Canopy	189	12.843	1.372		1131	17.819	0.652	0.003
Southern Texas Plains									
	Profile Curvature	8	0.406	0.054		8	0.118	0.071	0.006
Central Great Plains									
	Profile Curvature	3	-0.042	0.028		156	0.010	0.004	0.046
	Canopy	3	53.048	10.987		156	24.111	1.865	0.034
Cross Timbers									
	Profile Curvature	27	-0.034	0.013		451	0.007	0.004	0.006
	Planimetric Curvature	27	-0.029	0.011		451	0.005	0.002	<0.001
Total (all regions)									
	Profile Curvature	251	0.070	0.012		2322	0.044	0.003	0.009
	Canopy	251	15.787	1.240		2322	22.400	0.464	<0.001

Table 5. Results of significant ($P < 0.05$) t-tests between detection and non-detection points (including means and standard errors) during our 2009 randomly-distributed surveys for ecosite proportions within a 100-m radius between detection and non-detection points. Details of t-tests are reported in Appendix E.

		Detection				Non-detection			
		n	mean	SE		n	mean	SE	p
Chihuahuan Desert									
	Draw	9	0.691	0.117		384	0.111	0.014	<0.001
Edwards Plateau									
	Steep Rocky	189	0.392	0.031		1131	0.203	0.011	<0.001
	Low Stony Hill	189	0.330	0.031		1131	0.193	0.011	<0.001
	Clay Loam	189	0.005	0.005		1131	0.079	0.007	<0.001
	Shallow	189	0.013	0.007		1131	0.083	0.007	<0.001
	Sandy Loam	189	0.001	0.001		1131	0.015	0.003	0.049
	Limestone Hill	189	0.000	0.000		1131	0.076	0.007	<0.001
	Redland	189	0.004	0.004		1131	0.058	0.007	0.001
	Loamy Bottomland	189	0.063	0.014		1131	0.022	0.003	<0.001
Southern Texas Plains									
	Steep Rocky	8	0.998	0.002		8	0.403	0.157	0.002
	Low Stony Hill	8	0.002	0.002		8	0.499	0.143	0.004
Central Great Plains									
	Low Stony Hill	3	0.802	0.100		156	0.138	0.026	0.001
Cross Timbers									
	Low Stony Hill	27	0.449	0.077		451	0.152	0.015	<0.001
	Sandy Loam	27	0.000	0.000		451	0.105	0.013	0.046
Total (all regions)									
	Steep Rocky	236	0.352	0.028		2156	0.156	0.007	<0.001
	Low Stony Hill	236	0.326	0.027		2156	0.147	0.007	<0.001
	Clay Loam	236	0.010	0.005		2156	0.074	0.005	<0.001
	Shallow	236	0.021	0.008		2156	0.064	0.005	0.003
	Sandy Loam	236	0.001	0.001		2156	0.039	0.004	0.001
	Limestone Hill	236	0.000	0.000		2156	0.066	0.005	<0.001
	Redland	236	0.009	0.006		2156	0.054	0.005	0.001
	Loamy Bottomland	236	0.053	0.012		2156	0.034	0.003	0.053
	Gravelly	236	0.004	0.003		2156	0.037	0.004	0.003
	Loamy	236	0.007	0.004		2156	0.027	0.003	0.032

Area-focused survey results

In 2010, we surveyed 6207 survey points within our 8 study areas between April and June; surveys occurred across 14 counties and 8 ecoregions. Vireos were detected within 100 m of 942 survey points (15.2 %; Table 6). The highest percent of detections relative to the number of points surveyed occurred at the Devil's River study area (detections at 176 of 652 points, or 27.0%), while the Fort Hood area had the lowest percentage of points with detections (detections at 191 of 2,037 survey points, or 9.4%; Table 6). The percent of survey points with detections generally decreased from west to east (Table 6). We detected 1,998 vireos both at and between survey points across all sites.

Table 6. Results from Texas A&M 2010 black-capped vireo surveys, including number of survey points, detections, and total vireos by study area. Total vireos include those that were detected more than 100 m from a point.

Study Area	**Survey points**	**Survey points with detection**	**Percent (%) of points with detections**	**Total no. vireos**
Devil's River	652	176	27.0	417
Kickapoo	1,009	249	24.7	443
Devil's Sinkhole	461	21	4.6	48
Taylor	38	6	15.8	23
Kerr	1,291	222	17.2	389
Mason	110	6	5.5	18
Balcones Canyonlands	609	71	11.7	207
Fort Hood	2,037	191	9.4	453
Total	6,207	942	15.2	1,998

Area-focused survey summary data

Aridity values (Table 7) were based on mean annual precipitation and mean annual potential evapotranspiration and differed by study area (Fig. 7). Sample size, means, and standard deviations for all other metrics are reported in Appendix F and discussed below by study area in order from west to east. Significant t-tests ($P < 0.05$) are reported in Tables 8 and 9. Since vegetation measurements were recorded at a subset of survey points, the numbers of survey points used in the analyses differed between remote sensing metrics and vegetation measurements (Appendix F). For all metrics, we did not report data that was not statistically significant unless we noted an obvious pattern (i.e., potentially biologically significant). Ecosites that were represented in ≥10% of the total survey points for a region were included in the t-tests. The reported differences (change in %) for percent canopy cover and the proportion of ecosites within 100m of the survey points are absolute.

Table 7. Mean aridity values of our all survey points within each of the 2010 study areas. Aridity is a ratio calculated as the mean annual precipitation over the mean annual potential evapotranspiration, multiplied by 10,000 (Fig. 7; Zomer et al. 2008). Higher aridity values correspond to wetter and cooler climates.

	Aridity	
Study Area	**Mean**	**Std. Dev**
Devil's River	3025.2	80.9
Kickapoo	3924.0	74.9
Devil's Sinkhole	4237.0	52.7
Kerr	4796.0	100.4
Taylor County	4651.0	74.6
Mason County	4434.2	65.7
Balcones Canyonlands	5609.7	86.3
Fort Hood	5590.1	160.8

Devil's River

At Devil's River, woody vegetation height at the top was significantly different between detection and non-detection points, but the difference was slight (0.25 m higher at detections; Table 8). The oak index was 0.15 higher at detections than non-detections, average slope was 1.9° higher at detections, and average profile curvature was 0.13°/100 m higher at detection points (Table 8). The proportion of Steep Rocky ecosite was 16% higher at the detection points (Table 9). Steep Rocky was represented in 162 of the 176 detection locations (92.0%; Appendix F), and 83 detection locations (47.2%) were 100% Steep Rocky. Low Stony Hill was 14% lower in the detection locations (Table 9). Low Stony Hill was represented in 45 of the 176 detections (25.6%; Appendix F). Of the detections, 118 (67%) had an average profile curvature > 0.

Kickapoo

At Kickapoo, vegetation height at the bottom was 0 at 151 of 242 (62.4%) detection points with vegetation surveys, but this height was only slightly lower (0.1 meters) at detections than non-detections (Table 8). Vegetation height at the top was significant but only slightly lower (0.4 meters) at detections than non-detections. The juniper index was 0.27 lower at detection points. Average slope was 1.2° higher at detection points than non-detections, and canopy closure was 5.6% lower at detection points. While statistically significant, profile curvature was only 0.02°/100 m greater at detection points (Table 8). Steep Rocky was represented in 132 of the 249 detections (53.0%; Appendix F) and was 10% higher at detections (Table 9). Low Stony Hill was represented at 121 (48.6%) of the survey points (Appendix F). 73.1% (182) of the survey points had an average profile curvature > 0.

Devil's Sinkhole

At Devil's Sinkhole, the oak index was 0.52 lower at detections than non-detections, and average slope was 3.9° higher at detections (Table 8). The Low Stony Hill ecosite was represented in 15 of the 21 detections (71.4%), but the difference between detections and non-detections was not significant. The proportion of Steep Rocky was 15% higher at the detection points (Table 9), and Steep Rocky was represented in 12 (57.1%) of the detection points (Appendix F).

Taylor

In Taylor Co., slope was significant and 4.2° greater at detection points, and planimetric curvature was 0.1°/100 m less at detections (Table 8). Steep Rocky was represented in 4 of the 6 detections (66.7%; Appendix F), but the difference in proportions between detections and non-detections was not significant (Appendix F). Four of the 6 had an average profile curvature mean < 0 (66.7%).

Kerr

At Kerr, the closeness of vegetation to the survey points averaged 1.5 m closer at detections than non-detections (indicating higher density of vegetation), height at the bottom was only slightly lower (0.3 m) at detections than non-detections, and height at the top was slightly lower (0.6 m) at detections than non-detections (Table 8). The proportion of Low Stony Hill was 10% higher at detections (Table 9) and was represented in 201 of the 222 detections (90.5%; Appendix F). Low Stony Hill comprised 100% of 96 (43.2%) of the detections (Appendix F).

Mason

In Mason Co., the vegetation height at the bottom was slightly lower (0.4 m) at detections than non-detections (Table 8). The average oak index increased by 1.1 at detections, and average slope was 2.3° greater at detections (Table 8). The proportion of Steep Adobe was 24% higher at detections (Table 9) and was represented in 4 of the 6 detections (66.7%; Appendix F). Five of the 6 detection points (83.3%) had an average profile curvature mean > 0.

Balcones Canyonlands

In the Balcones Canyonlands study site, the oak index was 0.54 higher at detections than non-detections (Table 8). Slope was 2.6° less at detection points, and the profile curvature was 0.03°/100 m less at detection points (Table 8). For profile curvature, 95% of the detections were less than 0.022. For planimetric curvature, 95% of the detections were less than 0.021. The proportion of Low Stony Hill ecosite was 46% higher at the detections (Table 9). Low Stony Hill was represented in 68 of the 71 survey points with detections (95.8 %; Appendix F). Sixty-three of the 71 detection points (88.7%) were composed of ≥ 50% Low Stony Hill and 52 detection points were entirely Low Stony Hill (73.2%). The proportion of Adobe was lower for the detections, differing by 27% (Table 9). Of the 71 detections, 57 (80.3%) were found in areas where the average slope was less than 3°.

Fort Hood

At Fort Hood, The vegetation was closer together at detections than non-detections by 1.5 m, (Table 8). While height at the bottom was significantly lower at detections than non-detections, the difference was small (0.1 m), and similarly, the juniper index was lower at detections than non-detections (Table 8). Slope, also, was only slightly higher at detections than non-detections (1.08°; Table 8). The proportion of Low Stony Hill ecosite was higher at the detections, differing by 10% (Table 9), and was represented in 114 of the 191 detections (59.7%;

Appendix F). The proportion of Adobe was 5% lower at the detections (Table 9). Adobe was represented at 88 detections (46.1%; Appendix F). The proportion of Redland also differed between detections and non-detections, but only by 4% (Table 9).

All locations

All metrics, except for Planimetric Curvature and Number Oak, were significant when looking at differences between detections and non-detections across the study areas (Table 8). Vegetation top height was 0.7 m lower at detections while vegetation height at the bottom averaged 0.2 m lower at detections than non-detections. The juniper index was slightly (0.15) lower at detections than non-detections (Table 8). Slope was 1.9° higher at detections than non-detections, and canopy cover was 3.2% lower at detections. Profile curvature was 0.03°/100 m higher at detections than non-detections, and distance to vegetation was 2.2 m less at detections.

Additionally, several ecosites had statistically significant differences between detections and non-detections (Table 9), but Steep Rocky is the only one that differed by >10%, the proportion of which was 14.9% higher at detections than non-detections (Table 9).

Table 8. Results of significant ($P < 0.05$) t-tests between detection and non-detection points (including means and standard errors) during the 2010 area-focused surveys for remote sensing metrics averaged over a 100-m radius. Details of t-tests are reported in Appendix F.

		Detection				Non-detection			
		n	mean	SE		n	mean	SE	p
Devil's River									
	Slope	176	13.776	0.454		476	11.860	0.303	0.001
	Profile Curvature	176	0.097	0.016		476	-0.031	0.010	< 0.001
	Veg Height - Top	174	2.039	0.062		468	1.791	0.029	< 0.001
	Oak Index	174	0.224	0.037		468	0.079	0.015	< 0.001
Kickapoo									
	Slope	249	8.788	0.272		760	7.547	0.162	< 0.001
	Canopy Cover	249	9.447	0.731		760	15.033	0.586	< 0.001
	Profile Curvature	249	0.038	0.008		760	0.019	0.005	0.052
	Veg Height - Top	242	2.644	0.052		754	3.022	0.036	< 0.001
	Veg Height - Bottom	242	0.163	0.019		754	0.235	0.013	0.004
	Juniper Index	242	1.649	0.080		754	1.920	0.048	0.005
Devil's Sinkhole									
	Slope	21	9.502	1.357		440	5.601	0.260	0.002
	Oak Index	21	0.476	0.148		421	0.998	0.055	0.037
Taylor									
	Slope	6	8.738	2.243		32	4.561	0.545	0.011
	Planimetric Curvature	6	-0.073	0.058		32	0.005	0.009	0.018
Kerr									
	Dist. to Veg	222	7.760	0.378		1069	9.248	0.221	0.004
	Veg Height - Top	222	3.212	0.082		1069	3.847	0.047	< 0.001
	Veg Height - Bottom	222	0.333	0.029		1069	0.623	0.018	< 0.001
Mason									
	Slope	6	4.858	0.940		104	2.608	0.143	0.001
	Veg Height - Bottom	6	0.298	0.152		104	0.717	0.048	0.044
	Oak Index	6	2.333	0.422		104	1.279	0.123	0.047
Balcones									
	Slope	71	2.765	0.329		538	5.392	0.175	< 0.001
	Profile Curvature	71	-0.028	0.007		538	0.001	0.004	0.010
	Oak Index	23	1.174	0.306		470	0.630	0.049	0.018
Fort Hood									
	Slope	191	4.650	0.255		1846	3.565	0.066	< 0.001
	Dist. to Veg	188	7.671	0.497		1803	9.252	0.211	0.031
	Veg Height - Bottom	188	0.497	0.037		1803	0.635	0.017	0.009
	Juniper Index	188	1.282	0.099		1803	1.505	0.033	0.035
Total (all locations)									
	Slope	942	7.320	0.181		5265	5.407	0.064	< 0.001
	Canopy Cover	942	22.577	0.785		5265	28.709	0.393	< 0.001
	Profile Curvature	942	0.028	0.004		5265	0.001	0.001	< 0.001
	Dist. To Veg	882	5.989	0.185		5121	8.151	0.109	< 0.001
	Veg Height - Top	882	2.919	0.044		5121	3.655	0.027	< 0.001
	Veg Height - Bottom	882	0.284	0.013		5121	0.476	0.008	< 0.001
	Juniper Index	882	1.319	0.044		5121	1.467	0.020	0.004

Table 9. Results of significant (*P* < 0.05) t-tests between detection and non-detection points (including means and standard errors) during the 2010 area-focused surveys for ecosite proportions within a 100-m radius. Details of t-tests are reported in Appendix F.

		Detection			Non-detection			
		n	mean	SE	n	mean	SE	p
Devil's River								
	Low Stony Hill	176	0.113	0.019	476	0.250	0.017	<0.001
	Steep Rocky	176	0.737	0.027	476	0.575	0.019	<0.001
Kickapoo								
	Steep Rocky	249	0.551	0.028	760	0.487	0.017	0.003
	Draw	249	0.011	0.006	760	0.033	0.006	0.038
	Shallow	249	0.058	0.012	760	0.133	0.011	<0.001
Devil's Sinkhole								
	Steep Rocky	21	0.326	0.086	440	0.173	0.016	0.040
Kerr								
	Low Stony Hill	222	0.660	0.026	1069	0.564	0.013	0.002
Mason								
	Adobe	6	0.289	0.115	104	0.049	0.014	<0.001
Fort Hood								
	Low Stony Hill	191	0.399	0.031	1846	0.293	0.009	0.001
	Adobe	191	0.178	0.020	1846	0.125	0.006	0.004
	Redland	191	0.087	0.018	1846	0.127	0.007	0.061
	Loamy Bottomland	191	0.003	0.003	1846	0.035	0.004	0.005
Balcones								
	Low Stony Hill	71	0.863	0.035	538	0.401	0.018	<0.001
	Adobe	71	0.068	0.023	538	0.342	0.018	<0.001
	Clay Loam	71	0.001	0.001	538	0.074	0.009	0.003
	Shallow	71	0.000	0.000	538	0.034	0.006	0.051
Total (all sites)								
	Low Stony Hill	942	0.429	0.014	5265	0.384	0.006	0.003
	Adobe	942	0.043	0.005	5265	0.080	0.003	<0.001
	Steep Rocky	942	0.329	0.014	5265	0.181	0.005	<0.001
	Redland	942	0.045	0.006	5265	0.076	0.003	<0.001
	Clay Loam	942	0.038	0.005	5265	0.079	0.003	<0.001
	Shallow	942	0.064	0.007	5265	0.101	0.004	<0.001

Spatial distribution

The results of the Getis-ord General G test indicated that the detection points are clustered (P < 0.05) at all of our study areas except Devil's River and Devil's Sinkhole (Table 10), where the pattern was not statistically different from random. We further determined that the clustering of both high and low values were not the cause of the insignificant P-values, as the Moran's I test indicated no clustering was occurring (Devil's River z-value = 0.479, p = 0.532, Devil's Sinkhole z-value = 0.270, p = 0.787).

Table 10. Results of the Getis-ord General G test to determine clustering of the vireo detections within each of our 8 study areas. Clustering was indicated in all study areas except Devil's Sinkhole and Devil's River, where the analysis indicated the pattern was not statistically different from random.

	General G			
	Observed	**Expected**	**Z-value**	**P-value**
Devil's River	0.002	0.002	0.475	0.634
Kickapoo	0.002	0.001	11.695	<0.001
Devil's Sinkhole	0.003	0.002	0.354	0.723
Taylor Co.	0.072	0.027	2.120	0.034
Kerr	0.002	0.001	12.677	<0.001
Mason Co.	0.039	0.008	11.069	<0.001
Balcones	0.004	0.002	17.758	<0.001
Fort Hood	0.001	0.000	33.654	<0.001

Predictive occurrence vegetation models

Devil's River

In the Devil's River study area we detected vireos at 174 of the 642 survey points at which we measured vegetation. After examining single effects, all combinations of additive models, and all interactions (Appendix H), 5 models were competitive with ΔAIC<2 (Table 11). The best approximating model included an additive effect of the vegetation height at the top and the oak index (Table 11). Examination of single effects models and model-averaging results supported the significance of these variables (Appendix H). Furthermore, model coefficient estimates suggested that the direction of effect of these variables was consistent because the 95% confidence intervals did not include 0 (Table 12). When the oak index increased from 0 to 2, predicted probability of vireo occurrence (PPO) increased from 0.25 to 0.59, holding the vegetation top height constant at its mean value of 1.86 m. When the vegetation height at the top increased from 1 to 5 m, PPO increased from 0.21 to 0.55, holding the oak index at its mean value of 0.12.

Table 11. Model selection results for models explaining vireo occurrence at Devil's River study area in 2010. We present models with ΔAIC<2.

	Deviance	AICc	ΔAIC
htTop + Oak	724.207	730.244	0.000
htTop + Oak + DistToVeg	722.991	731.054	0.810
htTop * Oak	723.988	732.051	1.807
htTop + Oak + Juniper	724.032	732.095	1.850
htTop + Oak + htBottom	724.116	732.179	1.935

Table 12. Beta (SE) and 95% confidence intervals for the best approximating model describing the effect of vegetation on predicted probability of black-capped vireo occurrence for Devil's River in 2010.

			95% CI	
Parameter	**B**	**SE**	**Lower**	**Upper**
Intercept	-1.824	0.260	-2.341	-1.312
Oak	0.742	0.232	0.293	1.207
htTop	0.385	0.129	0.131	0.639

Kickapoo

In the Kickapoo study area, we detected vireos at 242 of 996 points at which we measured vegetation. After examining single effects, all combinations of additive models, and all interactions (Appendix H), 6 models were competitive with ΔAIC<2 (Table 13). We considered the additive effect of the vegetation height at the top and the juniper index as the best approximating model describing PPO at Kickapoo. Although the variable vegetation height at bottom was included in the top AIC model, we did not consider this the best approximating model because it varied little from the second model (htTop + Juniper) indicating that htBottom did not contribute greatly to model approximation. We determined this based on evaluation of single effects, results from model averaging of all additive combinations (Appendix H), and model selection results (Table 13). Vegetation top height was included in all 6 of the competitive models and the juniper index was included in 5 of the top models (Table 13); however, model coefficient estimates did not indicate that the effects were consistent because the 95% CI included 0 (Table 14). When the juniper index increased from 0 to 4, PPO decreased from 0.27 to 0.19, holding the vegetation top height constant at its mean value of 2.93 m. When vegetation top height increased from 2 to 5 m, PPO decreased from 0.31 to 0.11, holding the juniper index at its mean value of 1.85.

Table 13. Model selection results for models explaining vireo occurrence at the Kickapoo study area in 2010. We present models with ΔAIC<2.

Model	Deviance	AICc	ΔAIC
htTop + Juniper + htBottom	1068.411	1076.451	0.000
htTop +Juniper	1070.455	1076.479	0.029
htTop + Juniper +htBottom + DistToVeg	1067.834	1077.894	1.443
htTop + Juniper + DistToVeg	1069.939	1077.980	1.529
htTop	1074.061	1078.073	1.622
htTop + Juniper + Oak	1070.387	1078.427	1.976

Table 14. Beta (SE) and 95% confidence intervals for the best approximating model describing the effect of vegetation on predicted probability of black-capped vireo occurrence for Kickapoo study area in 2010.

			95% CI	
Parameter	**β**	**SE**	**Lower**	**Upper**
Intercept	0.287	0.259	-0.218	0.799
Juniper	-0.112	0.059	-0.229	0.004
htTop	-0.433	0.09	0.613	-0.262

Devil's Sinkhole

In the Devil's Sinkhole study area we detected vireos at 21 of 442 points at which we measured vegetation. After examining single effects, all combinations of additive models, and all interactions (Appendix H), 6 models were competitive with ΔAIC<2 (Table 15). Each of the 6 top models included the oak index (Table 15) but model averaging of all additive combinations did not support a consistent effect on PPO (Appendix H). When the oak index increased from 1 to 4, PPO decreased from 0.07 to 0.01 (β = -0.56, 95% CI = -1.18, -0.072).

Table 15. Model selection results for models explaining vireo occurrence at Devil's Sinkhole study area in 2010. We present models with ΔAIC<2.

	Deviance	AICc	ΔAIC
Oak	163.744	167.772	0.000
Oak + Juniper	162.077	168.132	0.360
Oak + htBottom	163.219	169.274	1.502
Oak + Juniper + DistToVeg	161.328	169.419	1.648
Oak + Juniper + htBottom	161.378	169.470	1.698
Oak + DistToVeg	163.592	169.647	1.875
Oak + htTop	163.719	169.774	2.002

Kerr

In the Kerr study area we detected vireos at 22 of 1,291 points at which we measured vegetation. After examining single effects, all combinations of additive models, and all interactions (Appendix H), 4 models were competitive with ΔAIC<2 (Table 16). The best approximating model describing PPO included additive effects of vegetation bottom height, vegetation top height, and the oak index (Table 16) and model-averaging results supported the significance of these variables (Appendix H). Model coefficient estimates suggested that the direction of effect of these variables was consistent (Table 17). When the oak index increased from 0 to 4, PPO increased from 0.09 to 0.30, holding the vegetation height at both the bottom and at the top constant at their mean values (0.57 m and 3.74 m, respectively). When vegetation bottom height increased from 0 to 2 m, PPO decreased from 0.27 to 0.03, holding the oak index and vegetation top height constant at their mean values (1.6 and 3.74 m, respectively). When vegetation top height increased from 2 to 5 m, PPO decreased from 0.19 to 0.12, holding the other 2 variables at their constant mean value.

Table 16. Model selection results for models explaining vireo occurrence at the Kerr study area in 2010. We present models with ΔAIC<2.

Model	Deviance	AICc	ΔAIC
htBottom + Oak + htTop + DistToVeg	1094.784	1104.831	0.000
htBottom + Oak + htTop + Juniper	1095.181	1105.228	0.397
htBottom + Oak + htTop + DistToVeg + Juniper	1093.319	1105.385	0.554
htBottom + Oak + htTop	1098.511	1106.542	1.712

Table 17. Beta (SE) and 95% confidence intervals for the best approximating model describing the effect of vegetation on predicted probability of black-capped vireo occurrence for Kerr study area in 2010.

			95% CI	
Parameter	β	SE	Lower	Upper
Intercept	-0.992	0.215	-1.417	-0.573
Oak	0.385	0.067	0.254	0.518
htBottom	-1.325	0.231	-1.785	-0.881
htTop	-0.169	0.075	-0.317	-0.024

Balcones

In the Balcones Canyonlands study area we detected vireos at 23 of 493 (4.7%) survey points at which we measured vegetation. After examining single effects, all combinations of additive models, and all interactions (Appendix H), 5 models were competitive (ΔAIC<2; Table 18). The best approximating model included an interaction between distance to vegetation and the juniper index, and an additive effect of the oak index (Table 18). Model coefficient estimates suggested that the direction of effect of these variables was consistent (Table 19). When the oak index increased from 0 to 4, PPO increased from 0.05 to 0.14, holding the juniper index and distance to the vegetation constant at their mean (2.08 and 10.82 m, respectively). The interaction between the distance to the vegetation and the juniper index indicated a varying effect of each variable on PPO depending on the level of the other variable (Fig. 8). For example, when the distance to the vegetation increased and the juniper index = 0, PPO decreased by 29%, but when the juniper index = 4, PPO increased from 0.01 to 0.31 (Fig. 8).

Table 18. Model selection results for models explaining vireo occurrence at the Balcones study area in 2010. We present models with ΔAIC<2.

	Deviance	AICc	ΔAIC
DistToVeg * Juniper + Oak + htTop	161.861	174.034	0.000
DistToVeg * Juniper + Oak	164.332	174.456	0.422
DistToVeg * Juniper + Oak + htBottom	162.313	174.486	0.452
DistToVeg * Juniper	167.093	175.175	1.142
DistToVeg * Juniper + Oak + htTop + htBottom	161.174	175.405	1.371

Table 19. Beta (SE) and 95% confidence intervals for the best approximating model describing the effect of vegetation on predicted probability of black-capped vireo occurrence for the Balcones study area in 2010.

			95% CI	
Parameter	**β**	**SE**	**Lower**	**Upper**
Intercept	-1.840	0.637	-3.207	-0.682
Oak	0.311	0.185	-0.057	0.681
DistToVeg	-0.122	0.045	-0.217	-0.039
Juniper	-0.858	0.269	-1.404	-0.337
DistToVeg * Juniper	0.083	0.022	0.043	0.129

Fort Hood

In the Fort Hood study area we detected vireos at 188 of 1,991 survey points at which we measured vegetation. After examining single effects, all combinations of additive models, and all interactions (Appendix H), 5 models were competitive (ΔAIC<2; Table 20). The best approximating model included an interaction between distance to the vegetation and the juniper index, and an additive effect of vegetation bottom height. Model coefficient estimates suggested that the direction of effect of these variables was consistent because the 95% confidence intervals did not include 0 (Table 21). When vegetation bottom height increased from 0 to 2 m, PPO decreased by 50% (0.12 to 0.06), holding the juniper index and distance to the vegetation constant at their mean (1.484 and 9.01 m, respectively). Distance to the vegetation interacted with the juniper index in that as the juniper index increased, the effect of distance changed from negative to positive (Fig. 9). For example, when the juniper index = 0, PPO decreased by 42% with an increase in distance to the vegetation from 1 m to 12 m. But when the juniper index = 4, PPO increased by 70% with an increase in distance to the vegetation from 1 m to 12 m.

Table 20. Model selection results for models explaining vireo occurrence at the Fort Hood study area in 2010. We present models with ΔAIC<2.

Model	Deviance	AICc	Delta	Weight
DistToVeg * Juniper + htBottom	1211.311	1221.341	0.000	0.255
DistToVeg * Juniper + htBottom + htTop	1209.355	1221.397	0.056	0.247
DistToVeg * Juniper + htTop	1212.025	1222.055	0.714	0.178
DistToVeg * Juniper + htBottom + htTop + Oak	1209.234	1223.290	1.950	0.096
DistToVeg * Juniper + htBottom + Oak	1211.294	1223.336	1.995	0.094

Table 21. Beta (SE) and 95% confidence intervals for the best approximating model describing the effect of vegetation on predicted probability of black-capped vireo occurrence for Fort Hood study area in 2010.

			95% CI	
Parameter	**β**	**SE**	**Lower**	**Upper**
Intercept	-1.301	0.179	-1.656	-0.955
htBottom	-0.391	0.139	-0.675	-0.13
DistToVeg	-0.057	0.014	-0.086	-0.03
Juniper	-0.377	0.086	-0.548	-0.21
DistToVeg * Juniper	0.027	0.009	0.009	0.044

Predictive occurrence remote-sensing models & model evaluation

Devil's River

We constructed additive and interactive effect models that included 4 ecosites (Low Stony Hill, Steep Rocky, Loamy Bottomland, and Shallow), slope, canopy, profile curvature, and planimetric curvature. Nine models were competitive (i.e., ΔAIC<2; Table 22) and each competitive model contained profile curvature. Because of the model uncertainty (i.e., no single model was strongly supported), we selected the model that included additive effects of profile curvature and proportion of Steep Rocky because the Steep Rocky ecosite was the most dominant ecosite in our sample from Devil's River (Appendix F). Additional assessment of our data indicated that the effect of Steep Rocky was opposite the additive effect of Low Stony Hill and Loamy Bottomland (Appendix H). Although slope was not selected as a significant variable alone, slope correlated positively with proportion of Steep Rocky (r = 0.751; Appendix G).

Model coefficient estimates suggested that the direction of effect of profile curvature and Steep Rocky were positive and consistent because the 95% confidence intervals do not overlap 0 (Table 23). For example, when proportion of Steep Rocky increased from 0.2 to 0.9, PPO increased from 0.20 to 0.26, when profile curvature was held constant at its mean of 0.004. When profile curvature changed from -0.2 to 0.2, PPO increased from 0.19 to 0.33, holding the proportion of Steep Rocky was held constant at its mean of 0.62.

Table 22. Model selection results for additive and interactive effects models explaining probability of occurrence of black-capped vireos in Devil's River study area in 2010. We present only models with ΔAIC<2. Profile curvature is abbreviated as Profile and Low Stony Hill is abbreviated as LSH.

Model	Deviance	AICc	ΔAIC
Profile + LSH + Loamy Bottomland	708.391	716.452	0.000
Profile + Steep Rocky	710.759	716.796	0.343
Profile + Steep Rocky + Shallow	709.333	717.395	0.942
Profile + LSH + Loamy Bottomland + Slope	707.879	717.972	1.520
Profile + Loamy Bottomland + Steep Rocky	710.010	718.072	1.619
Profile + LSH + Loamy Bottomland + Shallow	708.162	718.255	1.803
Profile * Slope	710.220	718.220	1.768
Profile + LSH + Loamy Bottomland + Steep Rocky	708.216	718.308	1.856
Profile + LSH + Loamy Bottomland + Planimetric	708.252	718.345	1.892

Table 23. Beta (SE) and 95% confidence intervals for the model Steep Rocky + Profile curvature for Devil's River study area in 2010.

			95% CI	
Coefficients	β	SE	Lower	Upper
(Intercept)	-1.501	0.189	-1.731	-0.305
Steep Rocky	0.658	0.247	0.179	1.150
Profile	2.279	0.445	1.422	3.169

Model projection

We used the best approximating model (Profile curvature + proportion of Steep Rocky, see above) to project the probability of vireo occurrence across the Devil's River study area (Fig. 10), which encompassed approximately 158,400 ha. Mean predicted probability of occurrence was 0.26 (*N* = 39,984 pixels; Appendix G).

Model evaluation

We evaluated the ability of the model to predict occurrence by comparing the probability of occurrence estimates from the selected model with 2010 survey results (training data set). In 2010, we surveyed 652 points in the Devil's River study area. The overall positive prevalence of vireos from the 2010 data set was 27%. Mean probability of occurrence for all survey points was 0.27 (*N* = 652; Appendix G). At points at which we detected a vireo, mean probability of occurrence was higher (mean = 0.309, *N* = 176) than at points at which we did not detect a vireo (mean = 0.258, *N* = 476; Appendix G).

We evaluated the model using an independent data set from surveys conducted during the randomly-distributed surveys in 2009. In 2009, we surveyed at 86 points in the Devil's River study area. The overall positive prevalence of vireos was 48%. Mean probability of occurrence for all survey points was 0.30 (*N* = 86; Appendix G). At points at which we detected a vireo, mean probability of occurrence was higher (mean = 0.335, *N* = 41) than at points at which we did not detect a vireo (mean = 0.271, *N* = 45; Appendix G and H).

Kickapoo

We constructed additive and interactive effect models that included 3 ecosites (Low Stony Hill, Steep Rocky, and Shallow), slope, canopy, profile curvature, and planimetric curvature. After examining single effects, all combinations of additive models, and all interactions (Appendix H), 2 models were competitive with ΔAIC<2 (Table 24). The best approximating model included an interaction between the proportion of Shallow ecosite and slope (Table 24). In our sample, Shallow was included in only 19.3% (Appendix F) of our samples; thus, for areas where Shallow was not represented the logistic regression model was reduced to an additive model of canopy + profile curvature + slope, consistent with model-averaging results (Appendix H). However, the interaction indicated that the effect of slope varied relative to the proportion of Shallow ecosite in the area (Table 25), in that there was a stronger effect of slope when there was a higher proportion of Shallow ecosite in the area (Fig. 11). For example, if the proportion of Shallow = 0 then there was a 51% increase in PPO when the slope increased from 4 to 11, but if the proportion of Shallow = 0.9 then PPO was 6.7 times higher when slope increased from 4 to 11 (Fig. 11). When canopy cover increased from 1 to 50, PPO decreased from 0.36 to 0.08, holding Shallow, profile curvature, and slope constant at their mean value (0.11, 0.024, and 7.8°, respectively). When profile curvature increased from -0.4 to 0.4, PPO increased from 0.16 to 0.37, holding Shallow, canopy cover, and slope constant at their mean value (0.11, 13.7, and 7.8°, respectively).

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Table 24. Model selection results for additive and interactive effects models explaining probability of occurrence of black-capped vireos in Kickapoo study area in 2010. We present only models with ΔAIC<2 and the next highest AIC model for comparison.

Model	Deviance	AICc	ΔAIC
Canopy + Profile + Slope * Shallow	1046.545	1058.629	0.000
Canopy + Profile + Slope * Shallow + Steep Rocky	1045.516	1059.628	0.999

Table 25. Coefficients (standard error) and 95% confidence intervals for the best approximating model predictive vireo occurrence in the Kickapoo study area in 2010.

			95% CI	
Parameter	**β**	**SE**	**Lower**	**Upper**
Intercept	-1.240	0.185	-1.608	-0.882
Canopy	-0.039	0.007	-0.053	-0.027
Profile	1.463	0.568	0.358	2.588
Slope	0.075	0.019	0.038	0.113
Shallow	-2.343	0.747	-3.987	-1.021
Shallow * Slope	0.381	0.135	0.128	0.664

Model projection

We used the best approximating model (Canopy + Slope + Profile curvature + Shallow + Shallow *Slope, see above) to project the probability of vireo occurrence across the Kickapoo study area (Fig. 12), which encompassed approximately 194,880 ha. Mean predicted probability of occurrence was 0.224 (N = 49,163 pixels; Appendix G).

Model evaluation

We evaluated the ability of the model to predict occurrence by comparing the probability of occurrence estimates from the selected model with 2010 survey results (training data set). In 2010, we surveyed 1,009 points in the Kickapoo study area. The overall positive prevalence of vireos was 25%. Mean probability of occurrence for all survey points was 0.25 (N = 1,009; Appendix G). At points at which we detected a vireo, mean probability of occurrence was higher (mean = 0.298, N = 249) than at points at which we did not detect a vireo (mean = 0.229, N = 760; Appendix G and H). To examine predictive errors we binned predicted probability of occurrence at a threshold of 0.25 based on the median value of the range of predicted probabilities (Appendix G).

We evaluated the model using an independent data set from surveys conducted during the randomly-distributed surveys in 2009. In 2009, we surveyed 63 points in the Kickapoo study area. The overall positive prevalence of vireos was 40%. Mean probability of occurrence for all survey points was 0.23 (N = 63; (Appendix G). There was no difference in probability of occurrence at points where we detected a vireo and non-detection points (mean = 0.229, N = 25; mean = 0.23, N = 39; Appendix G and H).

Devil's Sinkhole

We constructed additive and interactive effect models that included 3 ecosites (Low Stony Hill, Steep Rocky, 3 and Shallow), slope, profile curvature, and planimetric curvature. Slope significantly correlated with Canopy Cover (r = 0.688) and proportion of Steep Rocky ecosite (r = 0.849; Appendix G). Examination of single effects models indicated that slope predicted vireo occurrence better than canopy cover or Steep Rocky, thus we did not include these in any additive or interactive effects models. Model selection resulted in 2 competitive models (ΔAIC<2; Table 26). The best approximating model included an interaction between the proportion of Shallow ecosite and slope (Table 26). In our sample, Shallow was included in only 20.6% (Appendix F) of our samples, thus for areas where Shallow was not represented the logistic regression model was reduced to the single effect of Slope, consistent with model-averaging results (Appendix H). However, the interaction indicated that the effect of slope varied relative to the proportion of Shallow ecosite in the area (Table 27). The effect of slope was more evident when there was a high proportion of Shallow ecosite in the area (Fig. 13).

Table 26. Model selection results for additive and interactive effects models explaining probability of occurrence of black-capped vireos in Devil's Sinkhole study area in 2010. We present only models with ΔAIC<2.

Model	Deviance	AICc	ΔAIC
Slope * Shallow	157.100	165.100	0.000
Slope	162.400	166.426	1.326

Table 27. Coefficients (standard error) and 95% confidence intervals for the best approximating model predictive vireo occurrence in the Devil's Sinkhole study area in 2020.

			95 % CI	
Parameter	**β**	**SE**	**Lower**	**Upper**
Intercept	-3.748	0.433	-4.678	-2.968
Shallow	-1.023	1.350	-4.311	1.216
Slope	0.089	0.037	0.014	0.163
Shallow * Slope	0.644	0.438	0.068	1.769

Model projection

We used the best approximating model (Steep Rocky + Shallow + Slope + Shallow*Slope, see above) to project the probability of vireo occurrence across the Devil's Sinkhole study area, which encompassed approximately 183,912 ha (Fig. 14). Mean predicted probability of occurrence was 0.04 (*N* = 46,410 pixels; Appendix G).

Model evaluation

We evaluated the ability of the model to predict occurrence by comparing the probability of occurrence estimates from the selected model with 2010 survey results (training data set). In 2010, we surveyed at 461 points in the Devil's Sinkhole study area. The overall positive prevalence of vireos from the 2010 data set was 5%. Mean probability of occurrence for all survey points was 0.05 (*N* = 461; Appendix G). At points at which we detected a vireo, mean probability of occurrence was similar (mean = 0.01, *N* = 21) to points at which we did not detect a vireo (mean = 0.05, *N* = 440; Appendix G and H).

We evaluated the model using an independent data set from surveys conducted during 2009. In 2009, we surveyed at 68 points in the Devil's Sinkhole study area. The overall positive prevalence of vireos was 23%. Mean probability of occurrence for all survey points was 0.03 (*N* = 68; (Appendix G). At points at which we detected a vireo, mean probability of occurrence was similar (mean = 0.04, *N* = 38) than at points at which we did not detect a vireo (mean = 0.03, *N* = 30; Appendix G and H).

Kerr

We constructed additive and interactive effect models that included 4 ecosites (Low Stony Hill, Steep Rocky, Redlands, and Shallow), slope, canopy, profile curvature, and planimetric curvature. The best approximating model included an interaction between Low Stony Hill and Redland with the additive effect of profile curvature (Table 28). The interaction between Low Stony Hill and Redland ecosite indicated that the effect of one depended upon the proportion of the other ecosite. For Low Stony Hill, the effect was consistent based on coefficients and 95% CI for the best approximating model because the 95% CI do not overlap 0 (Table 29). The effect of Redland on PPO is inconsistent, as indicated by 95% CI that overlap 0 (Table 29) and by the example using varying levels of the proportions of ecosites (Fig. 15). For example, when there is no Low Stony Hill in the area, PPO decreased by 37% when proportion of Redland increased from 0 to 0.9; however, when the proportion of Low Stony Hill in the area was 0.5, PPO was twice as high when proportion of Redland was 0.5 (Fig. 15).

Table 28. Model selection results for additive and interactive effects models explaining probability of occurrence of black-capped vireos in Kerr study area in 2010. We present only models with ΔAIC<2. Low Stony Hill is abbreviated as LSH.

Model	Deviance	AICc	ΔAIC
LSH * Redland + Profile	1157.900	1167.900	0.000
LSH * Redland + Profile + Canopy	1156.300	1168.300	0.400
LSH * Redland	1160.900	1168.900	1.000
LSH * Redland + Canopy	1159.400	1169.400	1.500

Table 29. Coefficients (standard error) and 95% confidence intervals for the best approximating model predictive vireo occurrence in the Kickapoo study area in 2020.

			95% CI	
Parameter	β	SE	Lower	Upper
Intercept	-1.960	0.182	-2.330	-1.615
Profile	1.975	1.138	-0.267	4.199
LSH	0.532	0.219	0.109	0.971
Redland	-0.559	0.403	-1.388	0.200
LSH * Redland	5.087	1.343	2.440	7.727

Model projection

We used the best approximating model (Low Stony Hill + Profile curvature + Redland + Low Stony Hill*Redland, see above) to project the probability of vireo occurrence across the Kerr study area (Fig. 16), which encompassed approximately 322,894 ha. Mean predicted probability of occurrence was 0.16 (N = 80,652 pixels; Appendix G).

Model evaluation

We evaluated the ability of the model to predict occurrence by comparing the probability of occurrence estimates from the selected model with 2010 survey results (training data set). In 2010, we surveyed at 1,291 points in the Kerr study area. The overall positive prevalence of vireos from the 2010 data set was 17%. Mean probability of occurrence for all survey points was 0. 172 (N = 1,291; Appendix G). At points at which we detected a vireo, mean probability of occurrence was similar (mean = 0.19, N = 222) to points at which we did not detect a vireo (mean = 0.168, N = 1,069; Appendix G and H). We had no survey data from the randomly-distributed surveys in 2009 to compare against.

Balcones

We considered models that included Low Stony Hill, Adobe, slope, canopy, profile curvature, and planimetric curvature. Eight models were competitive (ΔAIC<2; Table 30). We selected as the best approximating model the interactive effects model of Low Stony Hill and profile curvature without additive effects of planimetric curvature and slope because including them did not change the explanatory power of the model (AIC values were all within 0.24). The interaction between Low Stony Hill and profile curvature indicate that the effect of profile curvature changes as the proportion of Low Stony Hill in the area increases (Table 31). For example, when the proportion of Low Stony Hill was 0 and when profile curvature increased from -0.2 to 0.2, PPO declined by 98% (Fig. 17). Alternatively, at a higher proportion of Low Stony Hill (e.g., 0.9), PPO increased from 0.15 to 0.22 when profile curvature increased from -0.2 to 0.2. We did not predict to values of profile curvature >0 when Low Stony Hill > 0.5 because our data indicated that as Low Stony Hill increased, the range of values for profile curvature were restricted values closer to 0 (Appendix H).

Table 30. Model selection results for additive and interactive effects models explaining probability of occurrence of black-capped vireos in Balcones study area in 2010. We present only models with ΔAIC<2 and the next highest AIC model for comparison. Low Stony Hill is abbreviated as LSH.

Model	Deviance	AICc	ΔAIC
LSH * Profile + Planimetric + Slope	352.590	364.590	0.000
LSH * Profile + Planimetric	354.740	364.740	0.150
LSH * Profile	356.830	364.830	0.240
LSH + Planimetric + Slope	357.423	365.489	0.899
LSH	361.711	365.730	1.140
LSH + Planimetric	359.729	365.768	1.178
LSH * Slope + Planimetric	355.920	365.920	1.330
LSH * Profile + Slope	355.920	365.920	1.330

Table 31. Coefficients (standard error) and 95% confidence intervals for the best approximating model predictive vireo occurrence in the Balcones study area in 2010.

			95% CI	
Parameter	**β**	**SE**	**Lower**	**Upper**
Intercept	-4.170	0.455	-5.196	-3.382
Low Stony Hill	3.230	0.504	2.337	1.345
Profile	-10.190	4.840	-19.810	-0.907
LSH * Profile	14.100	6.871	1.167	27.991

Model projection

We used the best approximating model (Profile curvature + proportion of Low Stony Hill + proportion of Loamy Bottomland, see above) to project the probability of vireo occurrence across the Balcones study area (Fig. 18), which encompassed approximately 174,347 ha. Mean probability of occurrence across the region was 0.058 (*N* = 43,681, Appendix G).

Model evaluation

We evaluated the ability of the model to predict occurrence by comparing the probability of occurrence estimates from the selected model with 2010 survey results (training data set). In 2010, we surveyed at 610 points in the Balcones study area. The overall positive prevalence of vireos from the 2010 data set was 12%. Mean probability of occurrence for all survey points was 0.122 (*N* = 610; Appendix G). At points at which we detected a vireo, mean probability of occurrence was higher (mean = 0.225, *N* = 72) than at points at which we did not detect a vireo (mean = 0.107, *N* = 538; Appendix G and H). There were no detections of vireos during surveys in this study area in the randomly-distributed surveys in 2009.

Fort Hood

We considered single effects, additive and interactive models that included 4 ecosites (Adobe, Low Stony Hill, Clay Loam, and Shallow), slope, canopy, profile curvature, and planimetric curvature. The proportion of Adobe correlated with slope (r = 0.679), and we did not consider Adobe in our combination models because the single effect of slope was more predictive (Appendix G). There were 3 competitive models when we included additive and interaction models and Low Stony Hill and slope were included in each of these (Table 32; Appendix G). The best approximating model included an interaction between slope and profile curvature and additive effects of Low Stony Hill and canopy cover (Tables 32 and 33). The interaction indicated that PPO is influenced by slope in a positive trend but that the effect of profile curvature is inconsistent (Fig. 19). When the proportion of Low Stony Hill increased from 0 to 0.9, PPO increased from 0.07 to 0.12, holding all other variables constant at their mean. When canopy cover increased from 10 to 70%, PPO decreased from 0.10 to 0.07, holding all other variables constant at their mean.

Table 32. Model selection results for additive and interactive effects models explaining probability of occurrence of black-capped vireos in Fort Hood study area in 2010. We present only models with $\Delta AIC<2$ and the next highest AIC model for comparison. Low Stony Hill is abbreviated as LSH.

Model	Deviance	AICc	ΔAIC
LSH + Canopy + Slope * Profile	1224.500	1236.500	0.000
LSH + Slope + Canopy	1229.703	1237.700	1.222
LSH + Slope * Profile	1228.300	1238.300	1.800
LSH + Slope + Canopy + Clay Loam	1228.765	1238.800	2.290

Table 33. Coefficients (standard error) and 95% confidence intervals for the best approximating model predictive vireo occurrence in the Fort Hood study area in 2010.

			95% CI	
Parameter	**β**	**SE**	**Lower**	**Upper**
Interaction	-2.847	0.157	-3.162	-2.547
Low Stony Hill	0.721	0.229	0.269	1.170
Canopy	-0.006	0.003	-0.011	0.000
Slope	0.128	0.025	0.078	-0.177
Profile	-5.555	2.459	-10.349	-0.693
Slope * Profile	0.591	0.264	0.070	1.110

Model projection

We used the best approximating model (Low Stony Hill + Slope + Canopy + Profile curvature + Slope * Profile curvature, see above) to project the probability of vireo occurrence across the Fort Hood study area (Fig. 20), which encompassed approximately 922,374 ha. Mean probability of occurrence for the region was 0.07 (*N* = 158,400; Appendix G).

Model evaluation

We evaluated the ability of the model to predict occurrence by comparing the probability of occurrence estimates from the selected model with 2010 survey results (training data set). In 2010, we surveyed at 2,037 points in the Fort Hood study area. The overall positive prevalence of vireos from the 2010 data set was 9%. Mean probability of occurrence for all survey points was 0.094 (*N* = 2,037; Appendix G). At points at which we detected a vireo, mean probability of occurrence was similar (mean = 0.11, *N* = 191) to points at which we did not detect a vireo (mean = 0.092, *N* = 1,846; Appendix G and H).

We evaluated the model using an independent data set from surveys conducted during the randomly-distributed surveys in 2009. In 2009, we surveyed at 82 points in the Fort Hood study area. The overall positive prevalence of vireos was 17%. Mean probability of occurrence for all survey points was 0.10 (*N* = 82; (Appendix G). At points at which we detected a vireo, mean probability of occurrence was higher (mean = 0.127, *N* = 14) than at points at which we did not detect a vireo (mean = 0.098, *N* = 68; Appendix G and H).

Range-wide predictive model

We constructed additive and interactive effects models that included Low Stony Hill, Steep Rocky, Redlands, Clay Loam, Adobe, and Shallow ecosites, and slope, canopy, profile curvature, and planimetric curvature. Two models were competitive (ΔAIC<2; Table 34) after we evaluated all possible interactive effects. The best approximating model included an interaction between the aridity index and the proportion of Low Stony Hill, and the additive effects of profile curvature, slope, canopy cover, and the proportion of Steep Rocky (Tables 34 and 35). The interaction between Aridity and Low Stony Hill indicated that in more arid environments (low aridity index), PPO decreased with increasing proportion of Low Stony Hill in the area; however, in less arid environments (high aridity index) PPO increased with increasing proportion of Low Stony Hill in the area (Fig. 21).

Table 34. Model selection results for additive and interactive effects models explaining probability of occurrence of black-capped vireos in Texas, 2010. We present only models with ΔAIC<15. Low Stony Hill is abbreviated as LSH.

Model	Deviance	AICc	Delta
Aridity*LSH + Profile + Slope + Canopy + Steep Rocky	4968.934	4984.957	0.000
Aridity*LSH + Profile + Slope + Canopy + Steep Rocky + Planimetric	4968.841	4986.870	1.913
Aridity*LSH + Profile + Slope + Canopy	4975.659	4989.677	4.721
Aridity*LSH + Profile + Slope + Canopy + Planimetric	4975.612	4991.636	6.679
Aridity*LSH + Profile + Slope + Steep Rocky	4985.885	4999.903	14.946

Table 35. Coefficients (standard error) and 95% confidence intervals for the best approximating model predicting vireo occurrence in Texas, 2010.

			95% CI	
Parameter	β	SE	Lower	Upper
Intercept	-0.636	0.373	-1.378	0.087
Low Stony Hill	-2.205	0.546	-3.276	-1.135
Aridity	0.000	0.000	-0.001	0.000
Steep Rocky	0.420	0.162	0.103	0.737
Slope	0.044	0.010	0.024	0.064
Canopy Cover	-0.007	0.007	-0.010	-0.004
Profile	1.663	0.293	1.092	2.243
Low Stony Hill * Aridity	-0.001	0.000	0.000	0.001

Model projection

We used the best approximating model (Low Stony Hill + Aridity + Steep Rocky + Slope + Canopy + Profile curvature + Low Stony Hill * Aridity, see above) to project the probability of vireo occurrence across the breeding range, which encompassed approximately 19,500,000 ha (Fig. 22). We did not project to the Chihuahuan Desert west of Devil's River, as we felt that we did not have sufficient data for that area. For comparison, we provide maps of the different study areas with the range-wide model output (Figs. 23-28), displayed at the same spatial extent as our regional model maps.

Model evaluation

We evaluated the ability of the model to predict occurrence by comparing the probability of occurrence estimates from the selected model with 2010 survey results (training data set). In 2010, we surveyed at 6,236 points across the breeding range in Texas. The overall positive prevalence of vireos from the 2010 data set was 15% (Table 36). Mean probability of occurrence for all survey points was 0.15 (N = 6,236; Appendix G). At points at which we detected a vireo, mean probability of occurrence was similar (mean = 0.19, *N* = 958) to points at which we did not detect a vireo (mean = 0.143, *N* = 5,278; Appendix G and H).

We evaluated the model using an independent data set from surveys conducted during the randomly-distributed surveys in 2009. In 2009, we surveyed at 2,570 points across the breeding range in Texas. The overall positive prevalence of vireos was 9% (Table 37). Mean probability of occurrence for all survey points was 0.18 (*N* = 2,570; Appendix G). At points at which we detected a vireo, mean probability of occurrence was higher (mean = 0.22, *N* = 252) than at points at which we did not detect a vireo (mean = 0.176, *N* = 2,318; Appendix G and H).

Table 36. Summary of the actual versus predicted data when the range-wide model was assessed using the 2010 data set.

		Actual	
		1	0
Predicted	1	646	2279
	0	312	2999

prevalence	0.154
correct classification rate	0.585
omission (false neg.)	0.326
commission (false pos.)	0.432
positive pred power	0.221
negative pred power	0.906
sensitivity	0.674
specificity	0.568

Table 37. Summary of the actual versus predicted data when the range-wide model was assessed using the 2009 randomly-distributed data.

		Actual	
		1	0
Predicted	1	178	1082
	0	74	1236

prevalence	0.098
correct classification rate	0.550
omission (false neg.)	0.294
commission (false pos.)	0.467
positive pred power	0.141
negative pred power	0.944
sensitivity	0.706
specificity	0.533

Bayesian network results

Remote-sensing scale

As an example application of our BBN, consider the remote-sensing scale network compiled for the Balcones study area (Fig. 29). The basic underlying structure of this network is a logistic regression model wherein the response variable (at this scale) is the likelihood of a site being potential habitat for a vireo (labeled as Vireo Susceptibility). The biological metrics used were those selected from a set of potential candidate models to build our regression models (see *Methods*). Each node represents the distribution of the input data, bounded appropriately at the upper and lower ranges, and following a normal distribution (mean, sd); other distributions could have been used for the range of the input data, but a normal distribution provides adequate coverage. Values associated with the histogram bars represent the probability that the parameter is in a particular state.

Each node has an arrow extending from it into the response node (Vireo Susceptibility). Each arrow (vertex) represents causality, or that node A affects node B (e.g., proportion of Low Stony Hill affects Vireo Susceptibility). As this BBN is based on an underlying logistic regression which included main effects for Profile Curvature and Proportion of Low Stony Hill, arrows extend from each node into the response node. The mean estimate predicted for each node is located at the bottom of each box; for instance, the mean estimate for Vireo Susceptibility at the initialized state in Balcones is 0.184 (Fig. 29).

When the BBN is initially parameterized, it can be looked at in a general If – Then format. For instance, if Profile Curvature is X, then Vireo Susceptibility is Y. If one changes the value for Profile Curvature to some value, then the resultant change is seen in the distribution of predictions for Vireo Susceptibility (Fig. 30). For instance, if we set the Profile Curvature between -1 and -0.5, Vireo Susceptibility shifts up to 0.479 (Fig. 30-A). If we set Profile

Curvature between 0.5 and 1, however, the predictions for Vireo Susceptibility decrease to 0.147 (Fig. 30-B).

Similarly, within the Devil's River study area, Profile Curvature and Steep Rocky influence Vireo Susceptibility (Fig. 31). In this region, Profile Curvature has an opposite effect. If we set Profile Curvature to be negative (here, -0. 5 to -0.25), the predicted value for Vireo Susceptibility is only 0.128 (Fig. 32-A). However, if we set Profile Curvature to be positive (0.25 to 0.5), the probability of Vireo Susceptibility increases to 0.301 (Fig. 32-B).

The reason the prediction is not exact for Vireo Susceptibility is that there is uncertainty in the values for Steep Rocky, and additionally because the bins are not unique single values (e.g., 0.5 to 0.75 includes values like 0.62 and 0.71, each providing a different prediction for Vireo Susceptibility). If we set Steep Rocky to 0 to 0.1 (meaning we are outside Steep Rocky ecosite) and keep Profile Curvature the same (0.25 to 0.5), the prediction for Vireo Susceptibility rises to 0.234 (Fig. 33-A) . If we are entirely within Steep Rocky (set to 0.9 to 1), the predicted Vireo Susceptibility rises only slightly to 0.359 (Fig. 33-B). Yet, even with both input metrics set, the prediction still is uncertain. Thus, while we are incorporating uncertainty into our predictions, we are also allowing for the benefit of additional information to be directly incorporated into our models which tend to reduce overall uncertainty in predictions.

Thus, using a BBN we can predict or identify, given some necessary level of the response, what conditions are most likely to ensure Vireo Susceptibility. Additionally, use of a network such as this allows us to quickly identify which parameters are important or unimportant for driving Susceptibility. For instance, in our example, changing Profile Curvature from slightly negative to slightly positive moves the distribution of Vireo Susceptibility higher (Fig. 32). However, increasing Steep Rocky from <0.1 to >0.9 only raises the distribution slightly (Fig. 33).

Additionally, the BBN allows the prediction to work backwards. For instance, in the Balcones region, if we set the prediction for Vireo Susceptibility to 0.9 to 1, we can see the necessary values required from the other nodes, indicating that Profile Curvature must be negative (between -1.5 and -0.5) and that the proportion of Low Stony Hill would most likely need to be below 0.4 (Fig. 34).

We provide the regional scale networks in the initialized state for Kickapoo (Fig. 35), Devil's Sinkhole (Fig. 36), Kerr (Fig. 37), and Fort Hood (Fig. 38), as well as across the range (Fig. 39).

Local scale

At the local scale, our data inform the BBN by helping predict whether an area is vireo habitat. The relationship between Vireo Susceptibility and Probability of Vireo Habitat is currently unknown, but we expect the relationship would be positive.

Using the vegetation models developed in our local scale modeling (see *Methods* above), we created local scale networks for Devil's River (Fig. 40), Kickapoo (Fig. 41), Devil's Sinkhole (Fig. 42), Kerr (Fig. 43), Balcones (Fig. 44), and Fort Hood (Fig. 45). Note that we incorporated the metrics as measured in the field, and the same methods would need to be used to compare additional data. Note that the local scale BBN for Devil's Sinkhole does not predict above 0.1 for probability of habitat. We could not determine a better model, indicating that in this region, either the metrics we measured were not important or our sample was too small.

Abundance

In 2009, we detected between 251 and 460 individual vireos within 35,090.3 ha (Table 38). In 2010, we detected between 1,337 and 1,998 individual vireos within 43,852.5 ha (Table 39).

Table 38. Minimum and maximum estimates of individual birds detected during 2009 randomly-distributed surveys by ecoregion. The minimum estimate includes only detections >200 m apart while the maximum estimate includes all detections.

	No. birds		
	Min.	**Max**	**Area surveyed (ha)**
Edwards Plateau	189	343	19,175.1
Cross Timbers	27	51	6,487.7
Chihuahuan Deserts	24	35	6,155.3
Central Great Plains	3	19	1,887.6
Arizona/New Mexico Mountains	0	0	739.9
Texas Blackland Prairies	0	0	200.8
Southern Texas Plains	8	12	268.5
Southwestern Tablelands	0	0	175.5
Total	251	460	35,090.3

Table 39. Minimum and maximum estimates of individual birds detected during 2010 area-focused surveys. The minimum estimate includes only birds detected during the 5 minute point counts at each point plus the number of points where no vireo were detected during the formal point count, but had at least one detection within 100 m. The maximum estimate includes all detections (at and between survey points).

	No. birds		
	Min.	**Max**	**Area surveyed (ha)**
Fort Hood	292	453	14,391.4
Kerr	247	389	9,120.9
Kickapoo	282	443	7,128.6
Devil's River	303	417	4,606.4
Balcones Canyonlands	177	207	4,302.6
Devil's Sinkhole	21	48	3,257.0
Mason	6	18	777.2
Taylor	9	23	268.5
Total	1,337	1,998	43,852.5

Using only the vireo detected during point count surveys, we counted 940 vireos at 6,207 survey points during the area-focused surveys in 2010, resulting in a mean number of vireos per point of 0.154 (SD = 0.492). We categorized counts of vireos as 0, 1, 2, or ≥3 because sample sizes were small for points with > 3 counts of vireos (Table 40). This yielded a sample size of 45 points with ≥3 vireos counted. We used the best approximating model for describing vireo occurrence as a guide for which measures to use to examine abundance. In this model PPO was described by an interaction between Low Stony Hill and aridity, thus we grouped the data into high and low aridity indices and examined the distribution of proportion of Low Stony Hill by vireo count. For areas with a low aridity index (e.g., Devil's River), few counts exceeded 2 vireos and the mean and 95 % confidence intervals for count = 1 and count = 2 overlapped but were lower than the mean and 95% CI for count = 0 (Fig. 46). For areas with a high aridity index (e.g., Balcones), the mean at count = 2 was higher than the mean for count = 1, although the 95% confidence intervals overlapped slightly. However, where count > 0, the mean and 95% confidence intervals were higher than those where count = 0 (Fig. 47). Relationships between abundance and other variables are reported in Appendix I.

Table 40. Summary of the point count numbers of vireos at points. We did not detect any vireo at 88.8% (5,514) of points. Two or more vireo were detected at only 2.9% (178) of points.

Number of vireos	**Number of points**
0	5,514
1	515
2	133
3	30
4	10
5	1
6	4

Discussion

This study substantially improves upon the current knowledge and understanding of the distribution, habitat use, and abundance of the black-capped vireo within its breeding range in Texas. In particular, we provide an assessment of which topographic features predict potential habitat, which vegetation characteristics are associated with vireo occupancy, and how individual vireos distribute themselves locally within their habitat. Below we summarize and discuss our findings, provide guidance on the application of our results, and indicate the need for and direction of additional research.

General patterns and regional models

We surveyed over 10,700 points in 57 counties across the breeding range in Texas during 2009 and 2010, increasing the knowledge of vireo distribution across the range. For our area-focused 2010 data, the proportion of survey points that had detections generally increased from east to west; the reasons for this pattern are discussed below.

On-site Vegetation

Looking across the range of our 2010 study areas, several patterns emerged from the vegetation data. In the east and central regions, the presence of low cover (low vegetation height at the bottom) was an important factor predicting vireo occupancy, whereas this measure was not predictive in the west. Differences in climate, type of vegetation available, and land management practices in the different regions likely affected the importance of low understory. In the west, vegetation is naturally kept at a low successional stage because of drier climate; mean height of vegetation at the bottom was lowest in the Devil's River region compared to the other 6 study areas. In the central and eastern part of the range, vegetation reaches a higher successional stage and management practices such as grazing can remove the lower sections of vegetation while leaving upper portions intact. In the west, grazing or any other disturbance would remove the entirety of the vegetation profile, and, as our model results indicated, vegetation height to the top was predictive of vireo occurrence. Also, the distance between the woody vegetation (i.e., a measure of vegetation density) was selected in the models for both Balcones and Fort Hood, both eastern study areas, where the probability of occurrence increased as the distance decreased (i.e., became more dense), although the results of the t-test showed the differences were not significant in these study areas. This effect is possibly due to a greater variation in how clumped or dense the vegetation was in those regions. Various land management practices such as grazing or clearing brush results in relatively bare areas, while lands that are unmanaged or allowed to reach a later successional stage and are more dense and forested are interspersed among the managed areas, creating a patchwork within this region (higher standard deviations, Appendix F) compared to the less managed western part of the range.

In general, none of our vegetation metrics showed strong patterns when looking across all locations at once, indicating that vegetation varied substantially by region. Therefore, keeping the vegetation models independent within each region is likely more informative than generalizing across the range in Texas.

Remote-sensing

The effect of profile curvature and Low Stony Hill on vireo occurrence showed a clear gradient from west to east. Across both years, we found that vireo occurrence in the west was associated with concave slopes (bowl-shaped, positive profile curvature) that were often on Steep Rocky ecosites and not on Low Stony Hill. In the east, vireo occurred on convex (bell-shaped, negative profile curvature) formations like hilltops, predominantly on or associated with Low Stony Hill. The extent of Low Stony Hill and Steep Rocky can be seen in Fig. 48; Steep Rocky is more prevalent in the west and Low Stony Hill is more prevalent in the east.

Our descriptive data indicated that slope was significantly different between detection and non-detection locations, but the direction of the effect varied by location. In 2010, slope was significant at all study sites except at the Kerr, and slope was always higher at detections except for at the Balcones study area, where detections were generally on lower slopes. In 2009, slope was only significant on the Edwards Plateau where slopes were almost 11% lower at detections on average.

The model for Devil's Sinkhole using the remote-sensing metrics did not predict well. Although the model predicted higher occupancy probabilities in the southern areas, the vast majority of our 2009 detection points from the randomly-distributed surveys fell within areas where the probability of occupancy was < 0.1. If we exclude Devil's Sinkhole, the study area models using remote-sensing metrics generally predict higher values from east to west.

Range-wide model

To account for the east-west gradient predicted in our regional models and vegetation models, we hypothesized that a regional model would need to include the effect of aridity. As the climate becomes more arid, the dominant vegetation differs in species composition, climax states, and structural characteristics. For example, vegetation in the west remains small and sparse compared to vegetation in the east that becomes dense without disturbance or control measures. Since we cannot measure vegetation structure efficiently by remote sensing, aridity was included to account for the gradient in vegetational changes associated with temperature and moisture. Following to the patterns predicted in the regional models, we determined that the best model for occupancy across the range included an interaction between Low Stony Hill and aridity.

Similar to the regional models, the range-wide model had higher predictive values in the west, in part due to the higher proportion of survey points with detections in the west. We suggest that the higher proportion of detections was because more habitat is available in the west. With increasing aridity, the vegetation community is naturally limited, and frequent disturbances, such that are needed in the east (e.g., prescribed fire), are not required to maintain habitat for the vireo. Because vireo habitat tends to be naturally sustained in the west and vegetation structure is relatively more homogenous, metrics such as ecosite and profile curvature tend to correlate more readily with vireo occurrence in the west rather than in the east. In the east, vireo habitat depends on management practices that limit the growth of vegetation such that it remains in an early-successional stage, thus vireo occurrence is less correlated with remotely-sensed metrics that are unable to distinguish subtle differences in vegetation (e.g., browse line). Based on comparisons with survey data from the area-focused and randomly-distributed surveys, the range-wide model was a better predictor of vireo occurrence than most of the individual study-area models using remotely-sensed metrics.

Although we projected the probability of vireo occurrence in the Chihuahuan desert region west of Devil's River, we cannot reliably predict vireo occurrences here because we lacked area-focused sampling locations in this ecoregion. When projected to that area, we see progressively higher predictive values as you move further and further west. Based on our randomly-distributed sample data and our knowledge from concurrent, local studies, we conclude that these high prediction values are being assigned to places where no habitat exists, as it is too hot and dry. Once the aridity gets too high and there is not enough water to sustain minimum required vegetation for vireo, the habitat is primarily restricted to riparian drainages and other locations where water tends to collect. This again serves to explain why vireos often occurred on concave slopes in the west as opposed to hilltops in the east. For instance, in the Big Bend region, the only locations we detected vireo during the 2009 randomly-distributed surveys were at higher elevations in the drainages out of the Chisos Mountains in Big Bend National Park, where the aridity is closer to that of locations further east (Fig. 49). Lower-elevation drainages in areas that are hotter and drier did not support the necessary vegetation. We do not currently have the necessary data to show what we suspect is happening—that vireo occupancy drops off once a certain aridity value is reached. Higher aridity index values indicate mesic conditions, therefore our data predict a linear, negative relationship between occurrence and aridity (Fig. 50). However, we suspect that the relationship is nonlinear and further investigations are needed to determine the presence of an aridity threshold (Fig. 50, dashed line). If the threshold is at a higher aridity value than that at the Devil's River study area (where the Aridity index is about 3,000), then the predicted occupancy values should decrease slightly anywhere with a lower (drier = generally more western) aridity value, so the occupancy predictions should drop as we move west of that area.

Spatial distribution

Our results support our prediction that vireos spatially cluster on the landscape. The lack of obvious clustering at some locations, such as Devil's Sinkhole and Devil's River, could indicate that suitable habitat is distributed across our designated sampling areas and that local populations are large enough to occupy most or all of the habitat. Additional work is needed to better identify clustering of birds across the landscape and how such clustering influences the results of research on habitat use. That is, vireos might be clustering at a scale that was not apparent with the spatial distribution of our survey points (300 m apart). For example, the birds might be clustered at a finer scale that we could not recognize by our methods. Additionally, because we seldom had unrestricted access to the landscape, we usually could not sample the entirety of a cluster (i.e., could not identify boundaries). A study design that focuses on delineating clustering across broad areas will be needed to resolve these issues. Nevertheless, we can conclude that the clustering behavior of the vireo does influence models of habitat occupancy and should be taken into account.

Bayesian network

Our proposed Bayesian network provides a tool that predicts the occurrence of vireos in a given area based on a number of user-defined values, which we express here as the "susceptibility" of a specific location to contain vireos. The tool provides a user-friendly interface that allows the user to quickly calculate the predicted occurrence of an area, just as the regression models would, while also incorporating the uncertainty that surrounds the regression outputs. Additionally, this tool works both forwards and backwards. For instance, consider a property that had vireos on it in the past but none have been detected in recent years. This indicates that broad-scale measures, such as ecosite, aridity, and topography, are appropriate for supporting vireo habitat. Given the appropriate range of these metrics, this tool allows the user to incorporate the effects of ground vegetation to predict the current occurrence of vireos. On the ground, this tool would allow a user to enter the known data about an area of the property (e.g., tree height, oak index, etc.) and will return the predicted occurrence for that area. Similarly, by fixing the desired predicted occurrence value, for example to ≥75%, the tool allows the user to determine what range of values for vegetation metrics would contribute to creating vireo habitat, allowing the land owner to manage the vegetation accordingly.

This network suggests that there are multiple levels of habitat requirements to determine occurrence of vireos in an area. First, the correct topographic, geologic, and climatic features must exist to support vireo habitat. For instance, if slopes are too steep or if too much water collects in an area, these regions would not likely support the types of vegetation required by vireos. Second, the vegetation growing in these areas must be in the suitable successional stage or managed in such a way that it is attractive to vireos. For example, if an area has the right conditions to support vireo habitat but the vegetation is allowed to become too thick or goats create a browse line, then the area might not support the birds themselves. Last, if an area has all the necessary features and is potential vireo habitat, the probability that a vireo will settle there is further influenced by the presence of conspecifics as well as by the presence of predators and nest parasites such as the brown-headed cowbird. In regions where cowbird trapping is used as a management tool, the probability of vireo presence increases.

Abundance

Our surveys yielded a minimum of 1,588 vireo individuals within nearly 79,000 ha across both years of surveys. The numerous challenges faced when modeling vireo habitat further complicate and limit our abilities to assess vireo abundance; thus, a range-wide estimate is not possible given our data.

Statistical comparisons suggested that the presence (count > 0) or absence (count = 0) of vireos was related to the proportion of Low Stony Hill both at high and low aridity values. A potential relationship between abundance and Low Stony Hill existed in areas with a high aridity index (>5300). Although not statistically different (overlapping 95% confidence intervals), the proportion of Low Stony Hill is greater where the count of vireos is >1 than when the count = 1. Overall, the abundance of vireos was predicted similarly as our models of predicted vireo occurrences. Given that our data set was predominately non-detections (count = 0) and that we did not conduct repeated surveys, we were unable to differentiate between true absences versus points at which a vireo was present but not detected. Further research is needed to examine differences in vireo abundance when accounting for probability of occupancy.

Research needs and future work

This research has substantially improved our understanding of vireo distribution and pattern of habitat use across the breeding range in Texas. We produced the first rigorous, range-wide assessment of the vireo, including an initial framework for predicting occurrence. Our current habitat models have many applications for conservation and management; however, we view the modeling as another step in our ongoing research into vireo distribution and habitat use, generating numerous opportunities for model testing and further refinement of their predictive ability.

As we expected from existing knowledge of vireo behavior, we demonstrated that vireos cluster on the landscape. Our access to adjacent properties was often incomplete, and further investigation should focus on the spatial scale and location of the clusters, along with whether the cluster boundaries correlate to changes in habitat. Also, understanding how and why new clusters form and where they form (i.e., spatial relation to other clusters) may increase the reliability of occupancy probabilities in locations near other vireos, as well as predict locations where the birds are likely to establish new territories.

Additional data are needed to assess the relationships between vireo abundance and various metrics so that a range-wide abundance might be estimated. We acknowledge that our study design lacked the ability to adequately measure abundance, because we were unable to account for the confounding effects of detection probabilities. Future surveys will need to incorporate detection probability and assess whether we can increase our ability to detect vireos, either by lengthening the point count duration or conducting >1 survey at a given point. As the occupancy models are refined, we will investigate further the relationships between occupancy and abundance.

We will continue to refine the Bayesian network tool as new information becomes available of vireo occupancy and habitat. Eventually, we want to be able to determine how the probability of occupancy is affected by the the vegetative and management metrics while also accounting for the probability that an area is geographically able to support vireos, further informing the relationships in our proposed network. Further research is needed to address the vegetation requirements of the vireo and how these can be modeled both between the study sites and across the range. Currently, we cannot model vegetation outside of our 2010 study areas, and because the models are specific to these areas, the tool cannot be used outside them. Without a way to measure the vegetation remotely across the range, creating a range-wide vegetation model is not feasible. Models for areas outside of our study areas would have to be created and would rely on vegetation surveys done locally.

Additional investigation is also needed in areas where management practices benefit the vireo and how the practices influence vireo abundance and clustering. For instance, at both the Kerr WMA and Fort Hood Military Reservation, specific management practices such as burning, cowbird trapping, and other forms of vegetation disturbance have substantially expanded the distribution and abundance of the vireo. Vireos seem to occupy all areas that are thought of as "typical" habitat at these sites, and individual birds often occupy habitat that is atypical of what the species usually use (Pope 2011). This may be the result of a growing vireo cluster reaching the edges of what has been considered typical vireo habitat. Thus, the range of conditions apparently suitable for the vireo may be broader than typically considered by resource managers. Other research has shown, however, that few birds in high abundance areas such as Kerr and Fort Hood move into the surrounding properties that have little or no direct management for the vireo (Morrison, unpubl. data).

One challenge to overcome is the NRCS ecosite map, as there are discrepancies in the ecosite classifications between some counties. The discrepancies in the definition of Steep Rocky and Low Stony Hill create uncertainty in our range-wide model and required additional examination of the classifications of these ecosites. These discrepancies arise when one ecosite ends at a county boundary instead of extending into the next county even when metrics that define the ecosite are consistent across the boundaries. One of the largest areas of this occurs in Val Verde County, where Low Stony Hill ends along some of the edges of the county. This can be seen even at low resolution (Fig. 48). This issue is acknowledged by NRCS, and they are in the process of refining and standardizing how ecosites are described. While these discrepancies happen throughout the range of the vireo, they are the most prevalent on edges of range. Before we can produce a reliable model for all areas of the range, this issue needs to be resolved by NRCS.

Acknowledgements

We would like to thank the Texas Department of Transportation for the funding of this research, and a special thanks to Dr. Cal Newnam. We thank Texas Parks and Wildlife Department, The Nature Conservancy, the U.S. Department of Defense, the U.S. Fish and Wildlife Service, and the many private landowners who participated in this study and allowed us access to their properties. Additionally, we thank the graduate students of Dr. Michael Morrison and our many field technicians for their hard work in the field to complete these surveys.

Figures

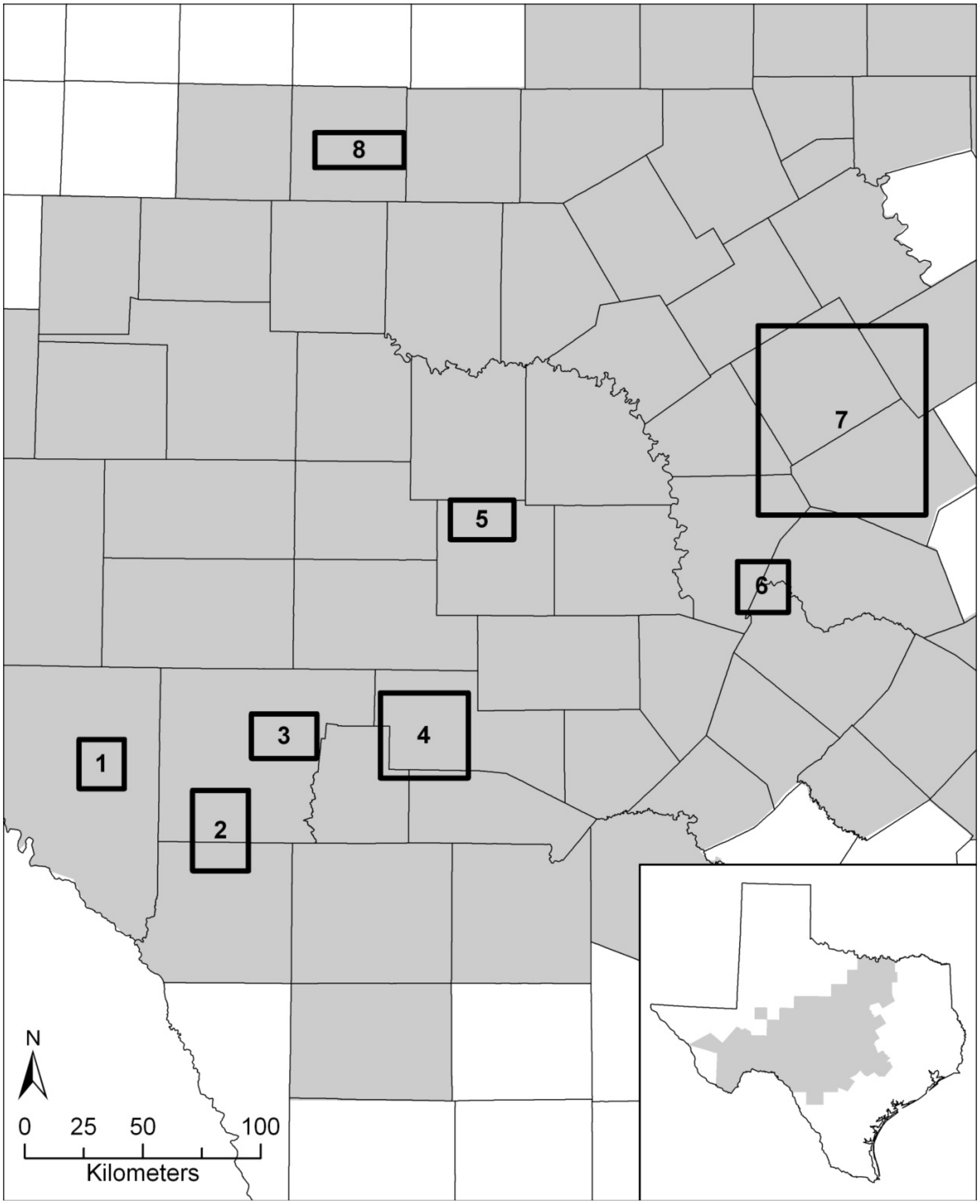

Figure 1. Locations of Texas A&M 2010 area-focused study regions for black-capped vireo surveys: 1) Devil's River State Park and surrounding area, 2) Kickapoo Caverns State Park and surrounding area, 3) Devil's Sinkhole State Park and surrounding area, 4) Kerr Wildlife Management Area and surrounding area, 5) Mason County area, 6) Balcones Canyonlands National Wildlife Refuge and surrounding area, 7) Fort Hood Military Reservation and surrounding area, and 8) Taylor County area. Black-capped vireo breeding range is shaded in gray.

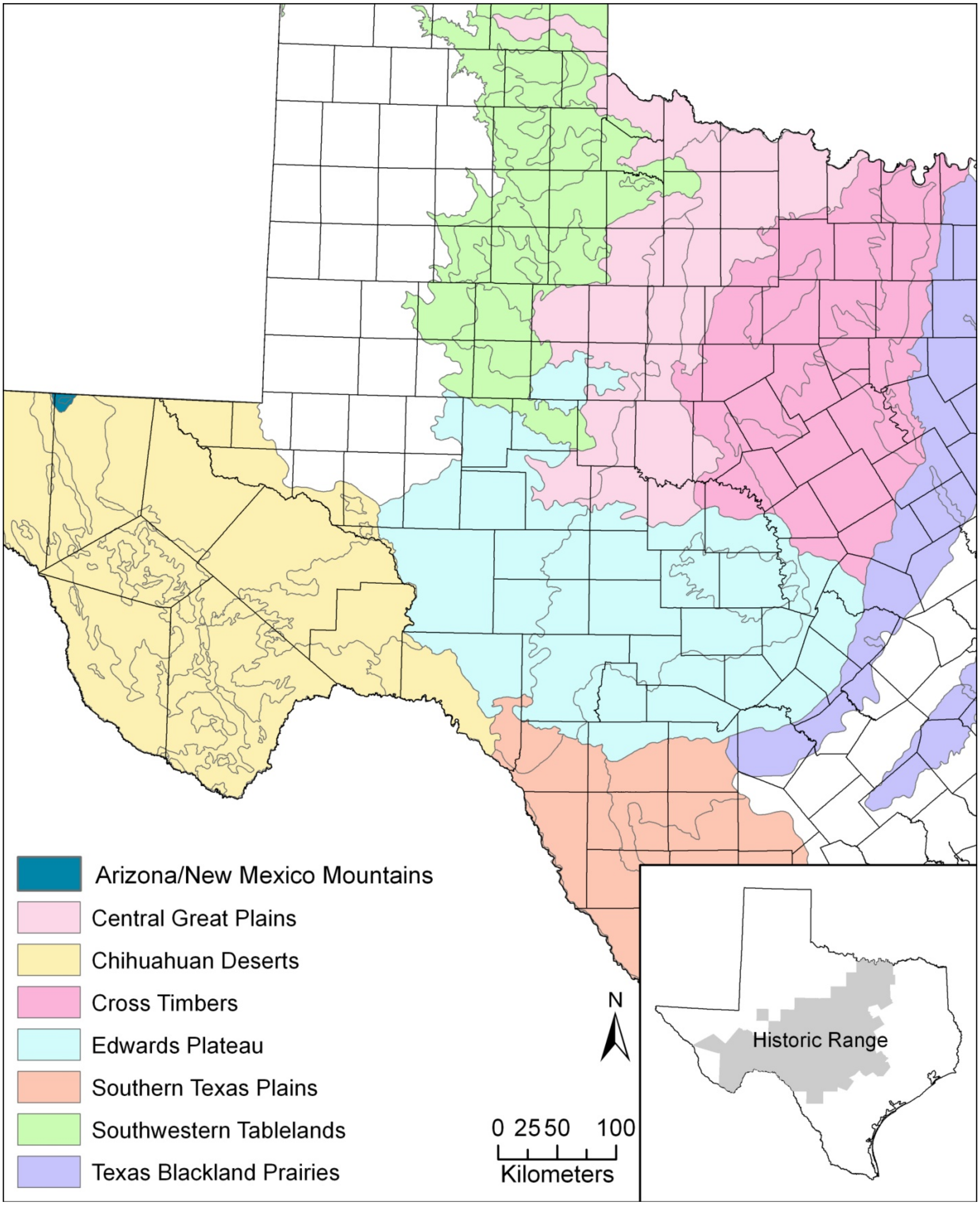

Figure 2. The Unites States Environmental Protection Agency (US EPA) Level III Ecoregions of the Conterminous United States, based on Omernik 2004.

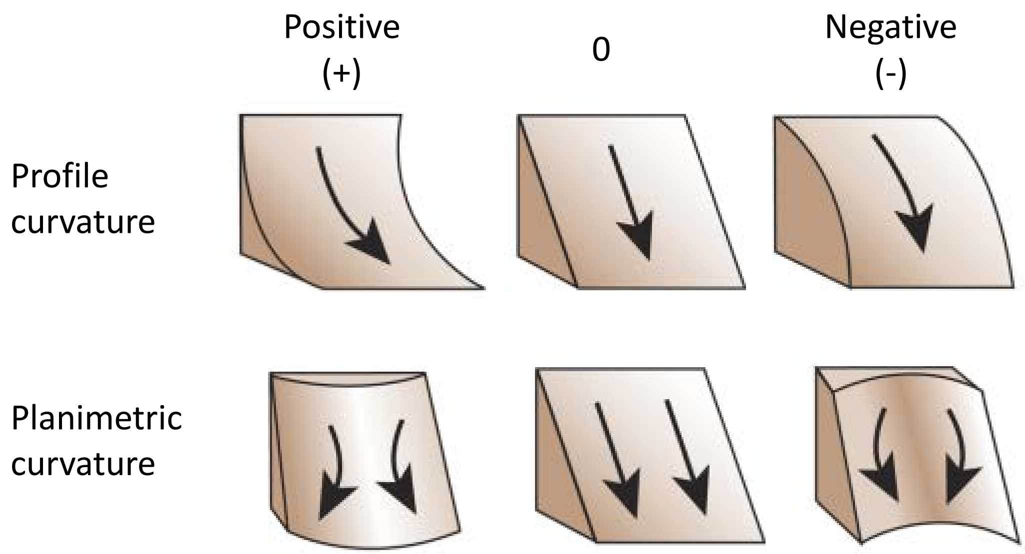

Figure 3. Depictions of profile and planimetric curvature values when the values are positive, zero, or negative. Figure adapted from the ESRI support site mapping center (http://blogs.esri.com/Support/blogs/mappingcenter/archive/2010/10/26/Understanding-Curvature-Rasters.aspx).

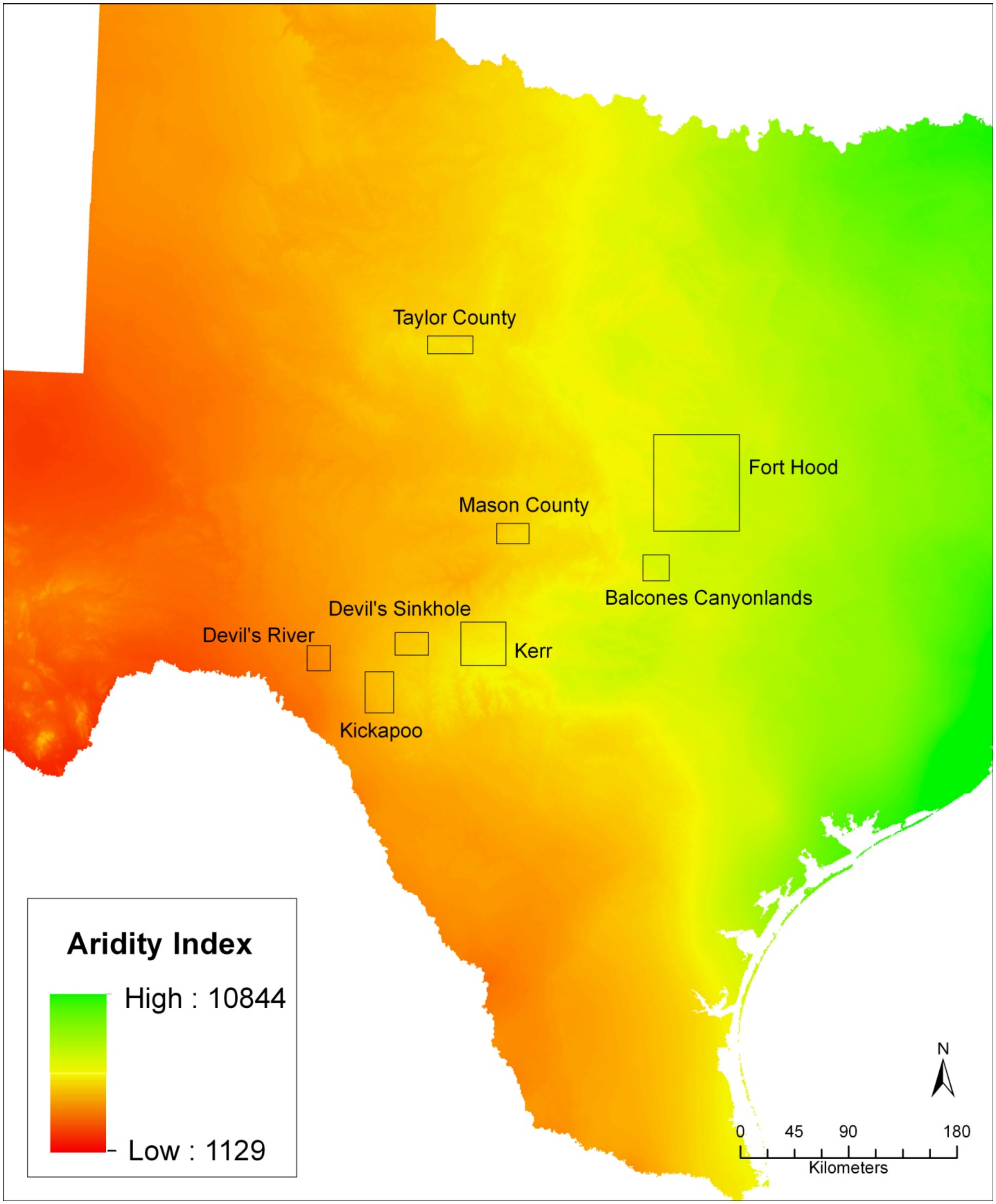

Figure 4. The aridity index used from Consultative Group on International Agricultural Research (CGIAR; Zomer et al. 2008). Average values for each region can be found in Table 8.

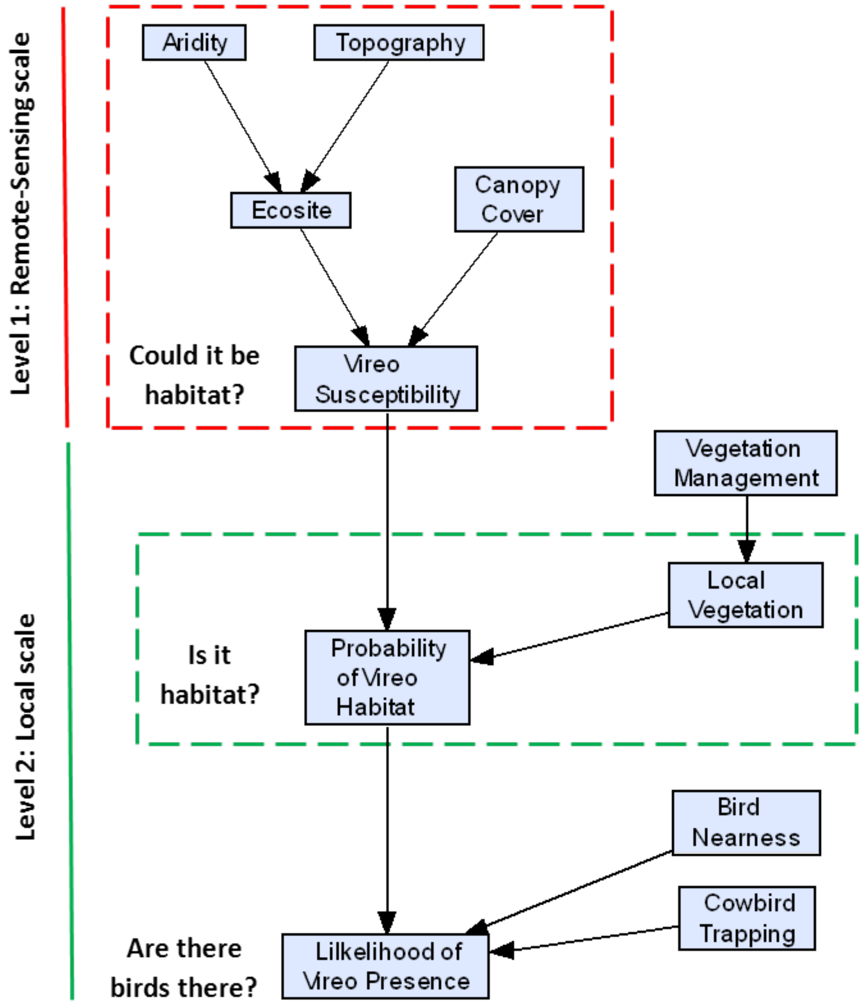

Figure 5. Theoretical Bayesian Belief network for vireo occurrence. We view the decision network that yields the likelihood of vireo presence as three levels at two scales, the remote-sensing scale, and the local scale (measurements taken on-the-ground). Our data informs the relationships in the red and green boxes.

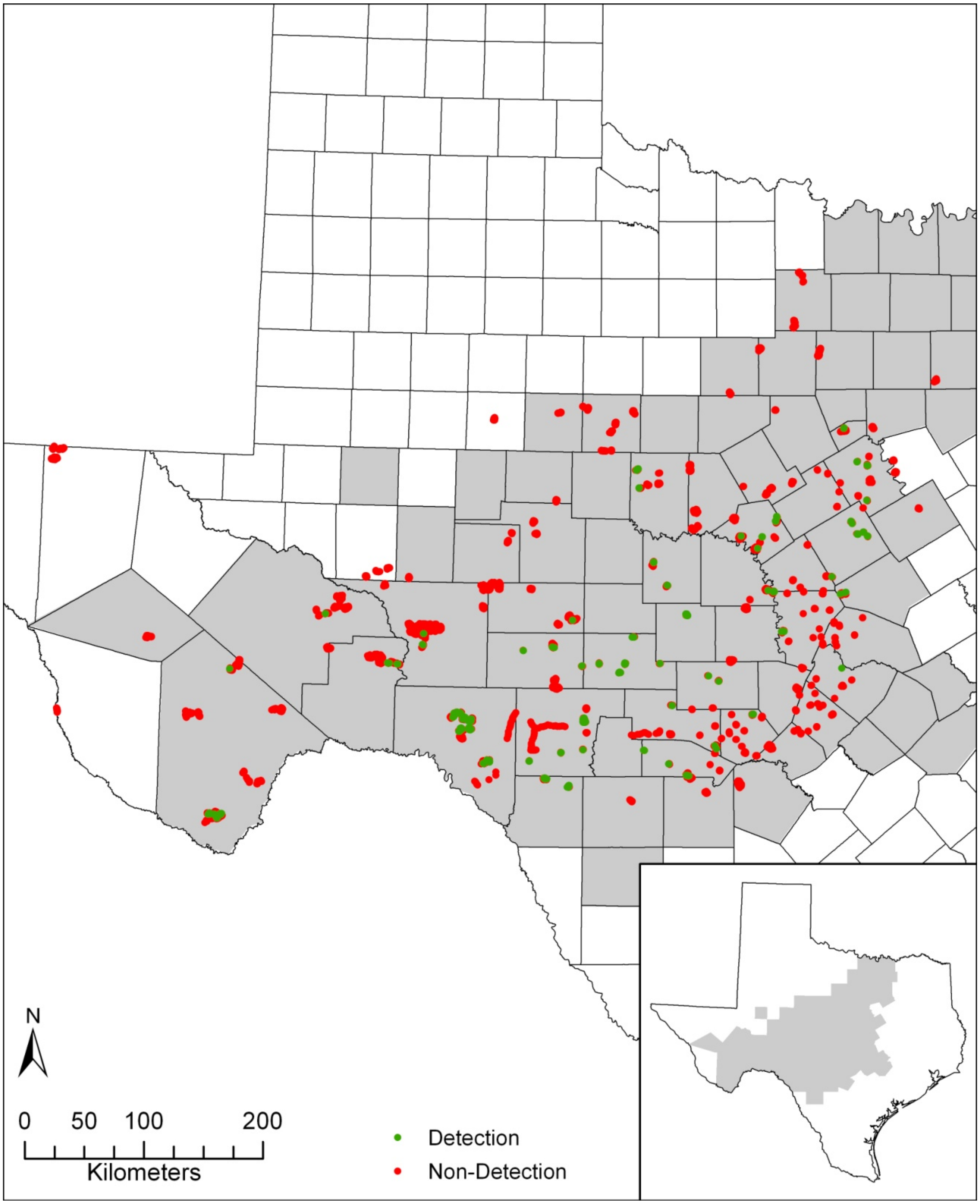

Figure 6. Results from Texas A&M 2009 black-capped vireo surveys. Sampling occurred in 57 counties in 21 different ecoregions across the range. Area shaded in gray indicates the vireo's breeding range in Texas.

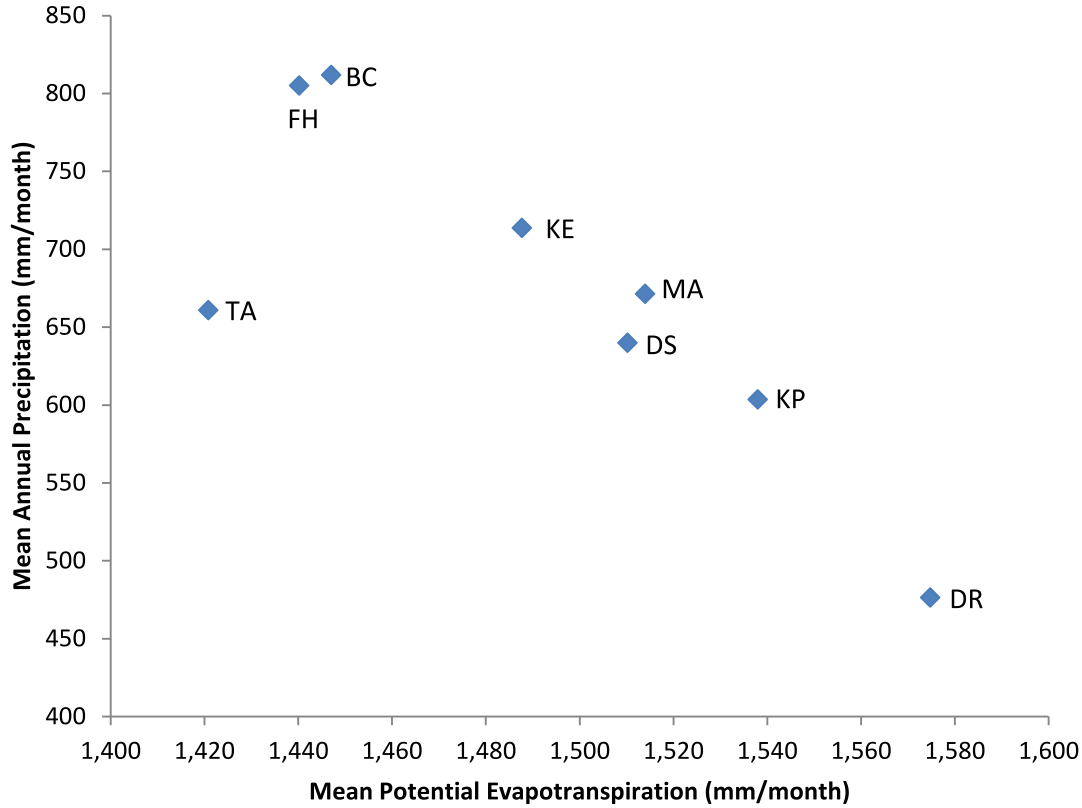

Figure 7. Mean annual precipitation and mean annual potential evapotranspiration for the 2010 study areas. These metrics are used to calculate the aridity index. BC = Balcones Canyonlands, DS = Devil's Sinkhole, DR = Devil's River, FH = Fort Hood, KE = Kerr, KP = Kickapoo, MA = Mason County, and TA = Taylor County.

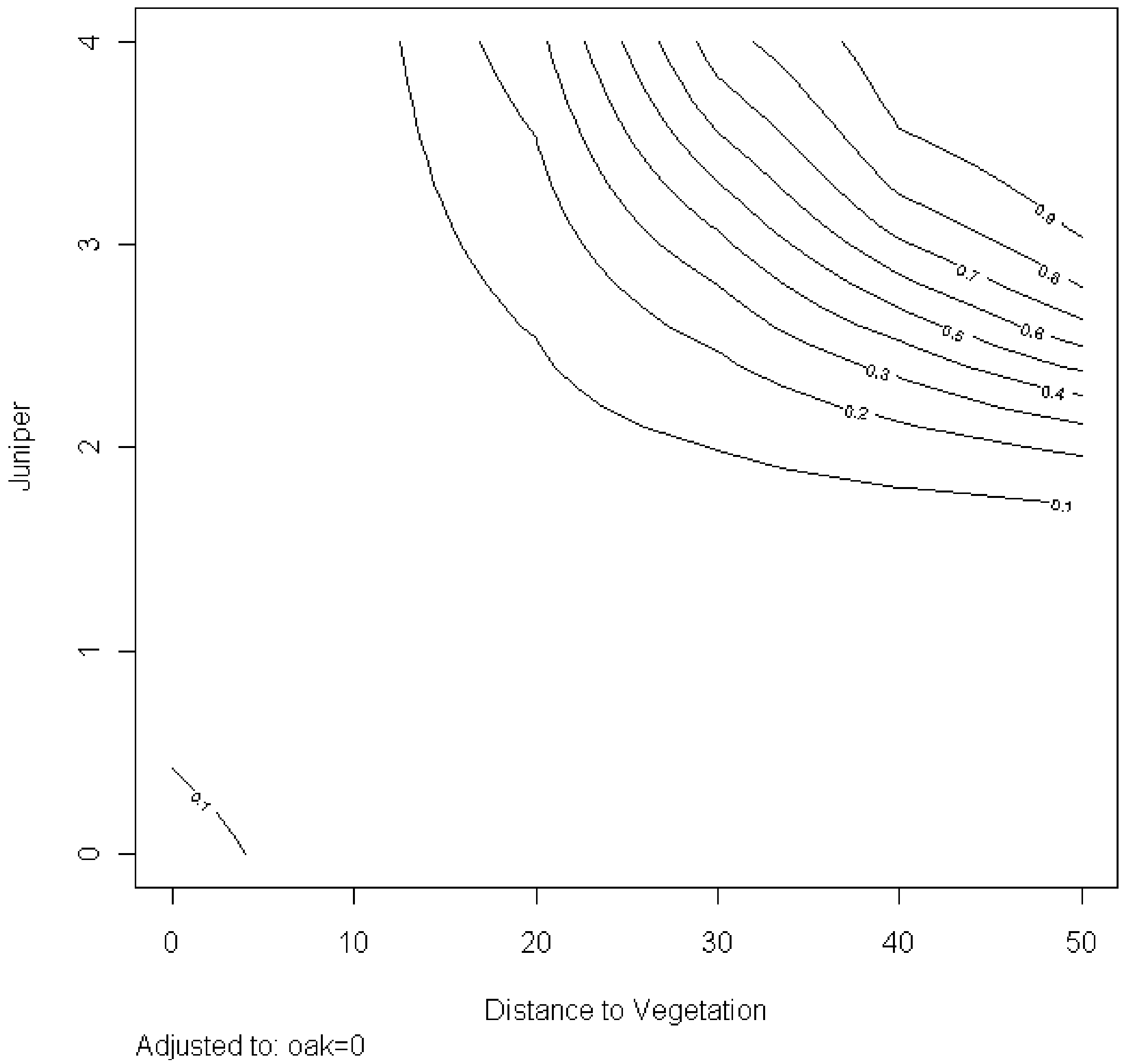

Figure 8. Contour plot depicting the interaction between the distance to the vegetation and the juniper index, showing the estimated probability of occurrence for black-capped vireos in the Balcones study area in 2010.

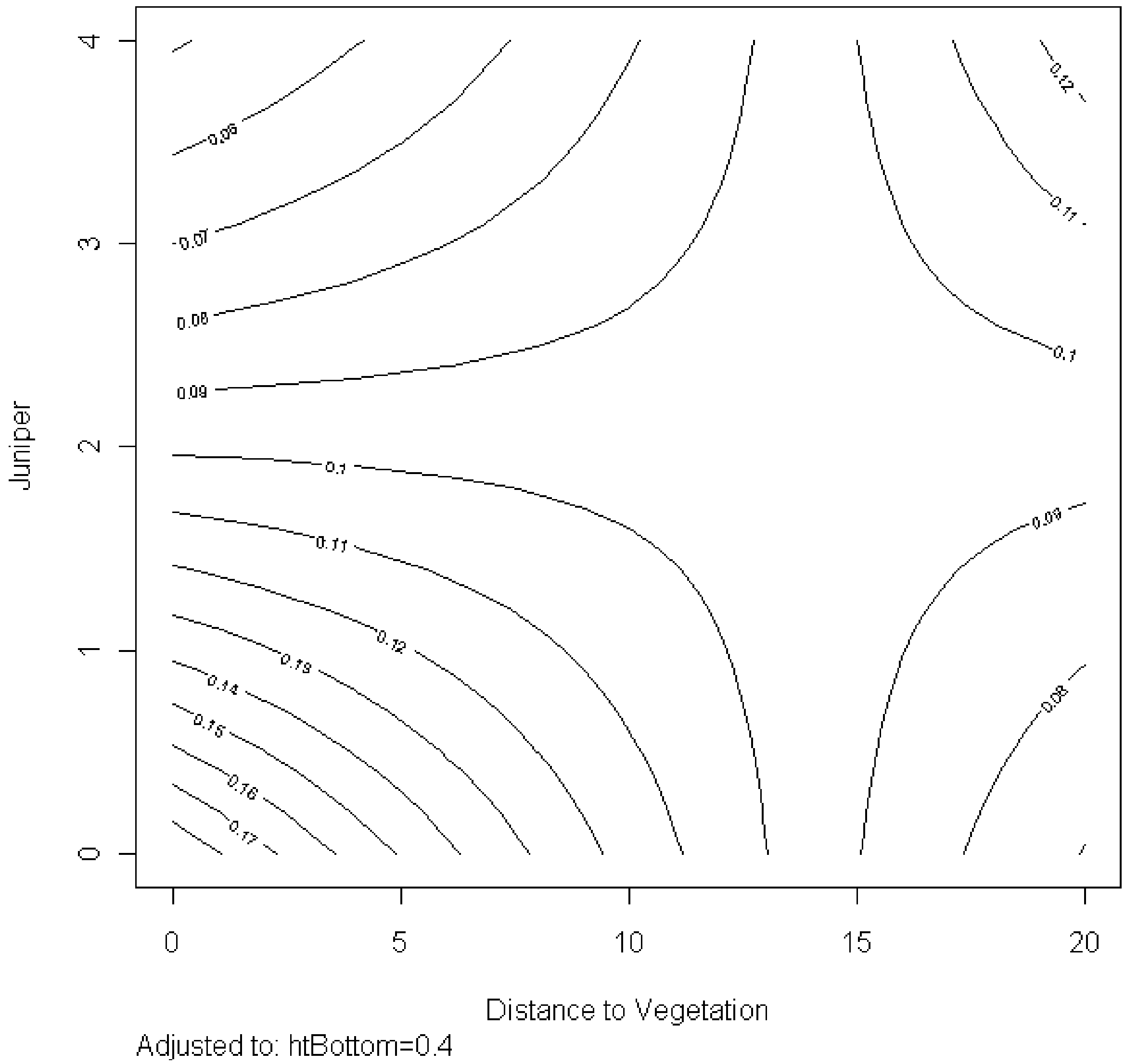

Figure 9. Contour plot depicting the interaction between the distance to the vegetation and the juniper index, showing the estimated probability of occurrence for black-capped vireos in the Fort Hood study area in 2010.

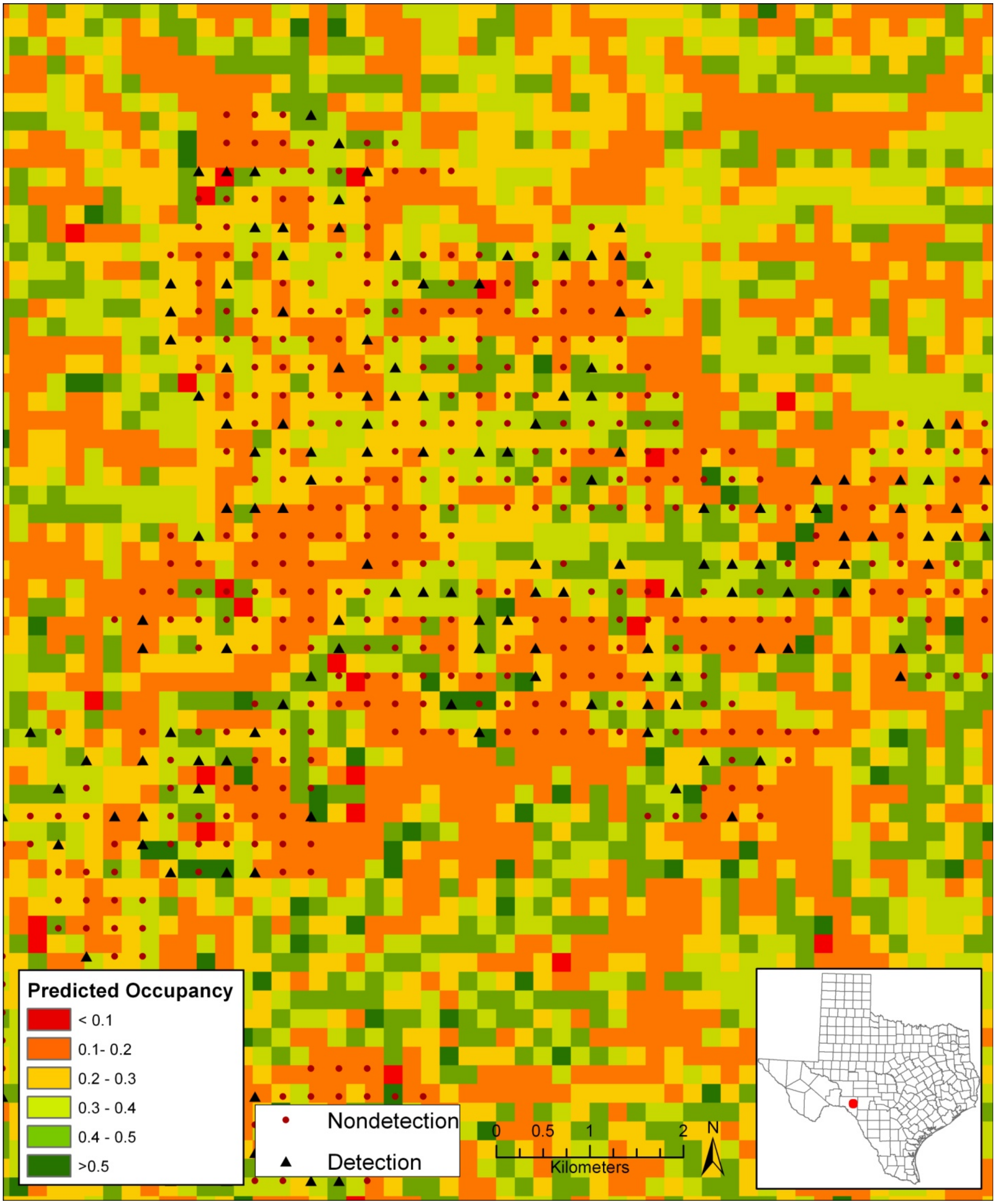

Figure 10. Predicted occupancy map of the regional model from the Devils River study area overlaid with our 2010 survey points. Map is zoomed in to show detail and does not include the entire area onto which the model was projected.

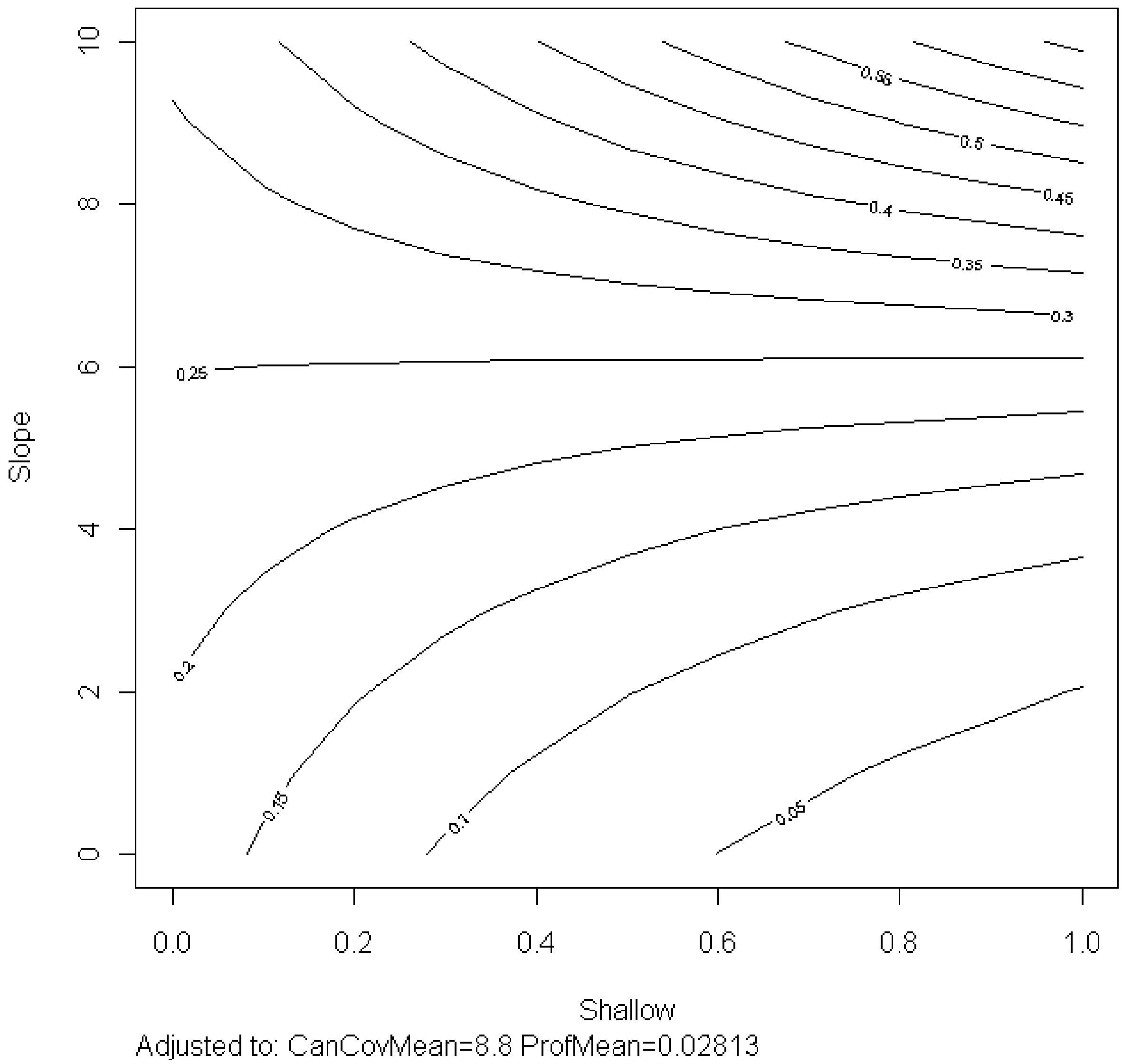

Figure 11. Contour plot depicting the interaction between Shallow ecosite and mean Slope showing estimate probability of occurrence for black-capped vireos in Kickapoo study area in 2010.

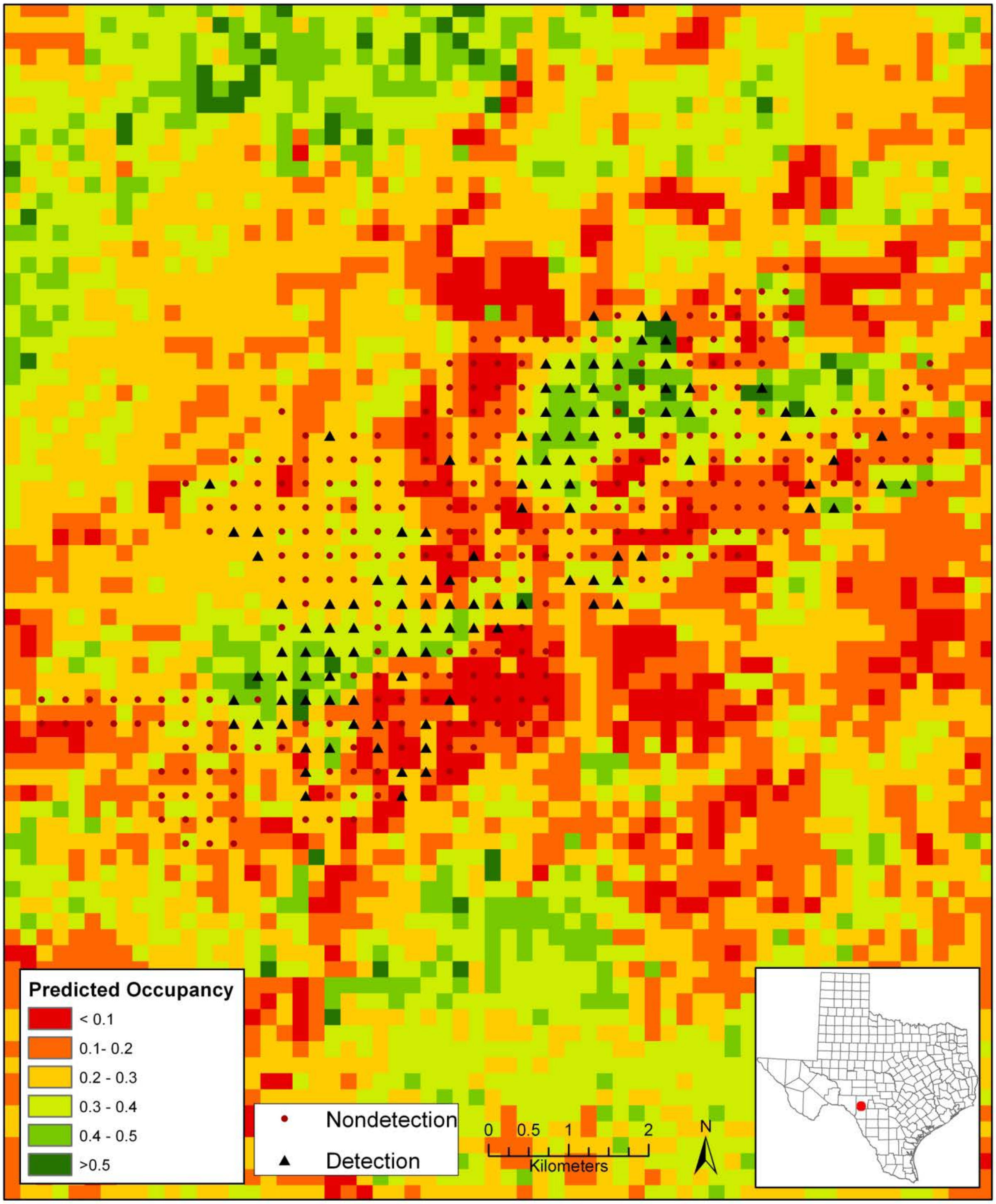

Figure 12. Predicted occupancy map of the regional model from the Kickapoo study area overlaid with our 2010 survey points. Map is zoomed in to show detail and does not include the entire area onto which the model was projected.

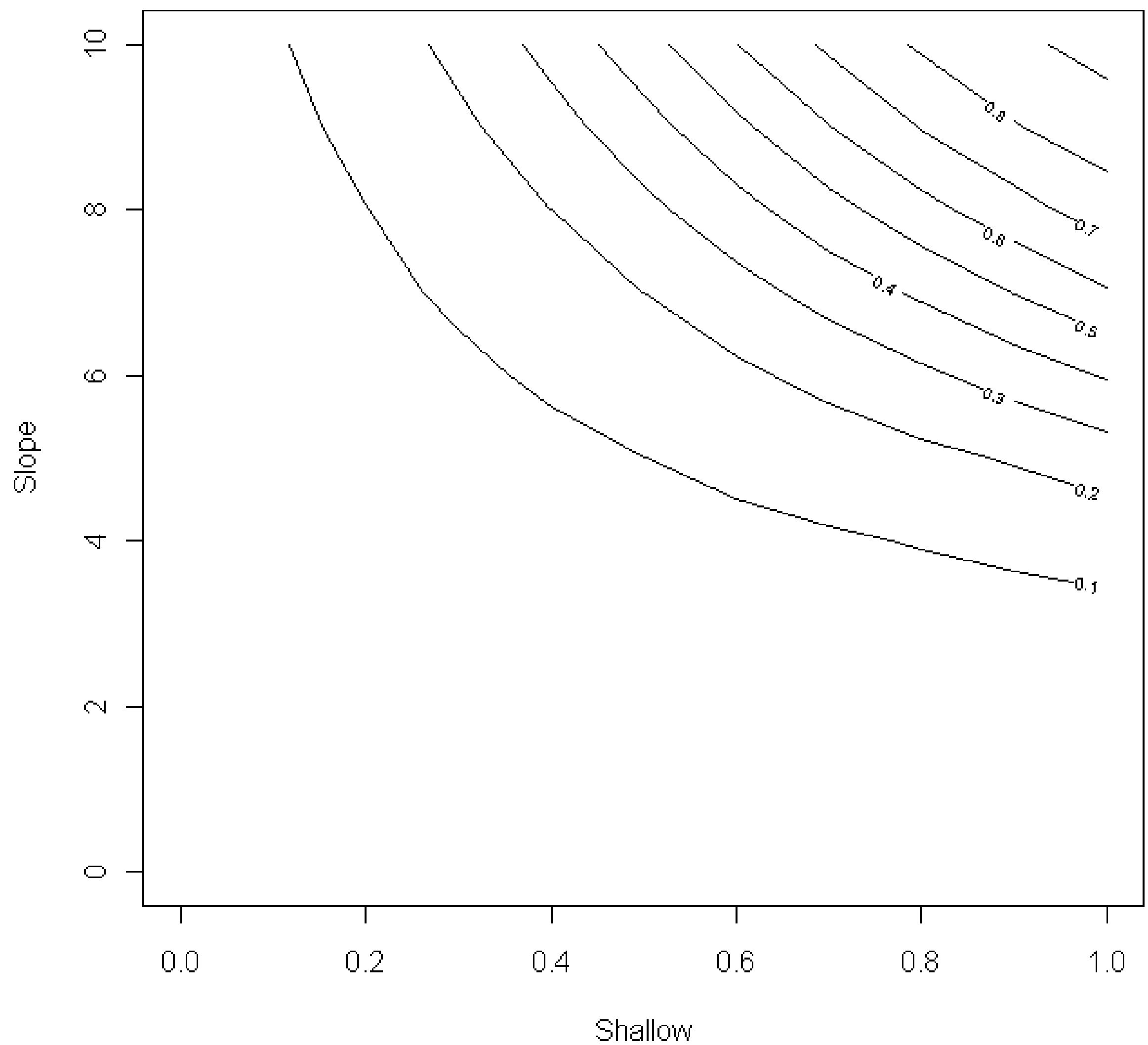

Figure 13. Contour plot depicting the interaction between Shallow ecosite and mean Slope showing estimate probability of occurrence for black-capped vireos in Devil's Sinkhole study area in 2010.

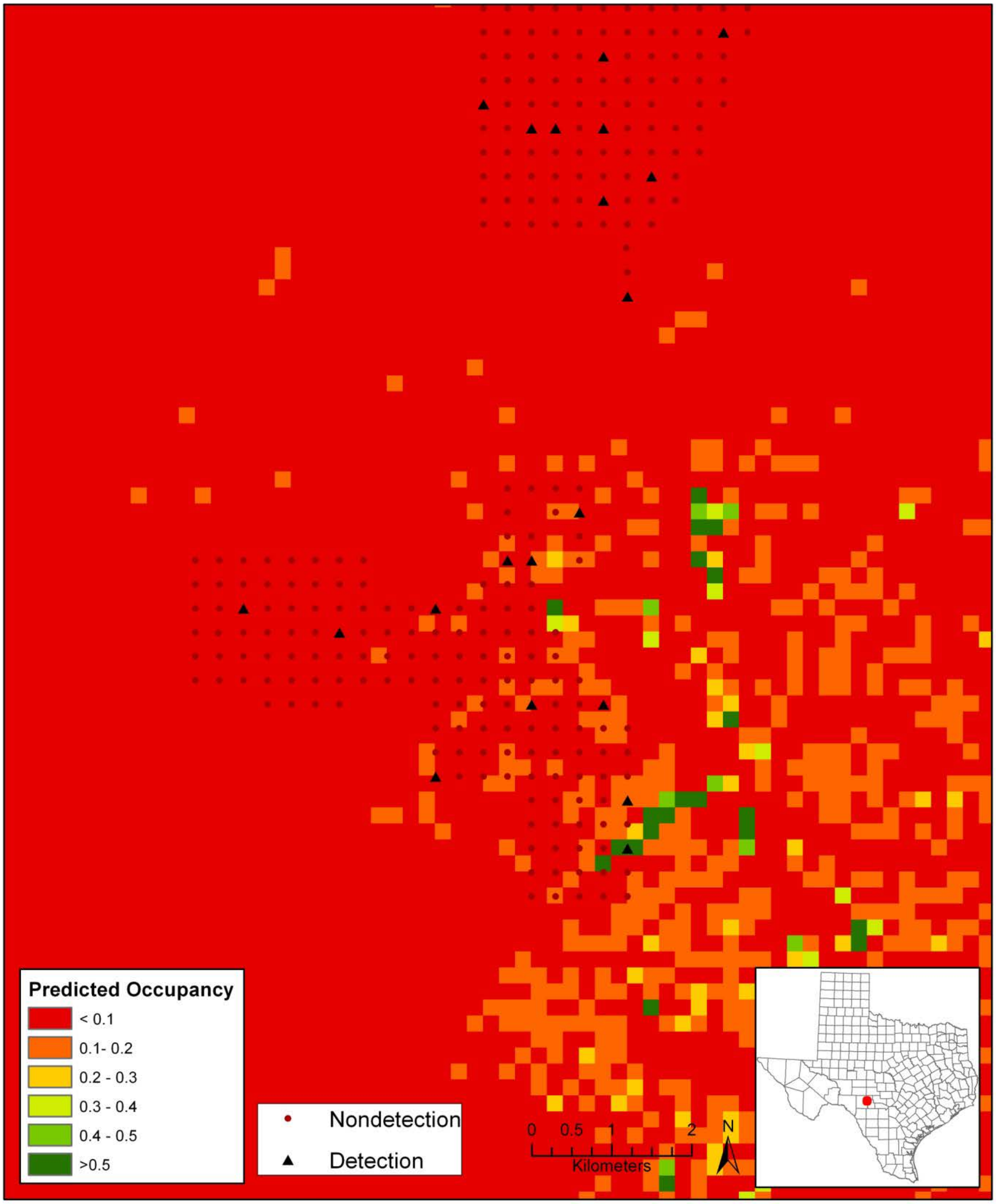

Figure 14. Predicted occupancy map of the regional model from the Devils Sinkhole study area overlaid with our 2010 survey points. Map is zoomed in to show detail and does not include the entire area onto which the model was projected.

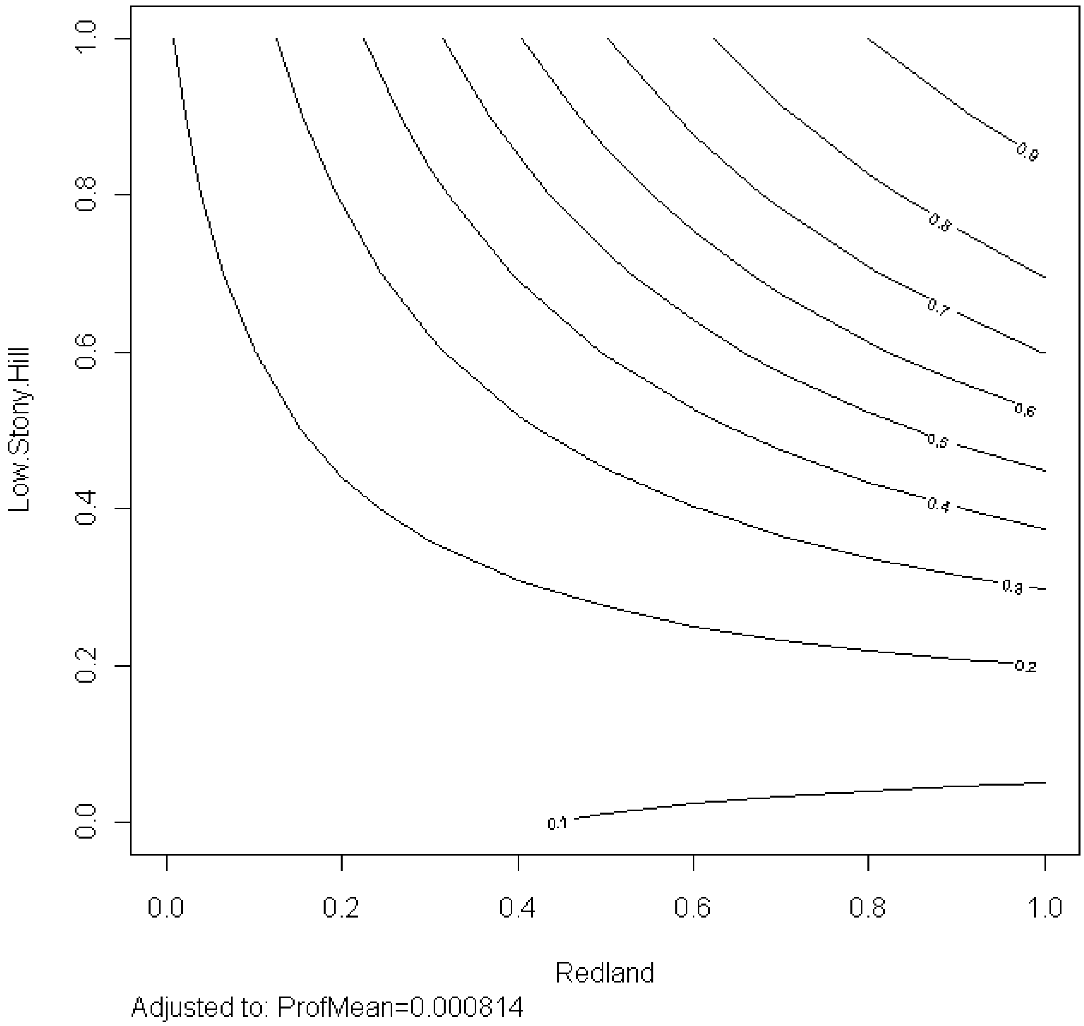

Figure 15. Contour plot depicting the interaction between Redland ecosite and Low Stony Hill ecosite and showing the estimated probability of occurrence for black-capped vireos in Kerr study area in 2010.

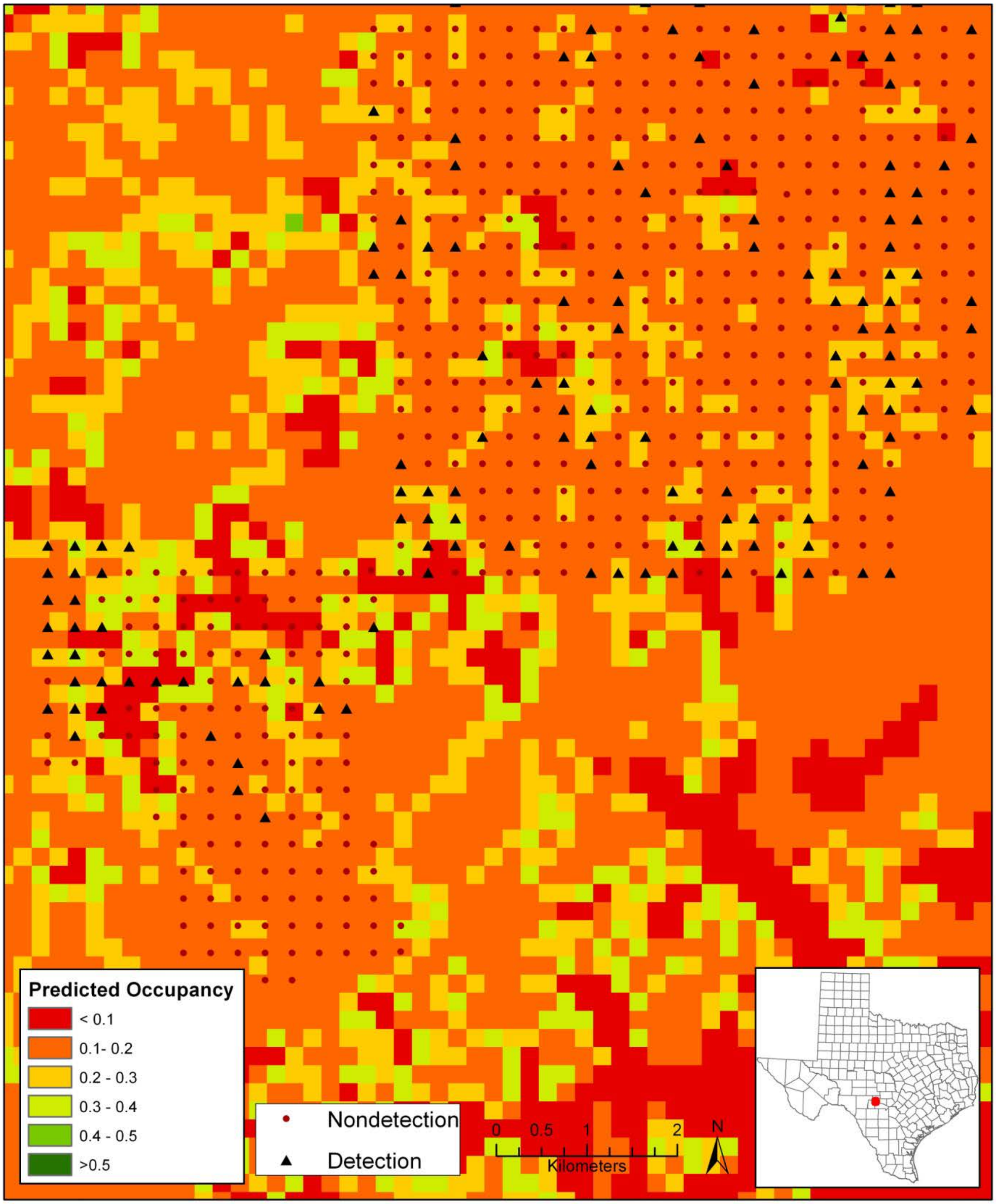

Figure 16. Predicted occupancy map of the regional model from the Kerr study area overlaid with our 2010 survey points. Map is zoomed in to show detail and does not include the entire area onto which the model was projected.

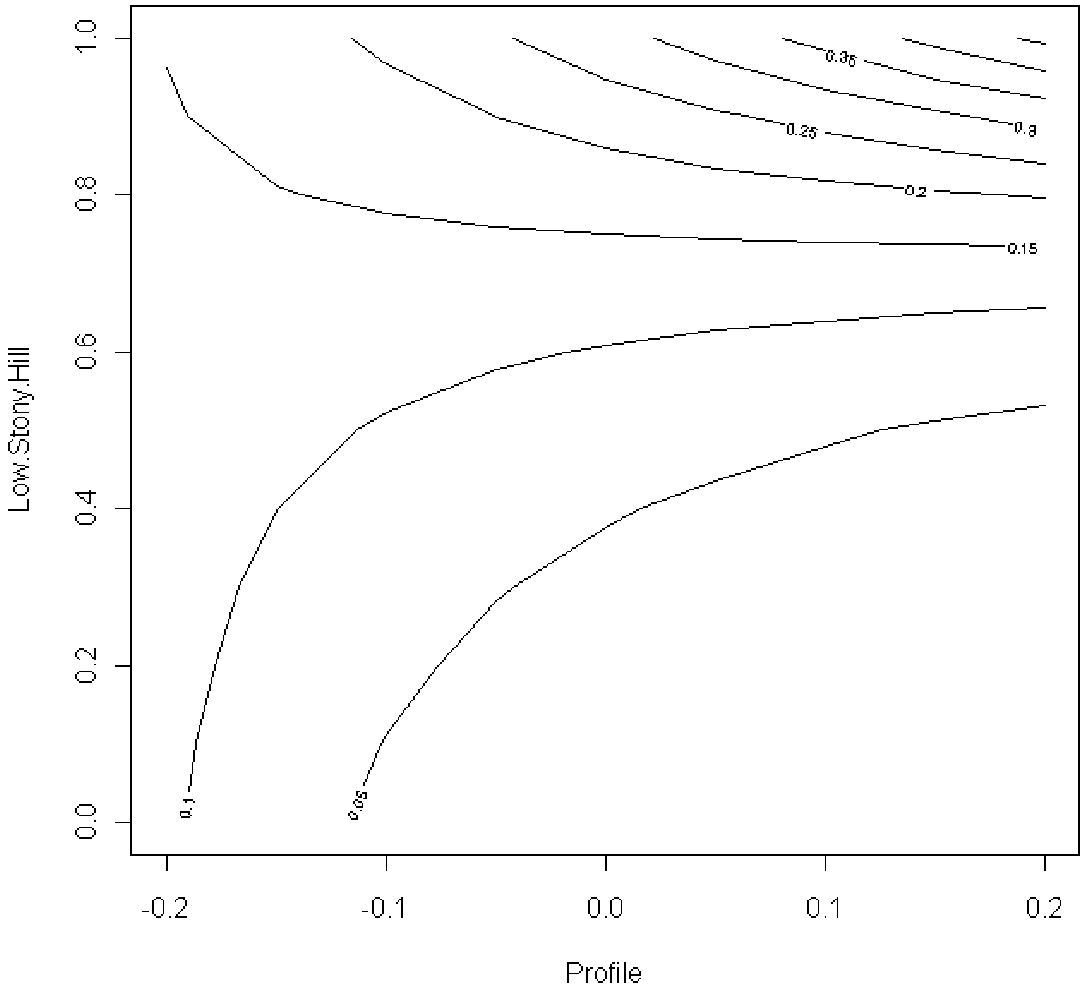

Figure 17. Contour plot depicting the interaction between profile mean and Low Stony Hill ecosite and showing the estimated probability of occurrence for black-capped vireos in Balcones study area in 2010.

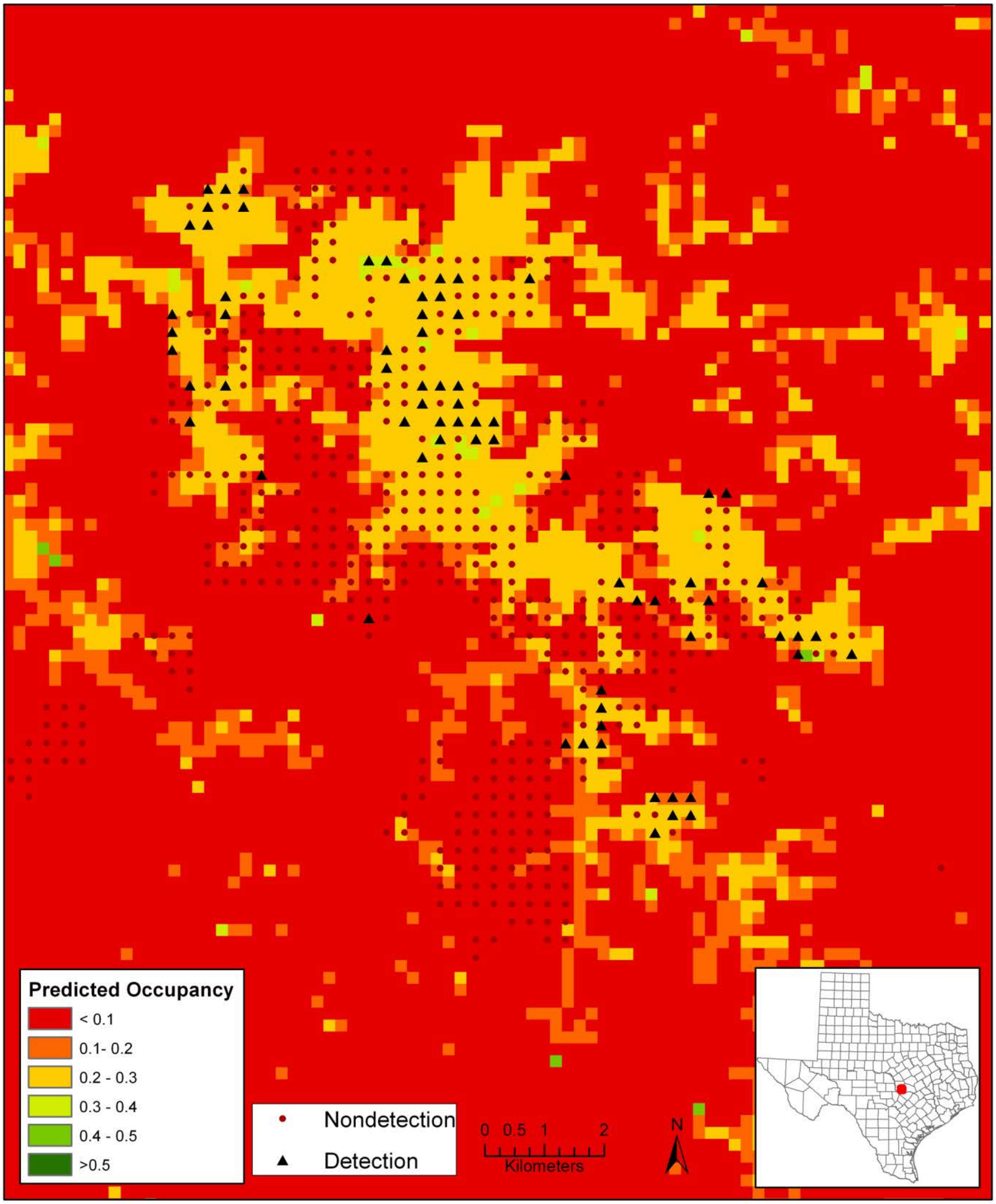

Figure 18. Predicted occupancy map of the regional model from the Balcones study area overlaid with our 2010 survey points. Map is zoomed in to show detail and does not include the entire area onto which the model was projected.

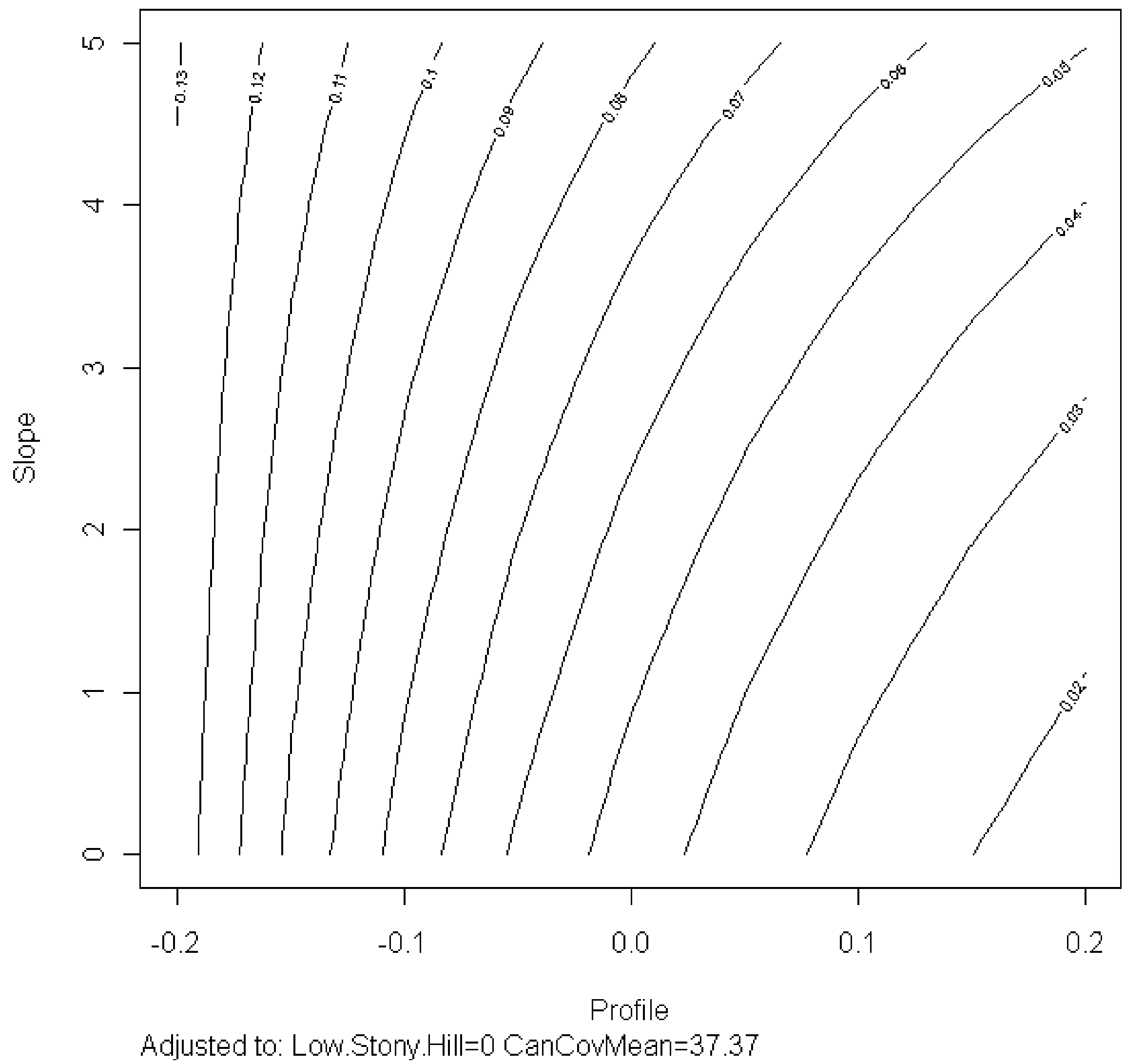

Figure 19. Contour plot depicting the interaction between profile mean and Slope showing estimate probability of occurrence for black-capped vireos in Fort Hood study area in 2010.

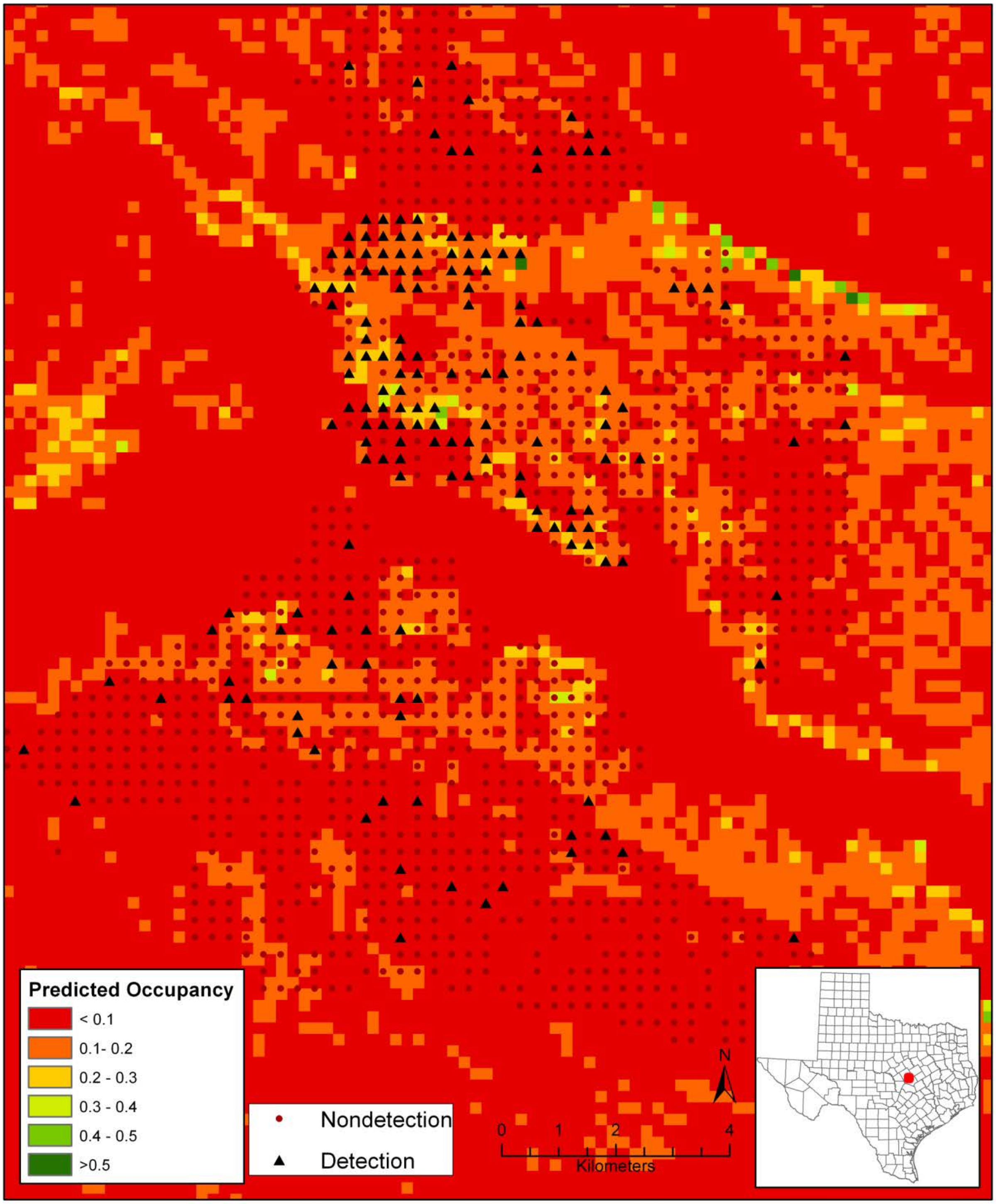

Figure 20. Predicted occupancy map of the regional model from the Fort Hood study area overlaid with our 2010 survey points. Map is zoomed in to show detail and does not include the entire area onto which the model was projected.

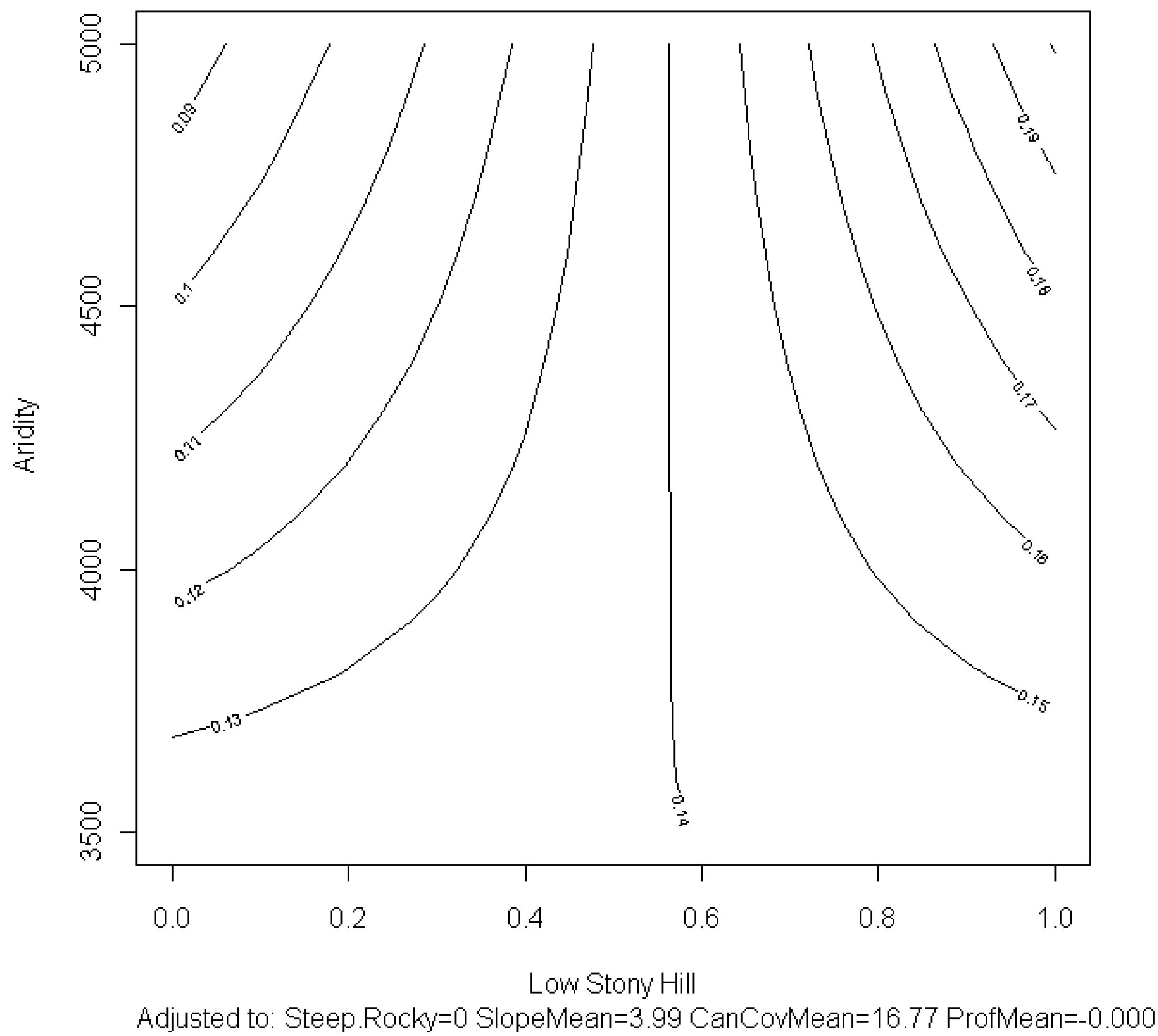

Figure 21. Contour plot depicting the interaction between slope and profile curvature, showing the estimated probability of occurrence for black-capped vireos across their range in Texas in 2010.

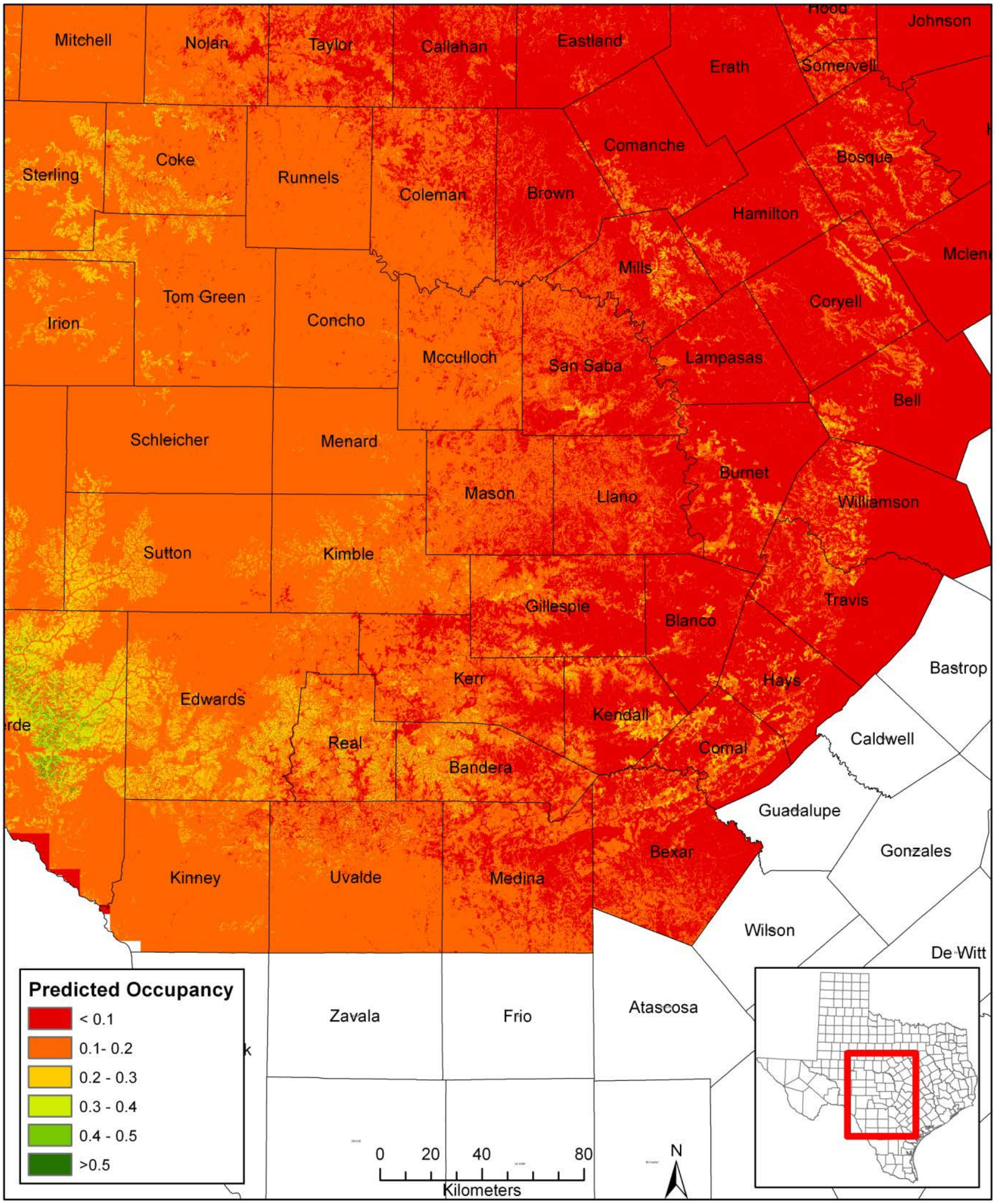

Figure 22. Range-wide predicted occupancy based on our 2010 data from all 8 study areas. Predicted occupancy increases with aridity (increases east to west).

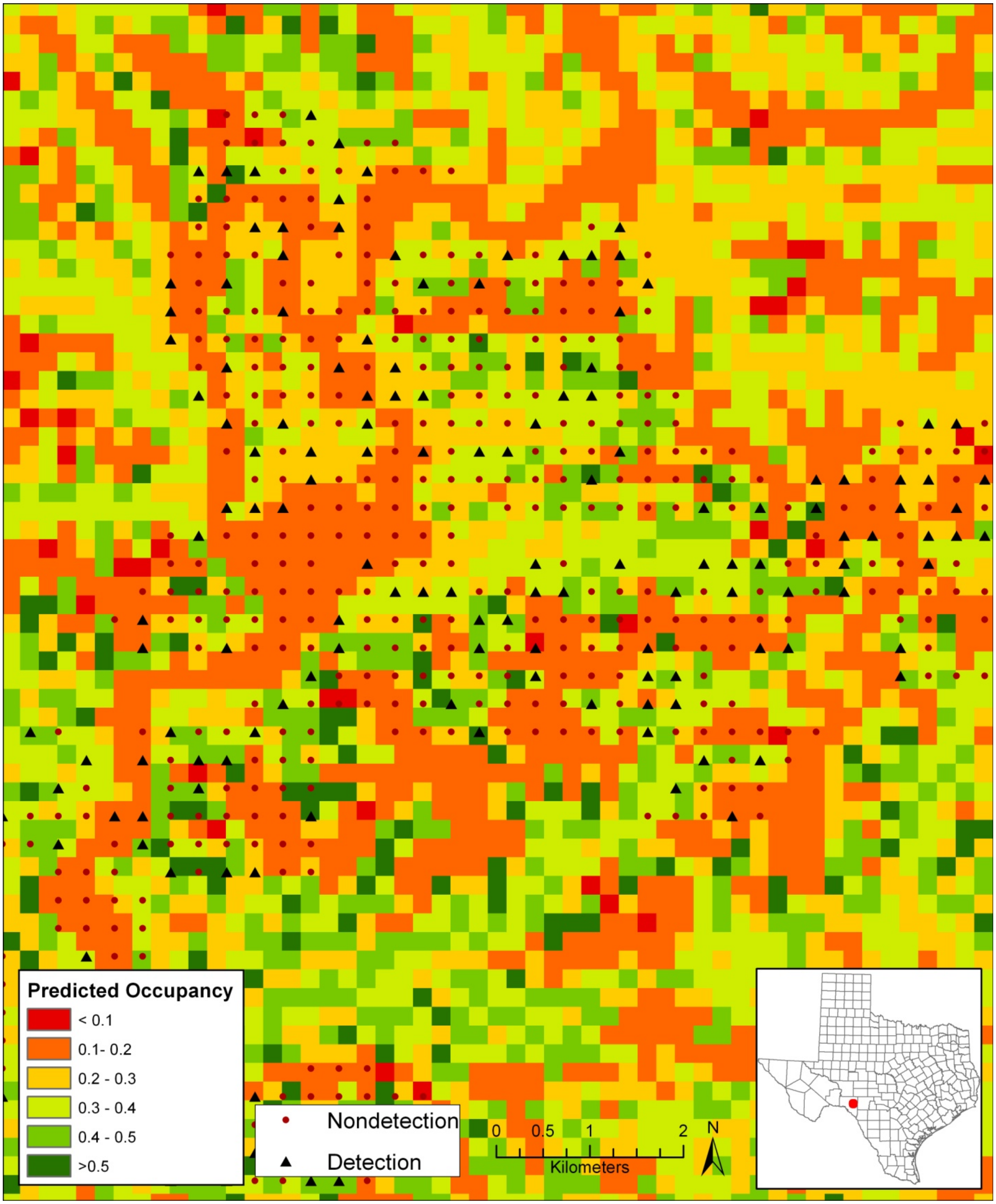

Figure 23. Predicted occupancy map of the range-wide model from the Devils River study area overlaid with our 2010 survey points. Map is zoomed in to show detail and does not include the entire area onto which the model was projected.

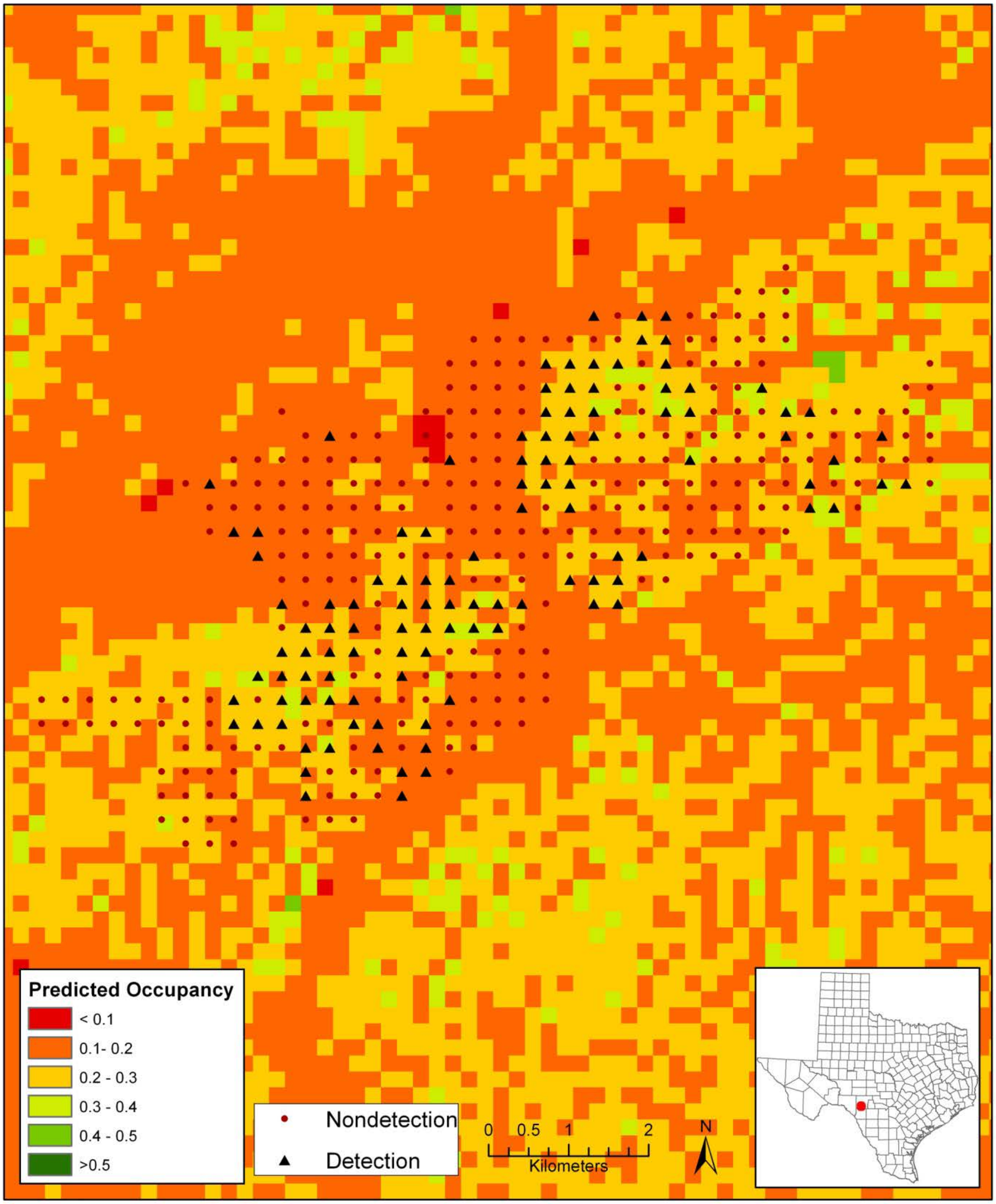

Figure 24. Predicted occupancy map of the range-wide model from the Kickapoo study area overlaid with our 2010 survey points. Map is zoomed in to show detail and does not include the entire area onto which the model was projected.

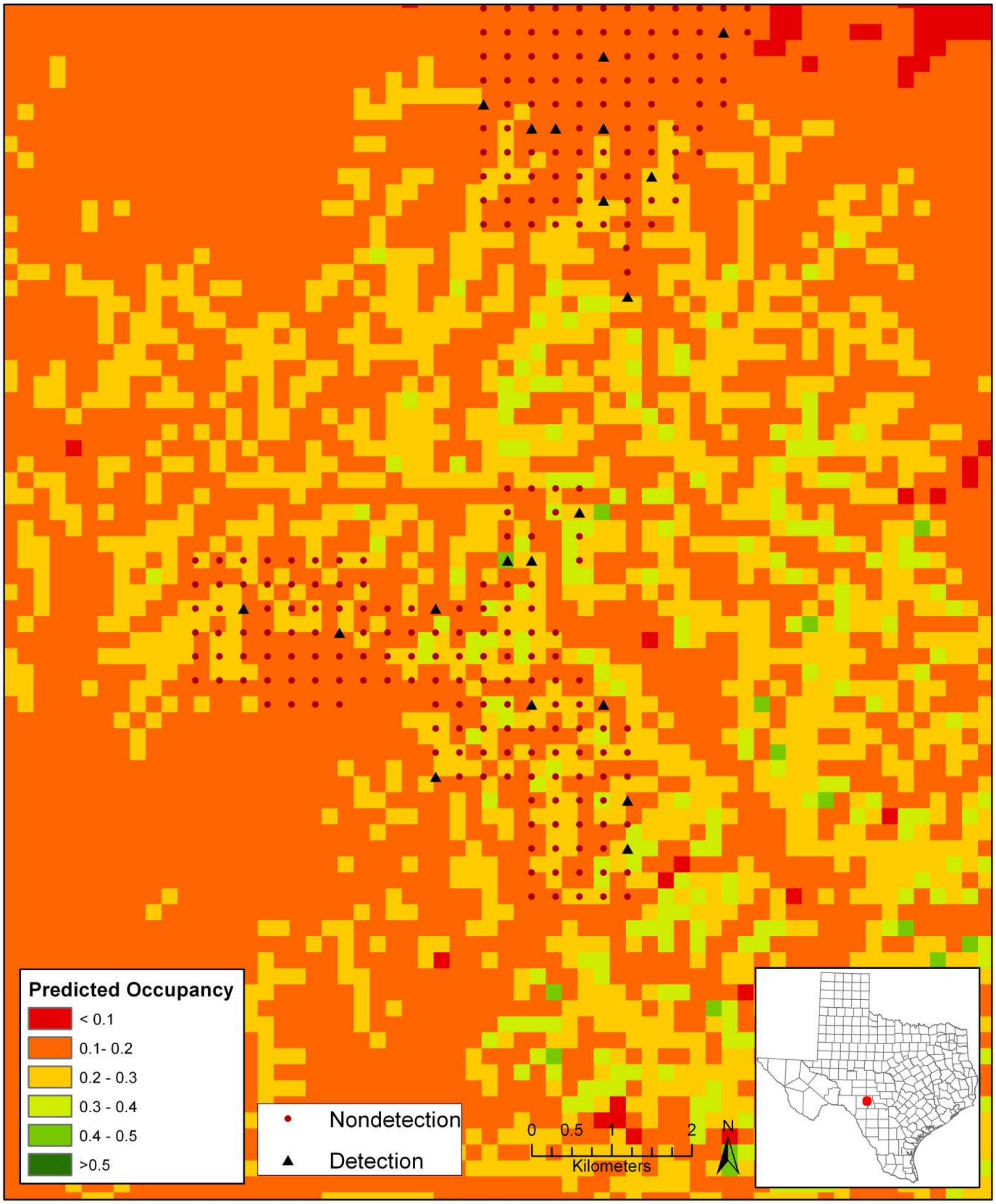

Figure 25. Predicted occupancy map of the range-wide model from the Devils Sinkhole study area overlaid with our 2010 survey points. Map is zoomed in to show detail and does not include the entire area onto which the model was projected.

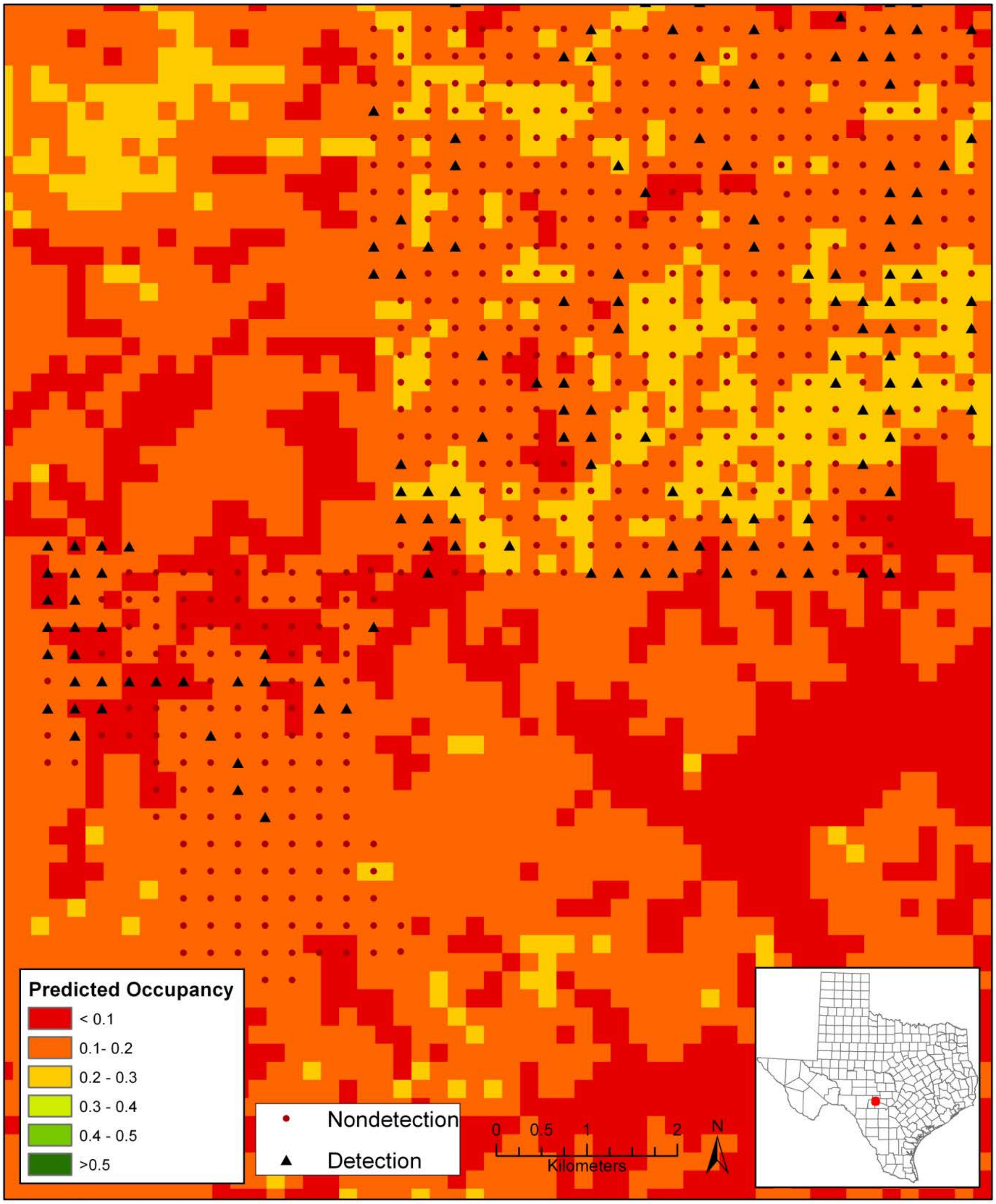

Figure 26. Predicted occupancy map of the range-wide model from the Kerr study area overlaid with our 2010 survey points. Map is zoomed in to show detail and does not include the entire area onto which the model was projected.

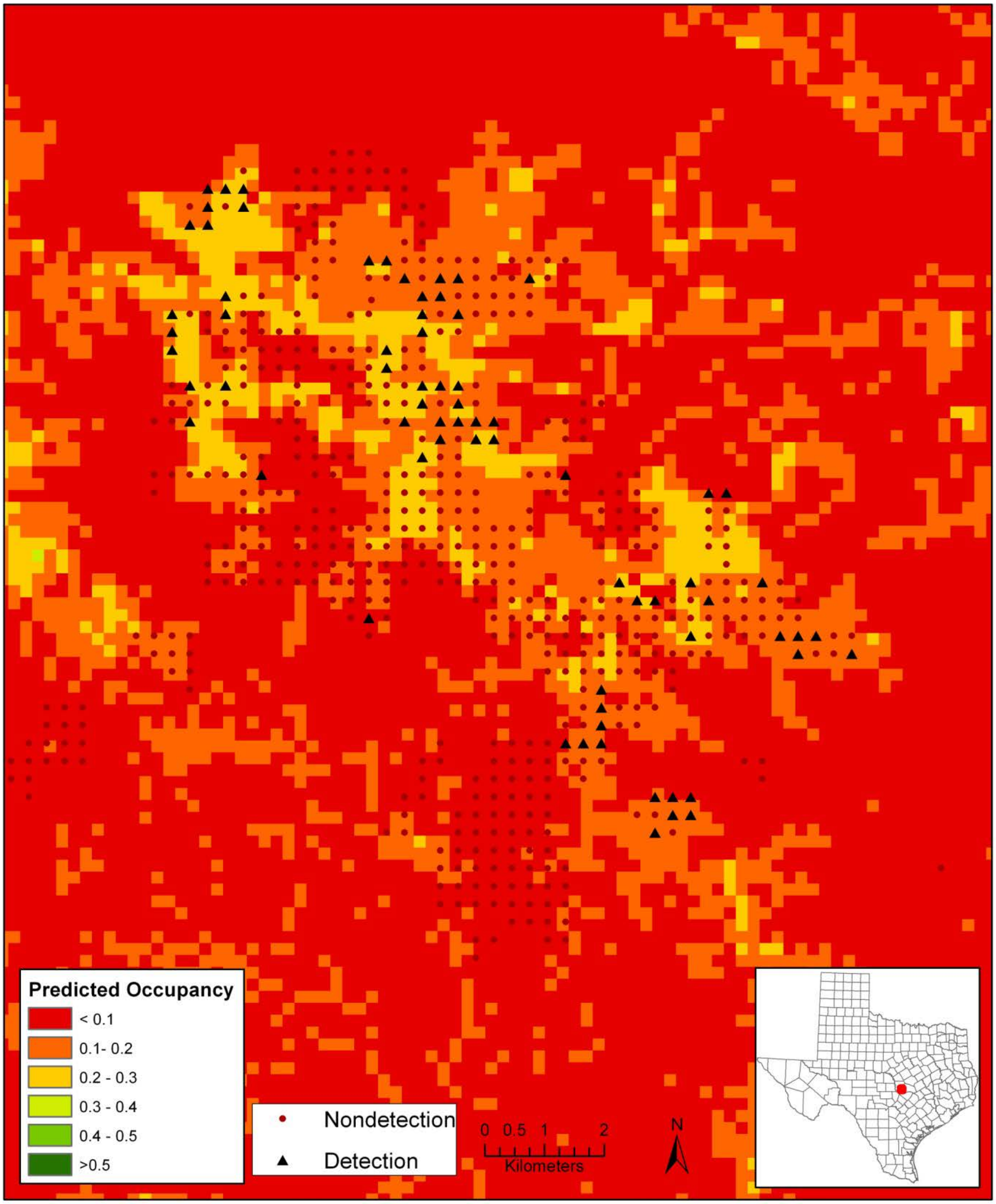

Figure 27. Predicted occupancy map of the range-wide model from the Balcones study area overlaid with our 2010 survey points. Map is zoomed in to show detail and does not include the entire area onto which the model was projected.

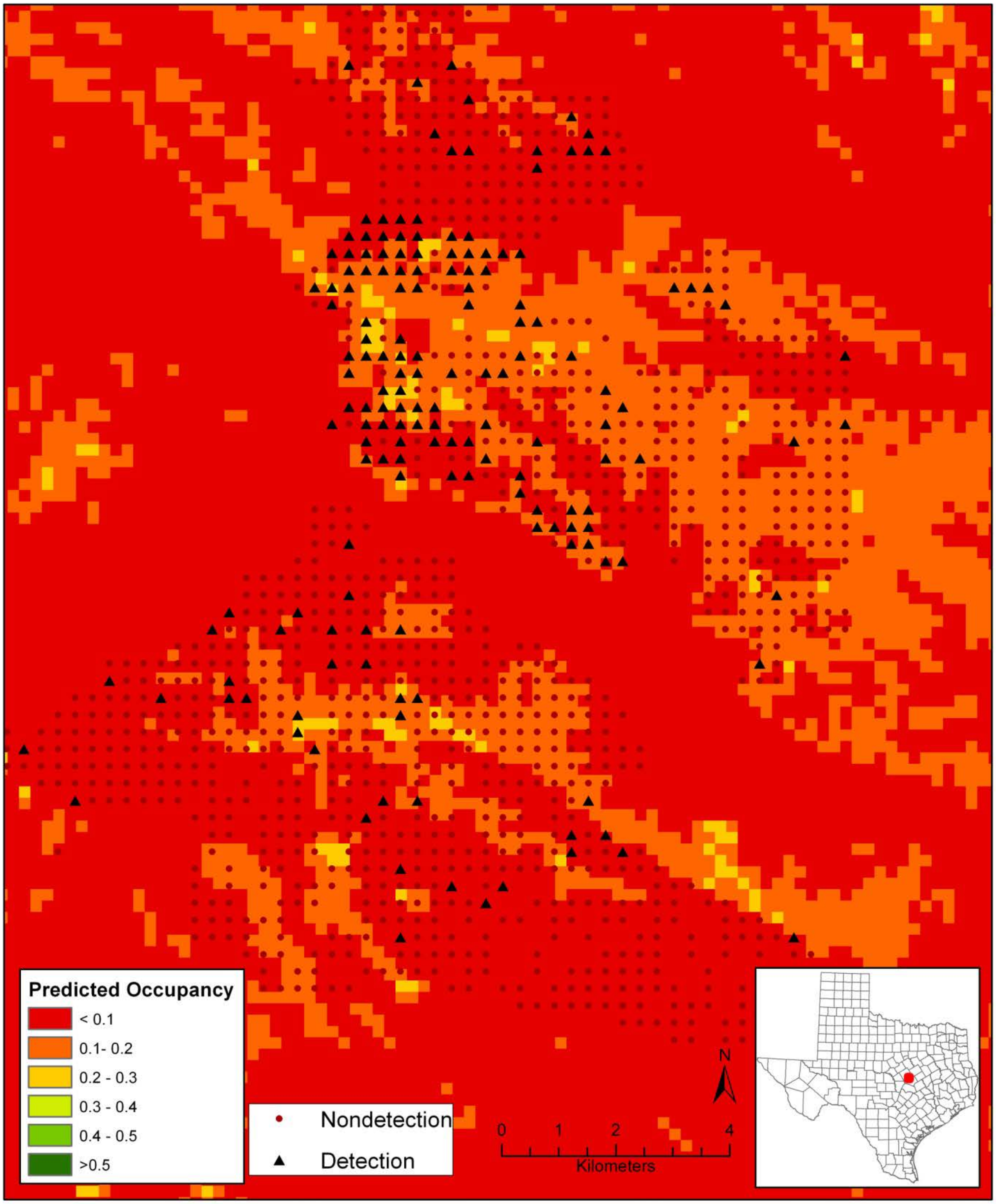

Figure 28. Predicted occupancy map of the range-wide model from the Fort Hood study area overlaid with our 2010 survey points. Map is zoomed in to show detail and does not include the entire area onto which the model was projected.

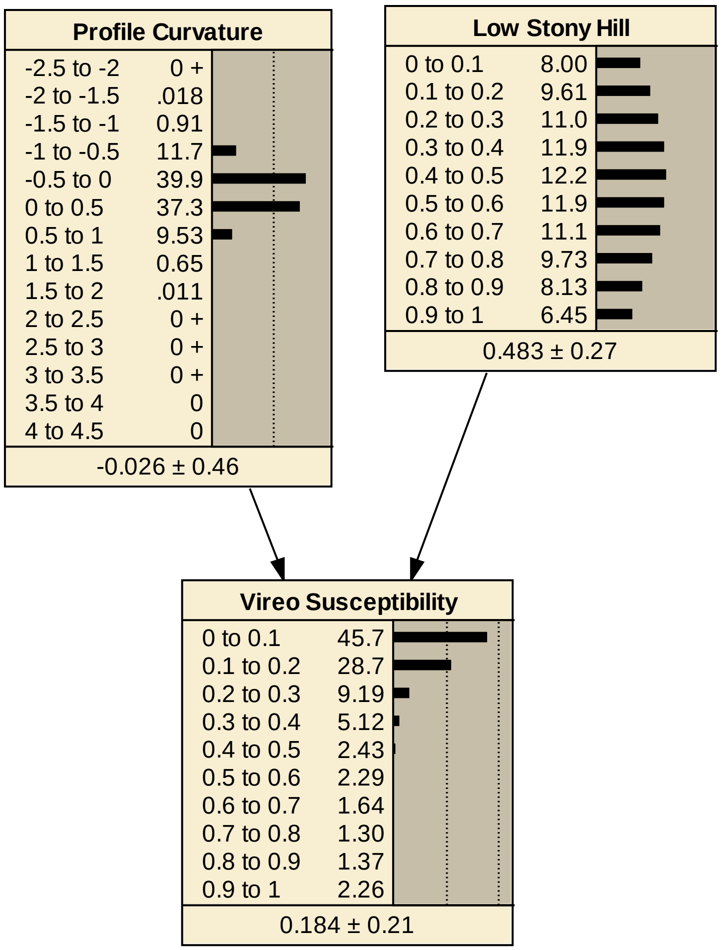

Figure 29. A remote-sensing scale probabilistic network for vireo susceptibility within the Balcones study site where each parameter is in its initialized state, where values associated with the histogram bars represent the probability that the parameter is in a particular state. Given the distribution of the parameters, probability of vireo susceptibility is low, with a 45.7% probability that the vireo susceptibility is 0 to 0.1 and a mean estimate of 0.184.

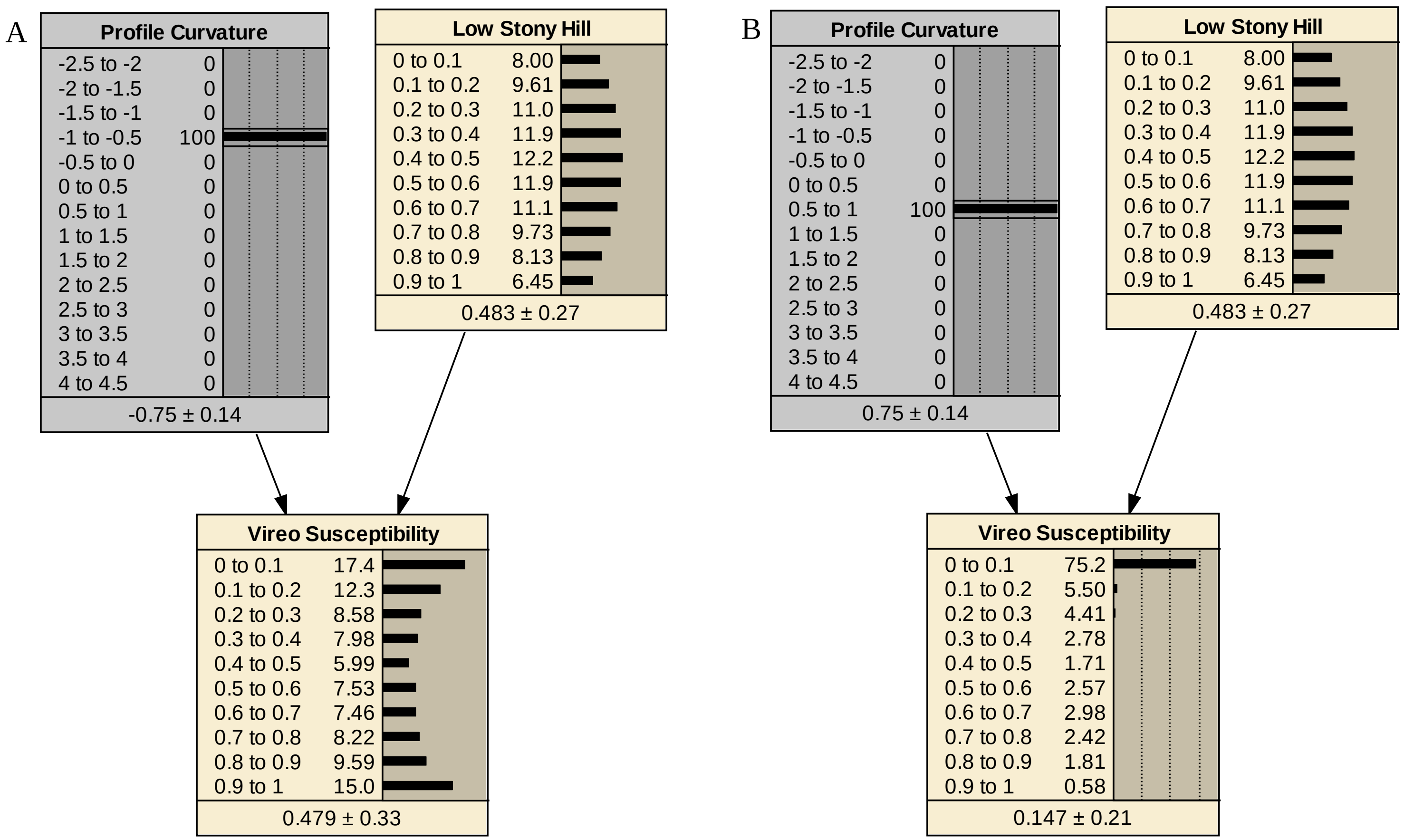

Figure 30. A remote-sensing scale probabilistic network for vireo occurrence within the Balcones study site in an updated form, where information regarding the state of a biological metric has been incorporated. For instance, we have set the value for Profile Curvature to a -1 to -0.5 (gray box A) which predicts a broad predicted susceptibility distribution. However, by changing the value for Profile Curvature to 0.5 to 1 (gray box B), the susceptibility prediction declines from a mean estimate of 0.479 to 0.147. Values associated with the histogram bars represent the probability that the parameter is in a particular state.

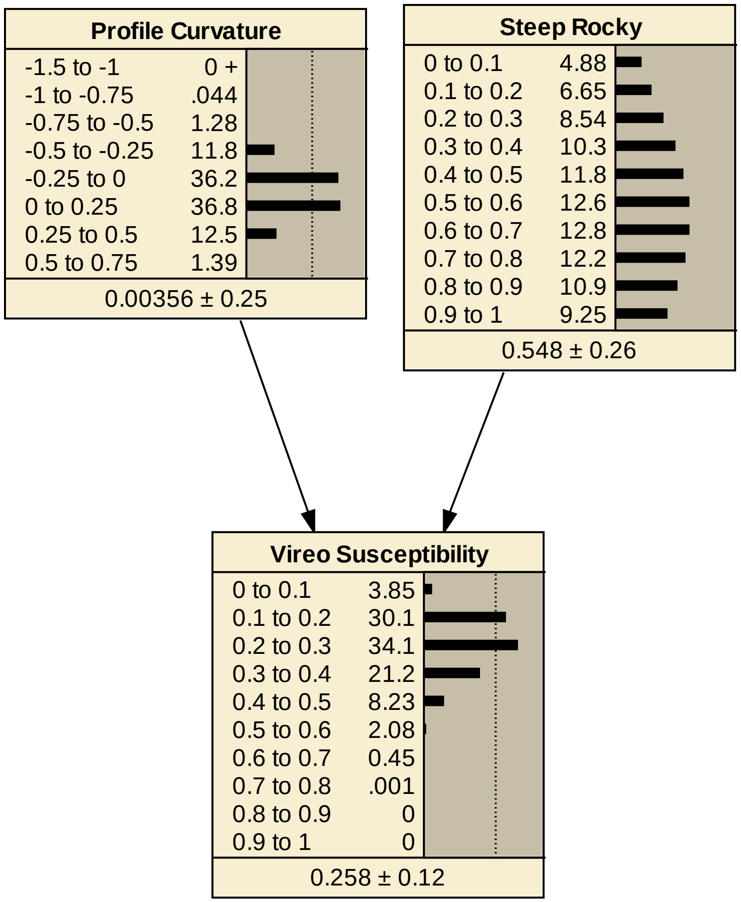

Figure 31. A remote-sensing scale probabilistic network for vireo susceptibility within the Devil's River study site where each parameter is in its initialized state, where values associated with the histogram bars represent the probability that the parameter is in a particular state. Given the distributions of the parameters, probability of vireo susceptibility has a mean estimate of 0.258.

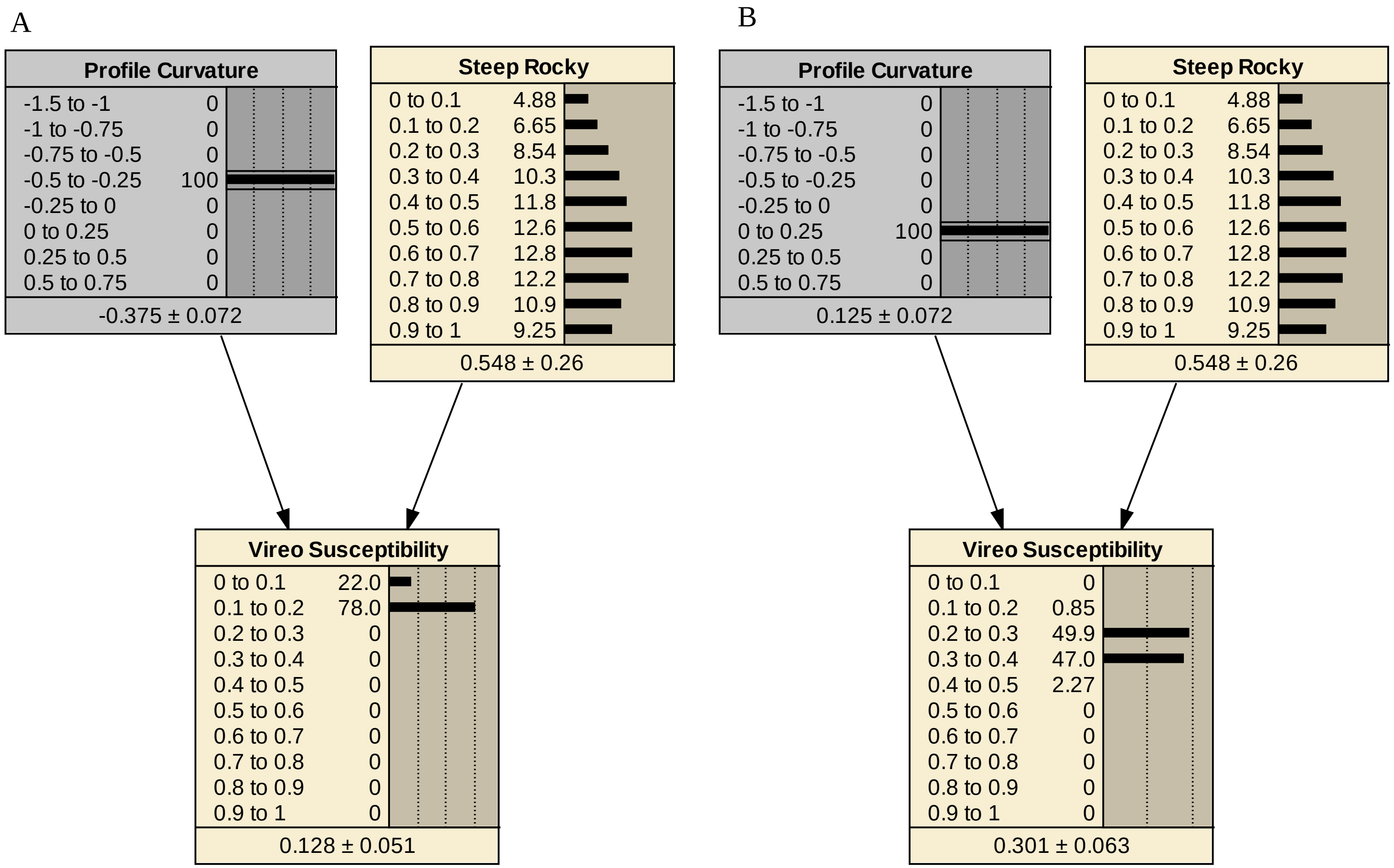

Figure 32. A remote-sensing scale probabilistic network for vireo susceptibility within the Devil's River study site in an updated form, where information regarding the state of a biological metric has been incorporated. Values associated with the histogram bars represent the probability that the parameter is in a particular state. For instance, if we know the value for Profile Curvature is -0.5 to -0.25 (gray box A), we predict a low susceptibility distribution, with mean estimate of 0.128. However, if the value for Profile Curvature was positive, say between 0 to 0.25 (gray box B), the susceptibility prediction increases to a mean estimate of 0.301.

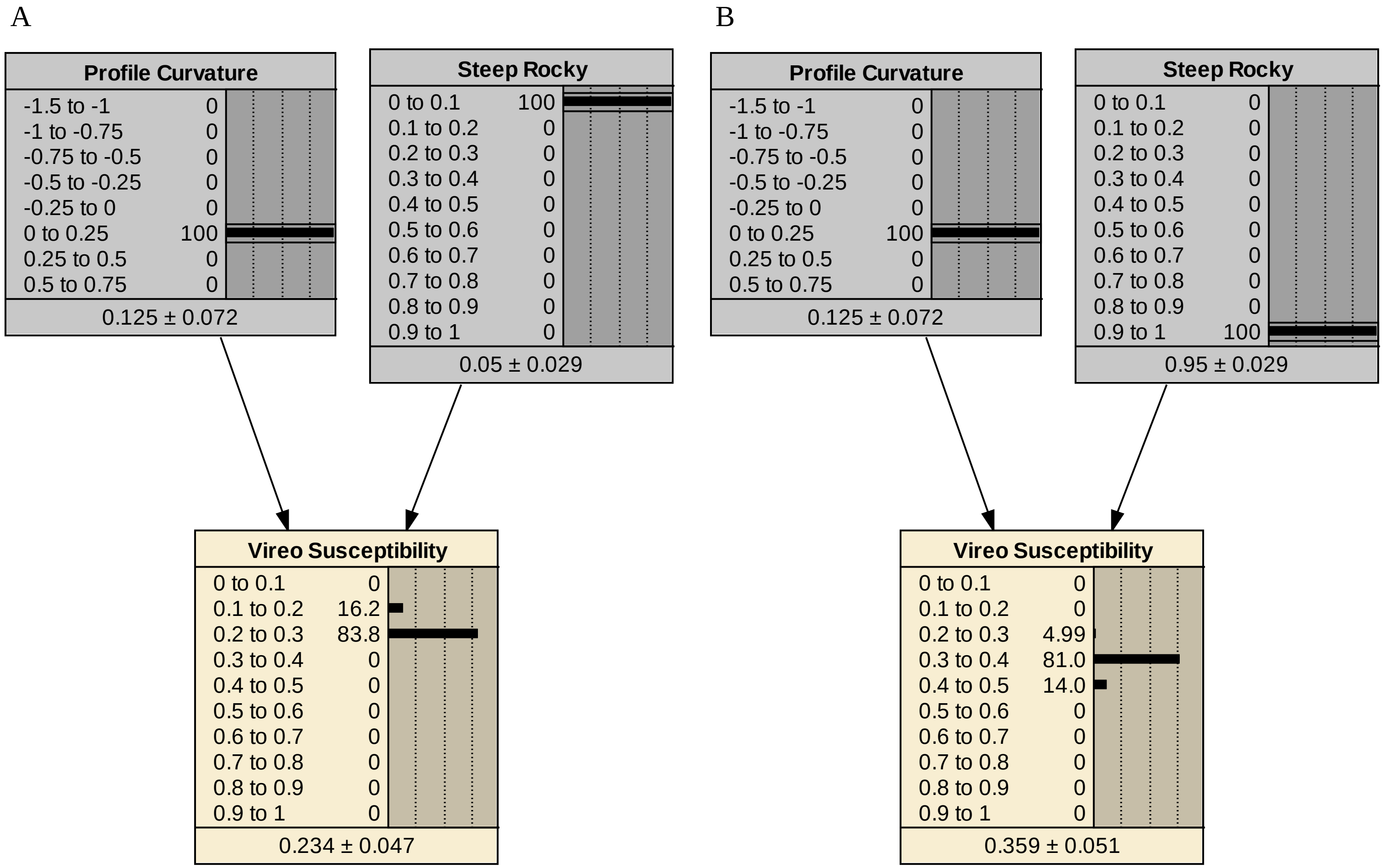

Figure 33. A remote-sensing scale probabilistic network for vireo susceptibility within the Devil's River study site in an updated form, where information regarding the state of several biological metrics have been incorporated. Values associated with the histogram bars represent the probability that the parameter is in a particular state. For instance, we have set the value for Profile Curvature to 0.25 to 0.5 and set the value for Steep Rocky to 0 to 0.1 (gray boxes A) which predicts a mean susceptibility estimate of 0.234. However, by changing the value for Steep Rocky to 0.9 to 1, (gray boxes B), the susceptibility prediction increases only slightly to a mean estimate of 0.359.

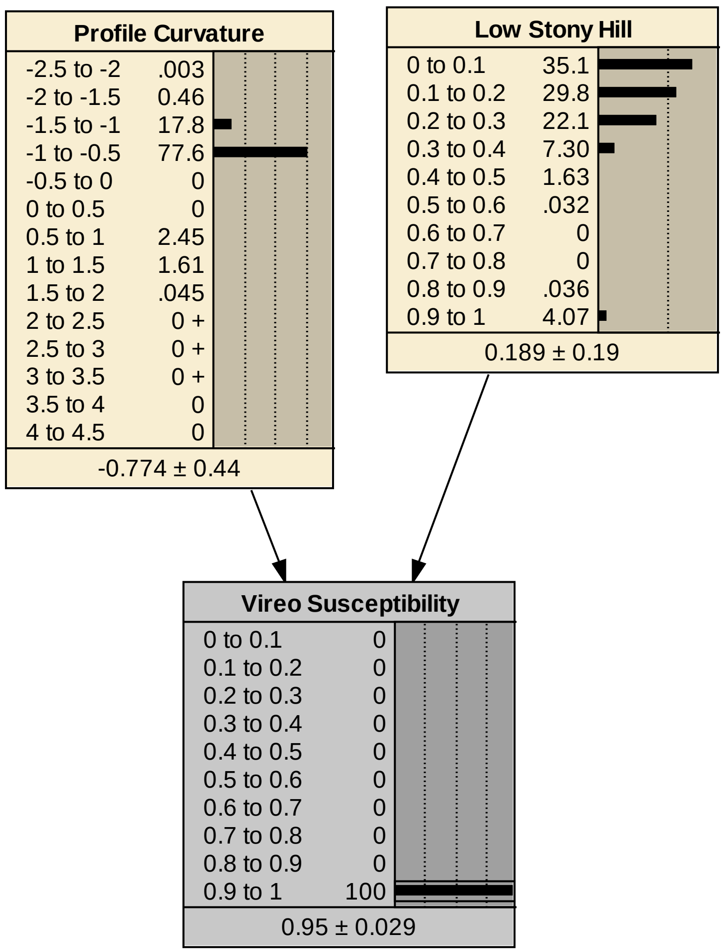

Figure 34. A remote-sensing scale probabilistic network for vireo susceptibility within the Balcones study site in an updated form, where information regarding the desired Vireo Susceptibility prediction has been incorporated. Values associated with the histogram bars represent the probability that the parameter is in a particular state. For instance, we have set the value for Vireo Susceptibility to 0.9 to 1 (gray box) which predicts the necessary values of the other nodes. This indicates that in order to have a 0.95 chance of being susceptible to vireo, an area must have a profile curvature of -1.5 to -0.5 and susceptibility is further increased if the proportion of Low Stony Hill is less than 0.4.

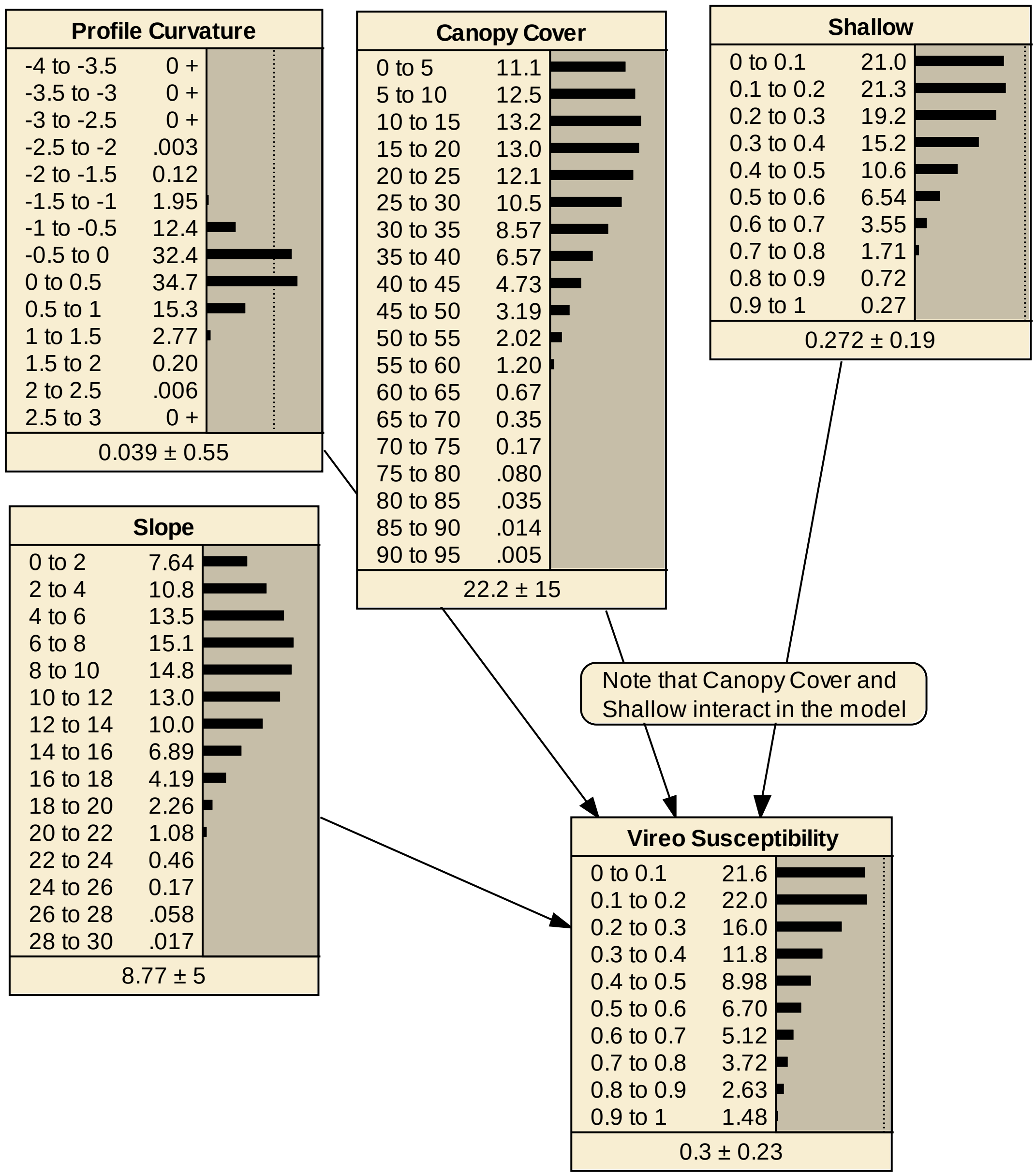

Figure 35. A remote-sensing scale probabilistic network for vireo susceptibility within the Kickapoo study site where each parameter is in its initialized state, where values associated with the histogram bars represent the probability that the parameter is in a particular state. Given the distribution of the parameters, probability of vireo susceptibility is fairly widely distributed, with a mean estimate of 0.3.

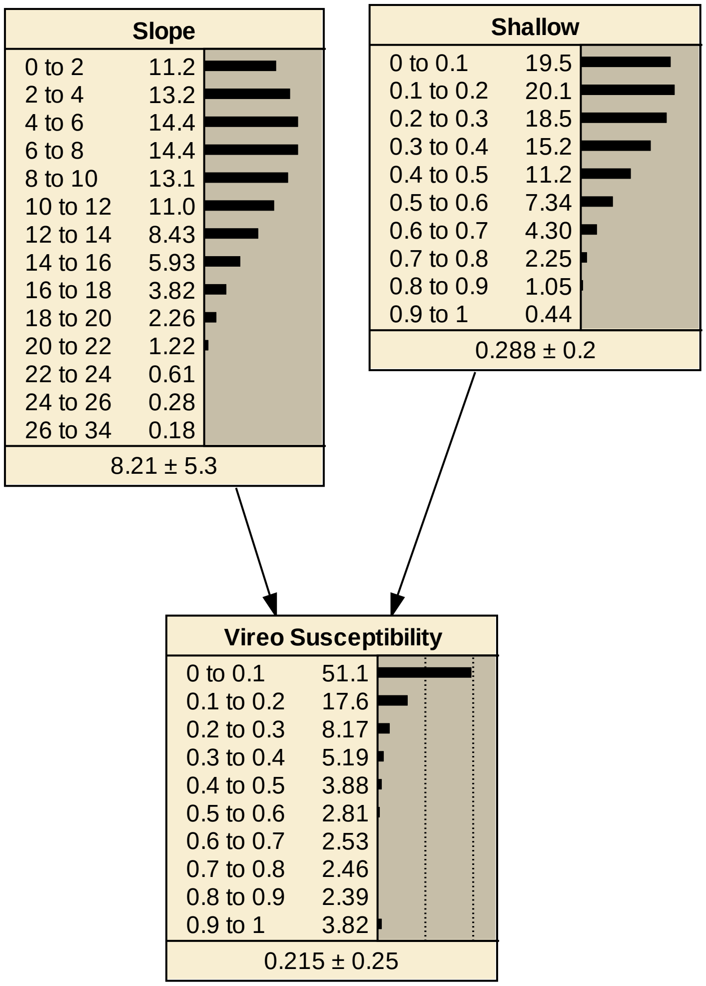

Figure 36. A remote-sensing scale probabilistic network for vireo susceptibility within the Devil's Sinkhole study site where each parameter is in its initialized state, where values associated with the histogram bars represent the probability that the parameter is in a particular state. Given the distribution of the parameters, probability of vireo susceptibility is low, with a 51.1% probability that the vireo susceptibility is 0 to 0.1 and a mean estimate of 0.215.

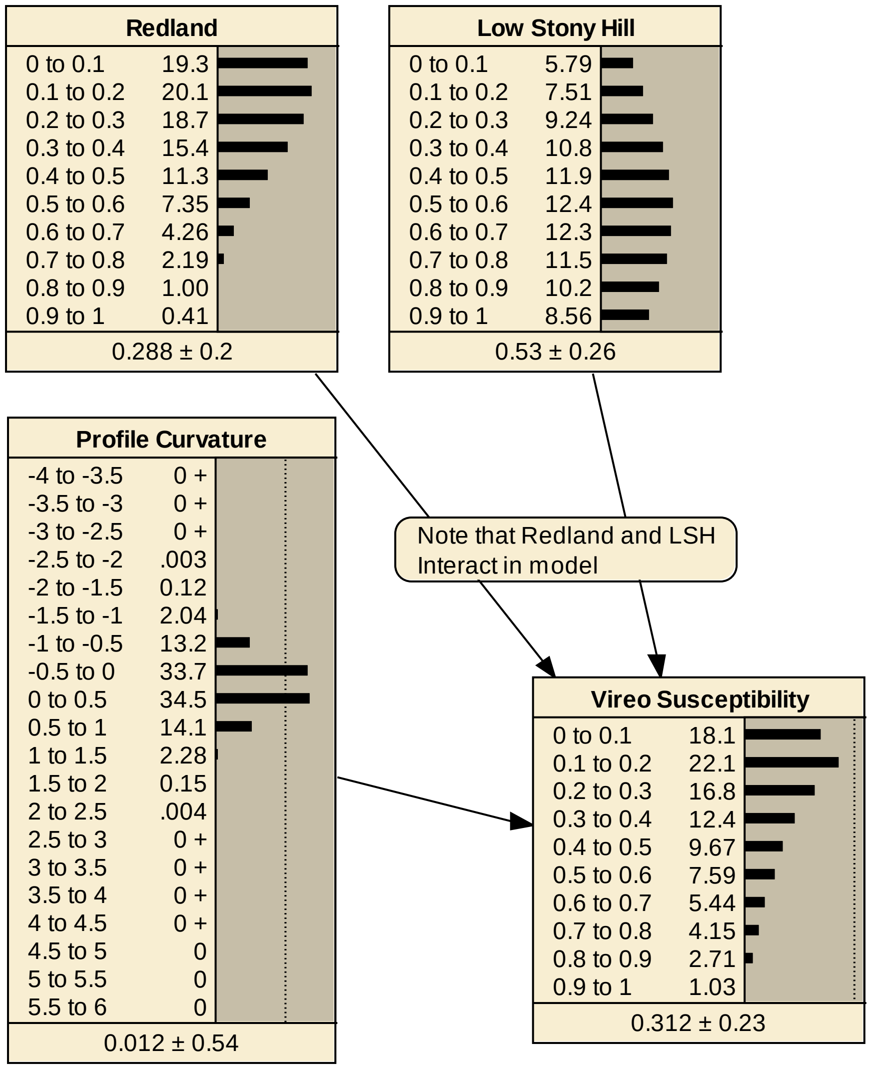

Figure 37. A remote-sensing scale probabilistic network for vireo susceptibility within the Kerr study site where each parameter is in its initialized state, where values associated with the histogram bars represent the probability that the parameter is in a particular state. Given the distribution of the parameters, probability of vireo susceptibility is fairly widely distributed, with a mean estimate of 0.312.

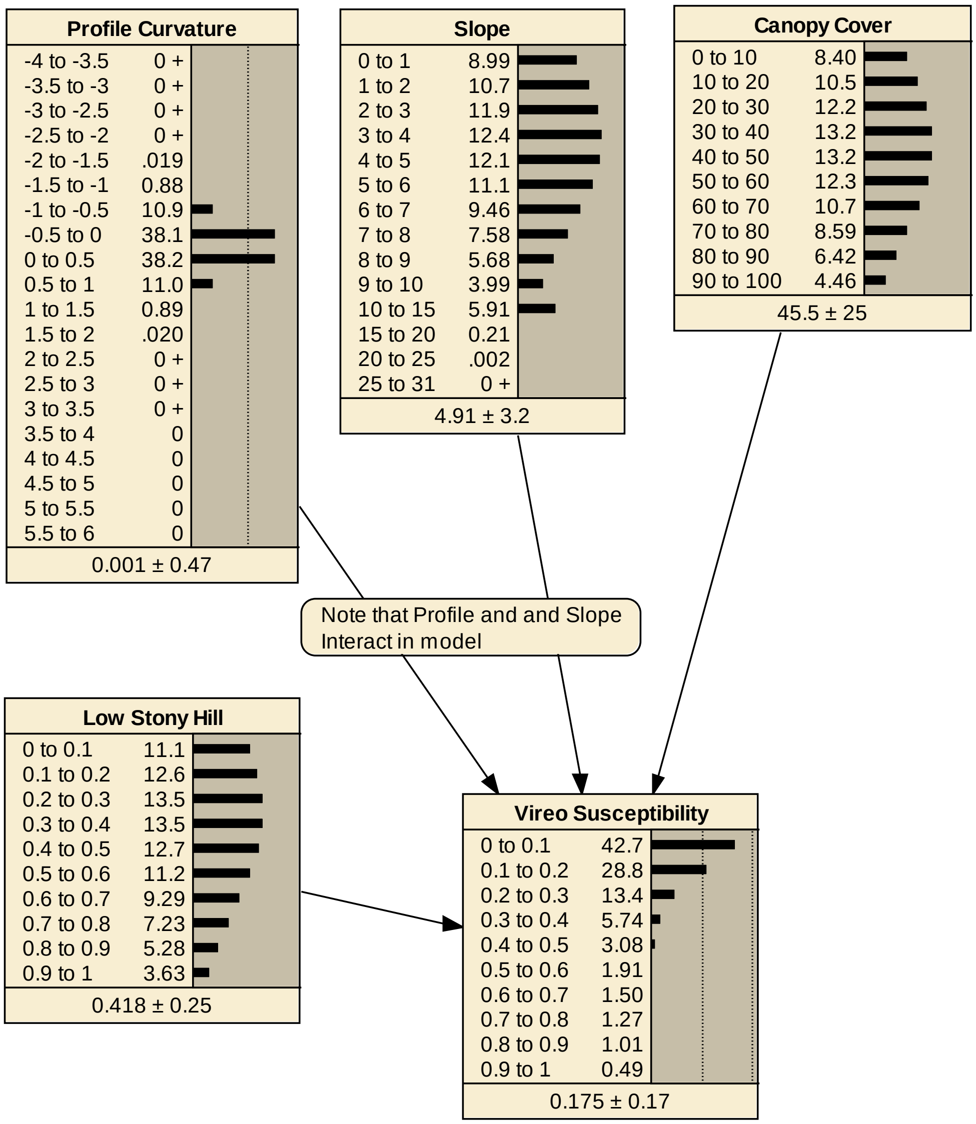

Figure 38. A remote-sensing scale probabilistic network for vireo susceptibility within the Fort Hood study site where each parameter is in its initialized state, where values associated with the histogram bars represent the probability that the parameter is in a particular state. Given the distribution of the parameters, probability of vireo susceptibility is relatively low, with a 42.7% probability that the vireo susceptibility is 0 to 0.1 and a mean estimate of 0.175.

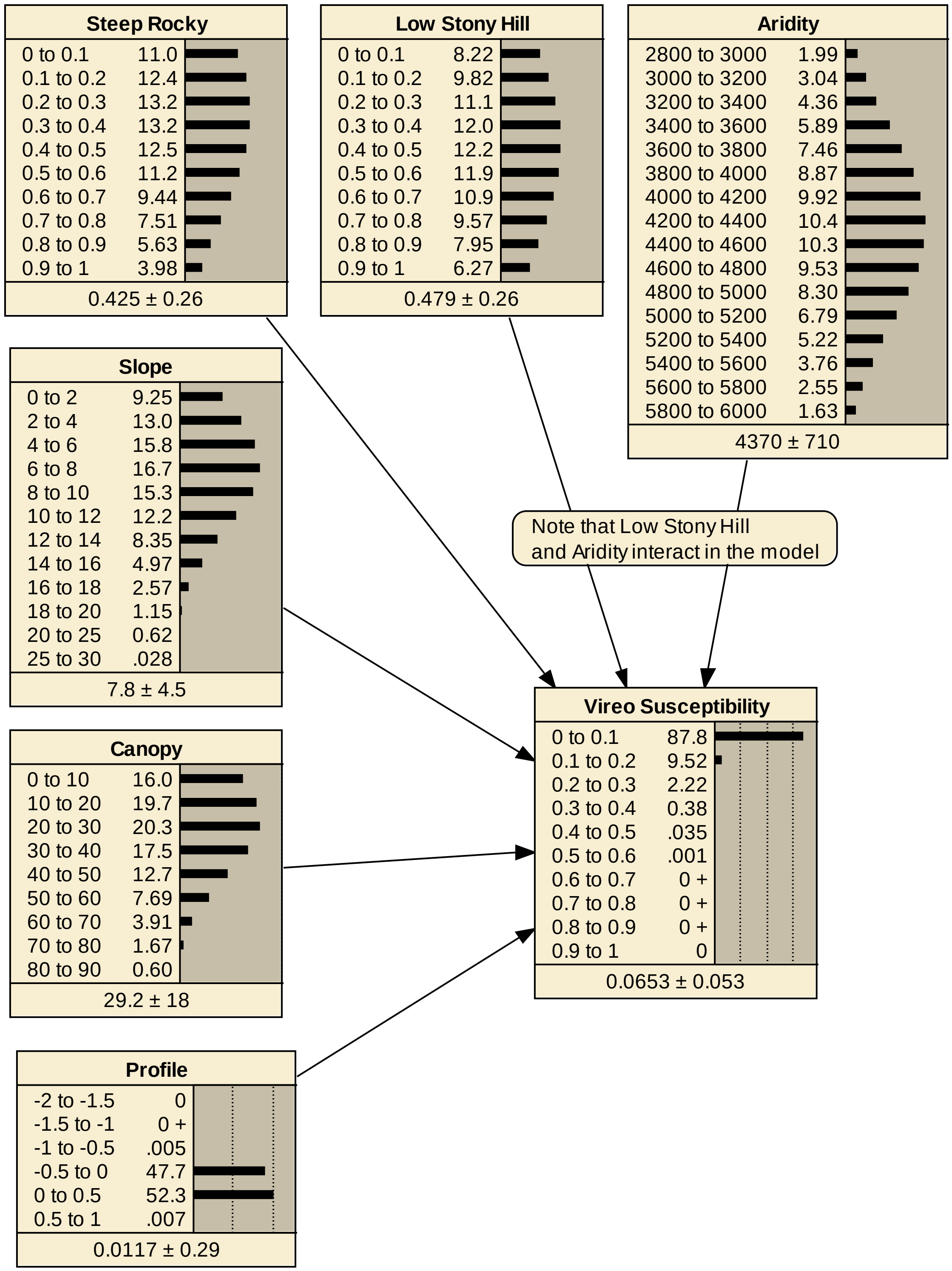

Figure 39. A remote-sensing scale probabilistic network for vireo susceptibility across the range of the vireo where each parameter is in its initialized state, where values associated with the histogram bars represent the probability that the parameter is in a particular state. Given the distribution of the parameters, probability of vireo susceptibility is low, with an 87.8% probability that the vireo susceptibility is 0 to 0.1 and a mean estimate of 0.065.

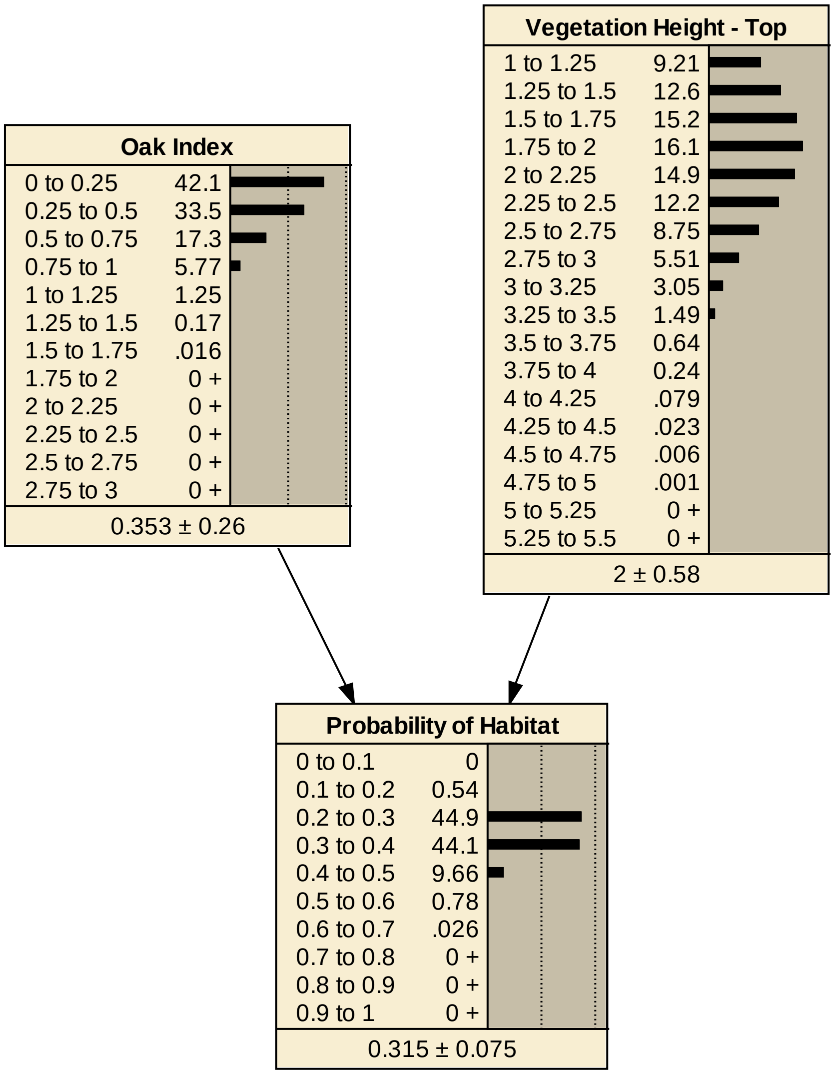

Figure 40. A local scale probabilistic network for probability of vireo habitat within the Devil's River study site where each parameter is in its initialized state, where values associated with the histogram bars represent the probability that the parameter is in a particular state. Given the distribution of the parameters, probability of vireo habitat has a mean estimate of 0.315.

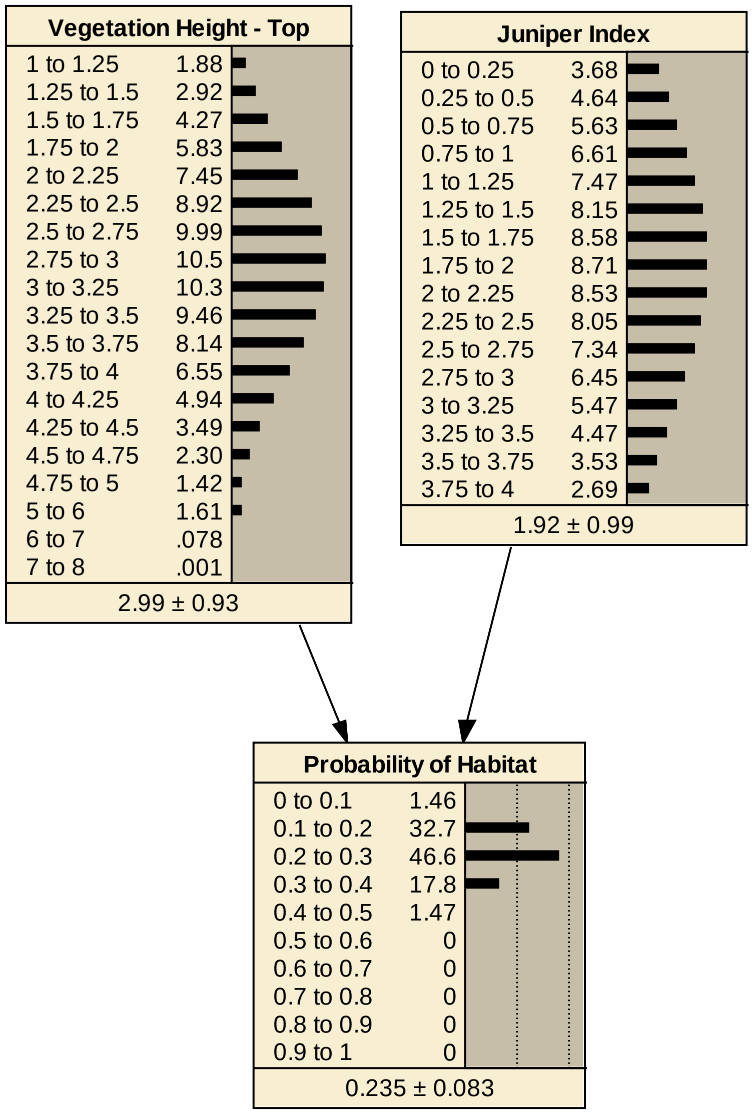

Figure 41. A local scale probabilistic network for probability of vireo habitat within the Kickapoo study site where each parameter is in its initialized state, where values associated with the histogram bars represent the probability that the parameter is in a particular state. Given the distribution of the parameters, probability of vireo habitat has a mean estimate of 0.235.

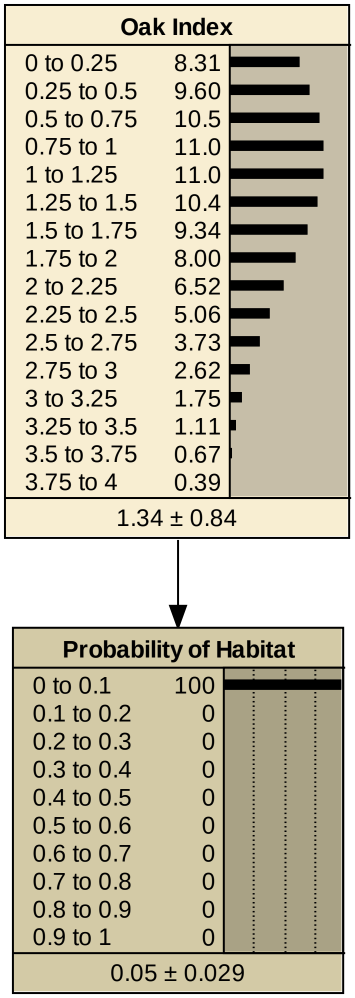

Figure 42. A local scale probabilistic network for probability of vireo habitat within the Devil's Sinkhole study site where each parameter is in its initialized state, where values associated with the histogram bars represent the probability that the parameter is in a particular state. Regardless of the value of the Oak Index, the probability of vireo habitat does not exceed 0.1. No better models could be found, indicating that the variables used may not have been sufficient or that the sample size was inadequate.

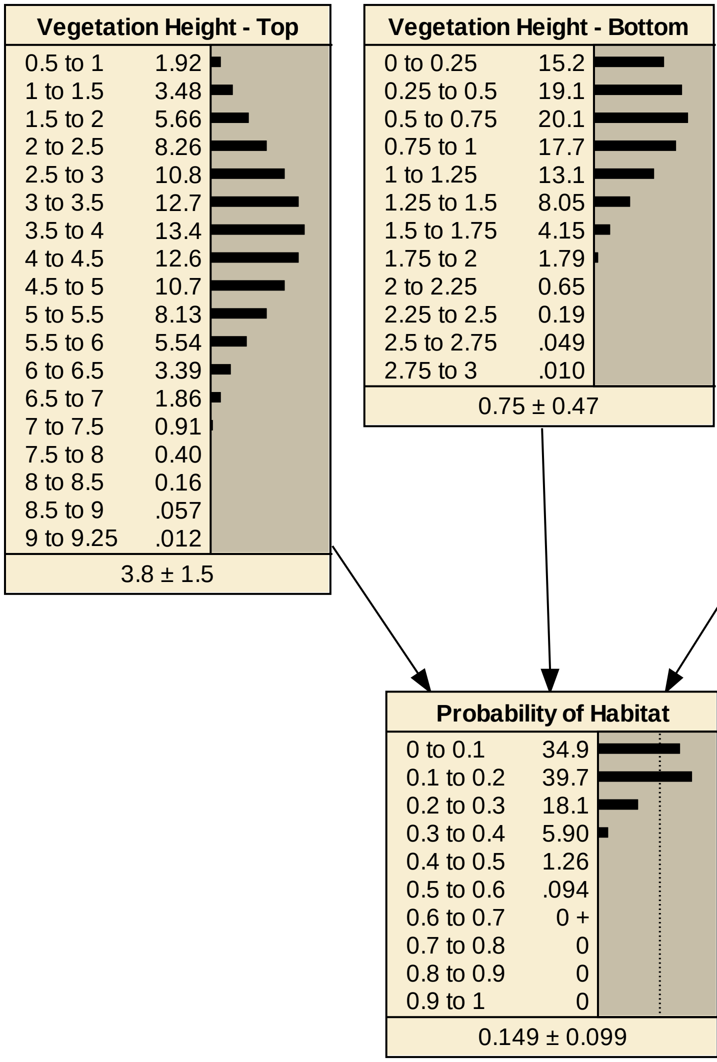

Figure 43. A local scale probabilistic network for probability of vireo habitat within the Kerr study site where each parameter is in its initialized state, where values associated with the histogram bars represent the probability that the parameter is in a particular state. Given the distribution of the parameters, probability of vireo habitat is low, with a 39.7% probability that the vireo susceptibility is between 0.1 and 0.2 and a mean estimate of 0.149.

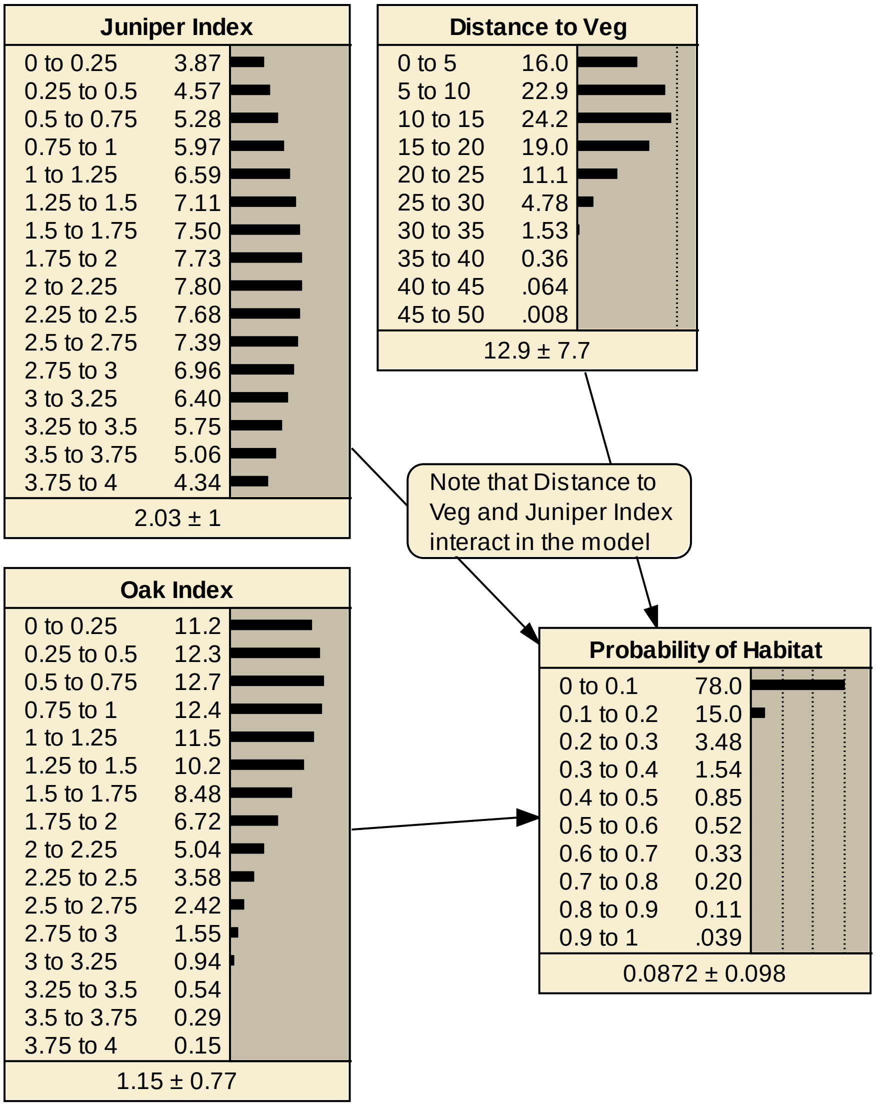

Figure 44. A local scale probabilistic network for probability of vireo habitat within the Balcones study site where each parameter is in its initialized state, where values associated with the histogram bars represent the probability that the parameter is in a particular state. Given the distribution of the parameters, probability of vireo habitat is low, with a 78.0% probability that the vireo susceptibility is 0 to 0.1 and a mean estimate of 0.087.

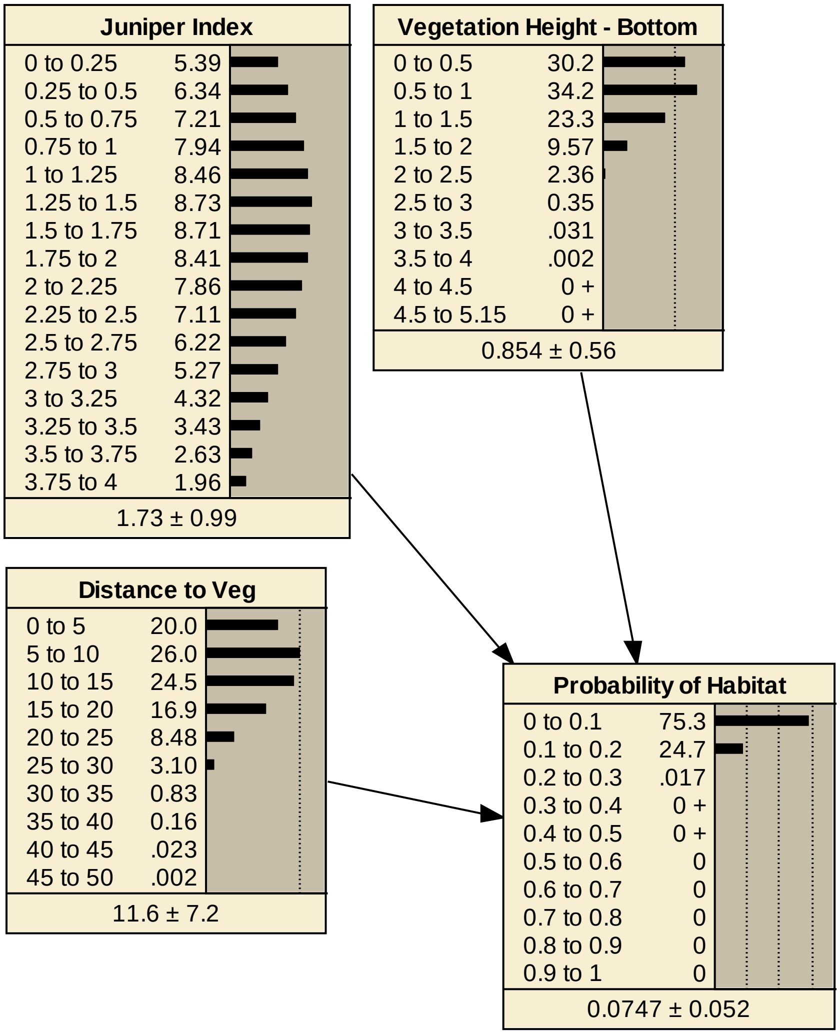

Figure 45. A local scale probabilistic network for probability of vireo habitat within the Fort Hood study site where each parameter is in its initialized state, where values associated with the histogram bars represent the probability that the parameter is in a particular state. Given the distribution of the parameters, probability of vireo habitat is low, with a 75.3% probability that the vireo susceptibility is 0 to 0.1 and a mean estimate of 0.075.

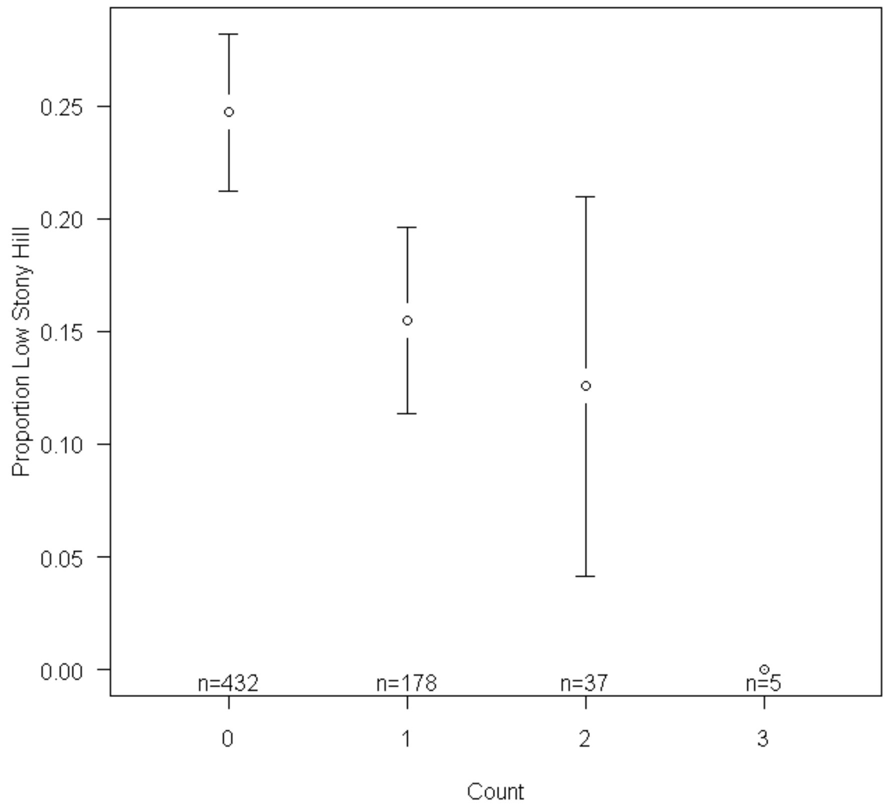

Figure 46. Means and 95% confidence intervals for proportion of Low Stony Hill ecosite within 100 m of survey points by the number of vireos detected at survey points (count) for study sites with a low Aridity index (<3500).

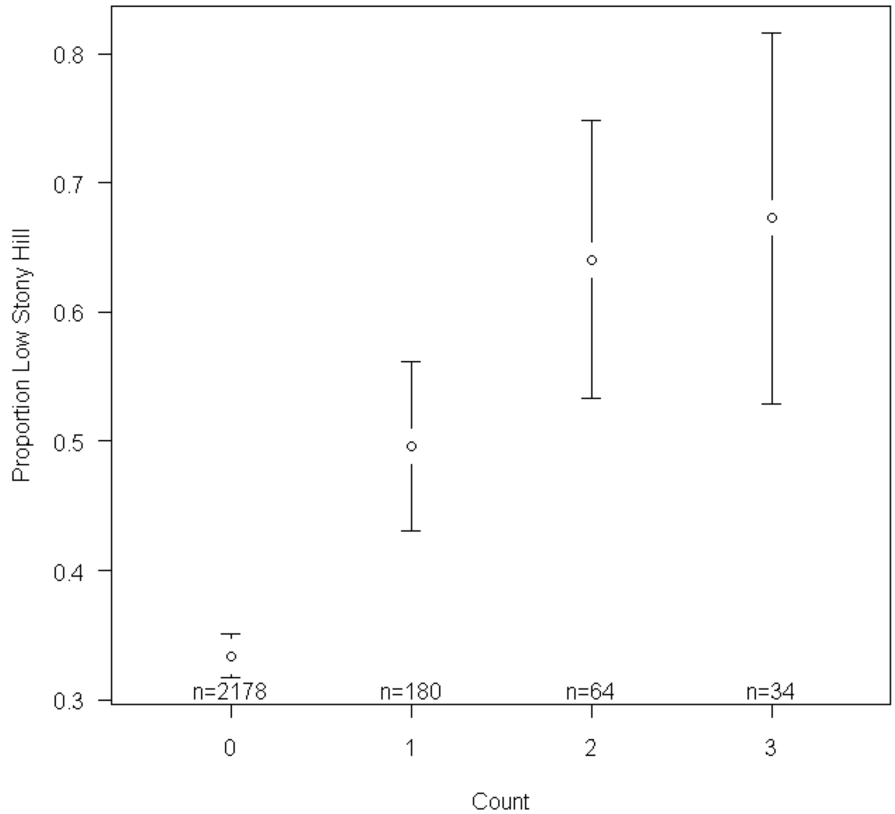

Figure 47. Means and 95% confidence intervals for proportion of Low Stony Hill ecosite within 100 m of survey points by the number of vireos detected at survey points (count) for study sites with a high Aridity index (>5300).

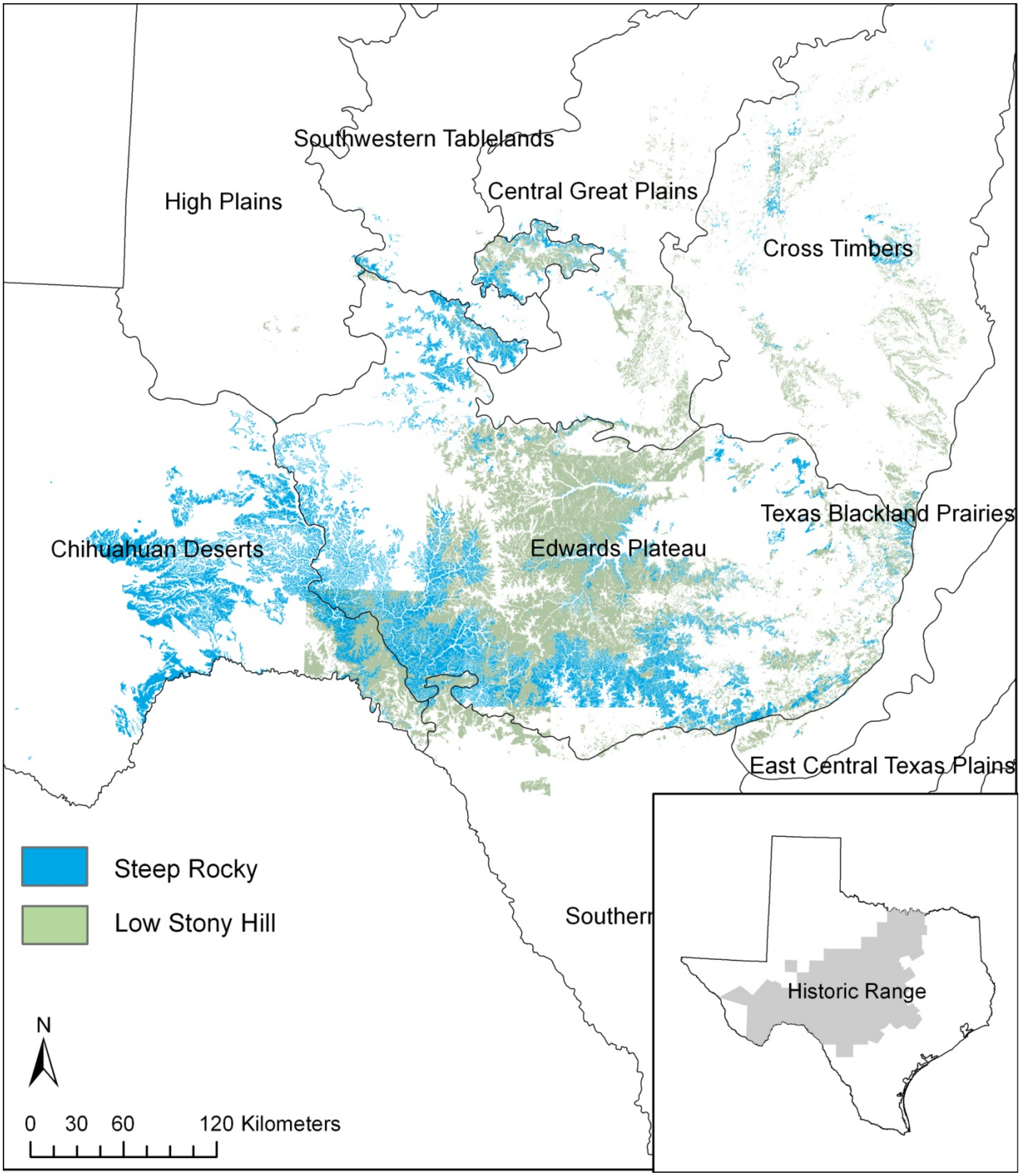

Figure 48. Extent of the Steep Rocky and Low Stony Hill ecosites according to the National Land Cover Database (NLCD). Note that Low Stony Hill does not extend far into the Chihuahuan Desert ecoregion, and Steep Rocky is less frequent in the eastern parts of the Edwards Plateau and in the Cross Timbers ecoregions.

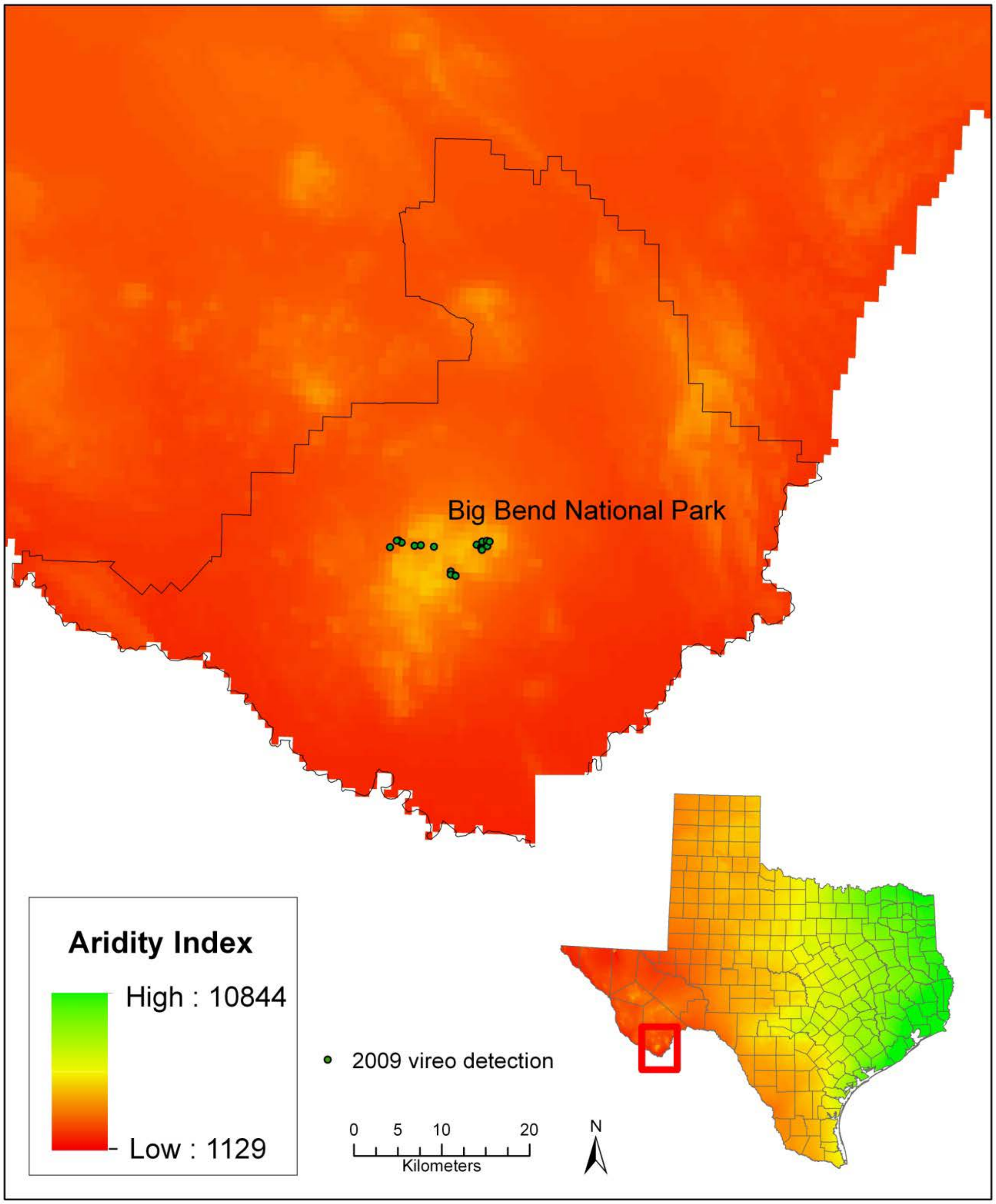

Figure 49. Example of aridity values at vireo detections in the Chihuahuan Desert. Vireos detected in 2009 in the Chihuahuan Desert were found in areas of higher aridity (cooler, wetter) than the surrounding area, where aridity values were similar to those in the central part of the state (further east). This suggests a minimum aridity index threshold, below which the probability of vireo occurrence may be close to 0.

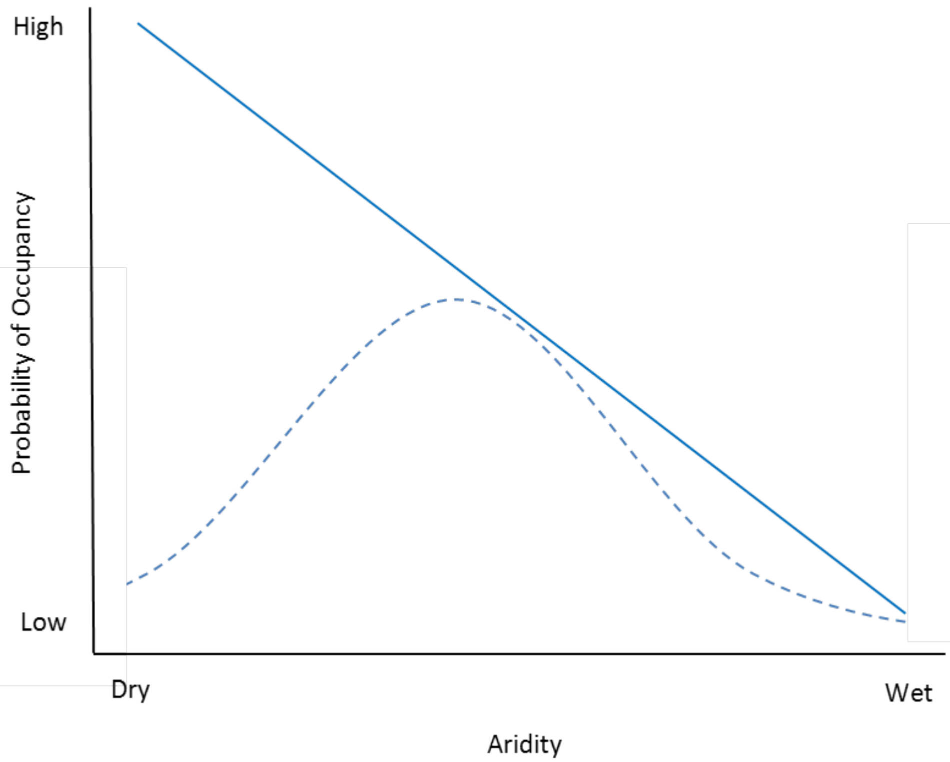

Figure 50. Graph of the theoretical relationship between the probability of vireo occupancy and aridity. While our range-wide model used a negative linear relationship between the two metrics (solid line), we hypothesize that the actual relationship is actually a curve (dashed line), where the probability of occupancy is low at extreme levels of dryness and wetness and is highest at a medium level.

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Appendices

Appendix A: Randomly-distributed surveys; 2009 sampling

2009 randomly-distributed sampling locations

We developed a two-step design to identify areas to survey for vireos between April and June 2009. In step one, we compiled current and recent data of vireo detections (1996 to 2008) from both private and public lands. We chose these years to approximately correspond to the 2001 National Land Cover Database (NLCD; http://landcover.usgs.gov/) dataset. We compiled approximately 8,000 known detections in a spatially explicit database with positional accuracies ranging from exact GPS coordinates to territory approximations delineated on United States Geological Survey (USGS) 1:24000 quadrangles. Several sources contributed data to our compilation, including Texas A&M University, Texas Parks & Wildlife Department (TPWD), Texas Department of Transportation (TXDOT), SWCA Environmental Consultants, PBS&J, Lower Colorado River Authority (LCRA), and other studies published in the literature and submitted to USFWS (McKinney 1996, Marcus et al. 1999, Lockwood and Hernandez 2000, Peck and Barlow 2000, SWCA Inc. Environmental Consultants 2000, Druid Environmental and The Nature Conservancy 2001, Maresh 2001, Maresh and Rowell 2001, Pinkston and Wright 2001, Pinkston et al. 2001, Bailey and Maresh 2002, Maresh 2002, Maresh and Rowell 2002, Pinkston et al. 2002, Turner 2002a;b, Environmental Defense 2003, Maresh 2003a;b, Fushille and Ramirez 2004, Maresh 2004;2005).

We selected sites to survey for vireo by first quantifying percent woody canopy cover at each vireo detection location using the 2001 NLCD canopy cover dataset. Due to the diversity of vegetation throughout the range of the vireo in Texas, we divided our canopy cover analysis into three distinct ecoregions: Edwards Plateau, Cross Timbers, and Chihuahuan Desert from the United States Environmental Protection Agency (US EPA) Level III Ecoregions of the Conterminous United States (based on Omernik 2004; Fig. A1). These Level III ecoregions envelop the vireo recovery regions as suggested for modification by USFWS 1996 (Fig. A2). Based on the frequency distribution of canopy cover for our compiled vireo detections, we classified appropriate survey sites as land with 1-40% canopy cover in the Edwards Plateau and Cross Timbers ecoregions and as land with >10% canopy cover in the Chihuahuan Desert (Table A1).

For step two, using the 2001 NLCD, we developed a layer of unsuitable survey sites by combining the following classes: Open Water, Perennial Ice/Snow, Developed, Barren, Pasture/Hay, and Cultivated. In addition, we considered all area lying within the Texas General Land Office (GLO) Urban Areas layer and the Texas Natural Resources Information System (TNRIS) StratMap City limits layer to be inappropriate sampling sites, and these areas were therefore excluded from our sampling frame.

Table A1. Sample size and mean canopy cover (with 95% CI) for vireo detection locations from historic data per ecoregion.

Ecoregion	No. of vireo detections	Canopy cover	
		Mean (95% CI)	Range for sampling
Cross Timbers	2884	28.8 (27.6 – 30.1)	1-40%
Edwards Plateau	4801	36.0 (35.1 – 37.0)	1-40%
Chihuahuan Desert	132	41.9 (37.7 – 46.2)	>10%

We created a 5 km x 5 km grid over the entire vireo range in Texas to optimize the selection of sampling locations for conducting vireo surveys. We removed any 5 km x 5 km square that did not overlap any part of our map of potential habitat (e.g.., appropriate canopy cover, see above). We classified the remaining squares (hereafter survey square) into one of two groups: (1) squares containing public lands or known vireo locations (from our 8,000 compiled recent and historic locations), or (2) squares where vireo occurrence was unknown. Based on the USFWS recovery regions (USFWS 1991), we performed a stratified random selection of survey squares with unknown occurrence for a total of 240 survey squares distributed across the range (Fig. A3) and used these squares as a tool to focus our sampling effort by targeting lands within the squares to obtain access for sampling. The number of random survey squares (240) was a maximum estimate based on available manpower and time available to conduct surveys. Additionally, we included all public or known-location survey areas, and we created an adjacent 5 km x 5 km survey square buffer around each location, thus creating clusters of sampling squares for a total of 574 squares (Fig. A3). Although these survey squares served as a guide to direct our sampling effort, not all of the area within each square was sampled. Often, squares contained multiple properties with different owners, and the actual properties sampled were largely determined by acquiring permission to access the property. We determined property ownership using publically available information collected from local county appraisal offices. We could not sample properties with unlisted contact information or where we were denied access. Thus the sampling unit for surveys in 2009 was based on property boundaries that differed in size from the original 5 km x 5 km survey squares used to select properties.

2009 (randomly-distributed) sampling methods

Field surveys

We developed a standardized survey protocol for detecting vireos in our survey locations. Two observers conducted auditory and visual surveys for black-capped vireos in areas of potential vireo habitat within each property. Both observers covered the same general area but did so independently of each other, and thus we considered their surveys 2 separate efforts. They surveyed from about 06:30 (sunrise) to 13:00, traversing the property thoroughly and systematically as they created paths (hereafter survey routes) covering the property, walking at a slow pace and looking and listening for vireos, and we only avoided areas of open pasture or dense woodlands (i.e., <1% or >85% canopy cover). In addition, observers stopped every 20 minutes along their routes for a 5-minute point survey (hereafter stop point), during which time they continued to look and listen for vireos from a single point. Observers did not broadcast recorded vireo calls during the survey because detection probabilities have not been shown to increase significantly with the addition of playbacks (MacKenzie 2006). When we detected a black-capped vireo, both along survey routes and while at stop points, the observer went to where the bird was first detected and recorded its location using a hand-held GPS unit (hereafter bird location).

We surveyed all potential habitat on each property over the course of 1 to 4 days depending on the size of the property. If we did not detect a vireo during the first complete survey of a property (i.e., 1 survey each by 2 independent observers), the observers attempted to revisit the property one more time, for a total of 4 surveys (i.e., 2 surveys each by 2 independent observers). To account for changes in detection probability across the season, the observers allowed ~2 weeks to pass before revisiting the same area (MacKenzie 2006). However, to maximize the geographic area covered, we conducted only 1 round of surveys on 282 of 317 properties (90%). The observers did not survey during inclement weather (e.g., excessive rain or wind >20 km/h), or any other conditions (e.g., fog) that would inhibit their ability to detect the birds. Protocols and datasheets for the surveys are provided below.

Vegetation surveys

We conducted vegetation surveys in conjunction with the black-capped vireo surveys to both verify any remotely sensed metrics and to collect information that cannot be determined via remote sensing (e.g., presence of a browse line). During these surveys the observers recorded the following information: percent canopy cover, presence and species composition of woody vegetation at different height classes (0-2 m, 2-4 m, >4 m), maximum tree/shrub height, and height of the base of the vegetation. Vegetation surveys occurred at a subset of stop points where vireos were not detected and at a subset of vireo detection points. The vegetation survey was designed for large-scale sampling with relatively few surveys on any one property; the result, however, was a dataset comprised of 1000s of survey locations throughout central and west Texas. Specific protocols for the vegetation surveys in 2009 can be found in Appendix B.

Initial analysis of 2009 data and adjustments to sampling for 2010

For 2009 data, we plotted the stop points and vireo locations in ESRI ArcMap 9.3.1 (ESRI 2009) using GPS coordinates collected in the field. We used the vireo locations as detection points while we defined non-detection points as stop points where a vireo was not detected during the 5-minute survey. Accounting for regional differences (using proposed recovery regions as suggested by USFWS 1996), we compared several remotely-sensed metrics, including slope, aspect, distance to water, and canopy cover, for detection versus non-detection points. We measured these metrics both at the point and by looking at the mean and SD of each metric within a 120-m radius (~4.5 ha zone) to approximate the size of a vireo territory based on previous Texas A&M University research (Morrison unpublished data). Additionally, we calculated differences in vegetation metrics taken on site, including tree height, height of the understory, and species diversity between detection and non-detection points. We used t-tests to compare means between the detection and non-detection locations.

These initial analyses yielded no statistical differences between locations where vireos were detected and locations where they were not detected (unpublished data). Based on our experience in the field, we hypothesized that these results might be due to either (1) only that vireos are not saturating all available habitat on the landscape due to their endangered status, or (2) there is an additional different process besides vegetation composition and structure or topography is driving vireo occurrence. For example, a vireo may be more likely to establish its territory close to conspecifics rather than in seemingly appropriate vegetation far away from other vireos. However, our 2009 sampling approach was not adequate to identify whether this clustering was taking place. We used this knowledge to plan a new sampling strategy for 2010. In addition to using our 2009 survey results to describe vireo habitat sue and distribution, we decided to also use the 2009 results to test our findings from our 2010 area-focused analyses as detailed in the Methods section.

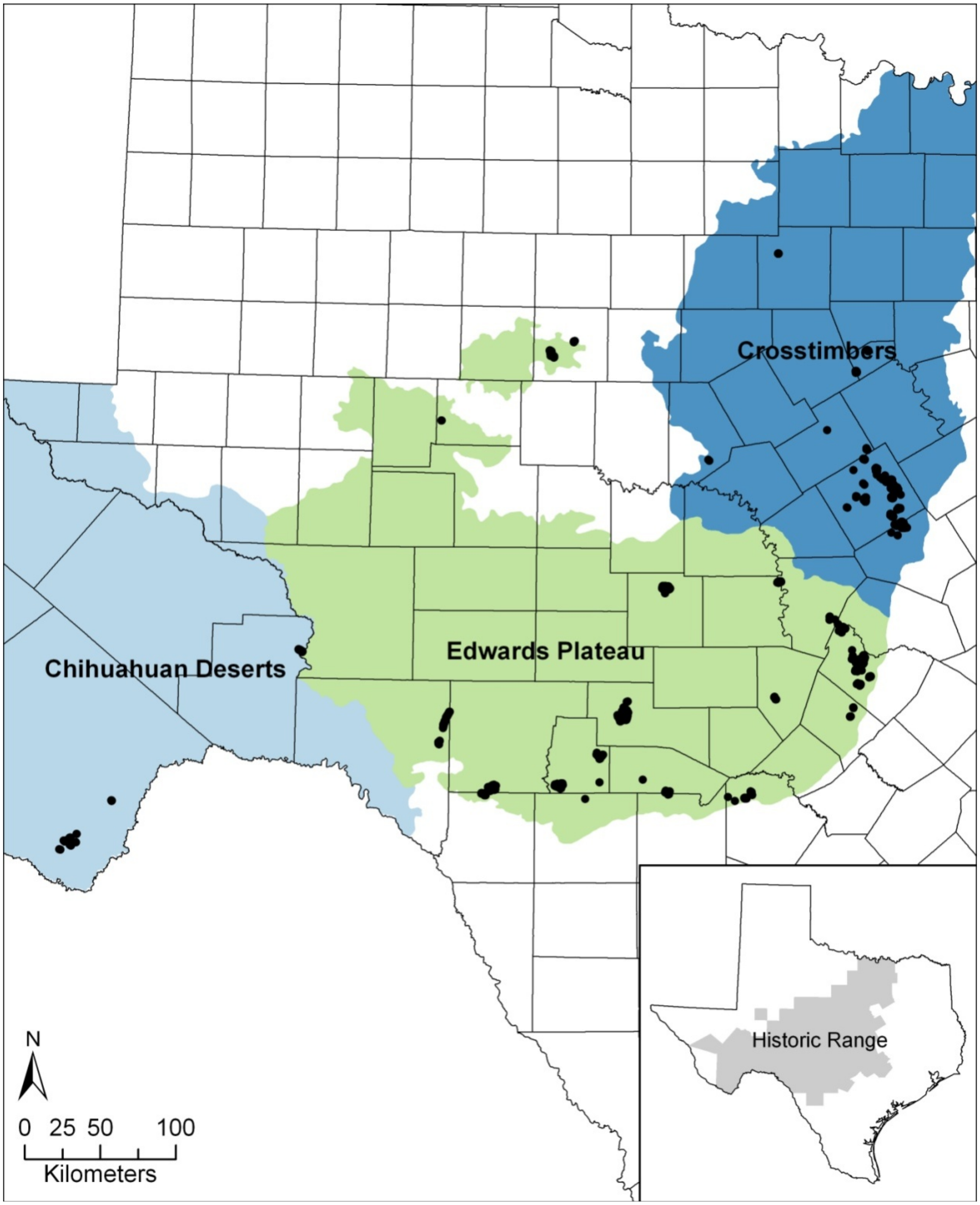


Figure A1. The three distinct ecoregions used to classify our potential habitat layer: the Edwards Plateau, Cross Timbers, and Chihuahuan Desert, as well as the ~8,000 compiled historic and known vireo locations. Based on canopy cover data from these locations, potential habitat was defined as 1-40% canopy cover in the Cross Timbers and Edwards Plateau, and >10% in the Chihuahuan Desert.

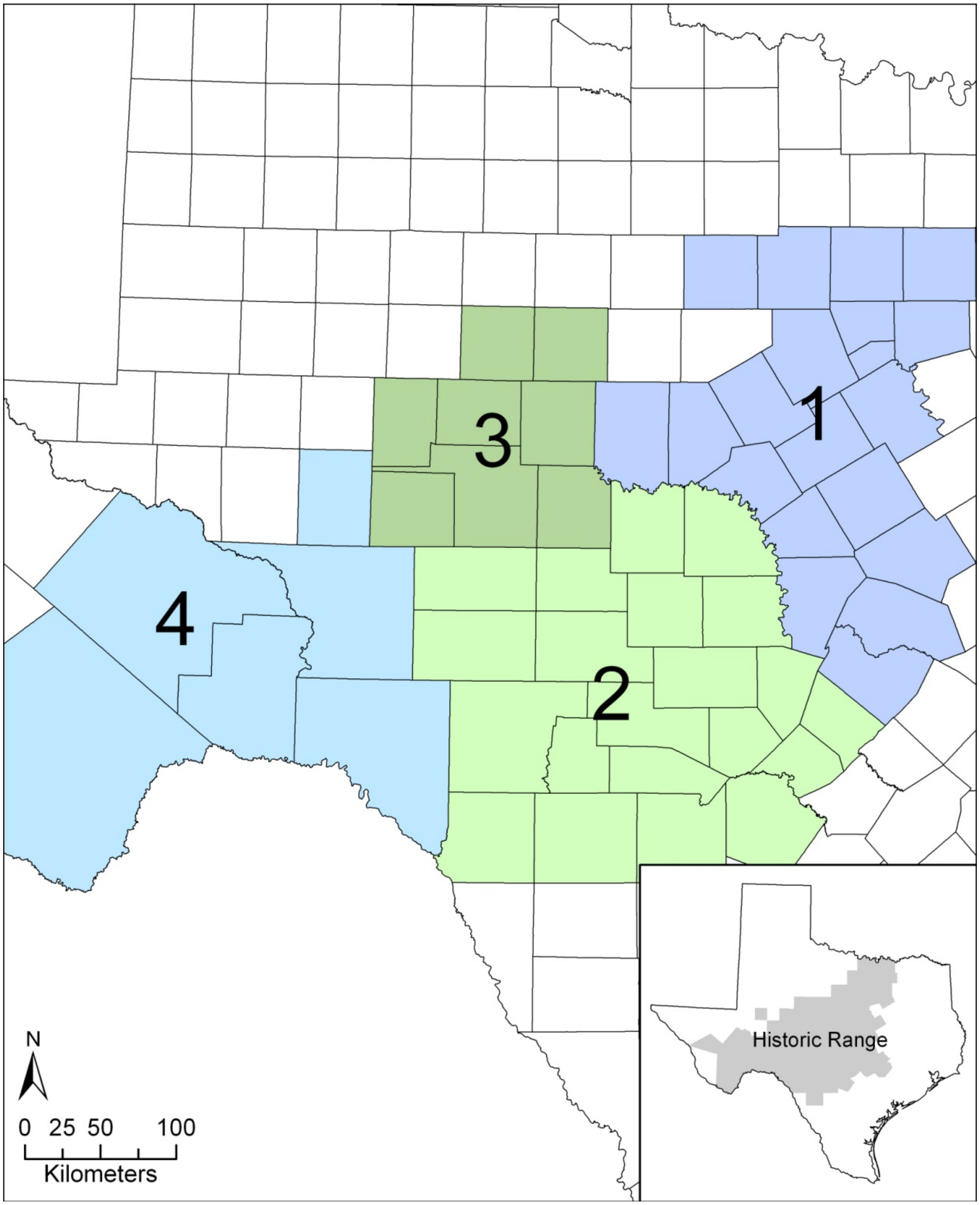
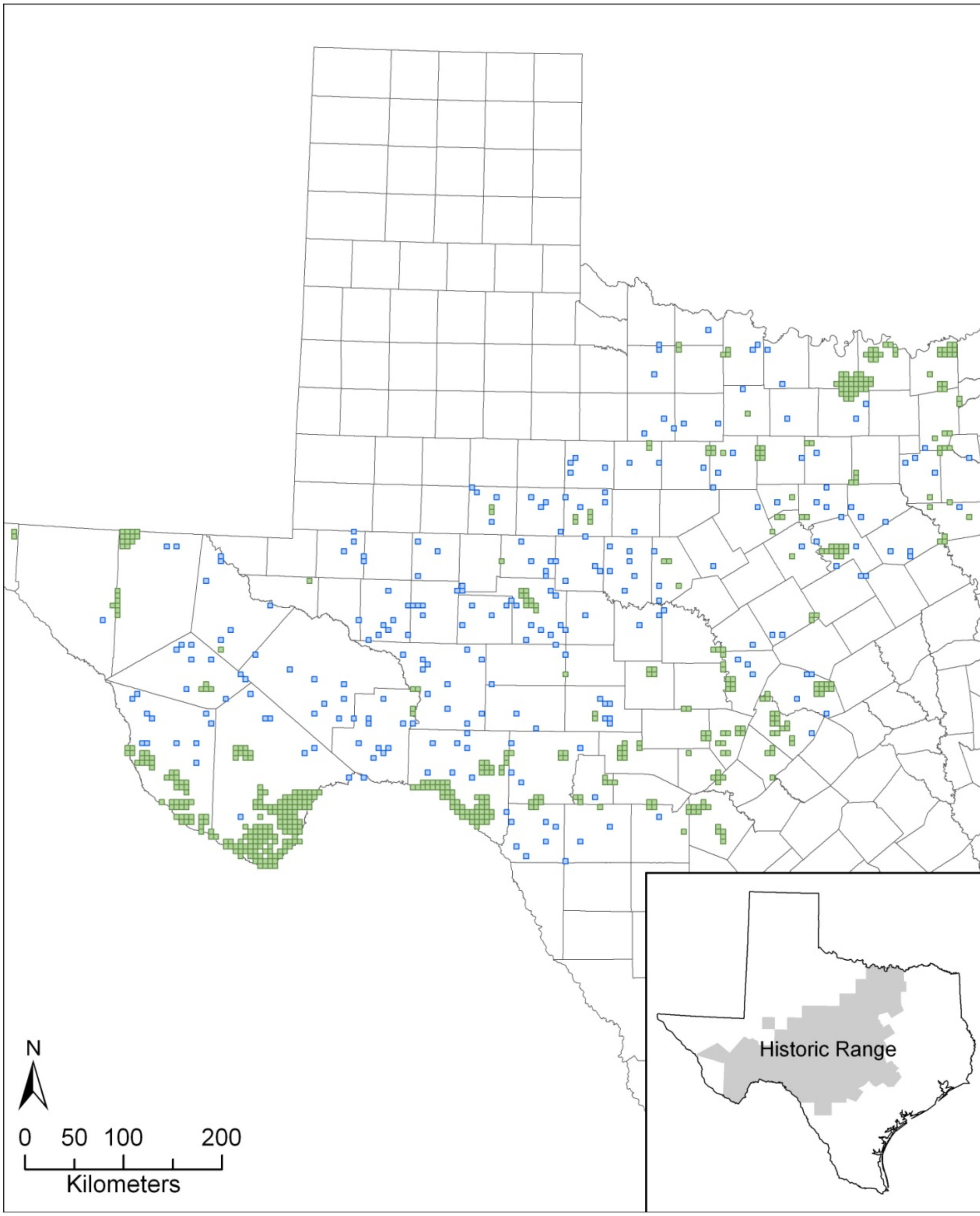


Figure A2. Black-capped vireo recovery regions as suggested by USFWS 1996.



Figure

Figure A3. Random sample of grid squares (5 km x 5 km) where sampling for 2009 was focused. The final selection included 240 random grid squares (shown in blue) and 574 grid squares centered on and around historic locations (shown in green) of vireos and public lands. While we focused our sampling within these squares, actual properties sampled were limited by property access and survey effort.

Appendix B: 2009 Protocols

2009 Black-capped vireo survey protocol

OBJECTIVE To gather point location information for black-capped vireos throughout the Texas portion of their breeding range.

NECESSARY EQUIPMENT
GPS unit
2-way radio
extra batteries
binoculars
compass
maps (local, state)
pencils
field notebook
protocol
data sheets
clipboard
water

PROTOCOL
General:

- Surveys occur from sunrise until ~1300.
- Survey area = all accessible potential habitat within a 5km grid cell.
- Potential habitat = all pixelated portions of map and areas within ~100 m of pixels.
- 2 observers work simultaneously and **independently** in each survey area.
- Observers begin on opposite ends of the survey area and each observer surveys the entire area him/herself. Survey thoroughly and systematically (e.g., zigzag through the area), moving slowly.
- **Do not communicate** bird detections with the other observer.
- If one or more BCVIs are detected anywhere in the 5km grid by either observer, the area does not have to be revisited. However, if no BCVIs are detected during a visit, the patch must be revisited one more time for a total of 4 surveys (i.e., 2 visits with 2 observers each).
- Allow ~2 weeks to pass before revisiting the same survey area.
- **Resighting:** If you get a visual detection of either a GCWA or BCVI, check if the bird has leg bands (see Resight protocol). If you see bands, record the color combo in the Notes field.
- Do not survey during inclement weather (e.g., excessive rain or wind >12 mph), or any conditions that would inhibit either our ability to detect the birds.
- Check your partner's data sheet at the end of the survey period. Make sure all fields are filled in correctly; only the Notes field may be left blank at the end of the survey.

Survey route:

- Each observer marks his/her route through the survey area using the GPS tool. Maintain ~200 m spacing between the "zigs" and "zags" of each route.

- GPS the location of every BCVI you detect. Go to the location where the BCVI was first seen or heard and take a GPS reading at that point. Do not chase the bird around to determine its “exact” location; rather, estimate location without causing unnecessary disruption to the bird. Record info on Data Sheet #1.
- Conduct a vegetation survey at each BCVI GPS location (see Vegetation Survey protocol).
- If property boundaries or unsafe terrain impedes your ability to access the BCVI location, use the “Projecting a Waypoint” feature in the GPS unit, insert the appropriate distance and bearing when prompted, and record the projected waypoint UTMs on the data sheet. Record info on Data Sheet #1. Do not conduct veg surveys if you are forced to project a waypoint.
- If you detect golden-cheeked warblers (GCWA), record their locations on Data Sheet #1 or #2 as appropriate. However, do not let many GCWA detections disrupt the BCVI survey. If many GCWAs are in the area, gather a few GPS locations for them and continue focusing on BCVIs.

Stop points along route:

- Stop every 20 minutes along your route for a 5-minute point survey. GPS the point where you stop and record info on Data Sheet #2. If BCVIs are detected from that point, find and record their specific locations after the 5-minute period has ended (as noted for ‘Survey route’ and using Data Sheet #1).
- Conduct a veg survey at each stop point (see Vegetation Survey protocol).

Code sheet for BCVI Inventory Data Sheet #1 – Survey route

D: 2-digit day of the month (e.g., the 8th of June = 08)
M: 2-digit month of year (e.g., June = 06)
Y: 4-digit year (already filled in)
County: 3-letter TX county code
Grid ID: 5-digit ID number of the grid cell in which the survey occurs (e.g., grid cell #183 = 00183)
Surv No.: 1, 2, 3, etc. for 1st, 2nd, 3rd, etc. survey. At each visit, one observer records the odd-numbered survey while the other observer records the even-numbered survey.
Obs: Record observer’s initials (first, middle, last)
Start Time: Time of survey start, 24-hr format (e.g., 7:00am = 0700, 2:00pm = 1400)
End Time: Time of survey end, 24-hr format
Spp.: Circle **B** for black-capped vireo or **G** for golden-cheeked warbler
Bird ID: Record a 2-digit sequential number for each bird detected during the survey, e.g., 01 for 1st bird detected, 02 for 2nd bird detected, regardless of whether it’s a BCVI or GCWA.
UTM Northing and Easting: Record the 7-digit Northing and 6-digit Easting UTMs of the bird’s location when it was 1st detected.
Notes: Record any additional notes related to survey and detection, including if the listed UTMs are for a projected waypoint or if you had a resight.

Code sheet for BCVI Inventory Data Sheet #2 – Stop points along route

D: 2-number day of the month (e.g., the 8th of June = 08)
M: 2-number month of year (e.g., June = 06)
Y: 4-number year (already filled in)
County: 3-letter TX county code
Grid ID: 5-digit ID number of the grid cell in which the survey occurs (e.g., grid cell #183 = 00183)
Surv No.: 1, 2, 3, etc. for 1st, 2nd, 3rd, etc. survey. At each visit, one observer records the odd-numbered survey while the other observer records the even-numbered survey.
Obs: Record observer's initials (first, middle, last)
Pt No.: A sequential 2-digit number for each point at which you stop for a point survey, beginning with 01 (already filled in; you may not ever reach 25 points per survey).
UTM Northing and Easting: Record the 7-digit Northing and 6-digit Easting UTMs for each location at which the 5-minute point survey occurs.
Start time: Time at which you begin the 5-min survey, using 24-hr format.
Species: Circle **B** for black-capped vireo, **G** for golden-cheeked warbler, or **N** for neither species detected. Use only one line per point, regardless of how many individuals are detected from that point.
Notes: Record any additional notes related to survey and detection.

2009 Inventory datasheet

				2009										Surv No.	Start Time				
D		M		Y	County			Grid ID					Obs	End Time				

Spp.	Bird ID	UTM Northing	UTM Easting	Notes
B G				
B G				
B G				
B G				
B G				
B G				
B G				
B G				
B G				
B G				
B G				
B G				
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B G				
B G				
B G				
B G				
B G				

Species:
B = black-capped vireo
G = golden-cheeked warbler

2009 Vegetation survey protocol

OBJECTIVE Estimate woody vegetation cover in areas containing potential GCWA or BCVI habitat to 1) compare areas of use versus available, and 2) ground-truth interpretations of satellite imagery.

NECESSARY EQUIPMENT

GPS unit	binoculars	protocol	tubular densiometer
2-way radio	compass	data sheets	clipboard
extra batteries	maps (local, state)	pencils	water

PROTOCOL

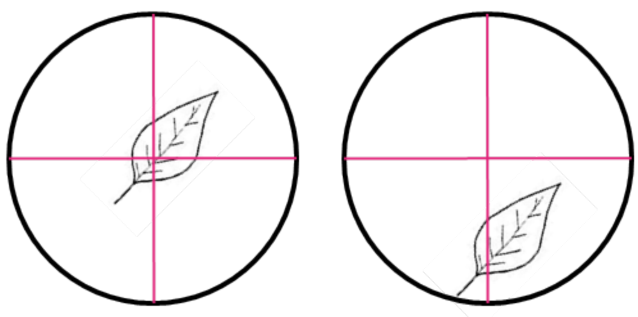
- Vegetation (veg) surveys occur at the following locations:
  For GCWA
    1) abundance survey point count stations (“D.O.” protocol)
  For BCVI
    2) stop points along survey route at which BCVIs were **not** detected (“S.P.” protocol)
    3) individual BCVI locations (“R.T.” protocol)
  For 1 and 2, the veg survey is centered at the survey point. For 3, the veg survey is centered on a BCVI location. If you are in a large cluster of BCVIs (>10 individuals), conduct veg surveys at every other individual.
- Veg surveys can occur concurrently with bird surveys. Conduct veg surveys with as little disturbance to the bird as possible.
  For GCWA, veg surveys occur
    1) after the 5-minute abundance point count survey
  For BCVI, veg surveys occur
    2) after each 5-minute stop-point survey if a BCVI was not detected
    3) when you detect a BCVI
  Or, if you have unlimited access to the property, you can conduct veg surveys at a later date than the bird surveys.
- Because UTMs are recorded on the respective bird survey data sheets, they are not recorded here.
- Record veg information at the center point and at every 10 m north, east, south, and west from the center point, out to 30 m (see figure above). Use magnetic north for bearings.
- **Canopy cover**: At the center and every 10 m point, record presence (**P**) or absence (**A**) of canopy cover using the tubular densiometer.
- **Vertical structure**: Imagine a line projecting vertically from each point and record P/A of live woody vegetation (i.e., leafy vegetation, not bare or dead branches) in each height class if the veg intersects that vertical line. If woody veg is present, record species for each height class; 1–3 species may be recorded per height class.
- **Max/min height:** Imagine a line projecting vertically from the center point and a wall projecting vertically from the 10-30 m section of each 30-m transect. Record the maximum height of the veg and the minimum height of the **base** of the veg where the height intersects the vertical projections.

Minimum base height may equal 0 m if base of veg reaches the ground. There will be 5 values for max and min heights for each veg survey area – center point and N, E, S, and W transects. Even if there is no veg at the 10-, 20-, or 30-m points along the transect, you may still have max and min values if veg occurs along the transect between those points.

- Write neatly and clearly circle the appropriate value on the data sheet. If you make a mistake, neatly cross out the incorrect value (don't just erase it) and circle or write in the correct value. Remember – someone other than yourself will be entering this data on the computer!

DEFINITIONS

Tubular densiometer = Instrument with which to determine presence/absence of canopy cover. To use the densiometer, look above you through the tube and visually line up the metal nut at the base of the tube with the intersection of the crosshairs at the top of the tube. This will result in the tube pointing directly upwards. If the center of the crosshairs intersects any live, leafy vegetation, canopy cover is considered to be present. If live, leafy vegetation is seen anywhere else through the tube but **not** at the crosshairs intersection, or if no vegetation is seen at all, canopy cover is considered to be absent.

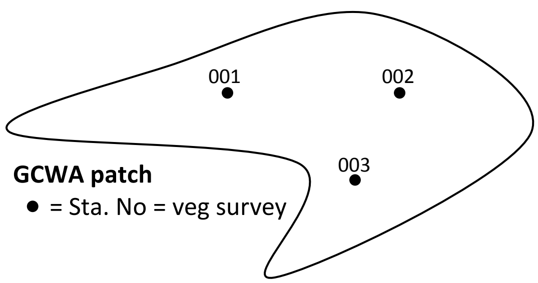


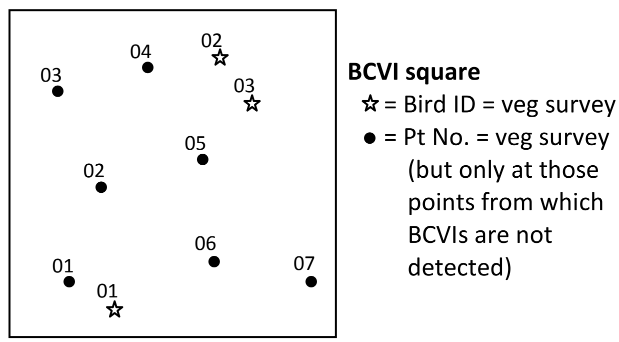
Canopy cover present **Canopy cover absent**

Browse line = A condition found in forests or brushland with an over population of browse animals like deer or goats, where all branches and twigs are eaten as high as the animals can reach (~1-2m).
Canopy cover = vertical projection of plant foliage onto a horizontal surface. For our surveys, this includes foliage of trees or shrubs.
Vertical structure = describes the top to bottom structure of a forest stand. For our surveys, we are interested in the presence or absence of vegetation in 3 height classes: low (0-2 m), mid (2-4 m) and high (>4 m).

Code sheet for 30m-Radius Vegetation Survey

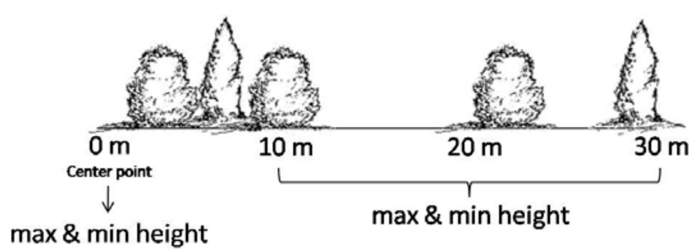
D: 2-digit day of the month (e.g., the 8th of June = 08)
M: 2-digit month of year (e.g., June = 06)
Y: 4-digit year (already filled in)
County: 3-letter TX county code
Protocol: 2-letter abbreviation for the bird protocol used when determining the veg survey center point.
Enter: **DO** (for Double Observer protocol) if the veg survey is centered on a GCWA abundance survey point
SP (for Stop Point protocol) if the veg survey is centered on a stop point during a BCVI survey
RT (for Survey Route protocol) if the veg survey is centered on an individual BCVI location
Patch or Grid ID: 5-digit ID number of the GCWA patch or BCVI grid in which survey occurs (e.g., patch #118 = 00118)
Pt No.: 3-digit number of veg survey center point. See images below (not to scale!). For GCWA, this will be the 3-digit identification number used at each abundance survey point count station (aka, "Sta. No"). For BCVI, this will be either the 2-digit number used at each stop point along the route (aka, "Pt No.") or the 2-digit number used for BCVI identifications (aka, "Bird ID"); preface these 2-digit numbers with a zero (0) on the data sheet.





Sta. No, Bird ID, and Pt No are all differentiated by the Protocol abbreviations

Obs.: Record initials of Observer (first, middle, last).
Average height of browse line: Circle N/A if there is no browse line; circle appropriate height category if there is a browse line.
Canopy cover: If vegetation crosses the intersection of the crosshairs of the tubular densitometer, circle **P** (present), otherwise circle **A** (absent). See definition of Tubular Densiometer above for details.
Vertical structure
0-2 m, 2-4 m, >4 m: Circle **P** (presence) or **A** (absence) of live, woody veg in each height class.
Species: Record up to 3 of the most dominant tree or shrub species that comprise each height class. Record **NO** for no species, **UN** for unknown species.
Max. height: Record maximum height of live, woody veg (estimated to the nearest 1 m) that intersects: 1) the center point, and 2) the 10–30 m segment of each 30-m transect. Record **0** for no woody veg.
Min. base height: Record minimum height of base of veg (estimated to the nearest 0.5 m) that intersects: 1) the center point, and 2) the 10–30 m segment of each 30-m transect. Record **0** for no woody veg.



2009 Vegetation datasheet

				2009														**Obs.**			
D		**M**		**Y**	**County**			**Protocol**		**Patch or Grid ID**					**Pt No.**						

Average height of browse line: N/A <1m 1-2m

CENTER	Canopy cover	Vertical structure 0-2m	species	2-4m	species	>4m	species
0 m	P A	P A		P A		P A	
0 m	Max. height	Min. base height					

NORTH	Canopy cover	Vertical structure 0-2m	species	2-4m	species	>4m	species
10 m	P A	P A		P A		P A	
20 m	P A	P A		P A		P A	
30 m	P A	P A		P A		P A	
10-30 m	Max. height	Min. base height					

EAST	Canopy cover	Vertical structure 0-2m	species	2-4m	species	>4m	species
10 m	P A	P A		P A		P A	
20 m	P A	P A		P A		P A	
30 m	P A	P A		P A		P A	
10-30 m	Max. height	Min. base height					

SOUTH	Canopy cover	Vertical structure 0-2m	species	2-4m	species	>4m	species
10 m	P A	P A	______ ______	P A	______ ______	P A	______ ______
20 m	P A	P A	______ ______	P A	______ ______	P A	______ ______
30 m	P A	P A	______ ______	P A	______ ______	P A	______ ______
10-30 m	Max. height		Min. base height				

WEST	Canopy cover	Vertical structure 0-2m	species	2-4m	species	>4m	species
10 m	P A	P A	______ ______	P A	______ ______	P A	______ ______
20 m	P A	P A	______ ______	P A	______ ______	P A	______ ______
30 m	P A	P A	______ ______	P A	______ ______	P A	______ ______
10-30 m	Max. height		Min. base height				

NOTES:

Appendix C: Area-focused surveys; 2010 study areas

Study areas

Our study areas were (in order from west to north-east):

1. Devil's River: located in Val Verde County on the western edge of the Edwards Plateau. The study area encompassed Devil's River State Natural Area (DRSNA; 79% of survey area) and Dolan Falls Preserve (21% of survey area). DRSNA is an 8,089 ha property managed by the TPWD, while Dolan Falls Preserve is a 1,942 ha property owned and managed by The Nature Conservancy (TNC). Both properties were primarily unmanaged land, but DRSNA has a large population of feral sheep (*Ovis* spp.) and aoudad (*Ammotragus lervia*). Thirty to 40 aoudads are killed during public hunts that take place several times a year (TPWD 2010), but there is currently no management of feral sheep on the property. Adjacent properties are undeveloped and used for recreation or wild game hunts. There is no active cowbird trapping at DRSNA or Dolan Falls (Smith 2011).

Topographic features of the area include a nearly-level plateau that is frayed into high-domed hills and flat-topped, hard scrabble ridges and several large drainage systems cut their way through canyons. Elevation ranges from approximately 409 to 632 m (Hedges and Poole 1999; Smith 2011). Annual average precipitation is 47.8 cm (NOAA 2010).

The natural plant communities at DRSNA and Dolan Falls Preserve exhibit elements of the mesquite-chaparral (*Prosopis* sp.) of the Southern Texas Plains, the oak-juniper (*Quercus-Juniperus*) of the central Edwards Plateau to the east, and the sotol-lechuguilla (*Dasylirion-Agave*) of the Trans-Pecos to the west (Hedges and Poole 1999). Vegetation includes stands of live oak (*Quercus fusiformis*) and pecan (*Carya illinoinensis*) near Devil's River and xeric grassland on the surrounding ridges and slopes. Several springs provide the majority of water to the river (Smith 2011).

2. Kickapoo: located in Edwards and Kinney Counties in southwestern Texas. The study area consisted of Kickapoo Caverns State Park owned by TPWD (32% of survey area) and several private properties in the area (68% of survey area). This area is characterized by steep canyons and narrow divides (North American Regional Center of Endemism 2008). Elevation ranges from 250 to 800 m, mean annual precipitation is 35 cm, and the mean annual temperature is 21 °C (North American Regional Center of Endemism 2008). Soil composition is mainly limestone bedrock and alkaline soils. Common tree species include Ashe juniper, live oak, and pinyon pine (*Pinus cembroides*; North American Regional Center of Endemism 2008). Patches of mixed oak-juniper woodlands occur within rangeland used for cattle grazing. The majority of the mature forests occur within the canyons and along the slopes leading up to mesas (Klassen 2011).

3. Devil's Sinkhole: located in eastern Edwards County in the south-central portion of the Edwards Plateau. Specific study sites were located on several private properties in the general vicinity of Devil's Sinkhole State Natural Area. Elevation is approximately 750 m and average annual precipitation is 59.9 cm (NOAA 2010). Live oak is the dominant tree species in the area. Deeply cut canyons in the area provide a more mesic environment and, therefore, support trees

such as escarpment black cherry (*Prunus serotina*), Texas oak (*Quercus buckleyi*), Lacey oak (*Quercus glaucoides*), and pinyon pine.

4. Taylor Co.: Study sites were on private properties located approximately 15 miles southwest and south of Abilene, Texas, near Buffalo Gap, Texas, within and near outcrops of the Edwards Plateau ecoregion. Average annual precipitation is 60.5 cm (NOAA 2010). The uplifted regions of the Edwards Plateau in the surrounding low South Central Plains ecoregion create canyons and slopes. The oak in this region is primarily Mohr oak (*Quercus mohriana*; M. Hutchinson, personal communication).

5. Kerr Co.: The study area was located in Kerr County entirely on private lands near Kerr Wildlife Management Area (WMA, managed by TPWD). This area is located at the headwaters of the North Fork of the Guadalupe River and consists of limestone landscape features typical of the Edward's Plateau ecoregion. While we did not survey the Kerr WMA, the WMA is representative of the Edwards Plateau habitat type of Texas, and harbors a known population of breeding black-capped vireos (422 singing males in 2002). Within Kerr WMA there are 3 black-capped vireo habitat types: shrubland, which consists of oak and other deciduous patches surrounded by a matrix of grassland; deciduous woodland; and oak-juniper woodland. Primary land uses are for ecological and wildlife-based research and public access for hunting and wildlife viewing. Management activities at Kerr WMA include active cattle grazing, brown-headed cowbird trapping, and prescribed burning. Localized cowbird trapping has been ongoing (TPWD 2008). Systematic cowbird trapping has reduced local parasitism rates to ~33% (T. L. Pope, personal communication). Average annual precipitation is 82.8 cm (NOAA 2010). The surrounding private lands where our study sites were located have varying management practices and habitat types.

6. Mason Co.: Study sites were located entirely on private properties surrounding Mason Mountain WMA, which is managed by TPWD. This region consists of areas of granite-derived soils supporting a community of post oak (*Quercus stellata*) and blackjack oak (*Quercus marilandica*) and other areas dominated by live oak and Texas oak on limestone-derived soils. The topography is rough, with steep canyons, caliche hills, and granite outcrops. Average annual precipitation is 71.1 cm (NOAA 2010).

7. Balcones: Balcones Canyonlands National Wildlife Refuge (BCNWR), located in Travis, Burnet, and Williamson Counties, was created in 1992 to preserve the nesting habitats of the black-capped vireo and golden-cheeked warbler (*Dendroica chyrsoparia*). The refuge and the surrounding public and private lands have a high-density population of vireos with at least 122 known territories (Sexton 2002, 2005, Wilkins et al. 2006). Study sites were both on the refuge (63% of survey area) and on the surrounding private lands (37% of survey area). Average annual precipitation is 92.5 cm (NOAA 2010).

Black-capped vireo habitat on the BCNWR typically consists of patchy clumps of shin oak (*Quercus sinuata*), but the composition varies greatly; other common shrub/tree species in black-capped vireo habitat on the refuge include Spanish oak (*Quercus texana*), live oak, texas persimmon (*Diospyros texana*), prickly ash (*Zanthoxylum hirsutum*), yaupon holly (*Ilex vomitoria*), elbowbush (*Forestiera pubescens*), hackberry (*Celtis laevigata*), gum bumelia (*Bumelia lanuginosa*), redbud (*Cercis canadensis*) and cedar elm (*Ulmus crassifolia;* USFWS 2001).

8. Fort Hood: Study areas were located on Fort Hood Military Reservation (61% of survey area) and nearby private properties (39% of survey area) in Coryell, Hamilton, and Bell Counties. This area of central Texas lies within the Leon and Bosque River watersheds. The topography consists of rocky limestone hillsides and mesas ranging in elevation from 200–500 m. Primary land uses include ranching, hunting, and farming. Vegetation in this region include improved or non-native pasture, grassland, mid-successional mixed woody vegetation, and mature oak-juniper woodland (S. Farrell, personal communication). Average annual precipitation is 83.6 cm (NOAA 2010). Sample units were located in the woodland and mixed woodland-shrubland habitat types. Woodlands were characterized by oak species including post oak, live oak, and shin oak (Cimprich and Kostecke 2006).

Appendix D: 2010 Protocols

2010 Survey protocol

BCVI Inventory Protocol Texas A&M University, 2010

OBJECTIVE To gather point location information for black-capped vireos throughout the Texas portion of their breeding range.

NECESSARY EQUIPMENT

GPS unit/radio	field notebook	data sheets	water
binoculars	maps (local, state)	protocol	clipboard
extra batteries	compass	pencils	watch/timer

PROTOCOL

General:

Surveys occur from sunrise until ~1300.

Do not survey during inclement weather (e.g., excessive rain or wind >12 mph), or any conditions that would inhibit our ability to detect the birds.

Survey area = all accessible potential habitat within each accessible property.

Potential habitat = all accessible grid-points (not agriculture, urban, etc.) within each accessible property.

1 or 2 observers work simultaneously and **independently** in each survey area.

<u>If 1 observer</u>: Observer surveys the entire area him/herself.

<u>If 2 observers</u>: Observers start on opposite ends of the property and survey grid points systematically so that each grid-point is surveyed by one observer only. Observers stop when they meet, hopefully in the middle.

There are no repeat visits to grid points.

Do not communicate bird detections with the other observer.

Locating grid points:

Use GPS to locate the point. Points are 300 m apart. Once you have arrived at the point within 5m accuracy, stop and sample at that location. If you are in a region where you cannot obtain 5m accuracy, set a standard for all pts (e.g., as soon as the GPS tells me I'm within 5 m of the point with 7 m accuracy, I stop).

Survey route:

Survey grid points systematically (e.g., follow a line of grid points in a cardinal direction to edge of property, turn 90 degrees and walk the next set of parallel grid points in the opposite direction), moving slowly. At each grid point, stop and do a 5-minute point count. Record the start time and end time. Record the approximate distance (in meters) and direction (0 to 360 degrees) to **each**

BCVI detected during the point count on the data sheet. Place checks in the box labeled "PC" on the datasheet to indicate the birds were detected during a point count. Note the detection type (auditory – A or visual – V) for each bird, and if bird is seen, note the sex if known.

Listen for vireos as you slowly walk to the next grid-point. If you detect any birds that you can reasonably assume are not ones you noted while at the last grid-point, mark your GPS location and record distance and direction to each new BCVI detected from this new point on the data sheet. Name these new GPS locations in the GPS unit with the 5 digit number from the last Grid Point you were at PLUS a letter (A). If you need to stop more than once between points, use subsequent letters for additional points (ie: DR00123 was the last point I was at; I name the two points I stop at on my way to the next point as 00123A and 00123B). On the data sheet, the number will go in the Grid Point field and the letter in the PC field (to indicate those birds were not detected at a point count). Make sure these additional marked points get saved and sent back with the statewide data. Use the statewide shapefile template.

At the next grid-point, during your point count, be sure to still give distance and direction to detections that you reasonably assume are the same ones you noted walking between points if you can hear those birds from the point count location (ie: all birds heard from a point should be noted with a distance and direction and associated with that point count, even if they were noted prior when walking between points).

If you detect golden-cheeked warblers (GCWA), record their locations on the data sheet as appropriate, making sure to list the correct species (G). However, do not let many GCWA detections disrupt the BCVI survey. If many GCWAs are in the area, gather a few distance and directions for them and continue focusing on BCVIs.

Conduct a vegetation survey at each grid-point (see Vegetation Survey protocol). These can be completed immediately prior to or after completing your point count or you can leave the vegetation surveys until the end, on your way back.

If property boundaries or unsafe terrain impedes your ability to access the next grid point location, skip it and do the ones you can safely access.

<u>If you get to a property and do not have the necessary grid points:</u>

Survey the property as best you can and make your own grid by marking waypoints every 300 meters or so. When making your own grid, name the points using the date (MDD) plus a letter (ie: if it's April 4, use 404A, 404B and have your partner start at Z and work backwards: 404Z, 404Y…). Make certain these waypoints get saved and sent back with the statewide data. Use the statewide shapefile template.

<u>Resighting:</u> If you get a visual detection of either a GCWA or BCVI, check if the bird has leg bands (see Resight protocol). In the "Bands" column, note whether they were banded (Y/N) if you saw the legs. It is equally important to record birds for which you did NOT see bands. If you see bands, put a number in the "Note #" column, and record the color combo on the back of the sheet (put corresponding note number on the back). Do not spend more than 10 minutes trying to resight a bird. If you detected a banded bird but are unable to acquire band combinations within the 10 minute period, return to the location at the end of the surveys and relocate the bird in order to acquire band combinations. It is imperative that we get complete color combinations for ALL BCVI and GCWA that are banded.

Check your partner's data sheet at the end of the survey period. Make sure all fields are filled in correctly; only the Notes field may be left blank at the end of the survey.

Code sheet for BCVI Inventory Data Sheet #1 – Survey route
StLoc: Statewide location, 2 letter code for region
D: 2-digit day of the month (e.g., the 8th of June = 08)
M: 2-digit month of year (e.g., June = 06)
Y: 4-digit year (already filled in)
County: 3-letter TX county code (all Grid points saved will start with this code)
Property #/name: ID number of the property (on the excel sheet of property access) and owner or contact last name
Obs: Record observer's initials (first, middle, last)
Start Time: Time of survey start, 24-hr format (e.g., 7:00am = 0700, 2:00pm = 1400)
End Time: Time of survey end, 24-hr format
Grid Point: 5 digit number identifying the grid point the point count occurs at (pre-saved in GPS unit)
SP: List **B** for black-capped vireo or **G** for golden-cheeked warbler
Dist: Approximate distance (in meters) to each detected BCVI or GCWA
Dir: Using N as 0 degrees, the direction (0 to 360) to each detected BCVI or GCWA
PC: point count, check if detected during standard point count
Bands?: if legs are seen, mark Y or N
Note #: if banded or note is needed, put number in this column and note under corresponding note number on back. Start with 1 on each sheet.

BCVI Statewide - Inventory Data Sheet | StLoc | Page ______ of ______

		2010				Start Time
D	M	Y	County	Property (#, name)	Obs.	End Time

Grid Point #	PC	Start Time	End Time	Species	Sex	Dist	Dir	DT	Bands?	Note

PC : check box if during a point count; insert letter (A, B, C..) if between points (for grid point, use last visited)

SP : insert B for black-capped vireo, G for golden-cheeked warbler — For notes, put # here, list on back

2010 Vegetation protocol

BCVI Statewide Vegetation Protocol Texas A&M University, 2010

OBJECTIVES 1) quantify vertical structure and species composition within BCVI habitat and other locations where BCVI are not present, 2) quantify mean and range of vegetation heights and start heights of lower foliage cover in known BCVI habitat and other locations. This data will allow us to compare these characteristics between areas that BCVI actively use and areas where BCVI are not found.

NECESSARY EQUIPMENT

GPS unit/radio	field notebook	data sheets	water
binoculars	maps (local, state)	protocol	clipboard
extra batteries	compass	pencils	

PROTOCOL

Follow protocol for locating grid points across study sites. Points are spaced 300 m apart.

Vegetation data

Leave no fields blank.

Record grid point number on data sheet. From grid point location, locate the nearest woody vegetation (1 m or greater in height, includes brush piles) within 50 m. If no vegetation exists within 50 m, write “X” in blank after “Closest (dir. 1)” on data sheet. Turn to face the closest woody vegetation and record the following:

1. Dir: Record direction you’re facing, approximated to the nearest 45 degrees.

2. Spp (species): record species of woody vegetation. If there is more than 1 species intertwined, list the dominant species (most veg cover or foliage volume). Use the 2-letter code (found in statewide files). If no woody cover exists within 50 m in that direction, write “X”. Include cactus-type plants as woody vegetation (yucca, prickly pear, ocotillo, etc.) if they are 1 m tall or greater.

   If you do not know the species and are within 5-10 m of the plant, take a sample to identify later (see bottom of sheet). If the plant is further away and you cannot ID the plant to species from the distance you are at, list it as it is best described by one of the following:
   Oak spp. – OS
   Juniper spp. - JS
   Unknown tree - UN
   Unknown bush - UB
3. Ht B (height bottom): Height obstructions start. Visually estimate and record the height at which the foliage and branches on the shrub or tree starts, in that they provide visual obstruction of the trunk or main stem of the tree or shrub to the nearest 0.1 meter. For example, if shrub is 1.5 m tall, but if the stem extends for 0.4 m from the ground before there is branching and leafing providing visual obstruction, record 0.4. If cover extends to the ground, record 0 for height. For brush piles, if cover of brush extends to the ground, write 0. If woody cover=N, record an “X” in the field.

4. Ht. T (height at top): Visually estimate and record the maximum height of the woody vegetation to the nearest half-meter. If no woody vegetation is present, write “X” in the field.

From the direction of the nearest woody cover, turn approximately 90 degrees, and repeat measurements 1 to 4. Repeat two more times until you have faced 4 directions, all at right angles. If no woody vegetation exists within 50 m of any direction you face, write “X” in the distance and height fields.

Code sheet for BCVI Statewide Vegetation Data Sheet

StLoc: Statewide location, 2 letter code for region
D: 2-digit day of the month (e.g., the 8th of June = 08)
M: 2-digit month of year (e.g., June = 06)
Y: 4-digit year (already filled in)
County: 3-letter TX county code
Property #/name: ID number of the property (on the excel sheet of property access) and owner or contact last name
Obs: Record observer’s initials (first, middle, last)
Start Time: Time of survey start, 24-hr format (e.g., 7:00am = 0700, 2:00pm = 1400)
End Time: Time of survey end, 24-hr format
Grid Point: 5 digit number identifying the grid point the point count occurs at (pre-loaded into GPS unit)
Dir. 1 to 4: Direction in degrees, 0 to 360, where 0 = North
Spp: Species code for woody vegetation
Ht. B: Height of lowest branches where visual obstruction starts to the nearest 0.1 m.
Ht. T: Height at the top of woody species to the nearest 0.5 m.

BCVI Statewide - Vegetation Data Sheet | StLoc | | | Page ______ of ______

		2010				Start Time	
D	M	Y	County	Property (#, name)	Obs.	End Time	

Grid Point				

Closest (dir. 1) _______				Dir. 2 _______			
Dist	Spp	Ht. B	Ht. T	Dist	Spp	Ht. B	Ht. T

Dir. 3 _______				Dir. 4 _______			
Dist	Spp	Ht. B	Ht. T	Dist	Spp	Ht. B	Ht. T

Grid Point				

Closest (dir. 1) _______				Dir. 2 _______			
Dist	Spp	Ht. B	Ht. T	Dist	Spp	Ht. B	Ht. T

Dir. 3 _______				Dir. 4 _______			
Dist	Spp	Ht. B	Ht. T	Dist	Spp	Ht. B	Ht. T

Grid Point				

Closest (dir. 1) _______				Dir. 2 _______			
Dist	Spp	Ht. B	Ht. T	Dist	Spp	Ht. B	Ht. T

Dir. 3 _______				Dir. 4 _______			
Dist	Spp	Ht. B	Ht. T	Dist	Spp	Ht. B	Ht. T

Grid Point				

Closest (dir. 1) _______				Dir. 2 _______			
Dist	Spp	Ht. B	Ht. T	Dist	Spp	Ht. B	Ht. T

Dir. 3 _______				Dir. 4 _______			
Dist	Spp	Ht. B	Ht. T	Dist	Spp	Ht. B	Ht. T

Grid Point				

Closest (dir. 1) _______				Dir. 2 _______			
Dist	Spp	Ht. B	Ht. T	Dist	Spp	Ht. B	Ht. T

Dir. 3 _______				Dir. 4 _______			
Dist	Spp	Ht. B	Ht. T	Dist	Spp	Ht. B	Ht. T

Appendix E: 2009 Descriptive statistics

Table E-1. Sample sizes, means, and standard deviations between non-detections (N) and detections (Y) among the 8 ecoregions of our 2009 data, listed from west to east. Significant differences (P < 0.05) in means are shown in bold (see Table E-9 for significant t-test results).

			Arizona/New Mexico Mountains			Chihuahuan Deserts			Edwards Plateau		
			N	Y	Total	N	Y	Total	N	Y	Total
N			57	0	57	493	24	517	1131	189	1320
Slope	(°)	mean	19.2	0.0	19.2	9.9	11.2	9.9	**21.2**	**10.5**	19.7
		sd	9.7	0.0	9.7	9.4	9.5	9.4	71.4	20.4	66.7
Canopy	(%)	mean	36.2	0.0	36.2	23.6	28.6	23.9	**17.8**	**12.8**	17.1
Cover		sd	25.7	0.0	25.7	17.5	17.3	17.6	21.9	18.9	21.6
Planimetric	(°/100m)	mean	-0.04	0.00	-0.04	0.02	0.02	0.02	0.00	0.00	0.00
Curvature		sd	0.19	0.00	0.19	0.12	0.11	0.12	0.06	0.08	0.06
Profile	(°/100m)	mean	0.26	0.00	0.26	0.10	0.11	0.10	**0.03**	**0.07**	0.03
Curvature		sd	0.29	0.00	0.29	0.22	0.18	0.22	0.12	0.18	0.13

Table E-1 (continued). Sample sizes, means, and standard deviations between non-detections (N) and detections (Y) among the 8 ecoregions of our 2009 data, listed from west to east. Significant differences (P < 0.05) in means are shown in bold (see Table E-9 for significant t-test results).

			Southwestern Tablelands			Southern Texas Plains			Central Great Plains		
			N	Y	Total	N	Y	Total	N	Y	Total
N			8	0	8	8	8	16	156	3	159
Slope	(°)	mean	1.4	0.0	1.4	10.7	14.7	12.7	2.5	3.7	2.5
		sd	0.9	0.0	0.9	6.7	4.1	5.7	2.2	1.6	2.1
Canopy	(%)	mean	17.7	0.0	17.7	0.4	2.9	1.6	**24.1**	**53.0**	24.7
Cover		sd	15.8	0.0	15.8	0.6	8.2	5.7	23.3	19.0	23.5
Planimetric	(°/100m)	mean	0.00	0.00	0.00	-0.02	0.07	0.03	0.00	-0.01	0.00
Curvature		sd	0.01	0.00	0.01	0.11	0.09	0.11	0.02	0.07	0.03
Profile	(°/100m)	mean	0.00	0.00	0.00	**0.12**	**0.41**	0.26	**0.01**	**-0.04**	0.01
Curvature		sd	0.02	0.00	0.02	0.20	0.15	0.23	0.04	0.05	0.04

Table E-1 (continued). Sample sizes, means, and standard deviations between non-detections (N) and detections (Y) among the 8 ecoregions of our 2009 data, listed from west to east. Significant differences (P < 0.05) in means are shown in bold (see Table E-9 for significant t-test results).

			Cross Timbers			**Texas Blackland Prairies**			**Total**		
			N	**Y**	**Total**	**N**	**Y**	**Total**	**N**	**Y**	**Total**
N			451	27	478	18	0	18	2322	251	2573
Slope	(°)	mean	4.4	4.7	4.5	3.9	0.0	3.9	14.0	10.0	13.6
		sd	2.9	2.6	2.9	2.2	0.0	2.2	50.7	18.1	48.5
Canopy	(%)	mean	29.9	24.7	29.6	42.7	0.0	42.7	**22.4**	**15.8**	21.8
Cover		sd	23.6	17.9	23.3	32.2	0.0	32.2	22.3	19.6	22.2
Planimetric	(°/100m)	mean	**0.01**	**-0.03**	0.00	0.02	0.00	0.02	0.01	0.00	0.01
Curvature		sd	0.04	0.06	0.04	0.04	0.00	0.04	0.08	0.09	0.08
Profile	(°/100m)	mean	**0.01**	**-0.03**	0.00	0.00	0.00	0.00	**0.04**	**0.07**	0.05
Curvature		sd	0.07	0.07	0.07	0.05	0.00	0.05	0.15	0.18	0.15

Table E-2. Ecosites represented within a 100-m radius around survey points in the Chihuahuan Desert ecoregion. Mean and standard deviation of proportions of each ecosite are given for all points, as well as the percent of those points that had each ecosite represented (non-zero value). Significant differences in means (P < 0.05) are in bold (see Table E-10).

		NonDetect	Detect	Total
N		384	9	393
Gravelly	%	32.3%	22.2%	32.1%
	Mean	0.19	0.02	0.19
	SD	0.34	0.04	0.34
Steep Rocky	%	28.1%	0.0%	27.5%
	Mean	0.19	0.00	0.19
	SD	0.36	0.00	0.36
Limestone	%	20.6%	0.0%	20.1%
Hill	Mean	0.15	0.00	0.15
	SD	0.34	0.00	0.33
Unclassified	%	19.8%	22.2%	19.8%
	Mean	0.15	0.11	0.15
	SD	0.34	0.33	0.34
Draw	%	18.0%	88.9%	19.6%
	Mean	**0.11**	**0.69**	0.12
	SD	0.27	0.35	0.29
Loamy	%	17.4%	44.4%	18.1%
	Mean	0.12	0.18	0.12
	SD	0.30	0.26	0.30
Igneous Hill	%	7.6%	0.0%	7.4%
Mountain	Mean	0.05	0.00	0.05
	SD	0.21	0.00	0.20
Loamy	%	2.1%	0.0%	2.0%
Bottomland	Mean	0.01	0.00	0.01
	SD	0.09	0.00	0.09
Low Stony	%	1.6%	0.0%	1.5%
Hill	Mean	0.00	0.00	0.00
	SD	0.06	0.00	0.06
Shallow	%	0.8%	0.0%	0.8%
	Mean	0.00	0.00	0.00
	SD	0.06	0.00	0.05
Shallow	%	0.5%	0.0%	0.5%
Divide	Mean	0.00	0.00	0.00
	SD	0.03	0.00	0.03

Table E-2 (continued). Ecosites represented within a 100-m radius around survey points in the Chihuahuan Desert ecoregion. Mean and standard deviation of proportions of each ecosite are given for all points, as well as the percent of those points that had each ecosite represented (non-zero value). Significant differences in means (P < 0.05) are in bold (see Table E-10).

		NonDetect	Detect	Total
N		384	9	393
Clay Flat	%	0.3%	0.0%	0.3%
	Mean	0.00	0.00	0.00
	SD	0.00	0.00	0.00
Hardland	%	0.3%	0.0%	0.3%
Slopes	Mean	0.00	0.00	0.00
	SD	0.02	0.00	0.02

Table E-3. Ecosites represented within a 100-m radius around survey points in the Edwards Plateau ecoregion. Mean and standard deviation of proportions of each ecosite are given for all points, as well as the percent of those points that had each ecosite represented (non-zero value). Significant differences in means (P < 0.05) are in bold (see Table E-10).

		NonDetect	Detect	Total
N		1131	189	1320
Steep	%	31.1%	56.1%	34.7%
Rocky	Mean	**0.20**	**0.39**	0.23
	SD	0.36	0.43	0.38
Low Stony	%	29.4%	50.3%	32.4%
Hill	Mean	**0.19**	**0.33**	0.21
	SD	0.36	0.42	0.37
Unclassified	%	19.3%	13.8%	18.5%
	Mean	0.11	0.12	0.11
	SD	0.28	0.31	0.28
Clay Loam	%	15.3%	0.5%	13.2%
	Mean	**0.08**	**0.01**	0.07
	SD	0.23	0.07	0.22
Shallow	%	13.1%	3.2%	11.7%
	Mean	**0.08**	**0.01**	0.07
	SD	0.25	0.10	0.24
Limestone	%	12.1%	0.0%	10.4%
Hill	Mean	**0.08**	**0.00**	0.07
	SD	0.24	0.00	0.22
Adobe	%	10.4%	9.0%	10.2%
	Mean	0.07	0.04	0.06
	SD	0.23	0.16	0.22
Redland	%	7.8%	0.5%	6.7%
	Mean	**0.06**	**0.00**	0.05
	SD	0.22	0.05	0.21
Loamy	%	5.3%	11.6%	6.2%
Bottomland	Mean	**0.02**	**0.06**	0.03
	SD	0.11	0.19	0.13
Shallow	%	5.1%	2.6%	4.8%
Granite	Mean	0.03	0.03	0.03
	SD	0.14	0.16	0.14
Sandy Loam	%	3.5%	1.6%	3.3%
	Mean	**0.02**	**0.00**	0.01
	SD	0.10	0.02	0.09
Draw	%	2.6%	0.5%	2.3%
	Mean	0.01	0.00	0.01
	SD	0.07	0.06	0.07

Table E-3 (continued). Ecosites represented within a 100-m radius around survey points in the Edwards Plateau ecoregion. Mean and standard deviation of proportions of each ecosite are given for all points, as well as the percent of those points that had each ecosite represented (non-zero value). Significant differences in means ($P < 0.05$) are in bold (see Table E-10).

		NonDetect	Detect	Total
N		1131	189	1320
Loamy	%	1.9%	0.0%	1.6%
	Mean	0.01	0.00	0.01
	SD	0.07	0.00	0.07
Granite Gravel	%	1.7%	0.0%	1.4%
	Mean	0.01	0.00	0.01
	SD	0.09	0.00	0.09
Granite Hill	%	1.4%	0.0%	1.2%
	Mean	0.01	0.00	0.01
	SD	0.09	0.00	0.08
Gravelly Sandy Loam	%	1.1%	0.0%	1.0%
	Mean	0.00	0.00	0.00
	SD	0.05	0.00	0.05
Gravelly	%	0.9%	1.1%	0.9%
	Mean	0.00	0.00	0.00
	SD	0.05	0.04	0.05
Blackland	%	0.7%	0.0%	0.6%
	Mean	0.00	0.00	0.00
	SD	0.05	0.00	0.04
Clay Flat	%	0.7%	0.0%	0.6%
	Mean	0.00	0.00	0.00
	SD	0.06	0.00	0.06
Red Savannah	%	0.5%	0.0%	0.5%
	Mean	0.00	0.00	0.00
	SD	0.02	0.00	0.02
Hardland Slopes	%	0.4%	0.0%	0.3%
	Mean	0.00	0.00	0.00
	SD	0.04	0.00	0.03
Shallow Clay	%	0.4%	0.0%	0.3%
	Mean	0.00	0.00	0.00
	SD	0.02	0.00	0.02
Salty Bottomland	%	0.2%	0.0%	0.2%
	Mean	0.00	0.00	0.00
	SD	0.01	0.00	0.01
Sandy	%	0.2%	0.0%	0.2%
	Mean	0.00	0.00	0.00
	SD	0.01	0.00	0.01

Table E-3 (continued). Ecosites represented within a 100-m radius around survey points in the Edwards Plateau ecoregion. Mean and standard deviation of proportions of each ecosite are given for all points, as well as the percent of those points that had each ecosite represented (non-zero value). Significant differences in means (P < 0.05) are in bold (see Table E-10).

		NonDetect	**Detect**	**Total**
N		1131	189	1320
Red Sandy	%	0.1%	0.0%	0.1%
Loam	Mean	0.00	0.00	0.00
	SD	0.03	0.00	0.03
Sandstone	%	0.1%	0.0%	0.1%
Hill	Mean	0.00	0.00	0.00
	SD	0.00	0.00	0.00
Stony Loam	%	0.1%	0.0%	0.1%
	Mean	0.00	0.00	0.00
	SD	0.01	0.00	0.01
Tight Sandy	%	0.1%	0.0%	0.1%
Loam	Mean	0.00	0.00	0.00
	SD	0.00	0.00	0.00

Table E-4. Ecosites represented within a 100-m radius around survey points in the Southwestern Tablelands ecoregion. Mean and standard deviation of proportions of each ecosite are given for all points, as well as the percent of those points that had each ecosite represented (non-zero value). Significant differences in means (P < 0.05) are in bold (see Table E-10).

		NonDetect	**Detect**	**Total**
N		8	0	8
Shallow	%	75.0%	0.0%	75.0%
	Mean	0.28	0.00	0.28
	SD	0.29	0.00	0.29
Clay Loam	%	62.5%	0.0%	62.5%
	Mean	0.30	0.00	0.30
	SD	0.40	0.00	0.40
Sandy Loam	%	50.0%	0.0%	50.0%
	Mean	0.19	0.00	0.19
	SD	0.34	0.00	0.34
Unclassified	%	50.0%	0.0%	50.0%
	Mean	0.14	0.00	0.14
	SD	0.19	0.00	0.19
Loamy	%	25.0%	0.0%	25.0%
	Mean	0.08	0.00	0.08
	SD	0.14	0.00	0.14

Table E-5. Ecosites represented within a 100-m radius around survey points in the Southern Texas Plains ecoregion. Mean and standard deviation of proportions of each ecosite are given for all points, as well as the percent of those points that had each ecosite represented (non-zero value). Significant differences in means ($P < 0.05$) are in bold (see Table E-10).

		NonDetect	Detect	Total
N		8	8	16
Steep	%	62.5%	100.0%	81.3%
Rocky	Mean	**0.40**	**1.00**	0.70
	SD	0.44	0.01	0.43
Low Stony	%	87.5%	12.5%	50.0%
Hill	Mean	**0.50**	**0.00**	0.25
	SD	0.40	0.01	0.38
Clay Loam	%	25.0%	0.0%	12.5%
	Mean	0.01	0.00	0.00
	SD	0.01	0.00	0.01
Shallow	%	25.0%	0.0%	12.5%
	Mean	0.03	0.00	0.02
	SD	0.07	0.00	0.05
Hardland	%	12.5%	0.0%	6.3%
Slopes	Mean	0.06	0.00	0.03
	SD	0.16	0.00	0.11
Loamy	%	12.5%	0.0%	6.3%
Bottomland	Mean	0.00	0.00	0.00
	SD	0.01	0.00	0.01

Table E-6. Ecosites represented within a 100-m radius around survey points in the Central Great Plains ecoregion. Mean and standard deviation of proportions of each ecosite are given for all points, as well as the percent of those points that had each ecosite represented (non-zero value). Significant differences in means ($P < 0.05$) are in bold (see Table E-10).

		NonDetect	Detect	Total
N		156	3	159
Loamy Bottomland	%	27.6%	0.0%	27.0%
	Mean	0.15	0.00	0.15
	SD	0.29	0.00	0.29
Clay Loam	%	26.3%	33.3%	26.4%
	Mean	0.12	0.11	0.12
	SD	0.25	0.19	0.25
Redland	%	23.1%	0.0%	22.6%
	Mean	0.17	0.00	0.17
	SD	0.34	0.00	0.34
Low Stony Hill	%	19.2%	100.0%	20.8%
	Mean	**0.14**	**0.80**	0.15
	SD	0.32	0.17	0.33
Sandy Loam	%	19.9%	0.0%	19.5%
	Mean	0.11	0.00	0.11
	SD	0.27	0.00	0.27
Shallow	%	17.3%	0.0%	17.0%
	Mean	0.08	0.00	0.08
	SD	0.23	0.00	0.23
Unclassified	%	7.7%	0.0%	7.5%
	Mean	0.03	0.00	0.03
	SD	0.11	0.00	0.11
Rocky Hill	%	7.7%	0.0%	7.5%
	Mean	0.03	0.00	0.03
	SD	0.14	0.00	0.14
Steep Rocky	%	7.1%	0.0%	6.9%
	Mean	0.03	0.00	0.03
	SD	0.15	0.00	0.15
Clay Flat	%	5.8%	0.0%	5.7%
	Mean	0.01	0.00	0.01
	SD	0.05	0.00	0.05
Loamy	%	5.8%	0.0%	5.7%
	Mean	0.02	0.00	0.02
	SD	0.08	0.00	0.08
Adobe	%	3.8%	33.3%	4.4%
	Mean	0.02	0.09	0.02
	SD	0.09	0.16	0.09

Table E-6 (continued). Ecosites represented within a 100-m radius around survey points in the Central Great Plains ecoregion. Mean and standard deviation of proportions of each ecosite are given for all points, as well as the percent of those points that had each ecosite represented (non-zero value). Significant differences in means ($P < 0.05$) are in bold (see Table E-10).

		NonDetect	**Detect**	**Total**
N		156	3	159
Claypan	%	3.8%	0.0%	3.8%
Prairie	Mean	0.02	0.00	0.02
	SD	0.13	0.00	0.13
Shallow Clay	%	3.8%	0.0%	3.8%
	Mean	0.01	0.00	0.01
	SD	0.08	0.00	0.08
Tight Sandy	%	2.6%	0.0%	2.5%
Loam	Mean	0.01	0.00	0.01
	SD	0.06	0.00	0.06
Clayey	%	1.3%	0.0%	1.3%
Bottomland	Mean	0.01	0.00	0.01
	SD	0.06	0.00	0.06

Table E-7. Ecosites represented within a 100-m radius around survey points in the Cross Timbers ecoregion. Mean and standard deviation of proportions of each ecosite are given for all points, as well as the percent of those points that had each ecosite represented (non-zero value). Significant differences in means ($P < 0.05$) are in bold (see Table E-10).

		NonDetect	Detect	Total
N		451	27	478
Low Stony	%	23.1%	77.8%	26.2%
Hill	Mean	**0.15**	**0.45**	0.17
	SD	0.32	0.40	0.34
Clay Loam	%	25.3%	7.4%	24.3%
	Mean	0.10	0.04	0.10
	SD	0.25	0.14	0.24
Adobe	%	20.4%	59.3%	22.6%
	Mean	0.11	0.19	0.11
	SD	0.26	0.29	0.27
Sandy Loam	%	17.7%	0.0%	16.7%
	Mean	**0.11**	**0.00**	0.10
	SD	0.27	0.00	0.27
Sandstone	%	13.3%	7.4%	13.0%
Hill	Mean	0.08	0.05	0.07
	SD	0.22	0.17	0.22
Shallow	%	10.4%	11.1%	10.5%
	Mean	0.06	0.09	0.06
	SD	0.22	0.27	0.22
Loamy	%	10.6%	3.7%	10.3%
Bottomland	Mean	0.04	0.03	0.04
	SD	0.15	0.13	0.15
Redland	%	9.8%	7.4%	9.6%
	Mean	0.05	0.05	0.05
	SD	0.20	0.21	0.20
Claypan	%	9.1%	7.4%	9.0%
Prairie	Mean	0.05	0.03	0.04
	SD	0.18	0.09	0.18
Pink Caliche	%	8.4%	3.7%	8.2%
	Mean	0.06	0.01	0.06
	SD	0.22	0.03	0.22
Steep Rocky	%	7.8%	7.4%	7.7%
	Mean	0.05	0.03	0.05
	SD	0.20	0.16	0.20
Unclassified	%	7.3%	0.0%	6.9%
	Mean	0.01	0.00	0.01
	SD	0.07	0.00	0.07

Table E-7 (continued). Ecosites represented within a 100-m radius around survey points in the Cross Timbers ecoregion. Mean and standard deviation of proportions of each ecosite are given for all points, as well as the percent of those points that had each ecosite represented (non-zero value). Significant differences in means ($P < 0.05$) are in bold (see Table E-10).

		NonDetect	Detect	Total
N		451	27	478
Tight Sandy	%	4.7%	0.0%	4.4%
Loam	Mean	0.01	0.00	0.01
	SD	0.09	0.00	0.08
Rocky Hill	%	4.4%	0.0%	4.2%
	Mean	0.03	0.00	0.02
	SD	0.14	0.00	0.14
Blackland	%	2.7%	3.7%	2.7%
	Mean	0.01	0.02	0.01
	SD	0.08	0.09	0.08
Stony Clay	%	2.9%	0.0%	2.7%
Loam	Mean	0.02	0.00	0.02
	SD	0.12	0.00	0.12
Bouldery Hill	%	2.2%	0.0%	2.1%
	Mean	0.01	0.00	0.01
	SD	0.10	0.00	0.10
Clayey	%	2.0%	0.0%	1.9%
Bottomland	Mean	0.01	0.00	0.01
	SD	0.09	0.00	0.09
Loamy Sand	%	1.8%	0.0%	1.7%
	Mean	0.01	0.00	0.01
	SD	0.09	0.00	0.09
Sandy	%	0.7%	0.0%	0.6%
	Mean	0.00	0.00	0.00
	SD	0.05	0.00	0.05
Shallow Clay	%	0.4%	0.0%	0.4%
	Mean	0.00	0.00	0.00
	SD	0.01	0.00	0.01
Chalky	%	0.2%	0.0%	0.2%
Ridge	Mean	0.00	0.00	0.00
	SD	0.01	0.00	0.01
Clay Flat	%	0.2%	0.0%	0.2%
	Mean	0.00	0.00	0.00
	SD	0.00	0.00	0.00
Deep Sand	%	0.2%	0.0%	0.2%
	Mean	0.00	0.00	0.00
	SD	0.00	0.00	0.00

Table E-8. Ecosites represented within a 100-m radius around survey points in the Texas Blackland Prairie ecoregion. Mean and standard deviation of proportions of each ecosite are given for all points, as well as the percent of those points that had each ecosite represented (non-zero value). Significant differences in means (P < 0.05) are in bold (see Table E-10).

		NonDetect	**Detect**	**Total**
N		18	0	18
Eroded	%	72.2%	0.0%	72.2%
Blackland	Mean	0.44	0.00	0.44
	SD	0.31	0.00	0.31
Low Stony	%	27.8%	0.0%	27.8%
Hill	Mean	0.18	0.00	0.18
	SD	0.38	0.00	0.38
Blackland	%	16.7%	0.0%	16.7%
	Mean	0.05	0.00	0.05
	SD	0.16	0.00	0.16
Chalky	%	16.7%	0.0%	16.7%
Ridge	Mean	0.10	0.00	0.10
	SD	0.29	0.00	0.29
Clay Loam	%	16.7%	0.0%	16.7%
	Mean	0.03	0.00	0.03
	SD	0.08	0.00	0.08
Unclassified	%	16.7%	0.0%	16.7%
	Mean	0.03	0.00	0.03
	SD	0.06	0.00	0.06
Clayey	%	5.6%	0.0%	5.6%
Bottomland	Mean	0.02	0.00	0.02
	SD	0.08	0.00	0.08

Table E-9. 2009 data results of significant ($P < 0.05$) t-tests between detection and non-detection points for remote sensing metrics averaged over a 100-m radius. For mean difference for slope and canopy cover, positive and negative values indicate the difference between detection and non-detection points (i.e., + = selection, - = non-selection). For profile and planimetric curvature, regardless of the positive or negative value, the mean difference indicates the magnitude of the difference in curvature.

					Mean	Std.	95% CI	
		t	df	p	Difference*	Error	Lower	Upper
Edwards Plateau								
	Slope	2.06	1318	0.040	-10.766	5.234	-21.030	-0.500
	Profile Curvature	-4.02	1318	<0.001	0.041	0.010	0.020	0.060
	Canopy	2.94	1318	0.003	-4.976	1.692	-8.290	-1.660
South Texas Plains								
	Profile Curvature	-3.22	14	0.006	0.288	0.089	0.100	0.480
Central Great Plains								
	Profile Curvature	2.01	157	0.046	-0.052	0.026	-0.100	0.000
	Canopy	-2.14	157	0.034	28.938	13.547	2.180	55.690
Cross Timbers								
	Profile Curvature	2.75	476	0.006	-0.041	0.015	-0.070	-0.010
	Planimetric Curvature	3.90	476	<0.001	-0.034	0.009	-0.050	-0.020
Total (all regions)								
	Profile Curvature	2.61	2571	0.009	-0.270	0.010	0.007	0.047
	Canopy	-4.50	2571	<0.001	-6.613	1.468	-9.493	-3.734

*detect - nondetect

Table E-10. 2009 data results of significant ($P < 0.05$) t-tests for ecosite proportions between detection and non-detection points averaged over a 100-m radius. For mean difference, positive and negative values indicate the difference between detection and non-detection points (i.e., + = selection, - = non-selection).

	t	df	p	Mean Difference*	Std. Error	95% CI Lower	95% CI Upper
Chihuahuan Desert							
Draw	6.33	391	<0.001	0.581	0.092	0.400	0.761
Edwards Plateau							
Steep Rocky	6.52	1318	<0.001	0.189	0.029	0.132	0.246
Low Stony Hill	4.76	1318	<0.001	0.137	0.029	0.081	0.194
Clay Loam	-4.37	1318	<0.001	-0.074	0.017	-0.107	-0.041
Shallow	-3.77	1318	<0.001	-0.070	0.018	-0.106	-0.033
Sandy Loam	-1.97	1318	0.049	-0.014	0.007	-0.027	0.000
Limestone Hill	-4.37	1318	<0.001	-0.076	0.017	-0.110	-0.042
Redland	-3.32	1318	0.001	-0.054	0.016	-0.086	-0.022
Loamy Bottomland	4.04	1318	<0.001	0.040	0.010	0.021	0.060
South Texas Plains							
Steep Rocky	3.78	14	0.002	0.595	0.157	0.258	0.932
Low Stony Hill	-3.48	14	0.004	-0.497	0.143	-0.803	-0.191
Central Great Plains							
Low Stony Hill	3.55	157	0.001	0.664	0.187	0.295	1.033
Cross Timbers							
Low Stony Hill	4.56	476	<0.001	0.297	0.065	0.169	0.425
Sandy Loam	-2.00	476	0.046	-0.105	0.053	-0.209	-0.002
Total (all regions)							
Steep Rocky	8.44	2390	<0.001	0.196	0.023	0.150	0.241
Low Stony Hill	7.85	2390	<0.001	0.179	0.023	0.134	0.224
Clay Loam	-4.45	2390	<0.001	-0.064	0.014	-0.092	-0.036
Shallow	-2.99	2390	0.003	-0.044	0.015	-0.072	-0.015
Sandy Loam	-3.45	2390	0.001	-0.037	0.011	-0.059	-0.016
Limestone Hill	-4.45	2390	<0.001	-0.066	0.015	-0.096	-0.037
Redland	-3.24	2390	0.001	-0.045	0.014	-0.072	-0.018
Loamy Bottomland	1.94	2390	0.053	0.020	0.010	0.000	0.039
Gravelly	-3.02	2390	0.003	-0.032	0.011	-0.053	-0.011
Loamy	-2.14	2390	0.032	-0.020	0.009	-0.039	-0.002

* detect - nondetect

Appendix F: 2010 Descriptive statistics

Table F-1. Sample sizes, means, and standard deviations between non-detections (N) and detections (Y) among our 8 study areas in 2010, listed from west to east. Statistically significant differences (P < 0.5) are in bold. Results of t-tests can be found in Table F-10. Sample sizes for vegetation metrics are less, as vegetation surveys were completed at a subset of survey points.

			Devil's River			Kickapoo			Devil's Sinkhole			Taylor		
			N	**Y**	**Total**	**N**	**Y**	**Total**	**N**	**Y**	**Total**	**N**	**Y**	**Total**
n			476	176	652	760	249	1009	440	21	461	32	6	38
Slope	(°)	mean	**11.9**	**13.8**	12.4	**7.5**	**8.8**	7.9	**5.6**	**9.5**	5.8	**4.6**	**8.7**	5.2
		sd	6.6	6.0	6.5	4.5	4.3	4.5	5.5	6.2	5.6	3.1	5.5	3.8
Canopy	(%)	mean	11.9	11.6	11.9	**15.0**	**9.4**	13.7	10.9	9.6	10.8	47.4	63.3	49.9
Cover		sd	10.7	10.6	10.7	16.2	11.5	15.3	19.3	14.6	19.1	20.3	18.0	20.6
Planimetric	(°/100m)	mean	0.01	0.03	0.01	0.03	0.03	0.03	0.00	0.00	0.00	**0.01**	**-0.07**	-0.01
Curvature		sd	0.12	0.13	0.12	0.08	0.08	0.08	0.07	0.08	0.07	0.05	0.14	0.08
Profile	(°/100m)	mean	**-0.03**	**0.10**	0.00	**0.02**	**0.04**	0.02	0.00	0.03	0.00	-0.04	0.01	-0.04
Curvature		sd	0.22	0.21	0.23	0.13	0.13	0.13	0.11	0.19	0.12	0.08	0.15	0.09
n (vegetation subset)			468	174	642	754	242	996	421	21	442	32	6	38
Distance	(m)	mean	4.3	3.9	4.2	4.0	3.5	3.9	9.0	7.4	8.9	7.9	7.1	7.8
To Veg		sd	3.0	2.7	3.0	3.6	3.0	3.4	7.3	7.9	7.3	6.4	1.6	5.9
Veg Height	(m)	mean	**0.1**	**0.2**	0.2	**0.2**	**0.2**	0.2	0.4	0.3	0.4	0.3	0.4	0.3
(Top)		sd	0.2	0.2	0.2	0.4	0.3	0.3	0.5	0.3	0.5	0.4	1.1	0.5
Veg Height	(m)	mean	1.8	2.0	1.9	**3.0**	**2.6**	2.9	2.9	2.5	2.9	3.6	3.7	3.6
(Bottom)		sd	0.6	0.8	0.7	1.0	0.8	1.0	1.2	1.1	1.2	1.3	1.3	1.3
Juniper	(0-4)	mean	0.6	0.8	0.7	**1.9**	**1.6**	1.9	1.1	1.0	1.1	2.7	2.8	2.7
Index		sd	0.9	1.0	0.9	1.3	1.2	1.3	1.4	1.1	1.4	1.3	1.2	1.3
Oak	(0-4)	mean	**0.1**	**0.2**	0.1	0.4	0.4	0.4	**1.0**	**0.5**	1.0	0.8	1.2	0.8
Index		sd	0.3	0.5	0.4	0.7	0.7	0.7	1.1	0.7	1.1	1.2	1.2	1.2

Table F-1 (continued). Sample sizes, means, and standard deviations between non-detections (N) and detections (Y) among our 8 study areas in 2010, listed from west to east. Statistically significant differences (P < 0.5) are in bold. Results of t-tests can be found in Table F-10. Sample sizes for vegetation metrics are less, as vegetation surveys were completed at a subset of survey points.

			Kerr			Mason			Balcones			Fort Hood		
			N	**Y**	**Total**	**N**	**Y**	**Total**	**N**	**Y**	**Total**	**N**	**Y**	**Total**
n			1069	222	1291	104	6	110	538	71	609	1846	191	2037
Slope	(°)	mean	4.4	4.1	4.4	**2.6**	**4.9**	2.7	**5.4**	**2.8**	5.1	**3.6**	**4.6**	3.7
		sd	2.7	2.2	2.6	1.5	2.3	1.6	4.1	2.8	4.0	2.8	3.5	2.9
Canopy	(%)	mean	25.6	22.8	25.1	7.7	9.3	7.8	46.3	39.8	45.5	40.5	43.6	40.8
Cover		sd	24.9	22.1	24.5	9.1	5.1	8.9	27.0	26.2	26.9	31.9	27.8	31.6
Planimetric	(°/100m)	mean	0.00	0.00	0.00	0.01	0.01	0.01	0.00	-0.01	0.00	0.00	0.00	0.00
Curvature		sd	0.04	0.04	0.04	0.03	0.04	0.03	0.06	0.05	0.06	0.04	0.05	0.04
Profile	(°/100m)	mean	0.00	0.01	0.01	0.01	0.01	0.01	**0.00**	**-0.03**	0.00	0.00	-0.01	0.00
Curvature		sd	0.07	0.06	0.07	0.04	0.11	0.04	0.09	0.06	0.09	0.07	0.09	0.07
n (vegetation subset)			1069	222	1291	104	6	110	470	23	493	1803	188	1991
Distance	(m)	mean	**9.2**	**7.8**	9.0	12.3	13.4	12.3	10.9	12.1	11.0	**9.3**	**7.7**	9.1
To Veg		sd	7.2	5.6	7.0	8.0	6.0	7.9	9.1	7.3	9.0	8.9	6.9	8.8
Veg Height	(m)	mean	**0.6**	**0.3**	0.6	4.7	4.5	4.7	0.3	0.2	0.3	0.6	0.5	0.6
(Top)		sd	0.6	0.4	0.6	2.0	1.3	1.9	0.6	0.3	0.6	0.7	0.5	0.7
Veg Height	(m)	mean	**3.8**	**3.2**	3.7	**0.7**	**0.3**	0.7	4.3	3.6	4.3	**4.2**	**3.6**	4.2
(Bottom)		sd	1.5	1.2	1.5	0.5	0.4	0.5	2.4	2.0	2.3	2.2	1.6	2.2
Juniper	(0-4)	mean	1.4	1.4	1.4	0.0	0.2	0.0	2.1	1.6	2.1	**1.5**	**1.3**	1.5
Index		sd	1.5	1.4	1.5	0.2	0.4	0.2	1.7	1.5	1.7	1.4	1.4	1.4
Oak	(0-4)	mean	1.6	1.7	1.6	**1.3**	**2.3**	1.3	**0.6**	**1.2**	0.7	0.8	0.9	0.8
Index		sd	1.4	1.3	1.4	1.3	1.0	1.3	1.1	1.5	1.1	1.0	1.0	1.0

Table F-1 (continued). Sample sizes, means, and standard deviations between non-detections (N) and detections (Y) among our 8 study areas in 2010, listed from west to east. Statistically significant differences ($P < 0.5$) are in bold. Results of t-tests can be found in Table F-10. Sample sizes for vegetation metrics are less, as vegetation surveys were completed at a subset of survey points.

			Total		
			N	**Y**	**Total**
n			5265	942	6207
Slope	(°)	mean	**5.4**	**7.3**	5.7
		sd	4.6	5.5	4.8
Canopy	(%)	mean	**28.7**	**22.6**	27.8
Cover		sd	28.5	24.1	28.0
Planimetric	(°/100m)	mean	0.01	0.01	0.01
Curvature		sd	0.06	0.08	0.07
Profile	(°/100m)	mean	**0.00**	**0.03**	0.00
Curvature		sd	0.11	0.14	0.11
n (vegetation subset)			5121	882	6003
Distance	(m)	mean	**8.2**	**6.0**	7.8
To Veg		sd	7.8	5.5	7.5
Veg Height	(m)	mean	**3.7**	**2.9**	3.5
(Top)		sd	1.9	1.3	1.9
Veg Height	(m)	mean	**0.5**	**0.3**	0.4
(Bottom)		sd	0.6	0.4	0.6
Juniper	(0-4)	mean	**1.5**	**1.3**	1.4
Index		sd	1.4	1.3	1.4
Oak	(0-4)	mean	0.8	0.8	0.8
Index		sd	1.1	1.1	1.1

Table F-2. Ecosites represented within a 100-m radius around survey points in the Devil's River region. Mean and standard deviation of proportions of each ecosite are given for all points, as well as the percent of those points that had each ecosite represented (non-zero value). Significant differences in means (P < 0.05) are in bold (see Table F-11).

		NonDetect	Detect	Total
N		476	176	652
Steep Rocky	%	82.6%	92.0%	85.1%
	Mean	**0.575**	**0.737**	0.619
	SD	0.416	0.360	0.408
Low Stony Hill	%	43.5%	30.7%	40.0%
	Mean	**0.250**	**0.113**	0.213
	SD	0.365	0.246	0.342
Loamy Bottomland	%	16.6%	13.1%	15.6%
	Mean	0.090	0.060	0.082
	SD	0.242	0.198	0.231
Shallow	%	10.7%	10.8%	10.7%
	Mean	0.062	0.060	0.062
	SD	0.216	0.205	0.213
Unclassified	%	6.9%	5.7%	6.6%
	Mean	0.020	0.029	0.023
	SD	0.091	0.127	0.102
Clay Loam	%	0.6%	0.6%	0.6%
	Mean	0.001	0.001	0.001
	SD	0.018	0.014	0.017

Table F-3. Ecosites represented within a 100-m radius around survey points in the Kickapoo region. Mean and standard deviation of proportions of each ecosite are given for all points, as well as the percent of those points that had each ecosite represented (non-zero value). Significant differences in means ($P < 0.05$) are in bold (see Table F-11).

		NonDetect	Detect	Total
N		760	249	1009
Steep Rocky	%	64.7%	76.3%	67.6%
	Mean	**0.49**	**0.55**	0.50
	SD	0.46	0.43	0.45
Low Stony Hill	%	45.1%	48.6%	46.0%
	Mean	0.31	0.34	0.32
	SD	0.42	0.42	0.42
Shallow	%	22.1%	10.8%	19.3%
	Mean	**0.13**	**0.06**	0.11
	SD	0.30	0.19	0.28
Draw	%	6.2%	2.0%	5.2%
	Mean	**0.03**	**0.01**	0.03
	SD	0.16	0.09	0.15
Loamy Bottomland	%	3.7%	4.4%	3.9%
	Mean	0.02	0.03	0.02
	SD	0.13	0.14	0.14
Clay Loam	%	0.9%	1.6%	1.1%
	Mean	0.00	0.01	0.00
	SD	0.04	0.06	0.05
Redland	%	0.8%	0.8%	0.8%
	Mean	0.00	0.00	0.00
	SD	0.04	0.01	0.04

Table F-4. Ecosites represented within a 100-m radius around survey points in the Devil's Sinkhole region. Mean and standard deviation of proportions of each ecosite are given for all points, as well as the percent of those points that had each ecosite represented (non-zero value). Significant differences in means (P < 0.05) are in bold (see Table F-11).

		NonDetect	Detect	Total
N		440	21	461
Low Stony Hill	%	82.5%	71.4%	82.0%
	Mean	0.64	0.51	0.64
	SD	0.42	0.47	0.42
Steep Rocky	%	27.7%	57.1%	29.1%
	Mean	**0.17**	**0.33**	0.18
	SD	0.33	0.39	0.33
Shallow	%	20.7%	19.0%	20.6%
	Mean	0.13	0.10	0.13
	SD	0.30	0.26	0.30
Clay Loam	%	10.0%	4.8%	9.8%
	Mean	0.04	0.03	0.04
	SD	0.14	0.15	0.14
Draw	%	3.4%	4.8%	3.5%
	Mean	0.01	0.03	0.01
	SD	0.08	0.13	0.08
Loamy Bottomland	%	0.2%	0.0%	0.2%
	Mean	0.00	0.00	0.00
	SD	0.04	0.00	0.04

Table F-5. Ecosites represented within a 100-m radius around survey points in the Taylor Co. region. Mean and standard deviation of proportions of each ecosite are given for all points, as well as the percent of those points that had each ecosite represented (non-zero value). Significant differences in means ($P < 0.05$) are in bold (see Table F-11).

		NonDetect	Detect	Total
N		32	6	38
Low Stony Hill	%	93.8%	83.3%	92.1%
	Mean	0.53	0.53	0.53
	SD	0.35	0.34	0.34
Steep Rocky	%	40.6%	66.7%	44.7%
	Mean	0.14	0.23	0.16
	SD	0.23	0.20	0.23
Clay Loam	%	25.0%	50.0%	28.9%
	Mean	0.11	0.22	0.13
	SD	0.26	0.25	0.25
Sandy Loam Prairie	%	25.0%	0.0%	21.1%
	Mean	0.13	0.00	0.11
	SD	0.25	0.00	0.23
Clay Flat	%	3.1%	16.7%	5.3%
	Mean	0.01	0.01	0.01
	SD	0.04	0.02	0.04
Shallow	%	3.1%	16.7%	5.3%
	Mean	0.02	0.00	0.02
	SD	0.14	0.00	0.13
Loamy Bottomland	%	3.1%	0.0%	2.6%
	Mean	0.00	0.00	0.00
	SD	0.03	0.00	0.03

Table F-6. Ecosites represented within a 100-m radius around survey points in the Kerr region. Mean and standard deviation of proportions of each ecosite are given for all points, as well as the percent of those points that had each ecosite represented (non-zero value). Significant differences in means ($P < 0.05$) are in bold (see Table F-11).

		NonDetect	Detect	Total
N		1069	222	1291
Low Stony	%	76.1%	90.5%	78.6%
Hill	Mean	**0.57**	**0.67**	0.58
	SD	0.43	0.39	0.43
Steep Rocky	%	33.2%	25.2%	31.8%
	Mean	0.20	0.15	0.19
	SD	0.34	0.31	0.33
Redland	%	26.0%	22.5%	25.4%
	Mean	0.14	0.11	0.14
	SD	0.30	0.26	0.29
Shallow	%	14.9%	13.5%	14.6%
	Mean	0.08	0.06	0.08
	SD	0.24	0.19	0.23
Loamy	%	1.2%	2.7%	1.5%
Bottomland	Mean	0.01	0.01	0.01
	SD	0.06	0.07	0.06
Clay Loam	%	0.9%	0.0%	0.8%
	Mean	0.00	0.00	0.00
	SD	0.04	0.00	0.04

Table F-7. Ecosites represented within a 100-m radius around survey points in the Mason Co. region. Mean and standard deviation of proportions of each ecosite are given for all points, as well as the percent of those points that had each ecosite represented (non-zero value). Significant differences in means (P < 0.05) are in bold (see Table F-11).

		NonDetect	Detect	Total
N		104	6	110
Gravelly	%	51.0%	16.7%	49.1%
Sandy Loam	Mean	0.29	0.02	0.27
	SD	0.38	0.04	0.37
Shallow	%	26.9%	33.3%	27.3%
Granite	Mean	0.14	0.32	0.15
	SD	0.28	0.49	0.30
Adobe	%	13.5%	66.7%	16.4%
	Mean	**0.05**	**0.29**	0.06
	SD	0.14	0.28	0.16
Unclassified	%	16.3%	0.0%	15.5%
	Mean	0.08	0.00	0.08
	SD	0.25	0.00	0.24
Clay Loam	%	13.5%	33.3%	14.5%
	Mean	0.08	0.16	0.07
	SD	0.23	0.33	0.22
Granite	%	13.5%	0.0%	12.7%
Gravel	Mean	0.08	0.00	0.07
	SD	0.23	0.00	0.23
Low Stony	%	9.6%	50.0%	11.8%
Hill	Mean	0.06	0.11	0.06
	SD	0.20	0.25	0.20
Loamy	%	10.6%	0.0%	10.0%
Bottomland	Mean	0.05	0.00	0.05
	SD	0.18	0.00	0.18
Sandy Loam	%	8.7%	33.3%	10.0%
	Mean	0.05	0.11	0.05
	SD	0.18	0.20	0.18
Tight Sandy	%	6.7%	0.0%	6.4%
Loam	Mean	0.03	0.00	0.03
	SD	0.13	0.00	0.13
Red Sandy	%	5.8%	0.0%	5.5%
Loam	Mean	0.03	0.00	0.03
	SD	0.14	0.00	0.14
Red	%	5.8%	0.0%	5.5%
Savannah	Mean	0.03	0.00	0.02
	SD	0.11	0.00	0.11

Table F-7 continued. Ecosites represented within a 100-m radius around survey points in the Mason Co. region. Mean and standard deviation of proportions of each ecosite are given for all points, as well as the percent of those points that had each ecosite represented (non-zero value). Significant differences in means (P < 0.05) are in bold (see Table F-11).

		NonDetect	Detect	Total
N		104	6	110
Granite Hill	%	4.8%	0.0%	0.0%
	Mean	0.01	0.00	0.01
	SD	0.09	0.00	0.08
Stony Loam	%	4.8%	0.0%	0.0%
	Mean	0.02	0.00	0.02
	SD	0.12	0.00	0.11
Shallow	%	1.9%	0.0%	0.0%
	Mean	0.01	0.00	0.01
	SD	0.04	0.00	0.04

Table F-8. Ecosites represented within a 100-m radius around survey points in the Balcones region. Mean and standard deviation of proportions of each ecosite are given for all points, as well as the percent of those points that had each ecosite represented (non-zero value). Significant differences in means (P < 0.05) are in bold (see Table F-11).

		NonDetect	Detect	Total
N		538	71	609
Low Stony Hill	%	61.0%	97.2%	65.2%
	Mean	**0.40**	**0.86**	0.45
	SD	0.43	0.30	0.44
Adobe	%	50.9%	16.9%	47.0%
	Mean	**0.34**	**0.07**	0.31
	SD	0.42	0.19	0.41
Clay Loam	%	16.2%	1.4%	14.4%
	Mean	**0.07**	**0.00**	0.07
	SD	0.21	0.01	0.20
Steep Rocky	%	8.0%	4.2%	7.6%
	Mean	0.04	0.02	0.03
	SD	0.15	0.12	0.15
Shallow	%	7.4%	0.0%	6.6%
	Mean	**0.03**	**0.00**	0.03
	SD	0.14	0.00	0.14
Redland	%	4.5%	1.4%	4.1%
	Mean	0.02	0.01	0.02
	SD	0.13	0.06	0.12
Blackland	%	2.4%	2.8%	2.5%
	Mean	0.01	0.01	0.01
	SD	0.08	0.03	0.07
Unclassified	%	0.7%	1.4%	0.8%
	Mean	0.00	0.01	0.00
	SD	0.03	0.08	0.04
Loamy Bottomland	%	0.6%	0.0%	0.5%
	Mean	0.00	0.00	0.00
	SD	0.02	0.00	0.02

Table F-9. Ecosites represented within a 100-m radius around survey points in the Fort Hood region. Mean and standard deviation of proportions of each ecosite are given for all points, as well as the percent of those points that had each ecosite represented (non-zero value). Significant differences in means (P < 0.05) are in bold (see Table F-11).

		NonDetect	Detect	Total
N		1846	191	2037
Low Stony Hill	%	47.9%	59.7%	49.0%
	Mean	**0.30**	**0.40**	0.31
	SD	0.39	0.42	0.40
Clay Loam	%	38.1%	35.6%	37.9%
	Mean	0.21	0.19	0.20
	SD	0.33	0.31	0.33
Adobe	%	33.5%	46.1%	34.7%
	Mean	**0.13**	**0.18**	0.13
	SD	0.24	0.28	0.24
Shallow	%	23.6%	16.2%	22.9%
	Mean	**0.13**	**0.11**	0.13
	SD	0.30	0.28	0.29
Redland	%	17.9%	13.1%	17.5%
	Mean	**0.13**	**0.09**	0.13
	SD	0.32	0.26	0.31
Loamy Bottomland	%	7.1%	0.5%	6.5%
	Mean	0.04	0.00	0.03
	SD	0.16	0.04	0.15
Blackland	%	2.8%	1.6%	2.7%
	Mean	0.01	0.01	0.01
	SD	0.09	0.07	0.09
Stony Clay Loam	%	2.7%	0.0%	2.5%
	Mean	0.01	0.00	0.01
	SD	0.11	0.00	0.10
Shallow Clay	%	1.5%	0.0%	1.4%
	Mean	0.01	0.00	0.01
	SD	0.07	0.00	0.07
Sandy Loam	%	1.0%	0.0%	0.9%
	Mean	0.00	0.00	0.00
	SD	0.06	0.00	0.06
Unclassified	%	0.6%	0.0%	0.5%
	Mean	0.00	0.00	0.00
	SD	0.02	0.00	0.02
Chalky Ridge	%	0.1%	0.0%	0.0%
	Mean	0.00	0.00	0.00
	SD	0.00	0.00	0.00

Table F-10. 2010 results of significant ($P < 0.05$) t-tests between detection and non-detection points for vegetation measurements on the ground and the remote sensing metrics averaged over a 100-m radius. For mean difference, positive and negative values indicate the difference between detection and non-detection points (i.e., + = selection, - = non-selection). However, for profile and planimetric curvature, regardless of the positive or negative value, the mean difference indicates the magnitude of the difference in curvature.

					Mean	Std.	95% CI	
		t	df	p	Differe	Error	Lower	Upper
Devil's River								
	Slope	3.36	650	0.001	1.917	0.570	0.798	3.035
	Profile Curvature	6.58	650	< 0.001	0.128	0.019	0.090	0.166
	Veg Height - Top	4.10	640	< 0.001	0.249	0.061	0.130	0.368
	Oak Index	4.45	640	< 0.001	0.145	0.033	0.081	0.209
Kickapoo								
	Slope	3.83	1007	< 0.001	1.241	0.324	0.606	1.877
	Canopy Cover	-5.05	1007	< 0.001	-5.586	1.107	-7.758	-3.414
	Profile Curvature	1.94	1007	0.052	0.019	0.010	0.000	0.037
	Veg Height - Top	-5.35	994	< 0.001	-0.378	0.071	-0.517	-0.239
	Veg Height - Bottom	-2.87	994	0.004	-0.072	0.025	-0.121	-0.023
	Juniper Index	-2.80	994	0.005	-0.272	0.097	-0.462	-0.082
Devil's Sinkhole								
	Slope	3.18	459	0.002	3.901	1.228	1.488	6.314
	Oak Index	-2.09	440	0.037	-0.521	0.249	-1.011	-0.032
Taylor								
	Slope	2.67	36	0.011	4.177	1.565	1.003	7.351
	Planimetric Curvature	-2.47	36	0.018	-0.078	0.032	-0.143	-0.014
Kerr								
	Dist. to Veg	-2.90	1289	0.004	-1.488	0.514	-2.496	-0.481
	Veg Height - Top	-5.77	1289	< 0.001	-0.634	0.110	-0.850	-0.419
	Veg Height - Bottom	-6.81	1289	< 0.001	-0.290	0.043	-0.373	-0.206
Mason								
	Slope	3.56	108	0.001	2.250	0.633	0.996	3.504
	Veg Height - Bottom	-2.04	108	0.044	-0.418	0.205	-0.824	-0.012
	Oak Index	2.01	108	0.047	1.054	0.524	0.016	2.093
Balcones								
	Slope	-5.29	607	< 0.001	-2.627	0.497	-3.602	-1.651
	Profile Curvature	-2.57	607	0.010	-0.029	0.011	-0.051	-0.007
	Oak Index	2.37	491	0.018	0.544	0.229	0.093	0.995
Fort Hood								
	Slope	4.89	2035	< 0.001	1.085	0.222	0.650	1.519
	Dist. to Veg	-2.16	1989	0.031	-1.456	0.673	-2.776	-0.137
	Veg Height - Bottom	-2.62	1989	0.009	-0.138	0.053	-0.241	-0.035
	Juniper Index	-2.11	1989	0.035	-0.223	0.106	-0.431	-0.016
Total (all locations)								
	Slope	11.32	6205	< 0.001	1.914	0.169	1.582	2.245
	Canopy Cover	-3.69	6205	< 0.001	-3.194	0.866	-4.891	-1.496
	Profile Curvature	6.72	6205	< 0.001	0.027	0.004	0.019	0.035
	Dist. To Veg	-7.90	6001	< 0.001	-2.162	0.274	-2.698	-1.626
	Veg Height - Top	-10.86	6001	< 0.001	-0.736	0.068	-0.869	-0.603
	Veg Height - Bottom	-9.12	6001	< 0.001	-0.192	0.021	-0.233	-0.150
	Juniper Index	-2.86	6001	0.004	-0.149	0.052	-0.250	-0.047
* detect - nondetect								

Table F-11. 2010 results of significant (*P* < 0.05) t-tests between detection and non-detection points for ecosite proportions within a 100-m radius. For mean difference, positive and negative values indicate the difference between detection and non-detection points (i.e., + = selection, - = non-selection). None of the t-tests for the Taylor study area were significant.

					Mean	Std.	95%CI	
		t	df	p	Difference*	Error	Lower	Upper
Devil's River								
	Low Stony Hill	-4.60	650	<0.001	-0.137	0.030	-0.195	-0.078
	Steep Rocky	4.56	650	<0.001	0.162	0.035	0.092	0.231
Kickapoo								
	Steep Rocky	3.01	1007	0.003	0.090	0.030	0.031	0.148
	Draw	-2.08	1007	0.038	-0.022	0.011	-0.043	-0.001
	Shallow	-3.67	1007	<0.001	-0.075	0.020	-0.115	-0.035
Devil's Sinkhole								
	Steep Rocky	2.06	459	0.040	0.153	0.074	0.007	0.299
Kerr								
	Low Stony Hill	3.18	1289	0.002	0.100	0.031	0.038	0.161
Mason								
	Adobe	3.71	108	<0.001	0.239	0.065	0.111	0.367
Fort Hood								
	Low Stony Hill	3.38	2035	0.001	0.102	0.030	0.043	0.161
	Adobe	2.90	2035	0.004	0.053	0.018	0.017	0.089
	Redland	-1.87	2035	0.061	-0.045	0.024	-0.092	0.002
	Loamy Bottomland	-2.84	2035	0.005	-0.032	0.011	-0.054	-0.010
Balcones								
	Low Stony Hill	8.81	607	<0.001	0.459	0.052	0.357	0.561
	Adobe	-5.38	607	<0.001	-0.274	0.051	-0.374	-0.174
	Clay Loam	-2.94	607	0.003	-0.073	0.025	-0.121	-0.024
	Shallow	-1.95	607	0.051	-0.034	0.017	-0.067	0.000
Total (all sites)								
	Low Stony Hill	2.95	6205	0.003	0.045	0.015	0.015	0.075
	Adobe	-4.85	6205	<0.001	-0.037	0.008	-0.052	-0.022
	Steep Rocky	11.60	6205	<0.001	0.149	0.013	0.123	0.174
	Redland	-3.79	6205	<0.001	-0.031	0.008	-0.047	-0.015
	Clay Loam	-5.42	6205	<0.001	-0.041	0.008	-0.056	-0.026
	Shallow	-4.14	6205	<0.001	-0.038	0.009	-0.056	-0.020
* detect - nondetect								

Appendix G: Descriptive statistics for predictive models

Regional models & model evaluation

The below tables and data are strictly descriptive of our data in relation to the creation of our predictive models, including correlations between metrics, and sample size, mean, standard deviation, upper and lower confidence intervals (95%), max, min and median values for detections and non-detections for both 2009 (randomly-distributed) and 2010 (area-focused) data for each study area.

Devil's River (DR)

Table G1. Correlations

	Low.Stony.Hill	None	Clay.Loam	Loamy.Bottomland	Steep.Rocky	Shallow.Ridge	SlopeMean	CanCovMean	ProfMean	PlanMean
Low.Stony.Hill	1.000	-0.127	-0.034	-0.215	-0.592	-0.174	-0.347	-0.021	-0.479	-0.343
None		1.000	-0.012	0.164	-0.225	-0.041	-0.131	0.099	0.158	0.048
Clay.Loam			1.000	-0.008	0.004	-0.016	-0.017	0.017	0.042	0.016
Loamy.Bottomland				1.000	-0.439	0.021	-0.399	0.314	0.122	0.039
Steep.Rocky					1.000	-0.376	0.751	-0.250	0.277	0.249
Shallow.Ridge						1.000	-0.379	0.121	0.025	0.008
SlopeMean							1.000	-0.334	0.123	0.111
CanCovMean								1.000	0.066	0.106
ProfMean									1.000	0.135
PlanMean										1.000

Model Projection

Table G2. Descriptive statistics for probability of vireo occurrence at DR

N	Mean	SD	Lower	Upper	Min	Max	Median
39,984	0.258	0.103	0.257	0.259	0.056	0.667	0.24

Model Evaluation

Table G3. Descriptive statistics for probability of vireo occurrence in DR at points surveyed in 2010.

N	Mean	SD	Lower	Upper	Min	Max	Median
652	0.272	0.117	0.263	0.281	0.056	0.631	0.246

Table G4. Descriptive statistics for probability of vireo occurrence in DR at points surveyed in 2010 where we detected vireos compared to points at which we did not detect vireos

Detection	N	Mean	SD	Lower	Upper	Min	Max	Median
Yes	176	0.309	0.122	0.292	0.328	0.056	0.631	0.299
No	476	0.258	0.111	0.248	0.268	0.077	0.565	0.258

Table G5. Descriptive statistics for probability of vireo occurrence in DR at points surveyed in 2009.

N	Mean	SD	Lower	Upper	Min	Max	Median
86	0.307	0.107	0.284	0.330	0.099	0.589	0.307

Table G6. Descriptive statistics for probability of vireo occurrence in DR at points surveyed in 2009 where we detected vireos compared to points at which we did not detect vireos

Detection	N	Mean	SD	Lower	Upper	Min	Max	Median
Yes	41	0.338	0.098	0.307	0.368	0.152	0.589	0.338
No	45	0.279	0.108	0.246	0.311	0.098	0.496	0.258

Kickapoo (KP)

Model Projection

N = 49,163 all XY coords
<u>Predicted Occupancy (PredOcc)</u>
Min. 0.0033
1st Qu. 0.152
Median 0.232
Mean 0.224
3rd Qu. 0.288
Max. 0.921
SD 0.1015
CI: 0.223, 0.225

Model Evaluation

2010

N = 1009
<u>PredOcc</u>
Min. 0.0172
Median 0.256
Mean 0.246
Max. 0.711
SD 0.112
CI: 0.239, 0.253

Yes, Detected vireo
N = 249
<u>PredOcc</u>
Min. 0.042
Median 0.294
Mean 0.298
Max. 0.711
SD 0.104
>CI: 0.285, 0.311

No vireo detected
n = 760
PredOcc
Min. 0.0172
Median 0.244
Mean 0.229
Max. 0.564
SD 0.1097
95% CI: 0.222, 0.237

2009

N = 63
PredOcc
Min. 0.0628
Median 0.239
Mean 0.23
Max. 0.495
SD 0.0817
CI: 0.209 0.250

Yes, Detected vireo
PredOcc
N = 25
Min. 0.0628
Median 0.23
Mean 0.229
Max. 0.495
SD 0.0874
CI: 0.193, 0.265

No vireo
PredOcc
N = 38
Min. 0.0737
Median 0.245
Mean 0.230
Max. 0.484
SD 0.079
CI: 0.204, 0.256

Devil's Sinkhole (DS)

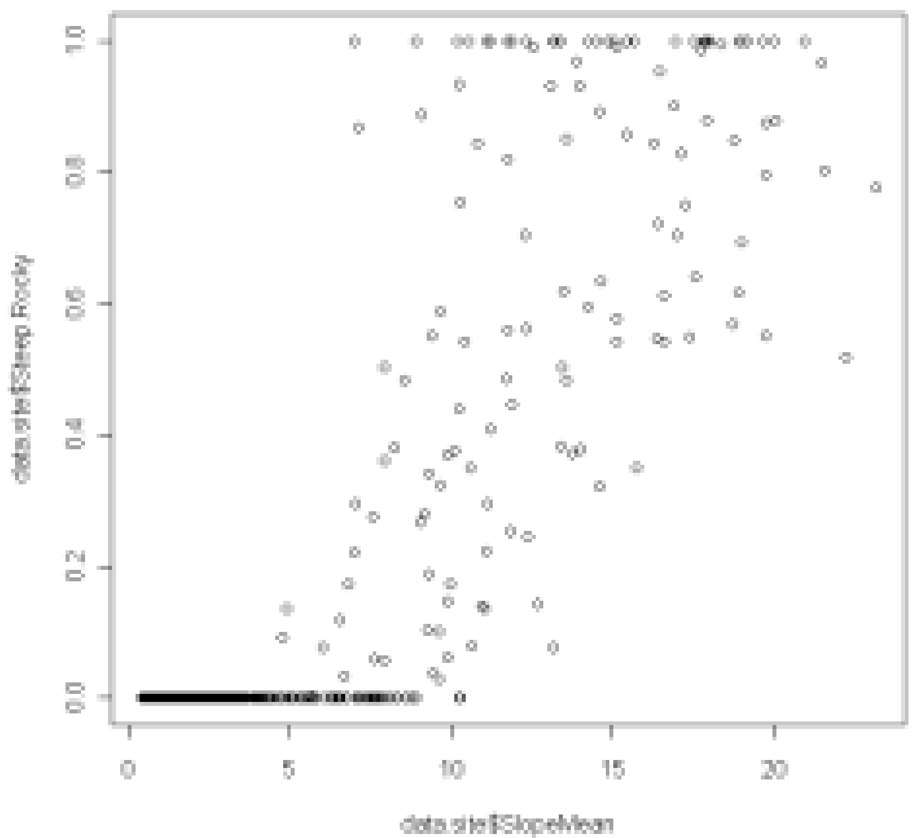


Figure G-1. Steep Rocky was correlated with mean slope (*r* = 0.849).

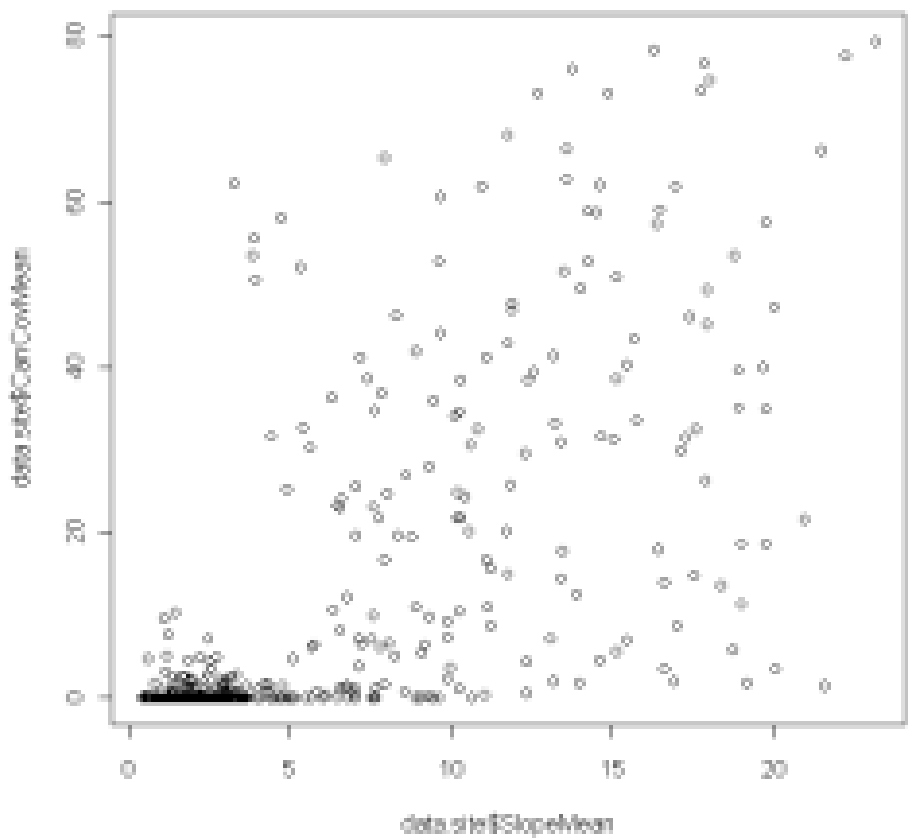


Figure G-2. Mean slope was correlated with mean canopy cover (r = 0.688)

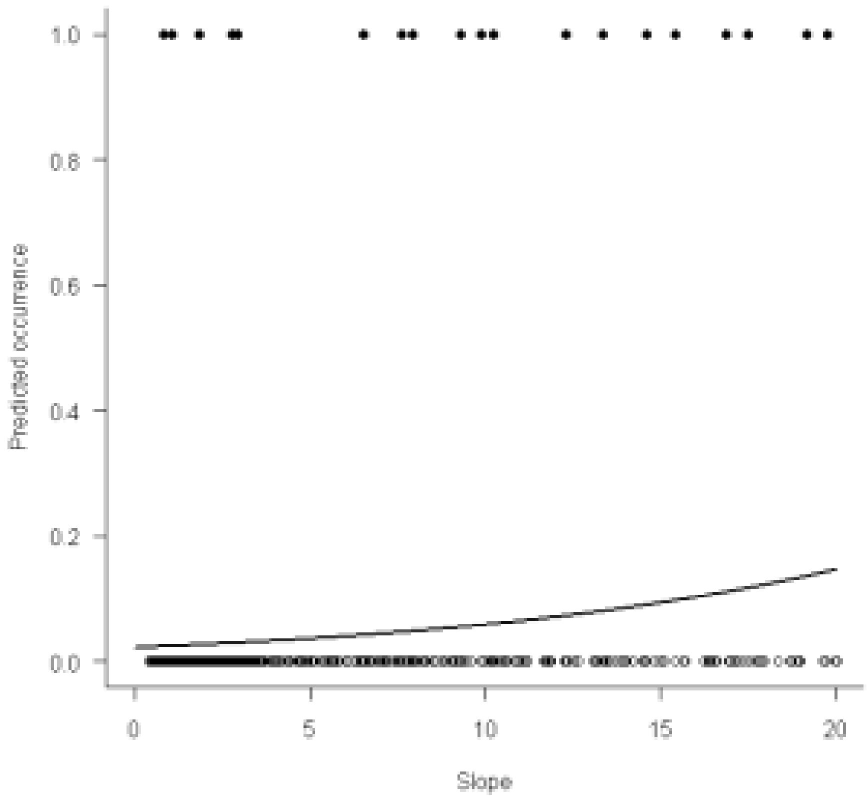


Figure G-3. Predicted occurrence increased with increasing mean slope (β = 0.101, 95% CI: 0.034, 0.167); however the effect was small, increasing from 0.02 to 0.09 with an increase in slope from 1 to 15ȯ.

Model Projection

N=46,410
Min. 0.0088 Max. 0.985
Median 0.031
Mean 0.044
SD 0.048
CI: 0.043, 0.044

Model Evaluation

Table G7. 2010

N	Mean	SD	lower	upper	min	max	median
461	0.045	0.051	0.041	0.05	0.01	0.94	0.032

Table G8. 2010, detected and non-detected

Detection	**N**	**Mean**	**SD**	**lower**	**upper**	**min**	**max**	**median**
Yes	21	0.1	0.196	0.011	0.189	0.015	0.941	0.056
No	440	0.043	0.028	0.040	0.045	0.010	0.223	0.031

2009

N = 68
Min. 0.02175000
Median 0.03209000
Mean 0.03659000
Max. 0.07481000
SD 0.01221874
CI = 0.03363649 0.03955162

Yes, detected
N = 38
Min. 0.02572000
Median 0.03730000
Mean 0.04141000
Max. 0.07481000
SD 0.01383319
> CI = 0.03686017 0.04595388

No, none detected
N = 30
Min. 0.021750000
Median 0.030230000
Mean 0.030500000
Max. 0.048400000
SD 0.005655243
> CI= 0.02838593 0.03260934

Kerr (KE)

Low Stony Hill was correlated with Steep Rocky (r = -0.590) and Steep Rocky was correlated with mean slope (r = 0.649; Table G9).

There was no relationship with Redland, Shallow, Steep Rocky, slope, canopy cover, profile curvature, or planimetric curvature.

Table G9. Correlations

	Redland	Shallow	Steep.Rocky	SlopeMean	CanCovMean	ProfMean	PlanMean
Low.Stony.Hill	-0.499	-0.327	-0.590	-0.399	-0.098	-0.157	0.011
Redland	1.000	-0.126	-0.136	-0.041	0.051	0.022	-0.020
Shallow		1.000	-0.166	-0.161	-0.134	0.026	-0.001
Steep.Rocky			1.000	0.649	0.183	0.129	0.000
SlopeMean				1.000	0.311	0.193	0.001
CanCovMean					1.000	0.024	0.045
ProfMean						1.000	-0.047

Model Projection

N = 80,652
Min. 0.025 Max. 0.428
Median 0.16
Mean 0.158, SD 0.051
CI: 0.157, 0.158

Model Evaluation

2010

N=1,291
Min. 0.058 Max. 0.376
Median 0.182
Mean 0.172, SD 0.054
95% CI = 0.169, 0.175

Yes, detected
N = 222
Min. 0.0703 Max. 0.376
Median 0.188
Mean 0.188, SD 0.053
CI 0.181, 0.195

Not detected
N = 1,069
Min. 0.058 Max. 0.37
Median 0.179
Mean 0.168, SD 0.0542
[1] 0.165, 0.172

Balcones (BC)

Table G10. Correlations

	Adobe	Clay.Loam	SlopeMean	CanCovMean	ProfMean	PlanMean
Low.Stony.Hill	-0.655	-0.287	-0.541	-0.132	-0.337	-0.105
Adobe	1.000	-0.122	0.610	0.208	0.134	0.035
Clay.Loam		1.000	-0.055	0.015	0.217	0.061
SlopeMean			1.000	0.439	0.108	-0.075
CanCovMean				1.000	0.068	-0.132
ProfMean					1.000	0.165

Model Projection

N= 43,681
Min. 0.00013 Max. 0.547
Median 0.017
Mean 0.058, SD 0.0844
95% CI = 0.057, 0.059

Model Evaluation

2010

N = 610
Min. 0.0013510
Median 0.0639000
Mean 0.1215000
Max. 0.3376000
SD 0.1146596
> CI 0.1123415 0.1305757

Yes, detected
N = 72
Min. 0.0138
Median 0.267
Mean 0.228
Max. 0.338
SD 0.083
> CI
[1] 0.2083378 0.2473273

Non detection
N=538
Min. 0.0013510
Median 0.0431500
Mean 0.1072000
Max. 0.3236000
SD 0.1108123
> CI
[1] 0.09783788 0.11660747

Fort Hood(FH)

Table G11. Correlations.

	Clay.Loam	Low.Stony.Hill	Redland	Shallow	SlopeMean	CanCovMean	ProfMean	PlanMean
Adobe	-0.187	-0.121	-0.194	-0.129	0.679	0.208	0.237	0.074
Clay.Loam	1.000	-0.386	-0.245	-0.165	-0.090	-0.304	0.226	0.071
Low.Stony.Hill		1.000	-0.270	-0.321	-0.036	0.380	-0.370	-0.125
Redland			1.000	-0.167	-0.239	0.071	-0.030	-0.033
Shallow				1.000	-0.049	-0.189	-0.019	0.042
SlopeMean					1.000	0.342	0.166	0.059
CanCovMean						1.000	-0.058	-0.038
ProfMean							1.000	0.120

Model Projection

N=225,605
Min. 0.004 Max. 0.782
Median 0.066
Mean 0.074, SD 0.027
> CI 0.0739, 0.0741

Model Evaluation

2010
N = 2,037
Min. 0.021
Median 0.081
Mean 0.094
Max. 0.384
SD 0.045
> CI 0.092, 0.096

Yes
N = 191
Min. 0.0415 Max. 0.307
Median 0.101
Mean 0.114
SD 0.0592
> CI
[1] 0.1055, 0.1224

Non detection
N = 1,846
Min. 0.021
Median 0.0796
Mean 0.0917
Max. 0.384
SD 0.043
> CI
[1] 0.0897, 0.094

2009
N = 82
Min. 0.04081000
Median 0.10310000
Mean 0.10320000
Max. 0.24510000
SD 0.04296987
> CI
[1] 0.09379433 0.11267736

Yes
N = 14
Min. 0.06085000
Median 0.11860000
Mean 0.127
Max. 0.24510000
SD 0.05066903
> CI
[1] 0.09759743 0.15610828

Non detect
N = 68
Min. 0.04081000
Median 0.10120000
Mean 0.098
Max. 0.21660000
SD 0.03991919
> CI
[1] 0.08871101 0.10803602

Range-wide predictive model

2010

N = 6,236
Min. 0.035
Median 0.145
Mean 0.151
Max. 0.69
SD 0.0817
> CI=t.test(pred2010$PredOcc)$conf.int
> CI
[1] 0.1486745 0.1527290

Detection

N = 958
Min. 0.04 Max. 0.569
Median 0.173
Mean 0.191, SD 0.0970
> CI = 0.185, 0.197

Non-detection

N = 5,278
Min. 0.0347 Max. 0.694
Median 0.138
Mean 0.143, SD = 0.076
> CI 0.141, 0.145

2009

N=2,570
Min. 0.034 Max. 0.93
Median 0.15
Mean 0.18 SD 0.118
95% CI = 0.176, 0.185

Detections

N = 252
Min. 0.05 Max. 0.58
Median 0.19
Mean 0.22, SD = 0.109
95 % CI = 0.209, 0.236

Not detected

N = 2,318
Min. 0.034 Max. 0.926
Median 0.145
Mean 0.176
SD 0.118
95% CI= 0.171, 0.181

Appendix H: AIC supplemental information for AIC model selection

Vegetation models

Devil's River

For single effects models predicted probability of occurrence (PPO) increased from 0.25 when the oak index = 0 to 0.67 when the oak index = 2 (β = 0.92, 95% CI = 0.485, 1.372; Fig. H-1). Predicted probability of occurrence increased from 0.19 when vegetation height at top = 1 m to 0.63 when vegetation height at top = 5 m (β = 0.486, 95% CI = 0.245, 0.731; Fig H-2).

Table H1. Model-averaged statistics for predictor variables from all combinations of additive effects models explaining vireo occurrence at Devil's River region, Texas in 2010. Variables in bold indicate a significant direction of effect.

	Coefficient	Variance	SE	Unconditional.SE	Lower.CI	Upper.CI
(Intercept)	-1.774	0.007	0.286	0.286	-2.335	-1.213
dist	-0.013	0.000	0.023	0.023	-0.057	0.031
htBottom	0.026	0.004	0.142	0.142	-0.253	0.305
htTop	**0.389**	**0.000**	**0.137**	**0.137**	**0.120**	**0.657**
juniper	-0.010	0.000	0.037	0.037	-0.082	0.062
oak	**0.738**	**0.003**	**0.233**	**0.233**	**0.281**	**1.195**

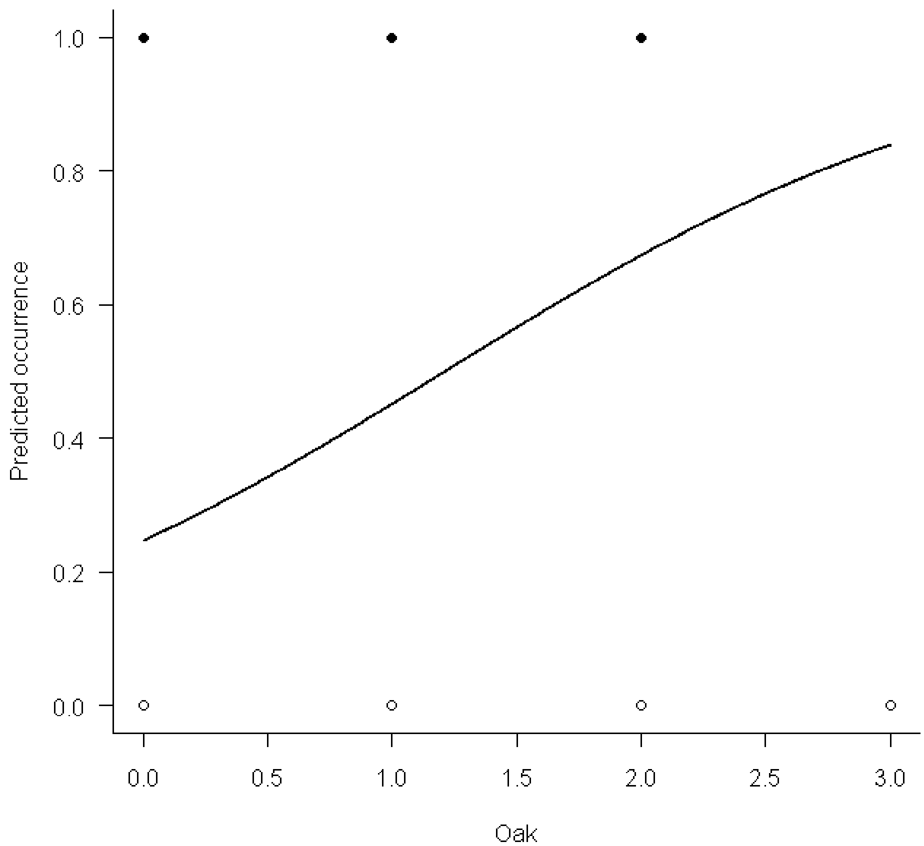


Figure H-1. Predicted probability of occurrence with increasing oak index at Devil's River in 2010.

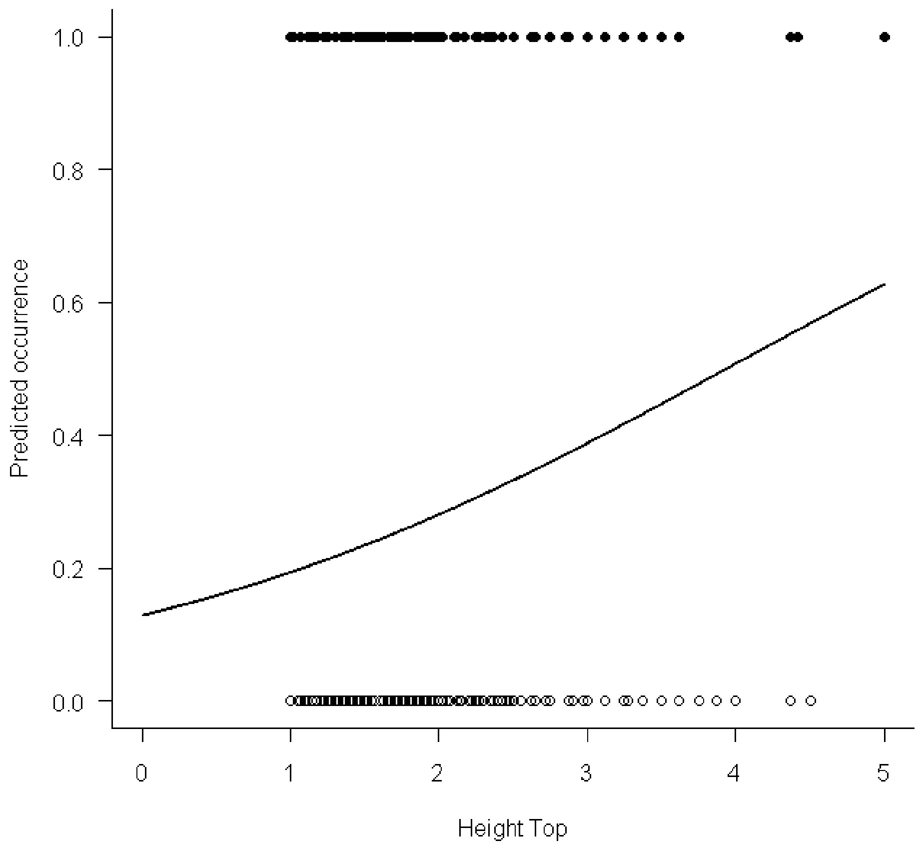


Figure H-2. Predicted probability of occurrence with increasing vegetation height at top at Devil's River in 2010.

Kickapoo

Predicted probability of occurrence decreased from 0.3 when the juniper index = 0 to 0.18 when the juniper index = 4 (β = -0.159, 95% CI = -0.272, -0.048; Figure H-3). Predicted probability of occurrence declined from 0.27 when mean vegetation height at bottom = 0 m to 0.04 when mean vegetation height at bottom = 3 m (β = -0.758, 95% CI = -1.31, -0.26). Predicted probability of occurrence declined from 0.43 with mean vegetation height at top = 1 m to 0.01 when mean vegetation height at top = 10 m (β = -0.464, 95% CI = -0.643, -0.293; Fig. H-4).

Model-averaging results indicated a significant negative effect of vegetation height at top (Table H2). The direction of the effect of number of junipers was not significant based on model-averaging results (i.e., the confidence intervals included 0) but the upper confidence interval was only 0.053 greater than 0, suggesting that the direction of the effect was predominately negative.

Table H2. Model-averaged statistics for predictor variables included in model selection for models explaining vireo occurrence at Kickapoo region, Texas in 2010. Variables in bold indicate a significant direction of effect.

	Coefficient	Variance	SE	Unconditional.SE	Lower.CI	Upper.CI
(Intercept)	0.253	0.005	0.266	0.266	-0.269	0.776
dist	-0.005	0.000	0.011	0.011	-0.026	0.017
htBottom	-0.180	0.006	0.266	0.266	-0.701	0.342
htTop	**-0.417**	**0.000**	**0.102**	**0.102**	**-0.617**	**-0.216**
juniper	-0.093	0.000	0.075	0.075	-0.240	0.053
oak	0.013	0.000	0.045	0.045	-0.076	0.101

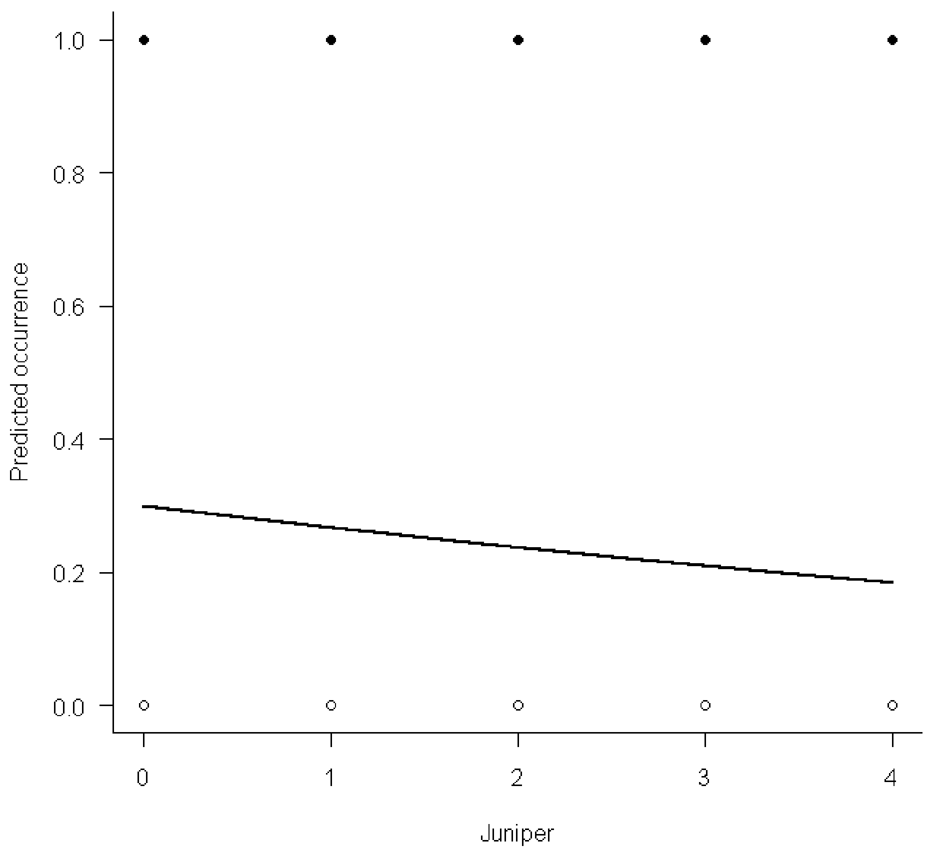


Figure H-3. Predicted probability of occurrence with increasing juniper index at Kickapoo in 2010.

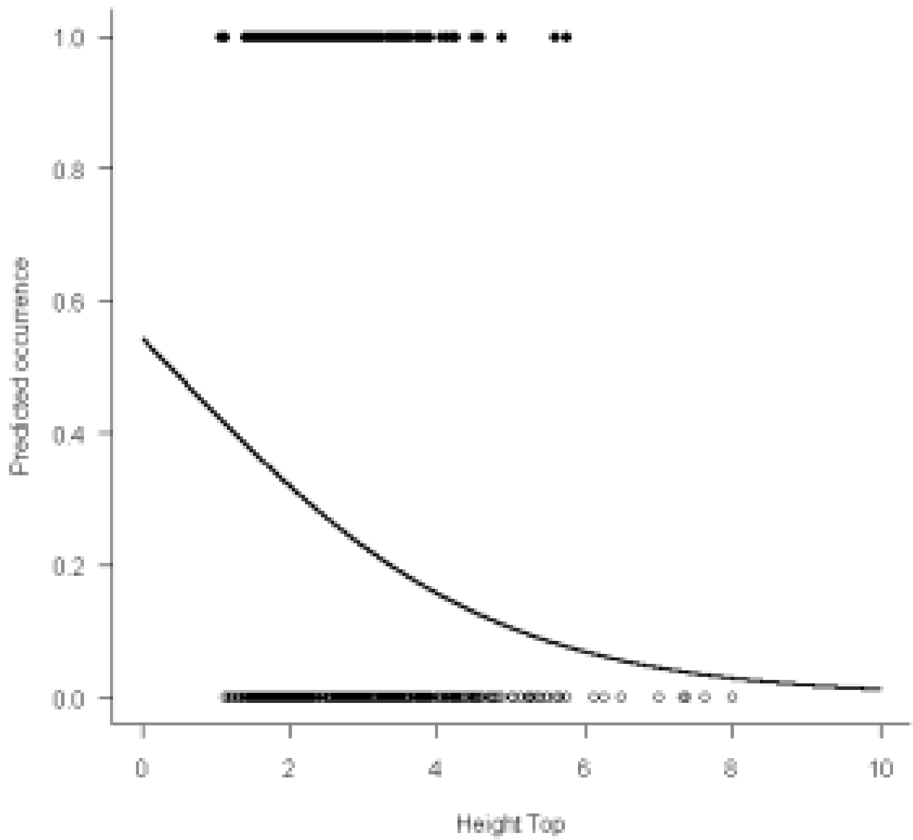


Figure H-4. Predicted probability of occurrence with increasing vegetation height at top at Kickapoo in 2010.

Devil's Sinkhole

Table H3. Model-averaged statistics for predictor variables included in model selection for models explaining vireo occurrence at Devil's Sinkhole region, Texas in 2010. Variables in bold indicate a significant direction of effect.

	Coefficient	Variance	SE	Unconditional.SE	Lower.CI	Upper.CI
(Intercept)	-2.413	0.057	0.472	0.473	-3.339	-1.487
dist	-0.007	0.000	0.017	0.017	-0.039	0.026
htBottom	0.176	0.058	0.375	0.375	-0.559	0.911
htTop	-0.008	0.000	0.081	0.081	-0.167	0.151
juniper	-0.113	0.001	0.167	0.168	-0.442	0.215
oak	**-0.627**	**0.019**	**0.362**	**0.363**	**-1.339**	**0.084**

Kerr

Predicted probability of occurrence decreased from 0.21 with mean distance to vegetation = 1 m to 0.065 with mean distance to vegetation = 40 m (β = -0.035, 95% CI = -0.059, -0.012). Predicted probability of occurrence declined from 0.25 when mean vegetation height at bottom = 0 m to 0.01 when minimum vegetaion = 3 m (β = -1.059, 95% CI = -1.39, -0.75). Predicted probability of occurrence declined from 0.31 when mean vegetation height at top = 1 m to 0.03 when mean vegetation height at top = 10 m (β = -0.303, 95% CI = -0.41, -0.20).

Table H4. Model-averaged statistics for predictor variables included in model selection for models explaining vireo occurrence at Kerr region, Texas in 2010. Variables in bold indicate a significant direction of effect.

	Coefficient	Variance	SE	Unconditional.SE	Lower.CI	Upper.CI
(Intercept)	-1.011	0.006	0.278	0.278	-1.556	-0.466
dist	-0.014	0.000	0.016	0.016	-0.045	0.017
htBottom	**-1.266**	**0.004**	**0.244**	**0.244**	**-1.745**	**-0.788**
htTop	**-0.183**	**0.000**	**0.093**	**0.093**	**-0.365**	**-0.001**
juniper	0.059	0.000	0.080	0.080	-0.099	0.217
oak	**0.433**	**0.000**	**0.091**	**0.091**	**0.254**	**0.612**

Balcones

Predicted probability of occurrence was 0.03 when oak index=0 and increased to 0.13 when oak index = 4 (β = 0.361, 95% CI = 0.034, 0.66). Distance to vegetation, juniper index, mean vegetation height at bottom, and mean vegetation height at top did not predict vireo occurrence. Values given in text

Table H5. Model-averaged statistics for additive predictor variables included in model selection for models explaining vireo occurrence at Balcones region, Texas in 2010. Variables in bold indicate a significant direction of effect.

	Coefficient	Variance	SE	Unconditional.SE	Lower.CI	Upper.CI
(Intercept)	-2.600	0.082	0.528	0.529	-3.637	-1.563
dist	0.003	0.000	0.009	0.009	-0.015	0.021
htBottom	-0.208	0.044	0.389	0.390	-0.972	0.556
htTop	-0.221	0.000	0.137	0.137	-0.489	0.048
juniper	0.007	0.000	0.044	0.044	-0.080	0.093
oak	**0.513**	**0.001**	**0.183**	**0.183**	**0.153**	**0.872**

Fort Hood

Table H6. Model-averaged statistics for predictor variables included in model selection for models explaining vireo occurrence at Fort Hood region, Texas in 2010. Variables in bold indicate a significant direction of effect.

	Coefficient	Variance	SE	Unconditional.SE	Lower.CI	Upper.CI
(Intercept)	-1.376	0.002	0.205	0.205	-1.779	-0.974
dist	**-0.028**	**0.000**	**0.011**	**0.011**	**-0.049**	**-0.006**
htBottom	-0.253	0.002	0.209	0.209	-0.662	0.157
htTop	-0.073	0.000	0.064	0.064	-0.198	0.051
juniper	**-0.166**	**0.000**	**0.066**	**0.066**	**-0.296**	**-0.036**
oak	0.010	0.000	0.032	0.032	-0.052	0.072

Single Effects

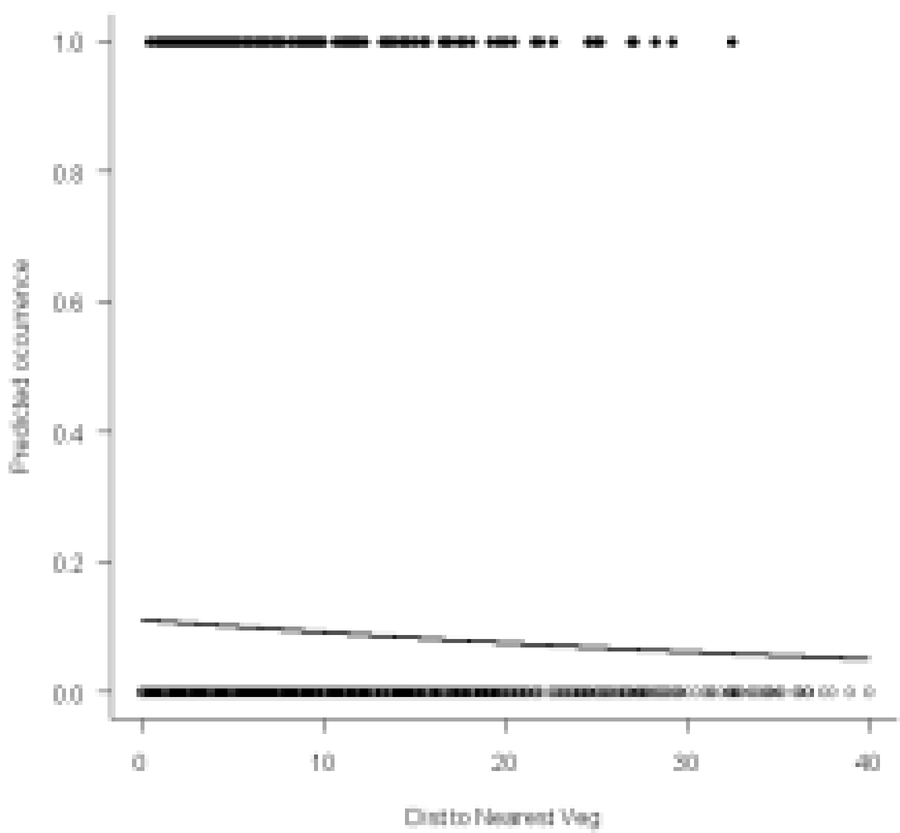


Figure H-5. Predicted probability of occurrence decreased with increasing mean distance to vegetation (β = -0.021, 95% CI = -0.042, -0.003).

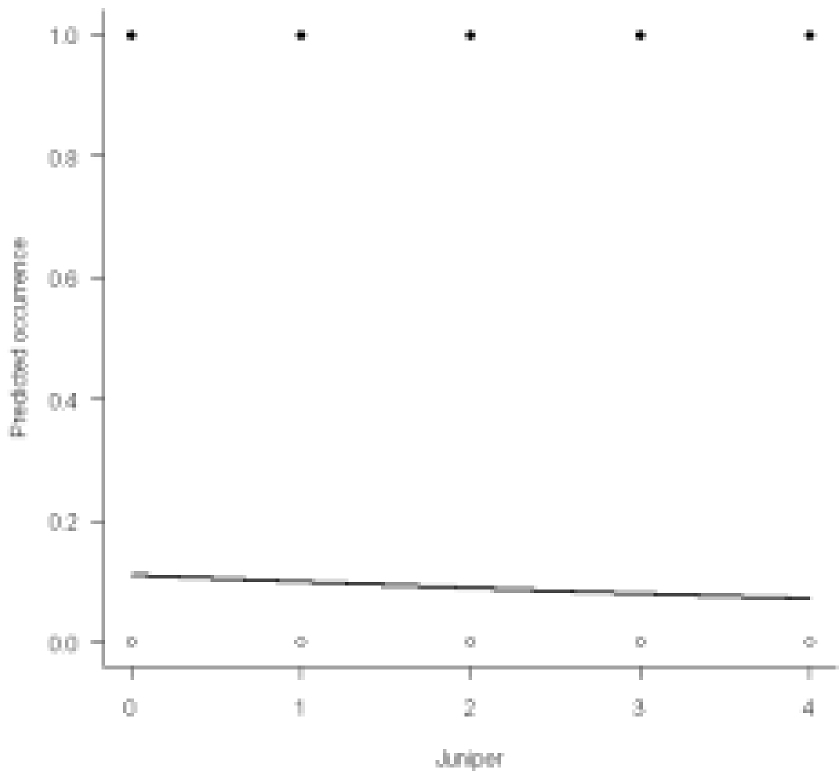


Figure H-6. Predicted probability of occurrence decreased with increasing number of juniper (β = -0.121, 95% CI = -0.236, -0.001) but this effect was small; occurrence probability decreased from 0.11 with 0 juniper to 0.07 with 4 juniper.

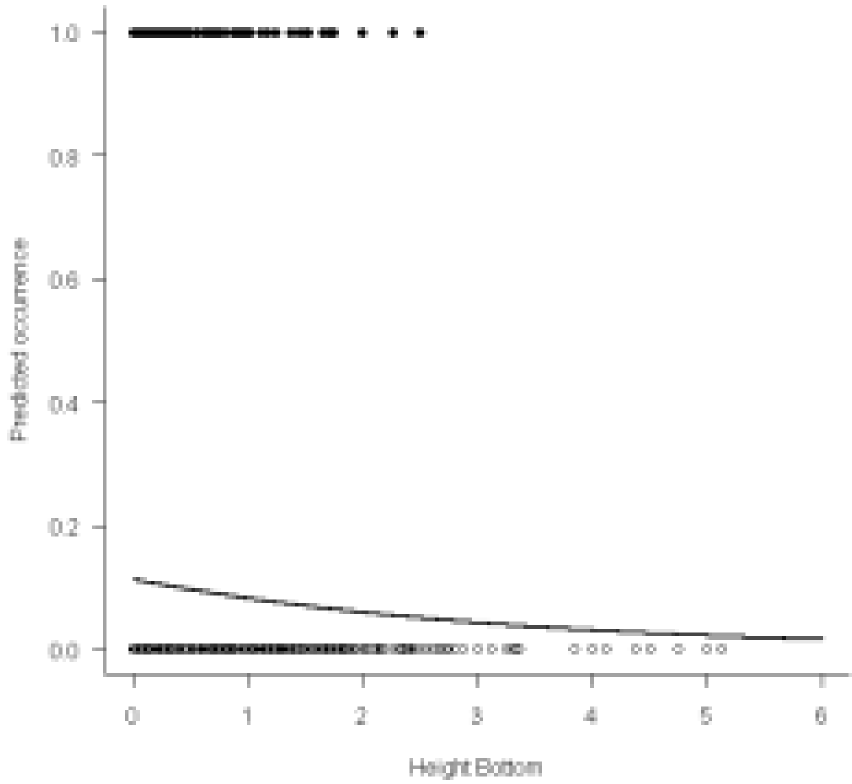


Figure H-7. Predicted probability of occurrence decreased with increasing height Bottom (β = -0.352, 95% CI = -0.628, -0.099). Predicted probability of occurrence was 0.11 when minimum vegetation height was 0 and it decreased to 0.04 when minimum vegetation height increased to 3 m.

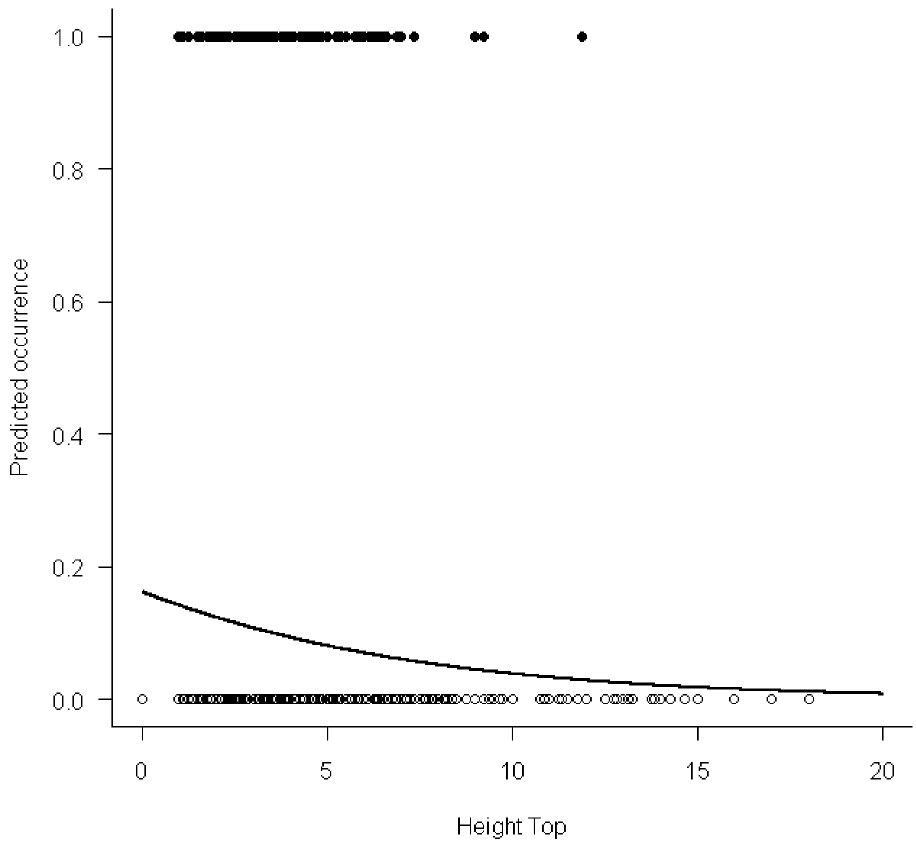


Figure H-8. Predicted probability of occurrence decreased with increasing maximum vegetation height (β = -0.16, 95% CI = -0.243, -0.077). Predicted probability of occurrence was 0.14 when maximum vegetation height was 1 m and 0.02 when vegetation reached 15 m.

Regional models

Devil's River

Table H7. Model-averaged statistics for predictor variables from all combinations of additive models explaining probability of occurrence of black-capped vireos in Devil's River region, Texas in 2010. Variables in bold indicate a significant direction of effect.

	Coefficient	Variance	SE	Unconditional.SE	Lower.CI	Upper.CI
(Intercept)	-1.268	0.022	0.373	0.373	-1.999	-0.537
Loamy.Bottomland	-0.466	0.130	0.584	0.584	-1.611	0.679
Low.Stony.Hill	-0.296	0.044	0.430	0.430	-1.139	0.547
PlanMean	0.092	0.031	0.270	0.270	-0.437	0.622
ProfMean	**2.276**	**0.055**	**0.483**	**0.484**	**1.329**	**3.224**
Shallow	0.085	0.015	0.236	0.236	-0.378	0.548
SlopeMean	0.006	0.000	0.012	0.012	-0.017	0.029
Steep.Rocky	0.310	0.028	0.395	0.395	-0.464	1.084

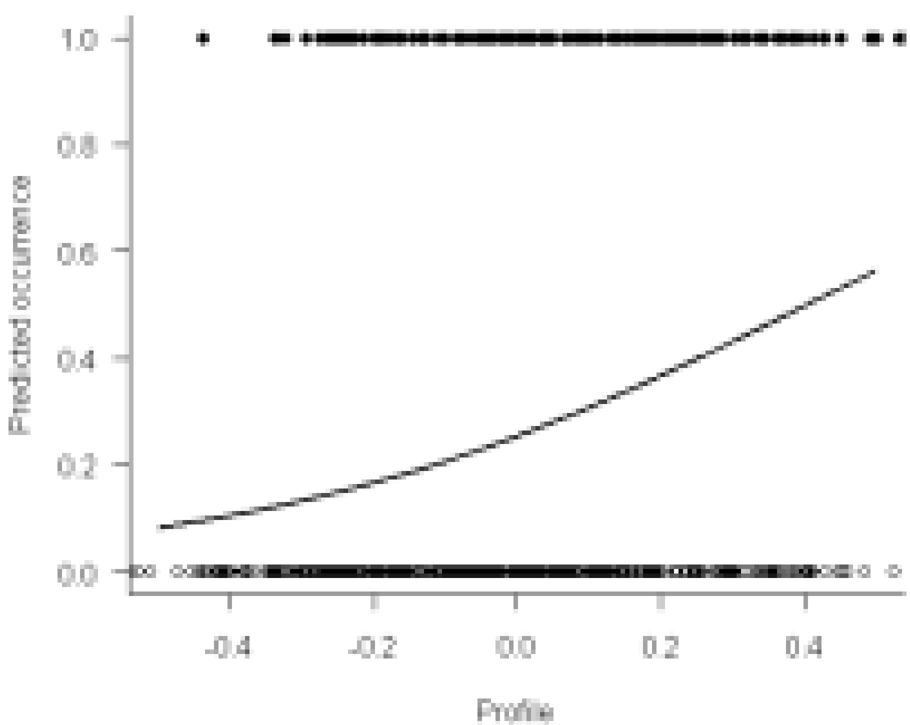


Figure H-9. Predicted probability of vireo occurrence with increasing profile curvature for Devil's River in 2010. For the single effect of profile curvature, predicted occurrence probability increased from 0.10 when profile curvature = -0.4 to 0.50 when profile curvature = 0.4.

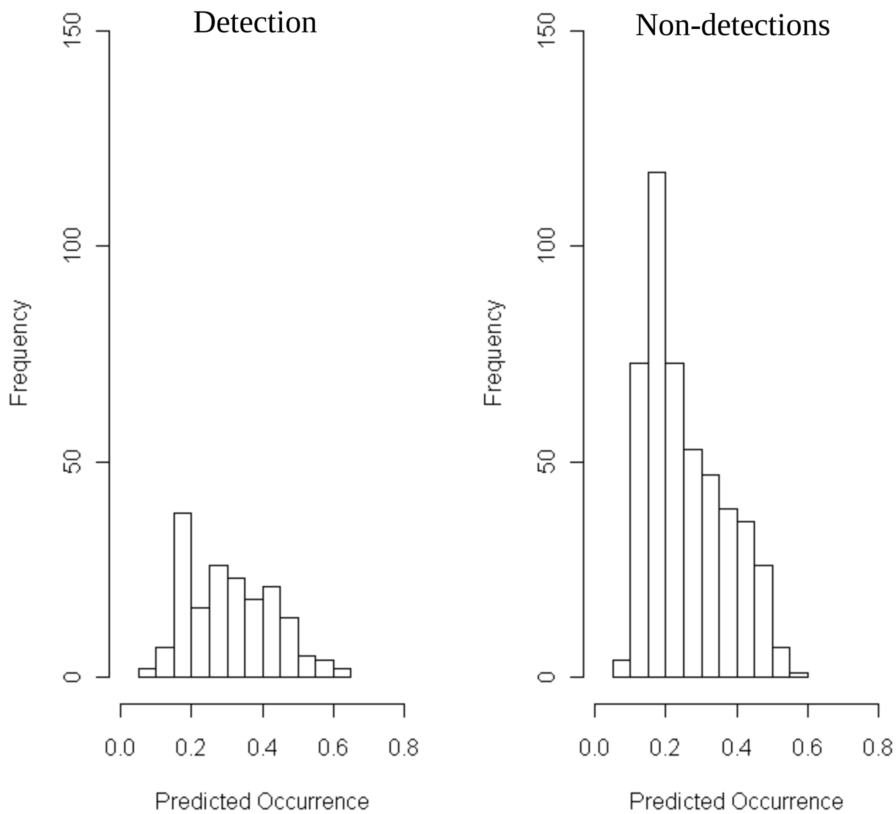


Figure H-10 . Histogram of probability of occurrence at points surveyed in 2010 within the Devil's River region where we detected vireos and at points at which we did not detect vireos.

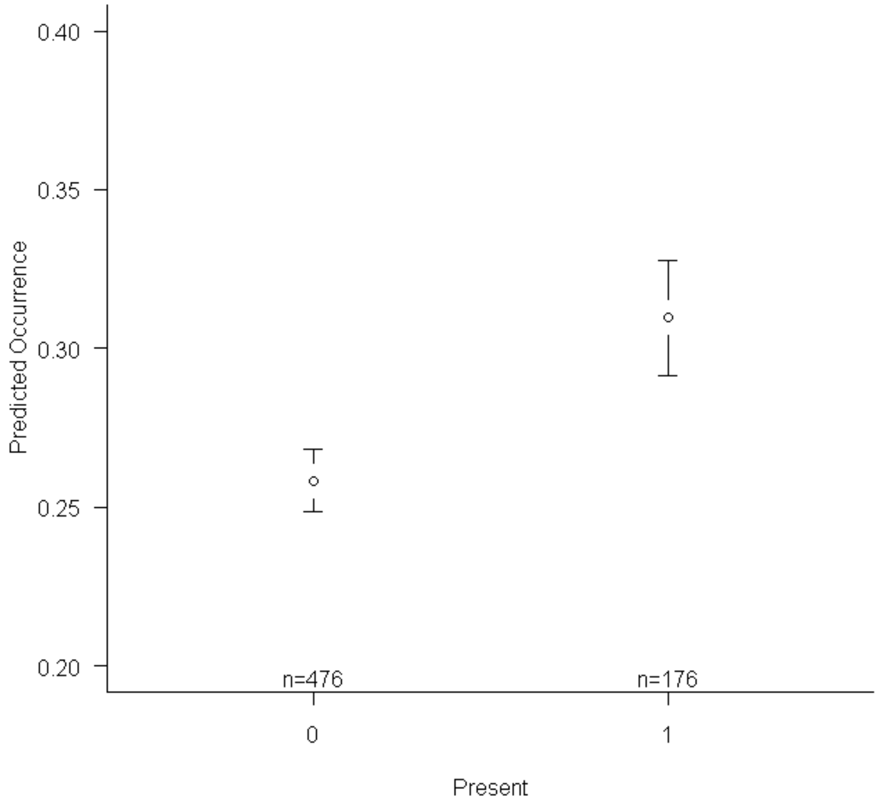


Figure H-11. Mean (95% CI) probability of occurrence at points surveyed in 2010 in the Devil's River region where we detected vireos (1) and points at which we did not detect vireos (0).

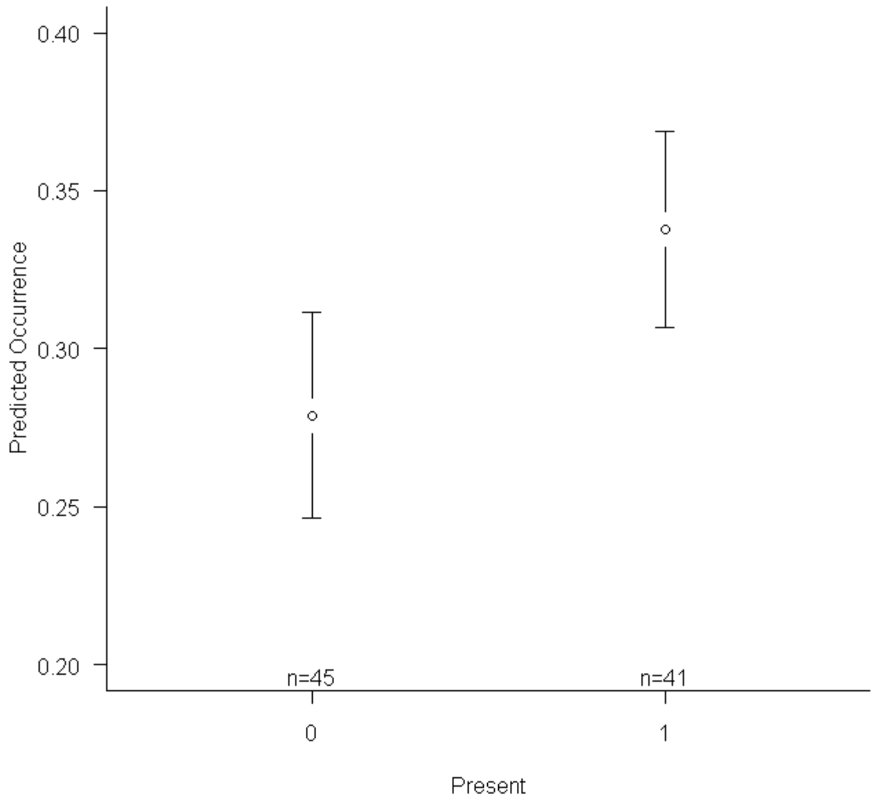


Figure H-12. Mean DR 2009. Mean (95% CI) probability of occurrence at points surveyed in 2009 in the Devil's River region where we detected vireos (1) and points at which we did not detect vireos (0).

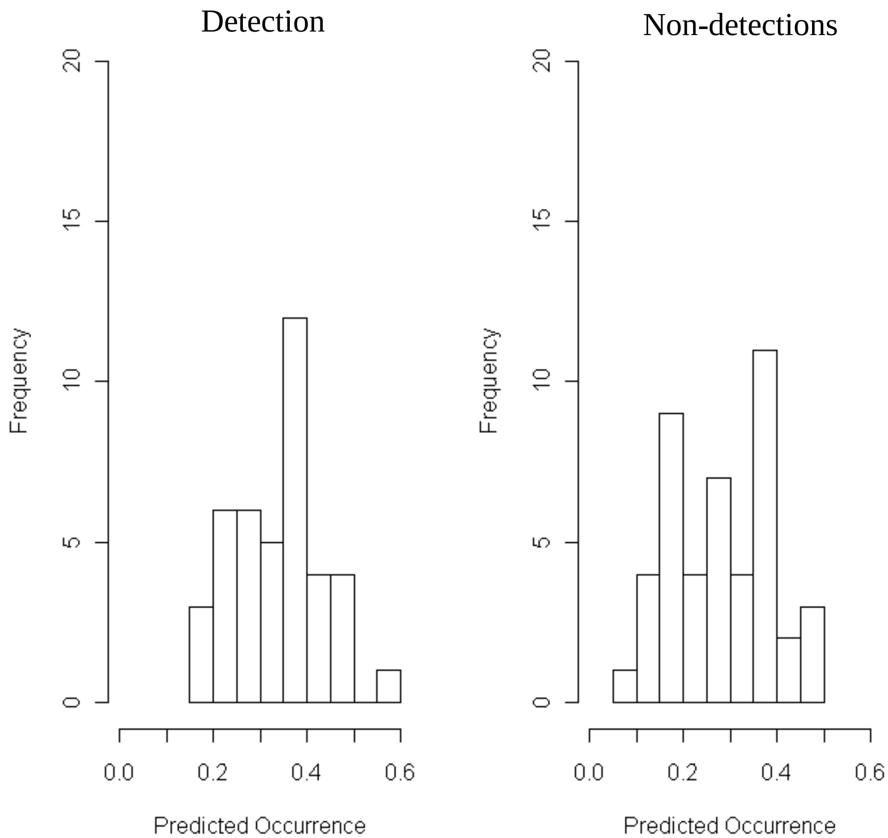


Figure H-13. Bar DR 2009. Histogram of probability of occurrence at points surveyed in 2009 within the Devil's River region where we detected vireos and at points at which we did not detect vireos.

Kickapoo

The predictor variables of Canopy, Profile, and Slope were significant based on the model-average results from assessment of all possible combinations of additive models because the confidence intervals on the beta coefficient did not include 0 (Table H8).

Table H8. Model-averaged statistics for predictor variables from all combinations of additive models explaining probability of occurrence of black-capped vireos in the Kickapoo region, Texas in 2010. Variables in bold indicate a significant direction of effect.

	Coefficient	Variance	SE	Unconditional.SE	Lower.CI	Upper.CI
(Intercept)	-1.517	0.008	0.294	0.294	-2.093	-0.941
Canopy	**-0.039**	**0.000**	**0.007**	**0.007**	**-0.052**	**-0.026**
Low.Stony.Hill	0.219	0.007	0.271	0.271	-0.311	0.750
Plan	-0.205	0.133	0.463	0.464	-1.113	0.704
Profile	**1.637**	**0.102**	**0.565**	**0.566**	**0.528**	**2.747**
Shallow	-0.502	0.050	0.471	0.472	-1.427	0.422
Slope	**0.099**	**0.000**	**0.022**	**0.022**	**0.055**	**0.143**
Steep.Rocky	-0.005	0.004	0.147	0.147	-0.293	0.284

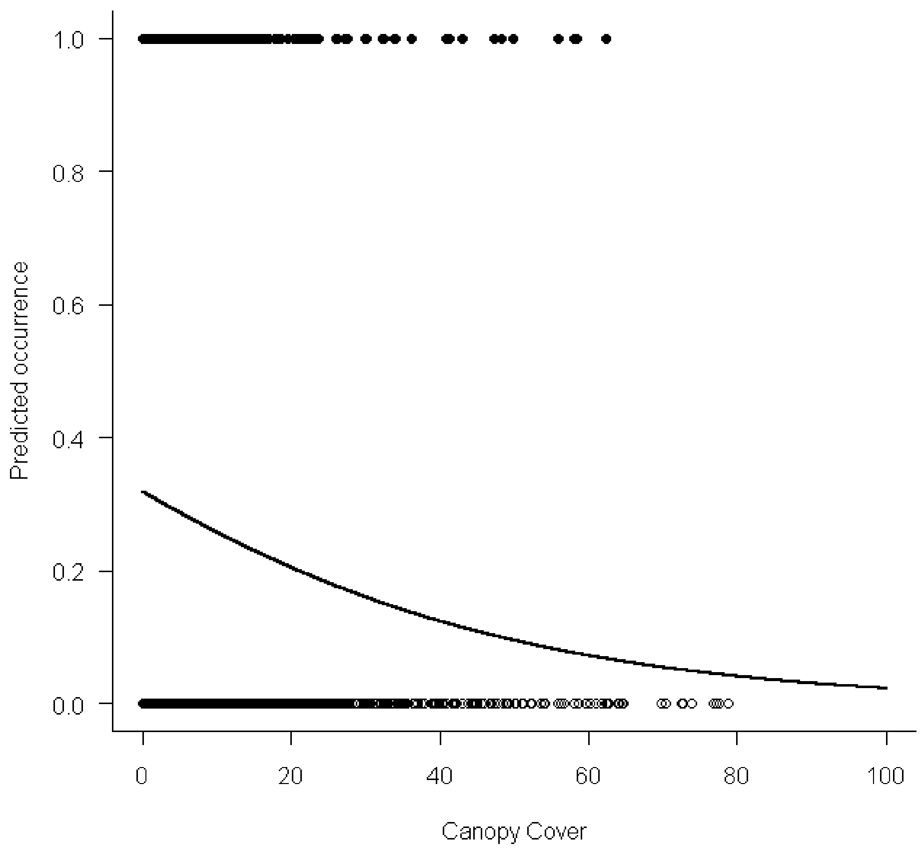


Figure H-14. Predicted probability of vireo occurrence compared to canopy cover in Kickapoo region in 2010. The single effect of canopy cover indicated that PPO decreased from 0.31 when mean canopy cover = 1 to 0.09 when mean canopy cover = 50.

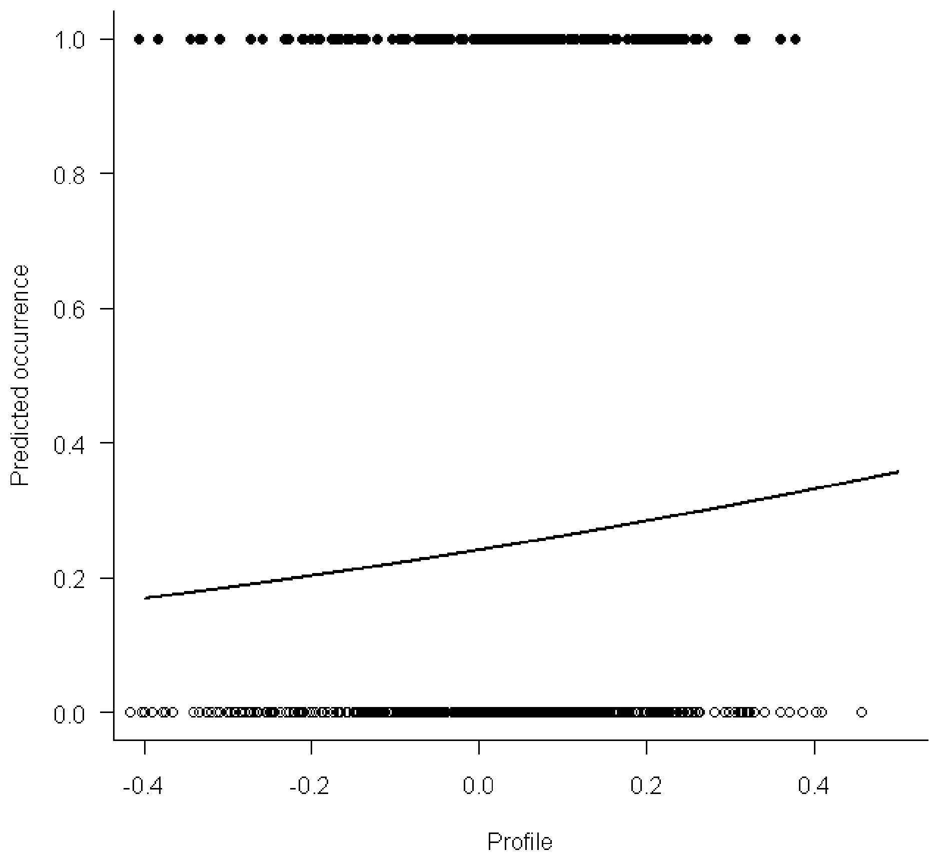


Figure H-15. Predicted probability of vireo occurrence compared to profile curvature in Kickapoo region in 2010. The single effect of profile indicated that PPO increased from0.17 when profile = -0.4 to 0.33 when profile curvature = 0.4.

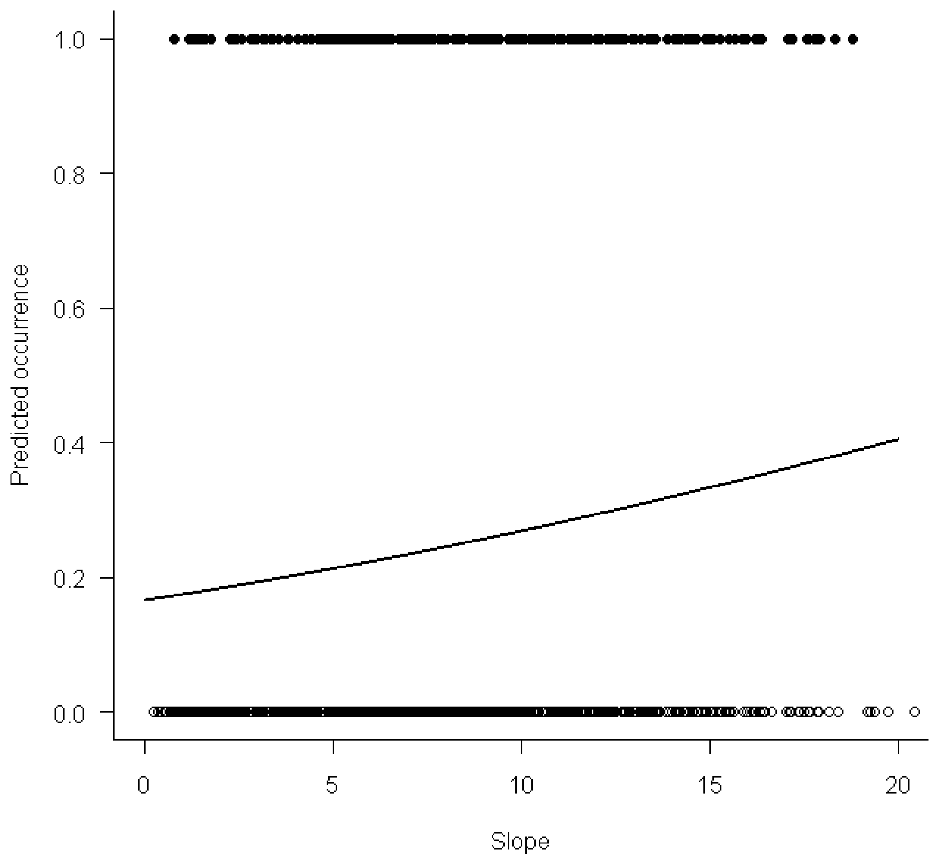


Figure H-16. Predicted probability of vireo occurrence compared to slope in Kickapoo region in 2010. The single effect of slope on PPO indicated that PPO increased from 0.17 when slope = 1° to 0.33 when slope = 15°.

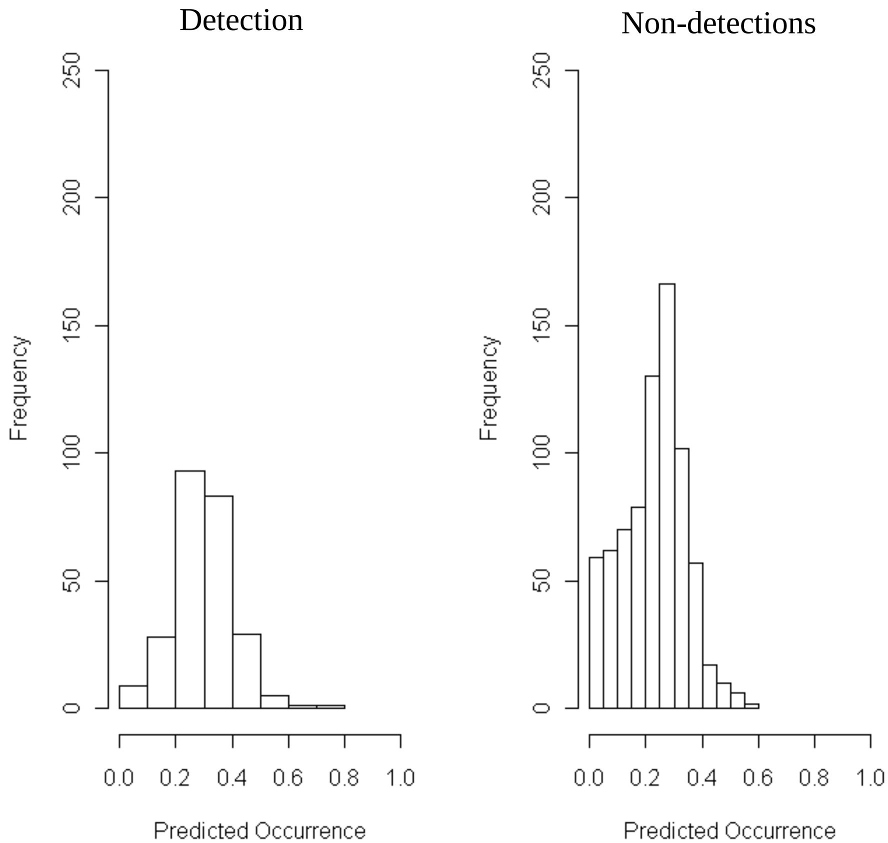


Figure H-17. Histogram of probability of occurrence at points surveyed in 2010 within the Kickapoo region where we detected vireos and at points at which we did not detect vireos.

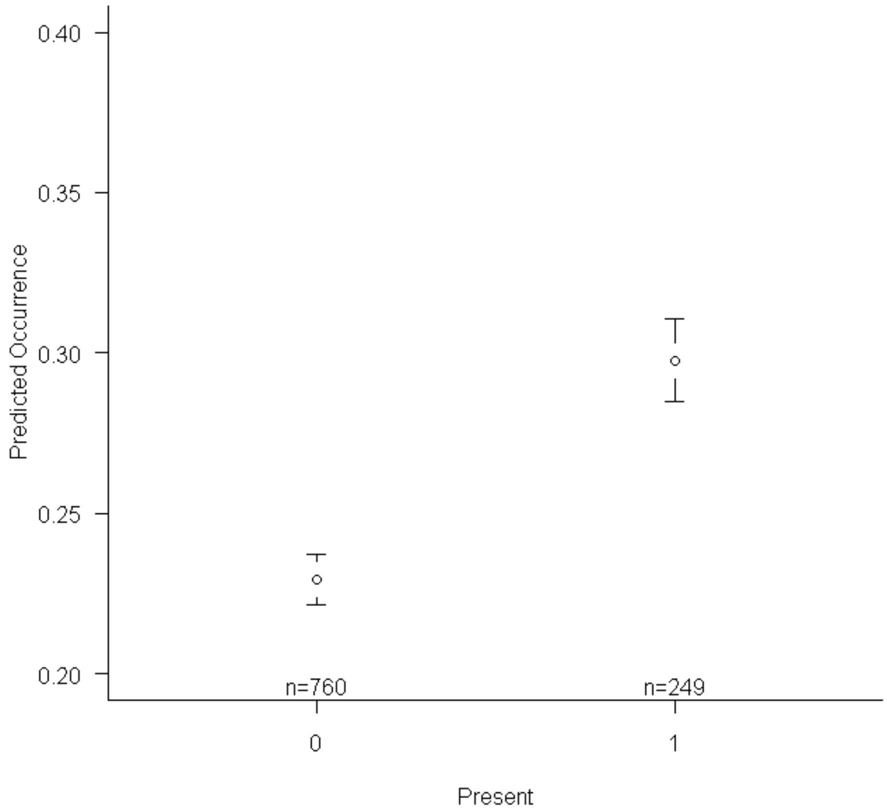


Figure H-18. Mean (95% CI) probability of occurrence at points surveyed in 2010 within the Kickapoo region where we detected vireos (1) and points at which we did not detect vireos (0).

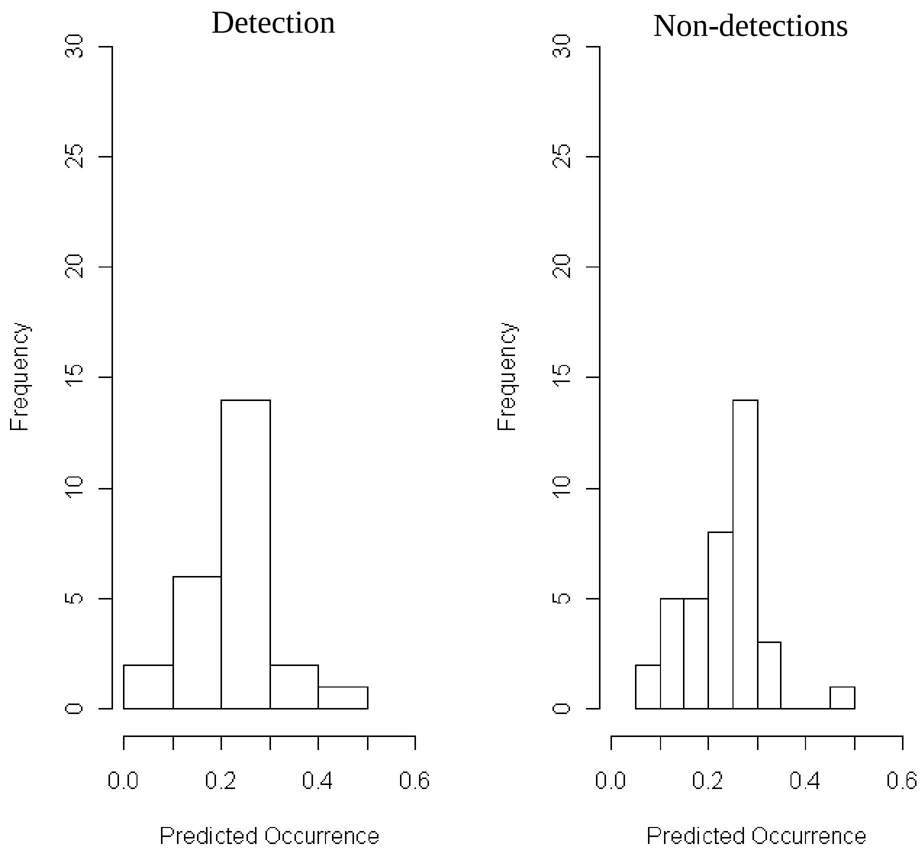


Figure H-19. Histogram of probability of occurrence at points surveyed in 2009 within the Kickapoo region where we detected vireos and at points at which we did not detect vireos.

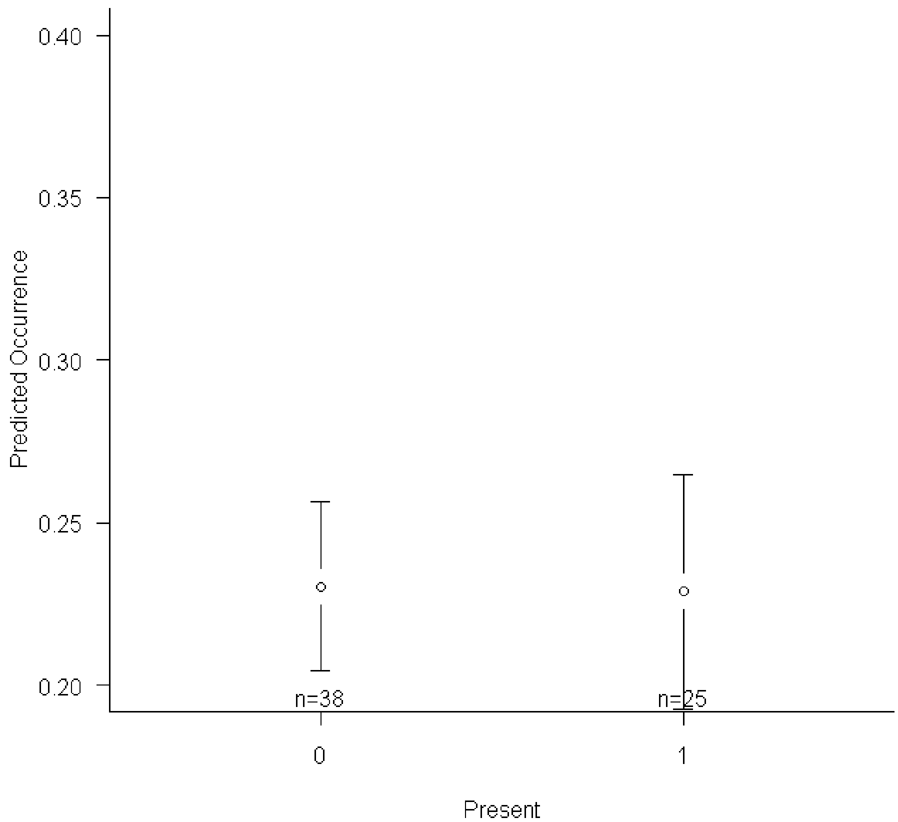


Figure H-20. Mean (95% CI) probability of occurrence at points surveyed in 2009 within the Kickapoo region where we detected vireos (1) and points at which we did not detect vireos (0).

Devil's Sinkhole

Table H9. Model-averaged statistics for predictor variables from all combinations of additive models explaining probability of occurrence of black-capped vireos in the Devil's Sinkhole region, Texas in 2010. Variables in bold indicate a significant direction of effect.

Parameter	Coefficient	Variance	SE	Unconditional.SE	Lower.CI	Upper.CI
(Intercept)	-3.852	0.085	0.500	0.502	-4.835	-2.869
Low.Stony.Hill	0.033	0.019	0.200	0.201	-0.361	0.427
Plan	0.166	1.524	0.662	0.663	-1.134	1.467
Profile	0.268	0.692	0.653	0.654	-1.014	1.551
Shallow	0.156	0.114	0.397	0.397	-0.623	0.934
Slope	**0.104**	**0.000**	**0.038**	**0.038**	**0.030**	**0.178**

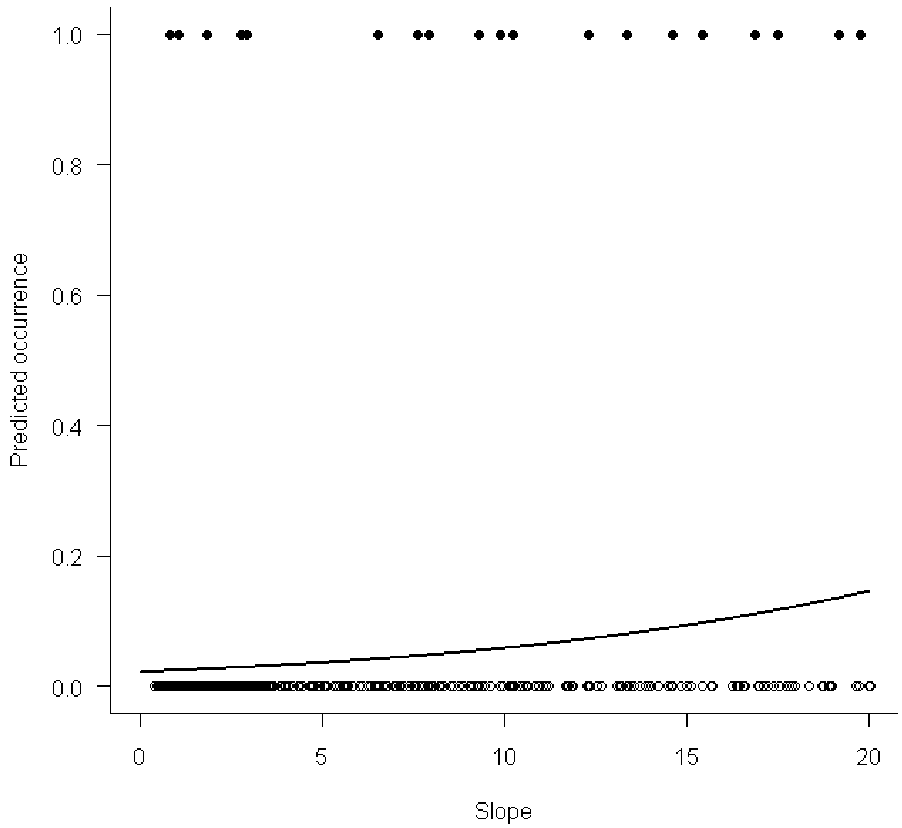


Figure H-21. Predicted probability of vireo occurrence with increasing slope for Devil's Sinkhole region in 2010. The single effect of slope was small; PPO increased from 0.024 when slope = 1 to 0.058 when slope = 10.

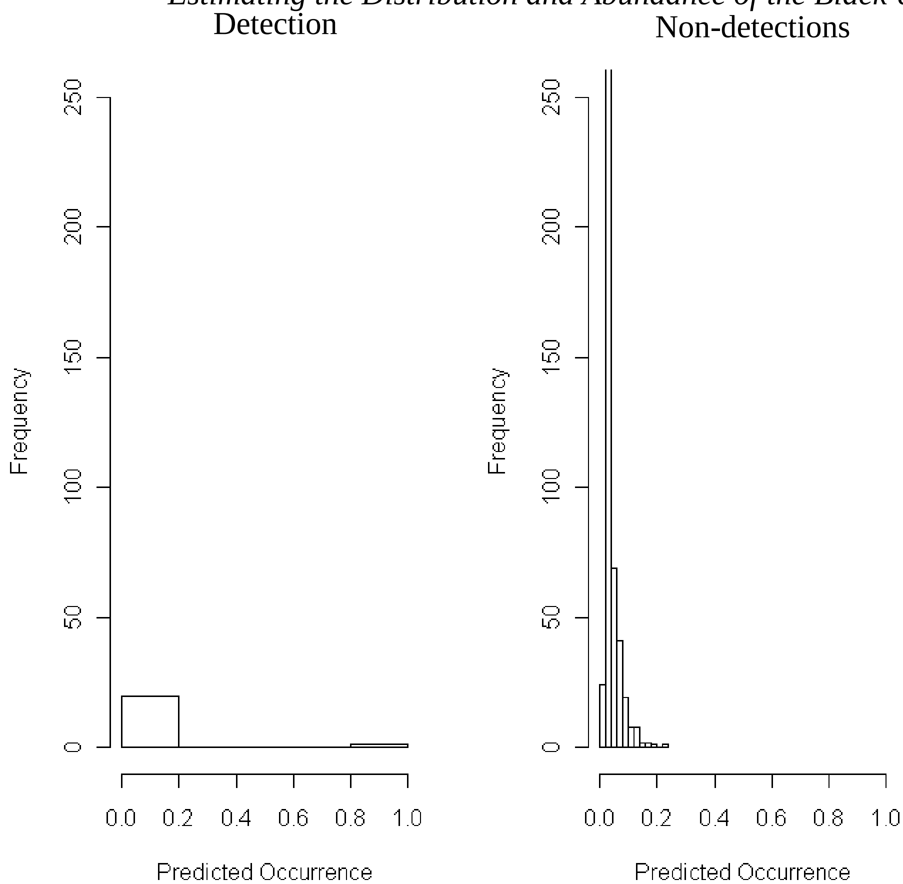


Figure H-22. Histogram of probability of occurrence at points surveyed in 2010 within the Devil's Sinkhole region where we detected vireos and at points at which we did not detect vireos.

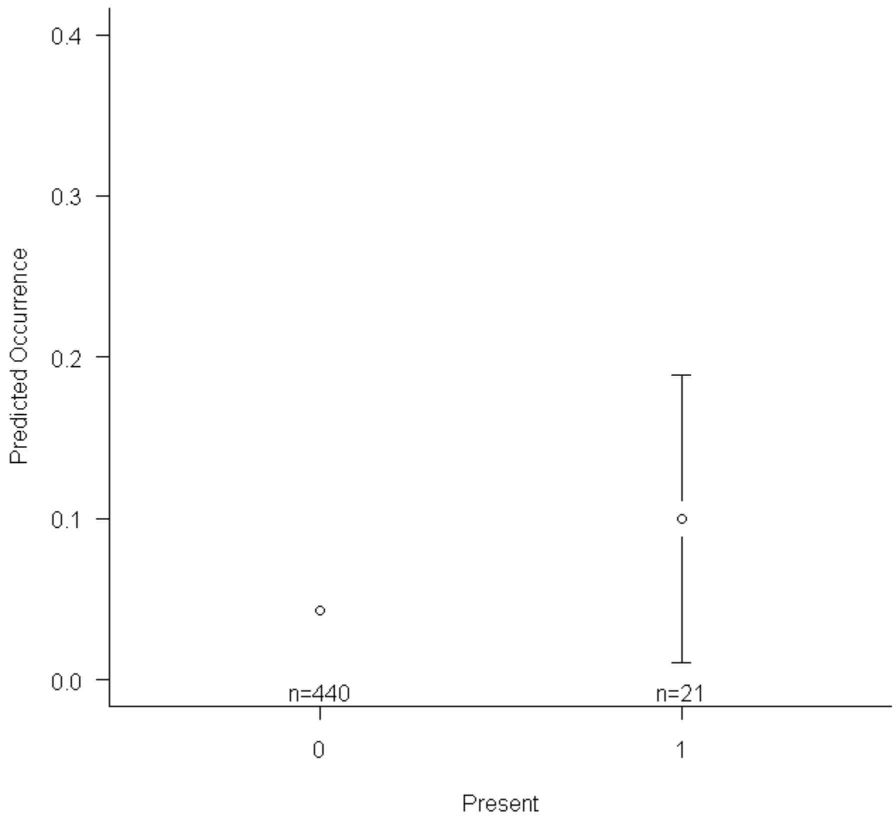


Figure H-23. Mean DR 2009. Mean (95% CI) probability of occurrence at points surveyed in 2010 within the Devil's Sinkhole region where we detected vireos (1) and points at which we did not detect vireos (0).

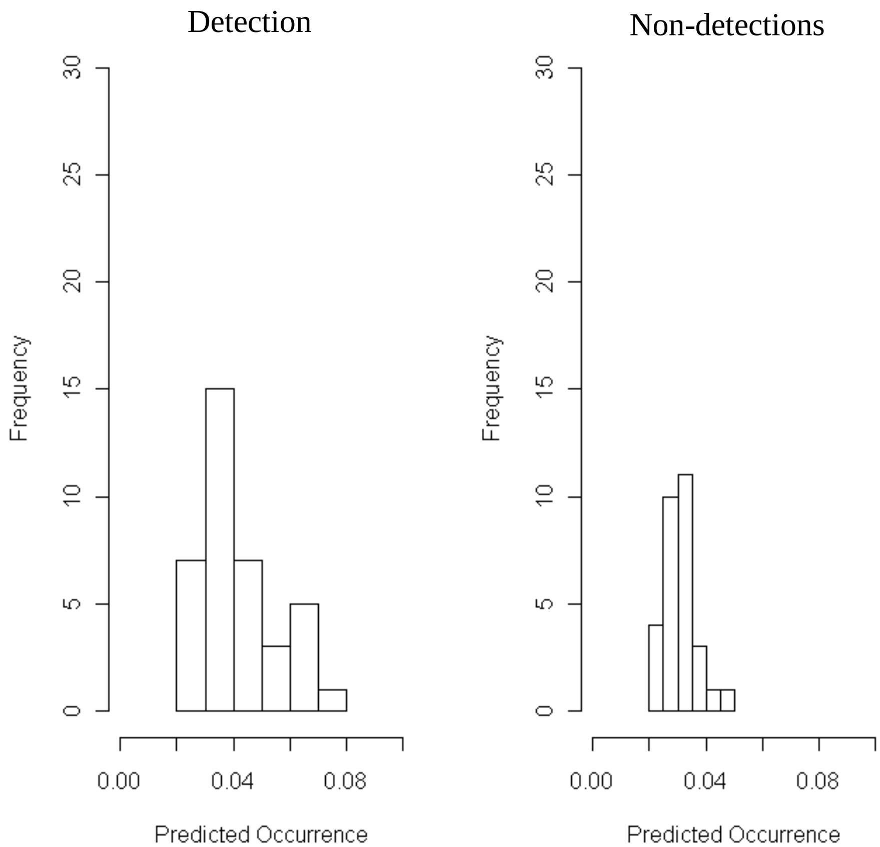


Figure H-24. Histogram of probability of occurrence at points surveyed in 2009 within the Devil's Sinkhole region where we detected vireos and at points at which we did not detect vireos.

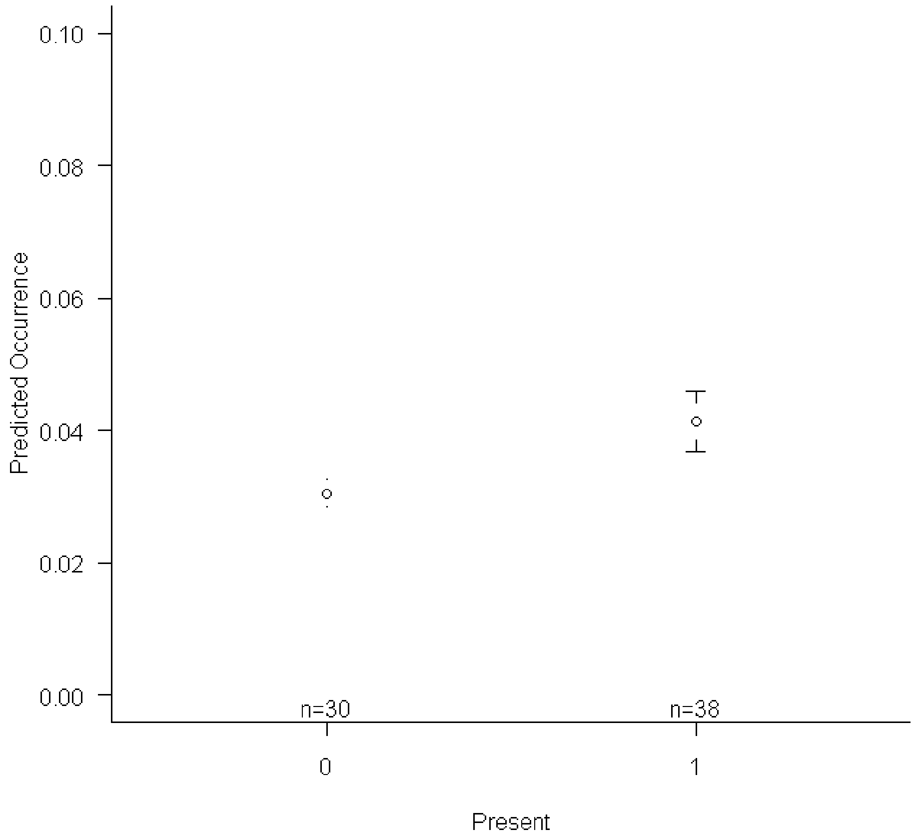


Figure H-25. Mean DR 2009. Mean (95% CI) probability of occurrence at points surveyed in 2009 within the Devil's Sinkhole region where we detected vireos (1) and points at which we did not detect vireos (0).

Kerr

For the main effect of Low Stony Hill, PPO increased from 0.14 when proportion of Low Stony Hill = 0.25 to 0.20 when Low Stony Hill = 0.95 (β = 0.569, 95% CI: 0.2119, 0.927).

Model-averaging indicated a significant direction of effect for Low Stony Hill (Table H10).

Table H10. Model-averaged statistics for predictor variables from all combinations of additive models explaining probability of occurrence of black-capped vireos in the Kerr region, Texas in 2010. Variables in bold indicate a significant direction of effect.

					95% CI	
	Coefficient	Variance	SE	Uncon.SE	Lower	Upper
(Intercept)	-1.880	0.002	0.210	0.211	-2.292	-1.467
CanCovMean	-0.002	0.000	0.003	0.003	-0.007	0.004
Low.Stony.Hill	**0.578**	**0.003**	**0.218**	**0.219**	**0.150**	**1.007**
PlanMean	-0.329	1.425	0.764	0.764	-1.827	1.169
ProfMean	1.382	2.883	1.302	1.302	-1.171	3.934
Redland	0.005	0.001	0.080	0.080	-0.152	0.163
Shallow	-0.071	0.004	0.171	0.171	-0.407	0.264
SlopeMean	-0.002	0.000	0.008	0.008	-0.019	0.014
Steep.Rocky	-0.008	0.001	0.079	0.079	-0.162	0.146

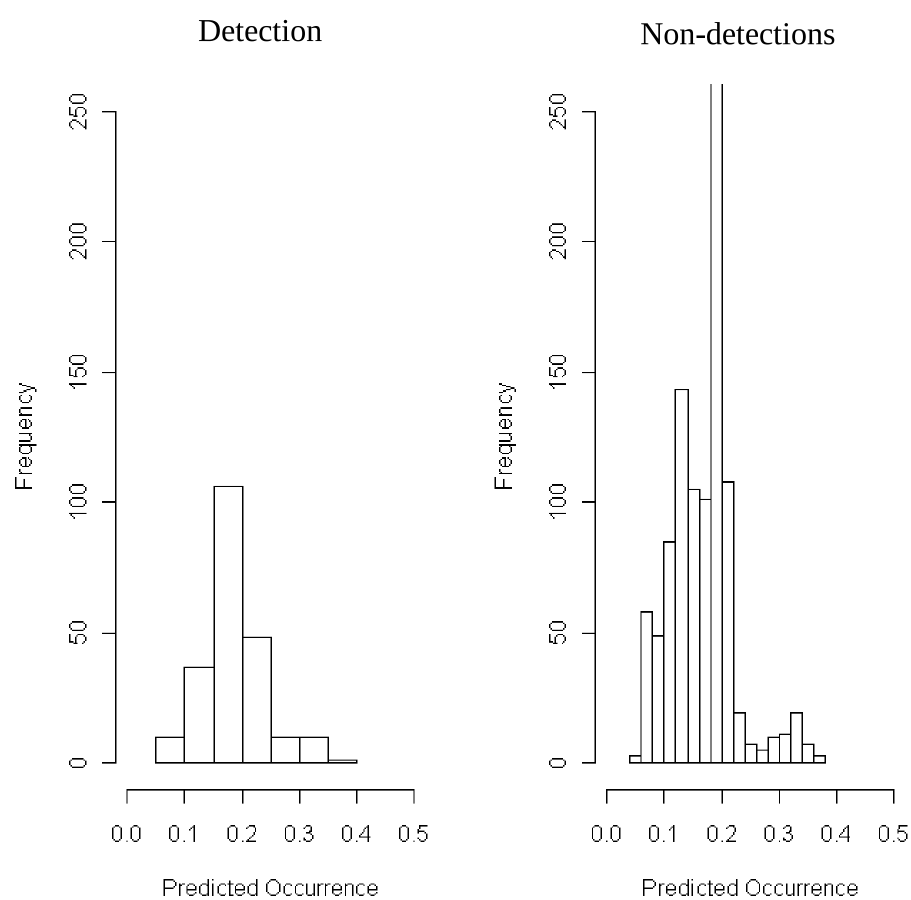


Figure H-26. Histogram of probability of occurrence at points surveyed in 2010 within the Kerr region where we detected vireos and at points at which we did not detect vireos.

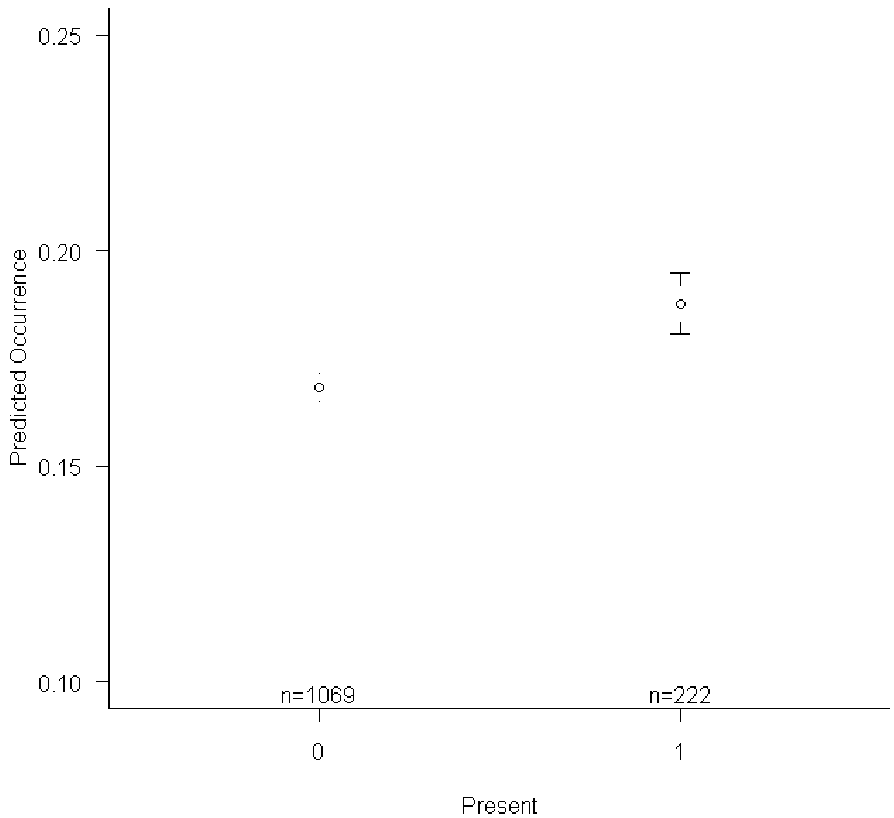


Figure H-27. Mean DR 2009. Mean (95% CI) probability of occurrence at points surveyed in 2010 within the Kerr region where we detected vireos (1) and points at which we did not detect vireos (0).

Balcones

Three single effects models had significant directions of effect: Low Stony Hill, slope, and profile.

Model selection results supported the single effect of Low Stony Hill among the 8 competitive models (Table A) and model-averaging on the additive combinations of models supported the significance of the effect of Low Stony Hill because the confidence intervals did not overlap 0 (Table B). However, examination of other competitive models suggested that Low Stony Hill alone was not the best approximating model for this region (Table H11).

Table H11. Model-averaged statistics for predictor variables from all combinations of additive models explaining probability of occurrence of black-capped vireos in the Balcones region, Texas in 2010. Variables in bold indicate a significant direction of effect.

	Coefficient	Variance	SE	Unconditional.SE	Lower.CI	Upper.CI
(Intercept)	-3.818	0.116	0.576	0.576	-4.948	-2.688
CanCovMean	-0.001	0.000	0.002	0.002	-0.006	0.004
Low.Stony.Hill	**2.926**	**0.085**	**0.537**	**0.538**	**1.872**	**3.980**
PlanMean	-3.426	268.055	3.944	3.948	-11.163	4.311
ProfMean	-0.344	3.287	0.944	0.945	-2.196	1.509
SlopeMean	-0.040	0.000	0.061	0.062	-0.160	0.081

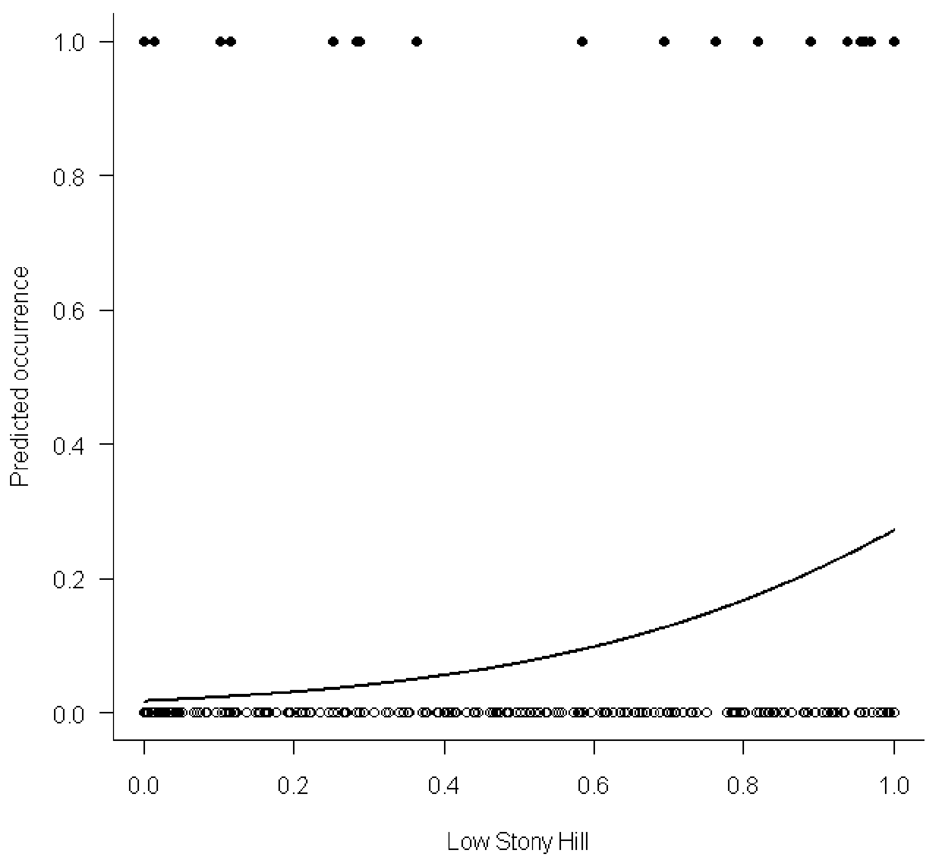


Figure H-28. Predicted probability of vireo occurrence with increasing proportion of Low Stony Hill in Balcones region in 2010. For Low Stony Hill, PPO increased from 0.04 when proportion of Low Stony Hill = 0.25 to 0.24 when proportion of Low Stony Hill = 0.95 (β = 3.08, 95% CI = 2.268, 4.042).

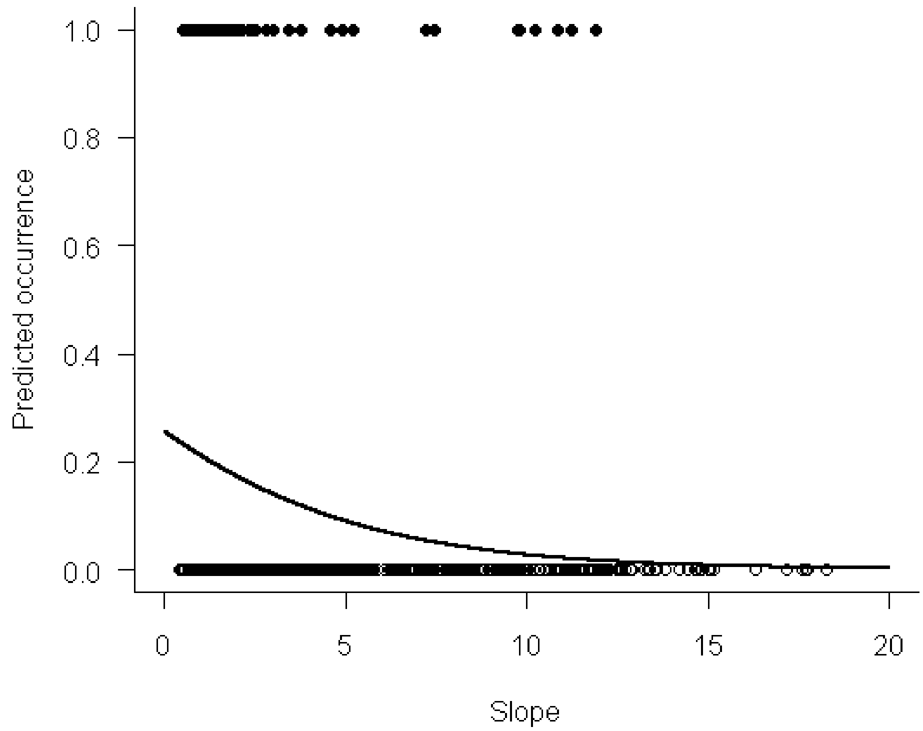


Figure H-29. Predicted probability of vireo occurrence with increasing slope in Balcones region in 2010. PPO decreased from 0.21 when slope = 1 to 0.03 when slope = 10 (β = -0.25, 95% CI = -0.361, -0.156).

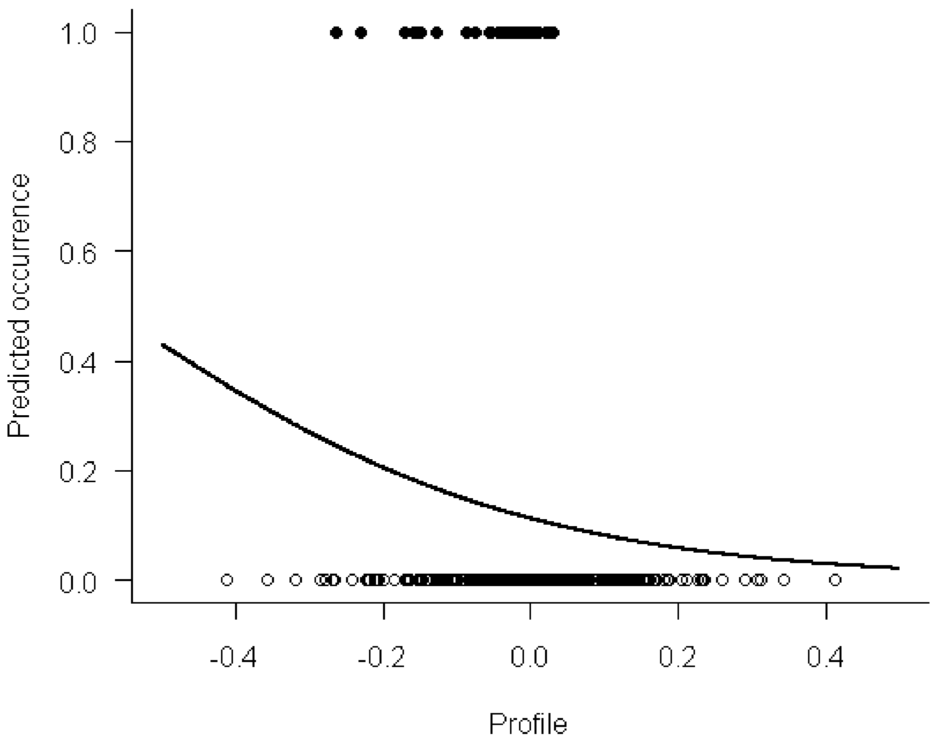


Figure H-30. Predicted probability of vireo occurrence with increasing profile curvature in Balcones region in 2010. PPO decreased from 0.21 when profile curvature = -0.2 to 0.06 when profile curvature = 0.2 (β-3.58, 95% CI = -6.326, -0.833).

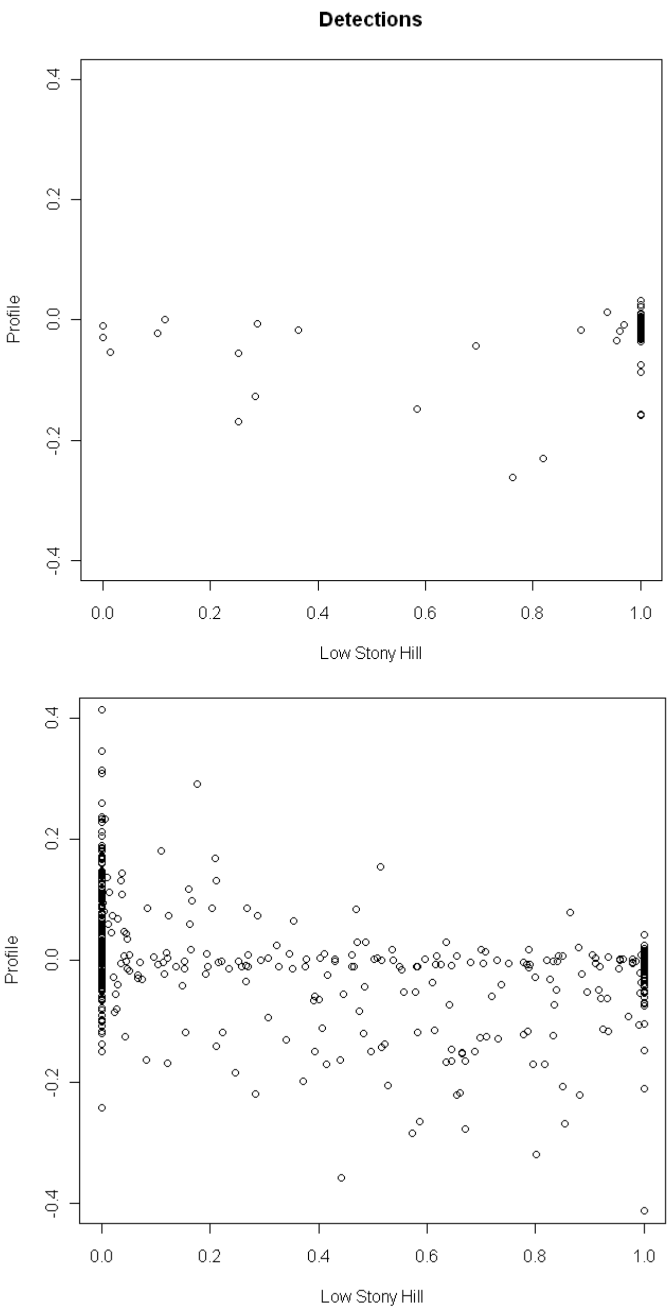


Figure H-31. Relationships between profile curvature and the proportion of Low Stony Hill for (A) vireo detections and (B) no vireo detections within the Balcones region in 2010.

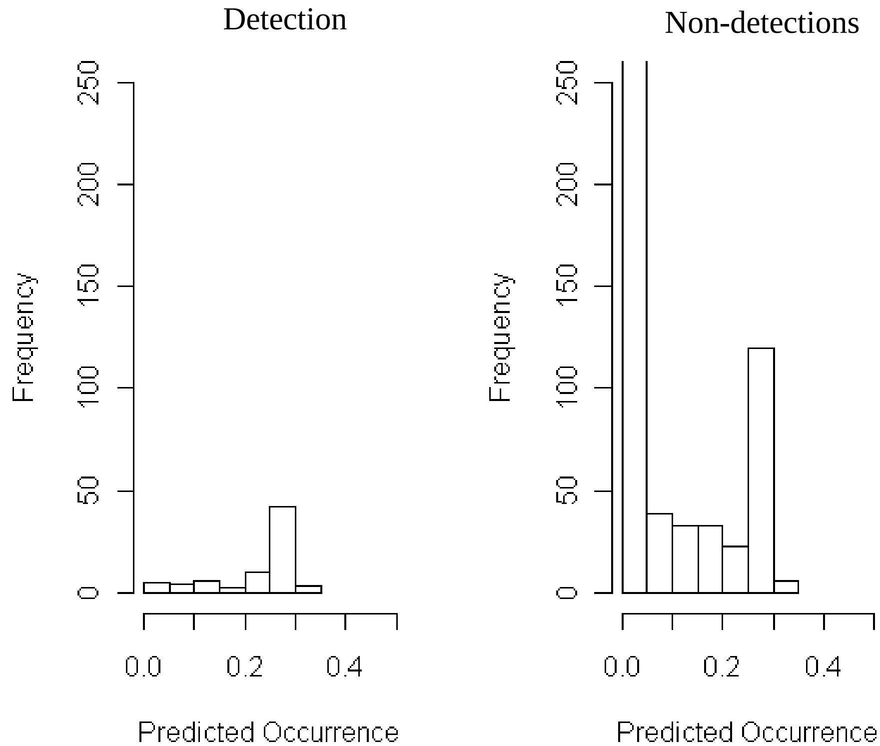


Figure H-32. Histogram of probability of occurrence at points surveyed in 2010 within the Balcones region where we detected vireos and at points at which we did not detect vireos.

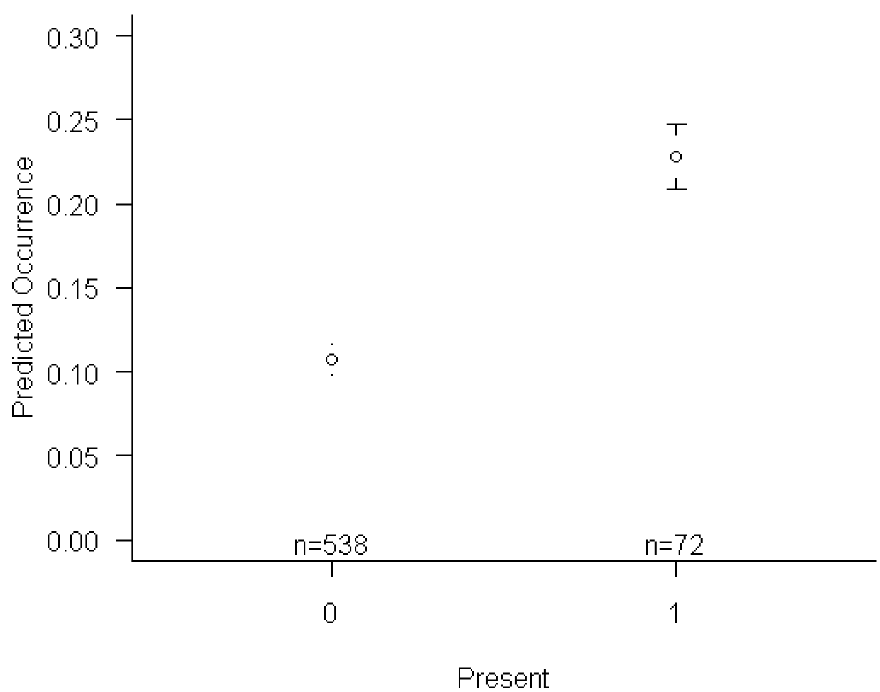


Figure H-33. Mean (95% CI) probability of occurrence at points surveyed in 2010 within the Balcones region where we detected vireos (1) and points at which we did not detect vireos (0).

Fort Hood

Model-averaging from all additive combinations indicated that the effect of Low Stony Hill and slope was consistent because the 95 % CI did not overlap 0 (Table H12).

Table H12. Model-averaged statistics for predictor variables from all combinations of additive models explaining probability of occurrence of black-capped vireos in the Fort Hood region, Texas in 2010. Variables in bold indicate a significant direction of effect.

	Coefficient	Variance	SE	Unconditional.SE	Lower.CI	Upper.CI
(Intercept)	-2.951	0.002	0.197	0.197	-3.337	-2.565
Adobe	0.067	0.004	0.169	0.169	-0.265	0.399
CanCovMean	-0.005	0.000	0.003	0.003	-0.012	0.001
Clay.Loam	0.139	0.005	0.229	0.229	-0.310	0.588
Low.Stony.Hill	**0.904**	**0.005**	**0.256**	**0.256**	**0.403**	**1.406**
PlanMean	-0.270	0.694	0.637	0.637	-1.518	0.979
ProfMean	-0.121	0.080	0.339	0.339	-0.785	0.543
Redland	0.087	0.003	0.178	0.178	-0.261	0.435
SlopeMean	**0.130**	**0.000**	**0.028**	**0.028**	**0.075**	**0.186**

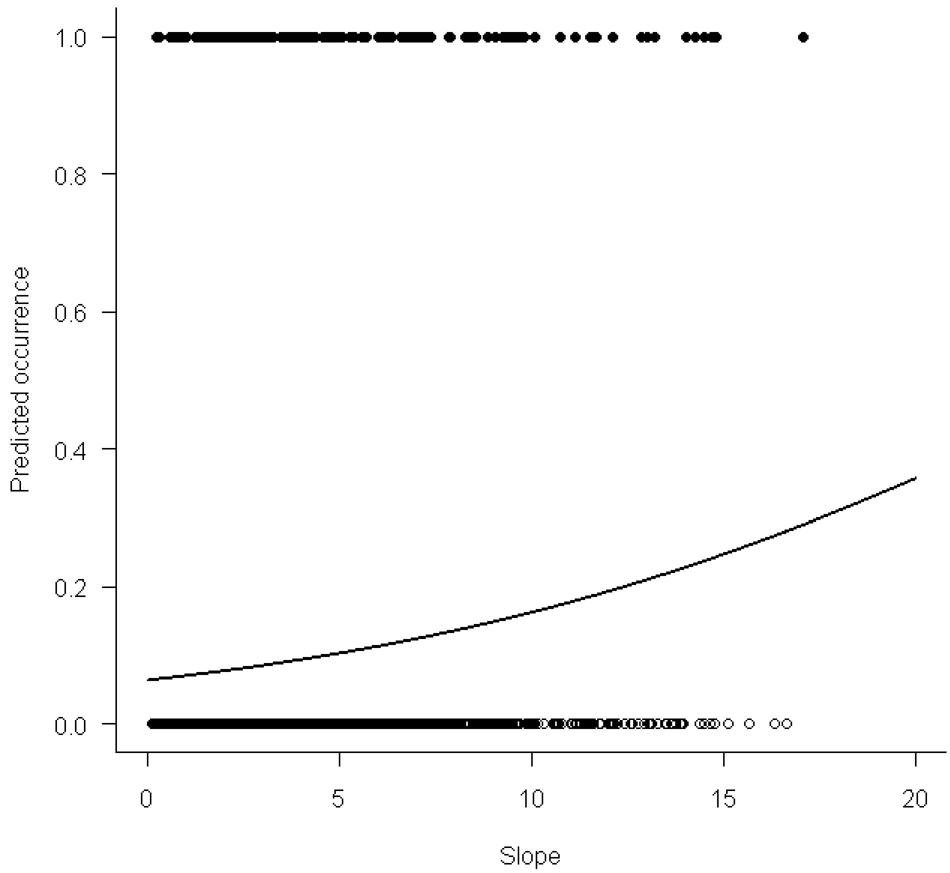


Figure H-34. Predicted probability of vireo occurrence with increasing slope in Fort Hood region in 2010. PPO increased from 0.07 when slope = 1 to 0.16 when slope = 10 (β = 0.105, 95% CI = 0.061, 0.148).

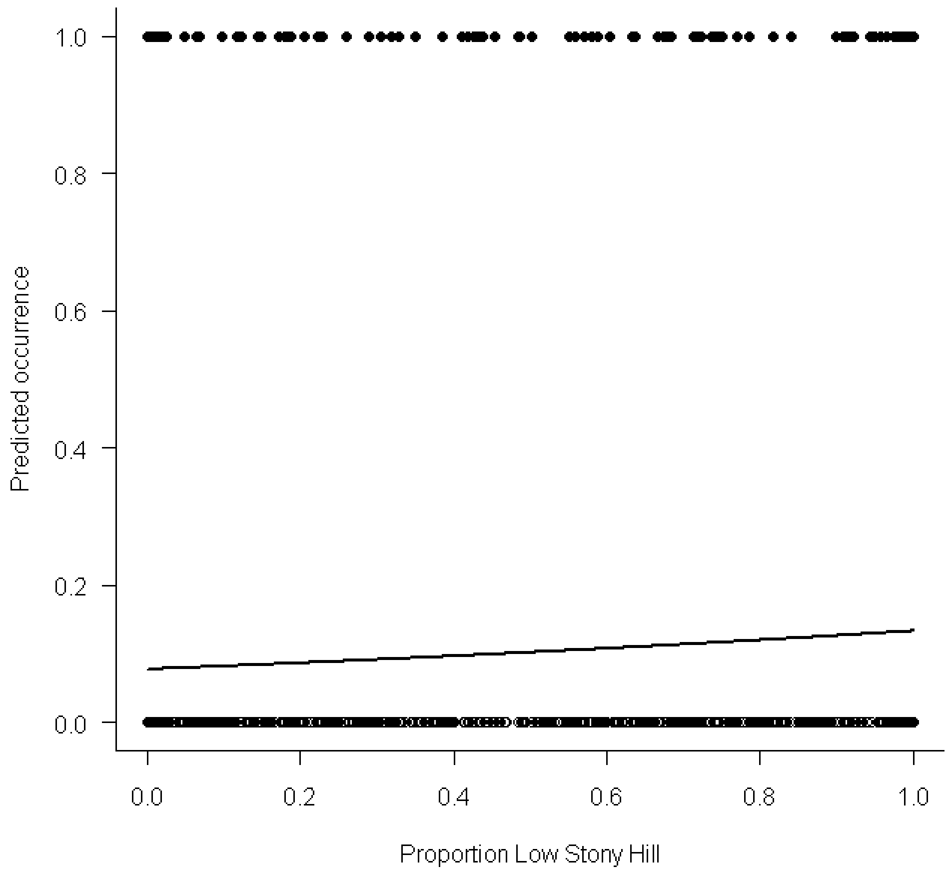


Figure H-35. Predicted probability of vireo occurrence with increasing proportion of Low Stony Hill in Fort Hood region in 2010. The effect of Low Stony Hill on PPO was consistent yet weak; PPO increased from 0.09 at proportion of Low Stony Hill = 0.25 to 0.13 at proportion of Low Stony Hill = 0.95 (β = 0.606, 95% CI = 0.248, 0.959).

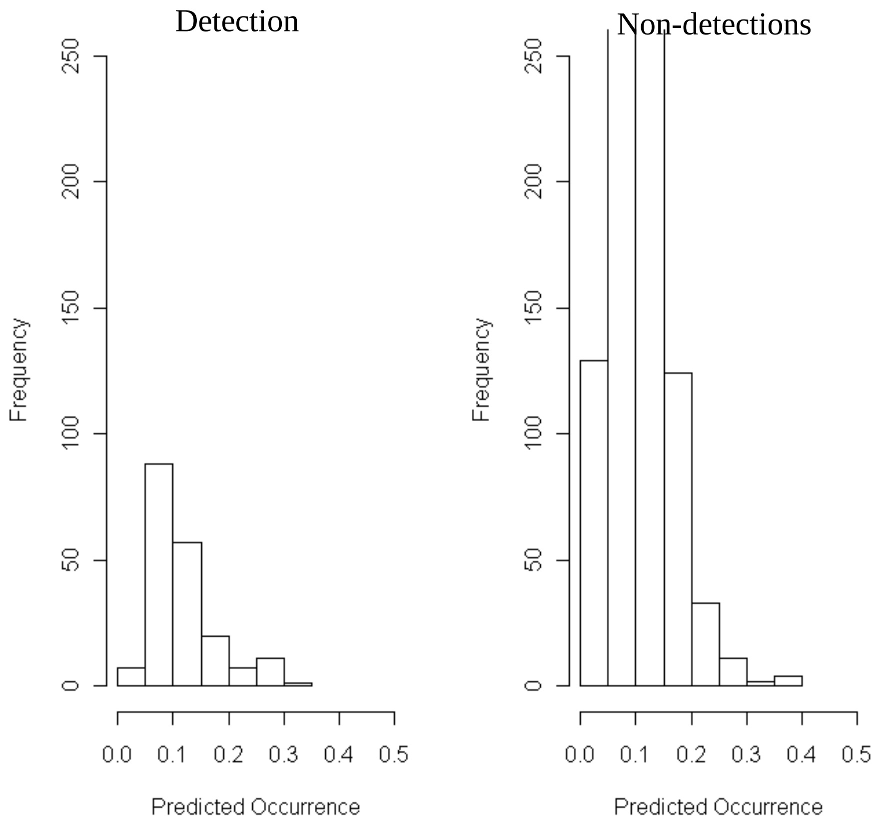


Figure H-36. Histogram of probability of occurrence at points surveyed in 2010 within the Fort Hood region where we detected vireos and at points at which we did not detect vireos.

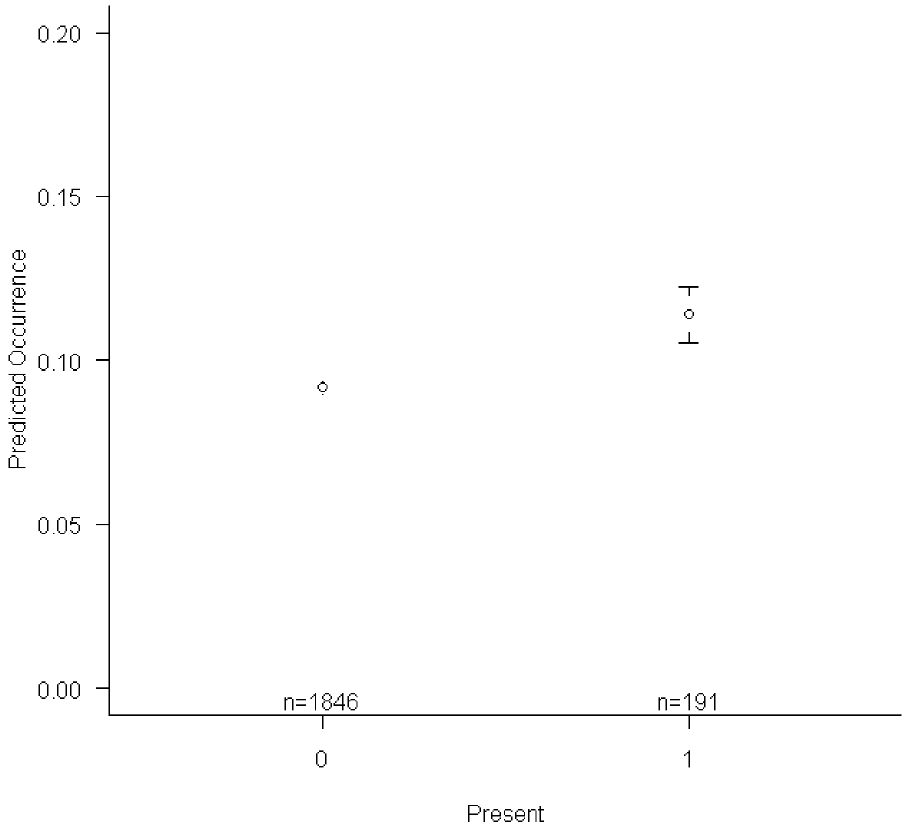


Figure H-37. Mean (95% CI) probability of occurrence at points surveyed in 2010 within the Fort Hood region where we detected vireos (1) and points at which we did not detect vireos (0).

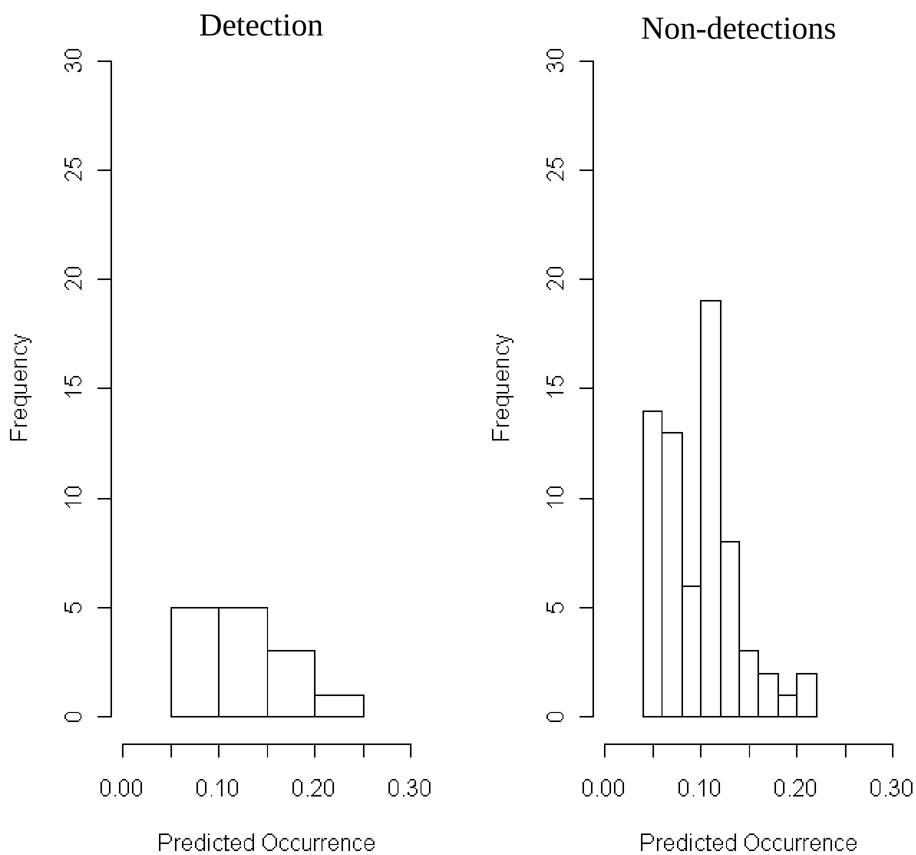


Figure H-38. Histogram of probability of occurrence at points surveyed in 2009 within the Fort Hood region where we detected vireos and at points at which we did not detect vireos.

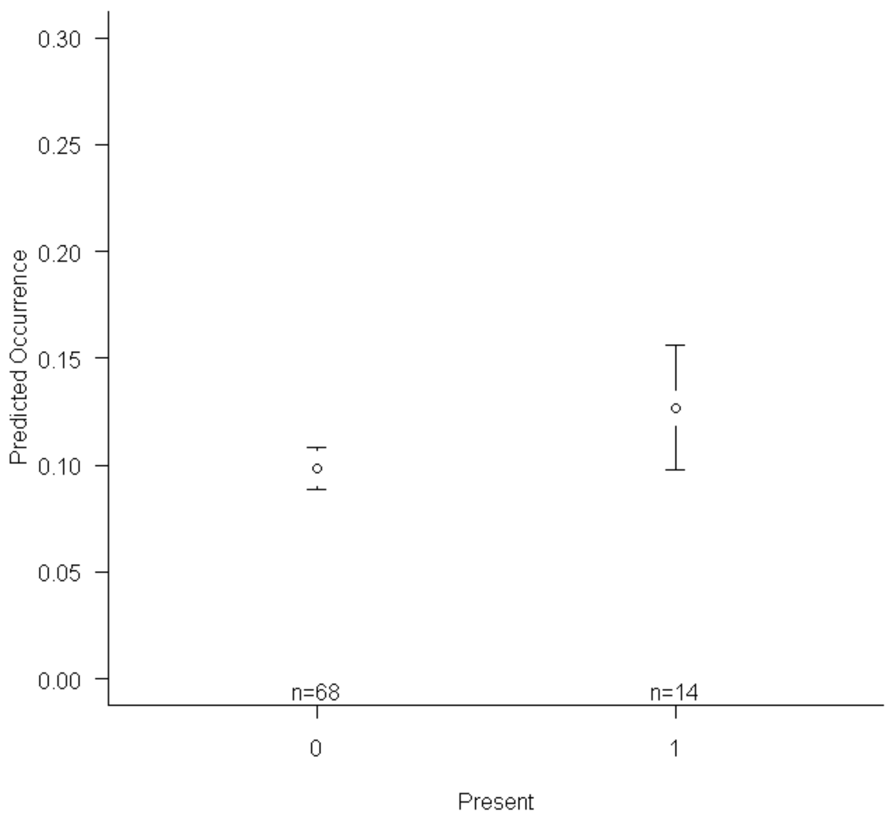


Figure H-39. Mean (95% CI) probability of occurrence at points surveyed in 2009 within the Fort Hood region where we detected vireos (1) and points at which we did not detect vireos (0).

Range-wide Model

Table H13. Model-averaged statistics for predictor variables from all combinations of additive models explaining probability of occurrence of black-capped vireos in Texas in 2010. Variables in bold indicate a significant direction of effect.

	Coefficient	Variance	SE	Uncond.SE	Lower.CI	Upper.CI
(Intercept)	-2.241	0.020	0.368	0.368	-2.963	-1.519
Adobe	-0.027	0.000	0.094	0.094	-0.211	0.157
Aridity	0.000	0.000	0.000	0.000	0.000	0.000
CanCovMean	-0.006	0.000	0.002	0.002	-0.009	-0.003
Clay.Loam	-0.026	0.000	0.092	0.092	-0.206	0.155
Low.Stony.Hill	**0.978**	**0.000**	**0.138**	**0.138**	**0.707**	**1.249**
ProfMean	**1.829**	**0.007**	**0.293**	**0.293**	**1.256**	**2.403**
Redland	0.184	0.003	0.230	0.230	-0.267	0.636
Shallow	0.114	0.001	0.176	0.176	-0.231	0.460
SlopeMean	**0.045**	**0.000**	**0.011**	**0.011**	**0.024**	**0.066**
Steep.Rocky	**0.847**	**0.001**	**0.172**	**0.172**	**0.510**	**1.184**

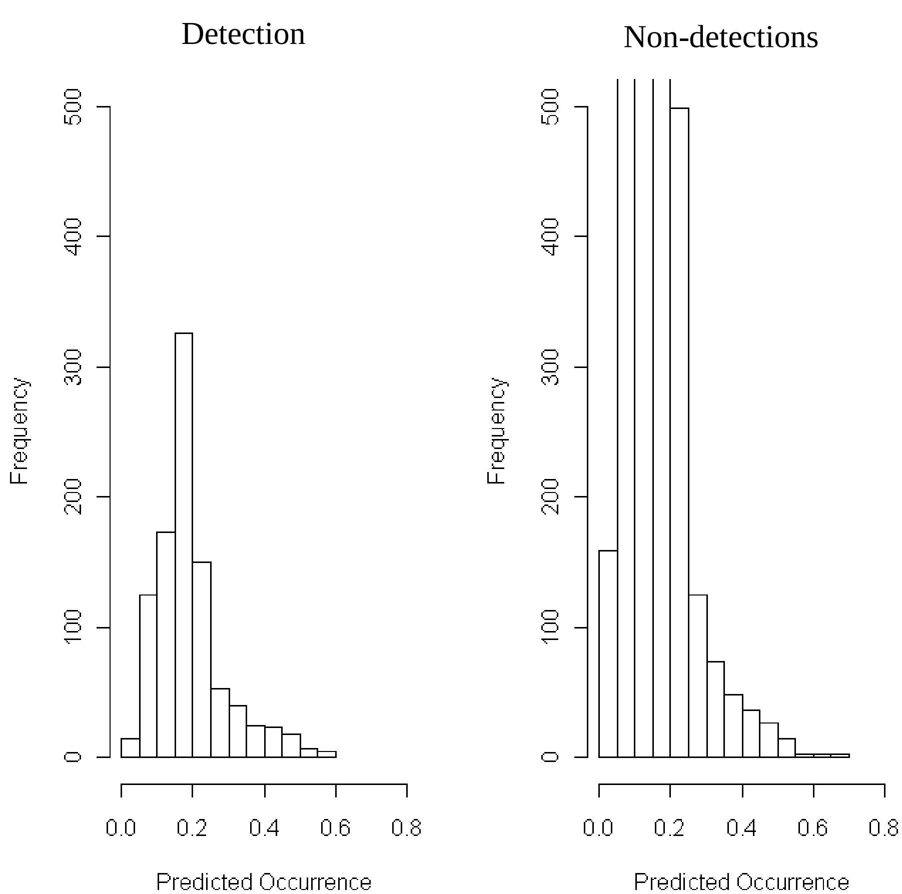


Figure H-40. Histogram of probability of occurrence at points surveyed in 2010 range-wide where we detected vireos and at points at which we did not detect vireos.

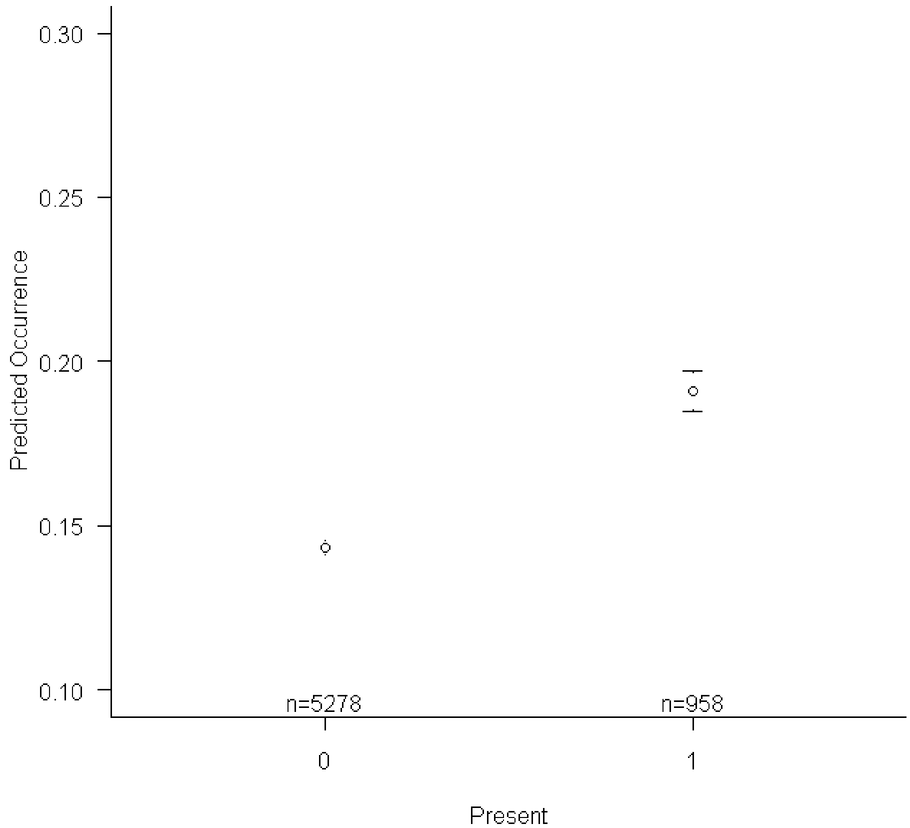


Figure H-41. Mean (95% CI) probability of occurrence at points surveyed in 2010 range-wide where we detected vireos (1) and points at which we did not detect vireos (0).

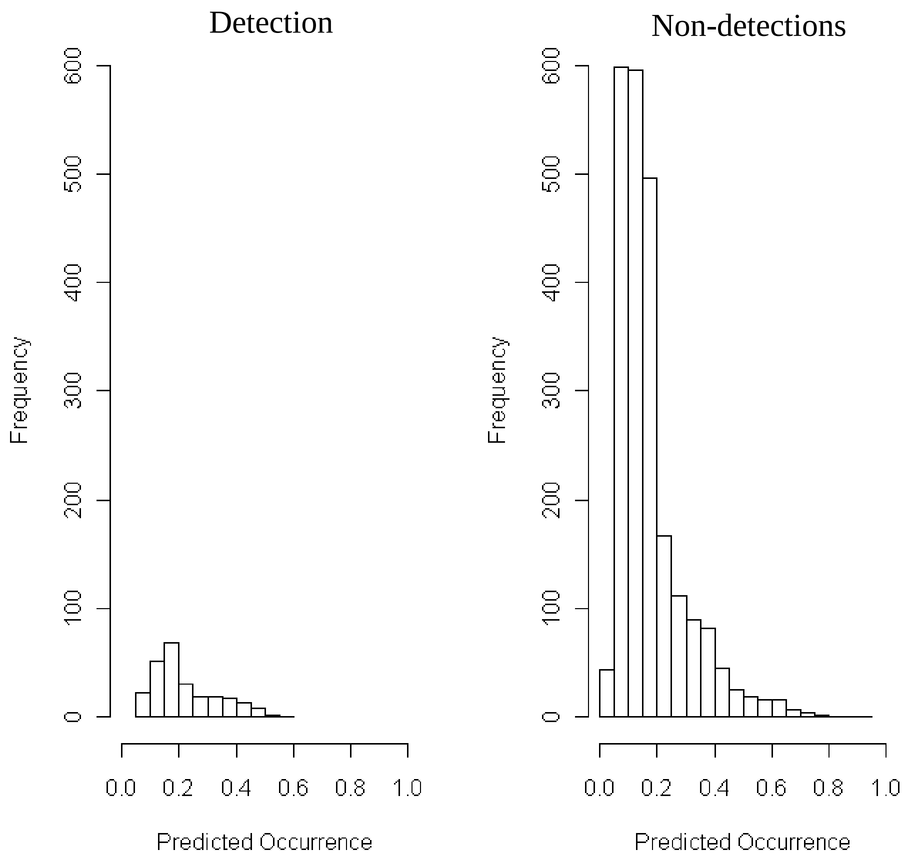


Figure H-42. Histogram of probability of occurrence at points surveyed in 2009 range-wide where we detected vireos and at points at which we did not detect vireos.

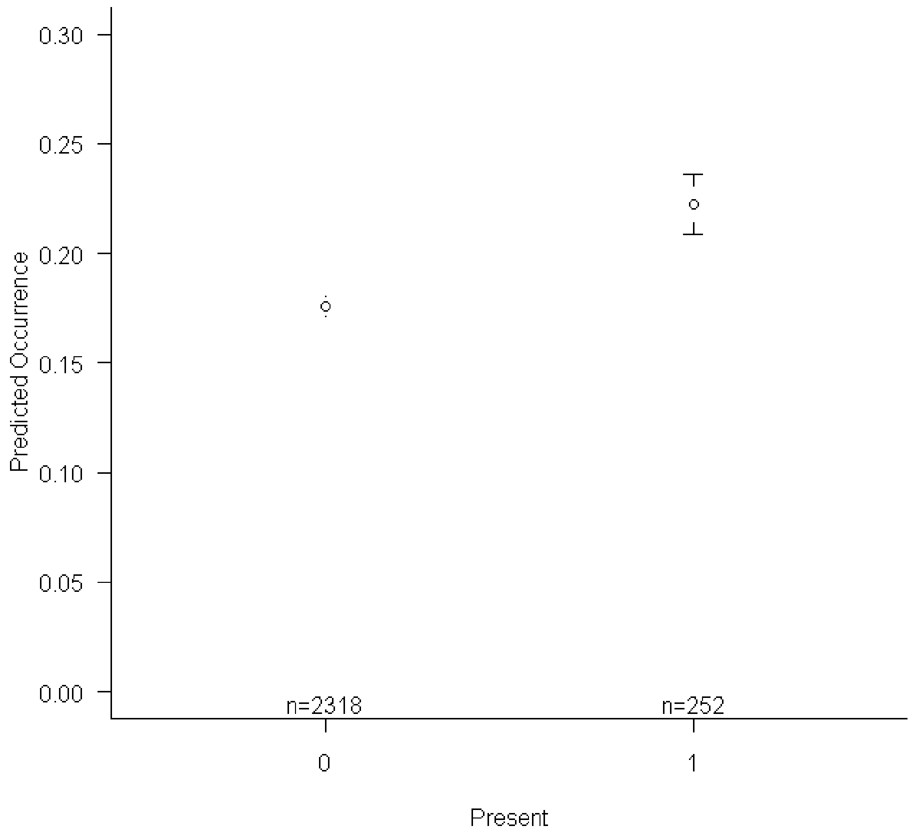


Figure H-43. Mean (95% CI) probability of occurrence at points surveyed in 2009 range-wide where we detected vireos (1) and points at which we did not detect vireos (0).

Appendix I: Supplemental information for abundance

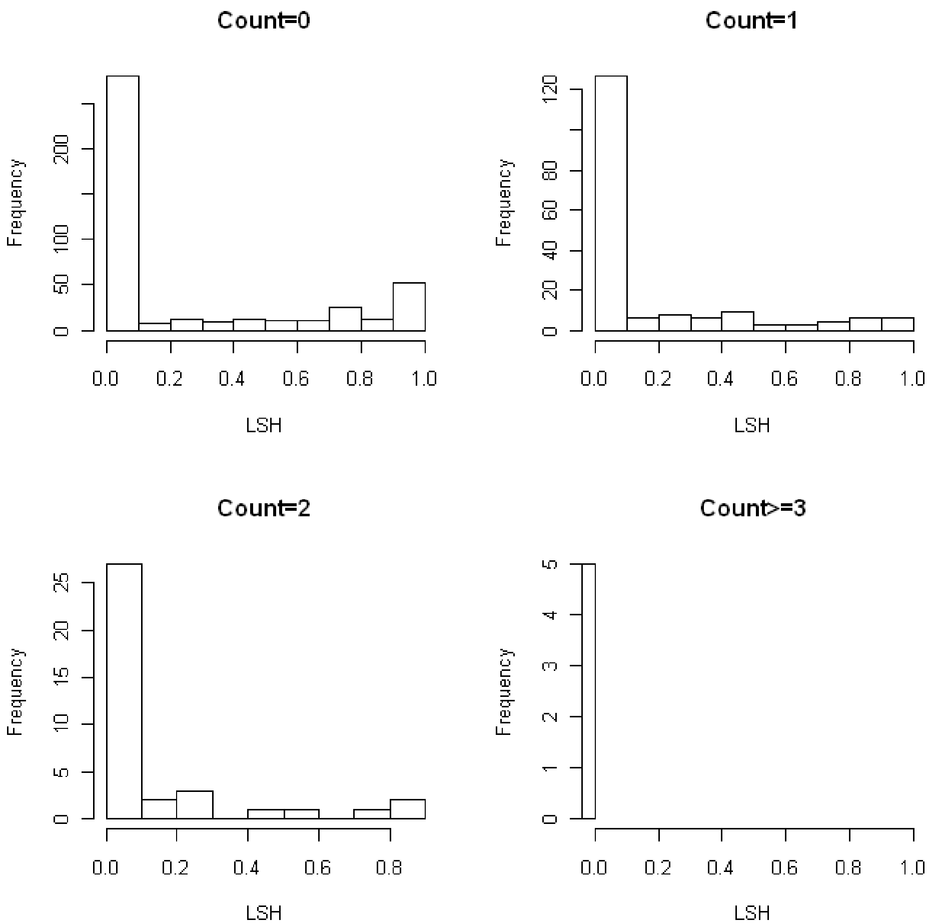


Figure I-1. Frequency distribution of proportion of Low Stony Hill ecosite when aridity index was low (Devil's River study area) by vireo count.

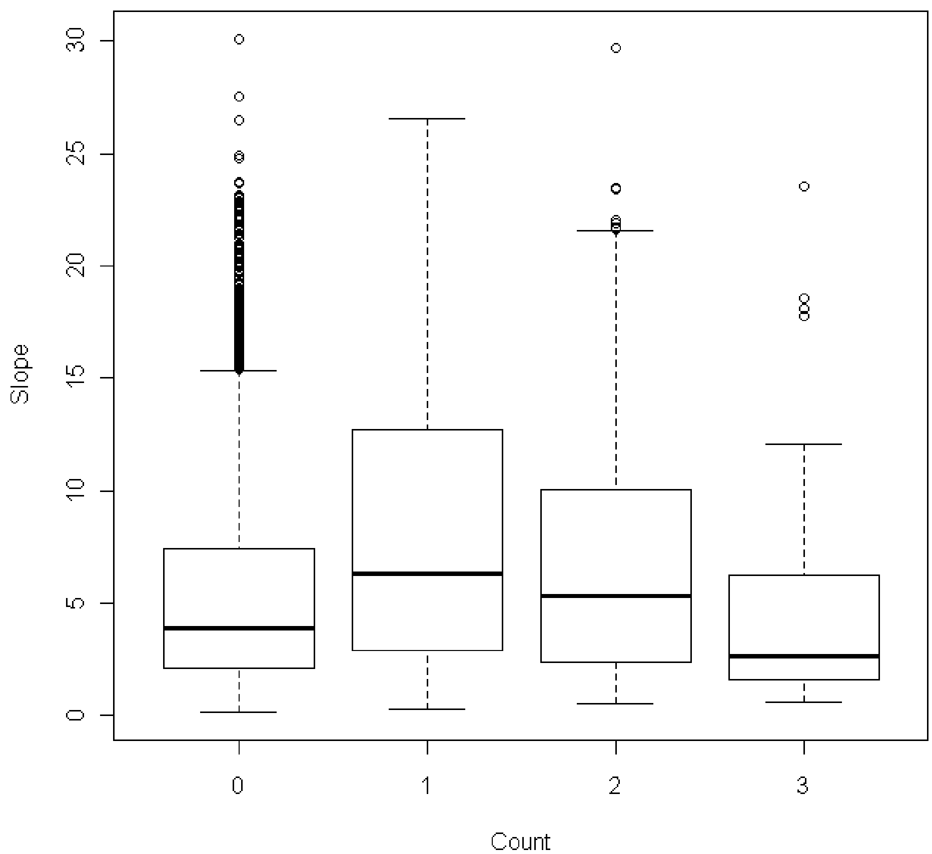


Figure I-2. Boxplot (median, quartiles, minimum, and maximum) of mean Slope within 100 m of point surveys from across the vireo range by number of vireos counted (count). A count of 3 includes all counts ≥ 3.

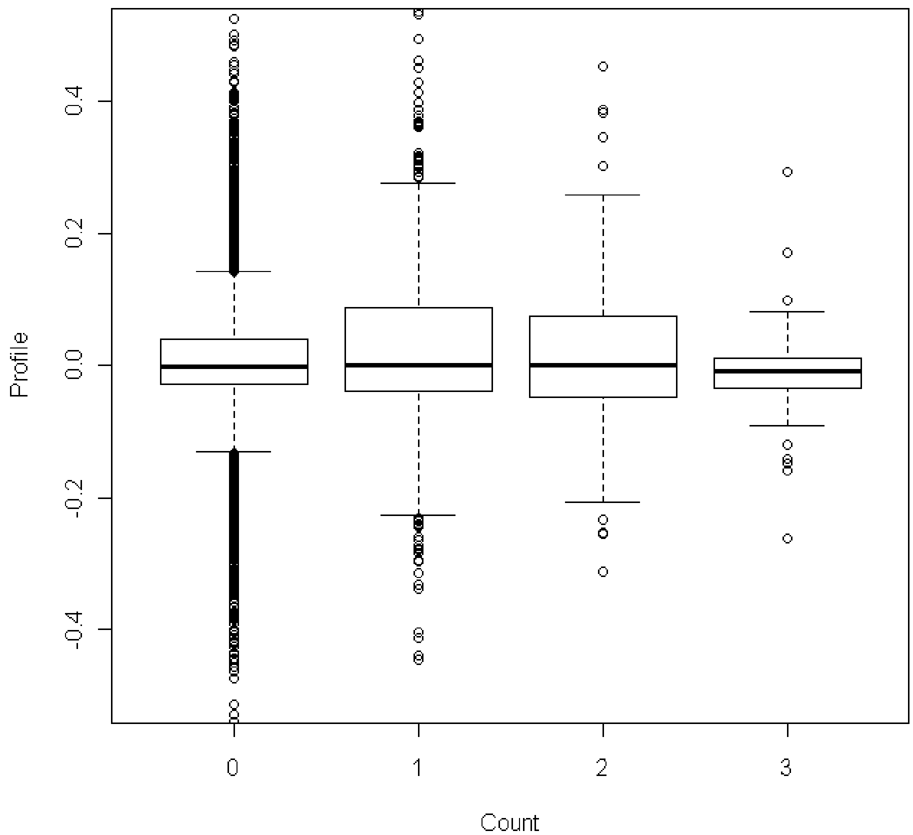


Figure I-3. Boxplot (median, quartiles, minimum, and maximum) of mean profile curvature within 100 m of point surveys from across the vireo range by number of vireos counted (count). A count of 3 includes all counts ≥ 3.

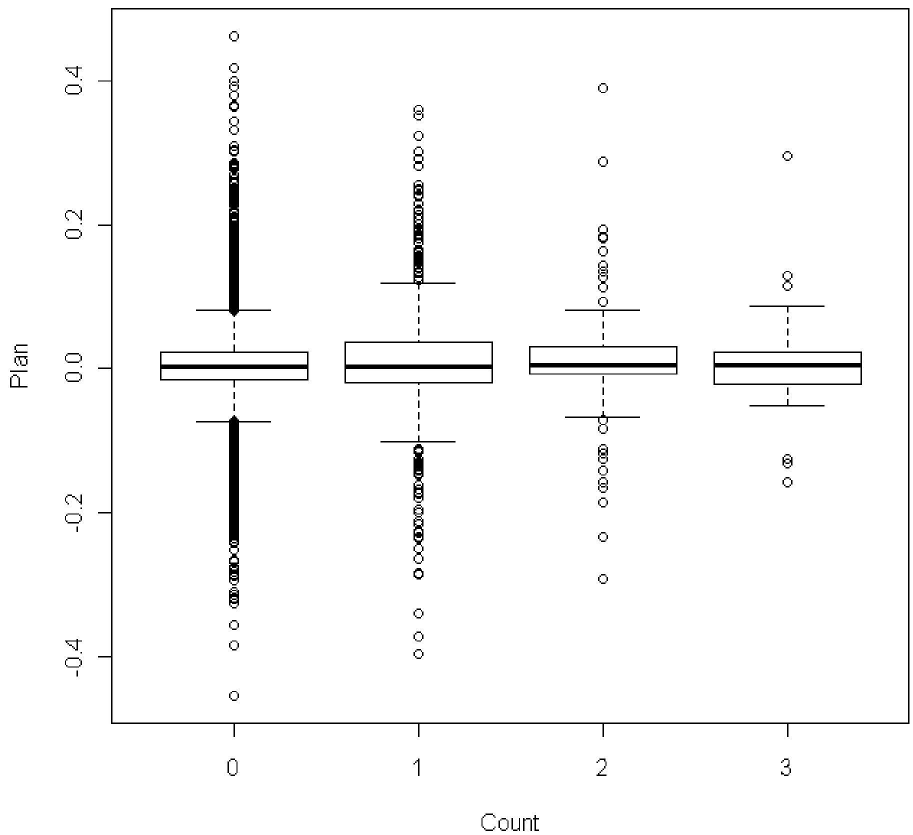


Figure I-4. Boxplot (median, quartiles, minimum, and maximum) of mean plan curvature within 100 m of point surveys from across the vireo range by number of vireos counted (count). A count of 3 includes all counts ≥ 3.

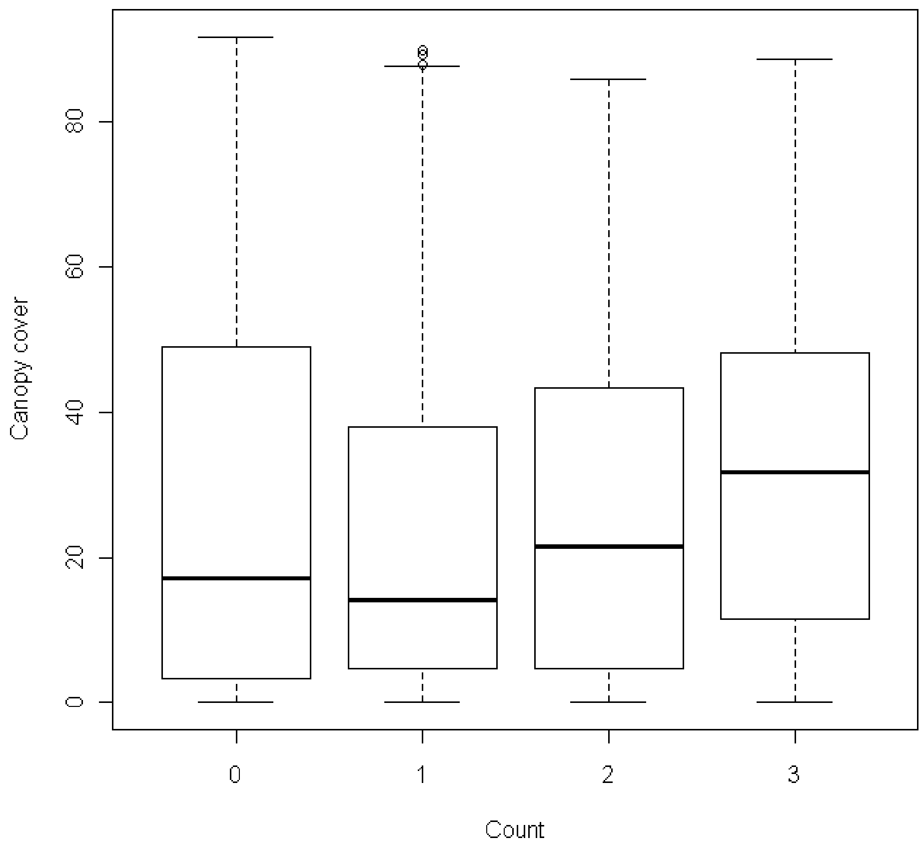


Figure I-5. Boxplot (median, quartiles, minimum, and maximum) of mean canopy cover within 100 m of point surveys from across the vireo range by number of vireos counted (count). A count of 3 includes all counts ≥ 3.

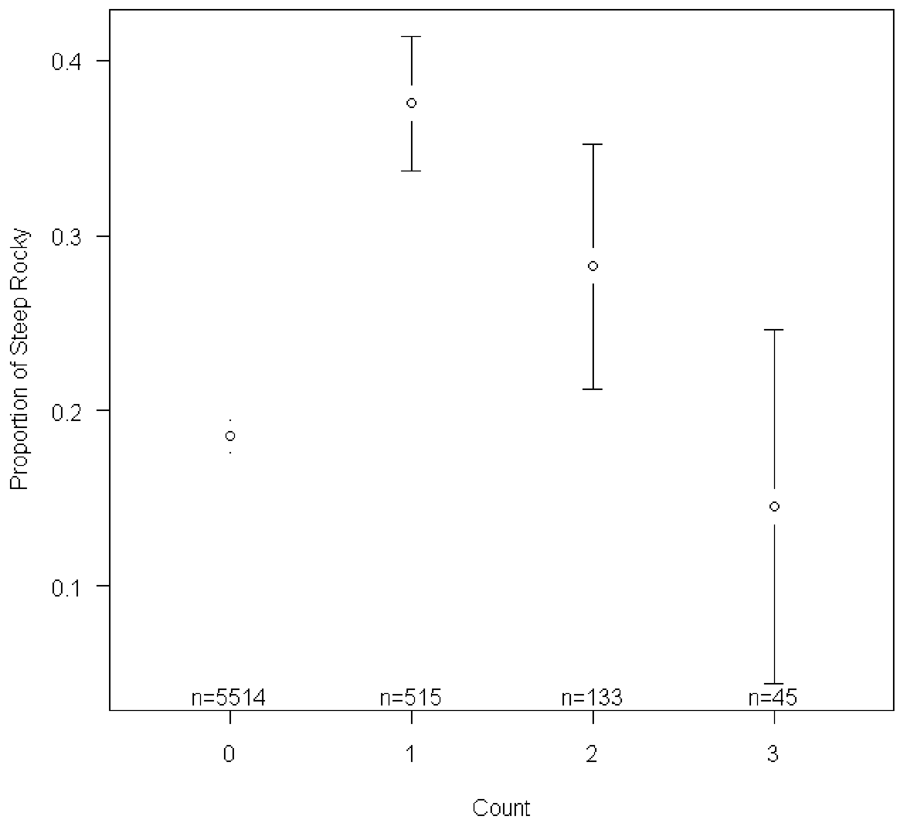


Figure I-6. Mean and 95% confidence intervals for proportion of Steep Rocky ecosite within 100 m of survey points by the number of vireos detected at survey points (count) for study sites across the black-capped vireo breeding range in Texas in 2010.

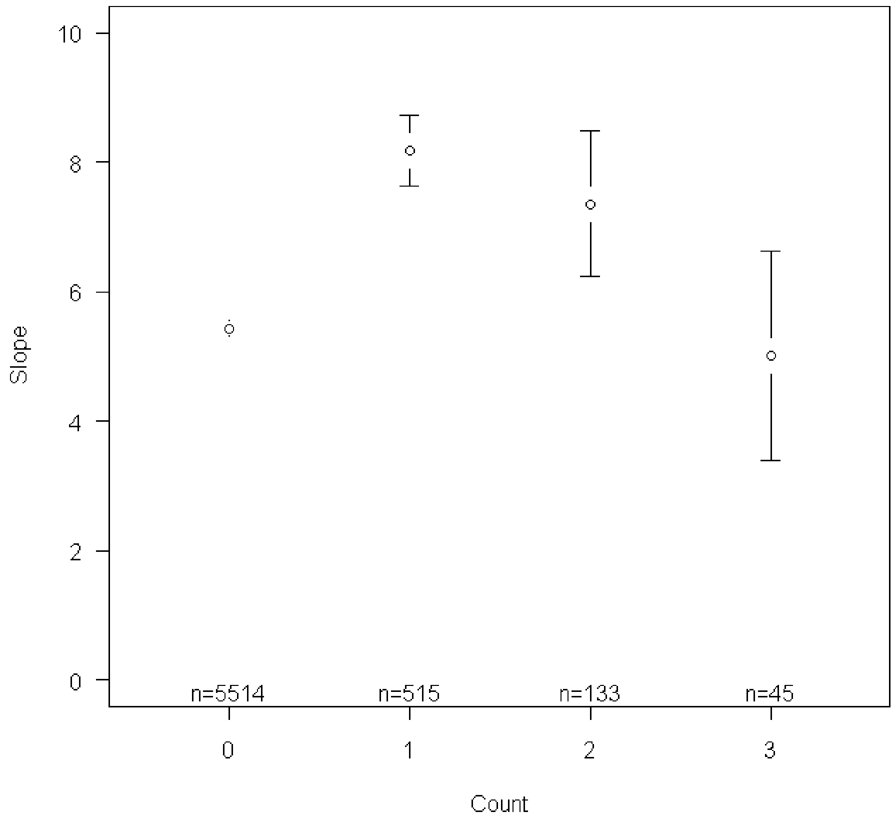


Figure I-7. Mean and 95% confidence intervals for slope (°) within 100 m of point surveys and number of vireos detected at the survey point (count) from study sites across the black-capped vireo range in Texas in 2010.

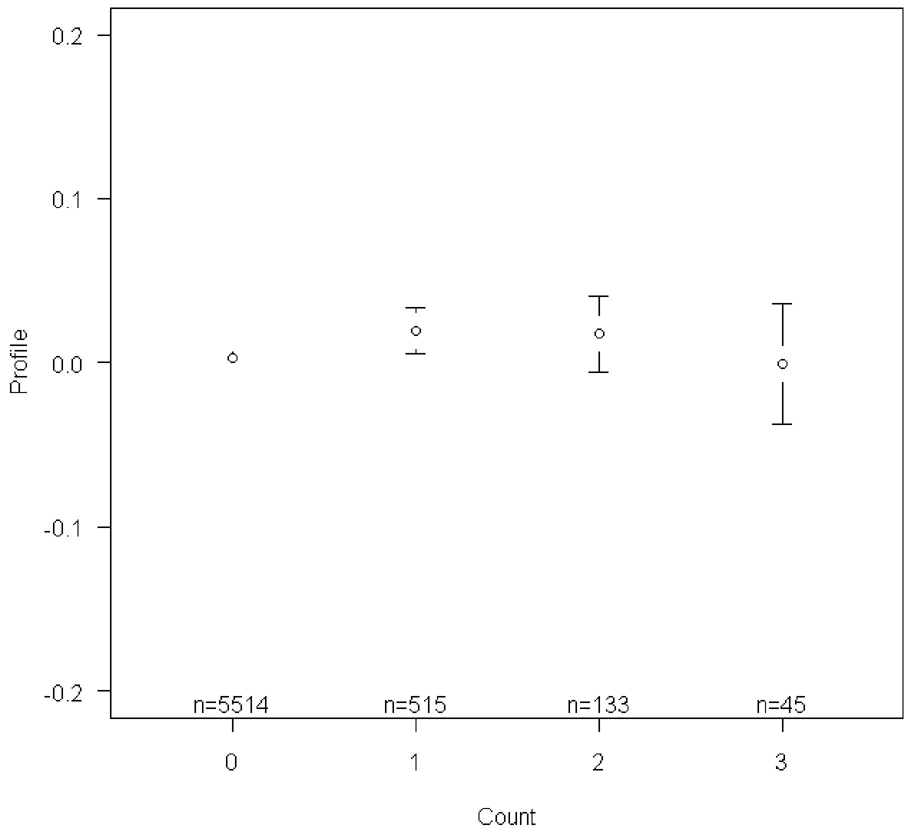


Figure I-8. Mean and 95% confidence intervals for profile curvature (°/100 m) within 100 m of point surveys and number of vireos detected at the survey point (count) from study sites across the black-capped vireo range in Texas in 2010.

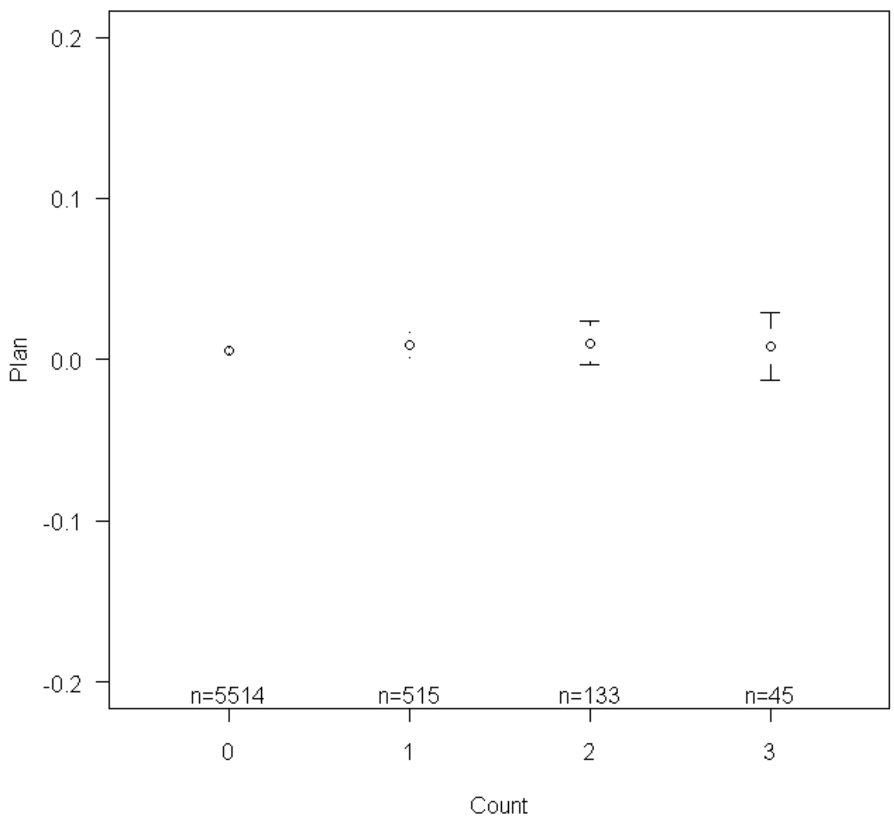


Figure I-9. Mean and 95% confidence intervals for planimetric curvature (°/100 m) within 100 m of point surveys and number of vireos detected at the survey point (count) from study sites across the black-capped vireo range in Texas in 2010.

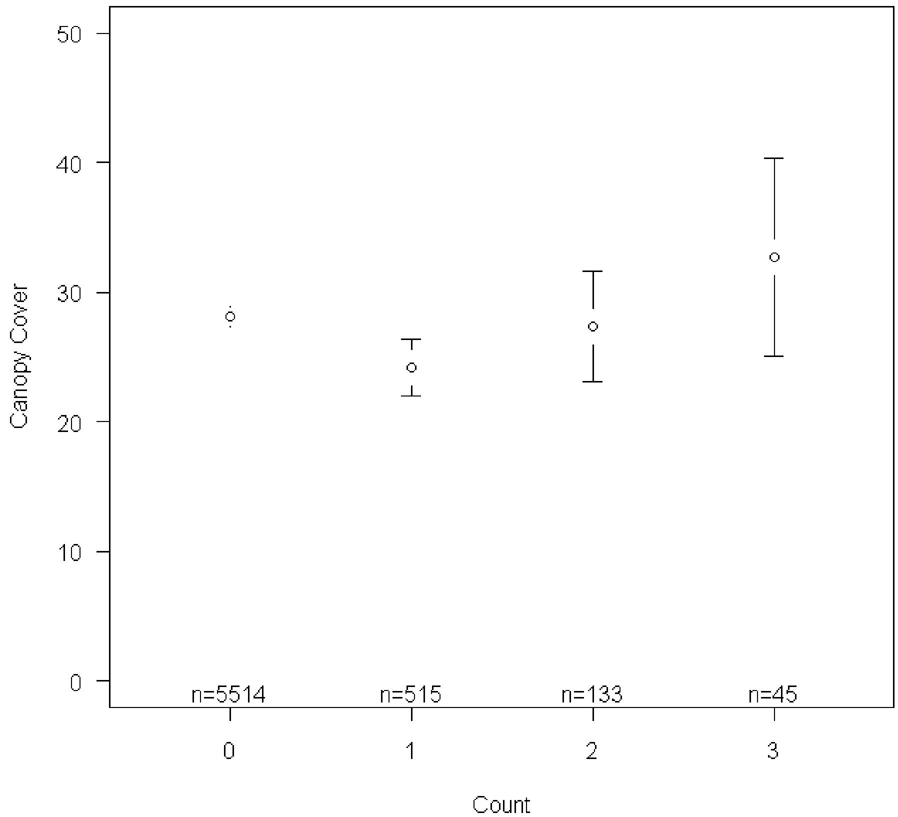


Figure I-10. Mean and 95% confidence intervals for canopy cover (%) within 100 m of point surveys and number of vireos detected at the survey point (count) from study sites across the black-capped vireo range in Texas in 2010.