Point Blue Report

Evaluating meadow restoration in the Sierra Nevada using birds and their habitat associations


Report to the National Fish and Wildlife Foundation

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Cover photos*: The Yellow Warbler (*Setophaga petechia*) is now an abundant species along this restored reach of Red Clover Creek in the Upper Feather River watershed. Photos by Tom Grey and Stefan Lorenzato, respectively.*

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EXECUTIVE SUMMARY

Restoration to reverse declines in meadow health has become a management priority in the Sierra Nevada. Any attempt to determine the extent to which natural resources have been conserved or restored requires an ecological status assessment. To help in the evaluation of Sierra Nevada meadow restoration, we analyzed bird and habitat data from 1242 point count locations across 171 transects in meadows surveyed by Point Blue Conservation Science (Point Blue) and the Institute for Bird Populations (IBP) from 2010 to 2012. The overarching goal of this project was to provide metrics for evaluating meadow restoration and current management across the Sierra Nevada, while filling important information gaps on meadow birds to more effectively inform their management. In this report: (1) we estimate the detection probabilities and abundances of a suite of 11 focal bird species in Sierra Nevada meadows and identify their habitat associations; (2) we recommend metrics and target densities of birds to be used on the National Fish and Wildlife Foundation scorecard; (3) using our proposed metrics and targets of restoration success, we evaluate the progress of meadow restoration at the scale of the Sierra Nevada since 2010.

The factors that influenced the abundance of focal species varied, as would be expected based on our criteria for selection. However, clear patterns emerged among species and for focal species richness. Willow cover, shrub height, conifer cover, and hardwood cover were the strongest vegetation predictors and elevation, latitude, and precipitation were the strongest geographical predictors. The habitat associations of meadow focal species presented in this report can be used to help prioritize and guide meadow restoration efforts across the Sierra Nevada.

Using our avian metrics to measure restoration success, progress has been slow between 2010 and 2012. In 2010, 10.8% of sampled transects/meadows met or exceeded the target of 0.54 Yellow Warbler per acre, and 27.9% met or exceeded the target of 1.03 focal species per acre. By 2012, 12.6% of the same transects/meadows originally sampled in 2010 had met or exceeded the target of 0.54 Yellow Warbler per acre, and 33.3% had met or exceeded the target of 1.03 focal species per acre.

INTRODUCTION

Montane meadows are among the most unique habitat types in the Sierra Nevada. Access to perennial water and distinctive soil types in meadow areas leads to unique plant communities from the adjacent upland (Kondolf et al. 1996). Meadows are also disproportionately valuable compared to the area they cover in the Sierra Nevada for the ecological services they provide (Kattlemann & Embury 1996; Kondolf et al. 1996). Ecologically functional montane meadows are hotspots for biodiversity in the Sierra Nevada (Kattlemann & Embury 1996), and provide vital services such as flood attenuation, sediment filtration, water storage, and water quality improvement (DeLaney 1995; Woltemade 2000; Hammersmark et al. 2008), carbon sequestration (Povirk et al. 2001), and livestock forage (Torrell et al. 1996). Though less than 1% of the area of the Sierra Nevada is comprised of riparian habitat (Kattlemann & Embury 1996), approximately one-fifth of the 400 species of terrestrial vertebrates that inhabit the Sierra Nevada are strongly dependent on riparian areas such as meadows (Graber 1996). The Sierra Nevada's meadows also support several rare and declining bird species, and almost every bird species that breeds in or migrates through the region uses meadows at some point in their life cycle (Siegel & DeSante 1999).

Unfortunately the majority of the meadows in the Sierra Nevada have undergone a long history of degradation to a state that is less productive, supporting fewer species and individuals of native animals and plants, and providing fewer ecological services (Ratliff 1985; Knapp & Matthews 1996; Castelli et al. 2000; Sarr 2002; Krueper et al. 2003). Grazing, timber harvest, roads, culverts, dams, diversions, mining, and alien species invasions have all contributed to meadow degradation (Ratliff 1985). While some meadows have been resilient to these impacts, once a threshold has been passed many of these systems cannot readily recover on their own (Allen-Diaz 1991; Micheli & Kirchner 2002; Chambers et al. 2004; Briske et al. 2008). Restoration to reverse the decline in meadow health has become a management priority in the Sierra Nevada region (NFWF 2010) because of their high ecological value and limited landscape extent. Restoration treatments vary from passive, such as rest from grazing, to active and aggressive, such as channel filling and reshaping with heavy equipment.

Any attempt to determine the extent to which natural resources have been conserved (or restored, in the case of restoration projects) will require some type of ecological status assessment, and, ideally, knowledge gained from such status assessments will inform subsequent conservation actions via the adaptive management process (Holling 1978). Ecological data from monitoring restoration and management actions helps stakeholders make more informed decisions to minimize tradeoffs, seek complementarities among values, and optimize benefits among objectives (Hutto & Belote 2013). One approach to ecological effects monitoring is to focus on groups of organisms that can provide cost-effective information about ecological conditions of interest (Vos et al. 2000; Gram et al. 2001). In this context, birds are an effective tool for monitoring because: (1) many species are easily and inexpensively detected using standardized sampling protocols; (2) these species are sensitive to a wide variety of habitat conditions and their abundance can be used as proxy of habitat quality (Bock and Jones 2004); and (3) accounting for and maintaining many species with different ecological requirements can be used to implement landscape conservation strategies (Hutto 1998). For these reasons, using meadow-dependent bird species as indicators of meadow form and function can be a powerful tool for informing adaptive management and restoration decisions in Sierra Nevada meadows. Birds can be used as indicators to identify conservation priorities, help guide meadow restoration design and management prescriptions, and establish and evaluate management and conservation targets. Birds are known to respond rapidly and dramatically to riparian restoration efforts in the Western United States (e.g. Krueper et al. 2003; Gardali et al. 2006)

We analyzed bird and habitat data from 1242 point count locations across 171 transects in meadows surveyed by Point Blue Conservation Science (Point Blue) and the Institute for Bird Populations (IBP) from 2010 to 2012. Pooling data from both organizations resulted in, to our knowledge, the largest meadow bird dataset ever analyzed from the Sierra Nevada. The data were collected from a diverse sample of meadows that covered an expansive range of latitudes, elevation, and meadow conditions. The overarching goal of this project was to fill important information gaps on meadow birds to more effectively inform and evaluate meadow restoration and current management across the Sierra Nevada.

In this report: (1) we estimate the detection probabilities and abundances of a suite of 11 focal bird species in Sierra Nevada meadows and identify their habitat associations; (2) we recommend metrics and target densities of birds to be used on the National Fish and Wildlife Foundation scorecard; (3) using our proposed metrics and targets of restoration success, we evaluate meadow restoration at the scale of the Sierra Nevada since 2010.

METHODS

Study Location

The study area for the analysis in this report is bounded by the US Forest Service Sierra Nevada Planning Area, which includes portions of the southern Cascades and Modoc Plateau (USDA 2004; Figure 1).

Sampling Designs

We combined data from three projects with varying spatial extents, sampling effort, and study designs that focus solely or partially on monitoring birds in meadow habitat in this region. For the purposes of this analysis, our definition of what constitutes a meadow may be both narrower and broader than others. Our definition follows American Rivers (2012) except we included in our definition low-gradient (<6%) willow- and alder-dominated "stringer meadows." In addition, the vast majority of meadows in this dataset contain a stream channel.

Each of the three projects followed a separate sampling design protocol. Point Blue's Sierra Meadows (SIEAMEA) project focuses on non-random site selection of public and private riparian meadows (meadows with a stream channel) in the Feather River and Deer Creek watersheds, with the majority of sites the focus of past or future management changes (e.g. pond-and-plug restoration, removal of grazing), and represent a range of elevations and habitat conditions. Point Blue's Sierra Nevada Management Indicator Species (SNMIS) project focuses on random sampling of riparian habitat throughout the USFS Region 5 Sierra Nevada Management Area. We used site visits, aerial imagery, and vegetation data to exclude those sampling locations on the SNMIS project outside of riparian meadow habitat. IBP's Bird Monitoring in Sierra Meadows project (BMSM) used non-random site selection focused on wet meadows with planned or recent hydrological restoration projects, but also included meadows with restoration involving only modified vegetation or other landscape features without attempting to restore hydrologic processes. Each of those restoration sites were paired with at least one nearby reference site and occurred on both public and private land.

Bird Data

Point count data allow us to measure secondary population parameters such as avian abundance, species richness, and diversity. This method is useful for making comparisons of bird communities across time, locations, habitats, and land-use treatments. Each of the three projects used different point count survey protocols. Point Blue conducted standardized five-minute variable circular plot point counts (Reynolds et al. 1980; Ralph et al. 1995). Point Blue recorded all birds detected in one of six distance categories (< 10 m, 10–20 m, 20–30 m, 30–50 m, 50–100 m, and >100 m; SIEMEA) or assigned each bird an exact distance up to 300 m (SNMIS) based on the initial detection distance from the observer, and recorded the method of initial detection (song, visual, or call). IBP conducted 7-minute point counts, divided into three smaller time intervals. All birds were classified as being either <50 m from the survey station at first detection, or at a distance >50 m. The highest resolution of data attainable from the pooled protocols was the count of individuals for each species detected in a five-minute period within 50 m of the observer. On all projects, survey locations were clustered on transects spaced at least 200 m apart. Transects were visited once or twice between 20 May and 15 July in 2010–2012, except all survey locations on IBP's project were not visited in 2011, and some IBP sites surveyed in 2010 were not surveyed in 2012, whereas a few were added in 2012. Surveys began after sunrise and were completed within 5 hours of sunrise.

Vegetation Habitat Data

Like the bird data, the vegetation data were also collected using three different, but very similar, survey protocols. For all protocols observers visually estimated the percent covers of vegetation as if looking down from above a 50-m radius plot centered on a point count location. Vegetation was split into multiple strata, each of which could theoretically achieve 100% cover. An absolute percent cover was estimated for each strata and the dominant (>5% cover) plant species or functional group (e.g. grass, sedge/rush, or forb) in each strata. For the SIEMEA project, the strata were ground cover, shrubs, trees <5 m tall, and trees >5 m tall. The IBP project had the same strata except the strata splitting height for trees was 4 m. For the SNMIS project, the strata were ground cover, shrubs, sub-canopy, and canopy. In addition to estimating percent covers, observers estimated the height of shrubs. For Point Blue projects, observers estimated the 75th percentile of shrub heights. The IBP project used the proportion of shrubs in three height categories: <1 m, 1–2m, and 2+ meters The highest resolution of data attainable from the pooled protocols yielded seven variables of interest for analysis (Table 1). To calculate conifer cover and deciduous tree cover we summed the covers of these tree types across the two tree strata in each project because there was an unknown amount of overlap between tree strata. Shrub height was calculated as the 75th percentile of shrub heights on the plot in one of four categories – 0 (0 m [i.e. no shrubs]), 1 (0.1–1 m), 2 (1.1–2 m), 3 (2.1+ m) – and treated as a continuous variable for analysis. Vegetation surveys were completed between June and mid-August.

Geographic Habitat Data

We used four geographic variables in our analysis of habitat associations of focal species (Table 1). Because the elevation range of each species' distribution in the Sierra Nevada is typically higher at lower latitudes (Siegel et al. 2011), we examined species' abundances in relation to latitude and to the residuals of a linear regression of elevation on latitude. The latter represents the response of birds to elevation after controlling for latitude. We also examined the effects of precipitation and watershed area on each species' abundance because of the influence of these variables in shaping meadow form and function. To define the watershed area for each survey location we first used the snap pour point tool in ArcGIS 10.1 on the NHDPlus Version 2 hydrological data layer (NHDPlus Team 2012) to find the cell with highest flow accumulation within 100 m of each survey location. We then applied the watershed tool to each of these 'pour points' to define the watershed area for each survey location. Finally, using the PRISM data layer for the average precipitation for the period 1981-2010 at 800 m resolution (PRISM Climate Group 2010), we calculated the average precipitation among all pixels in each watershed area using the zonal statistics toolbox.

Focal Species

We identified 14 focal species based on our cumulative expert opinions: Wilson's Phalarope (*Phalaropus tricolor*), Wilson's Snipe (*Gallinago delicata*), Red-breasted Sapsucker (*Sphyrapicus ruber*), Calliope Hummingbird (*Selasphorus calliope*), Willow Flycatcher (*Empidonax traillii*), Swainson's Thrush (*Catharus ustulatus*), Warbling Vireo (*Vireo gilvus*), Wilson's Warbler (*Cardellina pusilla*), Yellow Warbler (*Setophaga petechia*), MacGillivray's Warbler (*Geothlypis tolmiei*), Song Sparrow (*Melospiza melodia*), Lincoln's Sparrow (*Melospiza lincolnii*), Mountain West White-crowned Sparrow (*Zonotrichia* *leucophrys oriantha*), and Black-headed Grosbeak (*Pheucticus melanocephalus*). Our primary considerations for inclusion were a strong association with meadow or riparian habitat and appropriately surveyed with passive point count methods. As a sum they represented a range of meadow habitat attributes. These species constituted 34% of all detections in the dataset and seven of the top 20 most abundant birds in the dataset (Table 2).

Model Selection and Averaging

We used hierarchical N-mixture models to estimate the detection probabilities and abundances of 11 of the 14 focal bird species and identify their habitat associations. using the package unmarked (Fiske & Chandler 2011) in program R version 3.0.2 (R Core Team 2013). The sample unit of the analysis was a point count location-year, each year of data from a point count location were treated as independent ($N = 2446$). Models did not converge for Wilson's Snipe because of a low number of sample units with detections ($N = 55$), and Wilson's Phalarope and Swainson's Thrush were not sufficiently prevalent in our dataset to be considered for this analysis. The threshold level of significance for all statistical tests herein, unless otherwise noted, was $P = 0.05$ or 95% confidence intervals that did not overlap zero.

We used an F-test to determine whether a negative binomial or zero-inflated Poisson distribution fit better than a Poisson distribution for global models for each species. If there was no statistical difference, the Poisson distribution was used.

We used a forward stepwise model selection process split into two phases to select parameters that best described each species' abundance and detection probability (Table 1). Quadratic terms for those parameters that we determined *a priori* to have potential for a non-linear relationship with abundance or detection probability were included in the model selection process (Table 1). In the first phase we selected the detection parameters in a forward stepwise Akaike information criterion (AIC) ranking process, while keeping the abundance section of the model fully parameterized. All detection parameters in the models ranked within 2 AIC points of the top model were then included in the second phase of model selection, the forward stepwise selection of abundance parameters. For cases where the intercept-only model ranked highest for the detection component, the intercept-only model was used during the second phase. Models from the second phase of selection were again ranked according to AIC. We conservatively wanted to remove weak non-linear effects if the linear-only form had support, so we excluded models within 2 AIC points of the top model that contained non-significant quadratic terms for any parameter represented as significant in a linear-only (non-quadratic) form in a model within 7 AIC points of the top model. We model averaged the detection and abundance parameter coefficients for the remaining models within 2 AIC points using the "modavg.unmarked"function in the package AICcmodavg (Mazerolle 2013).

We calculated the predicted species richness at each sampling location by summing the model-averaged predicted number of species occupying (predicted abundance ≥ 1) each sampling location for each year. For those sampling locations with multiple years of data, we used the maximum number of species among years. Because of low estimated detection probability with the IBP point count protocol, predicted abundances of birds at IBP sampling locations were in some cases unrealistically large. To circumvent this problem, we generated the predictions at IBP sampling locations as if the SNMIS protocol was used, thereby increasing the estimated detection probability, and decreasing the predicted abundances.

We regressed species richness at each sampling location (N = 1242) against a global model containing all of the vegetation and geographic parameters (Table 1) using generalized linear models with Poisson error distribution. We then used backward stepwise model selection using the stepAIC function in the package MASS (Venables & Ripley 2002) to select the most parsimonious model.

Avian Metrics and Measures of Restoration Success

Sierra Nevada meadows are important habitat for a broad range of bird species including several of conservation concern. Thus, we felt it was important to identify targets that both represented the need to restore habitat for species of conservation concern (e.g. Willow Flycatcher) as well promote habitat for the broader meadow associated bird community. Unfortunately, due to its rarity, Willow Flycatcher may not respond to meadow restoration in the short term in many locations, even if ideal conditions are created for them. Indeed, we have yet to document a Willow Flycatcher colonizing a restored meadow where they were not already present on that stream. So while tracking Willow Flycatcher response to restoration is important it should not be the only measure of restoration success for birds. Of the 14 focal species, we determined that Yellow Warbler has the habitat requirements most similar to Willow Flycatcher and therefore a potential surrogate for assessing restoration of habitat conditions preferred by this endangered species. In our dataset, Yellow Warblers were detected at all sites with Willow Flycatchers, but Willow Flycatchers were not detected at all sites with Yellow Warblers. Creating conditions that promote high densities of Yellow Warbler may provide an indication that restoration efforts are on the right track to promoting Willow Flycatcher habitat.

Because meadows are important habitat to a broad range of birds, and species like Yellow Warbler and Willow Flycatcher do not occur across the full gradient of meadows, we desired an additional bird metric to measure the success of restoration. By using focal species density as a measure of meadow habitat quality, we can provide a measure of success for meadows where Yellow Warbler and/or Willow Flycatcher would not be expected to occur and ensure restoration is benefitting the broader ecological community.

The bird metrics that we selected are: (1) the percent of sampled meadows meeting or exceeding a target Yellow Warbler density; and (2) the percent of sampled meadows meeting or exceeding a target focal species density (see Loffland et al. 2014 for our proposed Willow Flycatcher metric). Because we lacked sufficient sampling effort in 2009, the first year of NFWF's Sierra Meadow Restoration Initiative, we used 2010 as the baseline year upon which progress toward NFWF's goals would be measured. The target density and richness were determined using point count data collected in 2010 across 35 IBP and 111 Point Blue point count transects that were also sampled in 2012. We determined the average density of Yellow Warblers and focal species at each transect by first averaging the density among visits to each point count location, and then averaging the density among point count locations in each transect. This yields a transect-scale estimate of density for each breeding season that is roughly equivalent to the scale of a restoration project or meadow.

We used several criteria to select our target densities, including our expert opinions. Our philosophy is that targets of success should aim high to encourage prioritization of sites with higher potential and restore to a high quality condition. Also, we were working under the premise that the majority of meadows in the Sierra Nevada were in a less than optimal state (NFWF Business Plan). Since we proposed the use of Yellow Warbler as a proxy for suitable Willow Flycatcher habitat, we investigated the density of Yellow Warbler in Willow Flycatcher occupied meadows to help inform our target value. Second, we considered previously used avian targets of the 75% of a species density distribution for evaluating restoration of riparian habitats in California (CVJV 2006; Golet 2011). In 2010, the 75th percentile of Yellow Warbler density in occupied meadows was the median value of the distribution of Willow Flycatcher density in Willow Flycatcher occupied meadows. Thus, for Yellow Warbler density, we assumed that the 75th percentile in 2010 represented good quality Yellow Warbler habitat and an indication of suitable Willow Flycatcher habitat. We excluded transects where Yellow Warbler were not detected to remove from the distribution of densities those meadows that are outside of the range of suitable habitat for Yellow Warbler because of abiotic constraints (e.g. the meadow is outside of the elevation range where Yellow Warbler occur, wrong type of meadow) or biotic constraints (e.g. naturally the meadow does not support willow cover sufficient for Yellow Warbler). Some percentage of the meadows excluded may be potential Yellow Warbler habitat, but due to management actions they no longer support a single Yellow Warbler. Excluding those meadows shifts our 75th percentile higher. Including all meadows would have a large effect in biasing this metric low, as we know a substantial percentage of Sierra Meadows are naturally not suitable for this species. For focal species density, we also assumed the 75th percentile of the distribution of transect densities in 2010 represented a good target for restoration. We used data for all 14 meadow focal species to calculate focal species density.

Density is calculated at the scale of a meadow or restoration project (i.e. transect), but can be scaled up to evaluate restoration success and progress toward goals at the scale of NFWF's Sierra Meadows Initiative. The metric is designed to inform us what percentage of the meadows that we monitor can be counted as high quality bird habitat (i.e. restoration success) without the need to explicitly track restoration and management activities. Using our combined monitoring program as a sample of the entire Sierra Nevada, success of the Sierra Meadow Initiative with respect to our bird metrics can be tracked at the Initiative scale as the percent of sampling sites where the target densities are met or exceeded. Improvement in the focal species densities is tracked at those meadows IBP and Point Blue has monitored since 2010. Sampling sites that meet or exceed the target density in 2010 or any year thereafter are counted as meeting the target for restoration success throughout the evaluation period and do not require additional monitoring. Ideally every meadow would be tracked through time since post-restoration management actions could result in meadows dropping below the success criterion after initially achieving it. However, because of the realities of continued funding to monitor all meadows across all years, we believed the approach we took here is more feasible.

Even though we excluded those meadows without Yellow Warbler detections for calculating the target, the target is applied to all monitored meadows because it is not feasible to differentiate exactly which should be excluded on the basis of abiotic constraints. Nonetheless, this discrepancy can be accounted for when tracking progress toward goals at the Initiative scale (see Discussion).

RESULTS

Habitat Associations

Individual species varied in their relationships with covariates of detection probability and abundance (Appendix A), but clear patterns emerged when the predicted species richness at each sampling location was regressed against the habitat covariates used to inform the initial models.

Willow cover and shrub height were the variables most consistently correlated with individual focal species' abundance. Willow cover and shrub height appeared as a significant variable in 9 and 8 of 11 focal species top models, respectively. In every case, including Yellow Warbler and Willow Flycatcher, they had a positive linear relationship with abundance (Figures 2 &3 Appendix A). The consistency among focal species for the selection for these variables resulted in strong positive relationships between these variables and focal species richness (Figures 2 &3, Appendix B).

Conifer cover appeared as a significant variable in 10 of 11 focal species' top model sets, however, among these species, relationships with conifer cover varied from negative linear to positive quadratic. Yellow Warbler and Willow Flycatcher both had a negative linear relationship with conifer cover (Figure 4). The overall relationship of focal species richness with conifer cover is a product of the patterns in individual species (Figure 4, Appendix B). Even those species that had a negatively linear relationship with conifer cover occupy areas with some conifer cover up to a certain extent. Despite the variation in selection for the lower levels of conifer cover among species, all avian metrics were negatively correlated with the sum of sub-canopy and canopy conifer covers greater than 43.5% at the 50-m scale.

Of vegetation covariates appearing in the focal species richness model, deciduous tree cover was the least prevalent of the vegetation covariates in individual focal species' top models, appearing as a significant variable in 6 of 11 top models, including Yellow Warbler (Figure 5, Appendix A). Deciduous tree cover was a nearly significant variable in the focal species richness model, with a weak positive relationship (Figure 5, Appendix B).

The last three vegetation variables – alder, sage, and herbaceous covers – did not appear in the focal species richness model (Appendix B), but were represented to a small extent in the individual focal species top models (Appendix A). Alder cover was significantly positively correlated with the abundances of four focal species. Sage cover was positively correlated with White-crowned Sparrow abundance and negatively correlated (nearly significant) with Wilson's Warbler abundance. Herbaceous cover was significant and positively correlated with Song Sparrow and Lincoln's Sparrow abundance and negatively correlated with MacGillivray's and Wilson's Warbler abundance.

Three geographic variables appeared in the focal species richness model: elevation, latitude, and precipitation (Appendix B). Elevation had a generally negative relationship, but with a slight increase in species richness at the highest elevations (Figure 6). The lowest elevation meadows had the highest predicted species richness of 3.1 species per acre while higher elevations, not quite to the top, had the lowest predicted species richness of 1.2 species per acre. Predicted species richness increased modestly to 1.5 birds per acre at highest elevations in the study area. Yellow Warbler and Willow Flycatcher were also both negatively associated with elevation (Figure 6). Focal species richness was positively associated with latitude, with a peak of 1.4 focal species per acre at 40.63°, just north of Lassen Volcanic National Park, and a slight decline to 1.3 focal species per acre at 41.85°, the highest latitude (Figure 7). Predicted Yellow Warbler density peaked at 39.79°, at the latitude of Blairsden, CA (Figure 7). Predicted Willow Flycatcher density peaked at 40.39°, just north of Chester, CA (Figure 7). Predicted focal species richness tripled from 13.9 inches to 62.4 inches of average precipitation, but past 62.4 inches, predicted focal species richness declined as quickly as it rose (Figure 8). There was no relationship between precipitation and Yellow Warbler and a weak relationship with Willow Flycatcher (Figure 8).

Watershed area was well represented in individual focal species top models, but it did not appear as significant predictor of focal species richness, likely because the relationship with watershed area was so variable among species (Appendix A). Of the species with significant relationships with watershed area, three were positive quadratic, including Yellow Warbler (Figure 8), five were negative linear (one nearly significant), and one was positive linear.

Measures of Restoration Success

In 2010, the 75th percentile of Yellow Warbler densities at transects where at least one Yellow Warbler was detected was 0.54 Yellow Warbler per acre. This was also the median value of Yellow Warbler density in Willow Flycatcher occupied meadows. The 75th percentile of richness was 1.03 focal species per acre.

We measured progress from the 2010 baseline through the year 2012. In 2010, 10.8% of sampled transects/meadows met or exceeded the target of 0.54 Yellow Warbler per acre, and 27.9% met or exceeded the target of 1.03 focal species per acre. By 2012, 12.6% of the same transects/meadows originally sampled in 2010 had met or exceeded the target of 0.54 Yellow Warbler per acre, and 33.3% had met or exceeded the target of 1.03 focal species per acre.

DISCUSSION

Habitat Associations

The habitat associations of meadow focal species presented in this report can be used to help prioritize and guide meadow restoration efforts across the Sierra Nevada. Using the remotely sensed variables can help identify priority geographies. Local scale variables of importance can be used to determine meadows where these attributes can most effectively be restored, guide restoration design, and inform long-term management.

With respect to elevation, the focal species richness, Yellow Warbler and Willow Flycatcher models suggests lower elevation meadows should be given higher priority if restoring habitat for these species and overall meadow bird richness is an objective.

However, we suggest that meadows at very low elevations should be prioritized cautiously. Inspection of our data suggests a third-order polynomial term, which was not included in this analysis, may have captured a drop in species richness at the lowest elevations. Unfortunately, the elevation extremes were not sampled evenly throughout the study area – there was a slight bias toward sampling the lowest elevations towards the center of the sampled latitudes, and the highest elevations (largest residuals) toward the highest latitudes. Thus, our latitude corrected measure of elevation predicted elevation values at both higher and lower elevations than our sampling frame. Indeed, there are very few if any wet meadows below 3,000 feet anywhere in the Sierra Nevada, even though our model predicted these low elevations would harbor the greatest focal richness.

We found that focal species richness and Yellow Warbler and Willow Flycatcher abundance currently peaks between Lassen Volcanic National Park and Truckee, CA. The Little Truckee River and Upper Feather River watersheds probably contain the highest concentration of meadow acres in the Sierra Nevada. The large meadow complexes found here (e.g. Perazzo, Warner Valley, Lake Almanor, Humbug Valley) support most of the remaining breeding Willow Flycatcher in the Sierra Nevada along with high densities of Yellow Warbler (Burnett et al. 2006; Loffland et al. 2014). The pace and scale of meadow restoration over the last 15 years has also been highest in these watersheds (except possibly the Upper Truckee River), potentially contributing to the area's importance to meadow dependent birds. Restoring and protecting additional meadows in this area should be a high priority.

With respect to precipitation, the focal species richness and Willow Flycatcher models suggest that meadows with watersheds that average 63 inches of precipitation should be given highest priority. Only 11% of the points in this study had precipitation greater than the level at which species richness was maximized. Thus, we suggest restoration target watersheds with higher annual precipitation – likely those further north and west of the crest.

Climate change is projected to result in geographic shifts in the climate envelope for meadow focal species (Stralberg et al. 2009) and should be carefully considered when prioritizing meadows for restoration. The lower elevation meadows are probably the most vulnerable to climate change impacts (Kershner 2014). Meadows with upstream watersheds that are identified as too wet to be optimal for focal species now may not be too wet in our future climate. Prioritizing elevations and latitudes that, according to our results, are too high or too far north now may also be warranted.

Willow is probably the single most important habitat feature for meadow dependent birds in the Sierra Nevada. Our results indicate that species richness continues to increase as shrub cover exceeds 50% within a 50 m radius. The combination of a strong association with both shrub height and willow cover can be translated as a strong association with shrub volume. Deciduous shrubs provide nesting and foraging substrate for the majority of the focal species. Re-establishing or enhancing a riparian deciduous shrub component in meadows should be among the top priorities of meadow managers and restoration practitioners to benefit birds in the Sierra Nevada. It is important to consider that even though willow cover was consistently correlated with focal species' abundance and richness, while alder cover was not, these were the only riparian deciduous shrub species included in this analysis. For some of the focal species, willow cover is likely selected in conjunction with other riparian deciduous shrubs that often coexist with willows. In a previous analysis of habitat associations of meadow birds in the North Fork Feather River and Deer Creek watersheds, MacGillivray's and Wilson's Warblers were more strongly associated with deciduous shrub cover in general compared to willow cover (Campos & Burnett 2012). To maximize species richness meadows that support both willow and other riparian shrubs (e.g. *Cornus spp*.) should be considered. There are several ways to increase willow cover and maximum shrub heights: restore floodplain function and ground water elevation, plant dense clumps of willow stakes, and reduce grazing pressure where livestock are high-lining existing willow cover or impacting regeneration. While meadows often do not naturally support more than 50% shrub cover averaged over the entire meadow area, managing for dense clumps of riparian shrubs interspersed with openings would provide habitat for the greatest number of meadow dependent birds. Some meadow associated birds; including Sandhill Crane, Wilson's Snipe, and Wilson's Phalarope; readily occur in meadows with no deciduous shrub cover. These species also readily used use meadows with substantial patches of deciduous shrub cover. Given the outstanding importance of deciduous shrubs to meadow birds, restoration efforts intending to benefit meadow breeding birds should prioritize meadow hydrogeomorhpic types (Weixelman et al. 2011), that support this vegetation component.

The positive association of a number of species and focal richness with conifer cover is of interest. Conifer removal is one of the most common meadow restoration actions occurring in the Sierra Nevada. The percent cover of conifers with which focal species are positively correlated seems high because it is the sum of two strata of vegetation, each of which could theoretically achieve 100% cover. In a previous analysis of a subset of this data, we found a peak in focal species richness at 18% conifer cover in either the sub-canopy or canopy (Campos and Burnett 2012). Those species in this analysis with maximum predicted abundances near 40% cumulative sub-canopy and canopy conifer cover are likely aligned with meadow edges and/or narrow meadows with a high edge-to-area ratio such as Wilson's and MacGillivray's Warbler, Warbling Vireo, and Calliope Hummingbird. For every species with a positive correlation with conifer cover, a negative quadratic term was also a significant predictor illustrating the negative aspects of too much conifer cover in meadows. We recommend that managers consider removing encroaching conifers when either the overstory or understory conifer cover in the meadow footprint exceeds 20% or at lower levels if they are negatively influencing other important meadow attributes (e.g. willow vigor, soil moisture). Except in areas occupied by Great Gray Owl (a species not analyzed herein), we do not recommend that smaller or narrower meadows with higher edge-to-area ratios be prioritized for restoration until further research is done to test the effects of meadow size and shape and bird species abundance and composition. But, our results here suggest that meadow edges with conifer cover may be important habitat for a number of focal species. Likewise, aspen and cottonwood both support high abundance of some meadow focal species. Enhancing these habitat components where they exist in meadows around their periphery would benefit a number of species.

We only found two species for which herbaceous cover was a significant predictor of abundance. There may be several reasons why high herbaceous cover was not positively associated with most focal species. The species in the analysis that were positively associated with herbaceous cover are the only two that nest in herbaceous cover. The other nine focal species nest in shrubs or trees and herbaceous cover is often reduced underneath dense patches of shrubs and trees. Better metrics of meadow health related to herbaceous cover that could be easily measured in the field and may influence more species' abundances could be the ratio of graminoids to forbs, a measure of bare ground and/or the height of herbaceous vegetation.

Sagebrush cover was included in top models for a number of focal species but was rarely a significant predictor, and was not included in the species richness model. Sagebrush is often an indicator of meadow degradation, but its distribution is limited to the eastern Sierra meadows and the Modoc plateau. We included it here as a potential proxy of meadows with impaired hydrology, but its limited extent within our study area likely limited its utility. An evaluation of depth to ground water or a measure of floodplain connectivity (e.g. bank height to width ratio) on meadow focal bird species is needed.

Measures of Restoration Success

According to our metrics of restoration success, in 2012 only one-third of Sierra Nevada meadows met the criteria of high-quality habitat for focal species richness and less than 15% met the criteria for high-quality habitat for Yellow Warblers. One challenge of using birds or any meadow wildlife species to evaluate restoration success is the lag time between restoration implementation and suitable habitat development. Changes in management or floodplain restoration may take a number of years to translate into high quality meadow bird habitat, namely dense thickets of relatively tall willow. In the Feather River watershed we found meadows restored using plug and pond techniques had significantly higher focal species richness and abundance within 4–5 years after restoration. Thus, it is possible to realize significant gains in habitat within the timeframe of the NFWF Initiative. We would expect a number of the sites in our dataset that have been restored in the last 3 years will begin to show increases in focal species in the next couple of years. These metrics should be evaluated for improvement on a yearly or biannual basis.

We did not define explicit goals for the percent of transects that meet or exceed the target metrics, however, here we present a possible way of setting such goals (Table 3). The goals could be based on the target of 60,000 acres NFWF hopes will be restored by 2019 according to the Sierra Meadow Business Plan. For example, 60,000 acres is 31.3% of the estimated total area of meadows in the Sierra (Viers et al. 2013). Because the focal species richness target applies to all meadows, the goal for focal species richness density would be to increase the 2010 baseline of 27.9% of transects meeting the target by 31.3%, such that (27.9% + 31.3% =) 59.2% of transects meet or exceed the target focal species richness density by the year 2019. For the Yellow Warbler density, because the target does not apply to all meadows, the acreage goal could be reduced to 60% (our estimate of what percentage of Sierra Nevada meadow acreage could support Yellow Warbler) of the 31.3% of all meadow acres, which is (60% × 31.3% =) 18.8%. The goal for Yellow Warbler density would then be to increase the 2010 baseline of 10.8% of transects meeting the target by 18.8%, such that (10.8% + 18.8% =) 29.6% of transects meet or exceed the target Yellow Warbler density by the year 2019. The percent progress toward the goal is calculated as the percent of sampling sites meeting the target density at the time of assessment, minus the baseline percent, then divided by the percent of sampling sites desired to be restored to the target density. For example, using the above goal for Yellow Warbler, the percent progress toward the goal in 2012 would be (12.6 – 10.8)/18.8 = 9.6%.

Setting targets and assessment of achievement should be an iterative process. Both the estimates of potential suitable acres and actual number of meadow acres in the Sierra are estimates. As additional information becomes available - including initial assessment of individual restoration projects – and as goals are refined (e.g. 60,000 acres listed in business plan) the targets can be adjusted. The percent progress toward the goal can be calculated on a yearly, or broader, time step. One caveat to this method of measuring restoration success through time is that the same sampling locations used to create the target need to be monitored through the end of the Sierra Meadows Initiative or until they meet the target threshold of restoration success.

Conclusions

Meadows are a small but disproportionately important component of the Sierra Nevada ecosystem. They provide a rich array of ecological services, not the least among them is the biodiversity they sustain. In no other habitat in the Sierra is bird diversity higher. Only three species of bird that breed in the Sierra Nevada are listed as endangered in California: Sandhill Crane, Great Gray Owl, and Willow Flycatcher – dependence on healthy meadows is their common thread. While this report is limited to evaluating breeding bird use of Sierra meadows, we also know that following the breeding season healthy wet meadows are inundated with high densities of a diverse bird assemblage that use these areas for molting and fueling migration. For these reasons, restoration of wet meadows should be among the highest priorities for avian conservation in the Sierra Nevada. In this report we provide new information to help prioritize and guide restoration to maximize benefits to the avian community. There is clearly much work to be done to restore the many thousands of meadow acres that are not currently supporting the densities or diversity of meadow birds they almost certainly once did. As momentum builds to restore the wet meadows of the Sierra Nevada, continued evaluation of meadow restoration projects will be needed to inform the adaptive management process.

LITERATURE CITED

Allen-Diaz, B. H. 1991. Water table and plant species relationships in Sierra Nevada meadows. American Midland Naturalist 126:30–43.

American Rivers. 2012. Evaluating and prioritizing meadow restoration in the Sierra. Report to the National Fish and Wildlife Foundation.

Briske, D. D., B. T. Bestelmeyer, T. K. Stringham, and P. L. Shaver. 2008. Recommendations for development of resilience-based state-and-transition models. Rangeland Ecology & Management 61:359–367.

Burnett, R. D., K. Maute, and D. L. Humple. 2006. Avian monitoring in the Lassen National Forest: 2005 annual report. PRBO Conservation Science, Stinson Beach, CA.

Campos, B. R., and R. D. Burnett. 2012. Avian monitoring in aspen and meadow habitats in the northern Sierra Nevada: 2011 Annual Report. Contribution Number 1881. PRBO Conservation Science, Petaluma, CA.

Castelli, R. M., J. C. Chambers, and R. J. Tausch. 2000. Soil-plant relations along a soil-water gradient in Great Basin riparian meadows. Wetlands 20:251–266.

Chambers, J. C., R. J. Tausch, J. L. Korfmocher, D. Germanoski, J. R. Miller, and D. Jewett. 2004. Effects of geomorphic processes and hydrologic regimes on riparian vegetation. in J. C. Chambers and J. R. Miller, editors. Great Basin riparian areas: ecology, management, and restoration. Island Press, Washington, D.C.

[CVJV] Central Valley Joint Venture. 2006. Central Valley Joint Venture implementation plan - conserving bird habitat. US Fish and Wildlife Service Sacramento, California.

DeLaney, T. A. 1995. Benefits to downstream flood attenuation and water quality as a result of constructed wetlands in agricultural landscapes. Journal of Soil and Water Conservation 50:620–626.

Fiske, I., and R. Chandler. 2011. unmarked: An R Package for Fitting Hierarchical Models of Wildlife Occurrence and Abundance. Journal of Statistical Software 43:1–23.

Gardali, T., A. L. Holmes, S. L. Small, N. Nur, G. R. Geupel, and G. H. Golet. 2006. Abundance patterns of landbirds in restored and remnant riparian forests on the Sacramento River, California, U.S.A. Restoration Ecology 14:391–403.

Golet, G. H. 2011. Using Ecological Indicators to Evaluate Ecosystem Integrity and Assess Restoration Success on the Middle Sacramento River. Final Report to California State University, Chico and the California Bay-Delta Program's Ecosystem Restoration Program.

Graber, G. D. 1996. Status of Terrestrial Vertebrates. Pages 709–734 Sierra Nevada Ecosystems Project: Final Report to Congress. University of California, Center for Water and Wildland Resources, Davis, CA.

Gram, W. K., V. L. Sork, R. J. Marquis, R. B. Renken, R. L. Clawson, J. Faaborg, D. K. Fantz, J. Le Corff, J. Lill, and P. A. Porneluzi. 2001. Evaluating the effects of ecosystem management: a case study in a Missouri Ozark forest. Ecological Applications 11:1667–1679.

Hammersmark, C. T., M. C. Rains, and J. F. Mount. 2008. Quantifying the hydrological effects of stream restoration in a montane meadow, northern California, USA. River Research and Applications 24:735–753.

Holling, C. S., editor. 1978. Adaptive Environmental Assessment and Management. John Wiley and Sons, Inc., New York, New York, USA.

Hutto, R. L. 1998. Using landbirds as an indicator species group. Pages 75–92 in J. M. Marzluff and R. Sallabanks, editors. Avian conservation: research and management. Island Press, Covelo, California.

Hutto, R. L., and R. T. Belote. 2013. Distinguishing four types of monitoring based on the questions they address. Forest Ecology and Management 289:183–189.

Kattlemann, R., and M. Embury. 1996. Riparian Areas and Wetlands. Sierra Nevada Ecosystems Project: Final Report to Congress. University of California, Center for Water and Wildland Resources, Davis, CA.

Kershner, J. M., editor. 2014. A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada. Version 1.0. EcoAdapt, Bainbridge Island, WA.

Knapp, R. A., and K. R. Matthews. 1996. Livestock grazing, golden trout, and streams in the Golden Trout Wilderness, California: impacts and management implications. North American Journal of Fisheries Management 16:805–820.

Kondolf, G. M., R. Kattlemann, M. Embury, and D. C. Erman. 1996. Status of Riparian Habitat. Sierra Nevada Ecosystems Project: Final Report to Congress. University of California, Centers for Water and Wildland Resources, Davis, CA.

Krueper, D., J. Bart, and T. D. Rich. 2003. Response of vegetation and breeding birds to the removal of cattle on the San Pedro River, Arizona (U.S.A.). Conservation Biology 17:607–615.

Loffland, H. L., R. B. Siegel, C. Stermer, B. R. Campos, R. D. Burnett, and T. Mark. 2014. Assessing Willow Flycatcher population size and distribution to inform meadow restoration in the Sierra Nevada and Southern Cascades. The Institute for Bird Populations, Point Reyes Station, CA.

Mazerolle, M. J. 2013. AICcmodavg: Model selection and multimodel inference based on (Q)AIC(c). Available from http://CRAN.R-project.org/package=AICcmodavg.

Micheli, E. R., and J. W. Kirchner. 2002. Effects of wet meadow riparian vegetation on streambank erosion. 1. Remote sensing measurements of streambank migration and erodibility. Earth Surface Processes and Landforms 27:627–639.

NFWF. 2010. Sierra Nevada Meadow Restoration Business Plan. National Fish and Wildlife Foundation.

NHDPlus Team. 2012. NHDPlus Version 2: User Guide. Available from http://www.horizon-systems.com/NHDPlus/index.php.

Povirk, K. L., J. M. Welker, and G. E. Vance. 2001. Carbon Sequestration in Arctic and Alpine Tundra and Mountain Meadow Ecosystems. Page 442 in R. F. Follett, J. M. Kimble, and R. Lal, editors. The potential of U.S. grazing lands to sequester carbon and mitigate the greenhouse effect. CRC Press, Boca Raton, Florida.

PRISM Climate Group. 2010. Gridded climate data for the contiguous USA. Oregon State University. Available from http://prism.oregonstate.edu.

Ralph, C. J., S. Droege, and J. R. Sauer. 1995. Managing and monitoring birds using point counts: standards and applications. Pages 161–169 in C. J. Ralph, J. R. Sauer, and S. Droege, editors. Monitoring bird populations by point counts. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, California.

Ratliff, R. D. 1985. Meadows in the Sierra Nevada of California: State of knowledge. Page 52. General Technical Report PSW-84. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Berkeley, CA.

R Core Team. 2013. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. Available from http://www.R-project.org/.

Reynolds, R. T., J. M. Scott, and R. A. Nussbaum. 1980. A variable circular-plot method for estimating bird numbers. Condor 82:309–313.

Sarr, D. A. 2002. Riparian livestock exclosure research in the western United States: A critique and some recommendations. Environmental Management 30:516–526.

Siegel, R. B., and D. F. DeSante. 1999. The draft avian conservation plan for the Sierra Nevada bioregion: Conservation priorities and strategies for safeguarding Sierra bird populations. Version 1.0, Institute for Bird Populations report to California Partners in Flight.

Siegel, R. B., R. L. Wilkerson, J. F. Saracco, and Z. L. Steel. 2011. Elevation ranges of birds in the Sierra Nevada’s west slope. Western Birds 42:2–26.

Stralberg, D., D. Jongsomjit, C. A. Howell, M. A. Snyder, J. D. Alexander, J. A. Wiens, and T. L. Root. 2009. Re-Shuffling of Species with Climate Disruption: A No-Analog Future for California Birds? PLoS ONE 4:e6825.

Torrell, L. A., J. M. Fowler, M. E. Kincaid, and J. M. Hawkes. 1996. The importance of public lands to livestock production in the U.S. 32, Range Improvement Task Force. New Mexico State University, Las Cruces.

USDA (U.S. Department of Agriculture) Forest Service. 2004. Sierra Nevada Forest Plan Ammendment, Final Environmental Impact Statement, Record of Decision.

Venables, W. N., and B. D. Ripley. 2002. Modern Applied Statistics with SFourth. Springer, New York. Available from http://www.stats.ox.ac.uk/pub/MASS4.

Viers, J. H., S. E. Purdy, R. Peek, A. Fryjoff-Hung, N. Santos, J. Katz, J. Emmons, D. Dolan, and S. Yarnell. 2013. Montane Meadows in the Sierra Nevada: Changing Hydroclimatic Conditions and Concepts for Vulnerability Assessment:63.

Vos, P., E. Meelis, and W. J. T. Keurs. 2000. A framework for the design of ecological monitoring programs as a tool for environmental and nature management. Environmental Monitoring and Assessment 61:317–344.

Weixelman, D., B. Hill, D. Cooper, E. Berlow, J. Viers, S. Purdy, A. Merrill, and S. Gross. 2011. A field key to meadow hydrogeomorphic types for the Sierra Nevada and southern Cascade Ranges in California. US Forest Service, Pacific Southwest Region, Vallejo, California, USA.

Woltemade, C. J. 2000. Ability of restored wetlands to reduce nitrogen and phosphorus concentrations in agricultural drainage water. Journal of Soil and Water Conservation 55:303–309.

TABLES

Table 1. Explanatory variables used in two different steps of modeling of focal species detection, abundance, and richness using point count data from Sierra Nevada meadows.

			Inidividual Species Models		Focal Spp. Richness Model	Quadratic Form Tested?
Variable Type	Variable Name	Description	Abundance	Detection		
Vegetation Habitat	willow cover	percent cover *Salix* species	X		X	
	alder cover	percent cover *Alnus* species	X		X	
	sagebrush cover	percent cover of *Artemisia* species	X		X	
	conifer cover	percent cover of conifer species	X		X	X
	deciduous tree cover	percent cover of deciduous tree species	X		X	
	herbaceous cover	percent cover of herbaceous plant species	X		X	
	shrub height	75th percentile of shrub heights	X	X	X	
Geographic Habitat	elevation	residual of elevation (m) regressed on latitude	X		X	X
	latitude	UTM latitude of the survey location	X		X	X
	watershed area	the area of land that supplies runoff for the survey area	X		X	X
	precipitation	average annual precipitation in watershed area for the period 1981-2010	X		X	X
Survey Covariate	protocol	protocol used for the point count survey		X		
	year	year of the point count survey		X		
	date	Julian date from January 1		X		X
	time	decimal time of survey		X		X

Table 2. The number of detections of focal species (shaded) relative to other species in our combined point count dataset.

Rank	Species	No. of Detections
1	Song Sparrow	2252
2	Yellow Warbler	1634
3	Dark-eyed Junco	1206
4	Red-winged Blackbird	1190
5	Brewer's Blackbird	1114
6	American Robin	871
7	Savanah Sparrow	805
8	Warbling Vireo	757
9	Mountain Chickadee	658
10	Lincoln's Sparrow	618
11	Yellow-rumped Warbler	612
12	MacGillivray's Warbler	558
13	Cliff Swallow	500
14	Wilson's Warbler	492
15	Western Wood-pewee	460
16	Golden-crowned Kinglet	414
17	White-crowned Sparrow	372
18	Brown-headed Cowbird	366
19	Dusky Flycatcher	339
20	Tree Swallow	303
32	Red-breasted Sapsucker	137
40	Calliope Hummingbird	102
46	Black-headed Grosbeak	84
48	Wilson's Snipe	79
49	Willow Flycatcher	74
86	Swainson's Thrush	14
104	Wilson's Phalarope	9

Table 3. An example derivation of Sierra-wide goals for restoration success using Yellow Warbler and focal species richness target densities.

Metric	Target for High-Quality Habitat	2010 Percent of Transects Meeting Target	2012 Percent of Transects Meeting Target	Percent of Meadows Metric Applies To	NFWF Goal for Percent of Sierra Nevada Meadow Acres Restored	Goal for Percent of Meadows Restored for Each Metric	Possible 2019 Goal (percent of transects at target)	Progress Toward Possible Goal (percent)
Yellow Warbler density	0.54 Yellow Warblers per acre	10.8%	12.6%	estimate = 60%	60,000 / 191,900 = 31.3%	60 × 31.3 = 18.8%	10.8 + 18.8 = 29.6%	(12.6 – 18.8) / 18.8 = 9.6%
Focal species richness density	1.03 focal species per acre	27.9%	33.3%	100%	60,000 / 191,900 = 31.3%	100 × 31.3 = 31.3%	27.9 + 31.3 = 59.2%	(33.3 – 27.9) / 31.3 = 17.3%

FIGURES

Figure 1. Sampling locations for the three IBP and Point Blue projects that were pooled for this analysis.

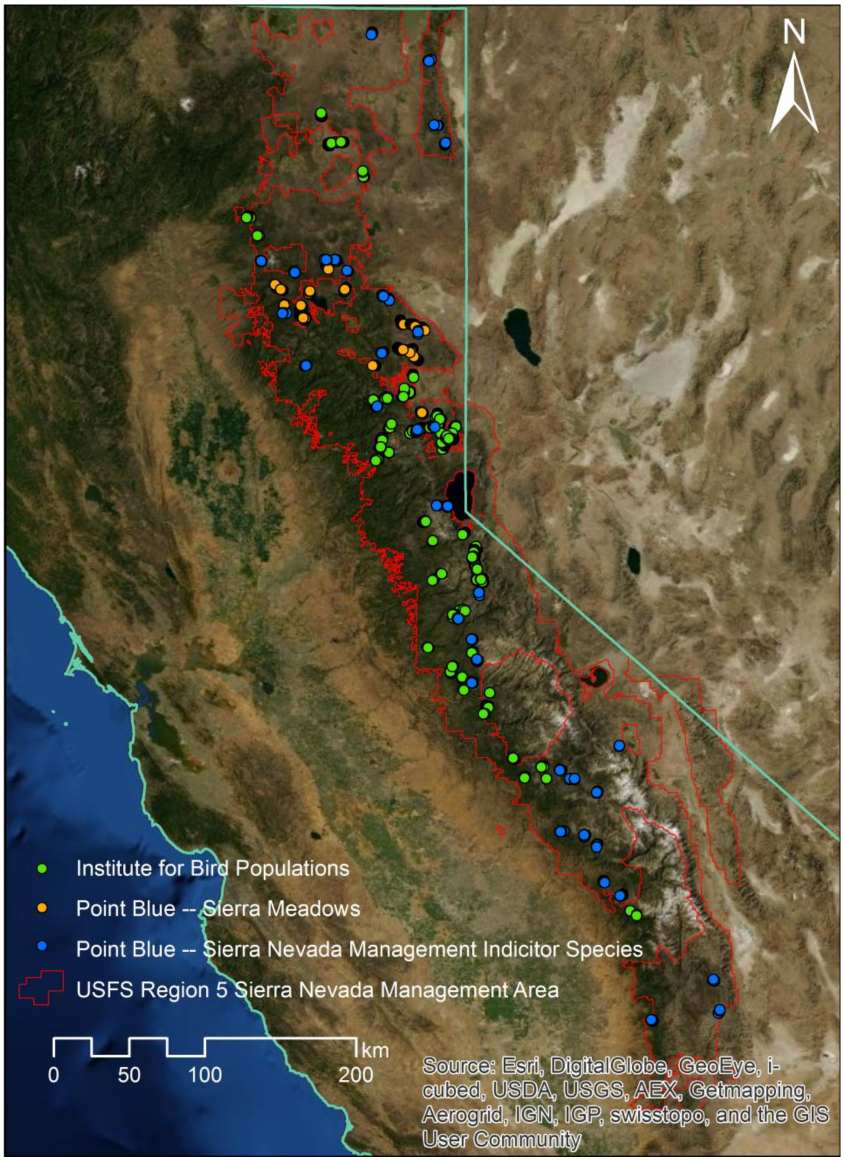


Figure 2. The relationship between willow cover and the predicted density of Yellow Warbler, Willow Flycatcher, and focal species richness (± SE) in Sierra Nevada meadows. All other covariates in the model are held at their mean values.

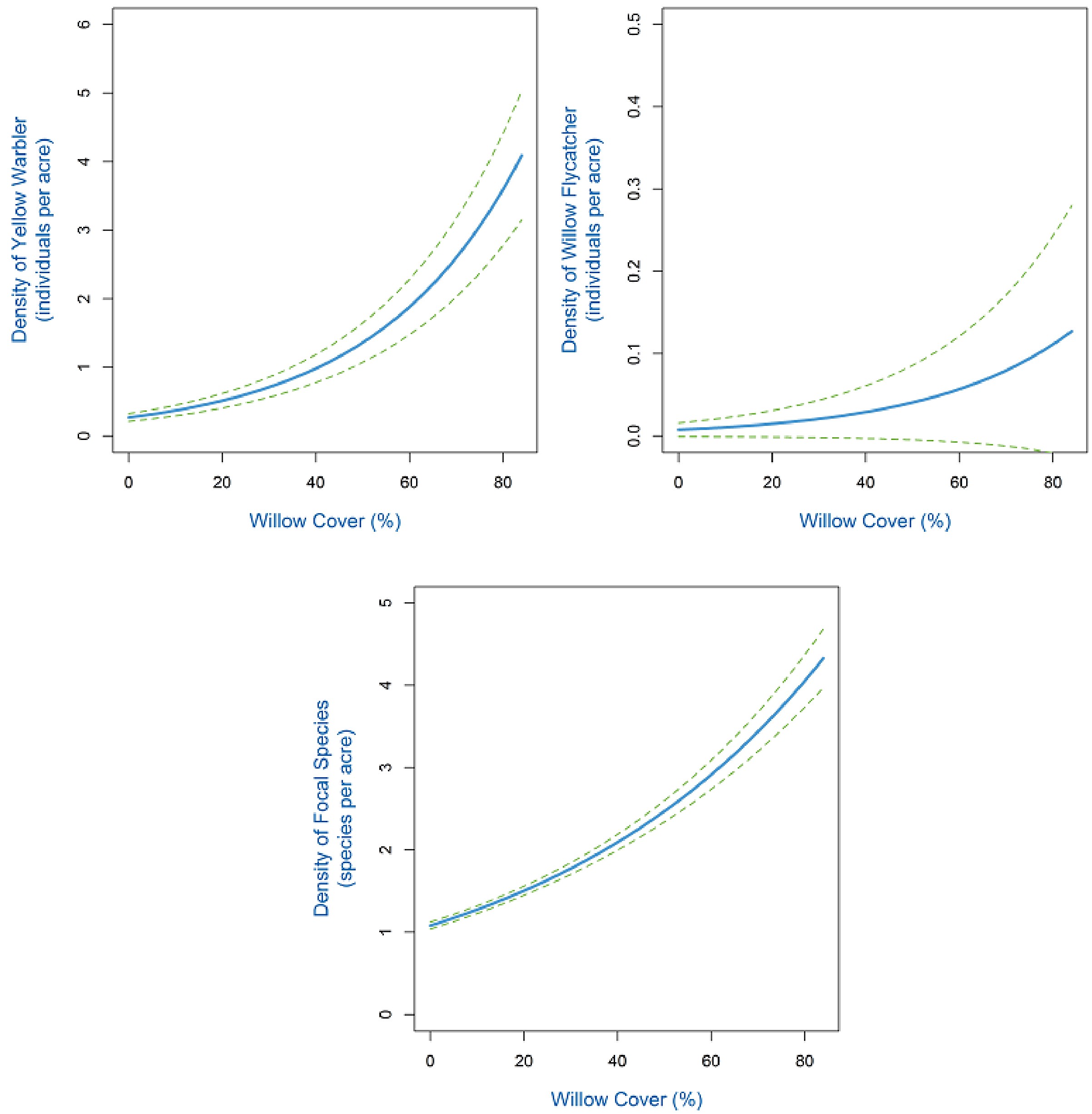


Figure 3. The relationship between shrub height and the predicted density of Yellow Warbler, Willow Flycatcher, and focal species richness (± SE) in Sierra Nevada meadows. All other covariates in the model are held at their mean values.

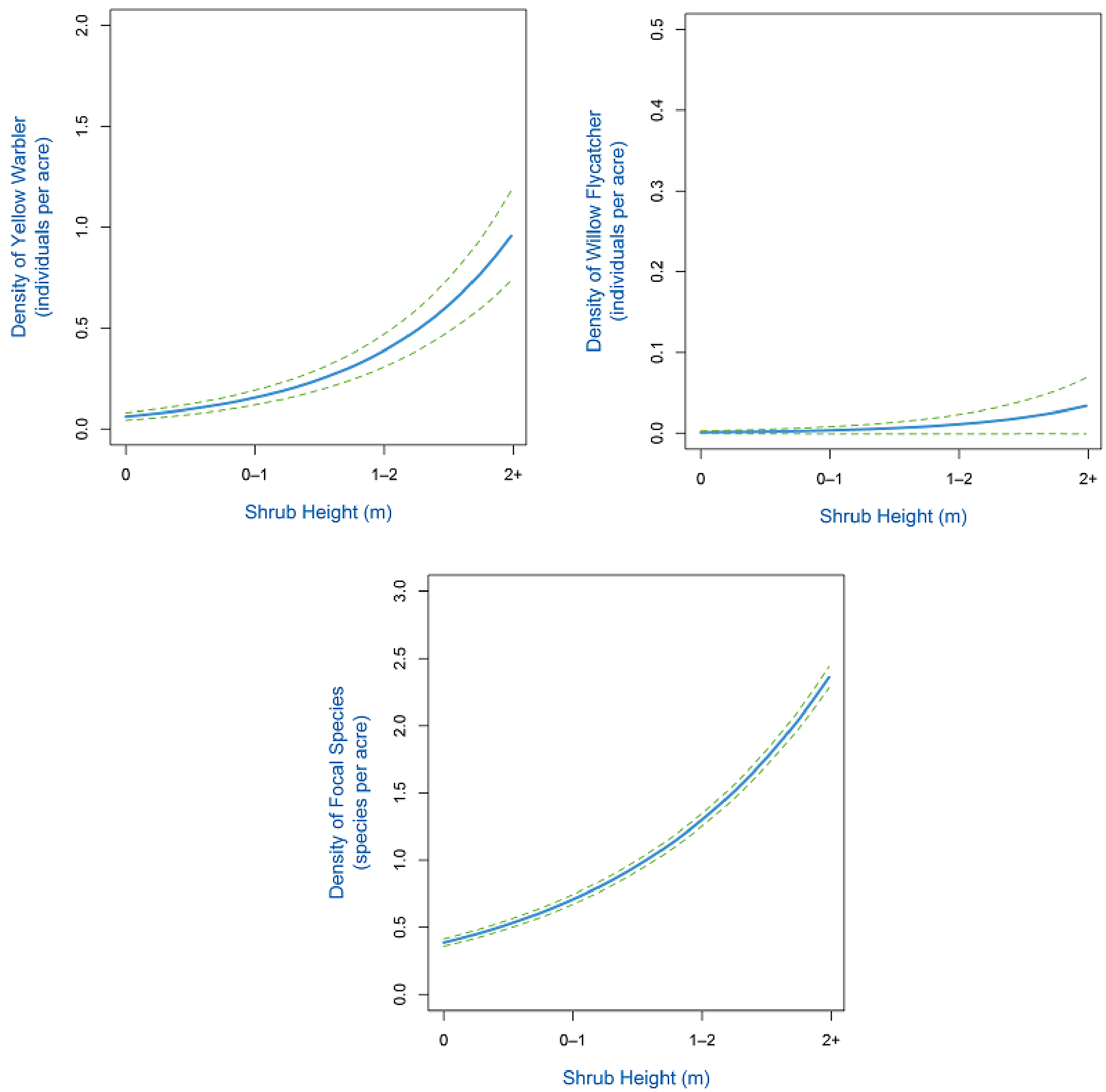


Figure 4. The relationship between conifer cover (calculated as the sum of sub-canopy and canopy) and the predicted density of Yellow Warbler, Willow Flycatcher, and focal species richness (± SE) in Sierra Nevada meadows. All other covariates in the model are held at their mean values.

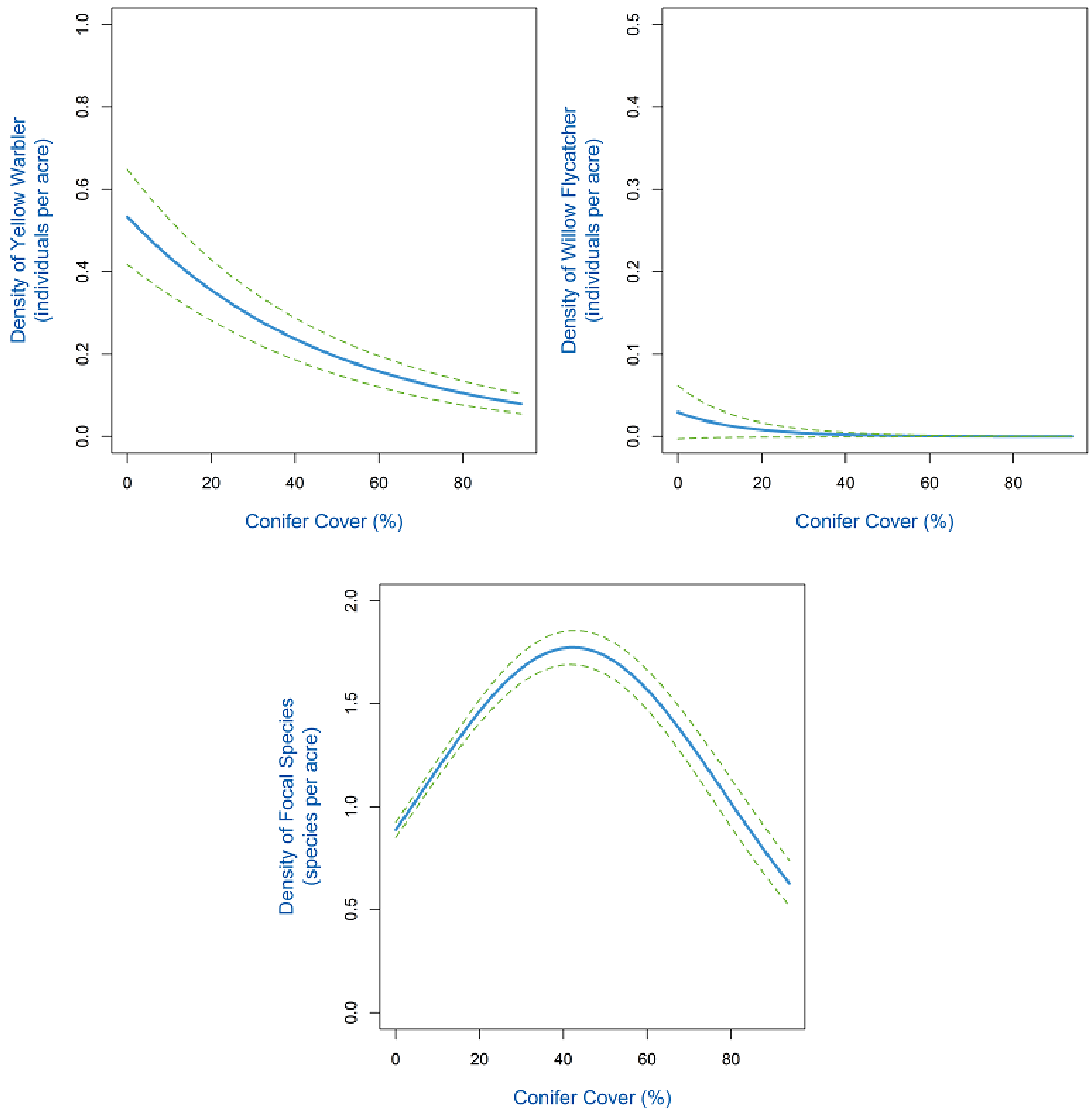


Figure 5. The relationship between deciduous tree cover (calculated as the sum of sub-canopy and canopy) and the predicted density of Yellow Warbler and focal species richness (± SE) in Sierra Nevada meadows. All other covariates in the model are held at their mean values.

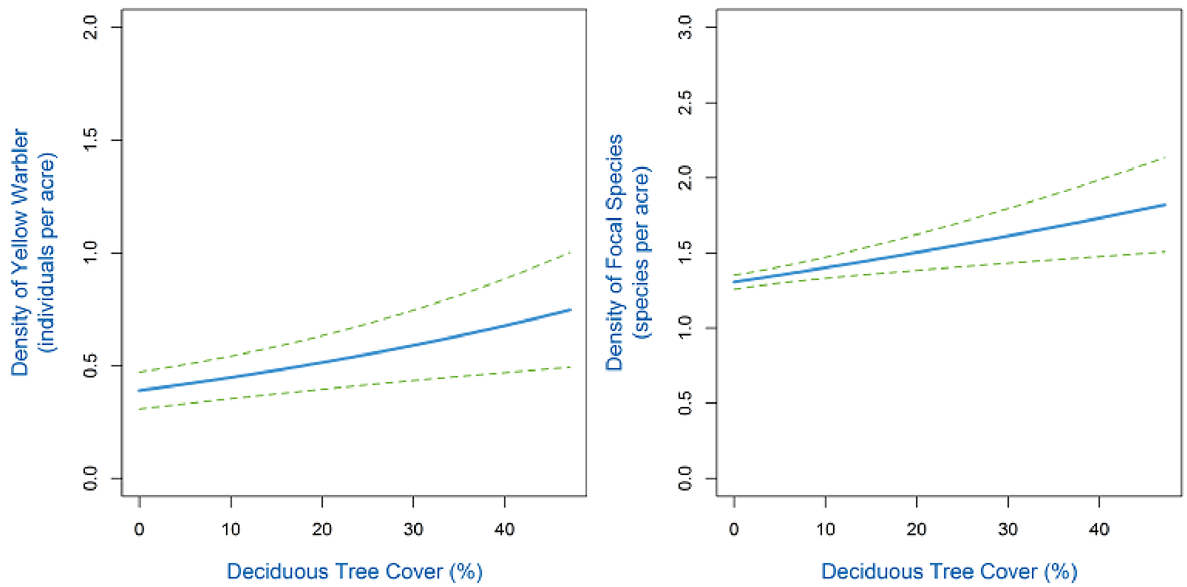


Figure 6. The relationship between the residuals of elevation regressed on latitude and the predicted density of Yellow Warbler, Willow Flycatcher, and focal species richness (± SE) in Sierra Nevada meadows. Higher residuals represent higher elevations and lower residuals lower elevations, after controlling for latitude. All other covariates in the model are held at their mean values.

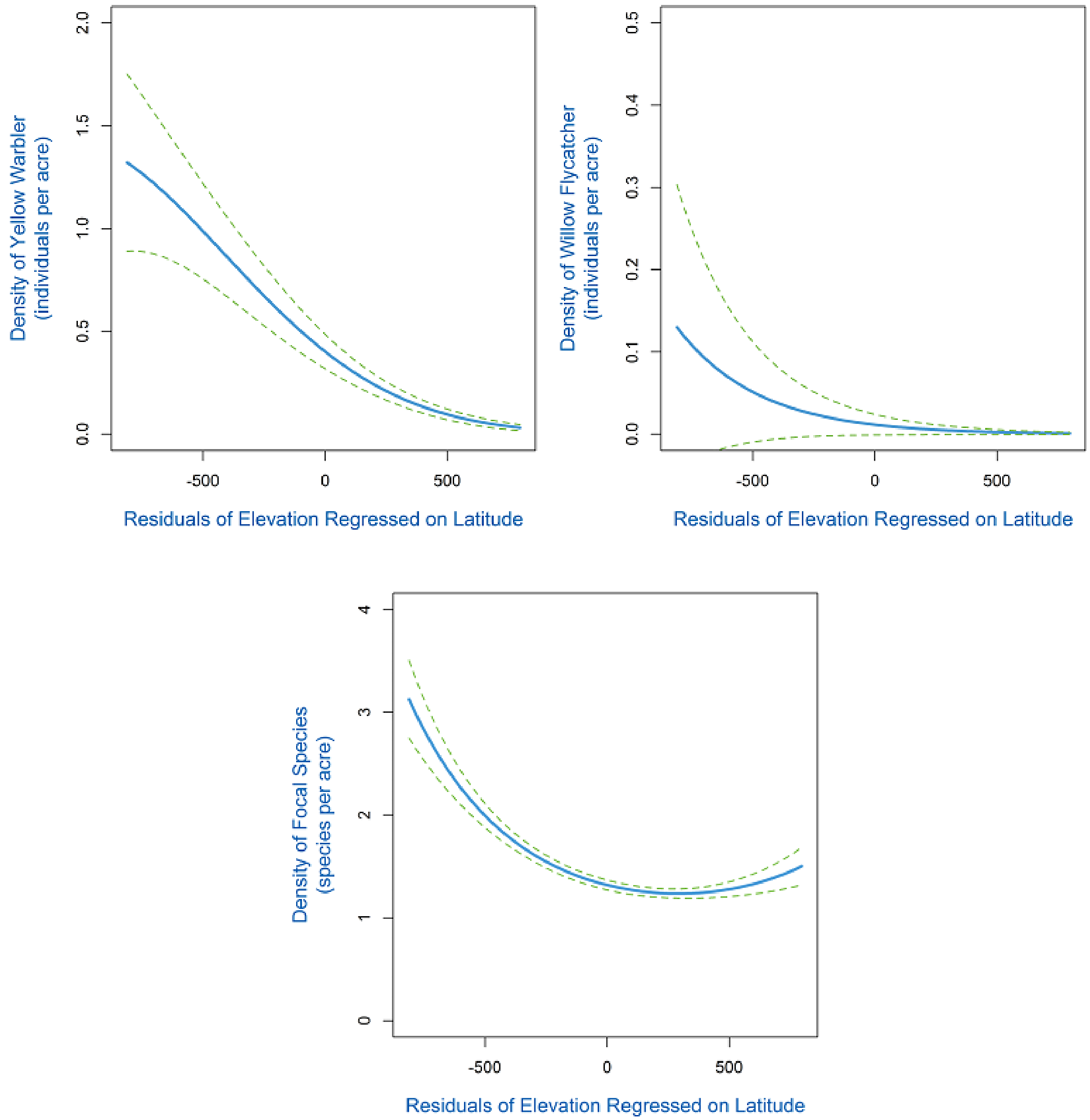


Figure 7. The relationship between latitude and the predicted density of Yellow Warbler, Willow Flycatcher, and focal species richness (± SE) in Sierra Nevada meadows. All other covariates in the model are held at their mean values.

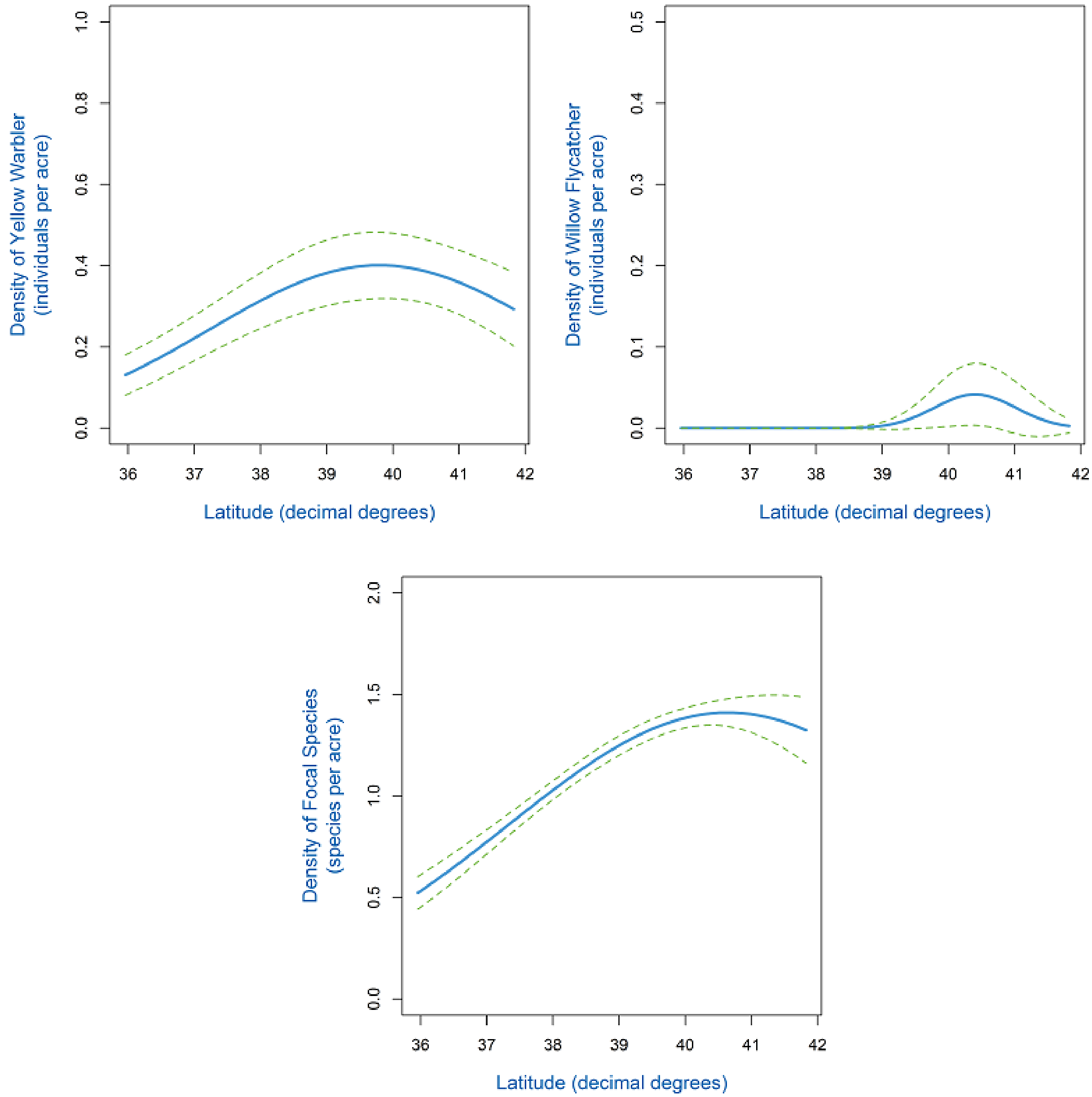
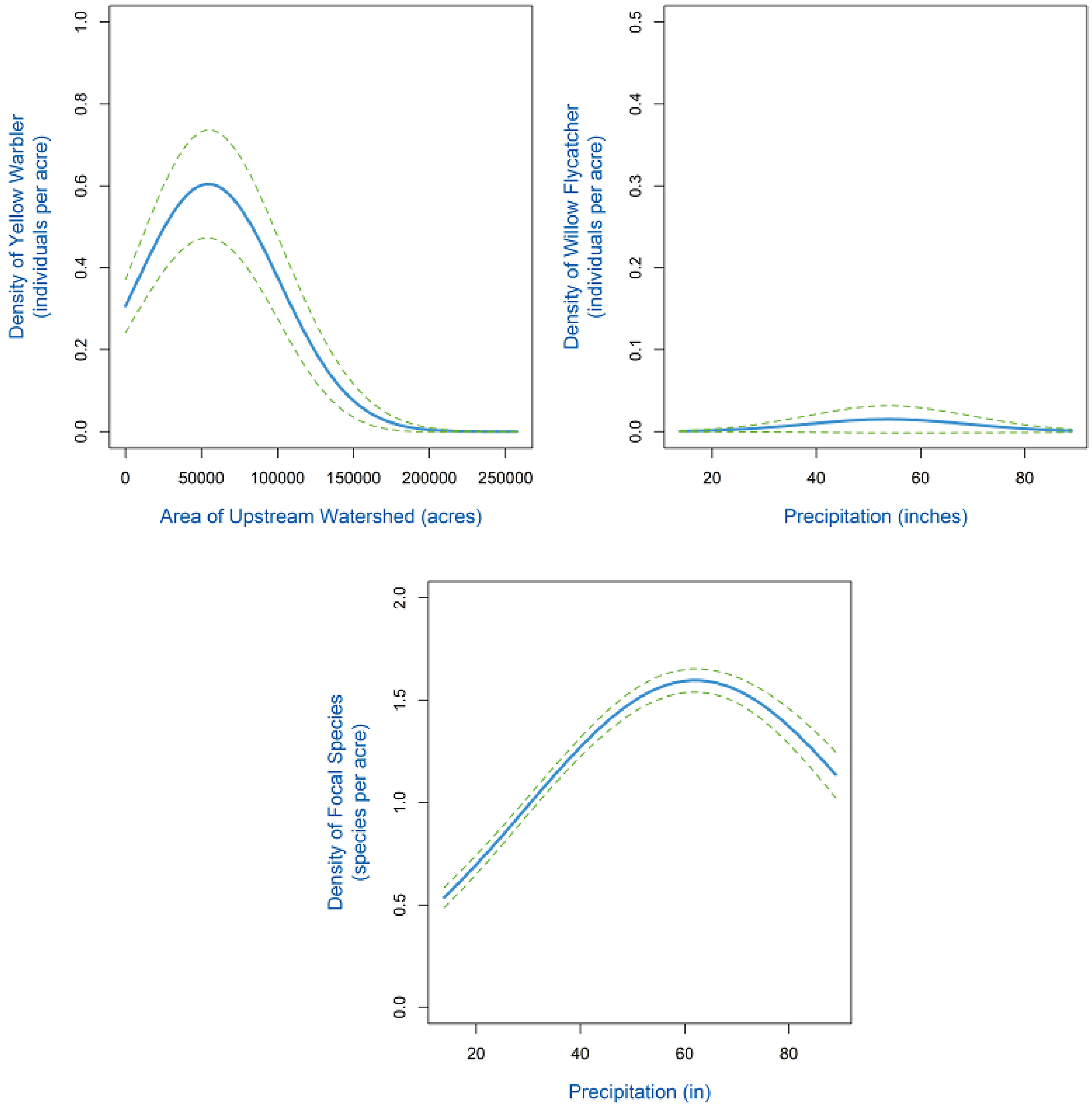


Figure 8. The relationship between the area of upstream watershed and the predicted density of yellow warbler (± SE) and the relationship between annual precipitation in the upstream watershed and Willow Flycatcher and focal species richness (± SE) in Sierra Nevada meadows. All other covariates in the model are held at their mean values.



APPENDICES

Appendix A. The model-averaged estimates of covariates on detection and abundance from hierarchical N-mixture models for 11 meadow focal species. Gray shading indicates a statistically significant parameter.

Species	No. of Sample Units with Detections	Latent Variable	Parameter	Beta	SE	Lower 95% CI	Upper 95% CI
Song Sparrow	951	detection	intercept	-1.41	0.32	-2.03	-0.78
			protocolcodeVCP10_30	0.98	0.44	0.11	1.84
			protocolcodeVCP300	0.92	0.32	0.28	1.55
			time	0.04	0.03	-0.02	0.10
		abundance	intercept	0.35	0.31	-0.25	0.96
			willow cover	0.35	0.02	0.31	0.40
			shrub height	0.69	0.05	0.59	0.79
			conifer cover	-0.31	0.05	-0.42	-0.21
			elevation	-0.41	0.04	-0.48	-0.34
			latitude	0.10	0.06	-0.01	0.22
			precipitation	-0.09	0.04	-0.16	-0.02
			latitude^2	-0.26	0.04	-0.34	-0.17
			deciduous tree cover	-0.09	0.04	-0.16	-0.01
			watershed area	0.32	0.06	0.19	0.44
			precipitation^2	-0.11	0.03	-0.17	-0.05
			herbaceous cover	0.06	0.03	0.00	0.11
			watershed area^2	-0.08	0.03	-0.13	-0.03
			protocolcodeVCP10_30	-0.68	0.25	-1.17	-0.19
			protocolcodeVCP300	-0.25	0.28	-0.80	0.30
			yearcollected2011	0.00	0.07	-0.13	0.13
			yearcollected2012	0.16	0.06	0.05	0.27
Yellow Warbler	708	detection	intercept	-1.67	0.23	-2.12	-1.22
			date	-0.23	0.04	-0.32	-0.14
			date^2	-0.12	0.05	-0.21	-0.03
			time	0.06	0.04	-0.01	0.13
			protocolcodeVCP10_30	1.76	0.27	1.23	2.29
			protocolcodeVCP300	1.19	0.35	0.50	1.87
			shrub height	-0.61	0.20	-0.99	-0.22
		abundance	intercept	0.00	0.19	-0.37	0.37
			willow cover	0.49	0.03	0.44	0.55
			elevation	-0.62	0.05	-0.72	-0.51
			conifer cover	-0.42	0.06	-0.55	-0.30
			elevation^2	-0.07	0.03	-0.14	0.00
			latitude	0.07	0.07	-0.07	0.21
			shrub height	1.09	0.13	0.84	1.34
			latitude^2	-0.11	0.05	-0.21	-0.01
			watershed area	0.51	0.07	0.38	0.65
			deciduous tree cover	0.07	0.03	0.01	0.12
			watershed area^2	-0.16	0.03	-0.21	-0.10
			herbaceous cover	-0.05	0.03	-0.11	0.02
			protocolcodeVCP10_30	-1.06	0.22	-1.49	-0.63
			protocolcodeVCP300	-0.26	0.27	-0.79	0.28
			precipitation	-0.05	0.04	-0.12	0.02
			alder cover	-0.04	0.03	-0.11	0.03

Appendix A (continued)

Species	No. of Sample Units with Detections	Latent Variable	Parameter	Beta	SE	Lower 95% CI	Upper 95% CI
Warbling Vireo	424	detection	intercept	-3.08	0.65	-4.35	-1.82
			protocolcodeVCP10_30	2.35	0.71	0.95	3.74
			protocolcodeVCP300	1.77	0.74	0.31	3.22
		abundance	intercept	0.58	0.62	-0.63	1.80
			precipitation	0.53	0.07	0.38	0.67
			willow cover	0.31	0.05	0.22	0.40
			conifer cover	0.74	0.10	0.55	0.93
			deciduous tree cover	0.18	0.03	0.12	0.24
			conifer cover^2	-0.23	0.04	-0.31	-0.16
			shrub height	0.34	0.07	0.20	0.48
			latitude	0.37	0.07	0.24	0.50
			precipitation^2	-0.20	0.05	-0.29	-0.11
			elevation	-0.22	0.06	-0.33	-0.10
			alder cover	0.08	0.03	0.01	0.14
			watershed area	-0.18	0.10	-0.38	0.02
			protocolcodeVCP10_30	-1.74	0.65	-3.02	-0.46
			protocolcodeVCP300	-0.55	0.68	-1.88	0.78
Lincoln's Sparrow	402	detection	intercept	-2.25	0.40	-3.04	-1.46
			date	0.18	0.05	0.07	0.29
			date^2	0.10	0.05	0.01	0.19
			protocolcodeVCP10_30	0.47	0.82	-1.15	2.08
			protocolcodeVCP300	0.35	0.40	-0.44	1.13
			shrub height	-0.37	0.23	-0.82	0.09
		abundance	intercept	-0.31	0.37	-1.03	0.41
			watershed area	-1.22	0.25	-1.71	-0.74
			latitude	-0.23	0.06	-0.35	-0.12
			precipitation	0.33	0.09	0.15	0.51
			sage cover	-0.17	0.11	-0.38	0.04
			precipitation^2	-0.16	0.06	-0.27	-0.05
			shrub height	0.69	0.20	0.31	1.07
			elevation	0.13	0.06	0.01	0.24
			conifer cover	0.48	0.10	0.28	0.67
			herbaceous cover	0.19	0.07	0.06	0.33
			conifer cover^2	-0.13	0.03	-0.20	-0.07
			protocolcodeVCP10_30	-1.26	0.57	-2.38	-0.15
			protocolcodeVCP300	0.11	0.52	-0.91	1.13
			yearcollected2011	-0.28	0.14	-0.57	0.00
			yearcollected2012	-0.13	0.11	-0.35	0.09
MacGillivray's Warbler	371	detection	intercept	-2.29	0.28	-2.84	-1.73
			protocolcodeVCP10_30	0.69	0.24	0.22	1.15
			protocolcodeVCP300	1.06	0.21	0.66	1.47
		abundance	intercept	-1.00	0.24	-1.47	-0.53
			precipitation	0.60	0.09	0.43	0.77
			willow cover	0.42	0.05	0.33	0.51

Appendix A (continued)

Species	No. of Sample Units with Detections	Latent Variable	Parameter	Beta	SE	Lower 95% CI	Upper 95% CI
			precipitation^2	-0.22	0.06	-0.34	-0.11
			elevation	-0.40	0.06	-0.52	-0.29
			shrub height	0.54	0.09	0.36	0.72
			conifer cover	0.63	0.11	0.43	0.84
			watershed area	-0.38	0.11	-0.60	-0.16
			conifer cover^2	-0.19	0.04	-0.26	-0.11
			herbaceous cover	-0.19	0.06	-0.31	-0.08
			elevation^2	0.08	0.04	0.01	0.14
			alder cover	0.06	0.03	-0.01	0.13
			latitude	0.30	0.09	0.13	0.48
			latitude^2	0.23	0.06	0.12	0.34
Wilson's Warbler	313	detection	intercept	-3.50	0.34	-4.16	-2.84
			date	-0.19	0.06	-0.31	-0.06
			date^2	0.11	0.06	-0.01	0.23
			time	-0.05	0.06	-0.17	0.06
			protocolcodeVCP10_30	1.10	0.23	0.64	1.56
			protocolcodeVCP300	1.29	0.21	0.89	1.70
			shrub height	0.54	0.35	-0.14	1.23
		abundance	intercept	-0.38	0.29	-0.96	0.19
			precipitation	0.73	0.11	0.51	0.94
			willow cover	0.45	0.06	0.34	0.56
			conifer cover	0.65	0.12	0.42	0.89
			latitude	0.38	0.09	0.20	0.55
			conifer cover^2	-0.21	0.05	-0.30	-0.11
			alder cover	0.13	0.04	0.06	0.20
			precipitation^2	-0.15	0.06	-0.26	-0.03
			herbaceous cover	-0.18	0.06	-0.31	-0.06
			watershed area	-0.29	0.14	-0.57	0.00
			sage cover	-0.30	0.16	-0.61	0.01
			deciduous tree cover	0.06	0.04	-0.02	0.14
			shrub height	0.43	0.54	-0.64	1.50
			elevation	0.06	0.08	-0.09	0.21
			yearcollected2011	-0.21	0.14	-0.48	0.07
			yearcollected2012	-0.09	0.13	-0.34	0.16
White-crowned Sparrow	244	detection	intercept	-2.40	0.22	-2.84	-1.97
			date	0.10	0.06	-0.02	0.21
			date^2	0.11	0.06	0.00	0.23
			protocolcodeVCP10_30	-0.43	0.29	-0.99	0.14
			protocolcodeVCP300	-0.01	0.26	-0.52	0.50
		abundance	intercept	-0.92	0.25	-1.41	-0.43
			elevation	1.50	0.22	1.07	1.93
			sage cover	0.31	0.06	0.21	0.42
			shrub height	0.34	0.10	0.15	0.53
			conifer cover	-0.31	0.12	-0.55	-0.07

Appendix A (continued)

Species	No. of Sample Units with Detections	Latent Variable	Parameter	Beta	SE	Lower 95% CI	Upper 95% CI
			willow cover	0.13	0.05	0.02	0.24
			elevation^2	0.13	0.10	-0.07	0.32
			watershed area	0.30	0.10	0.09	0.51
			latitude	0.14	0.16	-0.17	0.45
			latitude^2	-1.17	0.25	-1.66	-0.68
			precipitation	-0.06	0.11	-0.28	0.15
Red-breasted Sapsucker	120	detection	intercept	-3.32	0.42	-4.14	-2.50
			date	0.26	0.11	0.05	0.47
			time	0.52	0.13	0.27	0.77
			time^2	-0.28	0.10	-0.47	-0.09
		abundance	intercept	0.76	0.43	-0.08	1.60
			deciduous tree cover	0.21	0.05	0.12	0.30
			conifer cover	1.03	0.18	0.68	1.38
			shrub height	0.18	0.12	-0.05	0.42
			conifer cover^2	-0.40	0.09	-0.57	-0.23
			willow cover	0.17	0.10	-0.02	0.37
			elevation	-0.18	0.10	-0.38	0.02
			latitude	-0.08	0.14	-0.35	0.19
			latitude^2	-0.20	0.11	-0.41	0.02
			herbaceous cover	-0.15	0.10	-0.35	0.04
			sage cover	-0.14	0.14	-0.42	0.14
Calliope Hummingbird	90	detection	intercept	-2.27	0.72	-3.68	-0.86
			time	0.21	0.15	-0.08	0.50
			time^2	-0.41	0.13	-0.67	-0.15
		abundance	intercept	-1.26	0.66	-2.55	0.03
			willow cover	0.46	0.09	0.28	0.64
			elevation	-0.50	0.11	-0.71	-0.29
			shrub height	0.55	0.18	0.20	0.89
			watershed area	-0.42	0.20	-0.82	-0.03
			latitude	0.34	0.14	0.07	0.62
			deciduous tree cover	-0.38	0.19	-0.76	0.00
			conifer cover	0.80	0.20	0.41	1.19
			conifer cover^2	-0.59	0.19	-0.96	-0.23
Black-headed Grosbeak	69	detection	intercept	-2.75	0.87	-4.45	-1.04
			time	-0.06	0.15	-0.36	0.23
			time^2	-0.26	0.14	-0.53	0.01
		abundance	intercept	-2.26	0.84	-3.91	-0.61
			elevation	-1.63	0.34	-2.29	-0.97
			willow cover	0.68	0.11	0.47	0.89
			precipitation	-0.53	0.18	-0.88	-0.18
			deciduous tree cover	0.35	0.08	0.20	0.51
			alder cover	0.38	0.10	0.19	0.57
			shrub height	0.31	0.21	-0.11	0.72
			latitude	-0.59	0.18	-0.94	-0.24

Appendix A (continued)

Species	No. of Sample Units with Detections	Latent Variable	Parameter	Beta	SE	Lower 95% CI	Upper 95% CI
			elevation^2	-0.25	0.13	-0.50	-0.01
			watershed area	0.94	0.31	0.34	1.55
			watershed area^2	-0.24	0.08	-0.39	-0.09
Willow Flycatcher	57	detection	intercept	-2.06	0.78	-3.60	-0.52
		abundance	intercept	-3.95	0.93	-5.77	-2.13
			willow cover	0.51	0.12	0.28	0.74
			elevation	-0.79	0.25	-1.27	-0.30
			latitude	3.15	1.47	0.28	6.03
			shrub height	1.35	0.42	0.52	2.18
			herbaceous cover	0.18	0.17	-0.16	0.52
			precipitation	0.77	0.26	0.26	1.28
			deciduous tree cover	-0.45	0.29	-1.02	0.11
			precipitation^2	-0.53	0.18	-0.88	-0.18
			conifer cover	-1.35	0.44	-2.22	-0.48
			alder cover	0.18	0.12	-0.06	0.43
			latitude^2	-1.91	1.23	-4.31	0.50
			sage cover	-1.38	0.91	-3.16	0.40
			protocolcodeVCP10_30	-1.39	0.81	-2.97	0.19
			protocolcodeVCP300	0.14	0.79	-1.41	1.68

Appendix B. Estimates of covariates for the most parsimonious model of predicted species richness in Sierra Nevada meadows in relation to habitat covariates.

Dependent Variable	No. of Sample Units with Detections	Latent Variable	Parameter	Beta	SE	P-value
Focal Species Richness	946	abundance	intercept	0.94	0.04	<0.001
			willow cover	0.25	0.02	<0.001
			shrub height	0.72	0.03	<0.001
			conifer cover	0.45	0.03	<0.001
			conifer cover^2	-0.17	0.02	<0.001
			deciduous tree cover	0.03	0.02	0.050
			elevation	-0.12	0.02	<0.001
			elevation^2	0.05	0.01	<0.001
			latitude	0.13	0.03	<0.001
			latitude^2	-0.06	0.02	0.004
			precipitation	0.31	0.03	<0.001
			precipitation^2	-0.12	0.02	<0.001