Pinyon Jay Surveys in the Gila National Forest, New Mexico

Final Report 2021, 2022, & 2023

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

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Abstract

Pinyon Jay (*Gymnorhinus cyanocephalus*) populations have been declining steadily rangewide for over 50 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 and our recent analysis of BBS data 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, systematic surveys of the area had not been conducted prior to our 2021–2023 surveys. We surveyed for Pinyon Jays in the Gila NF from mid-March until mid-May 2021, 2022, and 2023. In 2021, Pinyon Jays were scarce in the south, common in the east, and abundant in the north, suggesting that the northern part of the forest may be a hotspot for Pinyon Jays in New Mexico. In March and April 2021, we surveyed 124, 5x5-km blocks, 29% of which were active (i.e., Pinyon Jays were present). In 2022, we surveyed 153 blocks, with 35.3% activity, and in 2023 we surveyed 103 blocks, with 14.6% activity. In 2021, we found 6 nests (67% active) in 5 Pinyon Jay nesting colonies (80% active), all in the northern Gila NF. In 2022, very few Pinyon Jays nested. We found 41 nests (7% active) in 9 nesting colonies (22% active). In late April and May 2023, we checked 19 previous and new colonies (63% active) and found 58 nests (57% active). Colonies were mainly in sparsely-treed or open areas, including in ponderosa pine woodlands, and 64% of 2023 colonies directly bordered meadows. Multi-scale occupancy models indicated 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, 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 90-day finding determined that further consideration of the petition is warranted, and it is currently under review.

The Pinyon Jay is important for its role in maintaining the piñon-juniper ecosystem. It is named for its coevolved mutualism with piñon trees (Colorado piñon, *Pinus edulis,* and single-leaf piñon, *P. monophylla*). Pinyon Jays are adapted for the "harvest, transport, caching, and retrieval of piñon-pine seeds" (Johnson and Balda 2020). A Pinyon Jay can carry up to 50 seeds in its expandable esophagus in a single trip, and a flock can potentially harvest, carry, and cache millions of seeds in a single autumn season (Ligon 1978). Physiologically, the presence of piñon seeds and green cones has been shown to reverse gonadal regression and stimulate 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. Pinyon Jays bury seeds in the ground in micro-habitats favorable to seed germination (Ligon 1978). No other species is capable of re-planting a piñon woodland decimated by fire, drought, or disease. Piñon trees, for their part, produce mast crops of nutritional seeds at irregular intervals. Their wingless seeds depend on animals for dispersal (Lanner 1981). Cones open upward near the crowns of the trees, facilitating harvest by birds, before the seeds drop to the ground. The nutritional boost provided by a mast crop increases Pinyon Jay population viability (Marzluff and Balda 1992).

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. 2017a). 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 abandoned 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 Department of Biology, and Animas Biological Studies, Durango, CO, have documented 57 Pinyon Jay nesting colony sites (e.g.; Petersen et al. 2014; Johnson et al. 2014, 2015, 2018, 2021, this report). These nesting colonies are spread throughout New Mexico and southwestern Colorado in suitable piñon-juniper and ponderosa pine (*Pinus ponderosa*) habitats.

Although prior to this study Pinyon Jays had been documented in the Gila National Forest (Gila NF), systematic surveys across suitable habitats had not been conducted there. The Gila NF is especially important because BBS 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).

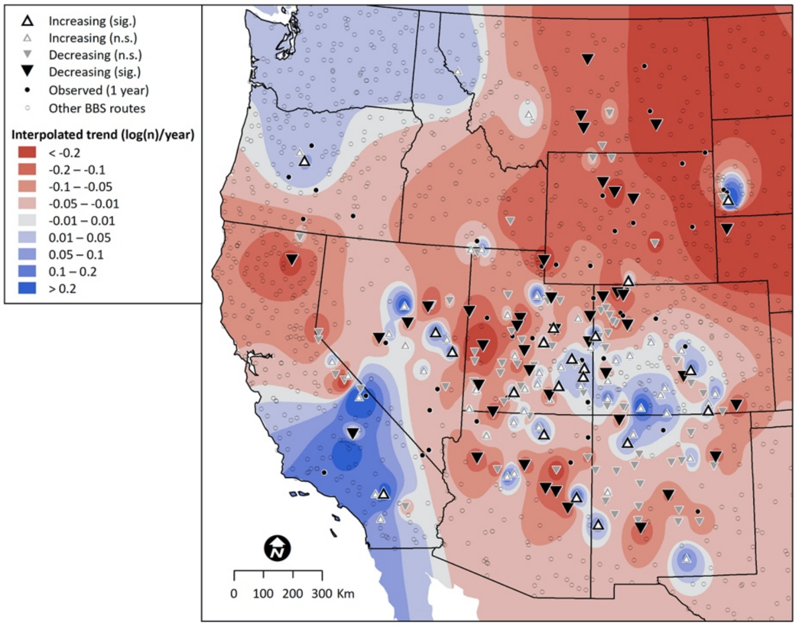

Figure 1. Pinyon Jay yearly population trends, 2002–2021, from North American Breeding Bird Survey data (Ziolkowski et al. 2022). Trends are based on total Pinyon Jay counts per year/route for any route with >1 year with Pinyon Jay detections (n = 187). We estimated trends by the best fit (lowest AICc) of Poisson or negative binomial distribution or best fit of zero-truncated (if no zeros) or zero-inflated version of either distribution, as appropriate (fit using the glmmTMB package; Brooks et al. 2022). Significant (sig.) trends are those with z-values > 1.96 or < -1.96. Nonsignificant (n.s.) trends are those within this range of z-values. Trends do not account for various survey characteristics.

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 occurrence of Pinyon Jays in the surveyed area.

The objectives of this three-year study were 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.

Methods

Field Surveys

From mid-March until mid-May 2021, 2022, and 2023, we conducted vehicle and walking surveys for Pinyon Jay flocks. We chose areas for survey based on compiled Pinyon Jay occurrence data (eBird 2020, NHNM observation database, and anecdotal observations), availability of suitable habitat (identified from land cover data), 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- or ponderosa-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 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 or ponderosa 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, Figure 2). Additional survey points at least 1 km from existing points were added in the field when adjacent suitable habitat was identified and accessible. Survey points were removed in the field when found to be in unsuitable habitat or poor road conditions limited access. Pinyon Jay surveys followed the protocol outlined in Johnson et al. (2023).

The surveyor drove slowly through designated blocks, listening for Pinyon Jay calls and watching for Pinyon Jays flying over. All Pinyon Jays detected while the surveyor was driving were noted on data sheets. The surveyor stopped at each pre-designated survey point and watched and listened for 6 minutes. 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 points in block) in Beaufort units;
3. start and end cloud cover (%); and
4. start and end temperature.

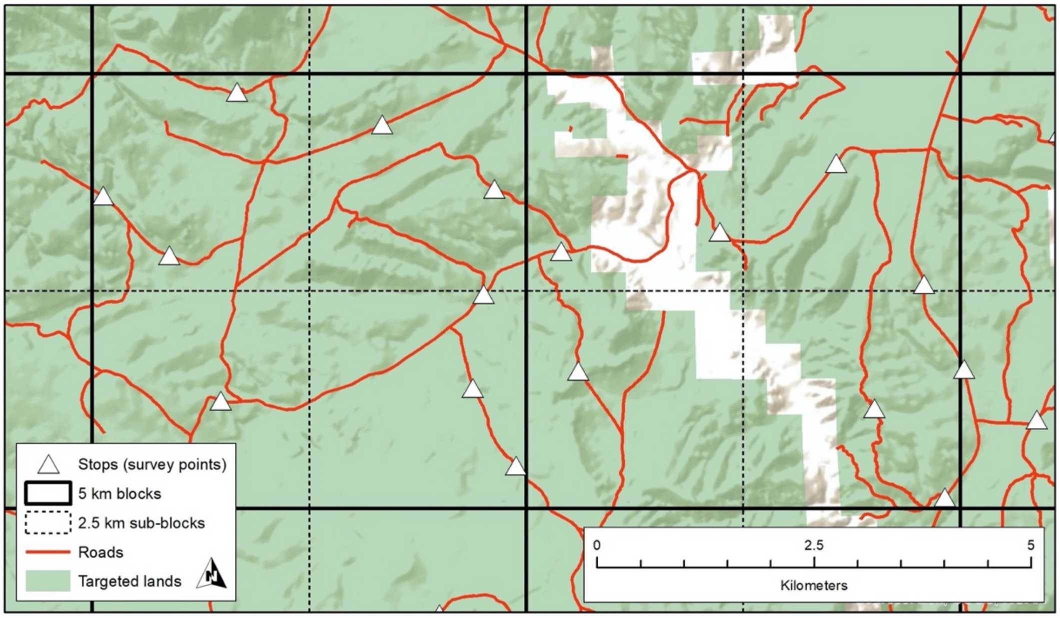

Figure 2. An example of pre-determined road routes for road-based Pinyon Jay surveys in the Gila NF.

For every point, the surveyor recorded:

1. time start and end and the minute birds were 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 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"); and
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, 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. 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. However, in March 2022, Pinyon Jays were found in large winter flocks and had not settled on nesting colony sites. 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 most 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 the jays were not actively 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.

In 2023, we surveyed 103 blocks, focusing survey on finding new active nesting colonies. Pinyon Jays remained in large winter flocks through April, and most active colonies were found in late April or early May, indicating that the Pinyon Jays nested much later in 2023 than in the two previous years.

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). Logistic regression can be used to determine 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, ψ, given imperfect availability for detection at each survey location and varying rates of detection. Psi, or ψ, is also known as site-level occupancy or, for this survey, block-level occupancy. Here we refer to ψ as “site occupancy.”

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

The probability of detecting a bird if present is also a consideration. This is estimated at the point level to better approximate local availability for detection 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 points 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 θ (theta, i.e.; “availability”). 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 occupancy and availability for detection. 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, 1-minute increments of each survey into three, 2-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 2-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 and availability covariates

To model both detectability and availability in 2021–2023 surveys, we employed the five covariates previously used to model detectability in 2021-2022 surveys. These covariates were hour of survey after sunrise, residual temperature, % cloud cover, wind (Beaufort scale), and Julian day. We revised the Julian day covariate to be year-relative (i.e., Julian day minus mean survey day of the year) to account for varying seasonal effects on the timing of breeding. We added a new covariate in 2023, local flock size index, to control for potential effects of movement (influencing availability) or detectability. This covariate was calculated as the mean flock size of all flocks having more than two birds (to remove single- or paired-bird influences) within a radius of 80 km in the week before and after the observation.

Site occupancy covariates

We employed block geographic coordinates and elevation (detailed below) as potential predictors of site occupancy. Covariates relating to vegetation and other factors were not modeled but may be included in subsequent analyses.

Modeling steps

We revised our approach to modeling 2021–2023 survey data using information from our 2021–2022 results and additional insights from the 2023 season. We built models in two stages. The first stage addressed survey time, date, flock size, and weather effects on detection and availability; the second stage addressed site attributes on occupancy.

In the first stage, we assessed support for a time-after-sunrise effect on both detectability and availability using combinations of time polynomial terms (up to fourth-order effects), removing covariate combinations exhibiting uninformative parameters in their highest-order terms (Arnold 2010). All models included year identity in both detection and availability. Using competitive models ($\Delta AICc < 2$) from this step, we next assessed support for including two indices of seasonal phenology in explaining patterns of detection and availability. The first was a more generalized year-relative Julian survey day (up to a third-order term) as well as year × date interactions. The second was a more specific linear local flock size index (log mean flock size within 80 km in the preceding and following weeks). Using competitive models from this step, we then considered all combinations of linear terms for residual temperature, cloud cover, and wind speed in predicting detectability and availability. Year terms and a single site covariate (north coordinate of block) were included in each model.

In the second stage of modeling, we retained combinations of detection and availability covariates that were present in competitive models from the first modeling stage using these terms in concert 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 survey year (2021, 2022, or 2023) was included as a predictor of all components. As with assessing detection models, we considered supported models to be those with ΔAICc <2, and containing no 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 ΔAICc of 4 following recommendations in Burnham and Anderson (2002) for inclusion of models with both "substantial" and "less substantial" support (but not "considerably less"; i.e., ΔAICc >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

We modified the sample of blocks included in analysis in 2023 slightly from 2022. This resulted in 376 blocks in the revised study area (Figure 3, Table 1). Table 1 summarizes raw survey results for the three years, including numbers of nesting colonies found and numbers of nests in each year. Creches of fledglings were found in April 2021, suggesting that Gila NF Pinyon Jays began nesting in March 2021. Very few pairs nested in 2022, and those that did nested later than is typical for Pinyon Jays, with nests detected on 16 and 30 April. In 2023, some winter flocks were present through April and into the first week of May. The jays nested very late, with active nests found in the first two weeks of May.

2021 Field Surveys

In 2021 (Johnson et al. 2021), the surveyor completed 124 25-km^2 blocks across the entire study area. These 124 blocks included 512, 6-min point surveys. Pinyon Jay flocks were detected in 36 (29% of) surveyed blocks and on 61 (12.1% of) points (Table 1). Because we detected very few Pinyon Jays in the southern blocks, we eliminated those blocks from surveys in subsequent years. To allow for comparison among years, only the northern and eastern blocks from 2021 were included in analyses. Including only the 376 blocks in the revised study area, the surveyor completed surveys of 83, 25-km^2 blocks representing 22% of blocks in the revised study area (Figure 3, Table 1). These 83 blocks included 359, 6-min point surveys. Pinyon Jay flocks were detected in 35 (42% of) surveyed blocks and on 61 (17%) of points (Table 1). Pinyon Jay group sizes ranged from 1 to 32 birds with an average of 5 birds detected (Figure 3, Table 2).

2022 Field Surveys

Using only 376 blocks in the revised study area, the surveyor completed surveys of 153, 25-km^2 blocks or 41.2% of the 376 blocks in 2022 (Figure 3, Table 1). The 153 blocks included 657, 6-min point surveys. Pinyon Jay flocks were detected in 54 (35.3%) of blocks and on 76 (11.6%) of points (Table 1). Pinyon Jay group sizes ranged from 1 to 125 birds with an average of 9 birds detected (Table 2).

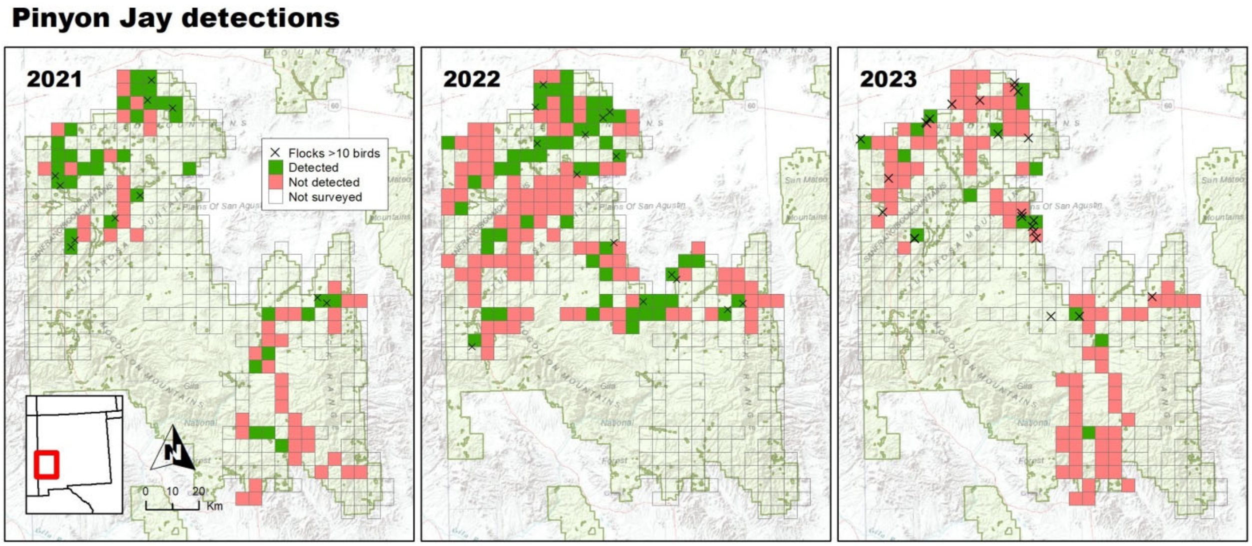

Figure 3. Block-level results from surveys of Pinyon Jays in the Gila National Forest, 2021–2023. South blocks surveyed in 2021 are not shown, allowing for comparison among years. Also shown are larger flocks (at least 10 birds) observed both during and between 6-minute point surveys.

Table 1. Three-year summary of complete field survey results. Results from 2021 include south, east, and north areas of the Gila NF (column 2) and north and east areas only (column 3), for comparison with 2022 and 2023. Southern areas surveyed in 2021 were removed for comparison with 2022 and 2023 results (see Results, 2021 Field Surveys). In 2021, we did not return to colony sites after colonies were first discovered to find additional nests. Hence, number of nests and percent activity for 2021 are not accurate indications of nesting activity. The total 376 for all years is the final study area of blocks common to all years and is not equal to the number of block-years surveyed in each year. *In 2021, incidental observations were incorporated as block surveys and were not recorded separately.

Year	2021	2021	2022	2023	All Years
5x5 km Blocks Surveyed	124 (N, E, & S)	83 (N & E)	153 (N & E)	103 (N & E)	376
No. and % positive blocks	36 (29.0%)	35 (42%)	54 (35.3%)	15 (14.6%)	105 (27.9%)
No. of 6-min Surveys	512	359	657	465	1634
No. and % positive surveys	62 (12.2%)	61 (17%)	76 (11.6%)	20 (4.3%)	158 (9.7%)
Incidental Detections	8	*	13	36	49
Nesting Colonies	5	5	9	19	33
% Active	80%	80%	22%	63%	55%
No. of Nests	6	6	41	58	105
% Active	67%	67%	7%	57%	38%
Dates of Active Nests	5, 6 April	5, 6 April	16, 30 April	9 April–12 May	

2023 Field Surveys

Using only 376 blocks in the revised study area, the surveyor completed surveys of 103, 25-km^2 blocks (27% of the 376 blocks) in 2023 (Figure 3, Table 1). The 103 blocks included 465, 6-min point surveys. Pinyon Jay flocks were detected in 15 (14.6% of) blocks and on 20 (4.3% of) points (Table 1). Pinyon Jay group sizes ranged from 1 to 128 birds with an average of 19 birds detected (Table 2).

Repeated and Non-surveyed Blocks, 2021–2023

Of 222 blocks surveyed among the 376 blocks in the revised study area, 33 were surveyed in 2021, 2022, and 2023. This represents 40%, 22%, and 32% of the 2021, 2022, and 2023 survey totals, respectively. Fifty-one blocks were surveyed in two years and 138 blocks were surveyed in one year. Pinyon Jays were detected on 14 blocks surveyed in three years (42% of surveyed blocks), 18 blocks surveyed in two years (36% of surveyed blocks), and 29 blocks surveyed in one year (21% of surveyed blocks). Of all blocks, 154 blocks (or 31% of the study area) were not surveyed in any year due to inaccessibility, habitat suitability, etc.

Table 2. Summary statistics of field detections of Pinyon Jays (PIJA) in the study area common to 2021, 2022, and 2023 (376 blocks, Figure 3), by point and 5 x 5-km block. Two-minute interval of first detection indicates in which 2-minute interval birds were first detected. Inverse interval of first detection translates to the % of intervals on which birds were detected, given truncation after the interval of first detection (possible values are 1, 0.5, 0.33). Positive points are those with PIJA detected.

Points	**2021**			**2022**			**2023**		
	n	**Mean**	**Range**	***n***	**Mean**	**Range**	***n***	**Mean**	**Range**
PIJA detected (% of *n*, points surveyed)	359	17.0	—	656	11.6	—	465	4.3	—
PIJA detected per surveyed point (*n,* points surveyed)	359	0.92	0–32	656	1.03	0–125	465	0.83	0–125
Two-minute interval of first detection (*n,* positive points)	61	1.61	1–3	76	1.53	1–3	20	1.45	1–3
Inverse interval of first detection (%), a.k.a. naïve detectability	61	77.3	33.3–100	76	77.6	33.3–100	20	82.5	33.3–100
Flock size (*n*, positive points,)	61	5.4	1–32	76	8.9	1–125	20	19.3	1–125

Blocks	**2021**			**2022**			**2023**		
	n	**Mean**	**Range**	***n***	**Mean**	**Range**	***n***	**Mean**	**Range**
Points surveyed (*n*, per block)	83	4.3	1–6	153	4.3	1–7	103	4.5	1–6
PIJA detected (% of surveyed blocks), a.k.a., naïve occupancy	83	42.2	—	153	35.3	—	103	14.6	—
Birds detected per surveyed block (*n*)	83	3.98	0–59	153	4.44	0–143	103	3.75	0–128
Percent of points with detections (%, blocks with PIJA only), a.k.a. naïve availability	35	35.3	17–100	54	31.5	14–100	15	34.6	17–100
Birds detected per block (*n*, blocks with detections only)	35	9.43	1–59	54	12.57	1–143	15	25.73	1–128

Multi-scale Occupancy Models

Six models were competitive following model-selection steps (Table 3). Model fits were fair (AUC between 0.7 and 0.8) for all models.

<u>Detection</u>: Throughout modeling steps, parameter estimates (Table 4) indicated similar detectability in 2021 vs. 2022, but higher detectability in 2023. Support for including polynomial terms of survey time (after sunrise) as a predictor of detection was similar to our analysis of 2021–2022. This effect indicated an overall 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 4). Residual temperature (temperature relative to that expected on a given

Julian date and time) appeared in several of the final models and indicated lower detectability with warmer relative temperature.

Availability: Parameter estimates (Table 4) consistently indicated lower availability for detection in 2022 and 2023 compared to 2021. Availability was positively associated both with residual temperature on the survey occasion and with the index of recent flock size in the vicinity of the survey point (Figure 4). Availability for detection was highest on earlier and later survey dates relative to the mean survey date in the season, with lowest availability mid-season (Figure 4).

Occupancy: Parameter estimates (Table 4) indicated lower availability for detection in 2022 and 2023 compared to 2021, though only significantly in 2023 in 4 of 6 competitive models. Occupancy was unimodally associated (though not significantly) with the east-west axis of the study area (peaking in the center, Figure 4) and positively associated with the north-south axis (i.e., more likely at higher latitudes in the study area). Covariate interactions of east × north and a year × north were present in single models, though only the former was significant. Predicted site occupancy over the study area for the three years is shown in Figure 5.

Back-transformed parameter estimates (Table 5) indicate a general pattern of declining occupancy and availability for detection from 2021 to 2023, and increasing detectability from 2021 to 2023. However, due to differences in blocks sampled each year, these are not directly comparable between years. Comparable statistics are possible for occupancy when predicted over the entire study area, which indicated mean occupancy probabilities of 0.74 in 2021 and 0.60 in 2022, and 0.40 in 2023 (Table 6).

Table 3. Competitive models of 2021–2023 5 x 5-km site occupancy (ψ) by breeding-season Pinyon Jays accounting for varying availability for detection on points (θ) and detectability within 2-minute survey time intervals (p). Superscripts indicate covariate is squared, cubed, etc. Indicated are the number of estimated parameters (k), Akaike information criterion adjusted for small samples (AICc), the difference between the AICc of a given model and the lowest AICc model (ΔAICc), and the Akaike weight of models (w_i). AUC is the area under the receiver operating curve, a measure of model accuracy.

	Model	**k**	**AICc**	**ΔAICc**	w_i	**AUC**
1	Ψ: year + north + east + east^2 θ: year + day + day^2 + flock+ temp p: year + hour + hour^2 + hour^3 + hour^4 + hour^5 + temp	22	1184.8	0.0	0.241	0.787
2	Ψ: year + north θ: year + day + day^2 + flock+ temp p: year + hour + hour^2 + hour^3 + hour^4 + hour^5 + temp	20	1185.2	0.4	0.200	0.765
3	Ψ: year + east + east^2 + north + east*north + east^2*north θ: year + day + day^2 + flock+ temp p: year + hour + hour^2 + hour^3 + hour^4 + hour^5 + temp	24	1185.3	0.5	0.191	0.784
4	Ψ: year + north θ: year + day + day^2 + flock+ temp p: year + hour + hour^2 + hour^3 + hour^4 + hour^5	19	1185.8	1.0	0.144	0.773
5	Ψ: year + north + east + east^2 θ: year + day + day^2 + flock+ temp p: year + hour + hour^2 + hour^3 + hour^4 + hour^5	21	1186.0	1.2	0.135	0.793
6	Ψ : year + north + east + east^2 + year*north θ: year + day + day^2 + flock+ temp p: year + hour + hour^2 + hour^3 + hour^4 + hour^5 + temp	24	1186.8	2.0	0.089	0.772

Table 4. Mean parameter estimates from the seven competitive (ΔAICc < 2) models of multi-scale occupancy by Pinyon Jays in the Gila NF, 2021–2023. Model components are site occupancy at the 5 x 5-km block scale (ψ), availability for detection (θ) 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 2022 and 2021, and year2023 indicates the difference between 2023 and 2021. Survey hour was calculated as the hour after sunrise, day is the Julian day centered on the mean survey day per year, temperature (temp) is residual temperature from a linear model (see Methods), and flock size (flock) is an index calculated from recent observations near the point (see Methods).

	Models					
Covariate	**1**	**2**	**3**	**4**	**5**	**6**
ψ: Intercept	2.96	1.23	3.14	1.19	2.85	2.75
ψ: year2022	-1.22	-0.56	-1.62	-0.53	-1.21	-1.60
ψ: year2023	-1.21	**-2.30**	**-3.50**	**-2.36**	-1.19	**-3.31**
ψ: east	0.03	—	0.44	—	0.04	-0.05
ψ: east^2	-1.12	—	-0.75	—	-1.07	-0.67
ψ: north	**1.89**	**1.04**	0.39	**1.02**	**1.86**	**2.07**
ψ: east:north	—	—	1.09	—	—	—
ψ: east^2:north	—	—	**1.55**	—	—	—
ψ: year2022:north	—	—	—	—	—	-0.85
ψ: year2023:north	—	—	—	—	—	-1.60
θ: Intercept	0.00	0.01	-0.05	0.17	0.15	0.00
θ: year2022	**-1.79**	**-1.86**	**-1.73**	**-2.08**	**-1.99**	**-1.81**
θ: year2023	**-4.27**	**-3.60**	**-3.17**	**-3.72**	**-4.45**	**-3.38**
θ: flock	**0.85**	**0.90**	**0.86**	**0.98**	**0.92**	**0.88**
θ: temp	**0.30**	**0.29**	**0.29**	**0.22**	**0.22**	**0.29**
θ: day	-0.05	-0.11	-0.16	-0.11	-0.04	-0.06
θ: day^2	**0.58**	**0.67**	**0.67**	**0.68**	**0.59**	**0.63**
p: Intercept	**-2.09**	**-2.05**	**-2.16**	**-2.08**	**-2.14**	**-2.09**
p: year2022	0.49	0.46	0.46	0.71	0.75	0.50
p: year2023	**2.02**	**1.93**	**1.99**	**1.74**	**1.85**	**2.00**
p: temp	**-0.28**	-0.26	**-0.27**	—	—	-0.26
p: hour	**-1.65**	**-1.73**	**-1.69**	**-1.87**	**-1.79**	**-1.69**
p: hour^2	**2.10**	**2.03**	**2.20**	**1.78**	**1.86**	**2.08**
p: hour^3	-0.34	-0.29	-0.38	-0.11	-0.16	-0.31
p: hour^4	**-0.81**	**-0.80**	**-0.86**	**-0.73**	**-0.76**	**-0.81**
p: hour^5	0.39	0.38	0.41	0.34	0.35	0.38

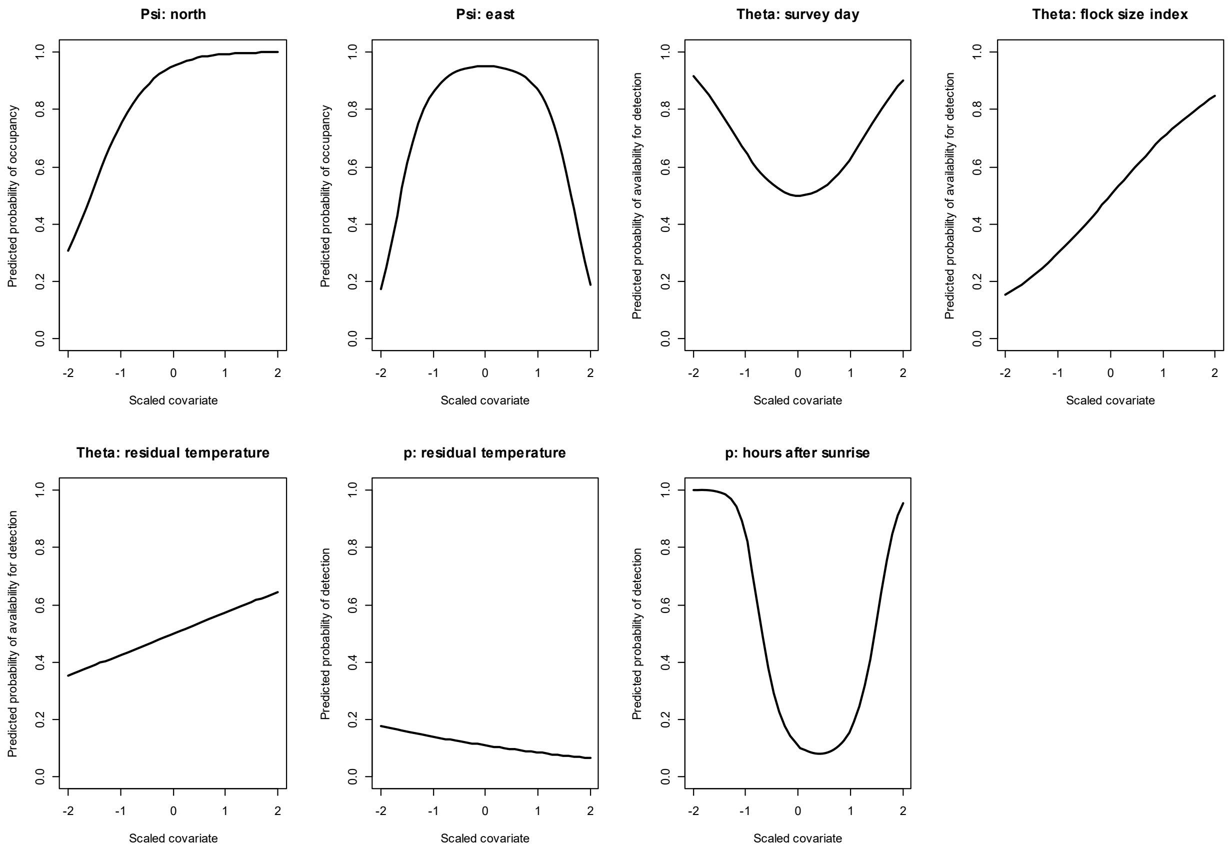

Figure 4. Generalized relationships between covariates and probabilities of occupancy (Psi), availability for detection (Theta), and detection (p) in the best multi-scale model of Pinyon Jay occupancy, 2021–2023. Covariate values are scaled (mean = 0, SD = 1). This model indicated greatest probabilities of occupancy in the central-north of the study area, greatest probabilities of availability for detection on days near the relative start and ends of seasons, greatest probabilities of availability for detection when observed flocks within 80 km were larger in the week before and after the survey, greatest probabilities of availability for detection on warmer days (after controlling for date and time), greater probabilities of detection on cooler days, and greater probabilities of detection in the mornings and late afternoons.

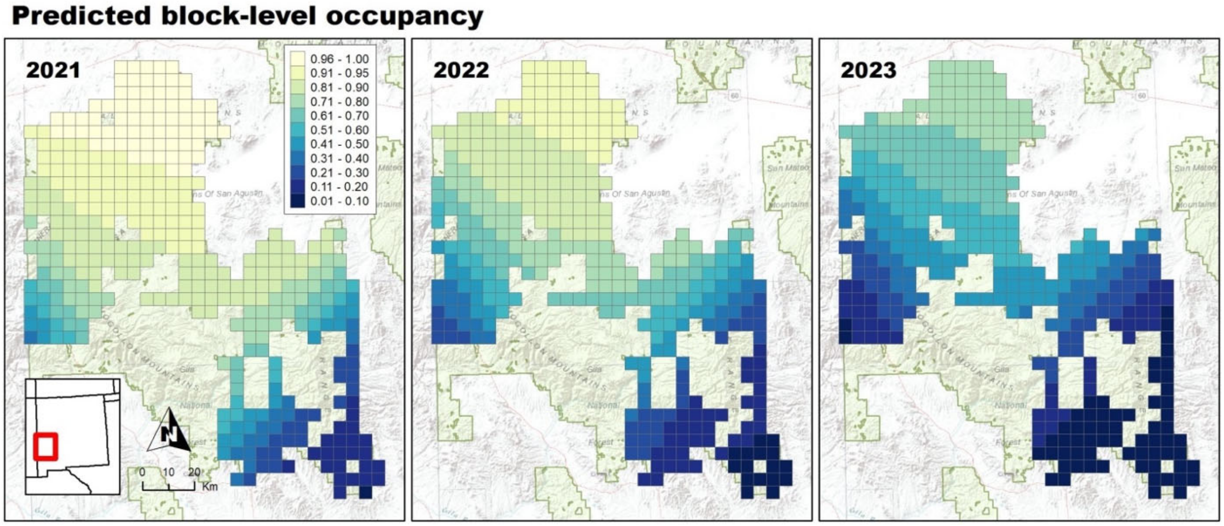

Figure 5. Predicted Pinyon Jay site occupancy (ψ, Psi) in the Gila National Forest, 2021–2023. Predictions are weighted averages across six competitive multiscale occupancy models employing survey data from March and April in each year (using weights [w_i] in Table 3).

Table 5. Summary of year-effect model parameters across the six competitive multi-scale occupancy models. Values are back-transformed from the logit scale to the probability scale. Mean and SD are weighted mean and standard deviation values across the six models and were calculated using model weights in Table 3.

Parameter	Mean	SD	Min	Max
Occupancy (ψ)				
2021	0.889	0.095	0.767	0.959
2022	0.769	0.092	0.659	0.851
2023	0.515	0.294	0.236	0.852
Availability (θ)				
2021	0.509	0.022	0.488	0.543
2022	0.139	0.006	0.130	0.145
2023	0.025	0.011	0.013	0.039
Detection (p)				
2021	0.109	0.004	0.104	0.114
2022	0.175	0.019	0.154	0.202
2023	0.458	0.027	0.415	0.483

Table 6. Predicted block-level occupancy by Pinyon Jays across all blocks in the Gila NF study area, 2021-2023. Predicted occupancy was calculated by averaging predictions from six competitive models using weights in Table 3.

Year	Mean	SD	Min	Max
2021	0.739	0.257	0.098	0.979
2022	0.600	0.277	0.064	0.945
2023	0.401	0.242	0.013	0.790

Table 7. Direct comparisons of naïve and predicted block-level occupancy by Pinyon Jays across only the surveyed locations in the Gila NF study area, 2021-2023. Predicted occupancy was calculated by averaging predictions from six competitive models using weights in Table 3. Summarized information is presented both for the complete set of blocks surveyed and the subset of 33 blocks surveyed in all years. With the exception of blocks in common in 2021, mean predicted occupancy was significantly higher than naïve occupancy in all comparisons (Wilcoxon paired signed-rank test; all $P < 0.001$).

			Predicted occupancy					
Year	Blocks (*n*)	Naïve occupancy	Mean	SD	Min	Max	Difference (%)	% comparison
All blocks								
2021	83	0.422	0.738	0.265	0.136	0.977	31.7	175
2022	153	0.353	0.749	0.165	0.323	0.943	39.6	212
2023	103	0.146	0.447	0.265	0.034	0.790	30.1	306
Blocks common to all years								
2021	33	0.727	0.889	0.119	0.549	0.977	16.2	122
2022	33	0.394	0.774	0.195	0.326	0.936	38.0	196
2023	33	0.091	0.569	0.212	0.138	0.774	47.8	625

Comparing naïve occupancy (the proportion of blocks with at least one detection) and predicted occupancy (averaged over competitive models) is possible for the subset of blocks surveyed across years (Table 7). Viewed as simple differences, predicted occupancy was between 30 and 40% higher than naïve occupancy in 2021–2023. Viewed as factors of naïve estimates, these model-predicted values ranged between 1.8 and 3.1 times their naïve-occupancy counterparts. If we only consider the 33 blocks common to all years, these values show greater variation, with 16–48% higher predicted than naïve occupancy using simple differences. These model-predicted values ranged between 1.2 and 6.3 times their naïve-occupancy counterparts. With the exception of the 33-block comparison in 2021, these differences were significant using paired Wilcoxon signed-rank tests (all with $P < 0.001$).

Nesting Colonies

We found five nesting colonies in 2021, four of which were active (Figure 6). We recorded only six nests (67% active) in 2021. Our primary focus that first year was on surveying blocks. After locating a colony, we did not return to nesting colonies to find additional nests. Therefore, the number of nests is underestimated, and the percentage of nests active is likely an overestimate.

We found 41 nests in 2022 (Figure 6). 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 Highway 32 colony, six were old nests at the Poison Canyon colony, and five were old nests at the Water Canyon colony (Figure 6).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 Black Mountain Mesa colony, and one new (2022, but inactive) and two active nests at the Sand Canyon colony.

In 2023, we visited 19 nesting colonies, 12 of which were active (Figure 6). Of those 12 colonies, 10 were new and two were from 2022 but included new active nests in 2023. The remaining the seven colonies visited were old colony sites and were inactive in 2023.

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. The surveyor noted whether cones were present at each survey point having piñon trees. Overall, the 2021 cone crop was poor. Pinyon Jays are known to avoid nesting when food is scarce (Ligon 1978). Pinyon Jays in the Gila NF may have responded to reduced piñon mast crops by deferring breeding. 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).

Nesting behavior differed again in 2023. The Pinyon Jays remained in large winter flocks through April, and one flock was detected in the first week of May. Unlike 2022, however, the jays nested in 2023, much later than in 2021. We suggest that the Gila NF Pinyon Jays timed nesting in 2023 to take advantage of insect availability. Although we did not sample insects, the Gila NF received much more precipitation than usual in the winter of 2022-2023, leaving muddy roads and extensive standing water along roadsides. The increased moisture might have contributed to increased insect availability. Ligon (1978) first documented late nesting to coincide with insect availability, in the absence of piñon cones.

Approximately two-thirds of survey points with jay detections had ponderosa pine 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. Nesting colonies found elsewhere in New Mexico were in piñon-juniper woodland or juniper savanna habitats (Johnson et al. 2014, 2015). Ponderosa pines were present at several nesting locations in the Gila NF. In 2023, all 12 active colonies were in sparsely-treed or open areas, including in ponderosa pine woodlands, and 64% directly bordered meadows. In 2023, the Pinyon Jays apparently nested near open, grassy areas where insect availability was high.

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. The area affected by the Black Fire was primarily roadless wilderness where we have not surveyed. The western edge of the fire impacted area was surveyed in 2021, but there were no Pinyon Jay or nest detections at these survey points.

Site Occupancy

Differences in the behaviors of birds between 2021, 2022, and 2023 appeared to drive patterns of lower occupancy in 2023 in four out of six competitive models. Most models indicated patterns of overall higher occupancy in the north-central part of the study area. In contrast with previous 2021 and 2022 models, elevation did not appear in competitive models. The gradient of higher occupancy in the north portion of the study area may be associated with an overall increasing ponderosa pine cover in this region, but additional testing is needed to assess this possibility.

Availability

In all six competitive models, estimated availability for detection—which translates to the proportion of locations where birds may be detected within an occupied area—was lower in both 2022 and 2023 relative to 2021 (Table 5). We cannot fully explain this pattern (which was only slightly evident in measures of naïve availability), but it appears to be driven in part by between-season behaviors. The strongest evidence for this suggestion was that birds tended to be observed in larger flocks exhibiting non-breeding behavior in 2022 and even more so in 2023 (Table 2). If considering an instantaneous snapshot of birds distributed within a given block, it is reasonable to suspect this pattern of greater Pinyon Jay aggregation led to less dispersion and thus lower probabilities of local occurrence. When flocks were smaller, as in 2021, Pinyon Jays were spread over more blocks and predicted probabilities of occupancy were higher across more blocks. When flock sizes were larger, as in 2023, the birds were clumped within fewer blocks, and predicted probabilities of occupancy were lower across more blocks (Figure 7). In partial contrast, the significant positive effect of the local flock size index on availability (Table 4, Figure 4) suggests that larger local bird aggregations exhibit other behaviors—e.g., greater movement rates within blocks—that could result in greater proportion of points with birds (given occupancy). Additional multi-scale survey data in the Gila NF and beyond will help to further explain these patterns.

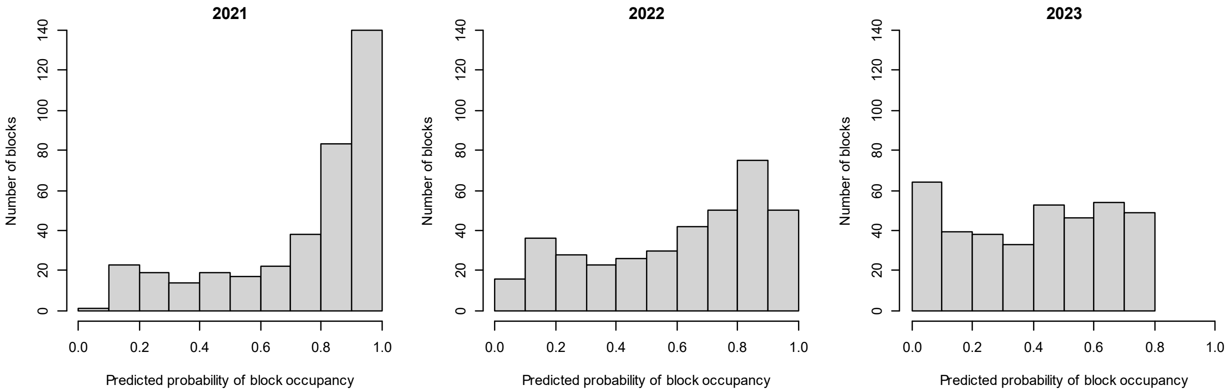

Figure 6. Distribution of predicted Pinyon Jays occupancy probabilities among 25-km^2 blocks in the Gila National Forest, 2021–2023. Probabilities are the average of six competitive multi-scale occupancy models.

Detectability

In contrast with availability, detectability—here approximated by the rate at which birds were first detected on points—was lowest in 2021, somewhat higher in 2022, and highest in 2023 (Table 5). The most plausible explanation appears to be the effect of flock size; larger flocks, if locally present, should be more quickly detected than smaller flocks. Flock size, however, did not appear in supported models. Only survey time and relative temperature had notable effects on detection (Table 4, Figure 4), with fifth-order effects indicating two periods of highest detection probabilities and lower detectability on relatively warmer surveys. This result would be unlikely in a study which limited surveys to the morning, which many bird surveys do. We conducted fewer surveys 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 0.11, 0.18, and 0.46 in 2021, 2023, and 2023, respectively (Table 5), using weighted averages across competitive models, similar to the detectability per visit of 0.18 (95% CI = 0.14–0.23) found by Magee et al. (2019).

Occupancy

Because the assumption behind occupancy modeling is that some occurrences are missed, it is not surprising that model-predicted occupancy estimates were higher than naïve occupancy estimates. This suggests that Pinyon Jays are more widespread across the study area than indicated by detections. Differences in occupancy between years were addressed in our multi-scale models with a categorical covariate denoting the survey year. This inclusion is also necessary when using a "stacked" occupancy model design such as ours. A limitation in this approach, however, is that the source of variation (i.e.; climate, food availability, etc.) in occupancy estimates between years remains unknown. While we expected some between-year differences in estimated occupancy, we suspect differences were inflated by patterns of aggregated flock occurrence in 2022 and 2023, such that birds associated with individual blocks during times of breeding likely joined birds from adjacent blocks during non-breeding periods. While the effect of this pattern is, to our knowledge, unexplored in the occupancy modeling literature, it warrants future investigation.

Using only block center coordinates and mean elevation as potential predictors, we found a gradient of increasing predicted occupancy peaking in the north-central part of the study area (Figure 5). Vegetation changes along this SE-NW gradient are generally from piñon-juniper woodlands to areas more dominated by mixed ponderosa and piñon.

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 (between 0.89 and 0.52) 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 availability 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 availability probabilities in their control ($\theta = 0.84$), mastication-treated ($\theta = 0.53$), and hand-thin treated areas ($\Psi = 0.42$) than our finding of θ between 0.51 and 0.03. 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 Magee et al.'s (2019) points during surveys due to their use of non-systematic (i.e., non-grid) site selection based on the occurrence of treatment areas. These availability 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 availability represent "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

Our Pinyon Jay surveys in the Gila NF have provided baseline information for management: distribution and habitat use, locations for future research focus, and areas where management can begin. However, additional information is needed for the forest to effectively manage Pinyon Jays, in light of other forest management goals. We recommend following the three years of surveys reported here with the important research topics below.

1) Survey additional areas of likely Pinyon Jay occurrence in the Gila NF to establish occupancy, nesting locations, and habitat use.

2) Research nesting success at active colonies. What are the effects of weather and piñon mast production on timing of nesting and nesting success? Does nesting success differ between vegetation types? How does predation affect nesting success?

3) How do woodland management practices interact with Pinyon Jay nesting and foraging (for piñon seeds and insects)? Compare Pinyon Jay use of treated vs. untreated areas, conduct pre- and post-treatment Pinyon Jay surveys, and characterize used vs. unused vegetation types.

4) Understand demography of the Gila NF Pinyon Jay population. Is the population increasing, decreasing, stable? What are the respective contributions of reproductive success, survival, and timing and frequency of nesting?

5) Monitor fire impacts on Pinyon Jay nesting and foraging areas.

6) Monitor climate impacts on Pinyon Jay nesting and foraging habitat.

Management

This three-year 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 responsibility to conserve this population of Pinyon Jays. General management recommendations for Pinyon Jays rangewide have been detailed by Somershoe et al. (2020), Johnson and Balda (2020), and others and are summarized in Appendix 1, below. 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. Below, we provide Pinyon Jay management recommendations specific to the Gila NF, based on our study.

Magee et al. (2019) state that: "At finer scales of habitat use (i.e., availability), Pinyon Jays may abandon treated forest patches that remove too much cover for nesting and roosting or severely reduce piñon pine seed availability." 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 is too sparse for nesting or roosting and/or too few cone-bearing trees are present, etc.). For the present, the fact that Pinyon Jays avoid thinned sites in piñon-juniper (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). In piñon-juniper areas of the Gila NF occupied by Pinyon Jays, these cautions should be noted.

However, in Gila NF ponderosa pine woodlands used by Pinyon Jays, interactions between woodland management practices and Pinyon Jays may differ from those in piñon-juniper woodlands. The combination of late nesting with use of sparse ponderosa pine and open piñon-juniper woodlands suggests that Pinyon Jays in the Gila NF adjust timing and location of nesting to food supply, nesting early when piñon seeds have been stored the previous fall and nesting late in insect-rich areas when seed crops fail. Pinyon Jays in the Gila NF nest in both major vegetation types, making the Gila NF an excellent laboratory for investigating questions on the timing and location of nesting and the management of both forest and bird.

Management Recommendations Specific to Gila NF Pinyon Jays

1) Where possible, employ woodland treatments that also enhance Pinyon Jay nesting or foraging habitat.
2) Repair and maintain existing wildlife water and strategically site water to target Pinyon Jay occupied areas.
3) Limit human impacts/access during the fall season in piñon mast-producing areas within Pinyon Jay home ranges.
4) Limit human impacts/access during nesting season in nesting areas.
5) Implement general management recommendations listed in Appendix 1.

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

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Appendix 1. General Habitat Management Recommendations for Pinyon Jays

The following general management recommendations were assembled from various sources. Management recommendations specific to the Gila NF are listed in Management, above. Pinyon Jay flocks use a variety of habitats within their large home ranges. Management should consider multiple habitats within home ranges and the respective Pinyon Jay activities they support (Johnson et al. 2014, 2015, 2016; Johnson and Balda 2020; Johnson and Sadoti 2019; Boone et al. 2021). We note high or medium priority for each recommendation.

General habitat management.

The following general habitat management guidelines are recommended. All general habitat recommendations are medium priority.

1) Seasonally restrict human impacts such as recreation or military activities in and near traditional nesting colony sites. Restrictions over as little as three to four months of the breeding season within predicted colony-scale habitat would provide significant support for nesting Pinyon Jays (Johnson et al. 2016).
2) Set aside piñon-producing areas and nearby caching sites for Pinyon Jays and other wildlife during the fall season, in mast years only (Johnson et al. 2016).
3) Limit collection of cone-producing piñon trees for fuelwood, especially within the home range of a Pinyon Jay flock (Johnson and Balda 2020).

Treatment design and application.

Treatment within active or recently active nesting sites is not recommended. However, if treatment is necessary within a known Pinyon Jay use area, guidelines are provided. Treatment design recommendations 4-11 are the highest priority; 12-20 are the next-highest priority but still important.

4) Prior to conducting woodland treatments, determine if and how Pinyon Jays are using the target area by conducting surveys following recommended survey protocols (Peterson et al. 2014; Somershoe et al. 2020; Pinyon Jay Working Group 2021, Johnson et al. 2023).
5) Avoid woodland treatments (thinning, burning, herbicides) within known Pinyon Jay colony sites for up to 10 years after a site is active (Marzluff and Balda 1992) and within a 500 m buffer around colonies, as colony locations may move (Wiggins 2005; Johnson and Balda 2020; Johnson et al. 2017a; Somershoe et al. 2020).
6) Avoid thinning in colony sites during the Pinyon Jay breeding season to avoid impacting nest success. Clearance surveys are necessary, as Pinyon Jays may nest at almost any time of year (Johnson et al. 2020; Somershoe et al. 2020).
7) Base thinning and management activities on local site conditions and Pinyon Jay use, rather than implementing the same prescription for all sites, because habitat choice varies across sites (Johnson and Sadoti 2019).
8) Avoid large reductions in canopy cover in Pinyon Jay use areas (e.g., from 36% cover to 5% cover, Magee et al. 2019; 85% reduction, Johnson et al. 2018), because large reductions have resulted in reduced Pinyon Jay use of occupied areas.
9) In piñon-juniper vegetation, retain larger trees to conserve suitable Pinyon Jay nesting habitat rather than thinning all size/age classes uniformly (Somershoe et al. 2020); e.g.,

retain trees within the 25-75% size quartiles at a site (Johnson and Sadoti 2019). In thinned patches, retain tall and densely crowned trees for nesting, particularly within areas of higher tree density (Wiggins 2005; Johnson and Sadoti 2019; Johnson et al. 2014, 2015).

10) Leave unthinned patches within piñon seed-producing woodlands containing large trees (Somershoe et al. 2020), which are the most productive (Parmenter et al. 2018; Crist et al. 2019). In one study, piñon trees <9 cm diameter at breast height (dbh) had little to no productivity, medium productivity occurred in trees 9-15 cm dbh, high productivity occurred in trees >16 cm dbh (Zlotin and Parmenter 2008).
11) Avoid removing most or all junipers in a treatment area, because Pinyon Jays will nest in juniper trees (Johnson et al. 2021a; Novak et al. 2021).
12) Assess surrounding woodlands for availability of similar habitat. If suitable nesting habitat exists nearby, avoid thinning there to allow for movement of colony sites (Johnson et al. 2020).
13) Utilize natural die-off areas (e.g., from drought or beetle kill) by expanding them, thinning within them, or determining that the natural die-off achieved project goals (Johnson and Balda 2020).
14) Prioritize lop and scatter for thinned trees over other slash management methods because lop and scatter may reduce erosion and promote healthy soils (Stoddard et al. 2008). To discourage *Ips* beetles, remove or scatter slash rather than piling (Cranshaw and Leatherman 2002).
15) Avoid treatment or other site disturbance in areas at high risk of invasion by cheatgrass (*Bromus tectorum)* or other invasive species, which may increase after thinning (Coop and Magee 2016). If treatment or disturbance in these areas cannot be avoided, employ post-treatment management and control of invasive plant species (Crist et al. 2019), including maintaining at least 20% perennial native herbaceous cover post-treatment (Chambers et al. 2014).
16) After thinning, follow-up thinning is recommended over prescribed fire. Fire is not recommended as a management tool in persistent piñon-juniper woodlands (Romme et al. 2009, Johnson et al. 2020; Somershoe et al. 2020).
17) To conserve wildlife habitat, employ firebreaks to protect infrastructure from fire in lieu of thinning large tracts of woodland (Johnson et al. 2020). In persistent piñon-juniper woodlands, confine fuels treatments to wildland-urban interface areas (Johnson and Balda 2020).
18) In piñon-juniper woodlands, conduct thinning or herbicide treatments in a patchy-clumpy mosaic, leaving other patches unthinned for nesting (Johnson et al. 2020; Somershoe et al. 2020). If juniper is targeted, leave areas with piñon trees untreated to avoid compromising piñon nut production (Johnson et al. 2020).
19) In the Great Basin, preferentially treat denser woodlands over less-dense woodlands (Somershoe et al 2020), as Pinyon Jays appear to use Phase I woodlands most frequently, followed by Phase II woodlands, and Phase III woodlands rarely (Somershoe et al 2020).

20) In the Great Basin, create “feathered” transition zones between treatments in sagebrush and piñon-juniper (~250-500 m) to mimic areas of Pinyon Jay activity (Crist et al. 2019; Somershoe et al. 2020).

Managing under climate change.

Recommendations 21-24 are high priority.

21) Manage for climate resilience by 1) identifying and protecting woodland patches likely to persist in the face of climate change, 2) maintaining ecological communities and processes and healthy soils, and 3) accepting, assisting, and allowing for change at sites where transformation is inevitable (Rondeau et al. 2017).
22) Favor south- and west-facing slopes for thinning, as opposed to north- and east-facing slopes, as the latter sites have lower heat loads and are predicted to better resist climate change (Rondeau et al. 2017, Flake and Weisberg 2019). Colony sites have been found on north-facing slopes with lower heat loads (Johnson et al. 2017b).
23) Retain trees within drainages and on healthier soils, because they may survive drought better than trees in drier areas (Johnson et al. 2020).
24) Place wildlife watering stations within 2 km of Pinyon Jay colony sites to support the species during drought (Peterson et al. 2014; Johnson et al. 2016).