National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Breeding Bird Inventory of Petroglyph National Monument, with Special Emphasis on Species Associated with Rocky Escarpment Habitat

Natural Resource Report NPS/SCPN/NRR—2024/2624





ON THIS PAGE
Semiarid grassland habitat on the west side of Petroglyph National Monument, with views of JA, Black and Vulcan volcanoes in the background (2022).
Image credit Harrison Jones

ON THE COVER
View of the rocky escarpment at Petroglyph National Monument near Piedras Marcadas Canyon, with Albuquerque's signature hot air balloons floating above it (2022).
Image credit Harrison Jones

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Natural Resource Report NPS/SCPN/NRR—2024/2624

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February 2024

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Jones, H., C. Walter, E. Cox, L. Schofield, and M. Johnson. 2024. Breeding bird inventory of Petroglyph National Monument, with special emphasis on species associated with rocky escarpment habitat. Natural Resource Report NPS/SCPN/NRR—2024/2624. National Park Service, Fort Collins, Colorado. https://doi.org/10.36967/2302308

NPS 354/192646, February 2024

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Abstract

Petroglyph National Monument, located in Albuquerque, New Mexico, hosts numerous bird communities. In 2019, a Visitor Use Management Plan formalized a sustainable trail system to manage public access and use on the monument's trails. This necessitates an understanding of how trails will impact birds along a 27-kilometer-long rocky escarpment, which may provide nesting habitat for raptors and habitat-specialist songbirds. Continued urban expansion around the monument's boundaries and climate change are additionally likely to impact bird populations. We therefore used (1) point-count surveys to inventory breeding birds across the full extent of the monument and (2) area searches to understand if proposed escarpment trail-crossing locations would affect nesting habitat. We conducted 196 point-count surveys and 15 area searches, detecting 57 species in over 1200 detections; using these data, we estimated breeding densities for nine species. We found distinct bird communities in grassland, shrubland, and rocky escarpment habitat, and at least 26 species of open-habitat and pinyon-juniper passage migrants. However, suburban expansion showed pronounced effects on bird spatial distributions: non-native and generalist species were most common near the suburban boundary, while grassland-specialist species showed an aversion to non-grassland edges. We found no evidence of raptor breeding behavior during area searches, likely because the nearby riparian corridor provides superior nesting habitat, and many areas of the escarpment are subject to high human disturbance. The proposed trail network will likely reduce the negative impacts of social trails on breeding birds and is unlikely to significantly affect raptor and songbird nesting habitat on the escarpment.

Acknowledgments

The authors would like to thank Skylar Mark, Jacob Bourque, and Max Leibowitz for their help in collecting survey data. Kristin Straka and Chris Calvo produced maps of survey areas and point count stations. Cindy Parker assisted with data wrangling and cleaning of the point count data. Chris Ray provided JAGS and R code to run models of breeding density, as well as troubleshooting errors with the code. Rodney Siegel provided comments and edits that improved the manuscript. We also wish to extend our thanks to the NPS staff at Petroglyph National Monument for their assistance with field logistics. Peer reviews from Chris Calvo, Jeff Schively, and Erin Borgman improved the manuscript. This is IBP contribution number 765.

Abbreviations used in this report

ANOVA: Analysis of variance

BCI: Bayesian credible interval

ha: Hectares

IBP: The Institute for Bird Populations

JAGS: Just another Gibbs sampler

km: Kilometers

LOF: Lack of fit

m: Meters

MCMC: Markov chain Monte Carlo

N: Sample size

NM: National Monument

NPS: National Park Service

SCPN: Southern Colorado Plateau Inventory & Monitoring Network

SCGN: Species of Greatest Conservation Need

spp.: Species

VUM: Visitor Use Management

Introduction

Petroglyph National Monument (NM) is a ~3,000 ha unit of the National Park Service in the city of Albuquerque, New Mexico that is located roughly three kilometers west of the Rio Grande. The monument was established on June 27, 1990, with the purpose to protect and promote the understanding of petroglyphs in context with the cultural and natural features of Albuquerque's West Mesa and to perpetuate the heritage of traditional communities connected to this landscape. The monument is located near the ecotone between the shortgrass prairie of the southern Great Plains and the Chihuahuan Desert, resulting in a diversity of soils and topography that support a diversity of habitats. The dominant topographic features are five volcanic cones along the western boundary of the monument and a rocky escarpment, formed from lava flows, that extends across its length. The dominant habitat on the mesa top is desert grassland with scattered cholla cacti (*Cylindropuntia* spp.) and junipers (*Juniperus* spp.), while the sandier soils below the escarpment contain a sandscrub habitat dominated by an assemblage of shrub species. While baseline inventories of bird species within the monument were carried out in the 1990s (unpublished report with species list) and 2000s (Johnson et al. 2007), these projects sampled spatial subsets of the monument rather than its whole extent.

A more expansive inventory of the Petroglyph NM avifauna is needed given the ongoing changes to the landscape context and climate of the monument. First, continuing suburban expansion to the north, east, and south of the monument has resulted in a greater urban-wildlands interface around most of the monument's boundary (Johnson et al. 2007), consisting primarily of suburban housing developments. These housing developments are typically watered and landscaped and may contain food subsidies for wildlife in the form of human garbage, flowering and fruiting yard plants, and bird feeders, which can shift the composition of bird communities (Robb et al. 2008, Galbraith et al. 2015). Furthermore, suburban neighborhoods are often dominated by generalist species at high densities (Moller et al. 2012, Marzluff 2017), and may contain higher densities of non-native birds (Mills et al. 1989, Blair 1996, Bonter et al. 2010, Lerman and Warren 2011) such as House Sparrow (*Passer domesticus*) and Eurasian Collared-Dove (*Streptopelia decaocto*). Nest predators, especially corvids, are also more abundant in urban areas (Marzluff and Neatherlin 2006, Benmazouz et al. 2021). These species that readily colonize or have high densities in suburban environments could therefore spillover into habitats within the monument. Because urban birds have been shown to avoid areas of higher use by people and dogs (Paker et al. 2014), some species within the monument might also avoid the boundary, limiting their distribution to the monument's core area. Second, the desert Southwest is undergoing increasing aridification under a megadrought (Williams et al. 2022), a phenomenon which is shifting the breeding ranges of aridland birds in the region (Iknayan and Beissinger 2018, Riddell et al. 2021). In particular, a modelling exercise found that, under a high emissions scenario, 22 bird species are projected to be locally extirpated and 13 species will colonize the monument by 2050 (Shuurmann and Wu 2018). Therefore, establishing a more complete baseline of the bird community at the monument can help to document changes to the local avifauna resulting from suburban encroachment and climate change.

Another concern with ongoing suburban expansion around the monument has been the increased recreational use of the area by local residents, and particularly the creation of visitor-created 'social' trails which contribute to trail widening, littering, soil erosion, vegetation loss, and establishment of invasive species (Petroglyph NM 2019). Social trails are not part of the official trail network, receive no maintenance, and are an indication of human disturbance. Since social trails are not planned or constructed, they are usually poorly located with respect to terrain and habitat. These factors substantially increase their potential for degradation in comparison to formal, designated trails. To counter these effects, the monument initiated a visitor use planning effort and a Visitor Use Management Plan/Environmental Assessment (VUM Plan) in 2019 to formalize some existing visitor-created trails and expand the trail network in the monument from ~13 km to ~63 km, while closing, reclaiming, and potentially revegetating visitor-created trails and former roads not comprising the formalized trail system. Controlling the number of visitor access points and the configuration of trail networks is important because the use of recreational trails can negatively impact habitat suitability for wildlife (Dertien et al. 2021), reducing richness and abundance in ~70% of cases (Larson et al. 2019). Recreational trails can contribute to the 'landscape of fear', in which wildlife avoid trail areas with higher foot traffic (Rosner et al. 2014, Patten and Burger 2018).

For birds in particular, the presence of trails can reduce the number and abundance of breeding species (Rodriguez-Prieto et al. 2014, Thompson 2015, Botsch et al. 2018), especially ground nesters (Kangas et al. 2010, Thompson 2015). While these effects have primarily been studied in temperate forests and may not hold true across all habitat types (e.g., Deluca and King 2014), Miller et al. (1998) found that grassland birds were less likely to nest near trails in a mixed-grass prairie habitat in Colorado. Higher visitation during sensitive periods of the nesting cycle, especially territory establishment, may lead to avoidance of specific areas (Botsch et al. 2017), and as such it is recommended that trail networks provide trail-free habitat to minimize effects on wildlife. One group that may be particularly vulnerable to human disturbance are nesting birds of prey (Richardson and Miller 1997), which are typically affected by trails at greater distances (> 400 m; Keeley and Bechard 2011, Dertien et al. 2021). Because the presence of hikers can reduce raptor nest attendance and survival (Spaul and Heath 2016), locating raptor nests prior to trail establishment may help mitigate negative trail effects.

When planning the layout of trail networks in protected areas, it is important to understand how trails will impact landscape features of disproportionate ecological importance, sometimes referred to as 'small natural features' (Hunter 2017). Rocky outcroppings often constitute important natural features (Fitzsimons and Michael 2017), particularly in the open landscapes of the Southwest, because they provide unique microclimates and topography (e.g., cliff faces and cavities). In this region, many habitat-specialized bird species are associated with the boulder fields and cliffs that form rocky outcroppings (Rumble 1987, Wiens et al. 1987, Ward and Anderson 1988), notably Rock Wren (*Salpinctes obsoletus*), Canyon Wren (*Catherpes mexicanus*), Say's Phoebe (*Sayornis saya*), and Rufous-crowned Sparrow (*Aimophila ruficeps*). Rocky outcroppings, particularly those with cliff faces, are also important nesting microhabitats for many raptors of open habitats (Smith and Murphy 1982, Keough and Conover 2012), including Prairie Falcon (*Falco mexicanus*), Red-tailed Hawk (*Buteo jamaicensis*), Ferruginous Hawk (*B. regalis*), and Great Horned Owl (*Bubo virginianus*).

Therefore, trail crossings of the rocky escarpment at Petroglyph NM have the potential to negatively impact the breeding habitat of both raptors and habitat-specialist passerines.

In this study, we used unlimited-radius point-counts with distance estimation, combined with area searches, to conduct an inventory of breeding birds at Petroglyph NM and provide breeding-season densities and species occurrence across the full extent of the monument. There was a special focus on areas not inventoried in previous efforts (2001–2003), including all exclaves and recent land acquisitions. Field data were collected by The Institute for Bird Populations (IBP) staff, in close collaboration with monument staff and with extensive input from the Southern Colorado Plateau Network (SCPN); IBP has collaborated on bird monitoring and inventory projects in the SCPN since 2021. Our main objectives were to document current species composition during the early breeding season, and density of some grassland species, to provide baseline information; document species extirpations or range expansions by comparing our field observations to historical monitoring data; and identify populations of rare or habitat-specialist species within the monument. We additionally sought to determine if high-use areas (i.e., trail crossings) along a major topographical feature of the park, a 27-km volcanic escarpment running the length of the monument, appeared to be important breeding habitat for birds of prey and habitat-specialist songbirds. Our ultimate goal was to inform the NPS decision-making process for placement of escarpment crossing points along the monument's existing trail network by identifying sensitive breeding habitat.

Methods

Sample design

Bird species composition and breeding population densities were inventoried using point-count stations on a 300 m × 300 m regular grid placed across the full monument (N = 194 count stations; Figure 1), including its exclaves (the Northern Geologic Window, Southern Geologic Window, and Piedras Marcadas Pueblo site). Thus, the spatial extent and density of points sampled in this study (the full spatial extent of the monument) greatly exceeded the most recent partial inventory effort of Johnson et al. (2007). We thinned the sampling points by removing every fourth point to reduce the number of survey points to a number that was both sufficient for inventory objectives and that aligned the sampling effort and timeframe with available project resources. We additionally conducted area searches across six areas identified by monument staff as potential or probable escarpment trail crossings in the 2019 VUM Plan (Petroglyph NM 2019; Figure 2). These areas included Rinconada Canyon, escarpment crossings in the northern and southern portions of Piedras Marcadas Canyon, the Mesa Prieta area, monument lands near Chamiza Elementary School, and west of the Las Imágenes Visitor Center.

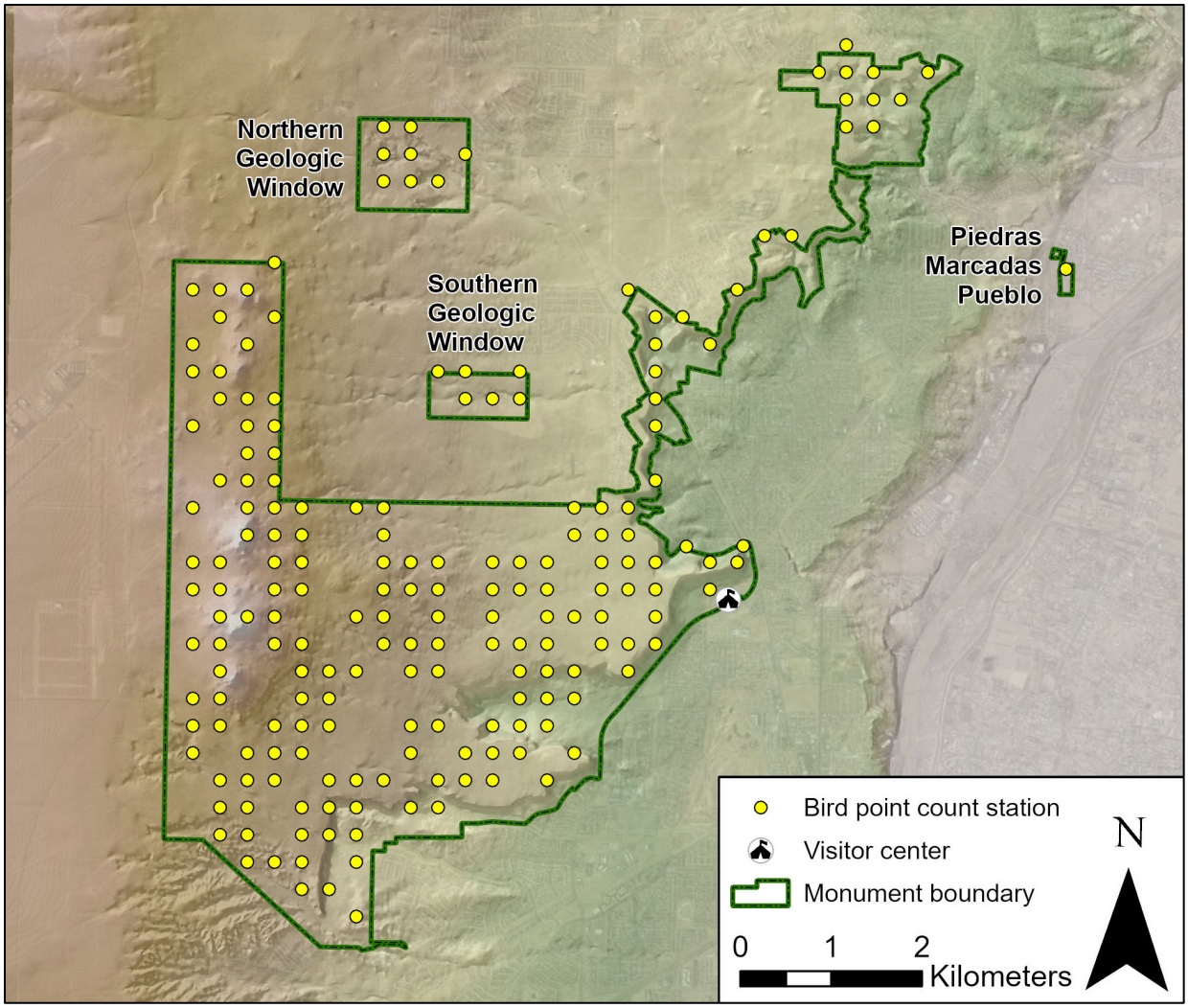


Figure 1. Locations of point count stations within Petroglyph National Monument. Count stations were placed as a 300 m × 300 m regular grid, thinned by removing every fourth point.

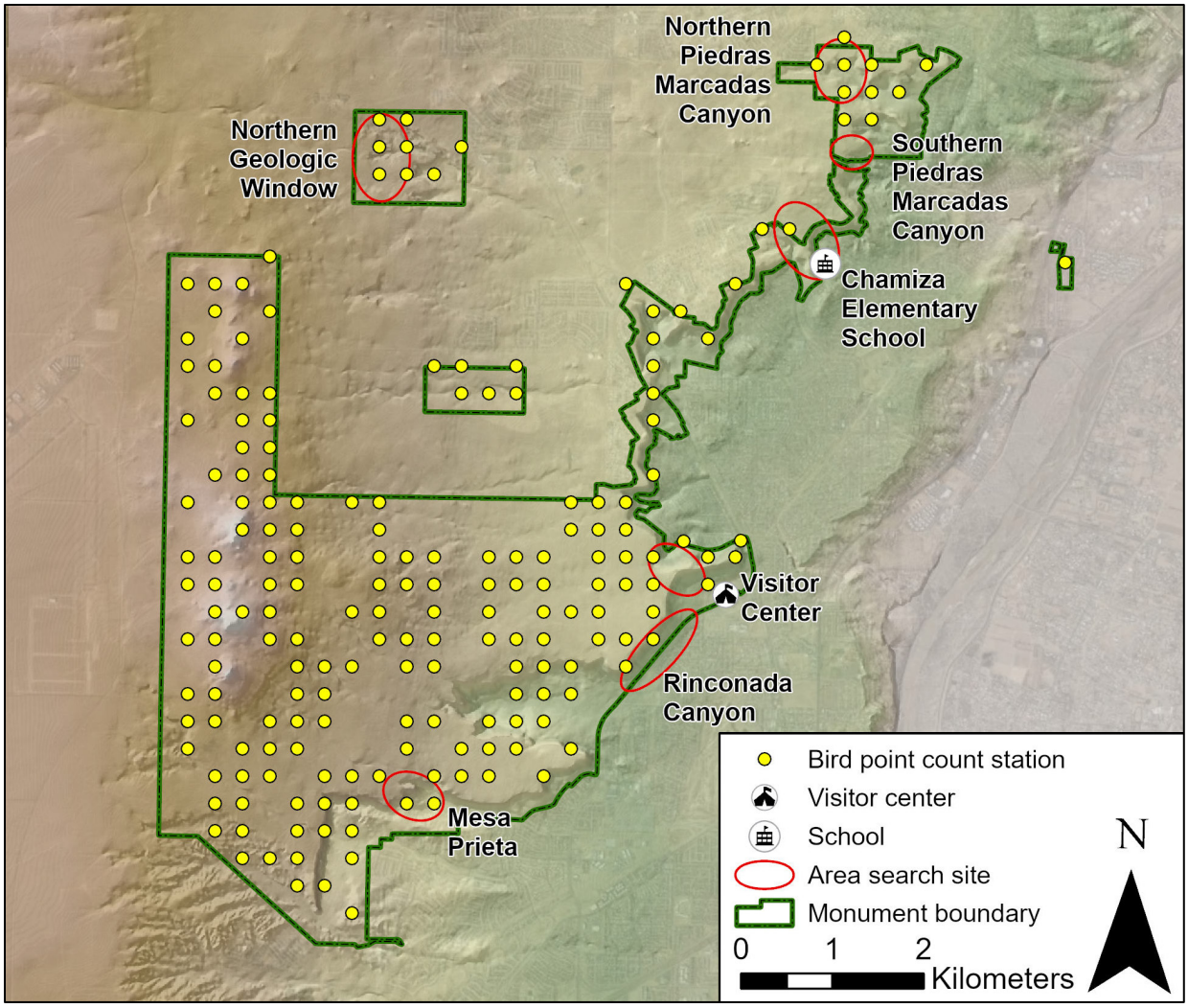


Figure 2. Locations of area search sites within Petroglyph NM. Area searches were conducted either along 900 m transects (red ovals) or in 200 m radius circles (red circles) around proposed trail crossing points of the rocky escarpment.

Survey methods

We conducted unlimited-radius point-count surveys with distance sampling to inventory the breeding bird community at the monument. All surveyors took part in a three-week intensive training course to identify all species by sight and sound and were required to pass visual and aural tests of bird identification before being allowed to collect survey data in the field. Each count station was only surveyed once within a one-week period (April 19–24, 2022) that was timed to coincide with the breeding season for birds of prey, which was a special focus of the area search surveys. We used citizen science data from eBird (i.e., weekly bar charts of relative abundance at eBird hotspots within the monument) to determine the arrival dates of breeding species at the monument and ensure that our surveys would not be mistimed for passerines. Nevertheless, our survey window coincided with the spring migration period, which allowed us to document use of the monument by passage migrant

species. Each count station was surveyed by a single surveyor, and surveys took place starting 10 minutes prior to local sunrise and continuing until 3.5 hours after sunrise.

The count protocol consisted of seven-minute, unlimited-radius point counts with distance sampling. All adult birds seen or heard during the seven-minute count were recorded, keeping track of individual birds (or flocks) of each species; we did not record juvenile birds (identified using plumage differences from adults and begging behavior) because we were interested in estimating adult breeding densities, and because different species fledge young at different times of the year. The horizontal distance to each detected bird or flock was estimated to the nearest meter with the help of a laser rangefinder; when birds were heard but not seen the observer estimated the distance to the location of the sound. We also recorded whether each individual bird was detected during one of three time periods during the count (0:00–3:00, 3:01–5:00, and 5:01–7:00) to estimate the probability that a species is available for detection (e.g., its singing rate or conspicuousness to the surveyor). Birds detected prior to or in between surveys were not recorded. Surveyors additionally collected environmental data likely to affect their ability to detect birdsong for each survey. These factors included environmental noise (quantified on a 1–5 scale), wind velocity (estimated using the Beaufort scale), degree of precipitation, and percentage of cloud cover. We did not survey during high winds or precipitation events greater than a light drizzle.

We also conducted area searches around sites along the rocky escarpment where trail crossings have been proposed. For three sites (Rinconada Canyon, northern portion of Piedras Marcadas Canyon, and the Mesa Prieta area), these area searches were conducted on and around 900 m transects, while in three other locations (near Chamiza Elementary School, west of the visitor center, and the southern portion of Piedras Marcadas Canyon) the area searches were concentrated in a 200-meter radius around each proposed trail crossing point. The location and size of area search locations were selected based on proposed future trail locations, and were determined in consultation with monument staff. Area search data were collected using the eBird 'traveling' protocol, where the presence and estimated abundance of each species is noted, along with the total time and distance covered during the area survey. Time and distance data were collected using the eBird mobile app. A special focus of these surveys was on birds of prey (e.g., American Kestrel [*Falco sparverius*], Red-tailed Hawk, Swainson's Hawk [*B. swainsoni*], Ferruginous Hawk) and on songbirds that nest on rocky hillsides (e.g., Rufous-crowned Sparrow, Rock Wren, Canyon Wren). Observers also noted the occurrence of any breeding behaviors (e.g., copulation or pair duets, alarm calling near a potential nest, nest construction, or provisioning of young in the nest), but did not search explicitly for nests.

Estimating breeding bird densities

Following Ray et al. (2017), we estimated breeding adult density for nine common breeding bird species, selected by sample size of detections (bolded in Table 1 in Results section below). We adapted a three-level hierarchical mixture model, implemented in a Bayesian framework by Amundson et al. (2014), to the single-visit point count data. This model combines an N-mixture model of abundance (Royle 2004) with models of detection based on time-removal and distance sampling (Farnsworth et al. 2002) to allow for estimation of (1) availability or the probability that an individual was available for detection (p_a) by being present in the survey area and signaling its

presence, (2) perceptibility or the probability that an available individual was perceived by the observer (p_d), and (3) the overall abundance (N) and (by extension) density of individuals. For each species, we estimated perceptibility (p_d) by modeling the scale parameter (σ) of a half-normal detection function using distance analysis. We estimated availability (p_a) at the species level with a removal model (Farnsworth et al. 2002), using three uneven time intervals (the first interval lasted three minutes while the second and third lasted two minutes) for seven-minute counts. For each point count survey (k in 1, …, K surveys), we modeled local abundance (N_k) as a Poisson random variable with mean λ_k. We related each survey-specific total count, y_k, to a specific population size, N_k, through the estimated availability and perceptibility components of detectability. The general model was:

$$y_k \sim \text{Binomial}(p_{d,k}, n_k)$$

$$n_k \sim \text{Binomial}(N_k, p_{a,k})$$

$$N_k \sim \text{Poisson}(\lambda_k)$$

By fitting effects of survey conditions on availability and perceptibility, and a random effect of count station on abundance, we then estimated breeding density during our survey period. We fit fixed covariates of wind speed, cloud cover, and minute of day on species availability (removal sub-model), and a fixed effect of environmental noise and random effect of observer identity on species perceptibility (distance sampling sub-model). The random effect of count station was used to account for variation in habitat features across the monument; local abundance was thus modeled as $\log(\lambda_k) = \beta_0[\text{station}_k]$. The JAGS code used to run the model is provided in Appendix B.

Parameter estimation

All analyses were conducted in JAGS version 4.3.0 (Plummer 2003), called remotely using R version 4.3.1 (R Core Team 2023). Prior to analysis, we standardized each continuous covariate (setting mean = 0, SD = 1) to facilitate model convergence and comparison of effect sizes across variables. Each pair of continuous predictors had a Kendall's rank correlation of less than 0.3. We used vague normal priors with a mean of 0 and variance 0.001 for fixed effects and uniform priors bounded at 0 and 10 for the variance of random effects. We assumed random effects were normally distributed with mean 0 and precision τ (τ = 1/variance). We drew posterior estimates from 3 Markov chains of 40,000 samples each with a burn-in of 10,000 samples and a thinning rate of 1 in 30, yielding a joint posterior distribution of 3,000 samples. We assessed the convergence of parameter estimates through inspection of Markov Chain Monte Carlo summaries and the Gelman-Rubin potential scale reduction parameter, R-hat, and considered chains to have converged at values of up to 1.2 (Kéry and Schaub 2012). We measured goodness-of-fit for the availability and perceptibility sub-models using Bayesian P-values generated from posterior distributions, as suggested by MacKenzie et al. (2017) and as detailed in Amundson et al. (2018). We assumed a good fit for P-values near 0.5 and inadequate fit where $P < 0.2$ or $P > 0.8$. We also estimated sub-model fit for p_a and p_d based on the Freeman-Tukey statistic, calculated as the chi-square discrepancy between observed and expected (modeled) response values divided by the chi-square discrepancy between expected and predicted (simulated) response values (Kéry and Royle 2016). We assessed support for the effect of each

covariate on availability or perceptibility using the 95% Bayesian credible interval (BCI) for the estimate of its beta coefficient; we considered that a relationship was supported when the 95% BCI did not contain zero.

Results

Point count surveys and area searches

Across the two survey methods, we observed 57 bird species at Petroglyph NM; no federally listed Threatened or Endangered species were detected. Over six survey mornings, four surveyors conducted 196 point counts at 194 count stations (two stations were accidentally surveyed twice). These resulted in 1109 detections, of which 1009 could be identified to species. In total, 53 unique species were identified during point count surveys (Table 1), of which the most abundant were Horned Lark (*Eremophila alpestris*; $N = 138$), Mourning Dove (*Zenaida macroura*; $N = 124$), and House Finch (*Haemorhous mexicanus*; $N = 76$). Maps of detections of species are provided in Appendix A.

We additionally conducted 15 area searches across six mornings at seven sites (Table 2). These included the six originally proposed trail crossings (Site: number of surveys = Rinconada Canyon: 3, Mesa Prieta: 3, Chamiza Elementary: 2, Visitor Center: 3, Piedras Marcadas Canyon-North: 1, Piedras Marcadas Canyon-South: 2) as well as one additional survey around the Northern Geologic Window, which field visits suggested might also contain suitable raptor nesting habitat. Overall, five surveyors spent ~11.5 hours and covered a distance of roughly 19.4 km (Table 2). We detected 44 species during area searches in 169 'detections' (i.e., observations of a species at a site; Table 1), of which 159 could be identified to species. These surveys identified four species not detected during the point count surveys (Sharp-shinned Hawk [*Accipiter striatus*], Ruby-crowned Kinglet [*Corthylio calendula*], Bewick's Wren [*Thryomanes bewickii*], and Brewer's Blackbird [*Euphagus cyanocephalus*]). We did not observe evidence of raptor nesting behavior at or around the proposed rocky escarpment crossings, though reproductive behavior of one species (Cooper's Hawk, *A. cooperi*) was observed in a suburban neighborhood near the monument boundary.

Table 1. List of bird species detected at Petroglyph NM during point count surveys (N = 196) and area searches (N = 15). Species are listed in taxonomic order, and bird taxonomy follows the American Ornithological Society's checklist. The table lists the total number of detections, the total number of count stations (or area searches) during which a species was detected, and the total number of individuals detected (accounting for the detection of flocks of birds during point count surveys).

		Point Count Surveys			Area Searches		
Common Name	**Scientific Name**	**Detections**	**Count Stations**	**Individuals**	**Detections**	**Areas**	**Individuals**
Scaled Quail [1]	*Callipepla squamata*	71	51	72	3	2	4
Gambel's Quail	*Callipepla gambelii*	15	12	15	4	2	9
Rock Pigeon	*Columba livia*	14	12	73	1	1	2
Eurasian Collared-Dove	*Streptopelia decaocto*	8	5	9	4	2	7
White-winged Dove	*Zenaida asiatica*	4	3	9	3	3	3
Mourning Dove [1]	*Zenaida macroura*	124	82	135	11	6	38
Greater Roadrunner	*Geococcyx californianus*	1	1	1	2	2	2
Black-chinned Hummingbird	*Archilochus alexandri*	18	16	18	8	6	15
Broad-tailed Hummingbird [2]	*Selasphorus platycercus*	1	1	1	0	0	0
Turkey Vulture	*Cathartes aura*	13	11	35	5	4	12
Golden Eagle [2]	*Aquila chrysaetos*	1	1	1	0	0	0
Northern Harrier [2]	*Circus hudsonius*	1	1	1	0	0	0
Sharp-shinned Hawk [2]	*Accipiter striatus*	0	0	0	1	1	1
Cooper's Hawk [2]	*Accipiter cooperii*	5	5	5	5	3	5
Swainson's Hawk	*Buteo swainsoni*	8	8	8	3	3	4
Red-tailed Hawk	*Buteo jamaicensis*	3	3	3	3	2	3
Northern Flicker [2]	*Colaptes auratus*	1	1	1	0	0	0
American Kestrel	*Falco sparverius*	8	8	8	0	0	0
Ash-throated Flycatcher	*Myiarchus cinerascens*	1	1	1	0	0	0
Cassin's Kingbird	*Tyrannus vociferans*	7	6	7	3	3	6
Western Kingbird	*Tyrannus verticalis*	27	20	31	6	5	16

[1] Species with modeled breeding densities, also shown in bold text.

[2] Indicates species detected as likely passage migrants within the monument.

Table 1 (continued). List of bird species detected at Petroglyph NM during point count surveys (N = 196) and area searches (N = 15). Species are listed in taxonomic order, and bird taxonomy follows the American Ornithological Society's checklist. The table lists the total number of detections, the total number of count stations (or area searches) during which a species was detected, and the total number of individuals detected (accounting for the detection of flocks of birds during point count surveys).

		Point Count Surveys			Area Searches		
Common Name	**Scientific Name**	**Detections**	**Count Stations**	**Individuals**	**Detections**	**Areas**	**Individuals**
Gray Flycatcher [2]	*Empidonax wrightii*	4	4	4	1	1	1
Say's Phoebe [1]	*Sayornis saya*	45	39	45	7	5	13
Loggerhead Shrike	*Lanius ludovicianus*	5	4	5	1	1	1
Woodhouse's Scrub-Jay [2]	*Aphelocoma woodhouseii*	1	1	3	2	2	2
Common Raven	*Corvus corax*	4	3	4	3	3	3
Mountain Chickadee [2]	*Poecile gambeli*	1	1	1	0	0	0
Horned Lark [1]	*Eremophila alpestris*	138	69	139	1	1	2
Violet-green Swallow [2]	*Tachycineta thalassina*	34	16	178	1	1	16
Northern Rough-winged Swallow [2]	*Stelgidopteryx serripennis*	1	1	1	0	0	0
Barn Swallow [2]	*Hirundo rustica*	1	1	1	2	2	2
Cliff Swallow [2]	*Petrochelidon pyrrhonota*	6	5	6	1	1	6
Ruby-crowned Kinglet [2]	*Corthylio calendula*	0	0	0	1	1	1
Blue-gray Gnatcatcher [2]	*Polioptila caerulea*	8	7	8	6	5	7
Rock Wren [1]	*Salpinctes obsoletus*	67	49	67	8	5	18
Canyon Wren	*Catherpes mexicanus*	4	4	4	1	1	2
Bewick's Wren [2]	*Thryomanes bewickii*	0	0	0	1	1	1
Curve-billed Thrasher	*Toxostoma curvirostre*	3	3	3	3	1	3
Crissal Thrasher	*Toxostoma crissale*	5	5	5	3	2	4
Sage Thrasher [2]	*Oreoscoptes montanus*	3	3	3	1	1	1
Northern Mockingbird	*Mimus polyglottos*	12	9	12	2	2	4
American Robin [2]	*Turdus migratorius*	3	2	3	3	2	3

[1] Species with modeled breeding densities, also shown in bold text.

[2] Indicates species detected as likely passage migrants within the monument.

Table 1 (continued). List of bird species detected at Petroglyph NM during point count surveys (N = 196) and area searches (N = 15). Species are listed in taxonomic order, and bird taxonomy follows the American Ornithological Society's checklist. The table lists the total number of detections, the total number of count stations (or area searches) during which a species was detected, and the total number of individuals detected (accounting for the detection of flocks of birds during point count surveys).

		Point Count Surveys			Area Searches		
Common Name	**Scientific Name**	**Detections**	**Count Stations**	**Individuals**	**Detections**	**Areas**	**Individuals**
House Sparrow	*Passer domesticus*	7	3	7	2	2	2
House Finch [1]	*Haemorhous mexicanus*	76	47	90	11	5	31
Lesser Goldfinch	*Spinus psaltria*	6	4	6	3	2	3
Cassin's Sparrow	*Peucaea cassinii*	1	1	1	0	0	0
Black-throated Sparrow [1]	*Amphispiza bilineata*	50	34	51	10	5	33
Lark Sparrow [2]	*Chondestes grammacus*	5	4	7	2	2	5
Chipping Sparrow [2]	*Spizella passerina*	2	2	7	0	0	0
Brewer's Sparrow [2]	*Spizella breweri*	51	30	53	10	5	53
White-crowned Sparrow [2]	*Zonotrichia leucophrys*	1	1	1	2	1	11
Vesper Sparrow [2]	*Pooecetes gramineus*	16	12	17	2	2	3
Green-tailed Towhee [2]	*Pipilo chlorurus*	4	4	4	6	3	8
Chihuahuan Meadowlark [1]	*Sturnella lilianae*	70	52	70	0	0	0
Western Meadowlark [1]	*Sturnella neglecta*	43	27	43	0	0	0
Brewer's Blackbird [2]	*Euphagus cyanocephalus*	0	0	0	1	1	15
Lucy's Warbler [2]	*Leiothlypis luciae*	1	1	1	0	0	0

[1] Species with modeled breeding densities, also shown in bold text.

[2] Indicates species detected as likely passage migrants within the monument.

Table 2. List of area searches conducted at proposed trail crossing locations within Petroglyph NM. Checklist number refers to the unique checklist identifier from the eBird citizen science database, and distance and duration information are extracted from each checklist.

Survey ID	Location	Checklist Number	Date	Start Time	Surveyors	Distance (km)	Duration (min)	Surveyor Name
1	Rinconada Canyon	S107472439	19-Apr-22	10:56	3	1.26	28	Harrison Jones, Jake Bourque, Skyler Mark
2	Mesa Prieta	S107489026	19-Apr-22	11:31	2	3.28	85	Emma Cox, Max Leibowitz
3	Chamiza Elementary	S107547850	20-Apr-22	10:52	3	1.06	47	Harrison Jones, Jake Bourque, Skyler Mark
4	Rinconada Canyon	S107562819	20-Apr-22	11:41	2	2.35	60	Emma Cox, Max Leibowitz
5	Piedras Marcadas Canyon-North	S107650063	21-Apr-22	10:02	2	0.63	19	Harrison Jones, Skyler Mark
6	Piedras Marcadas Canyon-South	S108100075	21-Apr-22	11:49	1	0.24	29	Emma Cox
7	Visitor Center	S107699744	21-Apr-22	10:06	1	1.21	45	Jake Bourque
8	Chamiza Elementary	S107705684	22-Apr-22	10:57	3	0.79	23	Harrison Jones, Jake Bourque, Max Leibowitz
9	Mesa Prieta	S108099616	22-Apr-22	11:21	2	1.48	46	Emma Cox, Skyler Mark
10	Northern Geologic Window	S108099439	22-Apr-22	7:30	1	0.80	50	Emma Cox
11	Piedras Marcadas Canyon-South	S107803017	23-Apr-22	10:59	2	0.84	25	Harrison Jones, Max Leibowitz
12	Mesa Prieta	S107804393	23-Apr-22	10:07	1	2.09	89	Skyler Mark
13	Rinconada Canyon	S107811282	23-Apr-22	11:00	1	0.80	45	Jake Bourque
14	Visitor Center	S108427504	23-Apr-22	6:30	1	1.61	45	Emma Cox
15	Visitor Center	S107904483	24-Apr-22	8:29	1	0.92	63	Jake Bourque

Estimated breeding densities and detectability

We modeled the breeding densities of nine common bird species at the monument; all models converged based on R-hat values of < 1.2 and a visual inspection of the Markov chain Monte Carlo (MCMC) chains. Breeding densities were generally low (0.19 ± 0.14 birds ha^{-1}, mean ± standard deviation of species estimates; Table 3), with House Finch (0.43 birds ha^{-1}), Horned Lark (0.40 birds ha^{-1}), and Black-throated Sparrow (*Amphispiza bilineata*; 0.30 birds ha^{-1}) showing the highest densities after adjusting for detectability. On average, species availability (the probability that a species was present and singing during a count) was estimated at middling values (mean p_a = 0.51; Table 4), though this value was variable across species (range = 0.28–0.67). By contrast, species perceptibility was generally low (mean p_d = 0.39). All Bayesian p-values were between 0.2 and 0.8 (Table 4), and 16 of 18 values (88%) were between 0.4 and 0.6, indicating a high goodness-of-fit for the removal and distance sampling sub-models; the lack-of-fit values were also ≈ 1 in all cases. We found few supported effects of covariates on species availability and perceptibility (Table 5), and effect sizes were generally < 1. There was a trend of increasing availability with minute-of-day (mean effect size across species = 0.14), and this relationship was supported for Black-throated Sparrow and Rock Wren. The percentage of cloud cover had an overall near-zero effect (mean effect size = −0.08), but this belies the highly variable responses across species. Chihuahuan (*Sturnella lilianae*) and Western (*S. neglecta*) Meadowlarks and Scaled Quail (*Callipepla squamata*) all showed supported decreases in availability with increasing cloud cover, while Mourning Dove showed the opposite trend. Availability increased on average with increasing wind speed (mean effect size = 0.32), and this relationship was supported for House Finch, Say's Phoebe (*Sayornis saya*), and Western Meadowlark; Chihuahuan Meadowlark showed the opposite supported trend. Finally, we found no supported effects of environmental noise on perceptibility, and the effect size for this covariate was on average quite small (0.05). Additional details about the parameterization of the distance sampling sub-model are provided in Table 6.

Table 3. Estimated breeding bird densities at Petroglyph NM. Species are listed in alphabetical order. Mean breeding densities (birds ha^{-1}) and the 95% Bayesian credible interval are listed. Estimated densities from a 2002 analysis (Johnson et al. 2007), along with the habitat(s) from which they are derived, are reproduced here for comparison.

Species	Density	2.50%	97.50%	2002 Density	2.50%	97.50%	Habitat
Black-throated Sparrow	0.303	0.172	0.684	–	–	–	–
Chihuahuan Meadowlark	0.080	0.059	0.118	0.18	0.13	0.25	Grassland and shrubland
House Finch	0.430	0.213	1.126	–	–	–	–
Horned Lark	0.401	0.297	0.562	0.71	0.43	1.17	Grassland and shrubland
Mourning Dove	0.202	0.146	0.292	0.55	0.35	0.86	All
Rock Wren	0.085	0.068	0.116	0.16	0.10	0.27	All
Say's Phoebe	0.072	0.059	0.096	–	–	–	–
Scaled Quail	0.065	0.048	0.092	–	–	–	–
Western Meadowlark	0.083	0.046	0.194	–	–	–	–

Table 4. Mean estimates of availability and perceptibility during point counts and sub-model goodness-of-fit statistics. Species are listed in alphabetical order. The median probability of availability for detection (p_a) and probability of perceptibility by the observer (p_d) are given along with the 95% BCI (2.5th and 97.5th centiles of the joint posterior distribution). The Bayesian P-value (Bp) and lack-of-fit (LOF) values for each sub-model, measures of model goodness of fit, are also tabulated.

Species	p_a	**2.50%**	**97.50%**	p_d	**2.50%**	**97.50%**	**Bp p_a**	**Bp p_d**	**LOF p_a**	**LOF p_d**
Black-throated Sparrow	0.328	0.137	0.587	0.407	0.276	0.680	0.580	0.608	1.025	1.036
Chihuahuan Meadowlark	0.537	0.356	0.746	0.483	0.350	0.669	0.549	0.601	1.026	1.014
House Finch	0.337	0.207	0.525	0.298	0.215	0.434	0.490	0.480	1.000	1.002
Horned Lark	0.671	0.509	0.814	0.415	0.331	0.530	0.498	0.543	1.004	1.017
Mourning Dove	0.636	0.507	0.750	0.345	0.265	0.449	0.425	0.489	0.910	0.806
Rock Wren	0.594	0.435	0.779	0.466	0.342	0.648	0.544	0.497	1.012	1.005
Say's Phoebe	0.605	0.420	0.782	0.372	0.270	0.545	0.571	0.655	1.020	1.042
Scaled Quail	0.605	0.412	0.818	0.421	0.305	0.577	0.475	0.561	1.014	0.994
Western Meadowlark	0.284	0.142	0.455	0.324	0.215	0.469	0.522	0.528	1.016	1.017

Table 5. Effects of covariates on detectability of birds on point count surveys. Species are listed in alphabetical order. The median, standard deviation, and 95% BCI are given for the joint posterior distribution for each species.

	Minute-of-day			Cloud Cover			Wind Speed			Noise		
Species	**Mean**	**2.50%**	**97.50%**	**Mean**	**2.50%**	**97.50%**	**Mean**	**2.50%**	**97.50%**	**Mean**	**2.50%**	**97.50%**
Black-throated Sparrow	**0.560 ***	0.110	1.080	0.048	−0.446	0.525	−0.194	−0.811	0.496	−0.076	−0.376	0.210
Chihuahuan Meadowlark	0.178	−0.330	0.671	**−0.535 ***	−0.873	−0.180	**−0.469 ***	−0.892	−0.024	0.182	−0.204	0.730
House Finch	0.174	−0.293	0.697	0.418	−1.972	1.398	**0.729 ***	0.219	1.292	0.054	−0.090	0.284
Horned Lark	−0.187	−0.658	0.313	−0.199	−0.469	0.098	0.020	−0.408	0.507	0.039	−0.162	0.300
Mourning Dove	0.222	−0.123	0.564	**0.664 ***	0.106	1.242	0.098	−0.259	0.460	−0.087	−0.194	0.035
Rock Wren	**0.597 ***	0.112	1.084	−0.327	−0.647	0.029	0.404	−0.084	0.913	−0.083	−0.303	0.122
Say’s Phoebe	−0.142	−0.672	0.432	0.262	−0.486	0.895	**1.008 ***	0.433	1.623	0.267	−0.001	0.823
Scaled Quail	0.438	−0.261	0.987	**−0.453 ***	−0.824	−0.069	0.063	−0.432	0.630	−0.165	−0.407	0.027
Western Meadowlark	−0.610	−1.330	0.079	**−0.607 ***	−1.059	−0.141	**1.195 ***	0.338	2.293	0.327	−0.111	0.919

* Bolded beta estimate values indicate supported covariate effects.

Table 6. Maximum detection distances and data truncation percentages for models of breeding season density at Petroglyph NM. The initial truncation percentage represents the percentage of the most distant observations initially omitted from the perceptibility sub-model, while the actual truncation distance represents the total percentage truncated to ensure that detection interval and detection-distance bin were statistically independent. A conservative alpha value (0.10) was used to test for this statistical independence (by ANOVA) except when small sample size combined with a conservative alpha led to excessive truncation of the tail of the detection distance distribution. The maximum detection distance is the farthest detection distance after truncation of the observation distances. The effective survey area at each point count station was estimated as the area of the circle defined by the maximum detection distance and centered on the station.

Species	Initial truncation percentage	Alpha value	Truncation percentage	Maximum detection distance (m)	Effective survey area (ha)
Black-throated Sparrow	95	0.05	4.00	156	7.65
Chihuahuan Meadowlark	90	0.10	10.00	236	17.50
House Finch	90	0.10	9.46	194	11.82
Horned Lark	90	0.05	10.14	145	6.61
Mourning Dove	90	0.10	13.01	216	14.66
Rock Wren	90	0.10	9.09	210	13.85
Say’s Phoebe	90	0.05	8.89	218	14.93
Scaled Quail	95	0.05	4.23	267	22.40
Western Meadowlark	95	0.05	4.76	316	31.37

Discussion

In this study, we conducted what is, to our knowledge, the first inventory of birds across the full extent of Petroglyph NM. We identified 57 species, including both resident breeders as well as spring passage migrants using the monument as stopover habitat. Like Johnson et al. (2007), we found that bird species were spatially segregated by habitat (Appendix A), with distinct species associated with desert grassland (Western and Chihuahuan Meadowlark, Scaled Quail, Horned Lark, Cassin's Sparrow [*Peucaea cassinii*]), rocky outcroppings (including the escarpment, volcanoes, and geologic windows; Rock Wren, Canyon Wren, Say's Phoebe), and sandscrub (Gambel's Quail [*C. gambelii*], Crissal [*Toxostoma crissale*] and Curve-billed Thrasher [*T. curvirostre*], Black-throated Sparrow, Black-chinned Hummingbird [*Archilochus alexandri*]). We detected three non-native bird species in the monument (House Sparrow, Rock Pigeon [*Columba livia*], Eurasian Collared-Dove), all of which are human commensal species that were only encountered where the monument borders suburban neighborhoods; other native species (House Finch, Gambel's Quail, White-winged Dove [*Zenaida asiatica*]) were also very abundant near the urban-wildlands interface, and watered suburban neighborhoods may provide higher quality habitat for these species than those within the monument. In contrast to these species, the grassland bird species described above were never encountered near the urban-wildlands interface and were most abundant on the western side of the monument, away from heavily visited areas. Many North American grassland birds are known to be area sensitive (i.e., avoiding small habitat patches; Herkert 1994, Johnson and Igl 2001), and to avoid nesting near grassland edges (Renfrew et al. 2005, Sliwinski and Koper 2012), though it is unknown if this remains true in arid Southwestern grasslands.

We additionally observed at least 26 species of passage migrants during the inventory (Table 1), which we defined in this study as species with no eBird detections at the monument in June. These were primarily species of open shrubland (e.g., Sage Thrasher [*Oreoscoptes montanus*], Vesper Sparrow [*Pooecetes gramineus*], Green-tailed Towhee [*Pipilo chlorurus*]) and pinyon-juniper (e.g., Blue-gray Gnatcatcher [*Polioptila caerulea*], Gray Flycatcher [*Empidonax wrightii*], Chipping Sparrow [*Spizella passerina*]) habitats, as well as day-migrating swallows (4 spp.) and birds of prey (at least 4 spp.). While riparian zones and montane forests have historically been thought to provide the most important stopover habitat for migratory birds in the arid Southwest (Carlisle et al. 2009), there is evidence that low-elevation shrubland and grassland habitat is also important (Ruth et al. 2012), even if migrant densities are lower in this habitat. Our findings were consistent with this view, as we encountered numerous migrant species but at relatively low densities (Table 1). Previous research suggests that many open-habitat migrant birds use stopover habitat that is similar to their breeding habitat (Igl and Ballard 1999, Petit 2000, Suomala et al. 2010), and many grassland, shrubland, and juniper-savanna associated species may therefore preferentially select for habitat in the monument. While passage migrants were encountered throughout the monument (Figure 3), small stands of junipers anecdotally appeared to be important stop-over habitat for many pinyon-juniper woodland species. We observed many 'non-migratory' pinyon-juniper species (Bewick's Wren, Mountain Chickadee [*Poecile gambeli*], Woodhouse's Scrub-Jay [*Aphelocoma woodhouseii*]) as (presumably) passage migrants within the monument, suggesting that local migratory or dispersal movements are occurring in spring. The small stands of desert willow (*Chilopsis linearis*) in the

southwestern region of the monument also notably supported higher migrant densities. Hardy et al. (2004) also found that xeric riparian scrub was important migrant habitat in the Sonoran Desert. However, the large areas covered by grasslands and shrublands within the monument and the surrounding landscape may mean that, despite low migrant densities, these represent the most important stopover habitat in aggregate (DeLong et al. 2005).

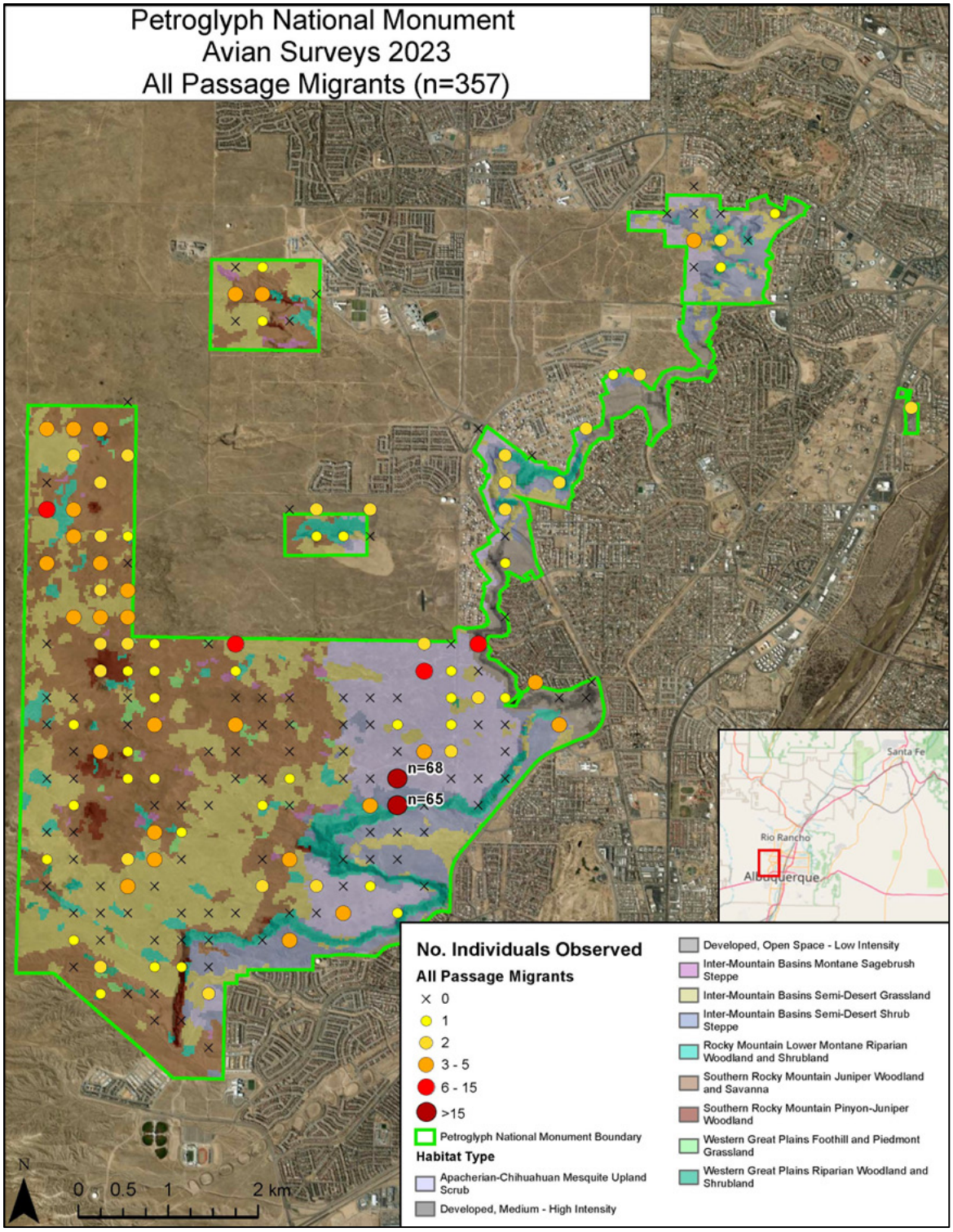


Figure 3. Plotted detections of all passage migrant species during point count surveys in Petroglyph NM. We considered species passage migrants if there were no eBird detections at the monument in May or June. Habitat data provided by NatureServe in collaboration with the International Union for Conservation of Nature (NatureServe 2014).

We estimated monument-wide breeding densities for nine bird species after accounting for imperfect detection, observing generally low densities (< 0.5 birds ha^{-1}). These densities are in line with those reported for similar grassland-shrubland communities in New Mexican Chihuahuan desert habitat (Naranjo and Raitt 1993), but lower than those observed in Colorado short-grass prairie (Augustine and Derner 2015) or in Colorado Plateau grassland-shrubland (Jones et al. *in press*). Notably, the estimated densities were uniformly lower than those estimated in 2002 by Johnson et al. (2007; reproduced in Table 3). However, we caution that these density estimates cannot be compared directly because the 2002 estimates are, in part, habitat-specific rather than monument-wide (we expect that densities should be higher when considering only high-quality habitat), and because those estimates were based on a smaller number of survey locations ($N = 49$ count stations in 2002, 194 count stations in 2022). The reduced spatial coverage, particularly in areas near the urban-wildlands interface (Johnson et al., 2007), may therefore increase the estimated densities. Similarly, the densities of grassland birds can fluctuate extensively from year to year based on climate (George et al. 1992) and are typically negatively impacted by drought (Conrey et al. 2016, Cady et al. 2019). In particular, drought negatively influences the volume and richness of grassland plants and associated arthropod communities (Peterson et al. 2021), a factor which has been tied to breeding bird density in arid shrublands (Mills et al. 1991). April 2022 was notably dry in Albuquerque, with no precipitation recorded and a Palmer Drought Severity Index of −4.27 (the third lowest recorded for the city; NOAA 2023), so differences in estimated density may reflect annual variation resulting from climate rather than long-term declines. Nevertheless, the lower densities over a twenty-year period are concerning and worthy of further study. In addition to continued fragmentation and isolation of habitat within the monument due to suburban encroachment, we also noted the likely extirpation of Gunnison's prairie-dog (*Cynomys gunnisoni*) from the monument. These rodents play a keystone role in maintaining grassland habitat by preventing shrubby encroachment (Ceballos et al. 2010), and some grassland specialist birds (e.g., Burrowing Owl, *Athene cunicularia*) are strongly tied to their colonies (Tipton et al. 2009). Burrowing Owl appears to be extirpated as a breeding species from the monument, despite occasional sightings of dispersing individuals. The widening of Atrisco Vista Boulevard to a four lane road, and planned future expansion of Double Eagle II airport are likely to increase the isolation of habitat on the monument by preventing dispersal from grassland habitats to the west of the monument.

Over the course of fifteen area searches and 196 point counts, we did not observe raptor nests or nesting behavior on the rocky escarpment. Because area searches are not a replacement for dedicated nest searching, and we spent a relatively limited number of hours in the field, we cannot definitively preclude the possibility that the escarpment serves as nesting habitat for some species. Furthermore, while many raptors re-use nest sites, the absence of nests in 2022 does not indicate the impossibility of future nesting attempts. Nevertheless, we find it unlikely that the rocky escarpment in Petroglyph NM, and the specific trail crossing points proposed in the Visitor Use Management Plan, represent important raptor nesting habitat. For one, the adjacent suburban neighborhoods and nearby Rio Grande riparian corridor provide numerous trees which act as alternative nest locations. We observed many tree-nesting birds of prey, especially Cooper's Hawk, displaying and collecting nesting materials in suburban neighborhoods, and many open-habitat *Buteo* hawks are thought to prefer tree nests (Smith and Murphy 1982, Bosakowski et al. 1996). Second, many cliff nesting raptors (e.g.,

Golden Eagle [*Aquila chrysaetos*], Prairie Falcon, Red-tailed Hawk) prefer steep and/or high cliff faces (Smith and Murphy 1982), and the escarpment at Petroglyph NM not only lacks vertical or near-vertical cliffs (with some exceptions in the southwestern region of the monument) but tends to have shorter cliff heights. Third, much of the escarpment habitat, especially in the northeastern section of the monument, is interspersed with suburban homes and an extensive road network. Furthermore, this region sees extensive human recreational foot traffic, as it contains frequently visited area of concentrated petroglyphs (Boca Negra Canyon, Piedras Marcadas Canyon, Rinconada Canyon, and Mesa Prieta). All these factors are likely to decrease the site's attractiveness to nesting raptors. For one, many open-habitat raptor species avoid nesting in urban areas (McConnell et al. 2008, White et al. 2018, Cooper et al. 2021), and those raptors that do nest in urban areas (*Accipiter* spp.) are typically tree-nesting species. Second, raptors also often preferentially build nests far from roads (Martinez-Abrain et al. 2010), and away from increased human foot traffic (Martinez-Abrain et al. 2010, Spaul and Heath 2016, Rabdeau et al. 2021). For example, human observers as far away as 650 m flushed nesting Swainson's Hawks off of nests (Keeley and Bechard 2011); most sections of the escarpment within Petroglyph NM are easily within this distance of foot paths and human habitation.

In addition to birds of prey, we detected songbird species that preferentially used the rocky escarpment habitat, most notably Canyon Wren, Rock Wren, and Say's Phoebe. However, we do not believe that the proposed trail infrastructure will negatively impact their populations in the monument given that territory sizes for these species tend to be small (e.g., territory core areas of < 1 ha for Rock and Canyon wrens; Warning and Benedict 2015) and the total escarpment habitat available is quite large (27 kilometers in length). These are common species of low management concern, and the volcanoes and geologic windows provide additional habitat for them within the monument.

Conclusions and Management Recommendations

Petroglyph NM is home to at least three distinct bird communities, comprising arid grassland, rocky escarpment, and sandscrub, and managers should consider impacts of future infrastructure on different habitat types. While we did not detect any federally threatened or endangered species during the inventory, the monument supports a relatively large population of the newly split Chihuahuan Meadowlark, as well as at least some individuals of Cassin's Sparrow (a New Mexico Species of Greatest Conservation Need [SGCN]), both endemic to Southwestern grasslands. Other SGCN in New Mexico detected on the monument include Loggerhead Shrike (*Lanius ludovicianus*; year-round resident and confirmed breeder), Vesper Sparrow (passage migrant), and Lucy's Warbler (*Leiothlypis luciae*; passage migrant). We also documented the monument being used by a high diversity of spring passage migrants, especially open-habitat and pinyon-juniper species; the monument likely represents important stopover habitat given its location on the Rio Grande riparian corridor. The ongoing suburban encroachment to the north, east, and south of the monument is likely affecting, and will continue to affect, bird communities and densities within Petroglyph NM. Similarly, the habitat loss and disturbance associated with the Double Eagle II airport to the west of the monument further isolates habitat on the monument and decreases habitat suitability for birds. Increasing fragmentation and isolation of habitat with suburban expansion is likely to decrease habitat suitability for many species, and grassland birds in particular may avoid non-grassland edges, limiting habitat suitability within the monument; efforts to maintain natural land-cover types around the monument (e.g., on city and state land) will help to limit further negative effects of suburban expansion. Second, suburban neighborhoods provide habitat for non-native species, and can support large populations of generalist bird species, such as House Finch and White-winged Dove. These large populations may spillover into the monument near the urban-wildlands edge, outcompeting other species for resources and influencing community composition.

In light of the negative effects of human and dog foot traffic on bird breeding behavior and nest territory placement (see Introduction), efforts to control the number of informal 'social' trails and access points to the monument are likely to have positive, if local, effects on bird breeding densities. Decreasing trail density and providing a core area of habitat without human foot traffic will likely increase breeding densities of many species. Proposed changes to the trail network, particularly at the locations proposed by the Visitor Use Management Plan, are unlikely to negatively influence raptor or songbird nesting habitat on the rocky escarpment, both because higher quality nesting habitat exists along the Rio Grande riparian corridor and because the high human footprint and foot traffic along much of the escarpment reduces habitat suitability for raptors. Given ongoing changes to the landscape context of the monument and the regional climate, we urge continued monitoring of bird populations as a tool to improve management outcomes and document changes to bird communities.

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Appendix A: Maps of species detections

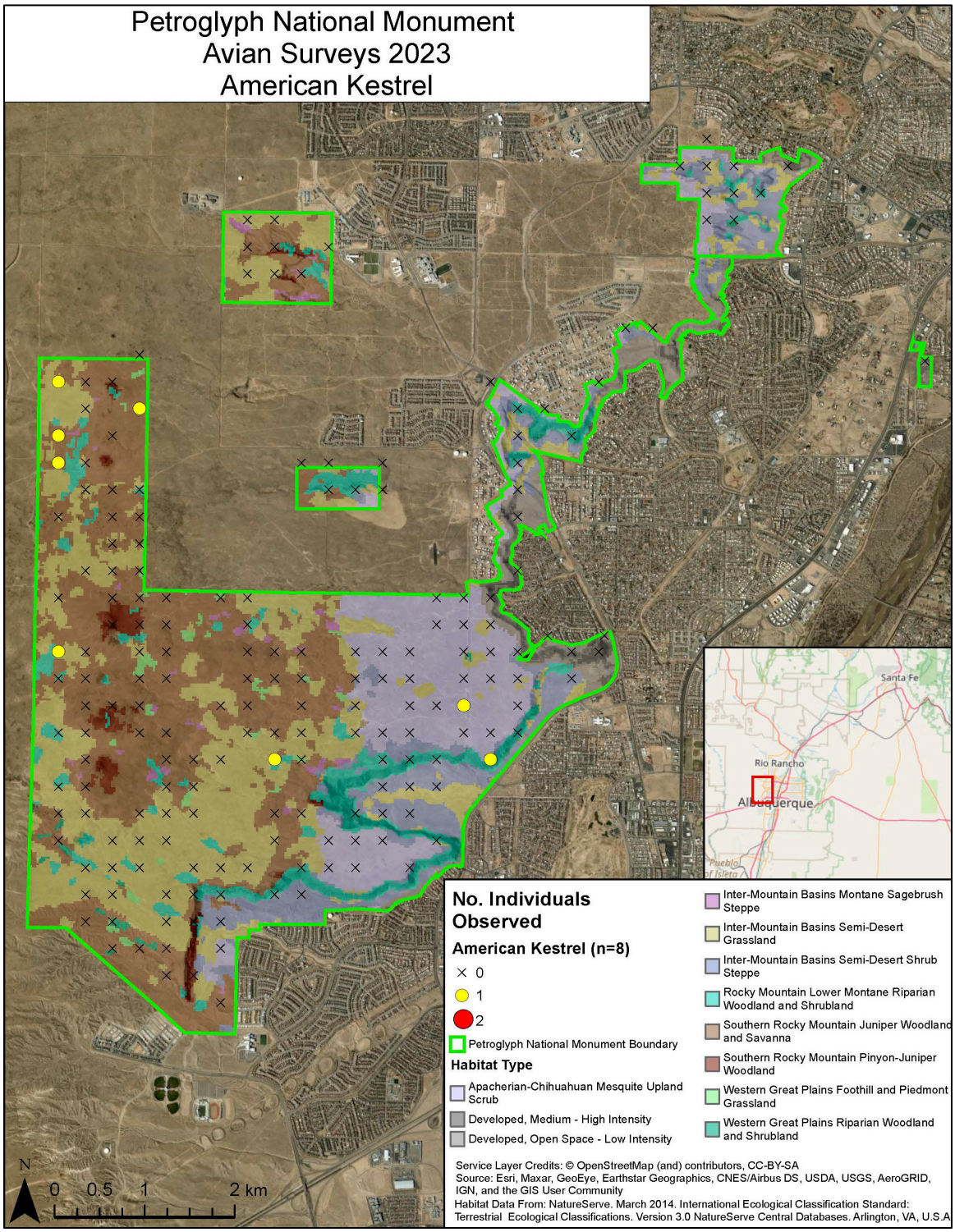


Figure 4. Plotted detections of American Kestrel (*Falco sparverius*) during point count surveys in Petroglyph NM. Habitat data provided by NatureServe in collaboration with the International Union for Conservation of Nature (NatureServe 2014).

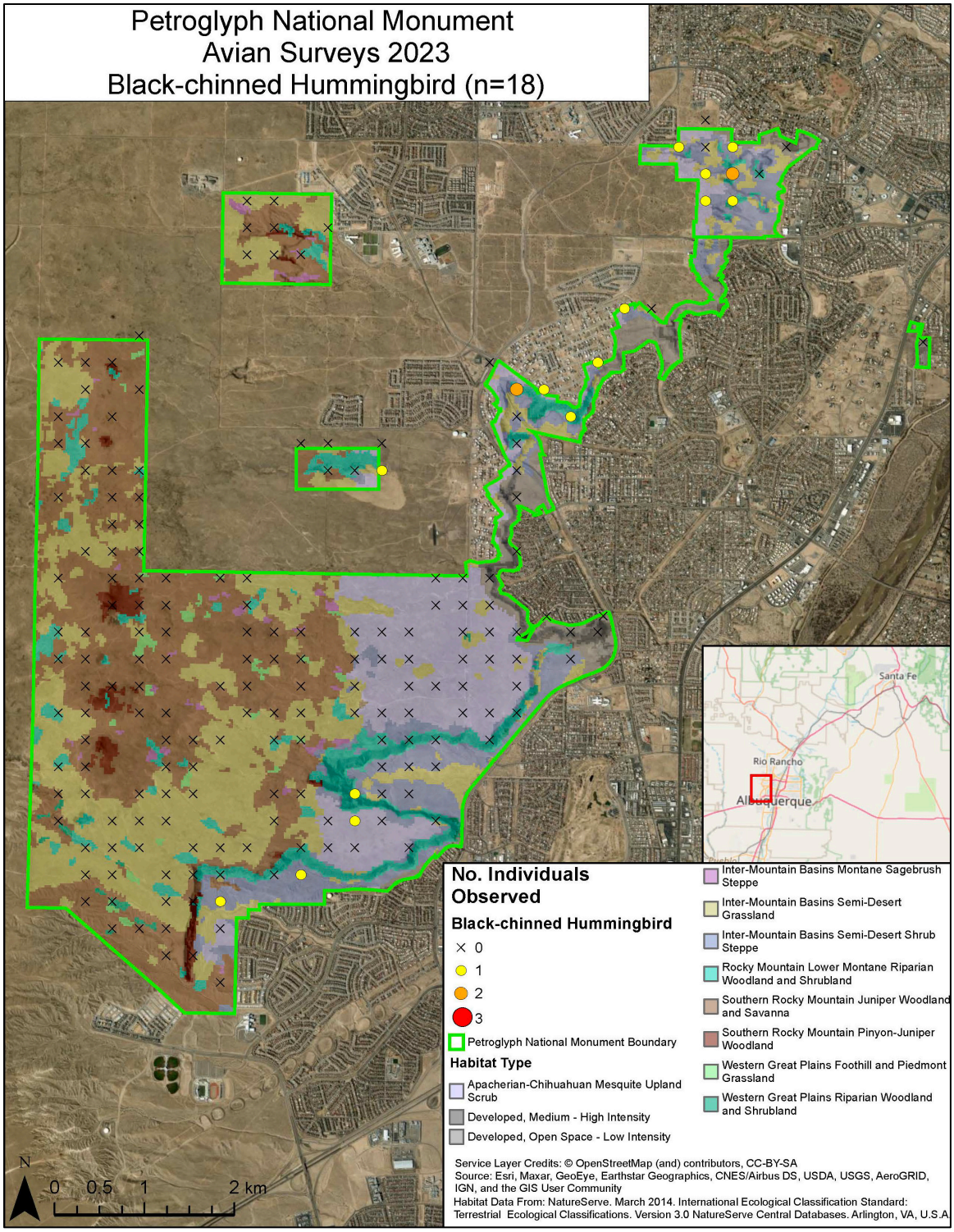


Figure 5. Plotted detections of Black-chinned Hummingbird (*Archilochus alexandri*) during point count surveys in Petroglyph NM. Habitat data provided by NatureServe in collaboration with the International Union for Conservation of Nature (NatureServe 2014).

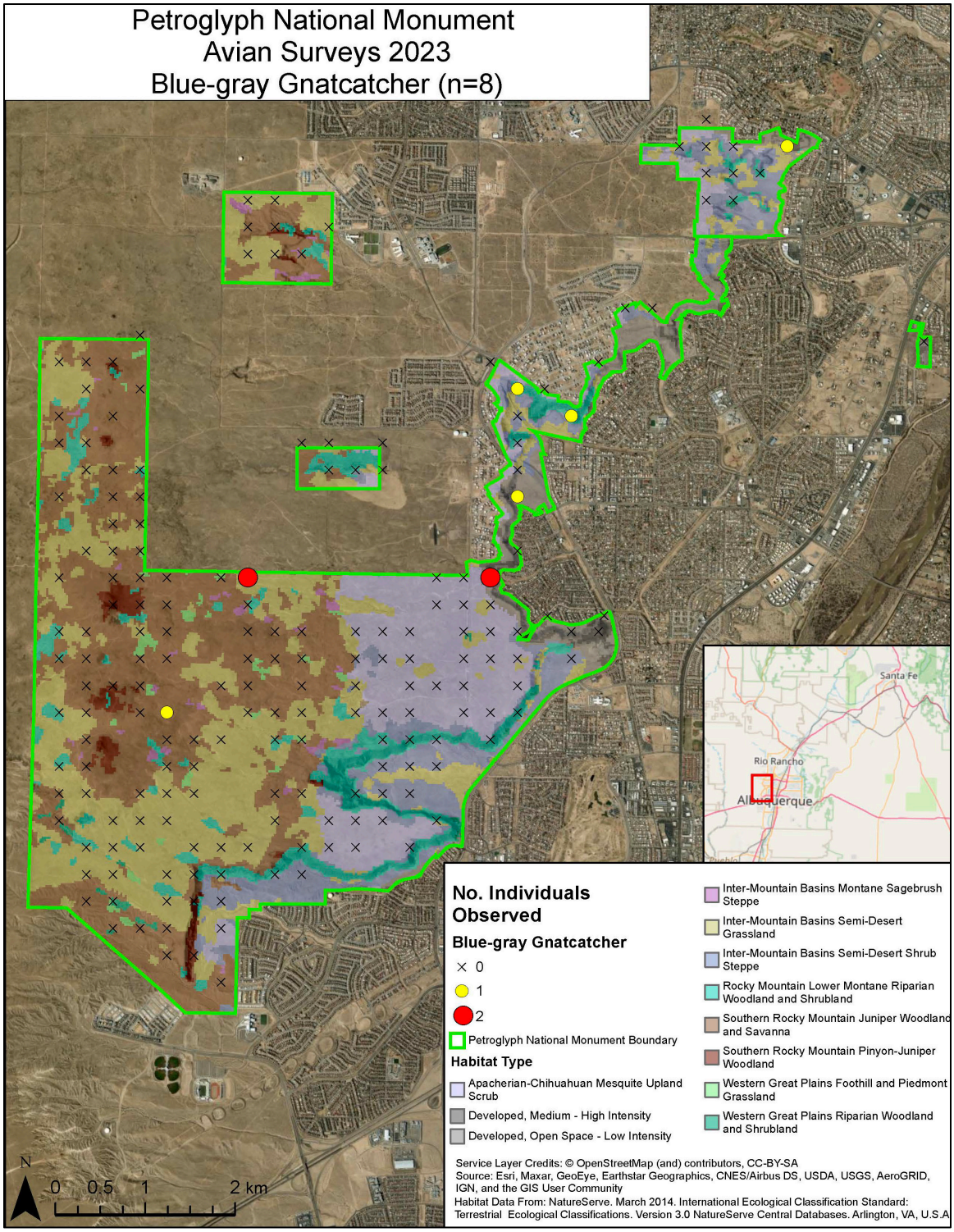


Figure 6. Plotted detections of Blue-gray Gnatcatcher (*Polioptila caerulea*) during point count surveys in Petroglyph NM. Habitat data provided by NatureServe in collaboration with the International Union for Conservation of Nature (NatureServe 2014).

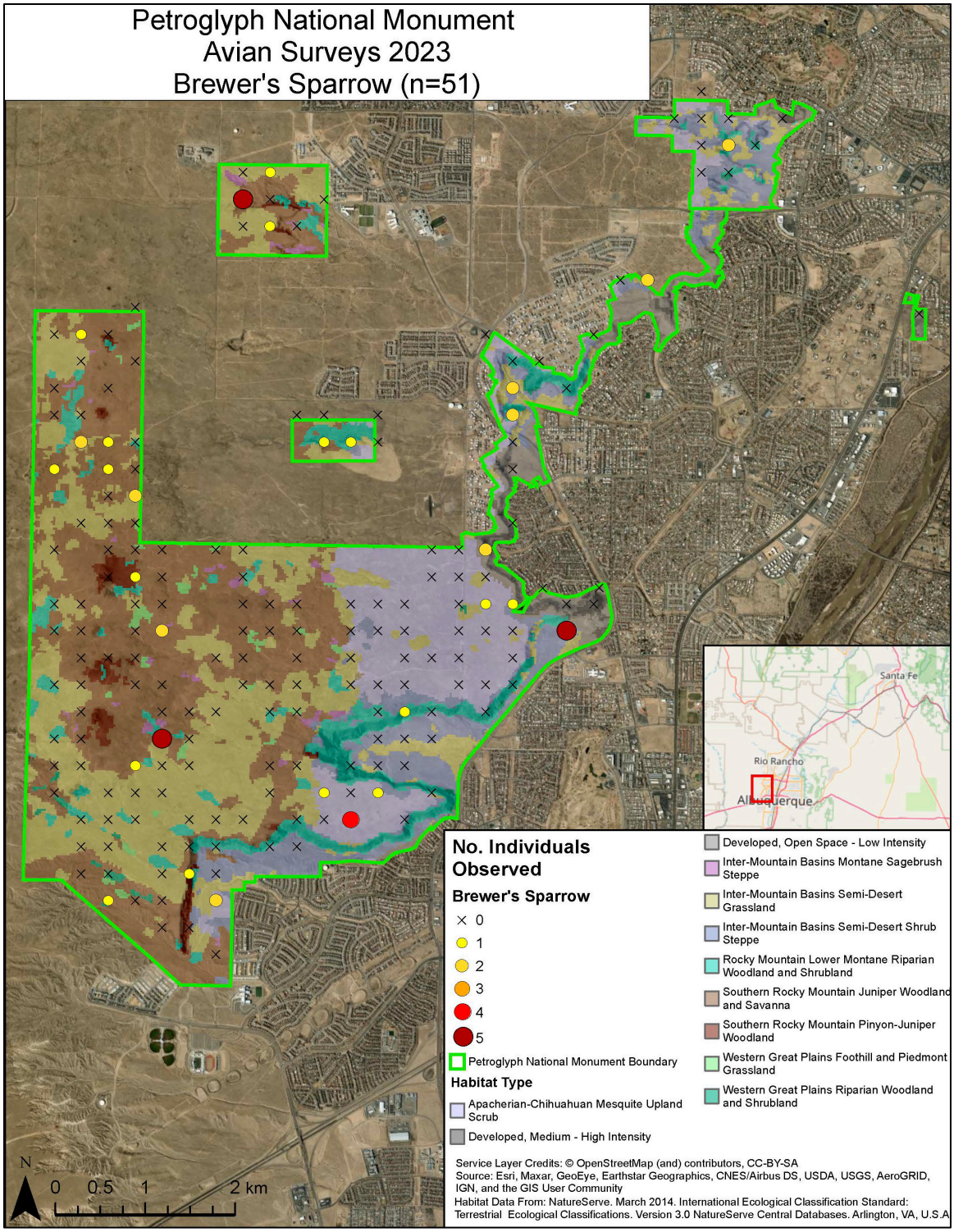


Figure 7. Plotted detections of Brewer's Sparrow (*Spizella breweri*) during point count surveys in Petroglyph NM. Habitat data provided by NatureServe in collaboration with the International Union for Conservation of Nature (NatureServe 2014).

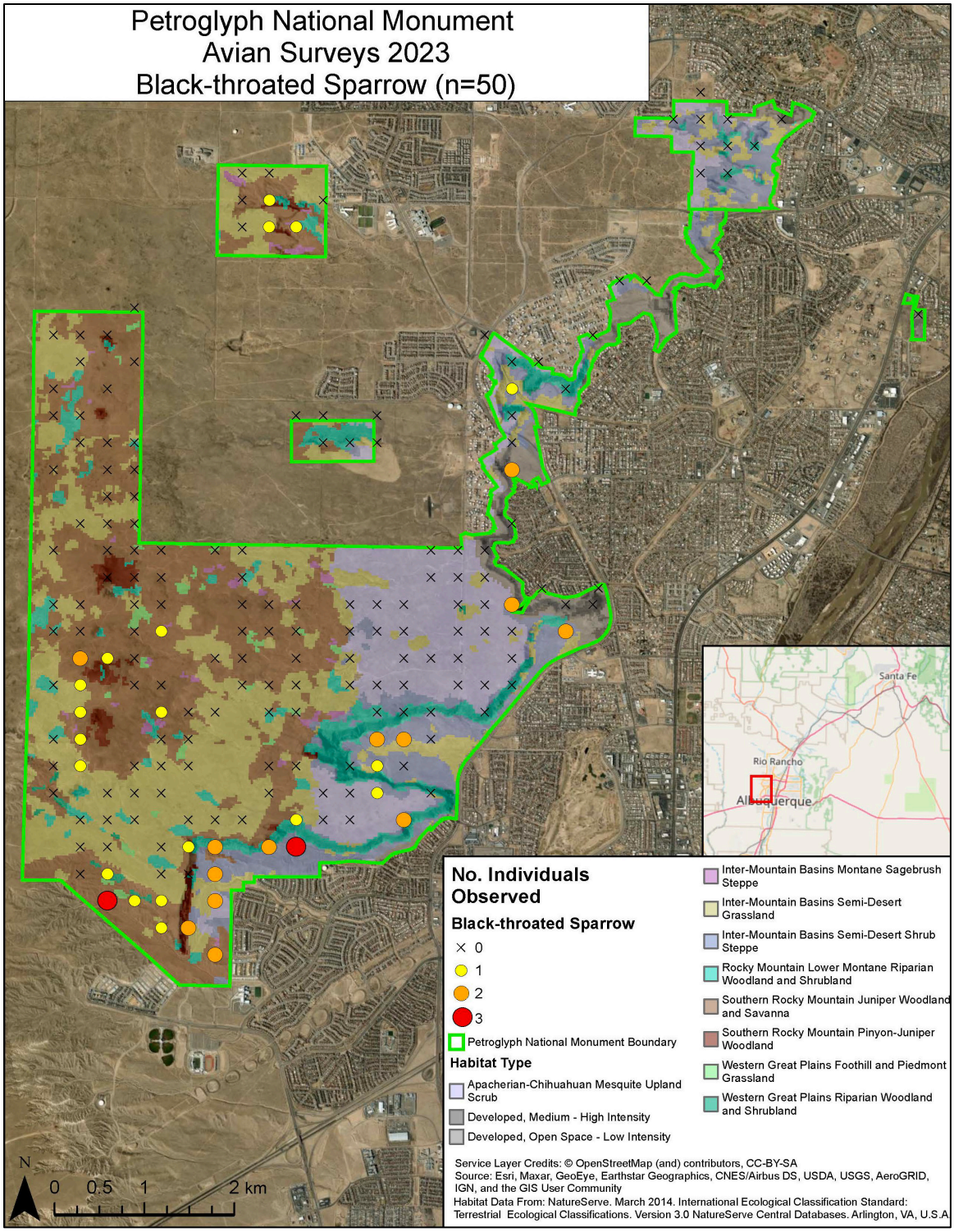


Figure 8. Plotted detections of Black-throated Sparrow (*Amphispiza bilineata*) during point count surveys in Petroglyph NM. Habitat data provided by NatureServe in collaboration with the International Union for Conservation of Nature (NatureServe 2014).

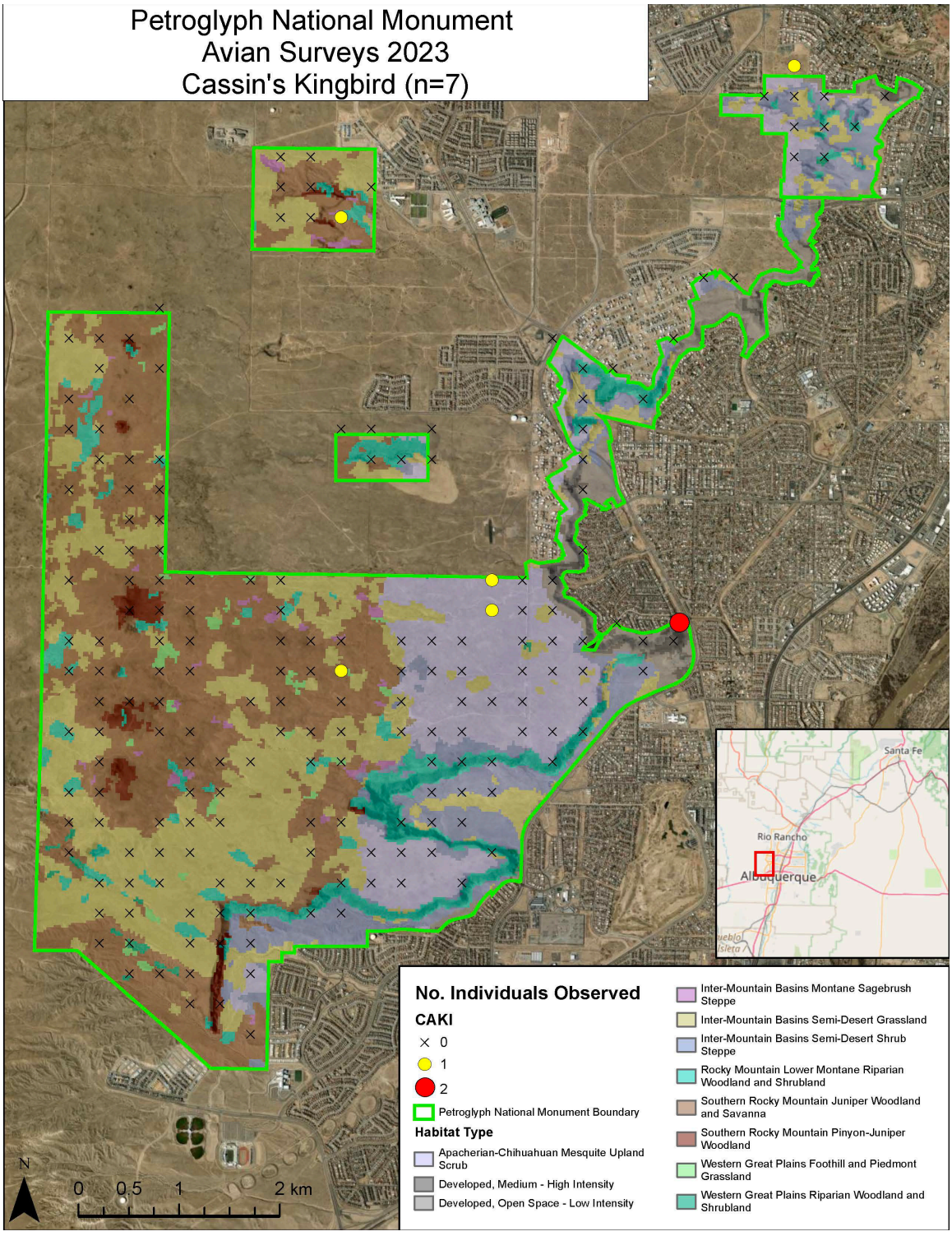


Figure 9. Plotted detections of Cassin's Kingbird (*Tyrannus vociferans*) during point count surveys in Petroglyph NM. Habitat data provided by NatureServe in collaboration with the International Union for Conservation of Nature (NatureServe 2014).

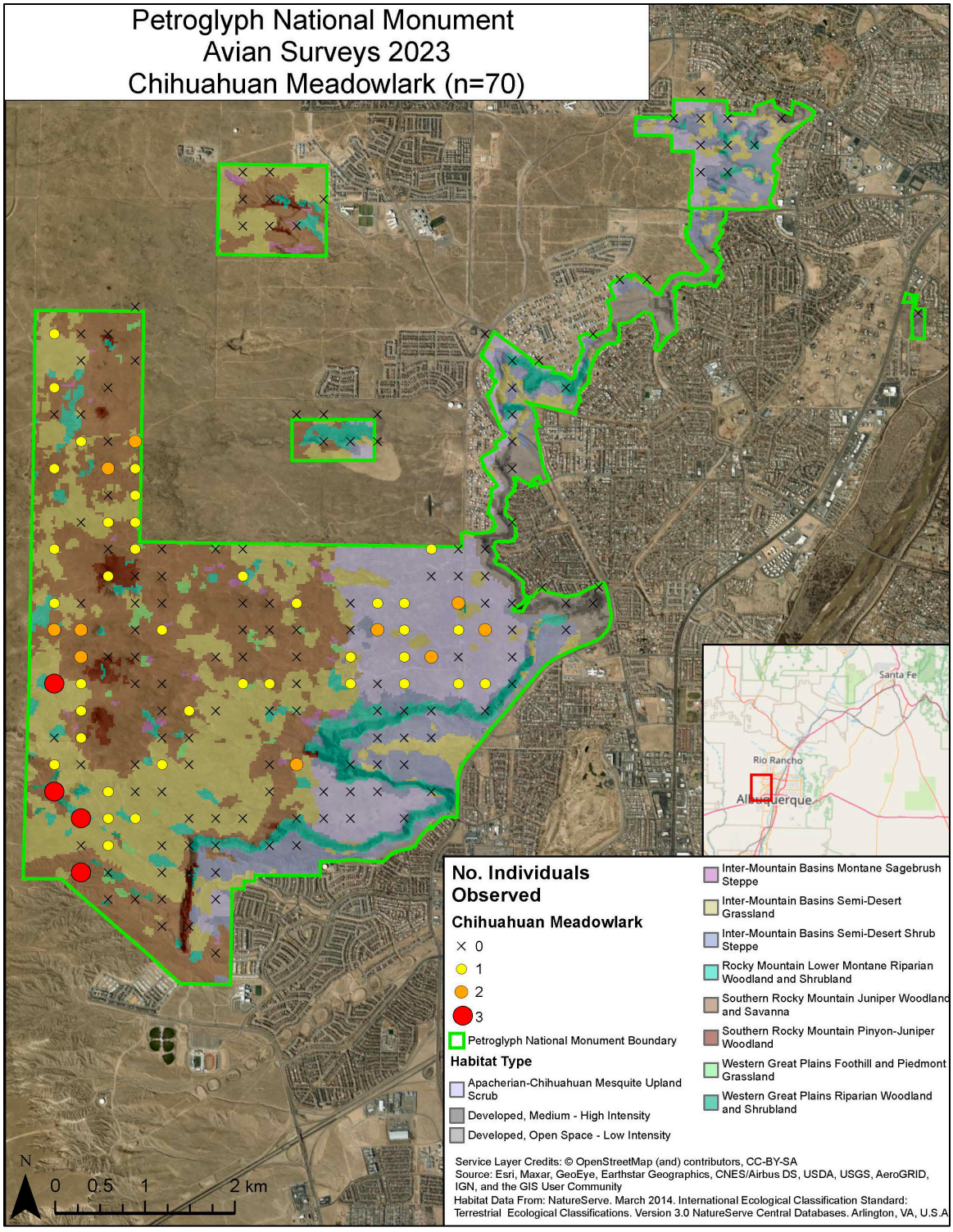


Figure 10. Plotted detections of Chihuahuan Meadowlark (*Sturnella lilianae*) during point count surveys in Petroglyph NM. Habitat data provided by NatureServe in collaboration with the International Union for Conservation of Nature (NatureServe 2014).

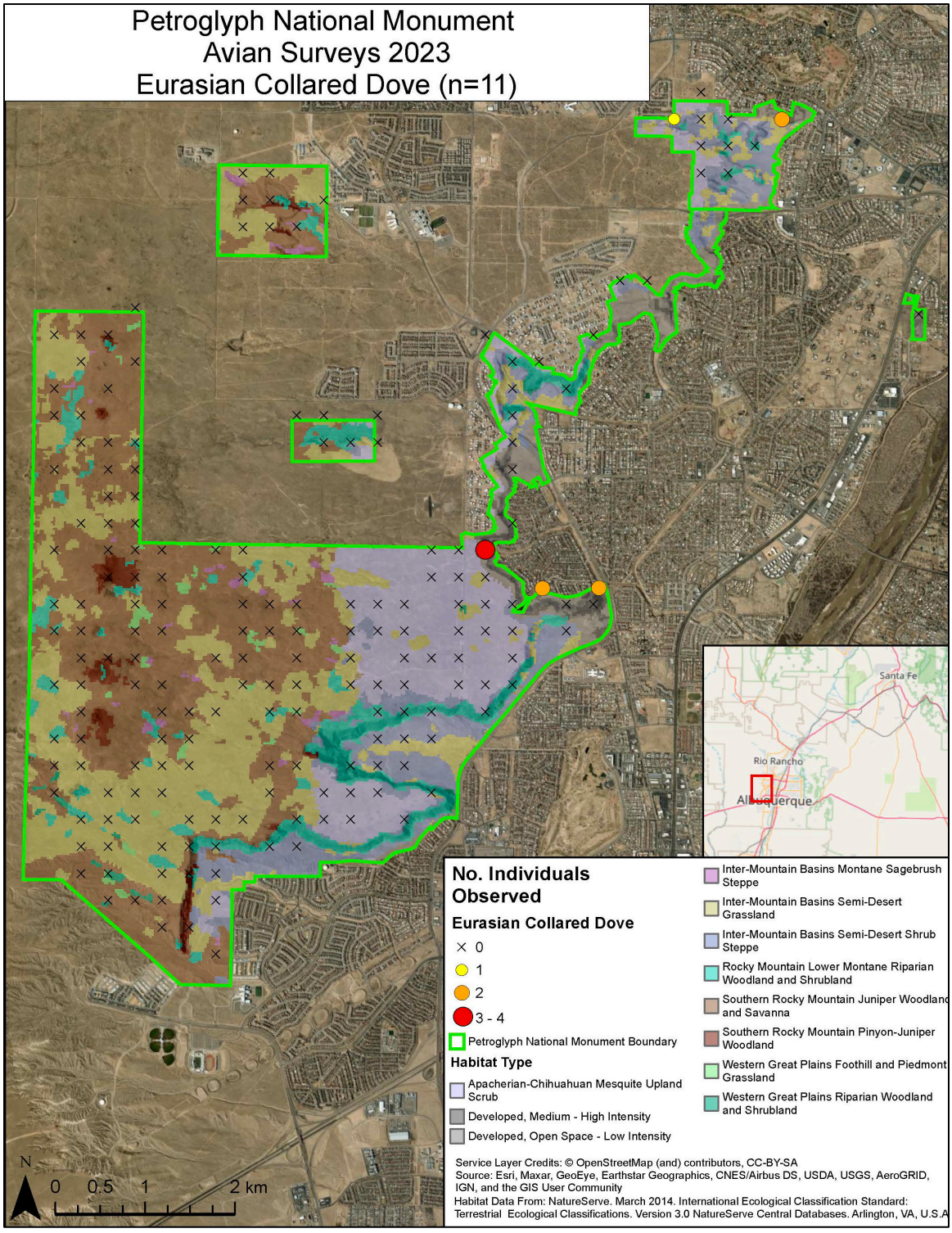


Figure 11. Plotted detections of Eurasian Collared-Dove (*Streptopelia decaocto*) during point count surveys in Petroglyph NM. Habitat data provided by NatureServe in collaboration with the International Union for Conservation of Nature (NatureServe 2014).

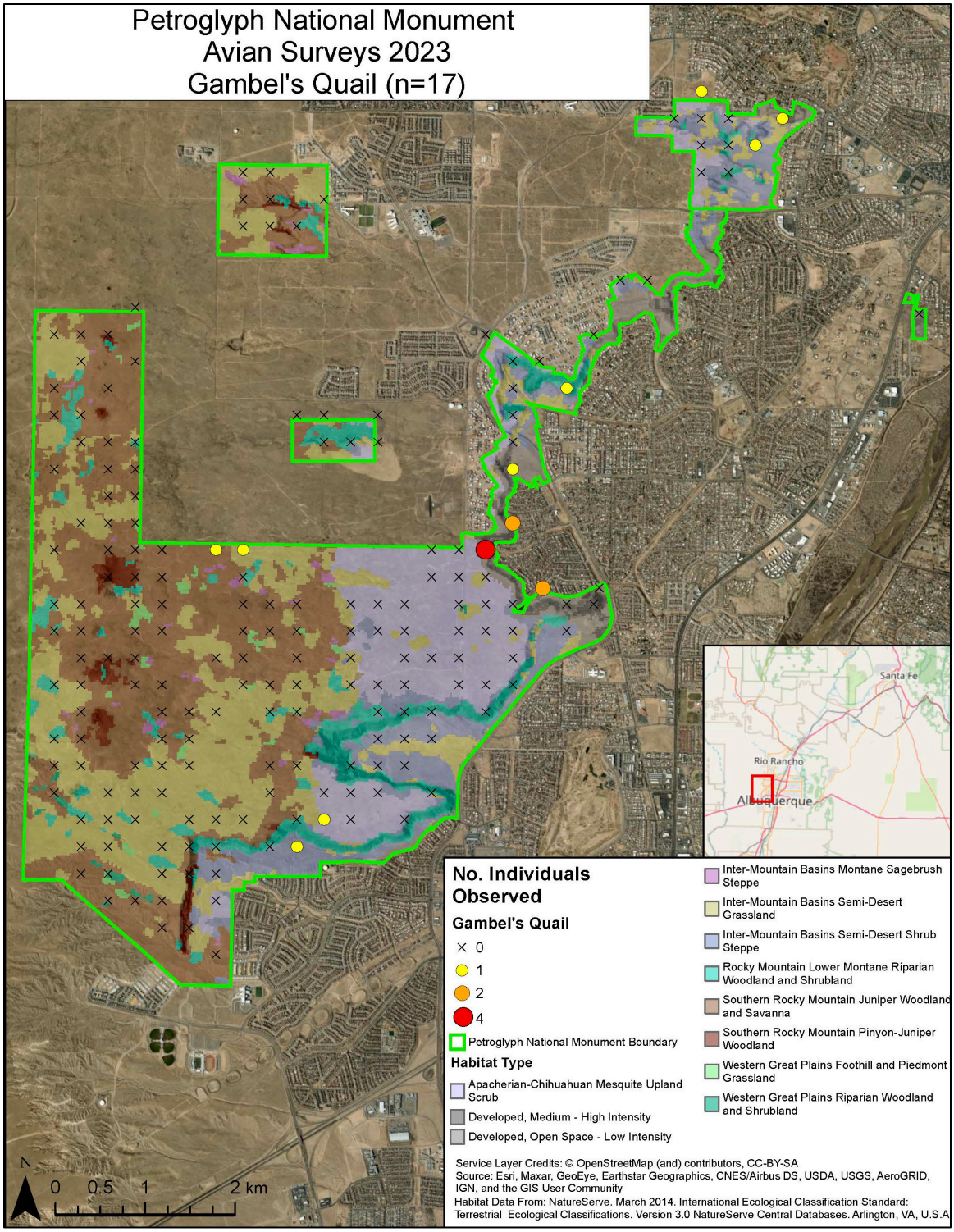


Figure 12. Plotted detections of Gambel's Quail (*Callipepla gambelii*) during point count surveys in Petroglyph NM. Habitat data provided by NatureServe in collaboration with the International Union for Conservation of Nature (NatureServe 2014).

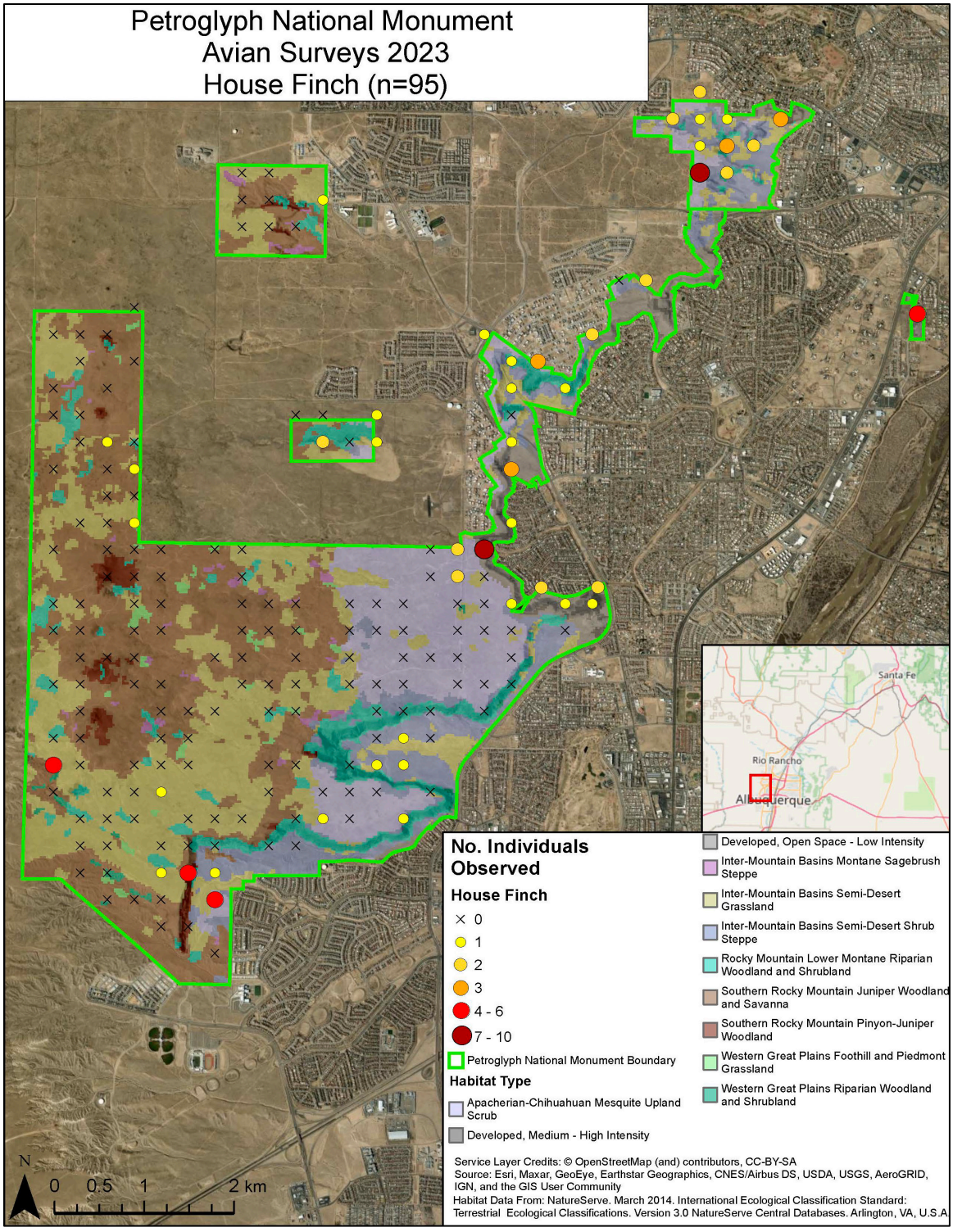


Figure 13. Plotted detections of House Finch (*Haemorhous mexicanus*) during point count surveys in Petroglyph NM. Habitat data provided by NatureServe in collaboration with the International Union for Conservation of Nature (NatureServe 2014).

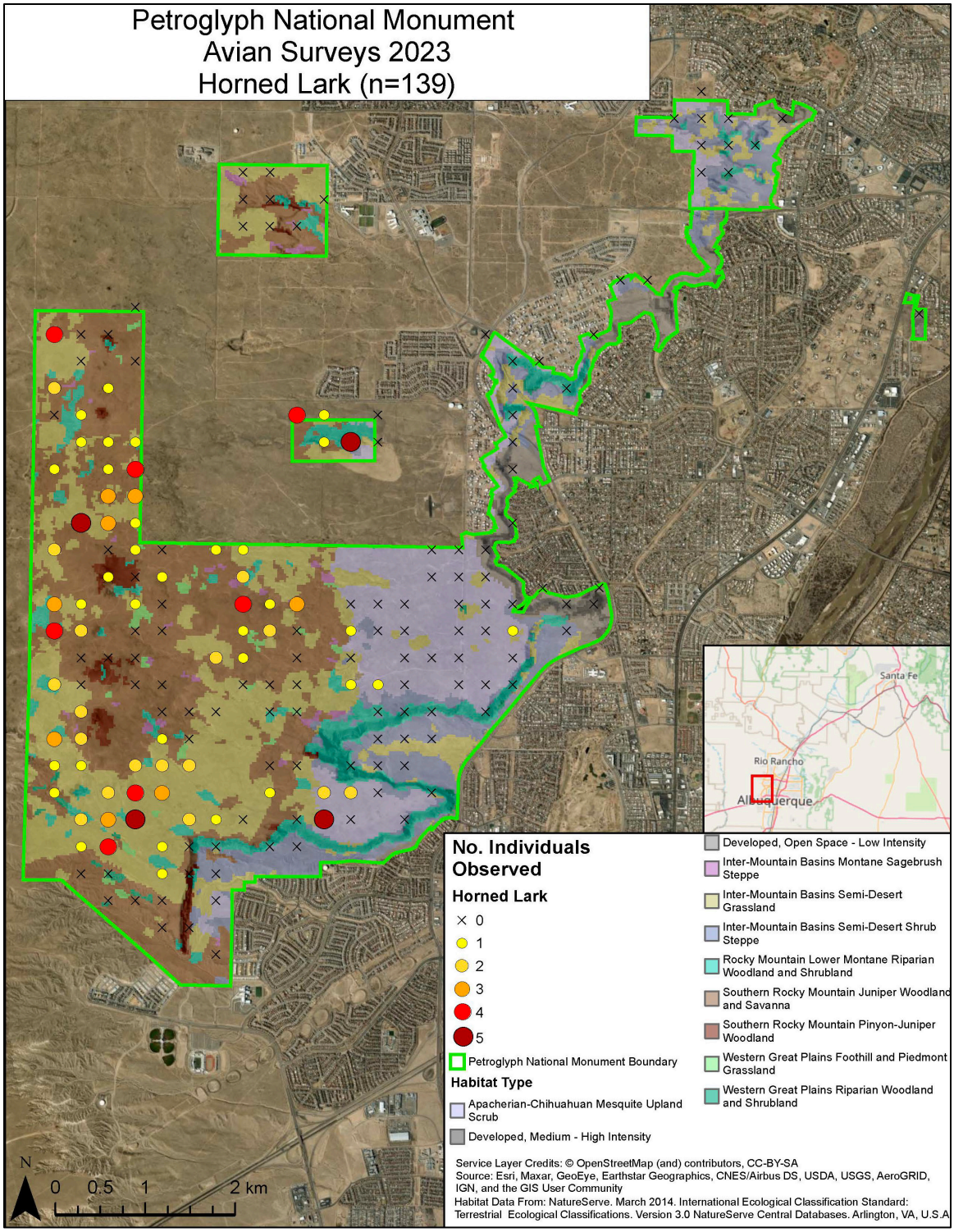


Figure 14. Plotted detections of Horned Lark (*Eremophila alpestris*) during point count surveys in Petroglyph NM. Habitat data provided by NatureServe in collaboration with the International Union for Conservation of Nature (NatureServe 2014).

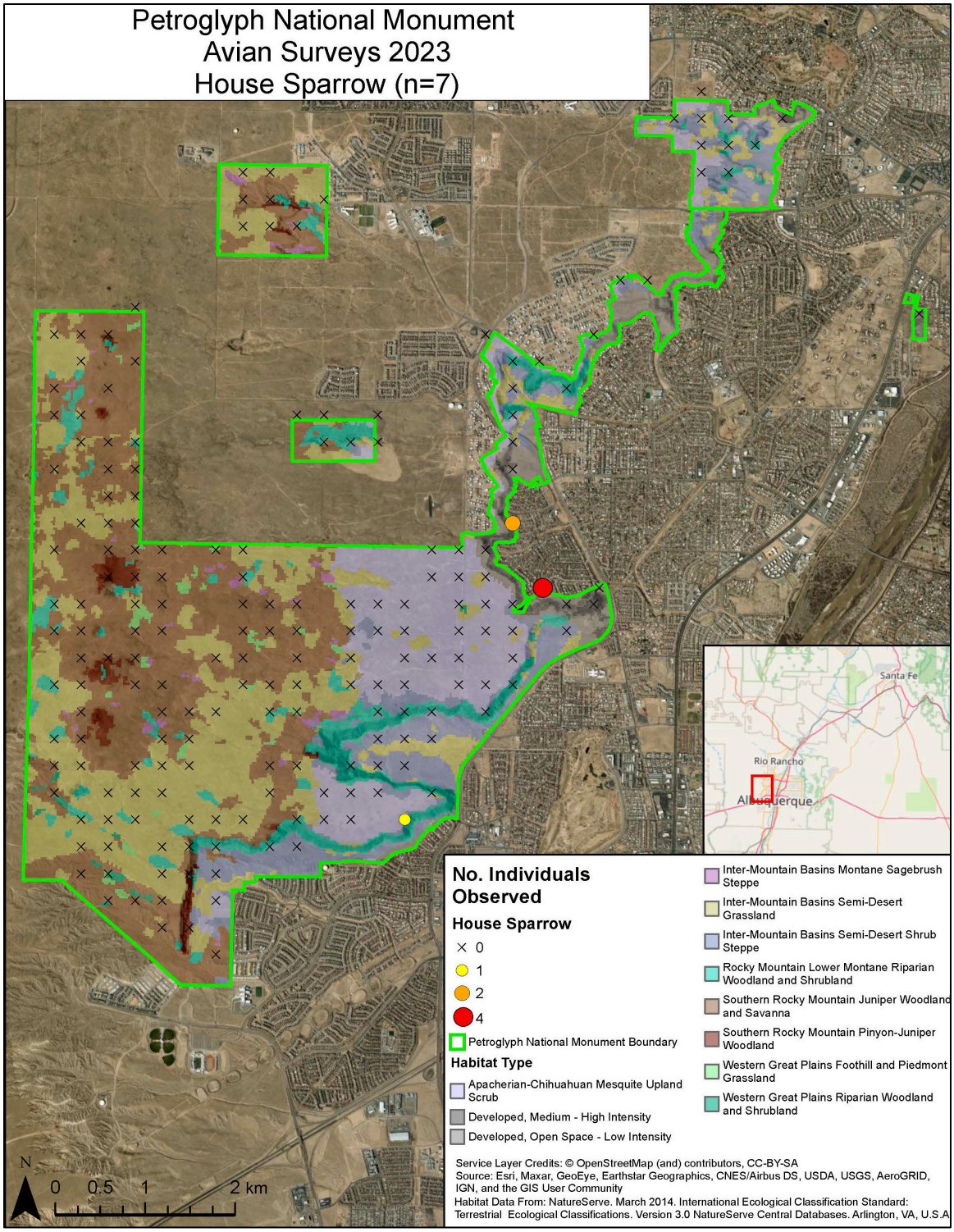


Figure 15. Plotted detections of House Sparrow (*Passer domesticus*) during point count surveys in Petroglyph NM. Habitat data provided by NatureServe in collaboration with the International Union for Conservation of Nature (NatureServe 2014).

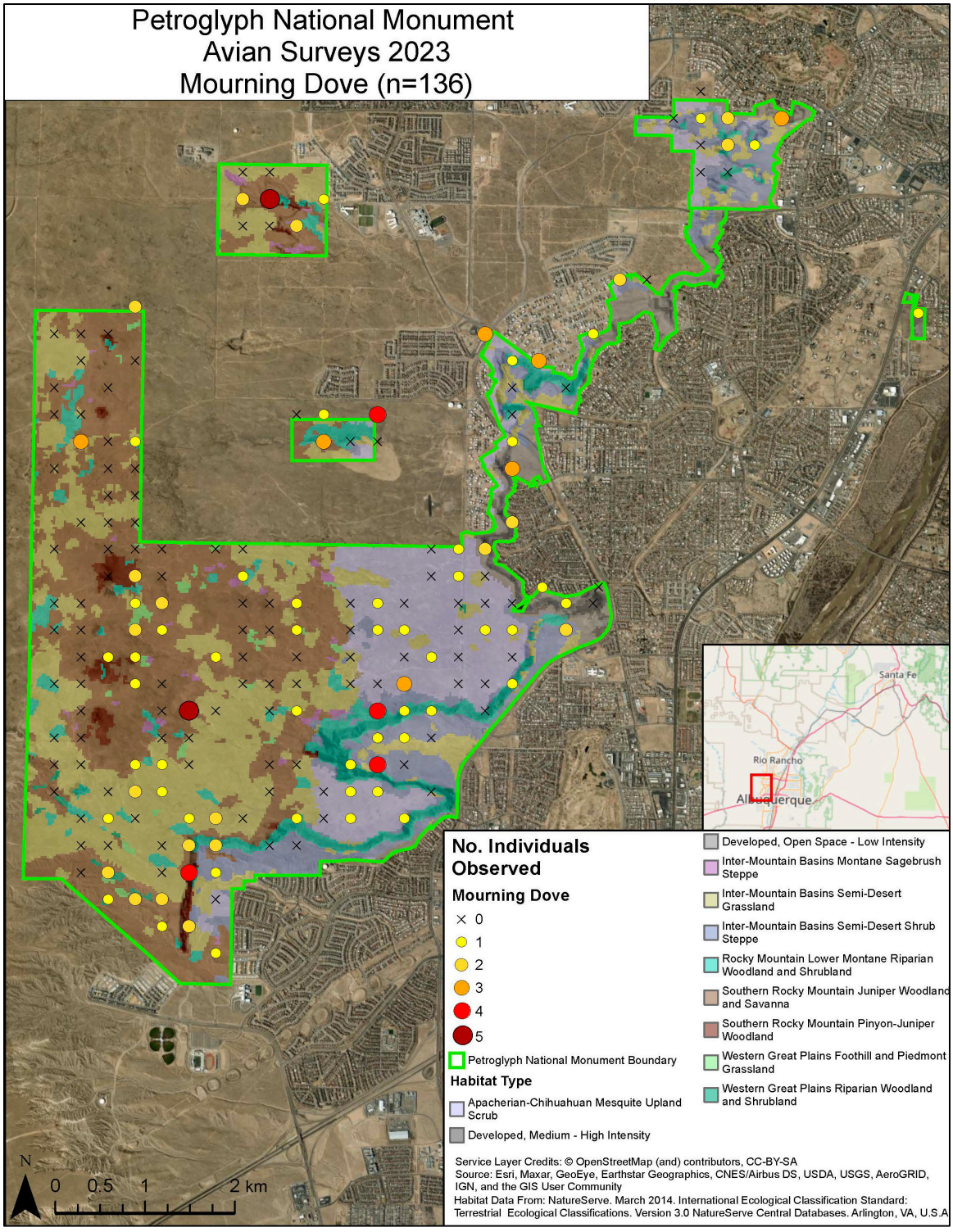


Figure 16. Plotted detections of Mourning Dove (*Zenaida macroura*) during point count surveys in Petroglyph NM. Habitat data provided by NatureServe in collaboration with the International Union for Conservation of Nature (NatureServe 2014).

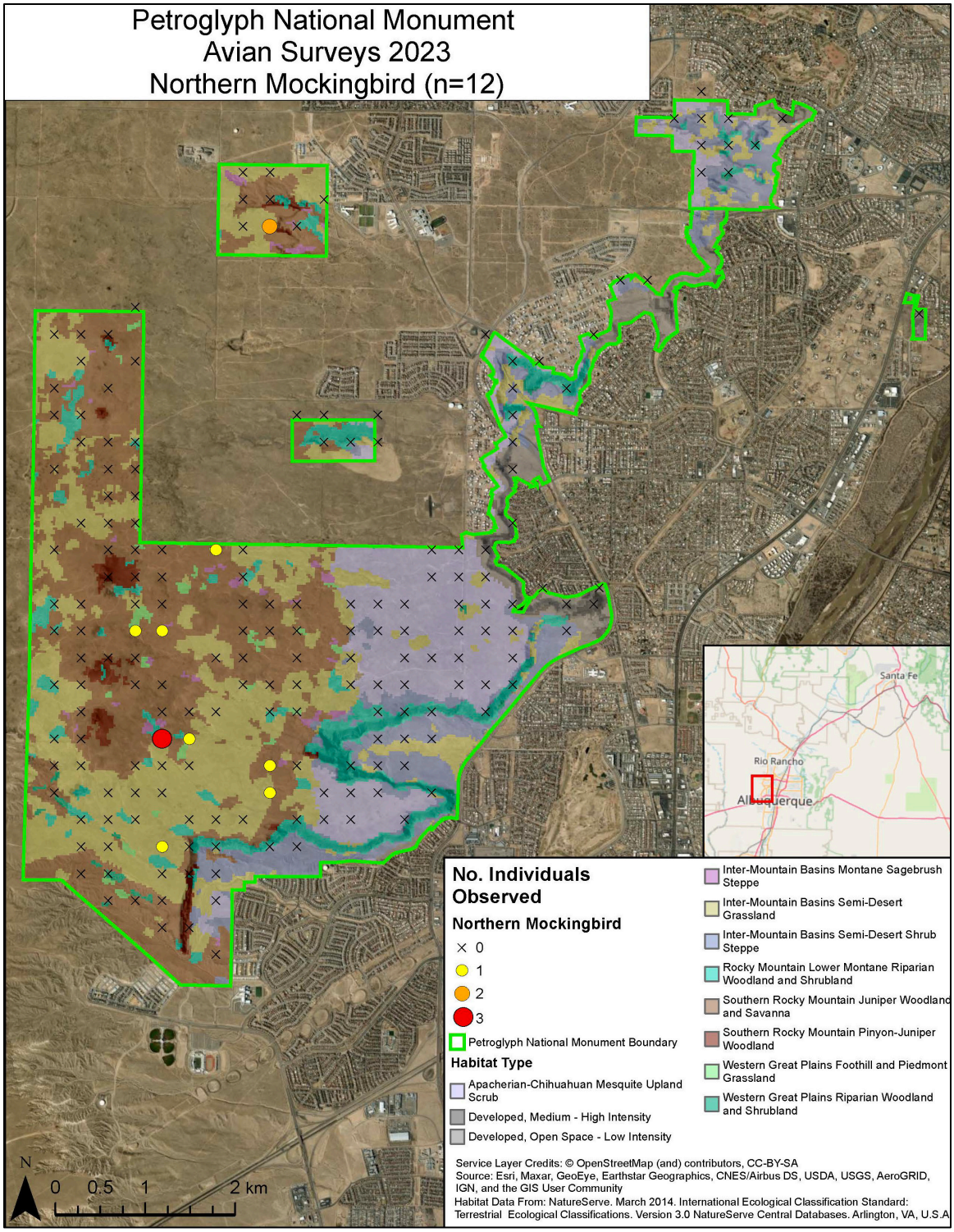


Figure 17. Plotted detections of Northern Mockingbird (*Mimus polyglottos*) during point count surveys in Petroglyph NM. Habitat data provided by NatureServe in collaboration with the International Union for Conservation of Nature (NatureServe 2014).

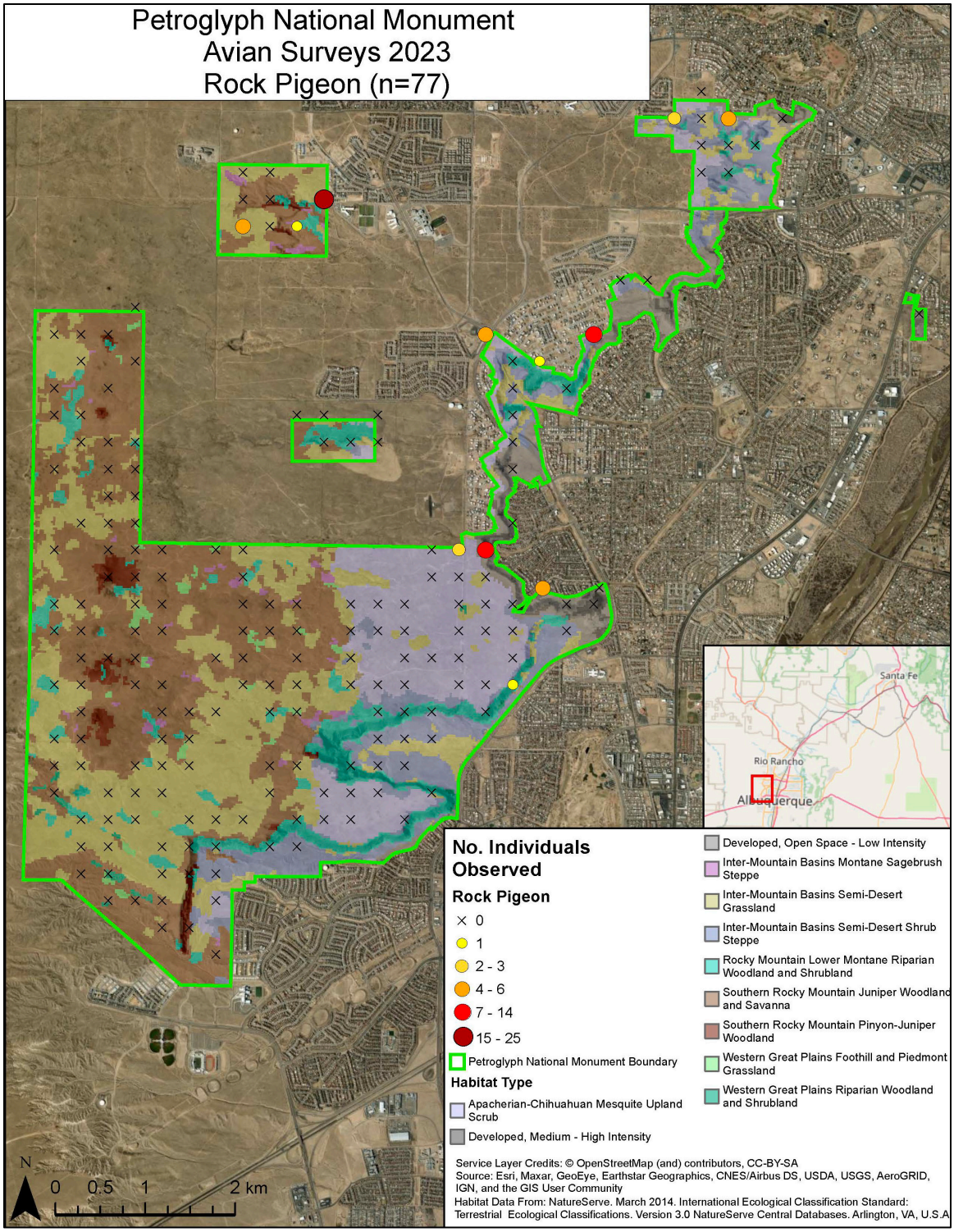


Figure 18. Plotted detections of Rock Pigeon (*Columba livia*) during point count surveys in Petroglyph NM. Habitat data provided by NatureServe in collaboration with the International Union for Conservation of Nature (NatureServe 2014).

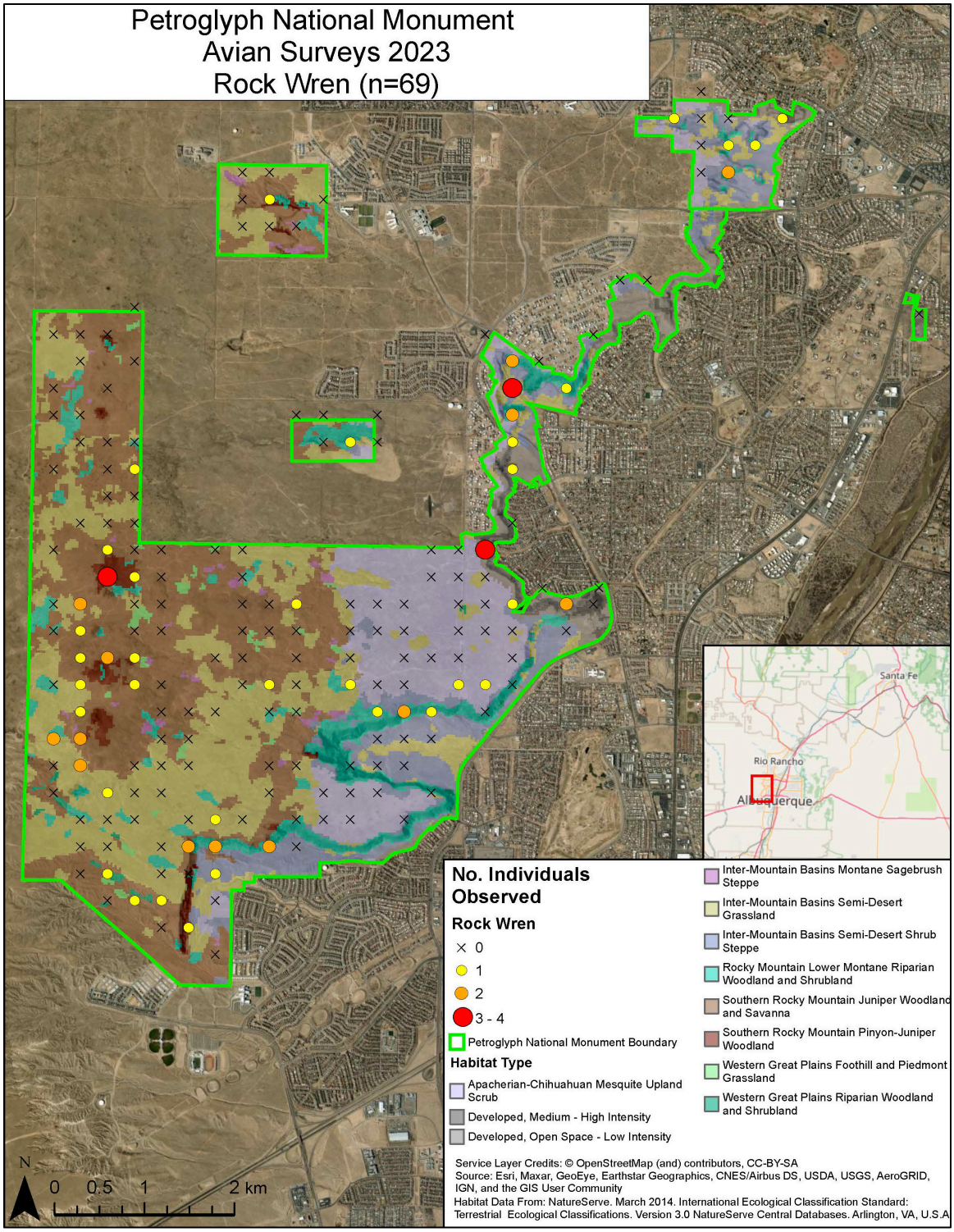


Figure 19. Plotted detections of Rock Wren (*Salpinctes obsoletus*) during point count surveys in Petroglyph NM. Habitat data provided by NatureServe in collaboration with the International Union for Conservation of Nature (NatureServe 2014).

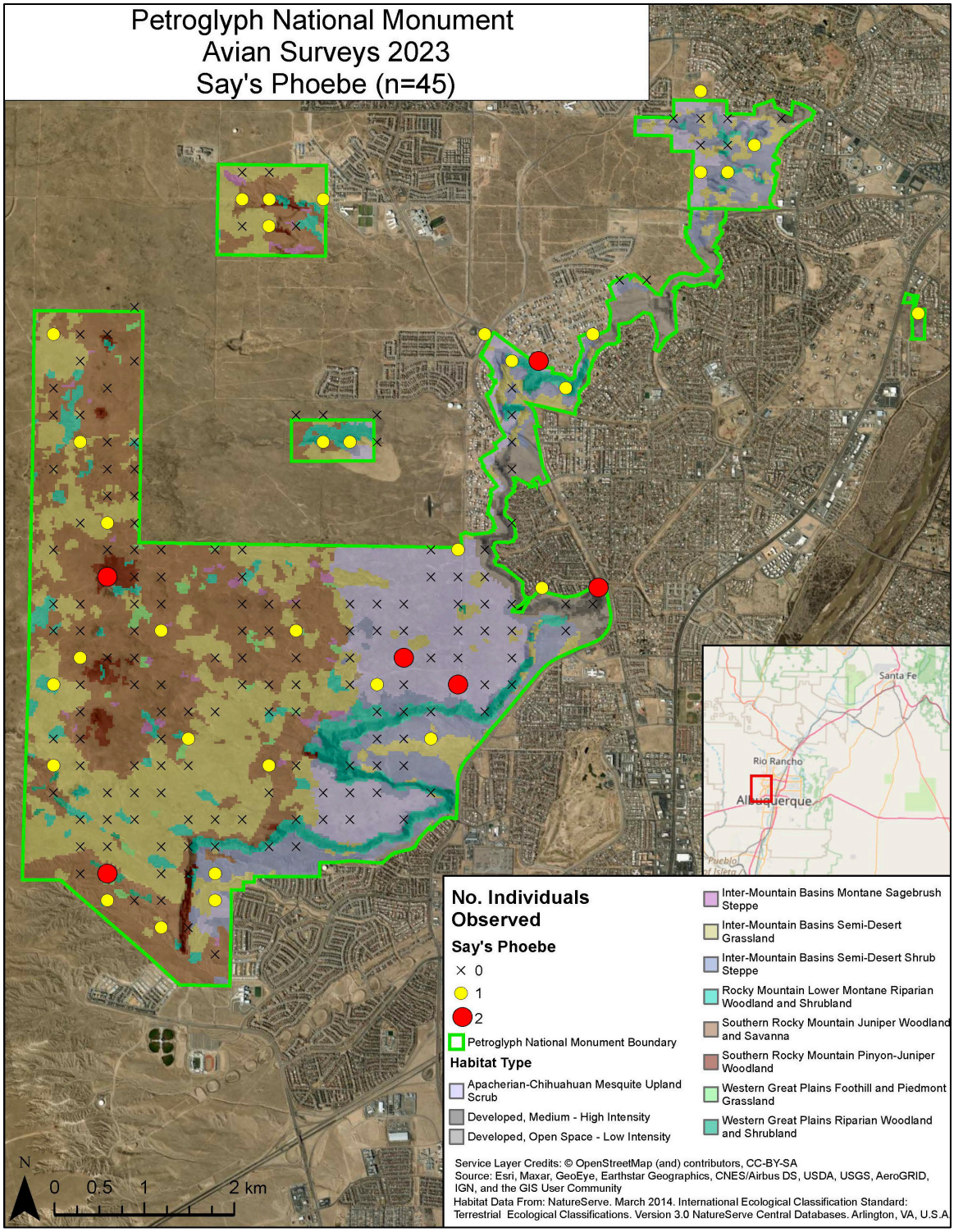


Figure 20. Plotted detections of Say's Phoebe (*Sayornis saya*) during point count surveys in Petroglyph NM. Habitat data provided by NatureServe in collaboration with the International Union for Conservation of Nature (NatureServe 2014).

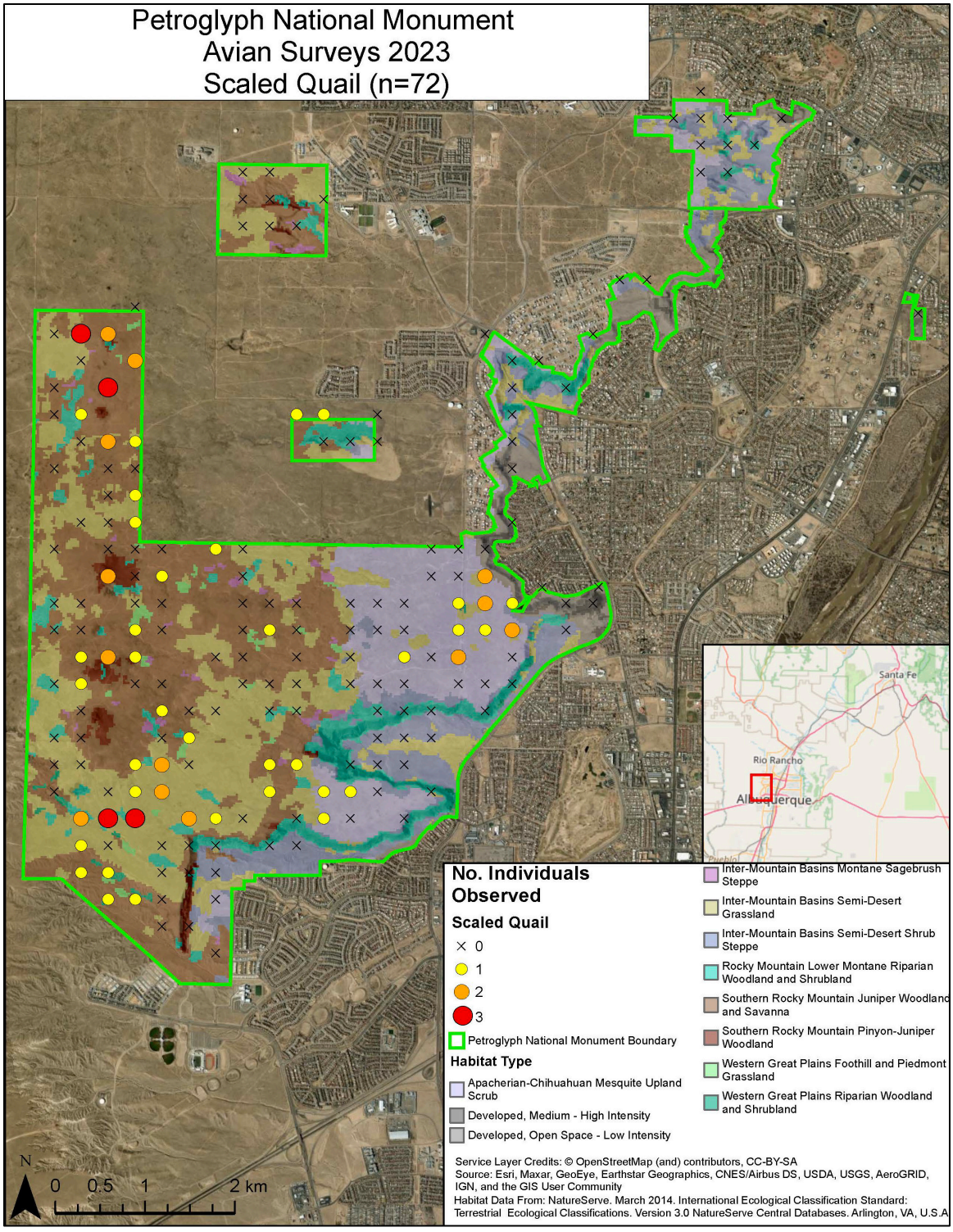


Figure 21. Plotted detections of Scaled Quail (*Callipepla squamata*) during point count surveys in Petroglyph NM. Habitat data provided by NatureServe in collaboration with the International Union for Conservation of Nature (NatureServe 2014).

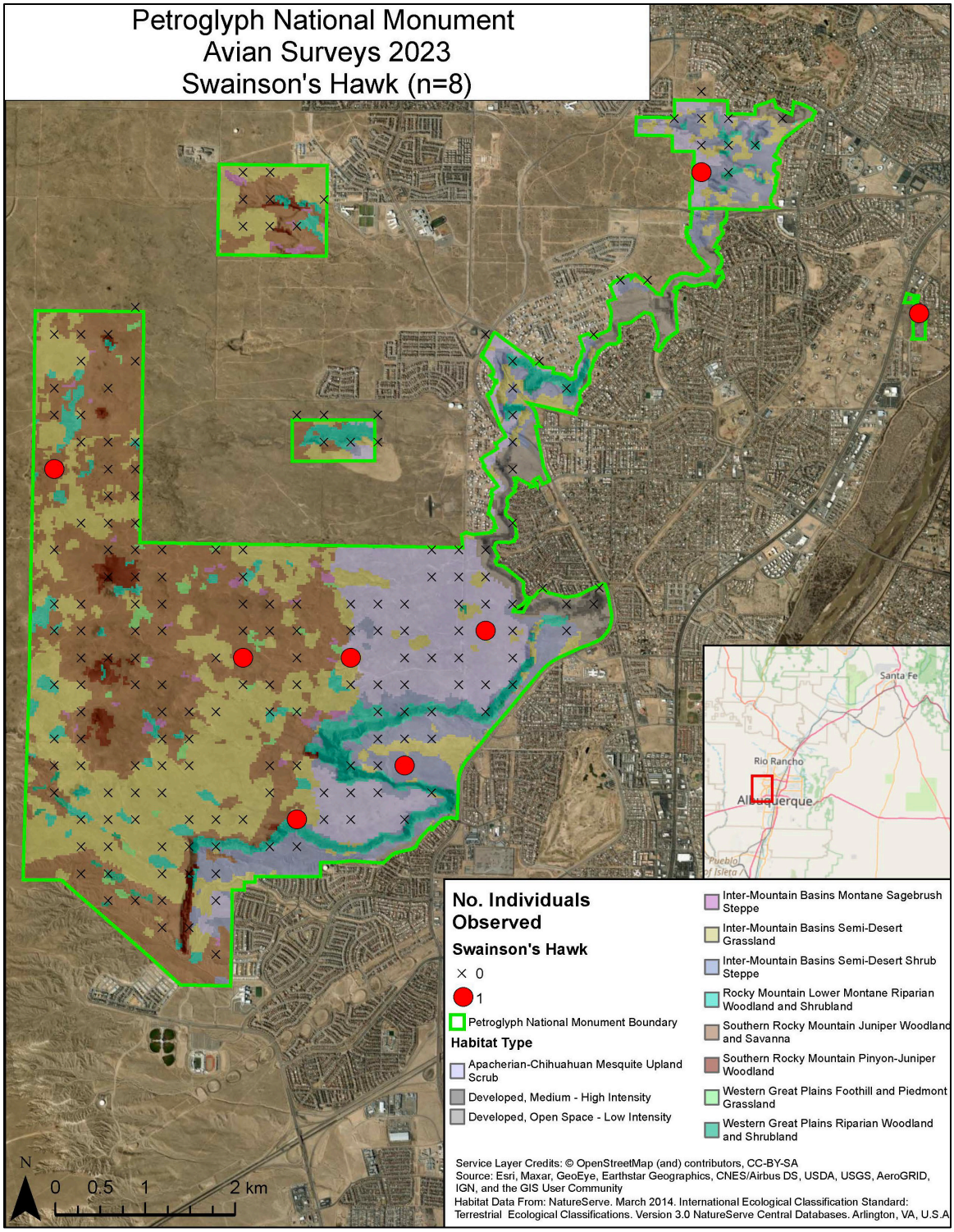


Figure 22. Plotted detections of Swainson's Hawk (*Buteo swainsoni*) during point count surveys in Petroglyph NM. Habitat data provided by NatureServe in collaboration with the International Union for Conservation of Nature (NatureServe 2014).

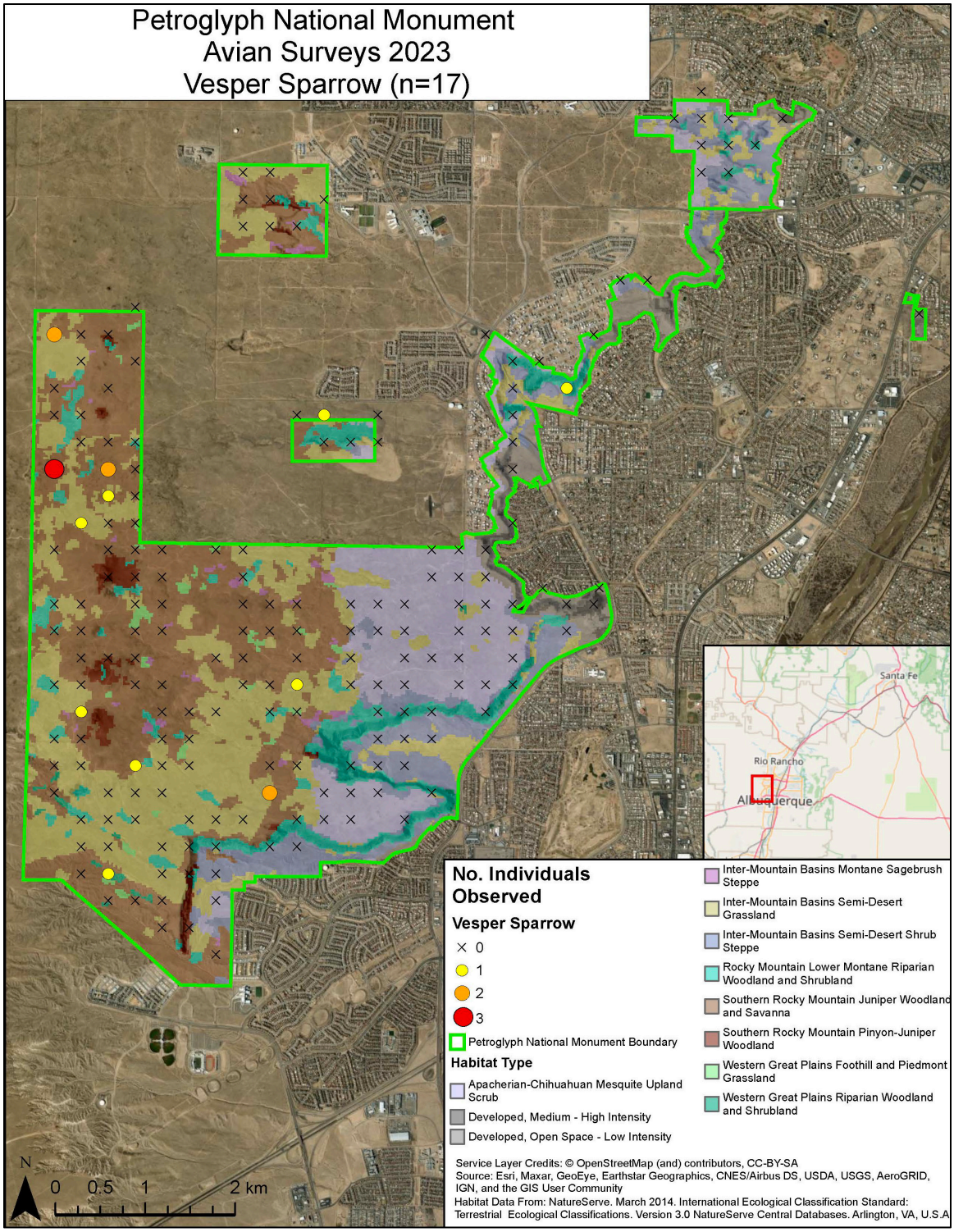


Figure 23. Plotted detections of Vesper Sparrow (*Pooecetes gramineus*) during point count surveys in Petroglyph NM. Habitat data provided by NatureServe in collaboration with the International Union for Conservation of Nature (NatureServe 2014).

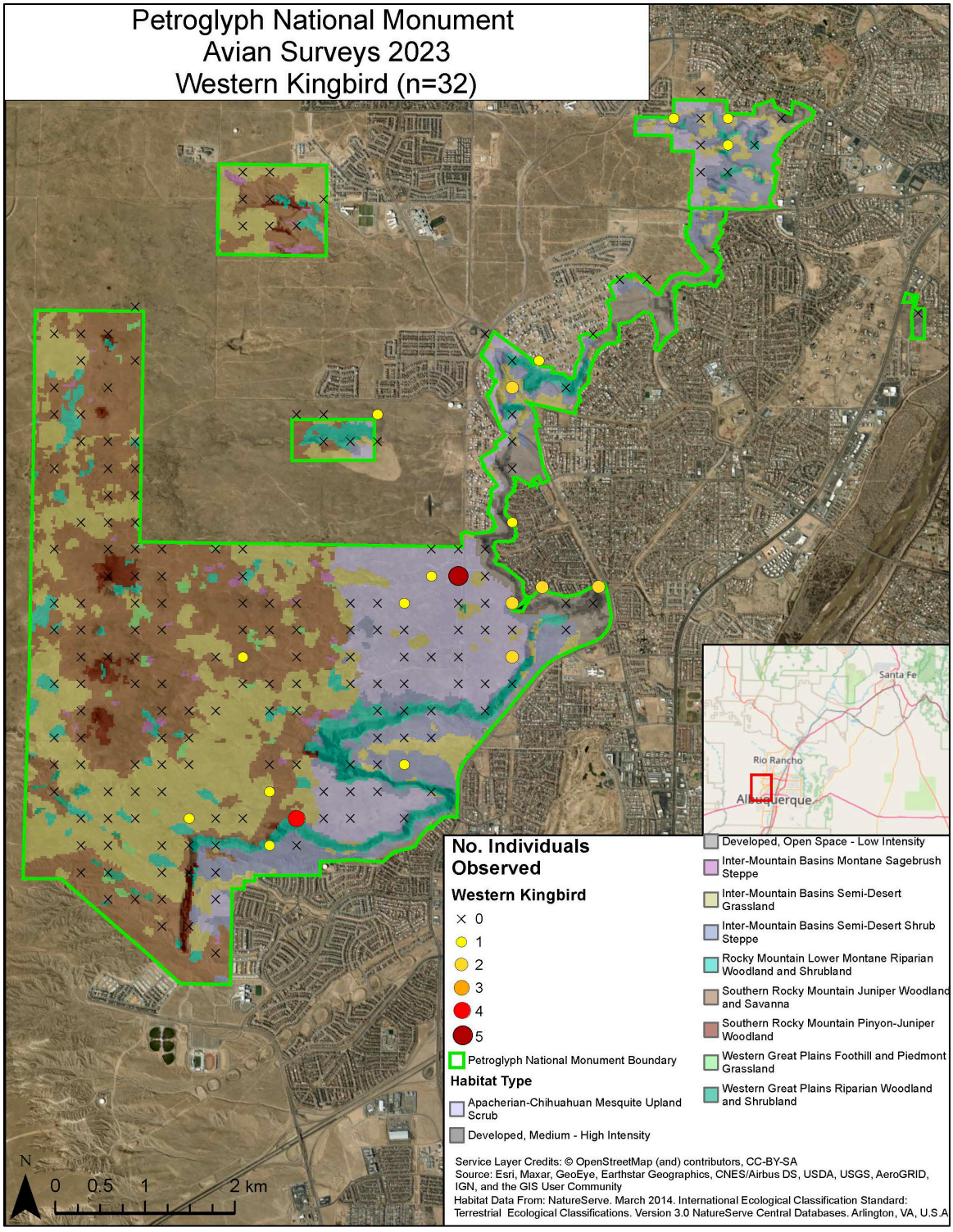


Figure 24. Plotted detections of Western Kingbird (*Tyrannus verticalis*) during point count surveys in Petroglyph NM. Habitat data provided by NatureServe in collaboration with the International Union for Conservation of Nature (NatureServe 2014).

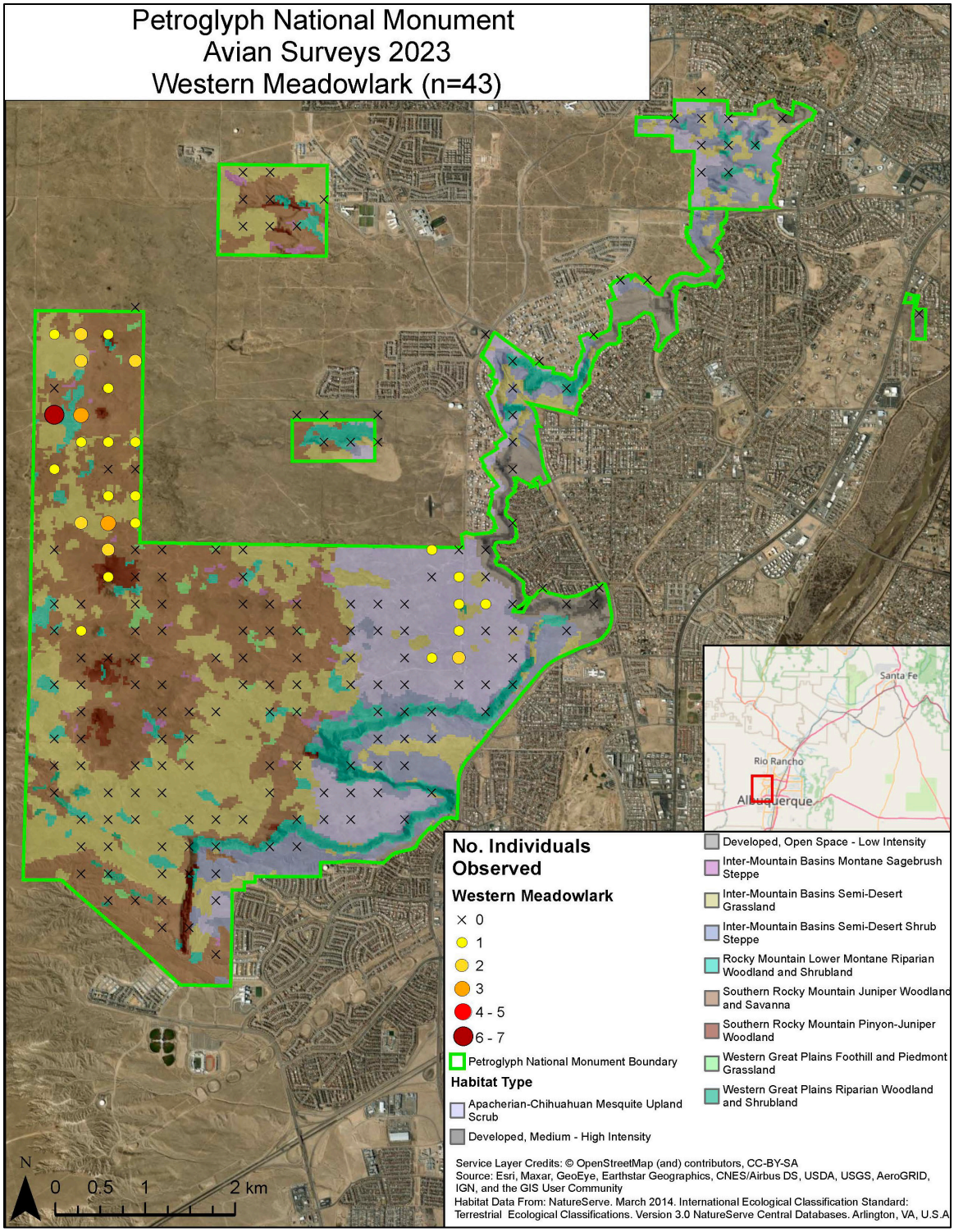


Figure 25. Plotted detections of Western Meadowlark (*Sturnella neglecta*) during point count surveys in Petroglyph NM. Habitat data provided by NatureServe in collaboration with the International Union for Conservation of Nature (NatureServe 2014).

Appendix B: JAGS code used to model breeding densities

```
model {
    # PRIORS
    # model: augGaps.repAll.mindaycloudWindNoiseObsY

    ba0 ~ dnorm(0,0.001)      # availability intercept
    baD ~ dnorm(0,0.001)      # coefs of availability covars that
affect
    baD2 ~ dnorm(0,0.001)     # Quadratic term of day of year
    baM ~ dnorm(0,0.001)      # the detection interval (like Day and
Minute)
    baC ~ dnorm(0,0.001)      # coef for cloud cover during survey
    baW ~ dnorm(0,0.001)      # coef for wind speed during survey

    sigma0 ~ dunif(0,200)     # scale of detection fn, bounded for
convergence
    bdN ~ dnorm(0,0.001)      # coefs of scale parameter covars like
Noise,

   # Random station effect on abundance
   for (s in 1:nsta) {   # accounts for differences in habitat
across stations
    staeff[s] ~ dnorm(0,tau.sta)
    }
    tau.sta <- pow(sd.sta,-2)
    sd.sta ~ dunif(0,10)

    # random observer effect on detection dist
    for (i in 1:nobservers) {
    obseff[i] ~ dnorm(0,tau.obs)
    }
    tau.obs <- pow(sd.obs,-2)
    sd.obs ~ dunif(0,10)

    # overdispersion
    for (k in 1:nsurveys) {
    od[k] ~ dnorm(0.0,tau.od)
    }
    tau.od ~ dgamma(0.001,0.001)
    #sd.od <- pow(tau.od,-0.5) # comment out unless tracking sd.od

    # DETECTION PROBABILITY FUNCTIONS
```

```
    for (k in 1:nsurveys) {

    # covariates of availability

    logit(q[k]) <- ba0 + baM*minute[k] + baC*cloud[k] + baW*wind[k]

    # covariates of perceptibility/detection

    log(sigma[k]) <- log(sigma0) + bdN*noise[k] +
obseff[observer[k]]

    # distance-based estimation of detection probability

    for (b in 1:nbreaks) {

    log(g[b,k]) <- -mdpts[b]*mdpts[b]/(2*sigma[k]*sigma[k]) # half-
norm density
    f[b,k] <- (2*mdpts[b]*delta[b])/(maxd*maxd) # delta[b] if bin
widths vary
    #f[b,k] <- (2*mdpts[b]*delta)/(maxd*maxd)   # no [b] on delta:
width static
    pi.d[b,k] <- g[b,k]*f[b,k]       # p(detection) per pt-bin
    pi.d.c[b,k] <- pi.d[b,k]/p.d[k]  # conditional form stdized by
p(detected)

    } # b in 1:nbreaks

    p.d[k] <- sum(pi.d[,k]) # p.d is a sum over all dclass bins

    # removal-based estimation of availability given UNEQUAL
intervals

    pi.a[1,k] <- 1-pow(q[k],3) # p(avail in the first 3 min,
interval j=1)
    pi.a[2,k] <- pow(q[k],3)*(1-pow(q[k],2)) # p(avail in next 2
mins, j=2)
    pi.a[3,k] <- pow(q[k],5)*(1-pow(q[k],2)) # p(avail in final 2
mins, j=3)
    # p(available in each interval j | available in at least one
interval)
    for (j in 1:J) {pi.a.c[j,k] <- pi.a[j,k]/p.a[k]}
    p.a[k] <- sum(pi.a[,k]) # p(available in at least one interval)
```

```
    } # k in 1:nsurveys

    # OBSERVATION-LEVEL MODEL

    for (i in 1:nobs) {

    # one binomial trial w/categorical distc linking dclass &
tinterval to ptct
    dclass[i] ~ dcat(pi.d.c[,surveyid[i]])    # p(outcome=1 to
nbreaks dclasses)
    tinterval[i] ~ dcat(pi.a.c[,surveyid[i]]) # p(outcome=1 to J
intervals)

    } # i in 1:nobs

    # ABUNDANCE ESTIMATION

    for (k in 1:nsurveys) {

    # counts as a function of number available and detection
probability

    y[k] ~ dbin(p.d[k],n.a[k])

    # number available for sampling as a function of abundance and
p(available)

    n.a[k] ~ dbin(p.a[k],N[k])

    # abundance model

    N[k] ~ dpois(lambda[k]) # predicted abundance per survey
(point-count)

    # covariates of abundance (*** update model)

    log(lambda[k]) <- staeff[sta[k]]

    } # k in 1:nsurveys

    # GOODNESS OF FIT STATS

    for (k in 1:nsurveys) {
```

```
    # first, for calculating Bayesian p-values based on simple
differences...
    y.exp[k] <- p.d[k]*n.a[k]           # expected values from the
model
    n.exp[k] <- p.a[k]*N[k]
    y.new[k] ~ dbin(p.d[k],n.a[k])      # predicted values from the
model
    n.new[k] ~ dbin(p.a[k],N[k])
    y.dis[k] <- y[k] - y.exp[k]         # observed discrepancies
    n.dis[k] <- n.a[k] - n.exp[k]
    y.new.dis[k] <- y.new[k] - y.exp[k] # modeled discrepancies
    n.new.dis[k] <- n.new[k] - n.exp[k]

    # next, for calculating LOF ratios based on the Freeman-Tukey
statistic...
    y.LOF[k] <- (((y[k])^0.5) - ((y.exp[k])^0.5))^2         # dev
of obs y
    y.new.LOF[k] <- (((y.new[k])^0.5) - ((y.exp[k])^0.5))^2 # dev
of pred y
    n.LOF[k] <- (((n.a[k])^0.5) - ((n.exp[k])^0.5))^2       # dev
of obs n
    n.new.LOF[k] <- (((n.new[k])^0.5) - ((n.exp[k])^0.5))^2 # dev
of pred n

    } # k in 1:nsurveys

    fit.pd <- sum(abs(y.dis[]))             # Bayesian p-values
    fit.new.pd <- sum(abs(y.new.dis[]))
    bayesp.pd <- step(fit.pd-fit.new.pd)
    fit.pa <- sum(abs(n.dis[]))
    fit.new.pa <- sum(abs(n.new.dis[]))
    bayesp.pa <- step(fit.pa-fit.new.pa)

    LOF.pd <- sum(y.LOF[])/sum(y.new.LOF[]) # Lack-Of-Fit ratios
    LOF.pa <- sum(n.LOF[])/sum(n.new.LOF[])

    # SUMMARY STATS

    mupavail <- mean(p.a[])       # mean probability of
availability
    mupdet <- mean(p.d[])         # mean probability of
perceptibility
```

```
    musigma <- mean(sigma[])      # mean scale parameter across
stations

    ha <- maxd*maxd*3.14159/10000 # hectares surveyed at each
station (pt)
    dens.ha <- mean(N[])/ha       # mean point-level density

    }
```

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 354/192646, February 2024

National Park Service
U.S. Department of the Interior

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