# Pinyon Jay Surveys in the Gila National Forest, New Mexico 2022

# Final Report to Share with Wildlife

**Fledgling Pinyon Jay, Gila National Forest 2022. Photo: Nate Petersen**

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*Animas Biological Studies, Durango, CO*
*January 2023*

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# Abstract

Pinyon Jay (*Gymnorhinus cyanocephalus*) populations have been declining steadily rangewide for over 40 years, raising concern over the species' conservation status. However, within the Pinyon Jay's range, Breeding Bird Survey (BBS) trend analyses suggest that some areas are trending strongly negative, while others appear to be stable or trending positive. BBS analyses suggest that the Gila National Forest (Gila NF), New Mexico, may be an area with a stable or increasing Pinyon Jay population. Despite the potential importance of the Gila NF to the Pinyon Jay's rangewide population, no systematic surveys of the area have previously been performed. We surveyed for Pinyon Jays in the Gila NF in March and April 2021 and 2022. Pinyon Jays were scarce in the south, common in the east, and abundant in the north, suggesting that parts of the forest may be a hotspot for Pinyon Jays in New Mexico. Multi-scale occupancy models indicate higher Pinyon Jays occupancy than indicated by naïve field survey results. This study indicates that the Gila NF has significant management responsibility for Pinyon Jays.

# Introduction

The Pinyon Jay (*Gymnorhinus cyanocephalus*) is an immediate priority Species of Greatest Conservation Need (SCGN) in New Mexico (New Mexico Department of Game and Fish [NMDGF] 2016). It is listed as vulnerable on the Red List of Threatened Species by the International Union for the Conservation of Nature (IUCN), suggesting that it is at risk of extinction in the medium-term future (Birdlife International 2017). It is a US Fish and Wildlife Service (USFWS) Species of Conservation Concern (USFWS 2019) and is the fastest declining bird associated with piñon-juniper habitats (Boone et al. 2018). Its rangewide population has declined an estimated 2% annually from 1967 to 2019; similar annual declines have been documented in New Mexico (Sauer et al. 2020). In April 2022, Defenders of Wildlife petitioned the USFWS to list the Pinyon Jay as threatened or endangered under the Endangered Species Act.

The Pinyon Jay is named for its coevolved mutualism with piñon trees (primarily Colorado piñon, *Pinus edulis,* and single-leaf piñon, *P. monophylla,* across the bird's range). Pinyon Jays are adapted for the harvest, transport, caching, and retrieval of piñon-pine seeds (Johnson and Balda 2020). Physiologically, the presence of piñon seeds and green cones reverses gonadal regression and stimulates testis growth in wild and experimental birds from central New Mexico (Ligon 1974, 1978). The bill is featherless at its base, which allows individuals to probe deep into green cones without pitch blocking the nostrils. A Pinyon Jay can carry up to 50 seeds in a single trip in its expandable esophagus. Pinyon Jays cache seeds in micro-habitats favorable to seed germination (Ligon 1978). Hence, the Pinyon Jay is the primary long-distance disperser of piñon-pine seeds and the only species capable of re-planting a piñon woodland decimated by fire, drought, or disease.

The causes of Pinyon Jay decline are not well documented, but climate change has been associated with widespread piñon mortality (Clifford et al. 2013), reductions in piñon canopy cover (Clifford et al. 2011), declines in piñon nut production (Wion et al. 2019), and reductions in piñon tree vigor (Johnson et al. 2017). In addition, the current management practice of thinning piñon-juniper woodlands for fuels reduction, habitat enhancement for other wildlife species (Boone et al. 2018), or ecological restoration can impact habitat quality for Pinyon Jays. In one study in the Southwestern US, thinning treatments that reduced canopy cover from 36% to 5% reduced local-level occupancy by Pinyon Jays in treated areas (Magee et al. 2019). In another study, Pinyon Jays stopped nesting within parts of a known colony site after the colony site was significantly thinned (87% reduction of trees per acre; Johnson et al. 2018).

In response to concern about the status of the Pinyon Jay and the need for information on its management, the Pinyon Jay Working Group released a Conservation Strategy for the Pinyon Jay (Somershoe et al. 2020). This comprehensive document outlines research necessary to understand Pinyon Jay biology, causes of decline, and management actions needed. A primary research need identified in the strategy is to document locations of flocks, home ranges, and nesting colonies across the Pinyon Jay's range. The location of Pinyon Jay nesting colonies is best known in New Mexico, where researchers with Natural Heritage New Mexico (NHNM), within the University of New Mexico Biology Department, have documented 54 Pinyon Jay nesting colony sites (e.g.; Petersen et al. 2014; Johnson et al. 2014, 2015, 2018, 2021). These nesting colonies are spread throughout New Mexico and southwestern Colorado in suitable piñon and juniper habitats.

However, a significant data gap exists for Pinyon Jays in the Gila National Forest (Gila NF). Although Pinyon Jays have been documented in the Gila NF (Figure 1), prior to this study, systematic surveys across suitable habitats in the NF had not been conducted. The Gila NF is especially important because Breeding Bird Survey data suggest that Pinyon Jay populations in the forest may be more stable than those in other areas of the state and range-wide and may even be increasing in some sites (Figure 1). The Gila NF may also be important to the species rangewide because New Mexico harbors an estimated 29% of the global population (Partners in Flight 2020).

**Fledgling Pinyon Jay, Gila National Forest 2022. Photo: Nate Petersen**

Occupancy modeling is a method that accounts for imperfect detection in surveys of birds and other animals via spatially or temporally repeated surveys. It provides an estimate of true occurrence in a surveyed area (MacKenzie et al. 2017). These models use information from repeated observations at each site to estimate and account for detectability, which may vary with site or survey characteristics. We employed occupancy modeling to estimate true occurrence of Pinyon Jays in the surveyed area.

The objectives of this study are to:

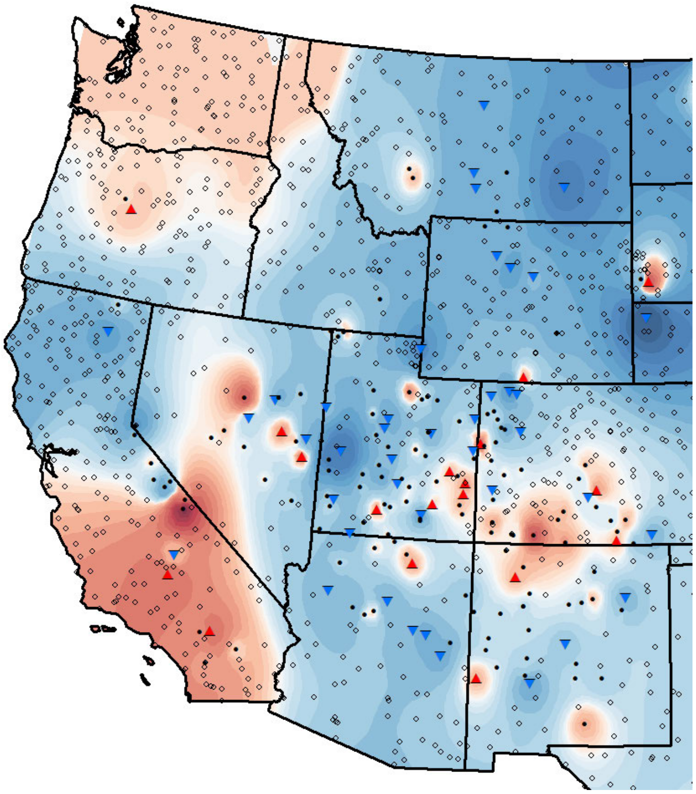
1. Conduct systematic Pinyon Jay breeding-season surveys in suitable habitat in the Gila NF.
2. Document locations of nesting colonies.
3. Use survey data and occupancy modeling techniques to estimate detection probabilities and occurrence of Pinyon Jays in the study area.
4. Delineate areas of Pinyon Jay population concentration and breeding.

## Tasks Accomplished in Year 2

The following tasks were accomplished in the second year of this study, 2022:

1. Conducted vehicle and walking surveys for Pinyon Jay flocks and nesting colonies, based on previously determined priority survey sites and occurrence data from 2021.
2. Modeled detection probabilities and occupancy of Pinyon Jays at Gila NF survey sites.
3. Mapped areas of Pinyon Jay occurrence and nesting.
4. Added 2022 occurrence data to the existing Pinyon Jay geodatabase.

Figure 1. Pinyon Jay yearly population trends, 2002–2021, from North American Breeding Bird Survey data. Trends are based on total Pinyon Jay counts per year/route (2002–2021), with trends estimated for any route with at least five years of survey data and two years with Pinyon Jay detections. Routes with Pinyon Jays detected in at least two years are shown with black dots, and routes with significant trends have a red (increasing) or blue (decreasing) triangle. Interpolations of trend weighted by *z*-values of the trend estimate are shown in the background using the same color gradient. Trends were estimated by the best fit (lowest AICc) Poisson or negative binomial distribution or best fit zero-truncated (if no zeros) or zero-inflated version of either distribution, as appropriate.



# Methods

## Field Surveys

In 2021 and 2022, we conducted vehicle and walking surveys for Pinyon Jay flocks in areas prioritized based on compiled Pinyon Jay occurrence data (eBird 2020, NHNM observation database, and anecdotal observations), availability of suitable habitat, and access via roads. The criteria for designating these priority areas were developed from known New Mexico nesting colonies (Johnson et al. 2014, 2015; Johnson and Sadoti 2019). For a given 25-km$^2$ area to be considered to contain suitable habitat, it had to encompass at least 2% piñon-containing vegetation classes (from the LANDFIRE 2016 Existing Vegetation Type raster layer; https://www.landfire.gov). This information on habitat suitability was generated in ArcGIS via a moving window analysis with a radius of 2821 m. This 25-km$^2$ area approximated the area used by southwestern Pinyon Jay flocks within the breeding season (Marzluff and Balda 1992, Johnson et al. 2014, Novak 2019). To conform to a standardized grid sampling framework, we then placed a 25-km$^2$ grid (5 km x 5 km blocks) over areas of suitable habitat, as defined above, within the Gila NF, retaining blocks that contained areas above the 2% piñon-class threshold. In this framework, blocks were treated as areas of potential occurrence by individual breeding flocks. For comparability to surveys in areas that may have employed scales recommended by Somershoe et al. (2020), each 5 × 5 km (25-km$^2$) block was further divided into four smaller, 2.5 × 2.5-km sub-blocks. Within each block prioritized for survey, all survey points were at least 1 km apart along public roads (with no minimum number of points per sub-block). Additional survey points were added in the field (at least 1 km from existing points) when adjacent suitable habitat was identified and accessible. Survey points were removed in the field when habitat was found to be unsuitable or poor road conditions limited access. Pinyon Jay surveys followed the general protocol outlined in Petersen et al. (2014), Johnson et al. (2020), and Pinyon Jay Working Group (2021). The surveyor drove slowly through designated blocks, listening for Pinyon Jay calls and watching for Pinyon Jays flying over. All Pinyon Jays detected while driving were recorded on data sheets.

The surveyor also stopped at each pre-designated survey point and watched and listened for 6 min. When Pinyon Jays gave breeding calls (rattle, piping rattle, begging) or displayed breeding behaviors (courtship chases or feeding, begging by females, nest construction, copulation, fledglings), suggesting that the birds were nesting nearby, the surveyor attempted to follow them to nesting colonies by vehicle or on foot.

For every block the surveyor recorded

1. date
2. wind at start and end of day (first and last point in block) in Beaufort units
3. start and end cloud cover (%)
4. start and end temperature.

For every point, the surveyor recorded

1. time start and end and minute birds recorded
2. detection method (if PIJA detected): aural (A) and/or visual (V) and an estimate of the number of birds
3. distance bin (if PIJA detected; 0–50, 51–100, 100–150, 151–200, and >200 m); an exploratory analysis of detection distances (Johnson and Sadoti, unpubl. data) indicated few birds were

seen beyond this 200 m, thus detections beyond this distance were not included in subsequent models.

4. bearing (if PIJA detected, in degrees)
5. behavior (if PIJA detected)
6. resighting (if PIJA detected; notes, e.g., "maybe")
7. comments on habitat, access, water availability, and additional behaviors

Surveys began in the southern part of the Gila NF in March 2021. Finding very few Pinyon Jays in the south in this year, the surveyor moved to the northern part of the study area, where Pinyon Jays were more abundant. Finally, priority blocks in the east, between the southern and northern areas, were surveyed.

Because Pinyon Jays were detected on many points, blocks, and sub-blocks, the surveys required substantial time. Given the limited length of the nesting season and available funding, we prioritized surveying as many blocks as possible instead of engaging in the more time-consuming activity of searching on foot for nesting colonies. Surveys were completed in late April 2021.

In 2022, we focused surveys in the northern and eastern sections of the Gila NF but also surveyed several sites previously assigned to the southern area. The goals for 2022 were to re-survey approximately 50% of the plots surveyed in 2021 (for modeling purposes), fill in northern plots not surveyed in 2021, find additional nesting colonies, and update the 2021 occupancy model with 2022 detections. Survey methods were the same as in 2021, except that in March 2022, Pinyon Jays were found in large winter flocks and had not settled into nesting colony groups. Although these survey data were not included in analyses, those blocks where the jays were not nesting were noted and saved for later re-survey. We continued to observe large winter flocks through the spring, which indicated that many Pinyon Jays did not breed in 2022. We followed the formal survey protocol after 1 April.

We revisited colonies detected in 2021 throughout the 2022 breeding season to monitor activity. If we did not observe active nesting, we searched for old nests to delineate the boundaries of the colony. We started our search in the vicinity of nests found in 2021, examining trees suitable for a Pinyon Jay nest. For example, nests were typically placed in piñon trees >1.5 m tall. We used the tracking feature of the Gaia GPS phone app to keep track of our search efforts and to waypoint nests.

### Multi-scale Occupancy Models

Our survey methodology employed a surveyor with extensive experience in surveying for, monitoring, and researching Pinyon Jays. Nonetheless, this species is well-known to exhibit behaviors that result in imperfect detection within areas of breeding season use. To address this challenge and improve estimates of Pinyon Jay prevalence in the Gila NF, we used an occupancy modeling approach (MacKenzie et al. 2017). Occupancy modeling depends on repeated sampling in time and/or space over a closed period (i.e., the state of a given site, species present or absent, does not change over the sampling period). For those familiar with logistic regression for determining relationships driving binary (i.e., yes/no or present/absence) responses, occupancy models can be considered to be a logistic regression nested within at least one other logistic regression.

The use of repeated point count visits using 100-m (or similar) radius areas as sites in occupancy models is often suitable for birds with small territories but is not ideal for Pinyon Jays, which range over several thousand hectares during the breeding season and may travel thousands of meters within the course of a day. These behaviors present a general challenge to the closure assumption of occupancy models (i.e., that the true occupancy and availability for detection does not vary over a sampling period). This challenge can be illustrated in two slightly different ways:

1) Spatially: Although birds may occupy a home range over a breeding season that encompasses a given point-sampling location, they may not be available for detection on a given sampling occasion (e.g., they may not be locally present, but may be in another area >1 km away).
2) Temporally: Although birds may be observed at a point on one occasion, they are not guaranteed to be present on the next occasion, even if this next occasion is within the hour.

We are interested in predicting the actual occurrence at a site, $\psi$, given imperfect availability for detection at each survey location and varying rates of detection. Psi, or $\psi$, is also known as site-level occupancy or, for this survey, block-level occupancy. Here we refer to $\psi$ as “site occupancy.”

To model site occupancy ($\psi$, psi), it is necessary to know whether the birds are available at the survey location to be detected. This is theta, or $\theta$, also called “local occupancy” or “availability for detection.” Throughout this report, we refer to $\theta$ as “local occupancy.”

The probability of detecting the bird if present is also a consideration. This is estimated at the point level to better approximate local occupancy and, in turn, site occupancy at the block level. In our implementation of the multi-scale model with a removal design, up to three consecutive two-minute intervals provide the probability, $p$, of detecting the bird within an interval, also called detectability. Here we refer to $p$ as “detectability.”

To address the challenges of modeling Pinyon Jay occupancy, we sampled hierarchically by first defining sites as 5 x 5-km blocks in which roaming, breeding-season Pinyon Jay flocks, if present, are likely to exploit food resources. Second, to address the tendency for birds to cluster temporarily (except where nesting) in small areas across the home range and to improve the probability of detecting birds at least once within sites, we selected multiple sampling locations within each site. Our sampling approach is ideally suited for the “multi-scale” occupancy (MSO) model of Nichols et al. (2008), which was later modified by Pavlacky et al. (2012). In these models, spatially-replicated points are used to model $\theta$ (theta, i.e.; “local occupancy”). This is essentially the estimated proportion of local sampling units (for this study, points) within a site where a species is likely to be detected, if it is present in the site.

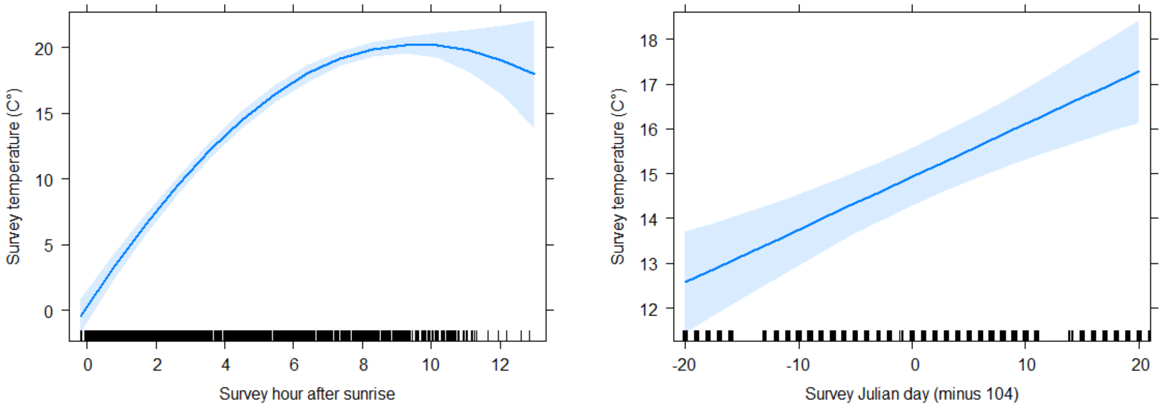
Finally, these models employ temporally repeated sampling at each point to estimate the detectability of a species under the assumptions of the robust design (Pollock 1982), given site and local occupancy. In the original model formulation (Nichols et al. 2008), multiple detection types (e.g., animal sign, cameras, auditory surveys) were used as repeated samples, although other types of repeated surveys have been employed in other studies (e.g., multiple observers; Jeffress et al. 2011). The study by Pavlacky et al. (2012), although not specific to Pinyon Jays, suggested treating individual intervals (i.e., single or multi-minute periods) within point visits as repeated sampling occasions using a removal design (counts are truncated at first detection of a species at a point). This single-visit, repeat-interval approach has been noted elsewhere (Rota et al. 2009) and, although not necessary for the MSO model, is ideally suited for the Pinyon Jay due to their highly mobile behaviors. We binned the six, one-minute increments of each survey into three, two-minute bins as repeated sampling events in our approach. We employed a removal design such that no positive or negative observation was recorded after the two-minute interval in which Pinyon Jays were first recorded. This removal design approach to sampling has been found to yield identical results to models in which full detection histories were included (Kery and Royle 2015).

## Modeling

### Detectability covariates

We considered six covariates as predictors of detectability: hour of survey after sunrise, temperature, % cloud cover, wind (Beaufort scale), and Julian day. Temperature was strongly associated with the after-sunrise hour and Julian day. To isolate its effect, we took residuals from a mixed effect model (using the lme4 package; Bates et al. 2017) with temperature as the response and hour of survey after sunrise and Julian day as predictors (Figure 2). Crossed random effects of unique date and block were used to account for within-day and within-block correlation.

Figure 2. The relationship between survey temperature and survey time and date. We employed these relationships to derive an independent effect of temperature for use in models.



Time limitations and accessibility dictated the clustering of samples across multiple week-long visits to the Gila NF. Although this is typically a non-ideal sampling strategy due to the possibility of confounding effects of date and location on detection, the surveyor assessed the overall phenology of the breeding season by flock sizes and behavior during each weekly visit to ensure birds were exhibiting behaviors typical of the early nesting season. To address this potential issue, we transformed Julian day to residual values from an ordinary least squares relationship between Julian day and site region in each year (see Johnson et al. 2021).

**Site and local occupancy covariates**

We employed block geographic coordinates and elevation (detailed below) as potential predictors of site and local occupancy. Covariates relating to vegetation and other factors were not modeled but may be included after year 2, pending sufficient sample sizes.

**Modeling steps**

To build MSO models, we first considered combinations of detection covariates. We assessed whether a linear or quadratic effect of each covariate was more supported by comparing the Akaike information criterion (AICc) of each model (removing uninformative parameters; Arnold 2010). We added third- and fourth-order effects of time-after-sunrise, as 1) surveys extended to 1800 hrs and 2) we expected activity, and in turn detectability, may exhibit bimodal patterns as has been observed by birds in other systems (Sullivan and Vierling 2009). We employed the combinations of all five detection covariates and their most-supported polynomial terms ($n = 33$ models) and held occupancy and theta covariates to an effect of year (2021 vs. 2022) and the interaction between site east and northing coordinates.

Using supported ($\Delta$AICc < 4) models of detection covariate combinations, we then combined these detectability terms with varying combinations of terms representing the geographic coordinates (easting, northing, and elevation) of sites. We considered second-order polynomials of all terms as well as their interactions. The study year (2021 or 2022) was included as a predictor of all components. This resulted in 170 models. As with assessing detection models, we considered supported models to be those with $\Delta$AICc < 4, with the additional conditions that all models converged and contained no highest-order terms (e.g., squared terms or interactions) that were uninformative parameters (Arnold 2010). In the event that more than one model was supported, we generated predictions using a weighted average of all models. We employed the $\Delta$AICc of 4 following rules-of-thumb in Burnham and Anderson (2002) for inclusion of models with both "substantial" and "less substantial" support (but not "considerably less"; i.e., $\Delta$AICc>4). We assessed the overall accuracy of models using the area under the receiver operating curve (AUC; Fielding and Bell 1997) where AUC > 0.7 indicated fair accuracy, > 0.8 good accuracy, and > 0.9 excellent accuracy. We calculated AUC from the comparison of actual detection (0 or 1) of a Pinyon Jay in site $i$, on point $j$, and time interval $k$ to the product of these predicted probabilities. Due to variation in the number of points per site and time intervals per survey due to the removal design, we calculated AUC by randomly selecting one point-interval per site. We repeated this step 1,000 times to generate a mean AUC value per model. We conducted occupancy modeling in R (R Development Core Team 2019) using the RMark package (Laake 2019), which serves as a front-end for Program MARK (White and Burnham 1999). Support packages included AICcmodavg (Mazerolle 2017) and AUC (Ballings and Van den Poel 2013).

## Results

### 2021 Field Surveys

After removing the southern section of 2021 blocks ($n = 91$ blocks and 163 points removed, for comparison with the 2022 sampling area), the surveyor completed surveys of 80, 25-km$^2$ blocks or 22% of the 359 blocks in the revised study area (Figure 3). These 80 blocks included 349, 6-min point surveys (Figure 3). Pinyon Jay flocks were detected in 35 (44% of) surveyed blocks and on 62 (18% of) points. Pinyon Jay group sizes ranged from 1 to 32 birds with an average of 5 birds detected (median = 3; Table 1, Figure 3).

### 2022 Field Surveys

In 2022, the surveyor completed surveys of 153, 25-km$^2$ blocks or 43% of the 359 blocks in the revised study area (Figure 3). The 153 blocks included 657, 6-min point surveys. Pinyon Jay flocks were detected in 54 (18% of) blocks and on 76 (12% of) points. Pinyon Jay group sizes ranged from 1 to 125 birds with an average of 9 birds detected (median = 3; Table 1).

### Repeated and Non-surveyed Blocks, 2021 and 2022

Of blocks surveyed, 54 were surveyed in both 2021 and 2022. This represents 68% of the 2021 survey total, 35% of the 2022 total, and 15% of the study area. Pinyon Jays were detected on 17 blocks surveyed in both years (31% of surveyed blocks). Of all blocks, 180 blocks (or 50% of the study area) were not surveyed in both years.

Despite limited time for colony searches and fewer nesting occurrences than in 2021, we detected four new nesting areas, as indicated by Pinyon Jay behavior, active or old nests, or fledglings (Figure 4). Two nesting colonies were in the northern part of the study area and two were in the eastern part.

We found 41 nests in 2022. Of 35 nests at colony sites first identified in 2021, three were old (inactive) nests at the Bastion Ranch colony, nine were old nests at the Bill Knight colony, two were old nests at the Boundary colony, ten were old nests at the Hwy 32 colony, six were old nests at the Poison Canyon colony, and five were old nests at the Water Canyon colony (Figure 4).The remaining six nests found in 2022 were at newly identified colony sites: one old nest at the Hardcastle Canyon colony, one active and one old nest at the Mountain Mesa colony, and one new (2022, but inactive) and two active nests at the Sand Canyon colony.

Figure 3. Results of Pinyon Jay surveys in the Gila NF, March and April 2021 and 2022. Shown are Pinyon Jay detection results (top row; at least one detection per block) and prevalence (% of points [up to 7] within blocks on which Pinyon Jays were detected). Additional blocks surveyed in 2021 in the southern Gila NF are not shown for easier comparison between years. Blocks are overlaid on National Forest lands (light green).

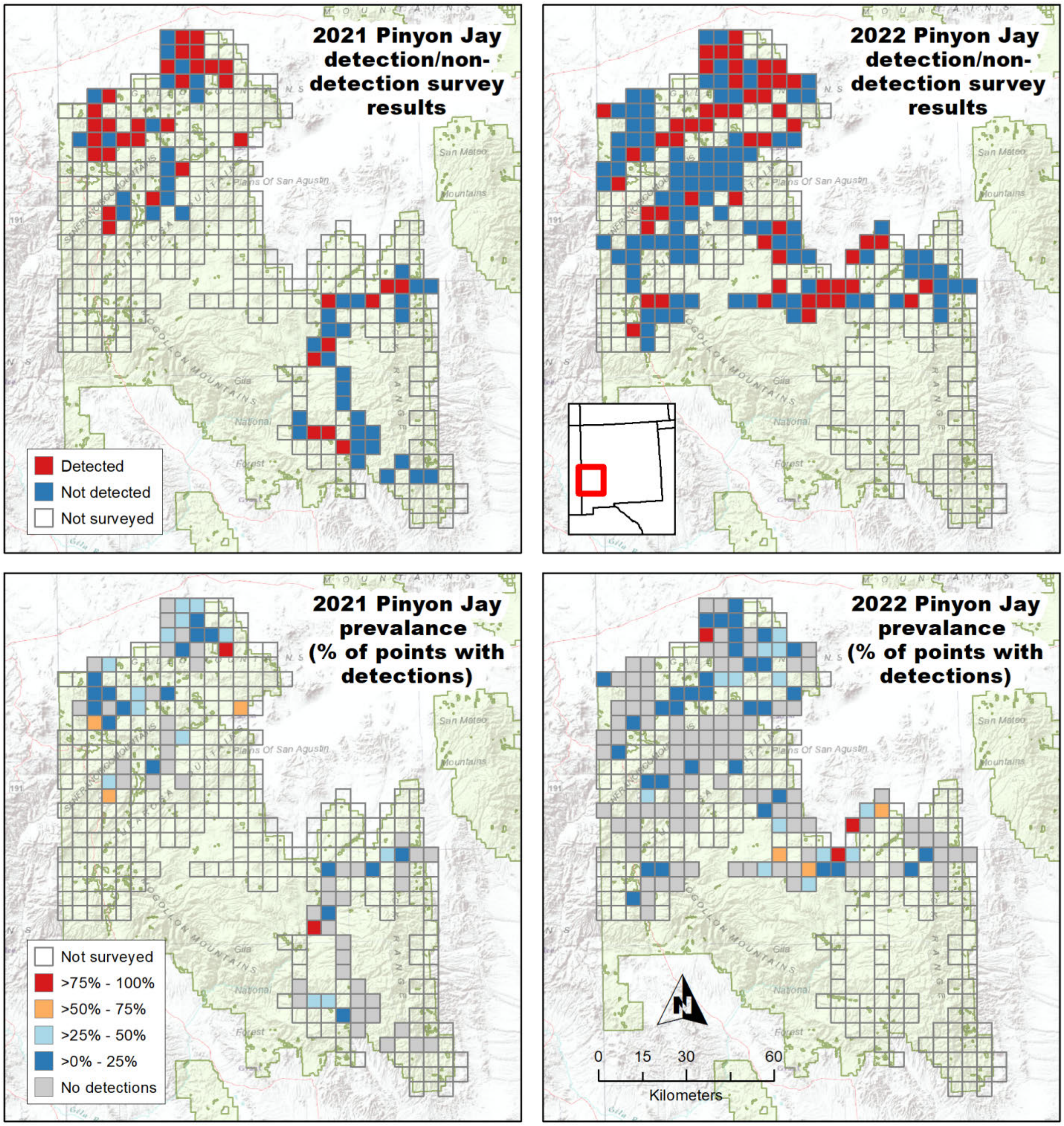


Figure 4. Locations of nesting colonies, 2021–2022. Also shown are study area blocks overlaid on National Forest lands (light green).

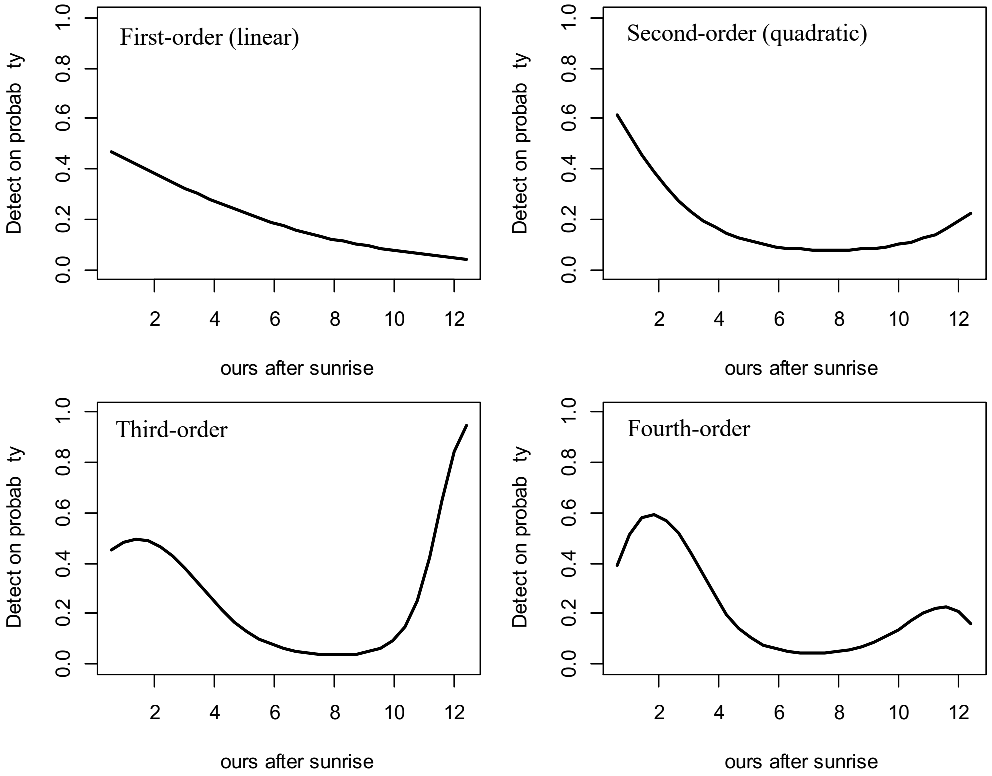
[redacted]

## Multi-scale Occupancy Models

In first assessing detection covariates, we found models with third- and fourth-order polynomial terms for survey time (after sunrise) to be most supported; all other models with $\Delta$AICc<4 included uninformative parameters. Increasing the number of survey time polynomial terms from one to four revealed a bimodal pattern of detectability with the first peak at approximately 800 local time followed by a second, smaller peak at approximately 1700 in the late afternoon (Figure 5).

After filtering out models that had convergence issues or included uninformative parameters, we identified seven supported models that predicted site occupancy by Pinyon Jays (Table 2). Parameter estimates for supported models are shown in Table 3. Models with a simple gradient of increasing occupancy at higher elevations or to the north or west were supported in one, three, and two models, respectively (Table 3). Parameter estimates on the year effect indicated lower occupancy in 2022 in 6 of 7 models, though occupancy was not significantly lower in 2022 in any of these models (Table 3).

Figure 5. Bimodal pattern revealed by increasing the order of polynomial terms (from linear [A] to fourth-order [D]) for survey time in removal-design models of detectability. This indicates that birds were more quickly detected in the morning and late afternoon.



More complex combinations predicting local occupancy were supported in all models and show patterns of higher local occupancy near the northeast edges of the study area, in addition to several less contiguous areas. Local occupancy was lower in 2022 in all models, as indicated by θ year2022 (Table 3). Third-order survey time (a detection covariate) was featured in three competitive models while fourth-order survey time was featured in four competitive models. Detectability was higher in 2022 in all models, though no models had a significant year effect on detectability. Model fits were fair (AUC between 0.7 and 0.8) for all models, an improvement over models employing region as a predictor (and with a different study extent) in 2021 (Table 3).

Due to differences in blocks sampled in 2021 and 2022, prediction or occupancy summary statistics are not directly comparable between years (Table 4). However, when predicted over the entire (amended) study area, these models indicated mean occupancy probabilities of 0.81 in 2021 and 0.78 in 2022 (Table 4, Figure 6). Similar patterns were indicated for local occupancy, with mean probabilities of 0.37 in 2021 and 0.20 in 2022. Detection probabilities (from the sample data) were 0.28 and 0.40 in 2021 and 2022 respectively. Block-level predicted probability of site occupancy and local occupancy are shown in Figure 7.

Table 1. Summary statistics of field detections of Pinyon Jays (PIJA) in 2021 and 2022 across the 2022 amended study area, by point and 5 x 5-km block.

| **Points** | **2021 (*n* = 349 points)** | | **2022 (*n* = 657 points)** | | **Combined (*n* = 1,006 points)** | |
|---|---|---|---|---|---|---|
| Statistic | Mean | Range | Mean | Range | Mean | Range |
| PIJA detected (% of surveyed points) | 17.5 | — | 11.6 | — | 13.6 | — |
| PIJA detected (mean % points per block with ≥1 detection)[a] | 32.6 | — | 28.3 | — | 30.0 | — |
| PIJA detected per surveyed point (*n*) | 0.95 | 0–32 | 1.03 | 0–125 | 1.00 | 0–125 |
| Flock size (*n*, points with PIJA only)[b] | 5.3 | 1–32 | 8.9 | 1–125 | 7.3 | 1–32 |

| **Blocks** | **2021 (*n* = 80 blocks)** | | **2022 (*n* = 153 blocks)** | | **Combined (*n* = 233 blocks)** | |
|---|---|---|---|---|---|---|
| Statistic | Mean | Range | Mean | Range | Mean | Range |
| Points surveyed (*n*, per block) | 4.4 | 1–6 | 4.3 | 1–7 | 4.3 | 1–7 |
| PIJA detected (% of surveyed blocks) | 43.8 | — | 35.1 | — | 38.1 | — |
| Birds detected per surveyed block (*n*) | 4.13 | 0–59 | 4.43 | 0–143 | 4.33 | 0–143 |
| Birds detected per block (*n*, blocks with detections only) | 9.43 | 1–59 | 12.57 | 1–143 | 11.34 | 1–143 |

a. These are weighted averages that use the number of points per block as the weight. Unweighted averages were 35.7, 31.4, and 33,1% % in 2021, 2022, and both years combined, respectively.

b. The median number of birds per point with Pinyon Jay detection was 3 in both 2021 and 2022.

Table 2. Competitive models of 2021–2022 5 x 5-km site occupancy ($\psi$) by breeding-season Pinyon Jays accounting for varying local occupancy ($\theta$) and detectability (p). Covariates (subscript) are presented for each model component. Indicated are the number of estimated parameters (k), the model log likelihood (LL), Akaike information criterion adjusted for small samples (AICc), the difference between the AICc of a given model and the lowest AICc model ($\Delta$AICc), and the Akaike weight of models ($w_i$). AUC is the area under the receiver operating curve, a measure of model accuracy.

| | Model | k | -LL | AICc | ΔAICc | $w_i$ | AUC |
|---|---|---|---|---|---|---|---|
| 1 | $\psi$: year2022 + east + elevation<br>$\theta$: year2022 + east + east2 + north + elevation + east:north + east$^2$:north + east:elevation + east$^2$:elevation<br>p: year2022 + hour + hour$^2$ + hour$^3$ | 19 | -474.3 | 990.1 | 0.0 | 0.415 | 0.766 |
| 2 | $\psi$: year2022 + east<br>$\theta$: year2022 + east + east$^2$ + north + elevation + east:north + east$^2$:north + east:elevation + east$^2$:elevation<br>p: year2022 + hour + hour$^2$ + hour$^3$ | 18 | -476.1 | 991.5 | 1.4 | 0.211 | 0.770 |
| 3 | $\psi$: year2022 + east<br>$\theta$: year2022 + east + east$^2$ + north + elevation + elevation$^2$ + east north + east$^2$:north + east:elevation + east:elevation$^2$ + east$^2$:elevation + east$^2$:elevation$^2$<br>p: year2022 + hour + hour$^2$ + hour$^3$ + hour$^4$ | 22 | -472.1 | 993.0 | 2.9 | 0.098 | 0.766 |
| 4 | $\psi$: year2022<br>$\theta$: year2022 + east + east$^2$ + north + elevation + elevation$^2$ + east north + east$^2$:north + east:elevation + east:elevation$^2$ + east$^2$:elevation + east$^2$:elevation$^2$<br>p: year2022 + hour + hour$^2$ + hour$^3$ + hour$^4$ | 21 | -473.4 | 993.2 | 3.1 | 0.086 | 0.759 |
| 5 | $\psi$: year2022 + north<br>$\theta$: year2022 + east + east$^2$ + north + elevation + east:north + east$^2$:north + east:elevation + east$^2$:elevation<br>p: year2022 + hour + hour$^2$ + hour$^3$ + hour$^4$ | 19 | -476.1 | 993.7 | 3.6 | 0.067 | 0.760 |
| 6 | $\psi$: year2022)<br>$\theta$: year2022 + east + east$^2$ + north + elevation + east:north + east$^2$:north + east:elevation + east$^2$:elevation<br>p: year2022 + hour + hour$^2$ + hour$^3$ + hour$^4$ | 18 | -477.4 | 993.9 | 3.8 | 0.062 | 0.758 |
| 7 | $\psi$: year2022 + north<br>$\theta$: year2022 + east + east$^2$ + north + elevation + east:north + east$^2$:north + east:elevation + east$^2$:elevation<br>p: year2022 + hour + hour$^2$ + hour$^3$ | 18 | -477.4 | 994.0 | 3.9 | 0.060 | 0.762 |

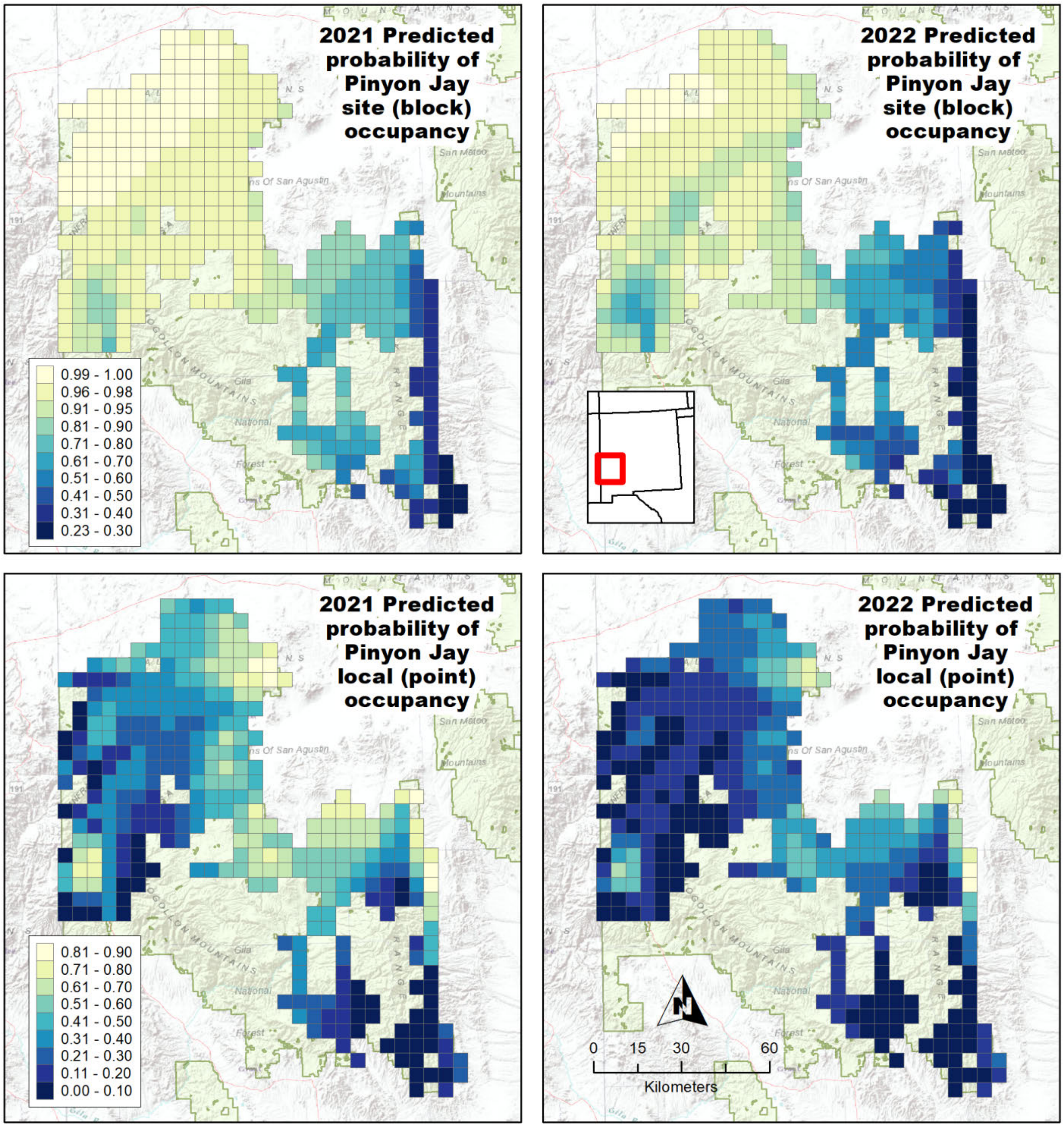
Table 3. Mean parameter estimates from the seven competitive ($\Delta$AICc < 4) models of multi-scale occupancy by Pinyon Jays in the Gila NF, 2021–2022. Model components are site occupancy at the 5 x 5-km block scale ($\psi$), local occupancy ($\theta$) at the point scale within blocks, and detectability ($p$) per 2-minute interval of a point survey. Values in bold indicate 95% confidence intervals that did not include zero. The reference (intercept) year level for each model component is 2021, year2022 indicates the difference between year 2022 and year 2021. Survey hour was calculated as the hour after sunrise.

| Covariate | Models | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| $\psi$: Intercept | 3.36 | 3.69 | 3.73 | 3.54 | 2.31 | 2.77 | 2.19 |
| $\psi$:year2022 | -1.59 | -0.30 | -0.41 | -0.39 | -0.54 | 0.50 | -0.46 |
| $\psi$:east | -2.08 | **-2.34** | -2.10 | — | — | — | — |
| $\psi$:north | — | — | — | — | 1.05 | — | **1.07** |
| $\psi$:elevation | **2.25** | — | — | — | — | — | — |
| | | | | | | | |
| $\theta$:Intercept | -0.89 | -0.91 | -0.98 | -0.97 | -0.83 | -0.86 | -0.75 |
| $\theta$:year2022 | **-1.11** | **-1.21** | **-1.03** | **-1.05** | **-1.09** | **-1.20** | **-1.18** |
| $\theta$:east | **1.44** | **1.19** | 0.79 | 0.43 | **0.81** | **0.66** | **0.88** |
| $\theta$:east$^2$ | **1.00** | **0.79** | 0.71 | 0.42 | 0.44 | 0.32 | 0.48 |
| $\theta$:north | 0.20 | 0.17 | 0.20 | 0.17 | -0.03 | 0.10 | -0.03 |
| $\theta$:elevation | **0.71** | **0.87** | **1.07** | **1.15** | **0.89** | **0.88** | **0.88** |
| $\theta$:elevation$^2$ | — | — | -0.32 | -0.36 | — | — | — |
| $\theta$:east:north | -0.67 | -0.64 | -0.52 | -0.63 | -0.76 | -0.78 | -0.74 |
| $\theta$:east$^2$ north | **1.65** | **1.41** | **1.38** | **1.28** | **1.33** | **1.24** | **1.36** |
| $\theta$:east:elevation | 0.70 | 0.75 | 0.54 | 0.64 | **0.91** | **0.92** | **0.89** |
| $\theta$:east:elevation$^2$ | — | — | 0.98 | **1.04** | — | — | — |
| $\theta$:east$^2$:elevation | **-1.70** | **-1.37** | **-1.80** | **-1.77** | **-1.24** | **-1.11** | **-1.30** |
| $\theta$:east$^2$:elevation$^2$ | — | — | 0.79 | 0.89 | — | — | — |
| | | | | | | | |
| $p$:Intercept | -1.76 | -1.77 | -1.88 | -1.95 | -1.87 | -2.02 | -1.67 |
| $p$: year2022 | 0.94 | 0.97 | 0.72 | 0.72 | 0.79 | 0.87 | 0.93 |
| $p$: hour | **-2.17** | **-2.19** | **-2.65** | **-2.72** | **-2.66** | **-2.70** | **-2.22** |
| $p$: hour$^2$ | 0.08 | 0.07 | 0.92 | **1.02** | 0.88 | 0.98 | 0.03 |
| $p$: hour$^3$ | **0.59** | **0.59** | **0.95** | **1.01** | **0.97** | **1.00** | **0.62** |
| $p$: hour$^4$ | — | — | -0.34 | **-0.38** | -0.34 | -0.37 | — |

Table 4. Predicted probabilities of site occupancy ($\Psi$), local occupancy ($\theta$), and detectability ($p$) of breeding-season Pinyon Jays. Values are weighted averages of predictions from seven competitive models (see Table 2). Note the differences in predictions made for the sample of sites visited and the entire study area.

| | 2021 | | | | 2022 | | | |
|---|---|---|---|---|---|---|---|---|
| Parameter | Estimate | SD | Min | Max | Estimate | SD | Min | Max |
| Blocks surveyed | | | | | | | | |
| $\psi$ (site occupancy) | 0.808 | 0.207 | 0.301 | 0.986 | 0.882 | 0.130 | 0.379 | 0.975 |
| $\theta$ (local occupancy) | 0.362 | 0.114 | 0.089 | 0.592 | 0.198 | 0.077 | 0.068 | 0.468 |
| $p$ (detection) | 0.278 | 0.179 | 0.040 | 0.536 | 0.399 | 0.246 | 0.089 | 0.734 |
| Study area | | | | | | | | |
| $\psi$ (site occupancy) | 0.847 | 0.196 | 0.230 | 0.988 | 0.778 | 0.237 | 0.205 | 0.985 |
| $\theta$ (local occupancy) | 0.373 | 0.214 | 0.000 | 0.870 | 0.195 | 0.146 | 0.000 | 0.751 |

Figure 6. Predicted Pinyon Jay site occupancy (ψ, Psi) and local occupancy (θ; Theta) in the Gila National Forest, March and April 2021 and 2022. Probabilities of local occupancy, although made at the point level, are presented here as the average value per block and approximate the predicted proportion of points at which birds are present, assuming presence in the block. Predictions are weighted averages across seven competitive multiscale occupancy models (using weights [$w_i$] in Table 2).



# Discussion

Notably, we detected fewer indications of active nesting in 2022 than in 2021. Large winter flocks were present through April, and we observed no nesting Pinyon Jays at any of the colony sites detected in 2021. Pinyon Jays are known to avoid nesting when food is scarce (Ligon 1978). Pinyon Jays in the Gila NF may be responding to reduced piñon mast crops by deferring breeding. The surveyor noted whether cones were present at each survey point having piñon trees. Overall, the 2021 cone crop was poor. This historically adaptive behavior may be resulting in decreased annual nesting as piñon seed production declines with climate impacts, which is one hypothesis for Pinyon Jay population decline. (Johnson and Balda 2020, Somershoe et al. 2020).

The habitats used by Pinyon Jays are of interest. Approximately two-thirds of points with jay detections had ponderosa pine (*Pinus ponderosa*) woodland and nearly 20% had ponderosa pine without recorded piñon-juniper. This is the first area of occurrence in New Mexico where we have found Pinyon Jays using ponderosa pine woodlands. A similar pattern of ponderosa pine presence was found among nesting locations in the Gila NF. Nesting colonies found elsewhere in New Mexico were in piñon-juniper woodland or juniper savanna habitats (Johnson et al. 2014, 2015). Threats to the Gila NF population include climate impacts to habitat and wildfires, two of which occurred over large areas of the Gila NF in 2022. Surveys in 2023 will investigate fire impacts to any of our survey blocks, sample additional blocks, and allow for more robust analyses of occupancy patterns. The number of blocks we will survey in 2023 will depend on several factors, such as whether the Pinyon Jays are nesting and how much time is devoted to finding colony sites, but we estimate we will survey about 150 blocks.

### Site and Local Occupancy

Despite differences in the behaviors of birds between 2021 and 2022, predicted occupancy was overall similar. Elevation was a significant but infrequent predictor of occupancy (1 of 7 models, Table 3) and a clear positive elevation-occupancy gradient is only really evident in the lower-lying areas near the San Francisco River in Catron County. The gradient of higher occupancy in the northwestern portion of the study area may be associated with an overall increasing ponderosa pine cover in this region, but additional testing is need to assess this possibility. Local occupancy was the only model component with a consistent and significant effect of year (lower in 2022 than 2021; Table 3, $\theta$ year2022). This is consistent with interannual differences in the percentage of points within blocks on which birds were detected (2021 = 32.6%, 2022 = 28.3%).

### Detectability

Only survey time had a notable effect on detection, with either third- or fourth-order effects indicating two periods of highest detection probabilities. The highest-order effect of survey time in each degree considered (first to fourth) was significant, though indicated increasingly better fits with more complexity. This result would be unlikely in a study which limited surveys to the morning, which many bird surveys do. Fewer were conducted later in the day, but surveys extended to the late afternoon on occasion (latest survey = 7:19 p.m.). Magee et al. (2019) found only observer effects on detectability of Pinyon Jays. Detectability of Pinyon Jays, although not directly comparable to Magee et al. (2019) due to these authors' use of a 100-m radius limit, were higher in our study. We found predicted per-two-minute detectability of 0.28 and 0.40 in 2021 and 2022, respectively, using weighted averages across competitive models while Magee et al. (2019) found detectability per visit of 0.18 (95% CI = 0.14–0.23). This difference may be explained by our use of a 200 m detection distance limit.

So-called naïve detectability in this study, in which we employed a removal design, is approximated by the inverse of how many two-minute bins of a 6-minute survey passed without a detection on points with Pinyon Jay detections (i.e., the more minutes without a detection, the lower the detectability). Viewed this way, detectability in Pinyon Jays is more likely a measure of activity and movement of birds through a flock's home range than other factors. It is unclear why detectability was higher in 2022 than in 2021 but may be due to the greater movement and call behaviors in this year of delayed (or non-) nesting. Flock sizes were, on average, larger in 2022, when winter flocks failed to break up for nesting. Larger flocks might have resulted in more contact calls more easily heard or bird arrivals or departures from point locations spread out over more minutes. Magee found different observers had different detectability based on experience, where more experienced observers had higher probabilities of bird detection. Because we had only one surveyor who is highly knowledgeable and experienced, we cannot address this factor's influence on our results.

## Occupancy

Site occupancy estimates were approximately 50% and 70% higher than naïve survey results in sampled blocks in 2021 and 2022, respectively. (Tables 1, 4). As the assumption behind occupancy modeling is that some occurrences are missed, this result is not surprising and suggests that Pinyon Jays are more widespread across the study area than indicated by naïve survey detections.

Using only block center coordinates and mean elevation, we found a gradient of increasing predicted occupancy generally from east to west, with a weaker trend from south to north. Vegetation changes along this SE-NW gradient are generally from piñon-juniper woodlands to areas more dominated by mixed ponderosa and piñon. Additional analyses will be performed in year 3, specifically implementing a multi-season version of the MSO model.

Magee et al. (2019) focused at the scale of woodland treatment areas (18–77 ha) and adjacent control sites (20–117 ha). Our study is not directly comparable with Magee et al. (2019) because of the difference in scale (our study used 2,500 ha sites). However, despite this scale difference, we found 2021 and 2022 occupancy of the Gila NF (0.85 and 0.78, respectively) to be comparable to that found by Magee et al. (2019) in their control ($\psi = 0.58$), mastication-treated ($\psi = 0.67$), and hand-thin treated areas ($\psi = 0.70$).

Estimates of point-level local occupancy probabilities below 1.0 were expected due to the large home ranges of breeding-season Pinyon Jays and their tendency to move through home ranges in flocks. Magee et al. (2019) found higher local occupancy probabilities in their control ($\theta = 0.84$), mastication-treated ($\theta = 0.53$), and hand-thin treated areas ($\Psi = 0.42$) than our finding of $\theta = 0.37$ and $\theta = 0.20$ across the study area in 2021 and 2022 respectively. The reasons for these differences are unclear but may be due to differences in habitat or behavior. For example, birds may have been more evenly distributed among their points during surveys due their use of non-systematic (i.e., non-grid) site selection based on the occurrence of treatment areas. These local occupancy differences may also be due to Magee et al.'s (2019) use of three separate visits to survey locations. In other words, our estimates of local occupancy are more "snapshots" of habitat use, while those of Magee et al. (2019) are closer to cumulative estimates of use at some point in a season and are potentially upwardly biased.

### Future Research

Goals for 2023 are as follows:

1. Two large fires occurred in the Gila NF in the summer of 2022. The Black Fire may have impacted 10–12 previously surveyed blocks, two of which were occupied. One goal of 2023 surveys will be to re-survey 2021 and 2022 plots burned in 2022.
2. Survey additional areas of likely Pinyon Jay occurrence in the Gila NF. Surveys will follow the 2021 and 2022 protocol.
3. Find additional nesting colonies, starting in blocks where Pinyon Jays were present and showed breeding behaviors in previous years, followed by areas in which Pinyon Jays were detected previously but were not showing breeding behaviors.
4. Find nests at colony sites found in 2021 and 2022 and at any new colonies detected in 2023.
5. Update the 2021–2022 occupancy model with 2023 survey results.
6. Create the 2023 report, including introduction, methods (field and occupancy modeling), results, discussion, management recommendations, and areas for further study.
7. Complete and deliver the final Natural Heritage New Mexico Pinyon Jay geodatabase with 2021-2023 survey data included.

### Management

Magee et al. (2019) state that: "At finer scales of habitat use (i.e., local occupancy), Pinyon Jays may abandon treated forest patches that remove too much cover for nesting and roosting or severely reduce piñon pine seed availability." It is worth noting that without knowing where breeding or nesting occurs in a site, it is difficult to reliably conclude exactly why birds are not detected at a particular point, given occupancy of the encompassing site. It could be due to one or multiple factors (i.e., cover too sparse for nesting or roosting and/or too few cone-bearing trees present, etc.). For the present, the fact that Pinyon Jays avoid thinned sites (Magee et al. 2019) provides sufficient caution against treating Pinyon Jay habitat without understanding how Pinyon Jays use the local habitat, as demonstrated by Johnson and Sadoti (2019). As Pinyon Jay activities occur at multiple scales, from the nest site to colony site to the year-round home range, habitat management should be matched to the scale at which targeted activities occur (Johnson and Sadoti in review).

Perhaps most importantly, this survey indicates that the northern Gila NF is an area of high Pinyon Jay occupancy and could reasonably be considered a hotspot for Pinyon Jays in New Mexico. This reinforces 1966–2019 North American Breeding Bird Survey (BBS) results indicating that the northern Gila NF is one of only a few sites rangewide where Pinyon Jay populations may be increasing. An inspection of more recent 2002–2021 BBS trends (Figure 1) indicated that observed abundance on the Reserve BBS route has increased significantly, though trends were negative for Pinyon Jays on the next closest routes just north and east of the northern Gila NF (Salt Lake and Horse Springs routes). The US Forest Service has a significant responsibility to conserve this population of Pinyon Jays. Management recommendations for Pinyon Jays have been detailed by Somershoe et al. (2020), Johnson and Balda (2020), and others. Pinyon Jay conservation should be a major consideration in any forest management planning that has the potential to impact Pinyon Jays or their habitats in the Gila NF.

**Pinyon Jay flock in flight. Photo: Christina M. Selby**

## Acknowledgments

This study was supported by the Share with Wildlife Program of the New Mexico Department of Game and Fish State Wildlife Grant T-73-R-1. We thank Amanda Gehrt, Jerry Monzingo, and Adam Mendonca of the US Forest Service, Gila NF, for granting permission to survey and facilitating access. Thanks to Christina M. Selby for sharing photographs of Pinyon Jays. Virginia Seamster and Karen Gaines provided helpful comments on an earlier draft.

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