Landscape-scale Habitat Map for Pinyon Jay and Gray Vireo at Farmington BLM Resource Area

Final Report

Gray Vireo photo: Dominic Sherony, https://commons.wikimedia.org. Pinyon Jay photo: Nate Petersen

Kristine Johnson[a], Mark Horner[a], Paul Neville[b],
Teri Neville[a], Nathan Petersen[a], Jacqueline Smith[a], and Lynn Wickersham[c]

[a]Natural Heritage New Mexico, Biology Department, *and*
[b]Earth Data Analysis Center, University of New Mexico, Albuquerque, NM
and
[c]Animas Biological Studies, Durango, CO

Natural Heritage New Mexico Report #401, July 2017

Contents

Figures

Table

Background

Piñon-juniper Habitats and Wildlife

Piñon-juniper (*Pinus edulis, P. monophylla, Juniperus* spp.) woodlands cover approximately 40 million hectares of the western US (Romme et al. 2009). Together, they are the dominant woodlands and most common vegetation type at the Farmington, NM BLM Resource Area (FRA), covering approximately 350,546 ha.

Several studies have attributed recent mortality, morbidity, and reduced productivity of piñon and juniper trees in the Southwest to climate change. Since 2001, dramatic, rapid, large-scale mortality of piñon trees has occurred in the southwestern US due to "global change-type drought" and associated insect and disease outbreaks (Allen-Reid et al. 2005, Breshears et al. 2005). A 2002–2004 drought in northern Arizona piñon-juniper woodlands reduced canopy cover by 55% (Clifford et al. 2011). Increased temperatures and drought have been associated with declines in piñon cone production (Redmond et al. 2012) and juniper, piñon, and oak mast production (Zlotin and Parmenter 2008). Under climate change, the range of piñon-juniper habitat is predicted to contract significantly across the Southwest (Cole et al. 2007, Thompson et al. 1998) and expand into northern New Mexico and Colorado (Cole et al. 2007). A recent modeling effort predicts massive, widespread piñon and juniper mortality across the Southwest before 2100, which will have "profound impacts on carbon storage, climate forcing, and ecosystem services" (McDowell et al. 2015).

Numerous game animals and sensitive wildlife species depend directly on piñon and juniper trees for food and nest sites. Game species include turkey (*Meleagris gallopavo*), mule deer (*Odocoilus hemionus*), and elk (*Cervus elaphus*). Several federal Birds of Conservation Concern (BCC) (US Fish and Wildlife Service 2008)—Gray Vireo (*Vireo vicinior*), Pinyon Jay (*Gymnorhinus cyanocephalus*), and Black-chinned Sparrow (*Spizella atrogularis*)—breed in piñon-juniper habitats. The above bird species plus Juniper Titmouse (*Baeolophus ridgwayi*) are classified as New Mexico Department of Game and Fish (NMDGF) Species of Greatest Conservation Need (SGCN) (NMDGF 2015).

Piñon and juniper are masting species, producing large seed crops at irregular intervals (Zlotin and Parmenter 2008). Pinyon Jays have a close mutualism with piñon trees, serving as short- and long-distance seed dispersers for piñon pines, and piñon mast crops enhance Pinyon Jay reproductive success and survival (Ligon 1978, Marzluff and Balda 1992). The close mutualism between piñon pines and Pinyon Jays means that impacts to one species affect the other; hence, Pinyon Jays are an indicator species for health and productivity of piñon-juniper habitats.

A recent model of climate effects on birds and reptiles in the southwestern US projected a 25–31 % decrease in the breeding range of the Pinyon Jay between 2012 and 2099. During the same time period, the Gray Vireo breeding range was projected to increase between 58% and 71% (van Riper et al. 2014). Another recent report on birds and climate change projects a 24% decrease in summer range and 37% decrease in winter range of the Pinyon Jay from 2000 to 2080 and an 832% increase in the summer range of the Gray Vireo during the same period (National Audubon Society 2015). These two bird species represent very different projected responses to climate change and can therefore serve as indicator species for the impacts of climate change on piñon-juniper wildlife habitats at the FRA. They can also be used to test the above predictions of climate impacts on wildlife.

Recent Research

In 2014, we completed a four-year study, Habitat Use at Multiple Scales by Piñon-Juniper Birds on Department of Defense (DoD) lands (Johnson et al. 2011, 2012, 2014). For that project, we modeled habitat use by two SGCN, Gray Vireo and Pinyon Jay, at the landscape, territory/colony, and nest scales at three New Mexico DoD installations: White Sands Missile Range (WSMR), Kirtland Air Force Base (KAFB), and Camel Tracks Training Area (CTTA). We have also studied other aspects of Pinyon Jay (WMSR and KAFB) and Gray Vireo (KAFB and CTTA) biology for several years. Our study of habitat use by two at-risk species that differ in seasonal movements, social structure, and foraging habits, viewed at multiple scales and several sites across the state, provides a broad perspective on the management of piñon-juniper woodlands for birds.

In 2012, we extended our study of Gray Vireo and Pinyon Jay habitat use to the FRA. The goals of that ongoing study are to:

1. create multi-scale habitat models for Gray Vireo and Pinyon Jay on BLM lands,
2. compare results to those of the four-year DoD study, and
3. provide management recommendations for piñon-juniper woodland habitats in the FRA.

We conducted the nest-scale habitat analysis for Pinyon Jays and Gray Vireos in 2013 and 2014 (Johnson et al. 2015). We began creating the landscape-scale habitat model in 2015 and completed it in 2016. In 2017, we will complete the final phase of the habitat modeling at the FRA, with the territory and colony scale models for Gray Vireo and Pinyon Jay, respectively. This report describes methods and presents the final landscape-scale habitat model.

Methods

Study Area

The study area includes the majority of land under BLM Farmington Field Office jurisdiction (Figure 1). We agreed with John Kendall (pers. comm.) of the Farmington BLM Field Office that small (primarily 1 mi.^{2}) areas surrounded by lands under other management could be eliminated from the study area. To map those parcels separately and include the surrounding lands would have added costs beyond the budget of the project. The final study area is 907,120 ha in area and includes the majority of piñon-juniper habitat in the Farmington Field Office area.

Field Methods

Pinyon Jay

We used Pinyon Jay locations derived from previously-collected radio telemetry locations and incidental observations of Pinyon Jays to delineate flock home ranges and define habitat use according to vegetation type. Detailed field methods are reported in Johnson et al. (2015). In June and July 2014, we captured jays in a walk-in pigeon trap or a modified Australian crow trap baited with *P. edulis* seed. We set and baited each trap before the feeder delivered seed in the morning. We watched feeders from a distance and approached traps when we had captured several jays.

Each captured bird was banded with a US Geological Survey (USGS) numbered aluminum band and a unique combination of three plastic color bands. We attached 2.0 g, tail-mounted, whip antenna radio transmitters (Holohil Systems, Ltd.) to a subset of the captured birds. We tied each transmitter to the base of the two central rectrices with sturdy thread, then glued the body of the transmitter to the top of the same two rectrices. All birds were released unharmed after processing. Pinyon Jays were captured and banded under USGS Federal Marking and Salvage Permit #22158 and NMDGF Scientific Permit #1795.

After transmitters had been attached to the birds, we used a TRX 1000S receiver from Wildlife Materials, Inc. to listen for transmitter birds two to three times each week from mid-June until mid-October 2014. Each time we received a signal, we recorded the time of day, our GPS coordinates, and the compass bearing of the strongest signal. We then attempted to take a second GPS point and directional bearing from a different location, to triangulate on the bird's specific location. Using ArcGIS, we mapped GPS coordinates for all jay sightings, transmitter detections, and vectors indicating the direction we heard the strongest radio signal. Where the vectors crossed on the map, we added a point to signify the approximate location of the bird. Each point was associated in the GIS with date, time, and transmitter frequency. We combined all GPS coordinates of Pinyon Jay locations into a GIS layer. This included points derived from visual and audio detection of Pinyon Jays and radio telemetry bearings.

On 30 April 2014, we surveyed for Pinyon Jay nests at Tank Mountain, near a wildlife guzzler frequented by Pinyon Jays. On 1 May 2014, we surveyed for Pinyon Jays and searched for nests at Palluche Canyon, where Pinyon Jays have been observed during the breeding season (Figure 1). From April to June 2014, we revisited two Pinyon Jay colonies active in 2013, at Crow Mesa and Rawhide Canyon. We found Pinyon Jay nests and marked their locations in the field using GPS. After nesting activities were complete, we collected nest-scale data following a modified BBIRD protocol (Martin et al. 1997).

Gray Vireo

In 2013 and 2014, we conducted presence/absence surveys for Gray Vireos at the following sites in the BLM FRA: Crow Mesa, Pump Canyon, Pump Mesa, and the canyons and rolling terrain around and north of Aztec, NM. During initial visits, we used playbacks of Gray Vireo vocalizations to elicit responses and determine presence/absence of territorial birds. We recorded the locations of vireo detections in the field using handheld GPS units. We documented the number of birds detected, sex, and behavior (e.g.; singing male, pair, etc.). During initial and

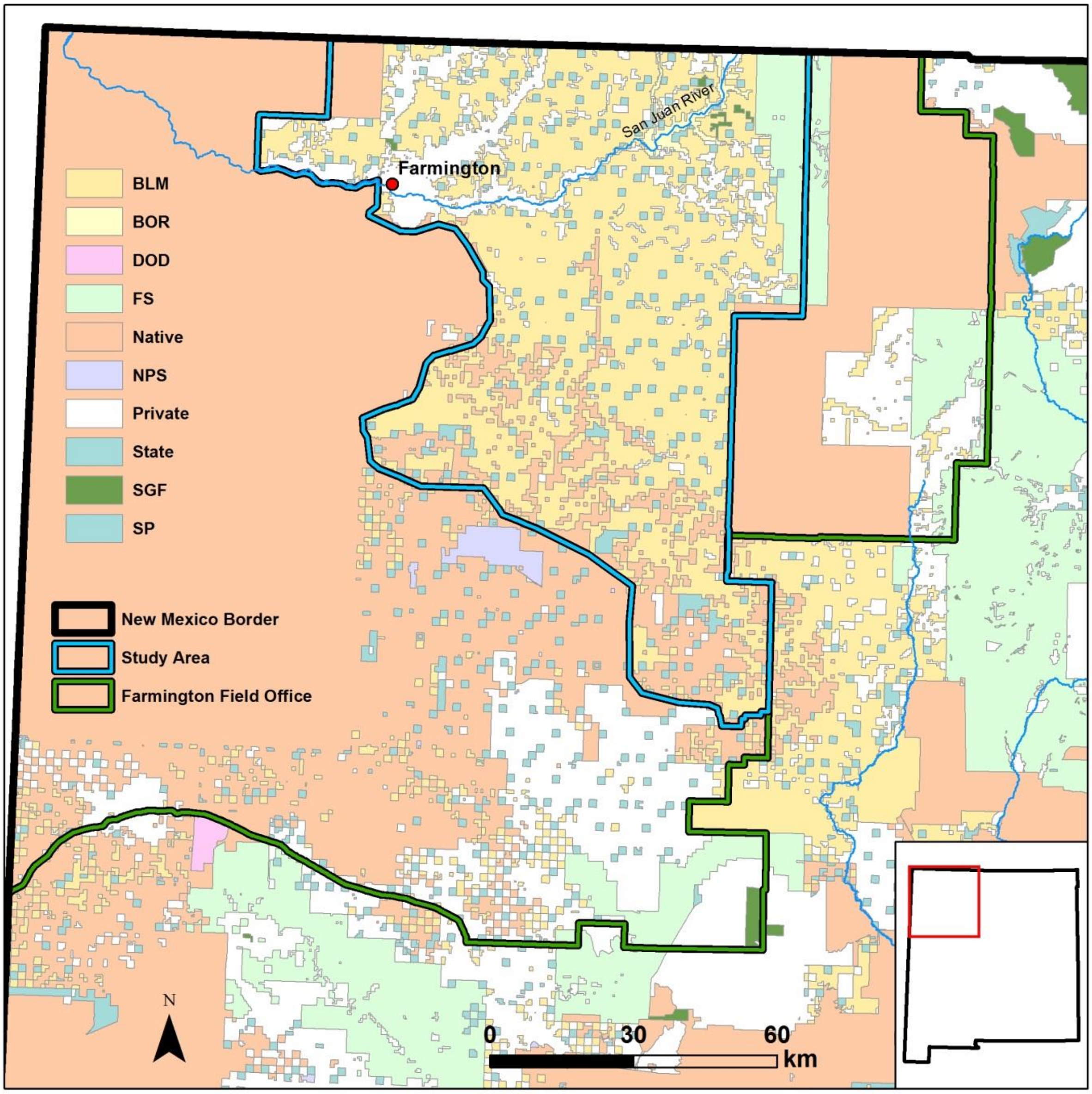

Figure 1. Study area within BLM Farmington Field Office jurisdiction. Small, disjunct parcels of BLM land in the south were eliminated from the study area due to mapping cost and their lesser importance to pinon-juniper birds.

follow-up visits to occupied territories, we also observed vireos for nesting behavior and searched for nests. Where we located nests, we checked their contents, if possible, and recorded their locations using GPS. Locations of territorial vireos and vireo nests served as the foundation for the landscape-scale habitat model.

Image Analysis

We used 2014 National Agriculture Imagery Program (NAIP 2014) high-resolution visible and near-infrared digital aerial photography and Landsat 8 satellite imagery to map and analyze vegetation types. All image processing tasks and editing of the raster habitat map were performed in ERDAS 2015 (ERDAS 2015). Image processing, digital elevation and slope data, aerial photo interpretation, nest plot data, and some existing vegetation layers provided the basis for a supervised classification. See Appendix 1 for details.

Habitat Map Creation and Editing

We utilized several resources to guide the creation and editing of the habitat map. These included recent habitat models created by researchers at New Mexico Highlands University (NMHU) and provided by the Farmington BLM Field Office. These models provided some details for certain landcover types. In addition, we initially planned to use publically available vector and raster data from various sources included in the Resource Geographic Information System (http://rgis.unm.edu) to identify roads, well pads, and other areas of human disturbance. However, issues with the scale of the data made it incompatible with our high spatial resolution map. We also attempted to classify human disturbance, but because of similarities in spectral signatures between certain landscape and road features, automated approaches for delineating roads and well pads were largely unsuccessful. Therefore, we hand-digitized these features in the areas dominated by piñon-juniper vegetation. Limited resources precluded digitizing well pads and roads in other habitats.

We queried four BLM Farmington Field Office range site vegetation databases developed as part of the Halofsky et al. (2014) Integrated Landscape Assessment Project. We assigned plant associations to 660 transects, following the United States National Vegetation Classification (USNVC 2016). These data were of limited use, however, because the four databases did not contain length or direction of transects, or whether the single coordinate pair represented the beginning or end of a given transect. Hence, our principal use of these data was for identifying grass species within the study area.

For the nest-scale phase of this project (Johnson et al. 2015), we collected data on 5-m and 11.3-m vegetation plots at each nest and paired random plot (all plots, *n*=236, Johnson et al. 2015). These plots, located at both nest and paired random sites for Pinyon Jays and Gray Vireos, included tree species, number, and size class; canopy cover; and cover of grasses, forbs, and shrubs. In focal areas where we lacked field data, we collected additional data on 20 m x 20 m vegetation plots (*n*=16, collected 5–6 and 14–15 September 2015). Data for these plots include dominant vegetation types and percent cover of trees, shrubs, herbaceous plants, and bare ground. We also collected an additional 81 map points. These were outlined on the printed field maps and annotated with comments on landcover type. Based on the supervised classification and field data, we defined map units (MUs) and developed a draft habitat map.

Through photo interpretation and detailed inspection, we identified questionable areas of the map and collected additional plot data on 14-15 October 2015 (n=35) to refine the classification and create summary descriptions of the MUs. Based on data collected on the second field visit, we edited and finalized the habitat map. The editing process included significant additional vector digitizing of dry arroyos and the Ponderosa Pine Woodland, Open Water, Human Disturbance, and Agriculture MUs. These vector layers were used as a mask to correct (recode) the habitat map.

To distinguish Gray Vireo from Pinyon Jay habitat, we created an ancillary geospatial layer depicting the combined canopy cover (in m^2) of three piñon-juniper vegetation types: Juniper Woodland and Savanna, Utah Juniper Woodland, and Piñon-Juniper Woodland (see Appendix 1 for details). We then collected zonal cover values from the combined tree canopy cover layer within a continuous series of 20 x 20 m grid squares (approximately the size of our nest and random vegetation data plots) over the entire study area.

To evaluate the accuracy of the tree canopy layer, we hand-digitized trees in a subsample (20 each) of Gray Vireo and Pinyon Jay nest and random plots (from nest-scale plots, Johnson et al. 2015) using the World Imagery map service (Esri 2016a). The Esri map service has a high spatial resolution (30 cm) component well suited for this purpose. We then compared the tree cover area of the combined canopy layer to the hand-digitized trees. To determine if the cover values from the combined tree canopy layer were true representations of tree density or canopy cover on the ground, we ran Pearson's correlations between the cover percentages from the canopy layer and the ground tree counts and ground canopy cover measures.

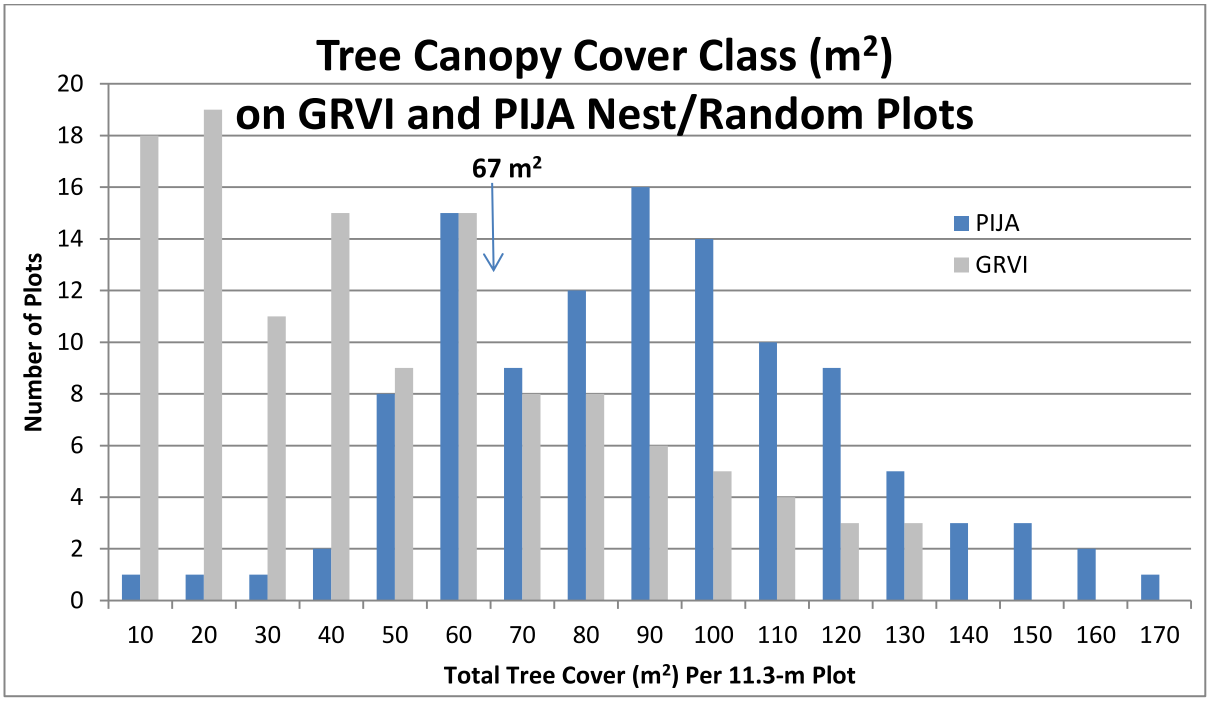

Figure 2. Distributions of geospatially-derived tree canopy cover on 11.3-m radius (400 m^2) nest and random BBird plots for Gray Vireo (GRVI) and Pinyon Jay (PIJA). The midpoint of the overlap in the 2.0 SD distributions, 67 m^2, was used as the dividing line between sparse and dense piñon-juniper map units.

After validating the canopy cover layer described above, we plotted the distributions of canopy cover values obtained from the canopy cover layer on Gray Vireo and Pinyon Jay nest and random plots (Figure 2). We included canopy cover on both nest and random plots to capture the canopy cover variation in nesting areas (Gray Vireo territories and Pinyon Jay colonies), not only at nests. Cover values from these distributions were then used to define the cutoff for the dense versus sparse piñon-juniper map units. Defined in this context, sparse piñon-juniper areas tend to better describe Gray Vireo habitat, whereas the dense piñon-juniper map unit is more associated with Pinyon Jay habitat. These two MUs are thus better representations of the two species' respective habitats than the original MUs.

Both species nested in areas with intermediate tree cover (Figure 2). The overlap in tree cover between the 2.0 SD ranges for Gray Vireos and Pinyon Jays is 22.61–111.53 m^2. Thus, we used the midpoint of the overlap (67 m^2) to separate sparse (Gray Vireo nesting habitat) from dense (Pinyon Jay nesting habitat) piñon-juniper classes; the 20 x 20 m grid squares having ≤67 m^2 tree cover are mapped as sparse piñon juniper, while grid squares having >67 m^2 tree cover are mapped as dense piñon juniper (Figure 2). We then aggregated the grid squares of similar (sparse, dense) classes into grouped polygons and reclassified the three piñon-juniper map units (Juniper Woodland and Savanna, Utah Juniper Woodland, and Piñon-Juniper Woodland) into three units: Sparse Piñon-Juniper, Dense Piñon-Juniper, and Scattered Piñon-Juniper (defined as areas having ≤ 1 m^2 of piñon or juniper trees per 400 $m^{2)}$. In this process, some small areas of Gambel Oak Woodland and Montane Chaparral habitat were likely subsumed within larger patches of piñon-juniper; hence, those two map units may be underrepresented in the classification. See Appendix 2 for map unit descriptions.

Results

Pinyon Jays and Gray Vireos at Farmington BLM

In the 2014 phase of the project, the Pinyon Jay flock that nested in Rawhide Canyon ranged over an area of 4033.66 ha from 10 June through 14 October 2014 (Johnson et al. 2015). Transmitter battery life (up to 14 weeks) prevented us from following the Rawhide Canyon flock past October; we have no location data for the flock during winter. Gray Vireos are only present on the study area during the breeding season and are conspicuous and vocal primarily from May through July. During that time they defend territories on which they nest and forage. Gray Vireo territories were not mapped for this phase of the project but are being modeled for the territory (Gray Vireo)/colony (Pinyon Jay) phase of the project in 2017.

Habitat Map

The habitat map includes 15 MUs (Figure 3) and covers 907,120 ha. The resolution of the habitat map is 1 m^2, and it is best viewed at a scale of 12,000 or greater. The most widespread MU is Sparse Piñon-Juniper Woodland (278,168 ha), followed by Grassland (258,586 ha) and Sagebrush Shrubland (109,723 ha). Dense Piñon-Juniper Woodland (44,036 ha) and Scattered Piñon-Juniper Woodland (28,343 ha) are the other piñon-juniper MUs; together the three piñon-juniper types comprise the vast majority of nesting habitat for Gray Vireos and Pinyon Jays. Detailed descriptions and areas of all MUs are provided in Appendix 2.

Habitat Types in Pinyon Jay and Gray Vireo Habitats

The Pinyon Jay breeding season home range includes Dense Piñon-Juniper Woodland, Sparse Piñon-Juniper Woodland, Human Disturbance, Sagebrush Shrubland, Ponderosa Pine Woodland, and other MUs covering less than 1% of the home range. Pinyon Jay nests were located in Dense Piñon-Juniper Woodland and Sparse Piñon-Juniper Woodland (Table 1, Figure 4, Appendix 2).

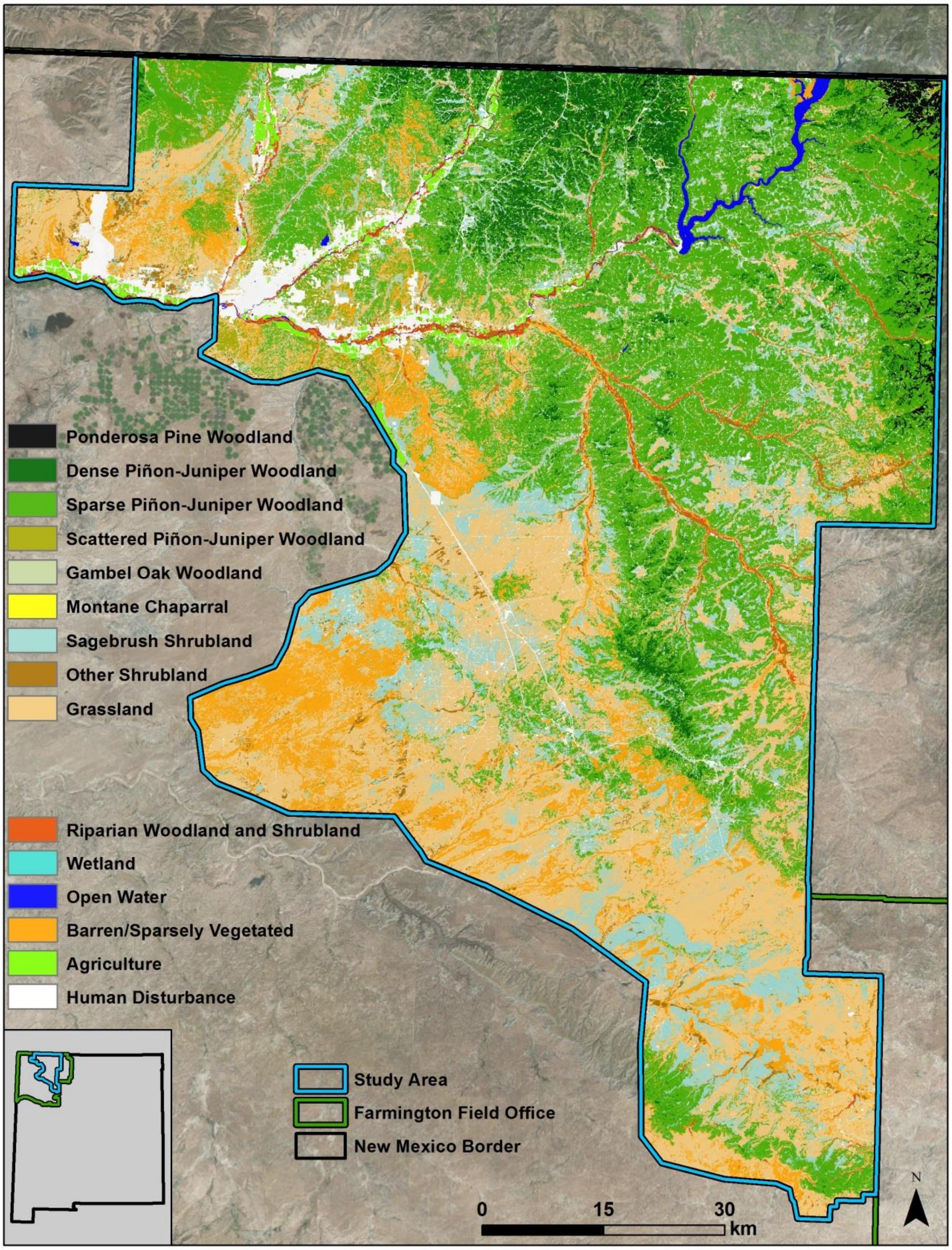

Figure 3. Habitat map for piñon-juniper birds at Farmington BLM Field Office. Map is based on observation and nest data for Pinyon Jays and Gray Vireos; piñon-juniper MUs are also suitable for managing other piñon-juniper bird species.

Table 1. Habitat types within Pinyon Jay home ranges, their concentration of use (CU) relative to availability within the home range, and % nests by habitat. Gray Vireo observations (*n*=250) vs. nests (*n*=62) in each habitat.

Map Unit	Pinyon Jay			Gray Vireo	
	% Home Range	CU	% Nests	% Observations	% Nests
Ponderosa Pine Woodland	2.42				
Dense Piñon-Juniper Woodland	74.50	0.99	76.8	22.00	16.13
Sparse Piñon-Juniper Woodland	12.39	0.38	23.2	65.60	72.58
Scattered Piñon-Juniper Woodland	0.40			2.80	
Sagebrush Shrubland	2.82			1.20	8.06
Other Shrubland	0.09			1.60	
Grassland	0.79			4.00	1.61
Human Disturbance	5.88	2.11		2.8	1.61

The concentration of use (proportion of observations in the habitat type divided by relative abundance of that habitat type) of our observations of Pinyon Jays are 0.99 in Dense Piñon-Juniper Woodland, 0.38 in Sparse Piñon-Juniper Woodland, and 2.1 in Human Disturbance. This means that Pinyon Jays used Dense Piñon-Juniper Woodland in approximately the same proportion as its availability and used Sparse Piñon-Juniper Woodland about 38% relative to its availability. Human Disturbance "use" was probably inflated slightly due to observers being on roads when we collected GPS points of Pinyon Jays observed; however, Pinyon Jays do not seem to strongly avoid gravel roads, occasionally nesting within 50 m of a road. Land cover classes comprising <5% of the home range tended to have inflated concentration of use values relative to the most-used habitat types (one detection in a very small area results in an inflated use value). We therefore computed concentration of use only for those land cover types comprising >5% of the home range polygons.

Because we did not delineate Gray Vireo territories for this phase of the project, we were not able to compute concentration of use for Gray Vireos. Gray Vireo observations (*n*=250) were in Sparse Piñon-Juniper Woodland, Dense Piñon-Juniper Woodland, Grassland, Scattered Piñon-Juniper Woodland, Human Disturbance, Other Shrubland, and Sagebrush Shrubland (Table 1, Figure 4, Appendix 2). Of 62 Gray Vireo nests found, 45 (~73%) were placed in Sparse Piñon-Juniper Woodland, 10 (~16%) in Dense Piñon-Juniper Woodland, 5 (8%) in Sagebrush Shrubland, and 1 each (<2%) in Grassland and Human Disturbance MUs. These percentages indicate slight preference for nesting in Sparse Piñon-Juniper Woodland and Sagebrush Shrubland, compared to non-nesting observations on territories. The nests in Grassland and Human Disturbance MUs provide somewhat misleading results, as both of these nests were placed in juniper trees. Their inclusion in atypical nesting habitat MUs may have occurred because these nest trees were isolated from other trees and/or occurred within or adjacent to smaller pockets of these atypical habitat patches. Similarly, the inclusion of five nests in the Sagebrush MU is slightly misleading, as only two Gray Vireo nests actually were placed in sagebrush shrubs. The remaining three nests were in relatively isolated juniper trees within pockets of sagebrush habitat.

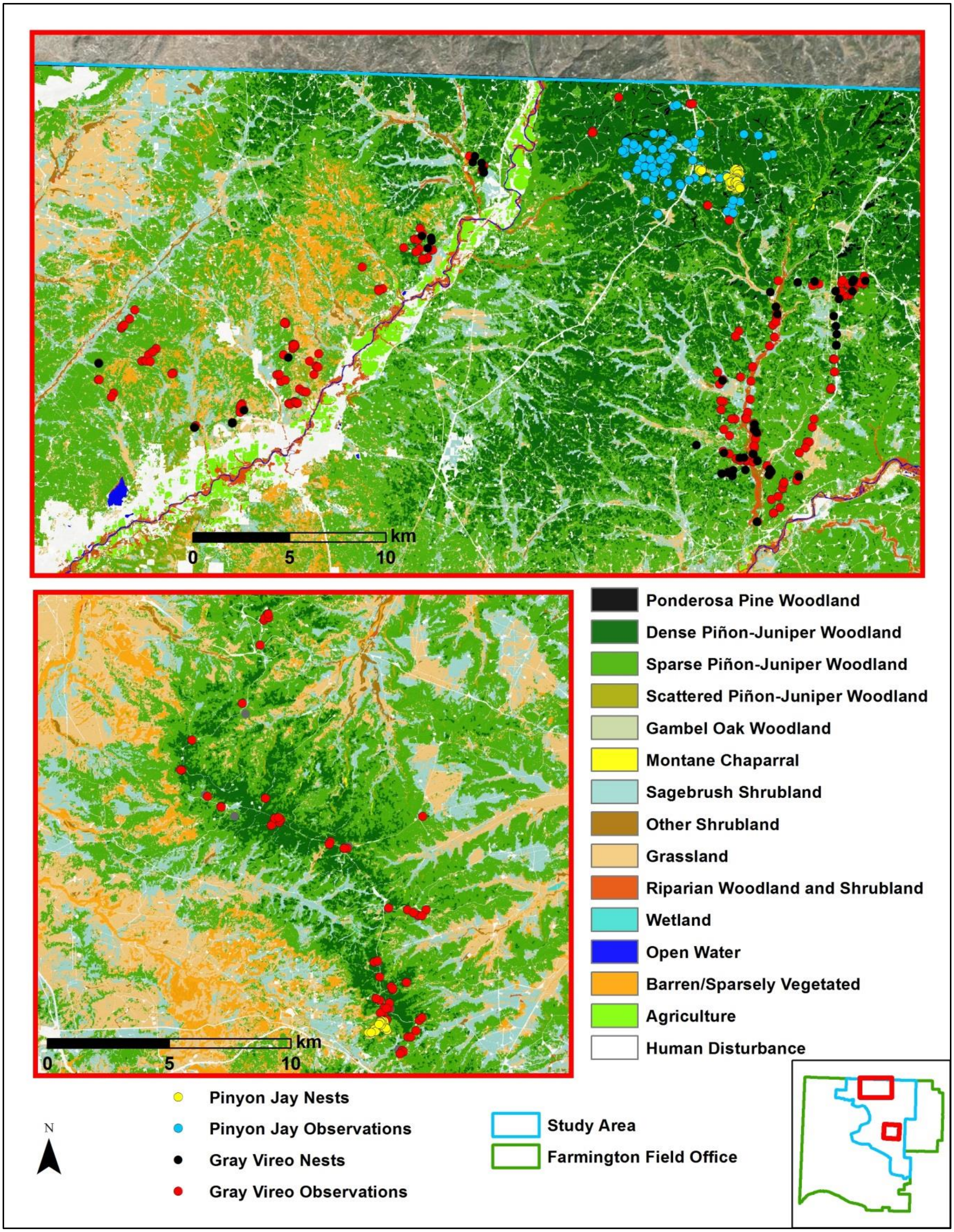

Figure 4. Pinyon Jay and Gray Vireo observation and nest locations showing habitats.

Tree Cover in Pinyon Jay and Gray Vireo Nesting Habitats

Pinyon Jays and Gray Vireos both nested in several piñon and juniper vegetation types, but their proportional use of those habitats differed. Constraints of processing time prevented us from analyzing and mapping cover on a nest-scale grid for each habitat type over the entire study area. However, when the three major piñon-juniper cover classes were combined, Pinyon Jays were more often found nesting in areas having higher tree canopy cover, while Gray Vireos more often nested in areas with sparse tree canopy cover (Figure 2).

The aerial tree canopy cover distributions of the 11.3-m nest and nearby random plots for the two birds overlapped considerably (Figure 2). One standard deviation (SD, ~68%) around the mean tree canopy cover for Gray Vireos contained 11.98–78.36 m^2 tree canopy cover, and 2.0 SD (~95%) contained 0–111.55 m^2 tree canopy cover. For Pinyon Jays, 1.0 SD ranged from 58.83 to 116.27 m^2, and 2.0 SD from 22.61 to 147.49 m^2. Another way of viewing these distributions is that 95% of Gray Vireo nests and associated random plots had tree canopy cover ranging from 0 to 111.55 m^2 (0–27.9% cover), and 95% of Pinyon Jay plots had tree canopy cover from 22.61 to 147.49 m^2 (5.7–36.9% cover). Gray Vireos did not nest in areas with >128 m^2 canopy cover per 400 m^2 plot, or 32% cover. Pinyon Jays were rarely found nesting where aerial canopy cover was less than 35 m^2 per 400 m^2 plot, or 8.8% (Figure 2).

Both species nested in areas with intermediate tree cover (Figure 2). Of all nest and random plots, 70.5% of Pinyon Jay plots are in Dense Piñon-Juniper, and 75% of Gray Vireo plots are in Sparse Piñon-Juniper. Conversely, ~30% of Pinyon Jay plots and ~25% of Gray Vireo plots are in areas with intermediate (where distributions overlap) tree cover. Scattered Piñon-Juniper was defined as areas having ≤ 1 m^2 of piñon or juniper trees per 400 m^2.

Mean canopy cover on 20 x 20 m grid squares in Dense Piñon-Juniper was 99.5 m^2 per 400 m^2grid square, or 25% (range: 1.0 – 376.0, SD = 35.44; Figure 5). The distribution of canopy cover on the Pinyon Jay nest and random vegetation plots was similar to that in Dense Piñon-Juniper. Both were fairly normally distributed and centered around approximately 100 m^2 per 400 m^2 grid, or 25% canopy cover (Figure 5).

Mean canopy cover on 20 x 20 m grid squares in Sparse Piñon-Juniper was 33.3 m^2 per 400 m^2 grid square, or 8.3% (range: 0.2 – 319.0, SD = 23.0; Figure 6). The distribution of canopy cover on Gray Vireo nest and random vegetation plots was skewed toward lower densities, approximating that of canopy cover in Sparse Piñon-Juniper (Figure 6). This is an unsurprising result, given that Dense Piñon-Juniper and Sparse Piñon-Juniper were defined based on use by the two bird species.

Cover values from the combined canopy layer were not highly correlated with the tree counts on the ground, although the correlation was higher on Gray Vireo plots (Pearson's correlations between canopy layer and tree counts: Gray Vireo r=0.42; Pinyon Jay r=0.18). This difference between the bird species probably occurs because tree density is low enough on many Gray Vireo plots that areas of canopy cover represent only one tree, allowing for a higher correlation between canopy cover and tree number. On Pinyon Jay plots, contiguous areas of canopy cover could result from one, a few, or many trees; hence a correlation would not be expected in areas having high tree cover, as in Pinyon Jay habitat.

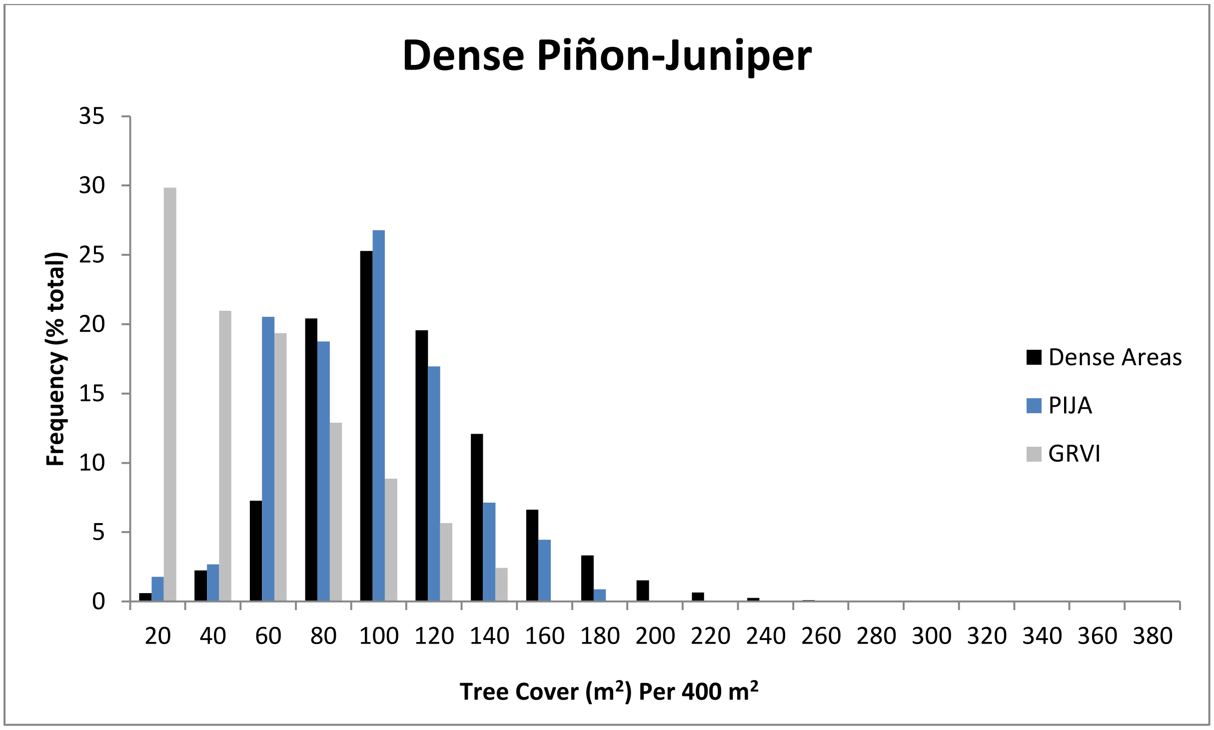

Figure 5. Distribution of canopy cover (m^2 per 400 m^2 grid cell) within grid cells entirely within the Dense Piñon-Juniper map unit, on Pinyon Jay (PIJA) nest and random plots, and on Gray Vireo (GRVI) nest and random plots. Distribution of canopy cover on PIJA plots approximates that of plots in Dense Piñon-Juniper.

Cover values obtained from the combined canopy cover layer were a fair reflection of the canopy cover measures taken at nest and random plots on the ground (Pearson's correlations between GIS and ground measures: Gray Vireo *r*=0.50; Pinyon Jay *r*=0.37). Several confounding factors could explain the lower *r* value for Pinyon Jays. Canopy cover for Pinyon Jays was taken in the field from 5-m-radius plots, compared to the larger (400 m^2, same size as the 11.3-m radius) grid cells in the canopy cover layer and 11.3-m plots for Gray Vireos. It is therefore possible that the cover layer could be more accurate at the larger, 11.3-m scale. We also know that the cover layer underestimated canopy cover in sparse areas and overestimated canopy cover in dense areas (see below).

Finally, correlations between the canopy layer and the subsample of hand-digitized tree cover values were high (Gray Vireo *r*=0.86; Pinyon Jay *r*=0.71, *n*=40). These correlations suggest that the combined tree canopy layer is considerably more accurate than either the field canopy measures or the tree counts as an indicator of canopy cover.

However, while a reasonably compelling predictor of nesting habitat, the derived tree canopy layer is not perfectly accurate. For Gray Vireo, seven of 20 hand-digitized plots had lower and 13 had higher tree cover than the derived values, for a mean error of 3.40% over the sample of 20

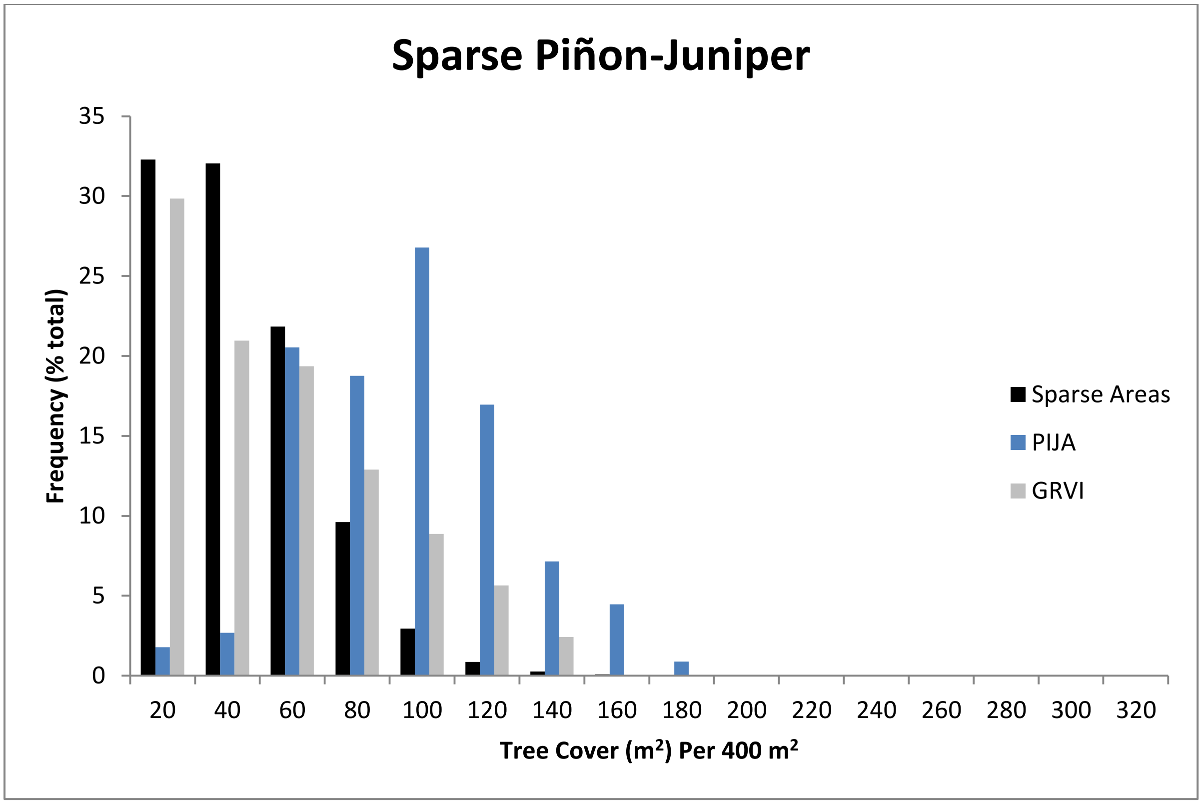

Figure 6. Distribution of canopy cover (m^2 per 400 m^2 grid cell) within grid cells entirely within the Sparse Piñon-Juniper map unit, on Pinyon Jay (PIJA) nest and random plots, and on Gray Vireo (GRVI) nest and random plots. Distribution of canopy cover on GRVI plots approximates that of plots in Sparse Piñon-Juniper.

plots. For Gray Vireo, this represents a pattern, on average, of a lower estimated cover from the canopy layer than the hand-digitized plots. In other words, the derived canopy cover values tended to slightly underestimate the cover values in areas of sparse canopy cover.

For Pinyon Jay, 12 of 20 hand-digitized plots had lower tree cover and eight plots had higher tree cover than the derived cover values, for a mean error of 5.88% over the sample of 20 plots. Thus, on Pinyon Jay plots, derived canopy cover values were on average larger than the hand-digitized values. This suggests that the canopy cover layer generally over-estimated tree cover in dense canopy areas. Assuming the hand-digitized values are more accurate than the derived values, error rates for the canopy cover layer were slightly higher on Pinyon Jay plots than on Gray Vireo plots.

A comparison of the two layers suggests that in dense areas the automated process used to derive the canopy cover layer tended to classify certain areas that could have been shadows, leafless oak, or other shrubs as trees, while missing small, green trees in sparse areas. The sparse areas have high albedo (are very bright) in the photography, which tends to saturate the sensor, making it difficult to differentiate small, isolated trees. Nonetheless, error rates for the canopy cover (sparse and dense alike) are small and thus a good characterization of canopy cover throughout the study area.

Discussion

Habitat Map Emphasis

The purpose of this study was to map habitat at the landscape scale for piñon-juniper bird species. Because of the emphasis on piñon-juniper habitats, other MUs will necessarily be less accurate than the woodland MUs. However, Ponderosa Pine Woodland, Sagebrush Shrubland, and Riparian Woodland and Shrubland MUs have been thoroughly reviewed and edited. Although the landscape-scale map is delineated based on Pinyon Jay and Gray Vireo habitat use, it will be useful in managing for other piñon-juniper birds of conservation concern (see Management sections below).

Pinyon Jay and Gray Vireo Differential Habitat Use

We found Pinyon Jay nests in Dense Piñon-Juniper Woodland and Sparse Piñon-Juniper Woodland. Gray Vireo nests were also located in both types, with the addition of Sagebrush Shrubland. However, the proportions of nests in each habitat differed between the two birds, as did the canopy cover at nest and random plots (Table 1, Figure 2). Two vireo nests were located in seemingly nontraditional MUs, Grassland and Human Disturbance; however, both nests were in juniper trees and may reflect the presence of isolated or scattered trees in areas dominated by other MUs.

Because of the error in the tree cover layer that we used to guide mapping of sparse versus dense piñon juniper map units, we caution against using the cover values derived from that layer as specific habitat management recommendations. For example, it would be inaccurate to say that areas with >16.8% tree cover (67 m^2 per 11.3-m plot) were Pinyon Jay nesting habitat and areas with less than that constituted Gray Vireo habitat, because of the overlap in cover distributions of the two species, as well as the error inherent in the GIS cover layer. Instead, we recommend using the map to indicate general areas where mainly Gray Vireos or mainly Pinyon Jays would nest, remembering that 25–30% of nests of both species can occur in similar habitat of intermediate tree density.

Pinyon Jay Habitat Use

Predictions of continued, sharp Pinyon Jay decline (van Riper et al. 2014, National Audubon Society 2015) are based mainly on models predicting heavy piñon mortality under climate change (e.g.; Cole et al. 2007, McDowell et al. 2015) and the dependence of Pinyon Jays on piñon trees for food and nest sites. Our results on Pinyon Jay habitat use generally support the latter factor: Pinyon Jays in this study nested primarily in Dense Piñon-Juniper Woodland, and they heavily used this habitat type for foraging when not nesting, even in years with no mast crop.

Pinyon Jays in the FRA used similar habitats to those used in the DoD Legacy study (Johnson et al. 2014). The general habitat types used at both Kirtland Air Force Base and White Sands Missile Range were Piñon Pine Woodland, Piñon-Juniper Woodland, and Juniper Woodland and Savanna (Johnson et al. 2014). At White Sands, Piñon-Juniper Woodland was used much less than the other two types, as the Pinyon Jay flock spent the breeding season in Piñon Pine Woodland and appeared to use Juniper Woodland and Savanna during the winter (although nonbreeding season data are scanty). At Kirtland, we had more breeding season observations of Pinyon Jays in Piñon-Juniper Woodland than the other two types (Johnson et al. 2014).

It is, however, difficult to compare the DoD and BLM studies, because we defined map units differently at the FRA and the DoD study. For the current study, our emphasis was on distinguishing Pinyon Jay from Gray Vireo habitat, and map units were defined accordingly. In this study, 74.5% of the home range of the Rawhide Canyon Pinyon Jay flock was covered in Dense Piñon-Juniper Woodland, and 12.4% was in Sparse Piñon-Juniper Woodland (Table 1). In contrast, at White Sands Missile Range, 25% of the landscape-scale habitat model was covered in Piñon Pine Woodland and 12.7% in Piñon-Juniper Woodland, with 47.3% in Juniper Woodland and Savanna. At Kirtland Air Force Base, the Pinyon Jay home range was covered in 27.6% Piñon Pine Woodland, 16.7% Piñon-Juniper Woodland, and 37.7% Juniper Woodland and Savanna. Combined, the Dense, Sparse, and Scattered Piñon-Juniper Woodland covered 87.3% of the Rawhide flock home range, and the three types combined covered 82% and 85% of the home ranges at Kirtland and White Sands, respectively. Hence, it appears that Pinyon Jays at all three widely separated study sites had home ranges with similar total proportion in piñon-juniper vegetation (82%-87.3%), but the subtypes varied among study sites. At all study sites, Pinyon Jays nested in the types with highest canopy cover and largest trees (Dense Piñon-Juniper Woodland, Piñon Pine Woodland) and spent relatively more time in lower-elevation, sparser habitats outside the nesting season.

Pinyon Jay Habitat Management

One result of this study points to the importance of home range size as a management consideration. The April–October home range of the Rawhide Canyon flock covered ~4033 ha, 3520 ha of which comprised Piñon-Juniper or Juniper Woodland vegetation types. Pinyon Jays tend to use a limited proportion of their home range during the nesting season, but after young fledge, a flock moves widely in search of piñon seeds or other foods. Because of the spatial and temporal variability in piñon mast crop production, Pinyon Jays need thousands of hectares of piñon trees. Due to the jays' need for such large home ranges, only land managers with jurisdiction over very large landscapes can effectively manage for the year-round habitat needs of even one flock of Pinyon Jays.

Aside from conserving large landscapes where Pinyon Jays are present, what would management of home range-sized landscapes for Pinyon Jays involve? Management for health and productivity of piñon trees over large landscapes may be the most helpful action that could be taken for Pinyon Jay conservation. Unfortunately, the best way to manage for piñon health is not well understood.

Most management of piñon-juniper vegetation currently consists of thinning for fuels reduction or forage production for large ungulates, including livestock. Some such thinning projects are conducted in conjunction with monitoring the effects on the woodland plant community or its hydrology; for example, changes in ground cover, species composition, invasive plants, and resistance to wildfire (Loftin 1999, Jacobs 2015). However, few data have been collected on the effects of thinning on the health and productivity of woodlands, pre- and post-thinning. Fewer data still are available on the impacts of thinning on wildlife. Although it may seem logical that thinning will benefit remaining trees, a few studies have suggested that density of piñon trees does not necessarily affect mortality (Meddens et al. 2014 and references reviewed therein). This could be because thinning also disrupts the ectomycorrhizal fungi networks so important to piñon trees (Mueller et al. 2005); multiple characteristics of the microsites on which trees live determine resistance to drought (Greenwood and Weisberg 2008, Redmond et al. 2015); or other factors.

Given the climate threats to this widespread ecosystem, it is important that more studies be conducted on the effects of thinning and other treatments on the remaining woodlands. Research on piñon-juniper management should include emphasis on understanding the conditions which increase woodland resilience to climate impacts and particular management actions which increase health and resilience of piñon-juniper communities (e.g., Rondeau et al. 2017).

We have studied nesting Pinyon Jays at 10 colony sites and found an additional nine colonies which we did not study in depth. Each of these colonies was within easy flying distance (3.2 km, except for one colony) of available water. Pinyon Jays use BLM wildlife waterers near Rawhide Canyon and Tank Mountain. Given expected drying of surface water under climate change (Gutzler 2013), maintaining and increasing numbers of wildlife waterers in suitable Pinyon Jay habitat are easy management actions that will allow Pinyon Jays to find suitable nesting colony sites near water, in the event of climate- or human-induced habitat impacts.

On seeing the habitat map, the vast area of Human Disturbance in the FRA, in the form of roads and well pads, is striking. These structures are clearly fragmenting habitat for many animals. In addition, active wells produce significant noise that could disrupt vital communication for a social species such as Pinyon Jay (Johnson et al. 2013). We have suggested that a moderate-sized Pinyon Jay flock like the Rawhide Canyon flock needs blocks of nesting habitat of at least 50 ha, with minimal road fragmentation, no active wells within 150 m of the edge of the habitat patch, and perennial water within 1–2 km (Johnson et al. 2015). As development proceeds in the FRA, blocks of suitable habitat fitting this description become scarce. We recommend that BLM identify and protect bird conservation areas that fit these criteria; this action would also provide habitat for important game species and other sensitive wildlife.

Gray Vireo Habitat Use

Most studies of Gray Vireo habitat use in New Mexico have found them primarily nesting in juniper-dominated habitats (DeLong and Cox 2005, Frei and Finley 2009, Wickersham and Wickersham 2016), including our study on DoD lands (Johnson et al. 2014). Our results at the FRA are mainly in agreement with this generalization. In this study, we found 82% (53) of nests in junipers ,15% (10) in piñons, and 3% (2) of nests in big sagebrush plants. Most Gray Vireo observations (65.6%) were in Sparse Piñon-Juniper, with 22% in Dense Piñon-Juniper, and 2.8% in Scattered Piñon-Juniper.

However, in southern New Mexico, Gray Vireos also occupy more open piñon-juniper woodlands and/or shrub-dominated canyons and may nest in a variety of tree and shrub species. On Fort Bliss, in the Organ and Sacramento Mountains (Dona Ana and Otero Counties), Britt and Lundblad (2009) reported 41% of vireo nests in junipers, 35% in shrubs, and 24% in piñons, though these data were based on a relatively small sample of 17 nests. Shrub species used for nesting at Fort Bliss included mountain mahogany (*Cercocarpus montanus*), fragrant ash (*Fraxinus cuspidata*), evergreen sumac (*Rhus virens*), and Wright's silktassel (*Garrya wrightii*). At White Sands Missile Range, we observed Gray Vireos in both juniper- and shrub-dominated habitats, but all nests found were in juniper trees (Johnson et al. 2014).

Predictions of Gray Vireo population and range increases under climate change (van Riper et al. 2014, National Audubon Society 2015) are based mainly on models assuming conversion of piñon-juniper woodlands to juniper woodland and savanna, as piñon trees, but not junipers, die. In 2014, large-scale, drought-associated juniper mortality in the foothills of the Sandia Mountains (K. Johnson, pers. obs.) and at Santa Ana Pueblo (G. Harper pers. comm.), near Albuquerque, suggest that juniper may not be as resilient to climate change as is often assumed.

These models also assume that Gray Vireos are juniper specialists. As more is learned about Gray Vireo habitat use in New Mexico, a picture emerges of a bird that is not a strict juniper specialist. This habitat flexibility could contribute to the species' climate resilience. However, if the additional habitats are, like piñon-juniper, even more heavily climate-impacted than juniper savanna, habitat flexibility may not necessarily serve the species well. Hence, the assumption that the Gray Vireo is not only resilient to climate change but actually benefits from it has yet to be tested. Continued monitoring of Gray Vireos and changes to their habitat will provide important insight into bird responses to climate change which are currently expected to be the opposite of species like the Pinyon Jay, whose dramatic decline is well documented.

Gray Vireo Habitat Management

Without an understanding of the Gray Vireo's climate resilience, it is difficult to evaluate potential management strategies. However, this study does provide some suggestions for habitat management. Gray Vireos nest in areas with relatively sparse canopy cover, compared to Pinyon Jays. These areas of juniper savanna and big sagebrush should not be dismissed or cleared. If thinning of juniper savanna or piñon-juniper woodland habitat suitable for vireos is contemplated for fuels reduction, prescriptions for thinning should take Gray Vireo nesting habitat into consideration. Thinning denser areas containing large juniper trees, the favored nesting habitat for Gray Vireos in the FRA, would degrade nesting habitat for this state-listed species.

Finally, Pinyon Jays and Gray Vireos can serve as surrogates for other piñon-juniper bird species that use similar habitats. For example, in Otero Canyon in the Manzanita Mountains, Black-throated Gray Warblers (*Setophaga nigrescens*) nest in large piñon trees in areas of relatively high canopy cover (A. Gorbett, pers. comm.), similar to Pinyon Jays. Juniper Titmouse (*Baeolophus ridgwayi*) nests in late successional woodlands with high juniper overstory cover (Pavlaky and Anderson 2001) and can overlap with both Pinyon Jays and Gray Vireos (N. Petersen, L. Wickersham pers. comm.).

Literature Cited

Allen-Reid, D., J. Anhold, D. Cluck, T. Eager, R. Mask, J. McMillan, S. Munson, T. Rogers, D. Ryerson, E. Smith, B. Steed, and R. Thier. 2005. Piñon pine mortality event in the Southwest: an update for 2005. US Forest Service. Accessed at: http://fhm.fs.fed.us/posters/posters05/pinon_pine.pdf

Breshears, D.D., N.S. Cobb, P.M. Rich, K.P. Price, C.D. Allen, R.G. Balice, W.H. Romme, J.H. Kastens, M.L. Floyd, J. Belnap, J.J. Anderson, O.B. Myers, and C.W. Meyer. 2005.

Regional vegetation die-off in response to global-change-type drought. Proceedings National Academy Sciences 102:15144-15148.

Britt, C., and C. Lundblad. 2009. Gray Vireo Status and Distribution on Fort Bliss: 2007. Pages 3–6 *in* Proceedings of the Gray Vireo Symposium Co-Sponsored by the New Mexico Department of Game and Fish and the New Mexico Ornithological Society. 12–13 April 2008; Albuquerque, New Mexico (H. A. Walker and R. H. Doster, Eds). The New Mexico Department of Game and Fish, Santa Fe, New Mexico.

Clifford, M.J., N.S. Cobb, and M. Buenemann. 2011. Long-term tree cover dynamics in a pinyon-juniper woodland: climate-change-type drought resets successional clock. Ecosystems 14:949-962.

Cole, K.L., K. Ironside, S. Arundel, P. Duffy, and J. Shaw. 2007. Modeling future plant distributions on the Colorado Plateau: an example using *Pinus edulis*. Pp. 319-330 *in*: the Colorado Plateau III; Integrating research and resources management for effective conservation. C. van Riper III and M. Sogge, eds. University of Arizona Press, Tucson, AZ.

DeLong, J. P., and N. S. Cox. 2005. Nesting Ecology of Gray Vireos in Central New Mexico: 2005 Results. Unpublished report to the Bureau of Land Management and New Mexico Department of Game and Fish. SORA and Eagle Environmental, Inc., Albuquerque, New Mexico.

ERDAS 2015. ERDAS Imagine, Hexagon Geospatial, Norcross GA 30092.

ERDAS 2016. ERDAS Imagine, Hexagon Geospatial, Norcross GA 30092.

Esri 2012. ArcGIS Desktop: Release 10.4. Redlands, CA: Environmental Systems Research Institute.

Esri 2016a. World_Imagery - Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

Esri 2016b. ArcGIS Desktop: Release 10.4. Redlands, CA: Environmental Systems Research Institute.

Frei, R. D., and C. A. Finley. 2009. Habitat Preference and Status of Gray Vireos on Kirtland Air Force Base in Albuquerque, New Mexico. Pages 7–10 *in* Proceedings of the Gray Vireo Symposium Co-Sponsored by the New Mexico Department of Game and Fish and the New Mexico Ornithological Society. 12–13 April 2008; Albuquerque, New Mexico (H. A. Walker and R. H. Doster, Eds). The New Mexico Department of Game and Fish, Santa Fe, New Mexico.

Greenwood, D.L. and P.J. Weisberg. 2008.Density-dependent tree mortality in pinyon-juniper woodlands. Forest Ecology and Management 255:2129-2137.

Gutzler, D.S. 2013. Regional climate considerations for borderlands sustainability. Ecosphere 4:7. http://dx.doi.org/10.1890/ES12-00283.1.

Halofsky, J.E., M.K. Creutzburg, M.A. Hemstrom, eds. 2014. Integrating social, economic, and ecological values across large landscapes. Gen.Tech.Rep. PNW-GTR-896. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR. 206 pp.

Jacobs, B. 2015. Restoration of degraded transitional (piñon-juniper) woodland sites improves ecohydrologic conditions and primes understory resilience to subsequent disturbance. Ecohydrology 9:1417-1428.

Johnson, K., L. Wickersham, T. Neville, J. Wickersham, J. Smith, M. Baumann, and C. Finley. 2011. Habitat use at multiple scales by pinyon-juniper birds on Department of Defense lands: landscape scale. Natural Heritage New Mexico Publ. 11-GTR-360. Natural Heritage New Mexico, UNM Biology Department, Albuquerque, NM.

Johnson, K., L. Wickersham, T. Neville, G. Sadoti, J. Smith, J. Wickersham, and C. Finley. 2012. Habitat use at multiple scales by pinyon-juniper birds on Department of Defense lands II: nest and territory/colony scale. Natural Heritage New Mexico Publ. 12-GTR-366. Natural Heritage New Mexico, UNM Biology Department, Albuquerque, NM.

Johnson, K., J. Smith, N. Petersen, L. Wickersham, and J. Wickersham. 2013. Habitat use by pinyon-juniper birds in Farmington BLM Resource Area. Natural Heritage New Mexico Publ. No. GTR-13-380. Natural Heritage New Mexico, UNM Biology Department, Albuquerque, NM.

Johnson, K., L. Wickersham, J. Smith, G. Sadoti, T. Neville, J. Wickersham, and C. Finley. 2014. Habitat use at multiple scales by pinyon-juniper birds on Department of Defense lands III: landscape, territory/colony, and nest scale. Natural Heritage New Mexico Publ. 14-GTR-381. Natural Heritage New Mexico, UNM Biology Department, Albuquerque, NM.

Johnson, K., L. Wickersham, J. Smith, N. Petersen, and J. Wickersham. 2015. Habitat use by Pinyon Jay and Gray Vireo in the BLM Farmington Resource Area 2013-2014, final report. Natural Heritage New Mexico Publication # GTR-15-386. University of New Mexico Biology Department, Albuquerque, NM.

LANDFIRE Existing vegetation type layer. 2012. U.S. Department of Interior, Geological Survey. http://landfire.cr.usgs.gov.

Ligon, J.D. 1978. Reproductive interdependence of piñon jays and piñon pines. Ecological Monographs 48:111-126.

Lillesand, T.M. and R.W. Kiefer, 1987. Remote sensing and image interpretation, 2nd Edition, John Wiley & Sons, New York. 721 pp.

Loftin, S.R. 1999. Initial response of soil and understory vegetation to a simulated fuelwood cut of a pinyon-juniper woodland in the Santa Fe National Forest. In: Monsen, Stephen B.; Stevens, Richard, comps. 1999. Proceedings: Ecology and management of pinyon-juniper communities within the Interior West; 1997. September 15-18; Provo, UT. Proc. RMRS-

P-9. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT.

Marzluff, J.M. and R.P. Balda. 1992. The pinyon jay: the behavioral ecology of a colonial and cooperative corvid. T & AD Poyser, London. 317 pp.

McDowell, N.G., A.P. Williams, C. Xu, W.T. Pockman, L.T. Dickman, S. Sevanto, R. Pangle, J. Limousin, J. Plaut, J. Ogee, J.C. Domec, C.D. Allen, R.A. Fisher, X. Jiang, J.D. Muss, D.D. Breshears, S.A. Rauscher, and C. Koven. 2015. Multi-scale predictions of massive conifer mortality due to chronic temperature rise. Nature Climate Change 2873:106, www.nature.com/natureclimatechange.

Meddens, A.J.H., J.A. Hicke, A.K. Macalady, P.C. Buotte, T.R. Cowls, and C.D. Allen. 2014. Patterns and causes of observed piñon pine mortality in the southwestern United States. New Phytologist 206:91-97.

Mueller, R.C., C.M. Scudder, M.E. Porter, R.T. Trotter III, C.A. Gehring, and T.G. Whitham. 2005. Differential tree mortality in response to severe drought: evidence for long-term vegetation shifts. Journal of Ecology 93:1085-1093.

NAIP 2014. USDA-FSA National Agriculture Imagery Program 4-band digital ortho imagery; https://gdg.sc.egov.usda.gov/. USDA FSA Aerial Photography Field Office, Salt Lake City, UT.

National Audubon Society. 2015. Audubon's Birds and Climate Change Report: A Primer for Practitioners. Version 1.3. Contributors: G. Langham, J. Schuetz, C. Soykan, C. Wilsey, T. Auer, G. LeBaron, C. Sanchez, and T. Distler. National Audubon Society, New York.

NHNM Species Information. From Natural Heritage New Mexico. 2017. NM Biotics Database. Museum of Southwestern Biology, University of New Mexico. Albuquerque, NM. Accessed online: http://nhnm.unm.edu.

New Mexico Department of Game and Fish. 2015. State Wildlife Action Plan for New Mexico. New Mexico Department of Game and Fish. Santa Fe, New Mexico. 234 pp + appendices.

Pavlacky, D.C. and S.H. Anderson. 2001. Habitat preferences of pinyon-juniper specialists near the limit of their geographic range. Condor 103:322-331.

Redmond, M.D., F. Forcella, and N.N. Barger. 2012. Declines in pinyon pine cone production associated with regional warming. Ecosphere 3:1-14.

Redmond, M.D., N.S. Cobb, M.J. Clifford, and N.N. Barger. 2015. Woodland recovery following drought-induced tree mortality across an environmental stress gradient. Global Change Biology 21:3685-3695.

Resource Geographic Information System (RGIS) 2017. http://rgis.unm.edu. Clearinghouse supported by the Earth Data Analysis Center, University of New Mexico, Albuquerque, NM.

Romme, W.H., C.D. Allen, J.D. Bailey, W.L. Baker, B.T. Bestelmeyer, P.M. Brown, K.S. Eisenhart, M.L. Floyd, D.W. Huffman, B.F. Jacobs, R.F. Miller, E.H. Muldavin, T.W. Swetnam, R.J. Tausch, and P.J. Weisberg. 2009. Historical and modern disturbance regimes, stand structures, and landscape dynamics in piñon-juniper vegetation of the western United States. Rangeland Ecology and Management 62:203-222.

Rondeau, R., M. Bidwell, B. Neely, I. Rangwala, L. Yung, and K. Wyborn. 2017. Pinyon-Juniper Landscape: San Juan Basin, Colorado. Social-Ecological Climate Resilience Project. North Central Climate Science Center, Ft. Collins, Colorado.

Thompson, R.S., S.E. Hostetler, P.J. Bartlein, and K.H. Anderson. 1998. A strategy for assessing potential future changes in climate, hydrology, and vegetation in the western United States. USGS Circular 1153. Accessed 6 August 2010 at: http://pubs.usgs.gov/circ/1998/c1153/.

U.S. Fish and Wildlife Service. 2008. Birds of Conservation Concern 2008. United States Department of Interior, Fish and Wildlife Service, Division of Migratory Bird Management, Arlington, Virginia. 85 pp. Accessed online at http://www.fws.gov/migratorybirds/NewReportsPublications/SpecialTopics/BCC2008/BCC2008.pdf.

USNVC. 2016. United States National Vegetation Classification Database, V2.0. Federal Geographic Data Committee, Vegetation Subcommittee, Washington DC. usnvc.org.

van Riper III, C., J.R. Hatten, J.T. Giermakowski, D. Mattson, J.A. Holmes, M.J. Johnson, E.M. Nowak, K. Ironside, M. Peters, P. Heinrich, K.L. Cole, C. Truettner, and C.R. Schwalbe. 2014. Projecting climate effects on birds and reptiles of the Southwestern United States. U.S. Geological Survey Open-File Report 2014–1050, 100 p., http://dx.doi.org/10.3133/ofr20141050.

Wickersham, L. E., and J. L. Wickersham. 2016. Gray Vireo (*Vireo vicinior*) population monitoring project: 2013–2015 report. Unpublished report to Kirtland Air Force Base by Animas Biological Studies, Durango, CO. 27 pp. + Appendices A–D.

Wickland, Diane E. 1991. Mission to planet earth: The ecological perspective. Ecology 72:1923-1933.

Zlotin, R.I. and R.R. Parmenter. 2008. Patterns of mast production in pinyon and juniper woodlands along a precipitation gradient in central New Mexico (Sevilleta National Wildlife Refuge). Journal of Arid Environments72:1562-1572.

Appendix 1. Image Analysis Methods

Data Sources

Satellite Imagery

We used two types of imagery over the study area, the Landsat 8 Operational Land Imager (OLI) and digital aerial photography from the USDA's 2014 National Agriculture Imagery Program (NAIP 2014). Multi-spectral satellite imagery like OLI records different natural reflectance of surface materials such as rocks, plants, soils, and water. Variation in plant reflection and absorption due to biochemical composition produces distinct spectral "signatures" (Wickland 1991, Lillesand and Kiefer 1987) that provide a measure of reflectance at specific wavelengths. These can be analyzed statistically to develop a landscape vegetation map of spectrally similar plant communities.

The OLI sensor has seven spectral bands representing the reflective visible and infrared wavelengths and two thermal bands which provide good spectral discrimination. Each band represents a specific range of light wavelengths (Table A1). OLI Bands 3, 4, 5, and 6 are particularly useful for vegetation mapping, while OLI Bands 4, 6, and 7 are useful for detecting variations in surface geology. Surface geology and soil discrimination are important in developing mapping units of the sparse vegetation communities that occur in the study area. OLI Bands 10 and 11 record thermal response, which indicates surface temperature. It can also indicate moisture content, which can be useful for discriminating different plant and soil types.

Each OLI band integrates the spectral response it receives over the Instantaneous Field of View (IFOV), the smallest area resolvable by the sensor and represented on the computer screen by individual pixels. The reflective visible and infrared IFOV bands cover an area of approximately 30 m x 30 m (98 ft x 98 ft). We did not use the thermal bands because of their much coarser spatial resolution (IFOV of 100 m x 100 m). The panchromatic OLI Band 8 integrates reflectance largely over the visible wavelengths. It also has a spatial resolution of 15 m x 15 m and is typically digitally merged with the other non-thermal bands to improve spatial resolution. Even with an IFOV of 15 m x 15 m, individual occurrences of plants are not resolved by the sensor; therefore, the OLI imagery is best suited for evaluating more generalized vegetation community or plant association occurrence patterns and their associated surface substrate characteristics.

We acquired our Landsat OLI imagery in 2014 in an attempt to match the conditions on the ground at the time of acquisition for the NAIP 2014. The Landsat OLI sensor acquires its imagery over orbital paths, which are approximately 185 km wide, every 16 days. The study area was so large that it fell under two separate satellite orbital paths—path 34(P34) and path 35 (P35). To capture the seasonal vegetation changes of deciduous shrub leaf-out, forb emergence, and transition from cool- to warm-season grasses (as compared to the all-season continuous vegetative response from the coniferous piñon and juniper), we acquired multi-temporal OLI scenes from 2014: P34 to the west:19 March, 11 September, and 13 October; and P35 to the east: 24 February, 15 May and 20 September.

Table A2. Landsat OLI band descriptions.

Landsat Band	Wavelength (μms)	Surface Response
Band 1	Ultra-Blue (0.43-0.45)	Water penetration and aerosol reflectance.
Band 2	Visible Blue (0.45-0.51)	Absorption by most materials except saline or sandy soils.
Band 3	Visible Green (0.53-0.59)	Minor green vegetation reflectance peak.
Band 4	Visible Red (0.64-0.67)	Green vegetation absorption, but senescent vegetation reflectance and iron-stained soils reflect in these wavelengths.
Band 5	Near Infrared (0.85-0.88)	Green vegetation reflectance peak.
Band 6	Mid-Infrared (1.57-1.65)	Woody vegetation has less reflectance than herbaceous vegetation due to shadowing.
Band 7	Mid-Infrared (2.08-2.35)	Hydrated vegetation, wet soil, and clayey soils have strong absorption features in these wavelengths.
Band 8	Panchromatic (0.58-0.68)	Overall albedo in the visible wavelengths at twice the spatial resolution of the other bands.

Aerial Photography

The NAIP 2014 aerial photography was the most recent high-spatial-resolution, publicly-available dataset available for the whole study area. This imagery was used for the detailed land cover map classification and to provide an image for background display. Although the NAIP 2014 imagery does not have the full spectral capabilities of the OLI, it does provide separate bands for the visible blue, green, red and near infrared color portions of the electromagnetic spectrum. These are similar to the OLI Bands 2, 3, 4 and 5, respectively, but at a 1-m spatial resolution. The NAIP 2014 was acquired only at one point in time, May 2014, and thus did not provide information on seasonal phenologies of different vegetation types. In May, however, some subtle differences are apparent between the early deciduous “green-up”, the steady “green” response of the conifers, and the lesser response in the drier shrublands and grasslands.

The NAIP data, which originally were divided into 7.5’ Quarter Quads, were mosaicked together then cut to match the east and west Landsat paths. In addition, we created an NDVI [Eq. 2], which emphasizes vegetative greenness. The NDVI was added to the NAIP 2014 mosaic to highlight green vegetation and aid in the NAIP 2014 classification efforts. Also, the NDVI was found to highlight individual tree crowns. A threshold version was later used to create a tree canopy map (see Canopy Map Creation, below).

Ancillary Map Geographic Information System (GIS) Layers

We acquired additional vector and raster data from various sources to use as background layers and objects for analyses. Roads (TIGER-Line®) were used on field maps to help identify established roads within the study area. We used Pinyon Jay and Gray Vireo occurrence data from the NHNM NMBiotics database (NHNM 2014) to create a GIS point layer showing the location of vegetation plot data. As the initial in-house vegetation data for this area was limited on the outset of this project, we also used information based on the 30-m spatial resolution USFS LANDFIRE Existing Vegetation Type map from 2012 (LANDFIRE 2012) that covered the area.

We intended to capture the roads and other human disturbance class through the imagery analysis. Unfortunately, much of the study area is barren or sparsely vegetated, making it impossible to discriminate natural barren features from human disturbance. Therefore, we used on-screen digitizing with the NAIP 2014 imagery to create our roads and human disturbance class; vector data such as TIGERLine® were not particularly helpful in that regard for features such as well pads and their associated roads, due to the rapid nature of development and their not being part of a nominal road system. This digitization was an unanticipated labor-intensive process; hence, we only digitized human disturbance within piñon-juniper vegetation, the habitats of interest.

Software and Hardware Used

We used Hexagon Geospatial, ERDAS Imagine, Version 2015 to process the raster imagery and develop the classification. Some editing was accomplished in ERDAS Imagine 2016 (ERDAS 2016). All digital imagery and geospatial layers were processed, manipulated, and analyzed within the Imagine and ArcGIS 10.4 (Esri 2016b) environments. We stored and manipulated all field data using Microsoft Access and Microsoft Excel 2010.

Image Processing

We obtained a different dataset for each satellite path, which had to be processed separately and later mosaicked together. The methods outlined in this section describe the initial effort. This was based on combining the spectral and temporal advantages of the OLI data with the spatial detail of the NAIP 2014.

Geometric Correction

We re-rectified the OLI images using the NAIP 2014 photo mosaic as a base, and projected them into the Universal Transverse Mercator, Zone 13 System, using the 1983 North American Datum and the 1980 Geodetic Reference System Spheroid.

Band Ratios

In addition to the spectral bands, we computed several vegetation indices to enhance various vegetation or ecosystem characteristics. The four indices used were Normalized Difference Vegetation Index (NDVI) [Eq. 1], Normalized Difference Senescent Vegetation Index (NDSVI) [Eq. 2], a moisture index [Eq. 3], and a canopy structure index [Eq. 4]. These were computed as follows:

$$\text{NDVI} = ((\text{Band } 5 - \text{Band } 4) / (\text{Band } 5 + \text{Band } 4) + 1) * 100 \quad (\textbf{Eq. 1})$$

$$\text{NDSVI} = ((\text{Band } 7 - \text{Band }) / (\text{Band } 7 + \text{Band }) + 1) * 100 \quad (\textbf{Eq. 2})$$

$$\text{Moisture index} = ((\text{Band } 6 - \text{Band } 7) / (\text{Band } 6 + \text{Band } 7) + 1) * 100 \quad (\textbf{Eq. 3})$$

$$\text{Structure index} = ((\text{Band } 5 - \text{Band } 6) / (\text{Band } 5 + \text{Band } 6) + 1) * 100 \quad (\textbf{Eq. 4})$$

Band ratios, in general, are designed to divide a reflectance peak against an absorption low to distinguish unique surface features. Due to the potential differences between image data ranges, the difference between bands is normalized against the total data range of the image bands. The addition of “1” and multiplying by “100” in each equation turns the original result into a positive integer value centered around 100.

The NDVI emphasizes vigorous green plant growth by comparing a strong chlorophyll reflectance in the near-infrared wavelengths (Band 5) against chlorophyll absorption in the visible red wavelengths (Band 4). The NDSVI enhances the spectral characteristics of senescent vegetation (specifically grasses), which have a relatively low reflectance response in the red wavelengths (Band 4) and a high reflectance in the mid-infrared wavelengths (Band 7). The moisture index compares relatively high reflectance values in the shorter wavelengths of the mid-infrared (Band 6) against strong absorption at the longer wavelengths of the mid-infrared (Band 7) caused by water molecules found in soil and vegetation. Similarly, the structure index enhances leaf-water-content response and some shadowing in plants by emphasizing a strong chlorophyll reflectance in the near infrared wavelengths (Band 5) against water absorption in the mid-infrared wavelengths (Band 6). We developed an additional NDVI for the NAIP imagery to enhance the spatial resolution of the datasets for our final compilation.

Image Classification and Land Cover Map Creation

Initial Landsat OLI Land Cover Classification

We combined each Landsat OLI scene and its derived indices into one file. We merged these files with the Panchromatic band to create an output image file of all these layers at a 15-m spatial resolution, one for each half of the study area. We then created an unsupervised classification using the Iterative Self-Organizing Data Analysis Technique (ISODATA) algorithm. The ISODATA technique divides the image data into statistically separable clusters and creates an unsupervised classification based on pixel similarities. The imagery was initially classified into 36 separate classes using the maximum likelihood decision rule [Eq. 5].

$D = [0.5\ln(cov_c)]-[0.5(X-M_c)^T * (cov_c^{-1})*(X-M_c)]$ (**Eq. 5**),

where **D** is the weighted distance, $\mathbf{cov_c}$ is the covariance matrix for a particular class, **X** is the measurement vector of the pixel, $\mathbf{M_c}$ is the mean vector of the class and $^{\mathbf{T}}$ is the matrix transpose function (ERDAS 2015). Each pixel was then assigned to the class with the lowest-weighted distance. An unsupervised classification is unreferenced as to the identity of the classes. Therefore, each of the 36 classes was compared to the land cover classes of the LANDFIRE (2012) map and through photo-interpretation of the NAIP 2014. This resulted in a land cover map with land cover classes based on the LANDFIRE 2012 classification schema. We cleaned up the east and west side classifications through on-screen heads-up editing, using the NAIP 2014 as a reference. These maps were then stitched together to create a stand-alone land cover map at 15-m spatial resolution suitable for landscape-scale management (e.g., 1:40,000 or coarser scale).

Follow-on NAIP 2014 Land Cover Classification

The NAIP 2014 has a finely resolved spatial detail but lacks the spectral detail to discriminate between many related land cover classes. We therefore used the OLI-derived land cover map to stratify a classification of the NAIP 2014 mosaic.

In a supervised classification strategy, field data are applied to the image data through an interactive process called “seeding.” A pixel at the field plot location was selected in the image, and its spectral characteristics were used to gather similar contiguous pixels to create a statistical model or “seed” of the field plot. The seeding algorithm [Eq. 5] searches around that point within user-defined parameters that contain a seed within: 1) a certain distance, 2) a certain area, and 3) a certain spectral distance defined as:

$$SD = \sqrt{\sum(\mu - X)^2} \quad \textbf{(Eq. 5)},$$

where **SD** is the spectral distance between a new pixel and the mean of the current seed group pixels across all bands, **μ** is the mean of the seed pixel group for each image band, and **X** is the spectral value of the new pixel for each band.

We iteratively constructed the best seed models by adjusting the parameters and comparing the resulting pixel distributions against the original imagery. The seed’s maximum area was initially defined by the estimated size of the vegetation community occurrence as determined in the field. Often this is noted as a scalar, with small occurrences defined as 1–5 ha and large occurrences as greater than 5 ha. We then defined the actual seed by increasing the spectral distance iteratively until the spectral signature collected within the seed generated a covariance matrix that could be inverted, a requirement for the maximum likelihood decision rule used later in the actual classification.

We checked the seed shape and location against field notes and maps and by direct interpretation of the seed in the image on the screen. Each seed was saved in a signature file with its field plot number, mean values for each image band, variance, number of pixels that were used to create the seed, and minimum and maximum values.

We then used statistics gathered in the seeding process to perform a supervised classification. Supervised classifications are based on a maximum likelihood decision rule containing a Bayesian classifier that uses probabilities to weight the classification toward particular classes. In this study the probabilities were unknown; therefore, the maximum likelihood equation [Eq. 6] for each of the classes is given as:

$$D = [0.5\ln(cov_c)]-[0.5(X-M_c)^T * (cov_c^{-1})*(X-M_c)] \quad \textbf{(Eq. 6)},$$

where **D** is the weighted distance, $\mathbf{cov_c}$ is the covariance matrix for a particular class, **X** is the measurement vector of the pixel, $\mathbf{M_c}$ is the mean vector of the class and $^{\mathbf{T}}$ is the matrix transpose function (ERDAS 2015). Each pixel is then assigned to the class with the lowest-weighted distance. This technique assumes the statistical signatures have a normal distribution.

Each NAIP2014 stratified image was classified until the resulting classification matched what could be visually verified on the NAIP2014. Each stratum was classified and cleaned up using an on-screen heads-up editing approach. Then we stitched together the individual stratified maps, and edited the final land cover map. This resulted in a land cover map at a1-m spatial resolution usable at a 1:5,000 or coarser scale.

Canopy Map

We created an NDVI layer from the NAIP 2014 imagery, using the formula:

NDVI = ((NIR – Red)/(NIR + Red) + 1) * 100 (**Eq. 7**).

NDVI enhances green vegetation. We found that values above 110 best separated tree canopies from both barren and other, less-green vegetation. We masked other green vegetation by using the original landscape-scale classification for those areas with values higher than 110 and the following classes: Piñon-Juniper Woodland, One-seed Juniper Woodland, Utah Juniper Woodland, and Sagebrush Shrubland. We divided this file into 76, 7.5’ quad tiles, then clumped the tiles to collect the individual area count for each canopy. We assigned clumps of ≤ 3 m^2 to sagebrush and considered clumps >200 m^2 to be riparian shrublands/woodlands. We then screen-edited the tiles, using the NAIP 2014 imagery as a background. Some larger areas classified as riparian shrubland had to be re-classed as piñon-juniper, and we also changed patches of piñon-juniper in the valley floors to Riparian Forest and Shrubland.

To distinguish Gray Vireo from Pinyon Jay nesting habitat, we created an ancillary geospatial layer depicting the combined canopy cover (in m^2) of the three piñon-juniper vegetation types: Juniper Woodland and Savanna, Utah Juniper Woodland, and Piñon-Juniper Woodland. We then collected zonal cover values from the combined tree canopy cover layer within a continuous series of 20 x 20 m grid squares (approximately the size of our nest and random vegetation data plots) over the entire study area. We plotted the distributions of Gray Vireo and Pinyon Jay nest data against the tree cover values obtained from the canopy cover layer (Figure 2). Cover values from these distributions were then used to define the cutoff for the Dense versus Sparse Piñon-Juniper map units.

Appendix 2. Map Unit Descriptions

Ponderosa Pine Woodland. 5,936 ha. This woodland map unit is composed of woodlands dominated by ponderosa pines (*Pinus ponderosa)*, which may occur as the only tree or with other canopy associates, including two needle (aka Colorado) piñon (*Pinus edulis*), Utah juniper (*Juniperus osteosperma*), and occasionally (e.g., along the edge of Rawhide Canyon) Douglas fir (*Pseudotsuga menziesii*). Understory shrubs may include big sagebrush (*Artemesia tridentata*), Gambel oak (*Quercus gambelii*), and mountain mahogany (*Cercocarpus montanus*). Various grasses and forbs comprise the herbaceous layer. This map unit occurs mainly in mesic canyons, with Piñon-Juniper on adjacent hills or uplands. Canopy cover ranges from 25% to 35% in sparse areas and up to about 45% at its highest density.

This map unit is similar to the Ponderosa Pine Southern Rocky Mountain Forest and Woodland Alliance (A3398) of the National Vegetation Classification (https://www1.usgs.gov/csas/nvcs/nvcsGetUnitDetails?elementGlobalId=899522). It occurs within Pinyon Jay nesting colonies at Rawhide Canyon and Lewis Canyon.

Dense Piñon-Juniper Woodland. 44,036 ha. All 20 x 20 m grid squares (the same area as BBird nest and random plots) in piñon-juniper vegetation having >67 m^2 tree canopy cover are mapped as Dense Piñon-Juniper, equivalent to ≥17% canopy cover. Mean canopy cover in Dense Piñon-Juniper was 25% (range on mapped grid squares = 0.25% – 94%). The mean shrub cover category on plots in Dense Piñon-Juniper was 1.66, meaning between 10 and 20% shrub cover. Mean grass cover in Dense Piñon-Juniper ranged from 0 to 10%, with most plots having less than 10% grass cover.

Areas classified as Dense Piñon-Juniper can be *Juniperus osteosperma*-dominated, *P. edulis*-dominated, or an equal mix of the two species. These two species dominate the tree canopy, and smaller individuals of both may form a sparse subcanopy. Shrubs provide low to moderate cover. Pinyon Jays nested in areas with up to 43% canopy cover. On a sample of dense Pinyon Jay nest and random plots (*n*=30), the most common shrubs and sub-shrubs were broom snakeweed (*Gutierrezia sarothrae*), Wyoming big sagebrush (*A. tridentata wyomingensis*), and *C. montanus*, followed by Utah serviceberry (*Amelanchier utahensis*), *Q. gambelii*, prickly pear cactus (*Opuntia* spp.), and other, less-common species.

This MU includes vegetation similar to the Two-Needle Pinyon – Utah Juniper / Shrub Understory Woodland Alliance (A3571) of the National Vegetation Classification (https://www1.usgs.gov/csas/nvcs/nvcsGetUnitDetails?elementGlobalId=899629). This is preferred Pinyon Jay nesting habitat; the jays nested in this habitat at the Rawhide Canyon and Lewis Canyon colonies. At all study sites where Gray Vireos were found nesting, a few Gray Vireo nests were found in this habitat.

Sparse Piñon-Juniper Woodland. 278,168 ha. All 20 x 20 m grid squares having ≥1m^2 ≤ 67 m^2 tree cover are mapped as Sparse Piñon-Juniper (*P. edulis* and probable *J. osteosperma*, although field identification of the latter is difficult), equivalent to 0–17% canopy cover. Mean canopy cover in Sparse Piñon-Juniper was 8.3% (range on mapped grid squares = 0–80%). Mean shrub cover category on plots in Sparse Piñon-Juniper was approximately 1, meaning 1–10%, and ranged from 0–20%. Mean grass cover category on Sparse Piñon-Juniper plots was 1 (0–10%), (range 0–3, or 0–30%).

Trees in this map unit are mainly junipers; 86% of BBird plots in Sparse Piñon-Juniper have >50% juniper trees, and most plots are even more heavily juniper-dominated. Shrubs and sub-shrubs on Pinyon Jay nest and random plots (*n*=13) in Sparse Piñon-Juniper were mainly *G. sarothrae* and *A. tridentata*, with banana yucca (*Yucca baccata*), *Opuntia* spp., *C. montanus*, and antelope bitterbrush (*Purshia tridentata*) also present. A sample of sparse Gray Vireo nest and random plots (*n*=85) had only three shrub species commonly present: *A. tridentata*, rabbitbrush (*Ericameria nauseosa*), and *P. tridentata*. The smaller number of shrub species on Gray Vireo plots probably occurs because Gray Vireos tend to nest in areas of lower canopy cover than Pinyon Jays, even within Sparse Piñon-Juniper.

This map unit is similar to the alliances listed in Dense Piñon-Juniper above, but it has much lower tree cover, and juniper:piñon ratio is higher than in Dense Piñon-Juniper. The majority of Gray Vireo nests but fewer than half of Pinyon Jay nests occurred in this habitat.

Scattered Piñon-Juniper Woodland. 28,343 ha. 20 x 20 m grid squares having <1 m^2 (0.25%) piñon or juniper tree cover are mapped as Scattered Piñon-Juniper; however, the majority of trees in these areas are junipers, and *P. edulis* is absent or has very low cover. This map unit has a sparse understory of scattered forbs and grasses and can have a moderate understory of shrubs and sub-shrubs, typically *A. tridentata* or four-wing saltbush (*Atriplex canescens*). Examples occur on small rises on either side of NM 371. Pinyon Jays did not nest in these very open habitats, and Gray Vireo nests were uncommon in Scattered Piñon-Juniper; hence, we have too few nest plot data to estimate grass or shrub cover in this habitat. Because tree cover is so low, this map unit might also be considered grassland or shrubland.

This map unit most closely resembles Utah Juniper / Shrub Understory Woodland Alliance (A3496) of the National Vegetation Classification (https://www1.usgs.gov/csas/nvcs/nvcsGetUnitDetails?elementGlobalId=899619), except that Scattered Piñon-Juniper has only scattered trees, and shrub species richness is more limited than in A3496. Tree and shrub cover in this MU are usually too sparse to support Gray Vireo nesting, and Pinyon Jays do not nest in this MU.

Gambel Oak Woodland. 464 ha. This MU is characterized by *Q. gambelii* in a moderately dense to dense tall or short shrub layer, typically 2–5 m tall. Structure is variable, including patches of oak shrubs with grass, dense oak thickets with little understory, and tall shrublands with a varied understory of short shrubs, grasses, and forbs. It typically occurs on steep rocky slopes but can occur in canyon bottoms and along drainages. Scattered trees, typically *P. edulis* or *J. osteosperma*, are typically present. Shrubs that may co-dominate or form a separate shrub layer are *A. tridentata* and *C. montanus.* The sparse to relatively dense herbaceous layer is dominated by grasses.

This MU is similar to the Gambel Oak / Mountain Snowberry Shrubland Alliance (A3735) of the National Vegetation Classification (https://www1.usgs.gov/csas/nvcs/nvcsGetUnitDetails?elementGlobalId=899787). Patches of this MU may occur within Pinyon Jay home ranges, but neither Pinyon Jay nor Gray Vireo typically nests in this MU.

Montane Chaparral. 322 ha. This MU is dominated by *C. montanus* and/or *P. tridentata*. Other characteristic shrubs may include cliff rose (*P. stansburiana*), *Quercus* spp., and *Opuntia* spp. The sparse to moderately dense herbaceous layer is dominated by perennial grasses, with annual grasses and forbs seasonally present. This dense shrubland occurs mainly on mesa sides and cliffs, in rocky, poorly developed soils. It is also scattered under piñon-juniper woodlands; for this model patches of Montane Chaparral within these woodlands have been lumped within Dense Piñon-Juniper and Sparse Piñon-Juniper. These shrublands are less mesic than the Gambel Oak Woodland. Fire may play an important role in this MU, as the dominant shrubs experience severe die-back with fire, although some plants will re-sprout. Fire suppression may have allowed trees to invade some of these shrublands.

This MU most closely resembles the Southern Rocky Mountain Mountain-mahogany-Mixed Foothill Shrubland Group (G276) of the National Vegetation Classification (https://www1.usgs.gov/csas/nvcs/nvcsGetUnitDetails?elementGlobalId=836926).

Sagebrush Shrubland. 109,723 ha. This semi-arid MU occurs throughout the study area (and much of the Colorado Plateau). Stands have a mixed shrub canopy dominated by *A. tridentata*. Other shrubs have low cover, except species that increase with disturbance, such as *G. sarothrae* and *E. nauseosa.* This MU occurs on alluvial bottomlands, mesa tops, and arroyos. Various grasses such as James' galleta (*Pleuraphis jamesii*), blue grama (*Boutelous gracilis*), alkali sacaton (*Sporobolus airoides*), and sand dropseed (*Sporobolus cryptandrus*) may comprise the herbaceous layer. Some of the sagebrush-dominated inter-montane valleys and mesa tops have been treated mechanically or with herbicides.

This map unit most closely resembles the Basin Big Sagebrush - Foothill Big Sagebrush Dry Shrubland Alliance (A3194) of the National Vegetation Classification. (https://www1.usgs.gov/csas/nvcs/nvcsGetUnitDetails?elementGlobalId=899318).

Other Shrubland. 18,841 ha. This MU occurs mainly in lowland sites associated with drainages, alluvial flats, washes, and along roadsides. It may also occur in association with Riparian Forest and Shrubland. It includes shrublands of short stature with fairly open canopy dominated by *A. canescens* and/or *E. nauseosa*. Other associated shrub species include *A. tridentata*, *G. saraothrae*, and skunkbush sumac (*Rhus trilobata*).The more alkaline flats included within this map unit are dominated by greasewood (*Sarcobatus vermiculatus*). Scattered, small junipers (*Juniperus* spp.) may be present. An herbaceous layer of sparse to moderate cover includes various forbs and grasses.

This map unit most closely resembles the Fourwing Saltbush – Rubber Rabbitbrush Desert Wash Alliance (A3266) of the National Vegetation Classification (https://www1.usgs.gov/csas/nvcs/nvcsGetUnitDetails?elementGlobalId=899390). The *S. vermicuilatus*-dominated areas most closely resemble the Greasewood Intermountain Wet Shrubland Alliance (A1046, https://www1.usgs.gov/csas/nvcs/nvcsGetUnitDetails?elementGlobalId=866470).

Grassland. 258,586 ha. The Grassland MU is characterized by an herbaceous layer of sparse to moderately dense perennial grasses with no significant shrub component. The BLM Range Site Database (Halofsky et al. 2014) indicates that *P. jamesii* is the most common grass within the study area. It ranges from nearly monotypic stands of open and sparse grasslands to associations with other native grasses that include Indian ricegrass (*Achnatherum hymenoides*), *B. gracilis*, squirreltail (*Elymus elymoides*), *S. airoides*, and *S. cryptandrus*. Other grasses such as crested wheatgrass (*Agropyron cristatum*) and western wheatgrass (*Pascopyrom smithii*) are minor components scattered in the eastern portion of the study area, typically in association with *P. jamesii*. *P. jamesii* can also be found within disturbed sites with non-native species such as cheatgrass (*Bromus tectorum*). Any of these common dryland native grasses may be dominant at Grassland sites within the study area.

This MU is similar to the James Galleta Grassland Alliance (A1287) of the National Vegetation Classification (https://www1.usgs.gov/csas/nvcs/nvcsGetUnitDetails?elementGlobalId=899104).

Riparian Woodland and Shrubland. 8,450 ha. This map unit is characterized by the presence of the Rio Grande Cottonwood (*Populus deltoids* ssp. *wislizeni*) with a wide range of tree densities. . Other tree species may be present such as, narrowleaf cottonwood (*Populus angustifolia*), peachleaf willow (*Salix amygdaloides*), boxelder (*Acer negundo*), and *Juniperus* spp. The shrub layer may contain New Mexico olive (*Forestiera pubescens*), *E. nauseosa*, *A. tridentata*, narrowleaf willow (*Salix exigua*), and *R. trilobata.* An herbaceous layer of grasses with diverse forbs and ruderals may be present. Non-native species such as Russian olive (*Elaeagnus angustifolia*) and saltcedar (*Tamarix ramosissima*) are found scattered throughout and may be dominant. Stands occur on narrow stream terraces and large floodplains. Soils are fine sandy, silty, and clay loams.

This MU most closely resembles the Rio Grande Cottonwood – Plains Cottonwood Flooded Forest & Woodland (A3802) of the National Vegetation Classification (https://www1.usgs.gov/csas/nvcs/nvcsGetUnitDetails?elementGlobalId=899854) and is representative of both the broad floodplain and seasonal drainages encountered throughout the study area. Additionally, narrow floodplains and dry arroyos are associated with the Rocky Mountain & Great Basin Lowland & Foothill Riparian & Seep Shrubland Group (https://www1.usgs.gov/csas/nvcs/nvcsGetUnitDetails?elementGlobalId=857235) with willow-dominated shrublands.

Wetland. 326 ha. This MU contains smaller wetland areas and wetland vegetation adjacent to rivers, springs, and seasonally wet drainages. The wetlands are often associated with check dams and may be dominated by ruderal species.

Open Water. 5,262 ha. This MU contains open water such as large reservoirs, rivers, and ponds.

Barren/Sparsely Vegetated. 79,535 ha. This MU is dominated by bare ground, exposed bedrock, or very sparse vegetation and tends to occur in small patches as inclusions within other MUs.

Agriculture. 9,040 ha. This MU includes cultivated fields, fallow fields, and irrigated areas.

Human Disturbance. 60,115 ha. This map unit contains urban areas, farmsteads, and other areas of human development. It includes vegetation such as lawns, gardens, weedlots, or irrigation ditches. Roads and well pads are included within the Human Disturbance MU.