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Title: 2024 Results for Avian Monitoring at the Technical Area 36 Minie Site, Technical Area 39 Point 6, Technical Area 16 Burn Ground, and DARHT at Los Alamos National Laboratory

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2024 Results for Avian Monitoring at the Technical Area 36 Minie Site, Technical Area 39 Point 6, Technical Area 16 Burn Ground, and DARHT at Los Alamos National Laboratory

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*Cover photo: Banded adult Western bluebird (*Sialia mexicana*) observed during nest box monitoring.*
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EXECUTIVE SUMMARY

Los Alamos National Laboratory (LANL) biological subject matter experts in the Environmental Protection and Compliance Division initiated a multi-year program in 2013 to monitor avifauna (birds) at two open detonation sites and one open burn site on LANL property. Additional monitoring began in 2017 at a third firing site, the Dual-Axis Radiographic Hydrodynamic Test (DARHT) Facility. In this annual report, we compare monitoring results from these efforts among years to identify and evaluate firing and open burn site impacts on the local bird community. The objectives of this study are

- to determine whether LANL operations impact bird abundance, species richness, or diversity;
- to examine occupancy and nest success of secondary-cavity nesting birds that use nest boxes; and
- to examine chemical concentrations (such as radionuclides, inorganic elements, and/or organic compounds) in nonviable eggs and deceased nestlings that are collected opportunistically with the upper-level bounds of background concentrations, when available.

During May through July 2024, LANL biologists completed multiple avian point count surveys at each of the following treatment sites:

- Technical Area (TA) 36 Minie Site,
- TA-39 Point 6,
- TA-16 Burn Ground, and
- DARHT.

We recorded a total of 1,088 birds that represented 65 species at the four treatment sites and compared these results with data from their associated control sites.

In 2024, abundance and species richness at treatment and control sites continued to trend similarly from year to year, with minor random deviations expected from bird communities. Species richness at firing sites differed little from the previous year's values. Two new bird species were observed at the firing sites—cedar waxwing (*Bombycilla cedrorum*) and pinyon jay (*Gymnorhinus cyanocephalus)*. Shannon diversity values at TA-36 Minie Site, TA-39, and DARHT were statistically higher than one or more of their associated controls. Annual species diversity at treatment sites was high in 2024 across all firing sites relative to similar habitat control sites.

We also monitored avian nest boxes to compare occupancy and nest success data from nest boxes at treatment sites with the overall avian nest box monitoring network and against a subset of relevant control sites. Nest box success has decreased at both treatment and control sites since monitoring began, suggesting that overlapping climatic factors are responsible for patterns of declining nest success.

In 2024, nonviable avian eggs and one nestling were opportunistically collected at Bandelier National Monument, TA-16 Burn Ground, TA-36 Minie, TA-39 Point 6, and DARHT. All egg samples and the one nestling sample were evaluated for per- and polyfluoroalkyl substances, which were detected from all locations, including the control site at Bandelier National Monument.

Overall results from 2024 continue to suggest that operations at the four treatment sites are not negatively impacting bird populations. This long-term project will continue to monitor for any changes over time.

1 INTRODUCTION

As part of the Resource Conservation and Recovery Act permit process, Los Alamos National Laboratory (LANL) started an annual avian monitoring program in 2013. The permit was for two open detonation sites—Technical Area (TA) 36 Minie Site and TA-39 Point 6; and one open burn site—TA-16 Burn Ground, hereinafter referred to as TA-36 Minie, TA-39, and TA-16, respectively; or together as treatment sites (Hathcock and Fair 2013; Hathcock 2014, 2015; Hathcock, Thompson, and Berryhill 2017; Hathcock, Bartlow, and Thompson 2018; Hathcock et al. 2019; Sanchez, Hathcock, and Thompson 2020; Rodriguez and Abeyta 2021). LANL biologists have been conducting point counts and monitoring nest boxes near an additional firing site—the Dual-Axis Radiographic Hydrodynamic Test (DARHT) Facility—since 2017. Results for DARHT are included in this report. The objectives of this long-term monitoring program are

- to determine whether LANL operations impact bird abundance, species richness, or diversity;
- to examine occupancy and nest success of secondary cavity-nesting birds that use nest boxes; and
- to document chemical concentrations (such as radionuclides, inorganic elements, and/or organic compounds) in nonviable eggs and deceased nestlings that are collected opportunistically and to compare them with the upper-level bounds of background concentrations, when available.

This effort involves comparing community and nest box data from treatment sites with control sites of similar habitat type that have been surveyed since 2011 (Hathcock, Zemlick, and Norris 2011).

Summer surveys provide information about which bird species could be breeding at each site. These surveys are most valuable when they are conducted over multiple years because they provide long-term trend data that can be compared with local, regional, or national trends in bird populations. These data can also be used to test for correlations between bird communities and the natural environment, including environmental changes at LANL.

Although point counts are a reliable way to assess community level metrics, their utility in detecting fine-scale landscape differences might be limited (Ralph, Sauer, and Droege 1995). Point counts cannot reliably distinguish between birds that use the local habitat to breed versus itinerant individuals that migrate through or are temporarily foraging. Assessing the success of birds known to nest near firing (treatment) sites and those that nest in similar habitats away from firing (control) sites provides increased power to connect local environmental disturbances with local biology. To perform this assessment, we monitored nest boxes around all four treatment sites to investigate any potential impacts to occupancy rates and productivity of secondary cavity-nesting birds. Occupancy and nest success were compared with the overall avian nest box monitoring network—established in 1997 (Fair and Myers 2002)—and a subset of sites of similar habitat type and nest box label number.

Another objective of this ongoing study is to document chemical concentrations in nonviable eggs and deceased nestlings that are collected opportunistically near TA-16 Burn Ground, TA-36 Minie, TA-39 Point 6, and DARHT. We compare concentrations of radionuclides, inorganic elements, and/or organic compounds (such as per- and polyfluoroalkyl substances [PFAS], polychlorinated biphenyls, dioxin, furans) observed in this study with the upper-level bounds of background concentrations, when available.

Radionuclides, inorganic elements, dioxins, and furans are of interest at open-detonation firing sites (TA-36 Minie and TA-39) and at DARHT, which performs detonations within steel vessels, as well as the burn ground at TA-16 (Fresquez 2011). PFAS compounds are being monitored to contribute to site-wide characterization at LANL in efforts to support the DOE PFAS Strategic Roadmap (DOE 2022). PFAS are a class of manufactured compounds that are used in many consumer and industrial products, such as cookware, food packaging, stain repellents, paints, and fire-fighting foams. PFAS compounds have useful properties—repelling oil, stains, grease, and water—that contribute to their widespread use. Several thousand known PFAS compounds exist, some of which have been more widely used and studied than others, and these compounds have been manufactured since the 1940s. PFAS compounds have been detected in the environment around the globe. PFAS have been detected in avian tissues in remote areas, such as oceanic environments or the Arctic region, where global deposition, or *fallout*, is the primary source of PFAS in the environment (Kannan et al. 2002; Martin et al. 2004). Toxicity data for PFAS compounds on avian ecological receptors are sparse (Dennis et al. 2021).

Biomonitoring is an important tool for assessing environmental contamination by analyzing chemicals or their metabolites from biological tissues (Becker 2003). Avian eggs and nestlings are useful as bioindicators because different species occupy many trophic levels. Additionally, the collection of nonviable eggs and/or nestlings that die of natural causes is noninvasive and nondestructive to populations. Inorganic elements (mostly metals) and organic chemicals can pose risks of adverse effects to birds if exposed at high enough concentrations (Jones and de Voogt 1999). Birds can be exposed to chemicals through multiple routes, including diet, ingestion of soil, drinking water, and inhalation. Levels of some constituents in biological tissues can also indicate whether adverse effects could be expected (Gochfeld and Burger 1998). Examining population parameters along with tissue concentrations provides a more comprehensive and robust assessment of potential impacts caused by environmental pollution.

2 METHODS

2.1 Field Methods for Point Count Surveys

LANL biologists conducted the point count surveys along single transects in the forested, undeveloped land surrounding the treatment sites (Figures 1 through 5). The habitat types included in this monitoring are piñon pine (*Pinus edulis*) and juniper (*Juniperus monosperma*) woodland (PJ), present at TA-36 Minie (Figure 1) and TA-39 (Figure 2); and ponderosa pine (*Pinus ponderosa*) forest (PIPO), present at TA-16 (Figure 3) and DARHT (Figure 4). The habitat types are based on the 1/4 ha physiognomic cover classes in the LANL land cover map (McKown et al. 2003). The treatment and control sites are monitored annually. The control sites were originally established in 2011 (Hathcock, Zemlick, and Norris 2011). Each habitat type control contained two replicate transects that LANL biologists monitored in the same way as the treatment sites, with the same number of points and during the same time periods. In each survey month, all treatment and control site transects are surveyed in random order.

The treatment sites at TA-36 Minie and TA-39 are similar to the PJ control sites at TA-70 and TA-71 in elevation, vegetation, and proximity to developed areas; however, the transect at TA-39 is located in the canyon bottom, and the controls are located on mesa tops. The treatment sites at TA-16 and DARHT are similar in elevation and overstory vegetation to the PIPO control sites, and all are located on mesa tops. One of the PIPO control transects is located adjacent to development, and the other transect is in an undeveloped area.

Transects are approximately 2.0 to 2.5 km in length, with nine survey points spaced approximately 250 m apart. These survey routes and points can change slightly over time due to construction activities or access constraints. The timeframe that we surveyed for breeding bird surveys in 2024 is May 11 through July 9. Ideally, the breeding bird surveys should take place during the second week of May, June, and July. Sites are surveyed three times, and surveys are conducted between 0.5 hours before sunrise and within 4.0 hours after sunrise.

The following steps apply to breeding bird surveys:

- Each survey consists of nine points spaced approximately 250 m apart along a transect.
- The surveyor looks and listens for 5 minutes, recording all birds encountered at each point on a data sheet. For each observation, the minimum data collected are point number, time, species, number of individuals, and distance from the point. The observation distance is considered to be an unlimited-distance circular plot; however, surveyors record the distance to each bird out to an estimated 100 m. A range finder should be used if available. Surveyors avoid re-counting individuals between points.
- While walking between points, surveyors record any obvious species not recorded at the previous point that also would not be counted at the next point. Surveyors do not spend excess time looking for birds between points.
- Surveyors do not conduct surveys during rain events or during winds greater than 24 kph.

Surveyors use the "NOTES" section on avian survey forms to document additional information about the survey that may affect the data. Examples include excess noise from nearby equipment, vehicles, or aircraft that make it hard to hear the birds. Surveyors also record other wildlife or unusual sightings that could be useful for other projects.

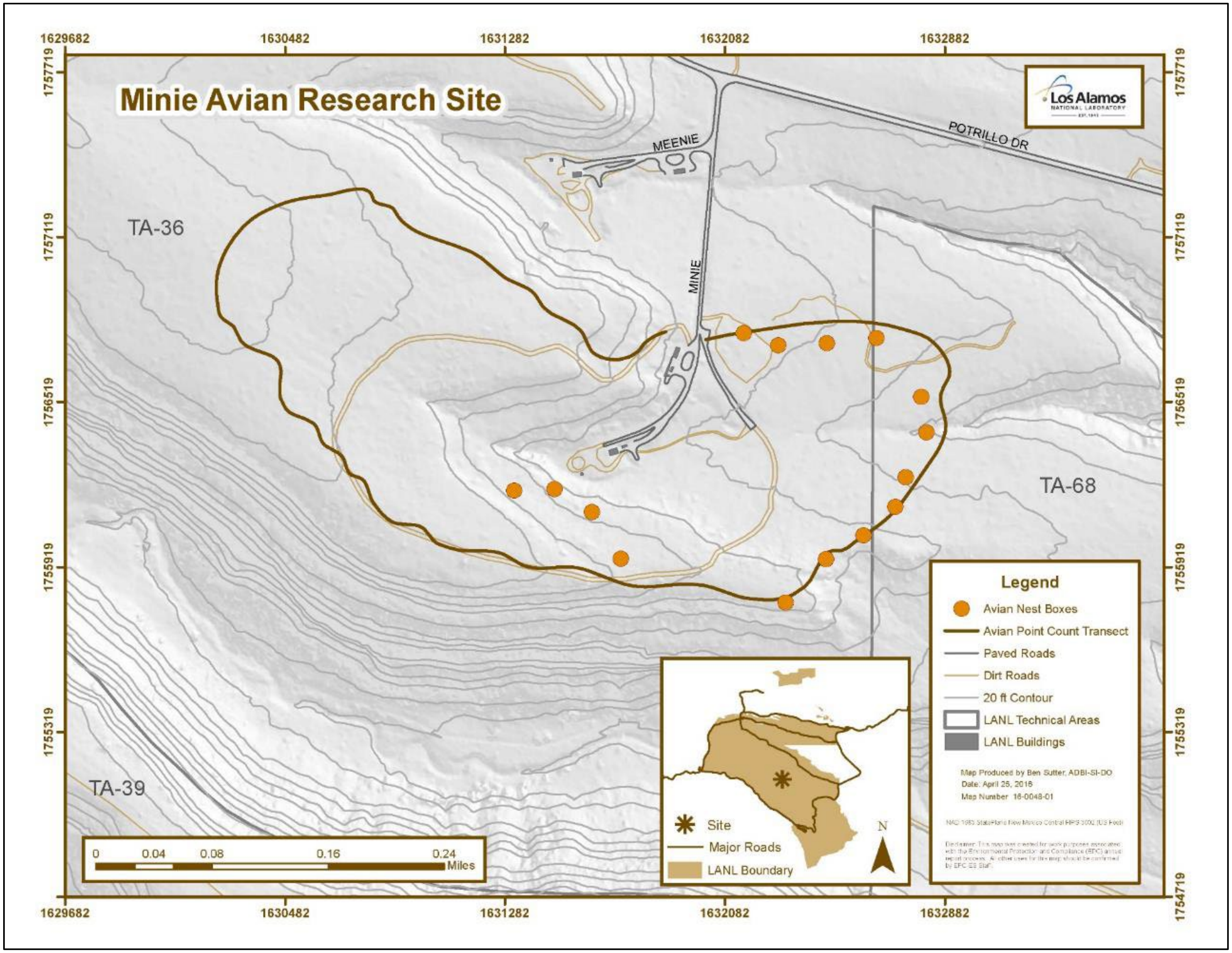

Figure 1. Breeding bird survey transect and nest box locations around TA-36 Minie Site.

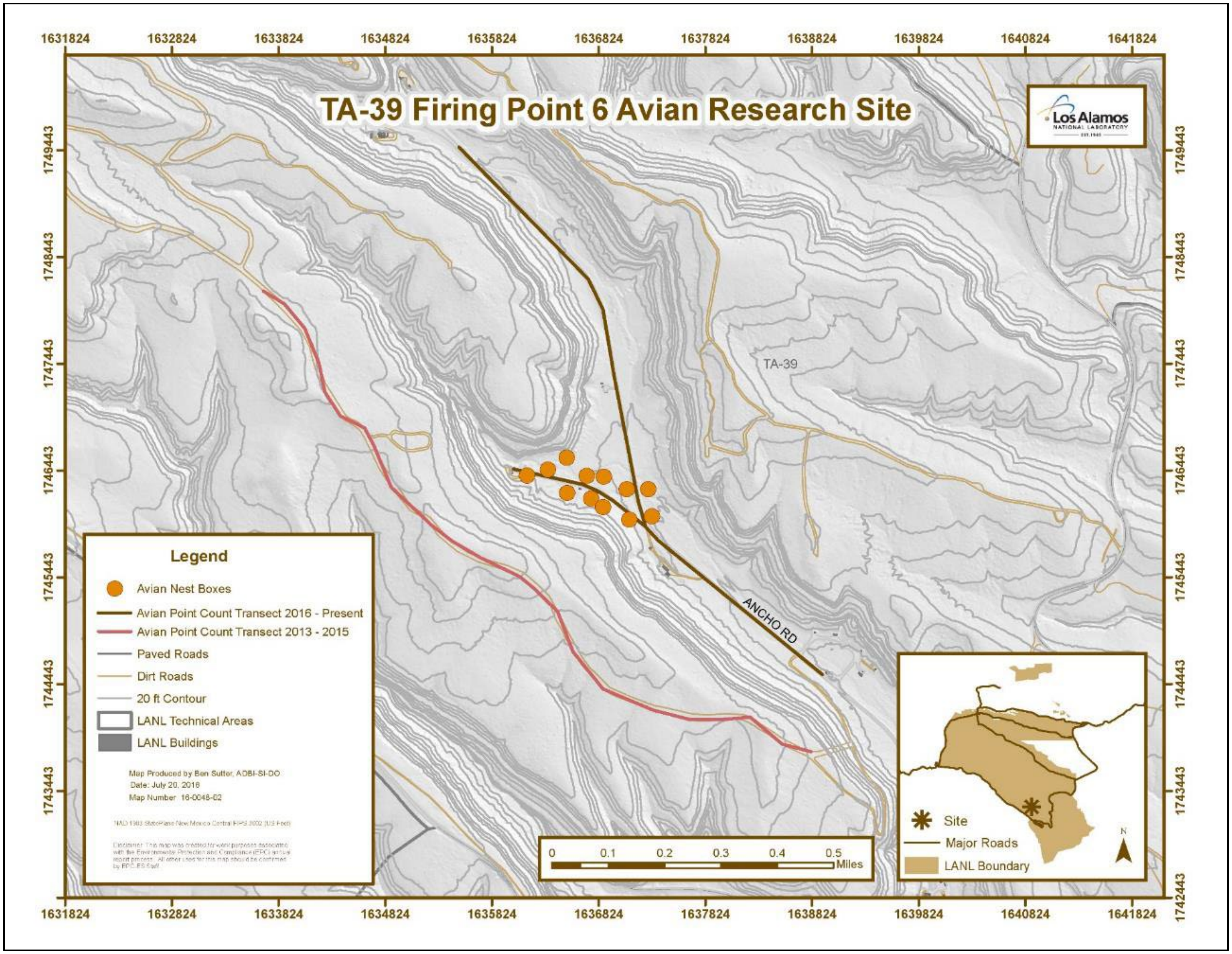

Figure 2. Breeding bird survey transect and nest box locations around TA-39 Point 6.

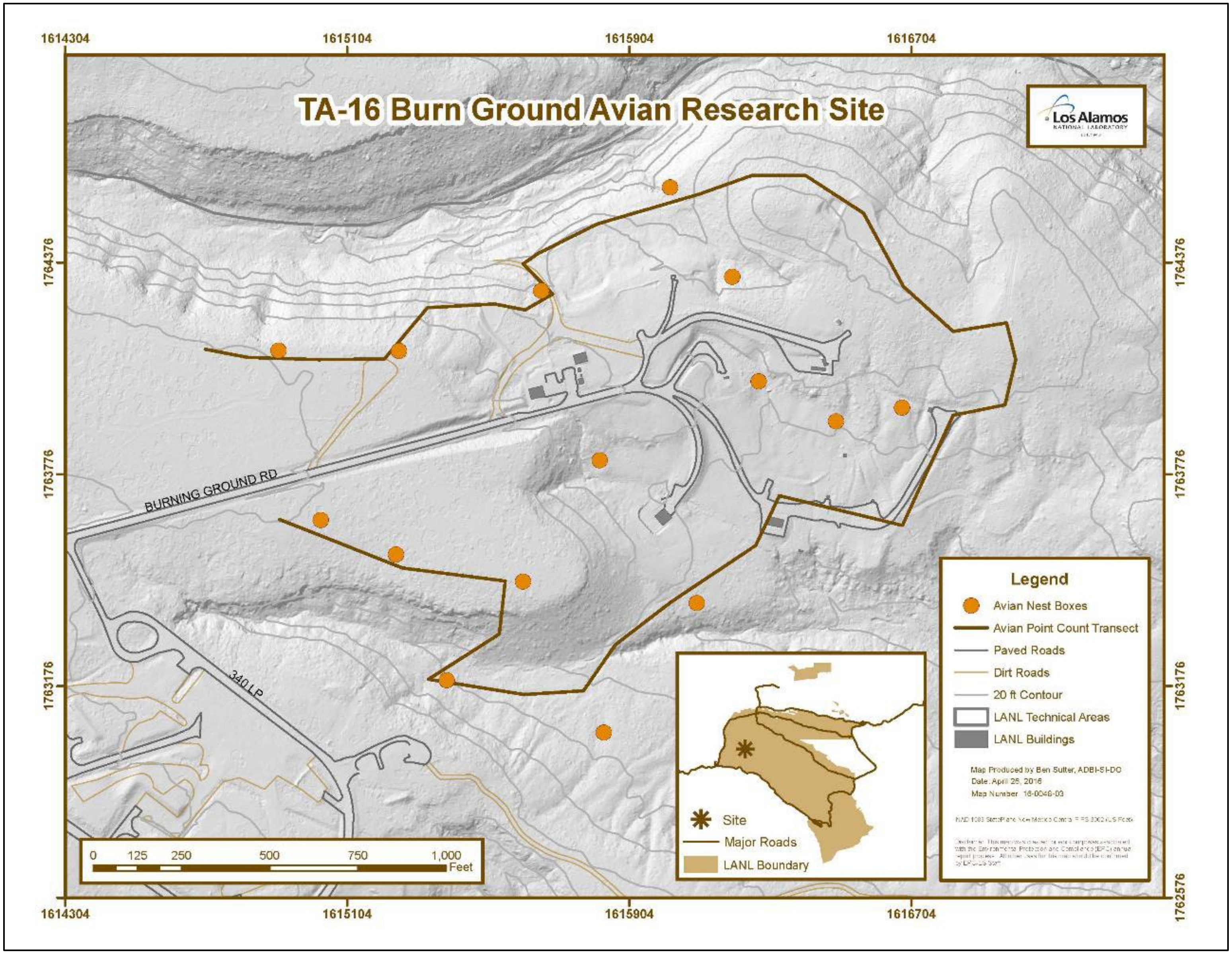

Figure 3. Breeding bird survey transect and nest box locations around TA-16 Burn Ground.

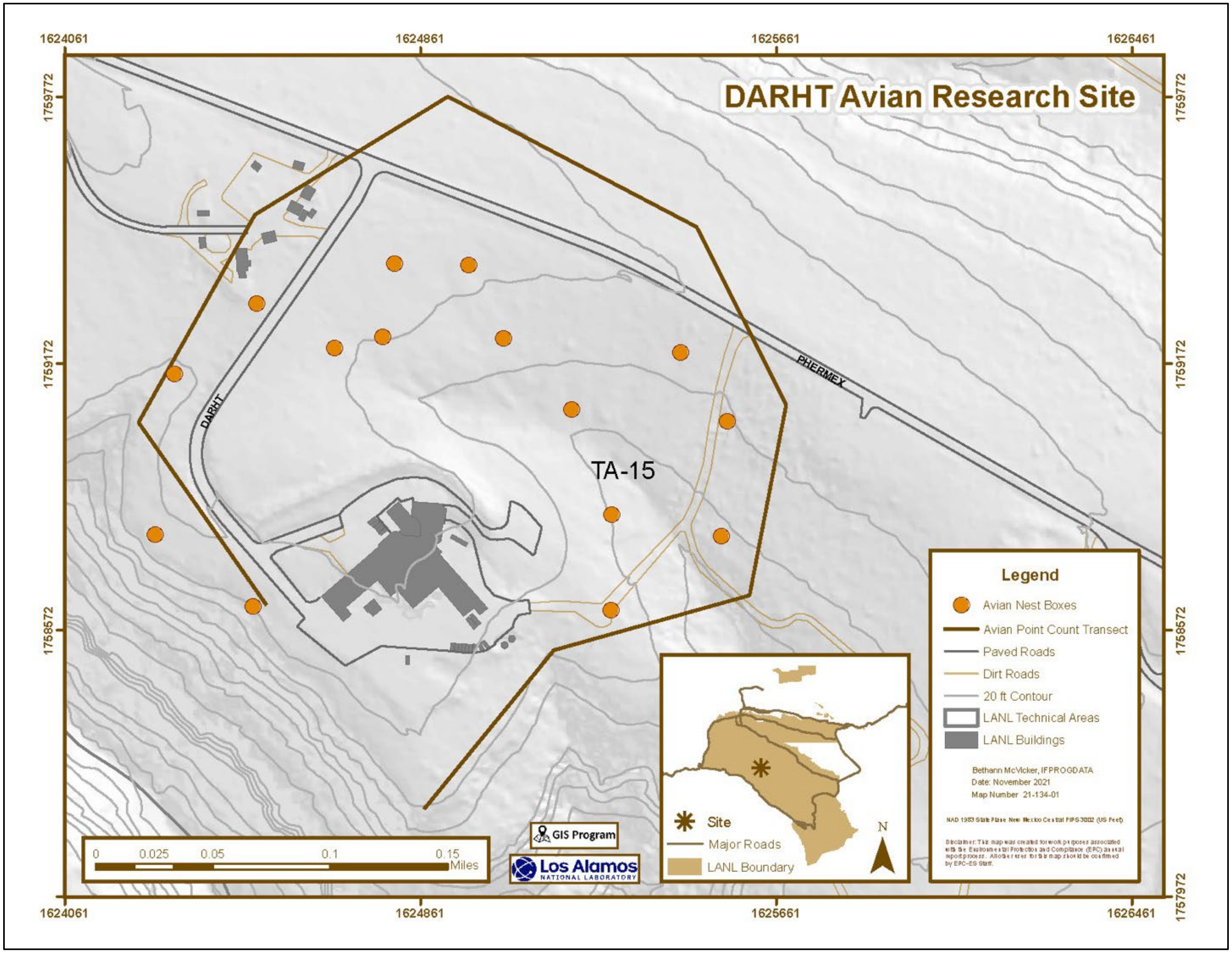

Figure 4. Breeding bird survey transect and nest box locations around the Dual-Axis Radiographic Hydrodynamic Test Facility.

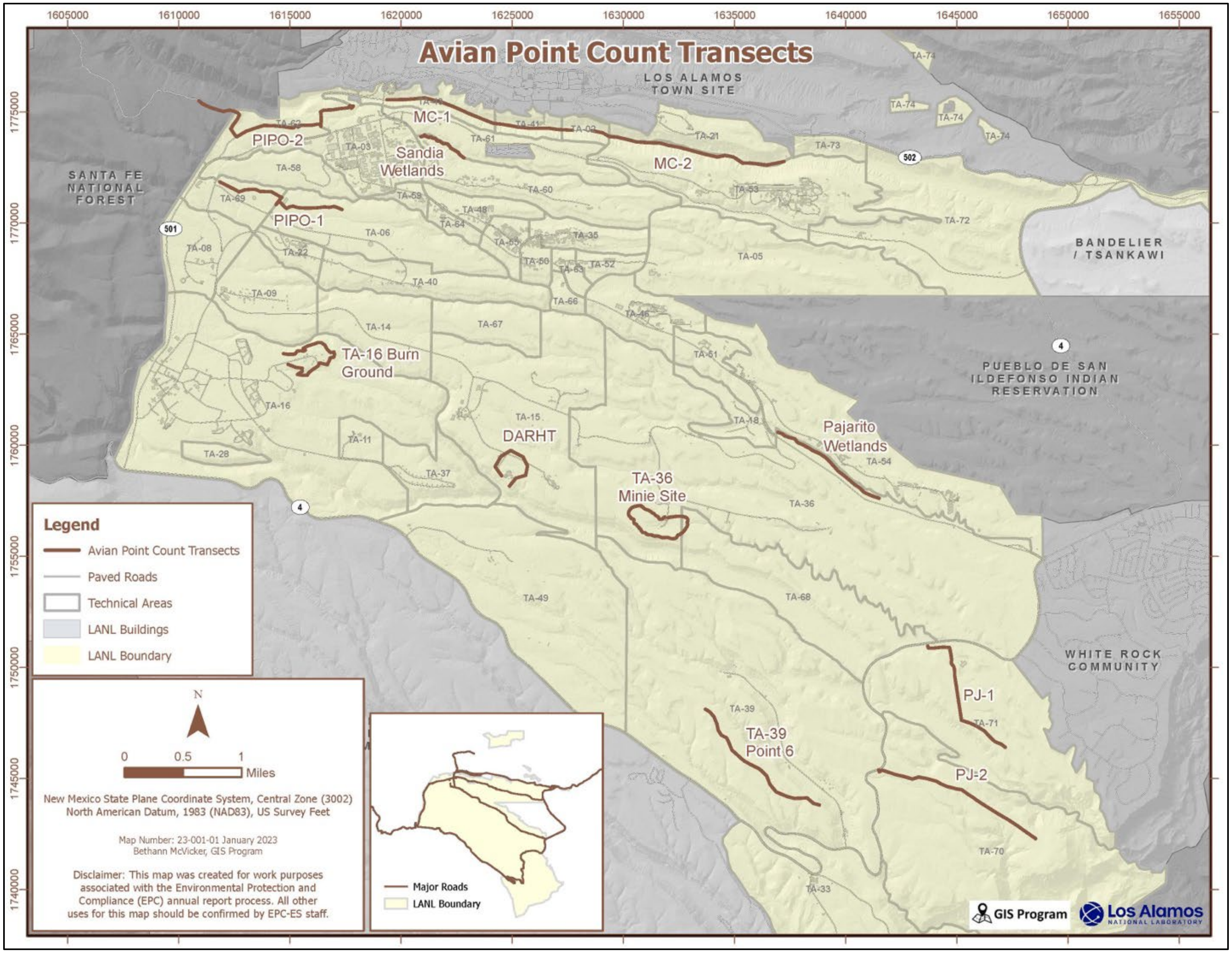

Figure 5. All avian point count transects around LANL ponderosa pine forest (PIPO) and piñon-juniper woodland (PJ). MC = mixed conifer.

2.2 Statistical Methods for Point Counts

In 2024, we improved our data processing workflow by identifying mislabeled location identification numbers that resulted in omitted data in past reports. The addition of these data does not qualitatively change the overall trends reported on in previous years, but we have updated values for all analyses in this document. We summarized breeding bird survey data to compare abundance, species richness, and Shannon's diversity between treatment and control sites and over time. We considered each treatment site and control to be an individual community and compared averaged metrics by combining treatment and control sites within the same habitat class.

Abundance is the total number of individuals recorded of a given species (Gotelli and Colwell 2011). Species richness is the number of different species represented in an ecological community and is simply a count of species (Boulinier et al. 1998). Species diversity is a measure that considers species richness and the overall abundance to compare evenness across a community (Tramer 1969). As a species diversity metric, we used Shannon's diversity index, which measures the probability that two individuals randomly selected from a sample will belong to different species (Shannon and Weaver 1949; Clarke et al. 2014). We used the diversity index to compare diversity between treatment and control sites. Shannon's diversity ranges for most ecological systems are between 1.5 and 3.5 and are rarely greater than 4.5, where higher values indicate higher diversity.

We calculated all community metrics using the statistical software R (version 4.4.0; R Core Team 2024) and the package *vegan* (Dixon 2003) and used simple linear models to estimate coarse trends across the study period. We used Hutcheson's t-tests in the R package *ecolTest* (Salinas and Ramirez-Delgado 2021) to test for differences between treatment and combined (averaged species abundances) control site diversity for each year from 2013 through 2023.

2.3 Field Methods for Nest Box Monitoring

In 2011, we added nest boxes to TA-36 Minie and TA-39 (Figure 1 and Figure 2). In 2015, we added nest boxes to TA-16 (Figure 3). In 2017, we added 15 nest boxes to DARHT (Figure 4). Beginning in May, we monitored nest boxes every 1 to 2 weeks for active nests. When an active nest was found, we monitored it more frequently to determine whether the nest failed or successfully fledged young. We also banded nestlings and determined the sex after the age of 10 days.

2.4 Statistical Methods for Nest Boxes

For the 2024 report, we made significant improvements to our data analysis. We reduced the control locations for nest boxes to make more accurate comparison to treatment sites. For PIPO control sites, we compared TA-16 and DARHT with nearby Anchor Ranch and DX building nest boxes, both of which are at similar elevations and have PIPO-dominated habitat. For PJ control sites, we compared TA-39 and TA-36 Minie to nest boxes in Ancho Canyon and Cañada del Buey. which are at comparable elevations and have PJ dominated habitat. We have rerun and presented all nest box analyses with this refined dataset. We calculated overall occupancy and site- and habitat-specific nest success rates of the nest boxes at the four treatment sites and in the overall network. For all monitored sites, the occupancy rate was the number of active nest boxes divided by the total number of nest boxes. The overall occupancy is an estimate because the number of nest boxes available to birds in any given year and site shifts and are not regularly recorded. Similarly, the nest success rate was the number of nest boxes that successfully fledged young divided by the number of active nest boxes. We compared the 2024 data from the four treatment sites with the overall avian nest box network at LANL, which was established in 1997 (Fair and Myers 2002). Because the overall nest box network comprises habitats and conditions not present at treatment sites, we also selected control sites that closely matched habitat type and nest box number of comparable treatment sites to examine nesting success metrics in a more balanced design. We calculated and plotted mean nest occupancy and success estimates by treatment and control sites between habitats across all study years.

As an additional comparison of nest success between control and treatment sites, we modeled nest success as a binary variable using a logistic mixed model in the R package *brms* (Bürkner 2017). We fit the model with a Bernoulli response family and tested the effect of year, site type (treatment or control), site habitat, and interactions among year and site type and year and site habitat. We controlled for location variation in nest success by including a random intercept of location. The model ran for 10,000 iterations with default priors, keeping only every 10th iteration, and we discarded the first 5,000 iterations as burn-in. We evaluated model convergence and fit by ensuring that effective samples sizes of parameter estimates >1,000 and Rhat values were around 1.0. We extracted and plotted model predictions with the conditional_effects() function.

2.5 Field Methods for Egg and Nestling Sample Collection

We collect eggs and nestlings from nest boxes when the eggs and nestlings are determined to be nonviable based on documented timing of known incubation periods for the species. In 2024, we collected a total of eight nonviable eggs and one deceased nestling from LANL and Bandelier National Monument. At TA-16 Burn Ground, we collected one nonviable western bluebird egg, which we submitted as an individual sample. At TA-36 Minie, we collected three western bluebird eggs from one nest and submitted it as a composite sample. At TA-39 Point 6, we collected one nonviable western bluebird egg and submitted it as an individual sample. At DARHT, we collected one nonviable western bluebird egg and submitted it as an individual sample. Additionally, we collected two egg samples from Bandelier National Monument; one western bluebird egg sample was collected and submitted as an individual sample, and one ash-throated flycatcher egg was collected and submitted as an individual sample. One deceased nestling was collected near the TA-16 Burn Ground. All samples were collected during May through July of 2024. Concentrations of PFAS compounds in eggs and nestlings have been monitored at these locations, when available, since 2022.

2.6 Chemical Analyses for Egg and Nestling Samples

Due to limited sample mass, nonviable eggs and deceased nestling samples were analyzed for PFAS only. Samples were analyzed at Eurofins Environmental Testing in Sacramento, California. PFAS compounds were analyzed by liquid chromatograph triple quadrupole mass spectrometry (EPA:1633). Note, prior to 2024, avian egg and nestling samples were analyzed for PFAS via 537.1M at GEL Laboratories in Charleston, South Carolina. All results were reported on a ng/g (nanogram per gram) wet weight basis.

2.7 Statistical Methods for Egg and Nestling Samples

The 2024 results were compared with the regional statistical reference levels (RSRLs), which represent natural and fallout levels of chemicals and are the upper-level bounds of background concentrations (mean + three standard deviations = 99% confidence interval). The RSRLs for eggs were calculated from nonviable eggs of western bluebirds and ash-throated flycatchers collected from Bandelier National Monument from 2022 through 2024 ($n = 6$ samples). The RSRLs for nestlings were calculated from deceased nestlings of western bluebirds collected from Bandelier National Monument from 2022 ($n = 2$ samples). Nonviable egg and nestling results are also compared with the levels associated with adverse effects from peer-reviewed literature, when available.

3 RESULTS

3.1 Point Count Surveys

LANL biologists completed three surveys at each of the three treatment sites and PIPO control sites between May and July 2024. Table 1 summarizes the species richness, diversity, and abundance for 2024 for each treatment and control site. A total of 946 birds representing 65 species were recorded at the treatment sites. A full account of the 2013–2024 data is detailed in Appendix A.

Table 1. Species Richness, Diversity, and Abundance Recorded during 2024 at All Treatment and Control Sites

	Minie	TA-39	PJ Control 1	PJ Control 2	TA-16	DARHT	PIPO Control 1	PIPO Control 2
Richness	39	39	39	35	41	48	39	44
Diversity	3.16	3.07	2.83	3.04	3.28	3.37	3.18	3.04
Abundance	263	301	337	291	273	251	359	502

Overall bird abundance has trended similarly for both treatment and control. Figure 1 and Table B-1 detail abundance measured across all years for all sites. Overall abundance has tended to increase since 2013, with minor fluctuations and no clear pattern that indicates bird numbers are reduced at treatment sites (Figure 6, Table 1, and Table B-1). Mean annual abundance significantly increased at control ($t = 2.91$, $p = 0.01$) and treatment ($t = 3.93$, $p<0.01$) PJ-dominated sites, and at control sites dominated by PIPO ($t = 3.21$, $p<0.01$). Mean annual abundance estimates trended higher at PIPO control sites than at comparable firing sites since 2016, with years of substantial overlap in site-specific abundances (Figure 6). Surveys began at DARHT in 2017 and increased raw abundance at combined PIPO treatment sites; however, mean estimates were calculated using survey-specific abundance values and account for the number of sites.

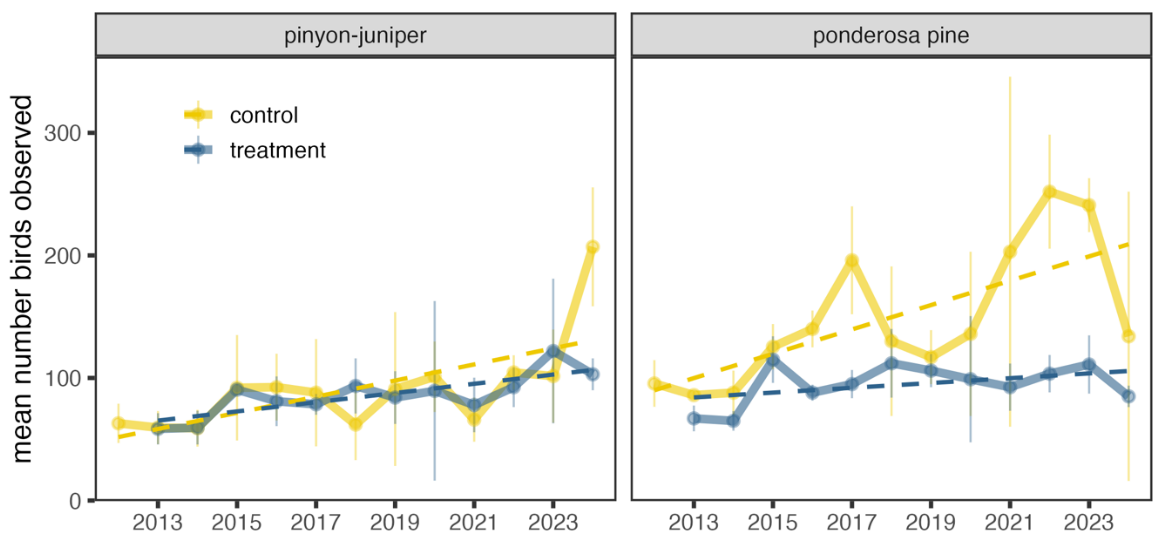

Figure 6. Mean bird abundances across all years of data collection for control (gold) and treatment (blue) compared by habitat type. Points indicate mean abundance from all annual surveys per treatment and control site. Vertical lines show standard error among surveys and sites. Thick solid lines connect annual means to show variability in trends. Dashed lines show simple linear model fits.

Figure 7 and Table B-2 illustrate changes in species richness over time at the treatment and control sites. Overall, the mean richness at treatment sites has marginally increased with annual fluctuations since monitoring began (Figure 7 and Table B-2). Species richness increased significantly across all years combined occurred at both PJ treatment and control sites ($t = 3.33$, $p < 0.01$; Figure 7). Species richness at both treatment and control sites in both habitat types has trended together, with average richness slightly higher at treatment sites than at control sites for most years. Though slight increasing trends seem promising, we cannot rule out that survey effort and detectability have changed across the study period, leading to increased identification ability. Future data collection should include surveyors' names to control surveyor variability in ongoing analyses.

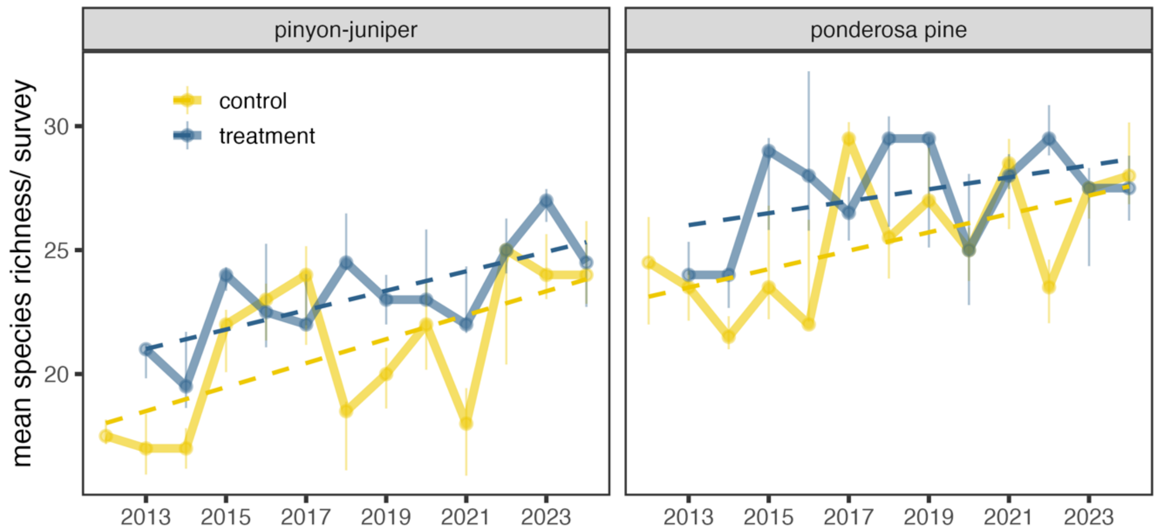

Figure 7. Mean bird species richness across all years of data collection for control (gold) and treatment (blue) compared by habitat type. Points indicate mean richness from three annual surveys per site. Vertical lines show standard error among surveys and sites. Thick solid lines connect annual means to show variability in trends. Dashed lines show simple linear model fits.

Figure 8 and Table B-3 through Table B-10 illustrate variation in species diversity over time between the treatment and control sites. Both treatment sites in PJ habitat and DARHT in PIPO habitat have historically had higher total diversity than the comparable control sites, and TA-36 Minie's diversity rose from a substantial drop in 2023 (Table B-3 through Table B-10). Across the entire study window in all significantly different comparisons, the diversity was higher at the treatment site than the combined controls (Table B-3 through Table B-10). Though we see substantial differences between treatment and control diversity in certain years, the total bird diversity at all sites has remained similarly high among both treatment and controls. Per-survey diversity indices between treatment and control sites in PIPO habitat diverge in 2017, driven by the addition of DARHT surveys (Figure 8). The location and additional security restrictions of firing sites reduce daily ambient disturbance from pedestrians, traffic and constructions. These lower disturbance conditions at Weapons Facilities Operations relative to control sites are likely driving the higher diversity we observed at treatment sites.

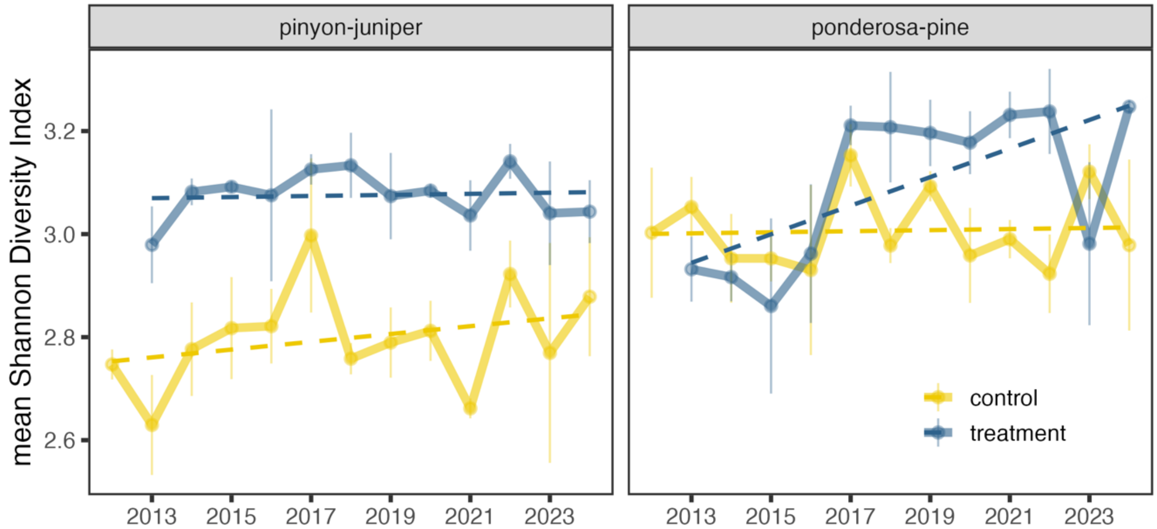

Figure 8. Mean Shannon Diversity Index across all years of data collection for control (gold) and treatment (blue) compared by habitat type. Points indicate mean diversity from three annual surveys per site. Vertical lines show standard error among surveys and sites. Thick solid lines connect annual means to show variability in trends. Dashed lines show simple linear model fits.

3.2 Nest Boxes

During the 2024 nesting season, LANL biologists actively monitored 15 nest boxes at each treatment site and a total of 356 nest boxes throughout the overall avian nest box network. Of those, 124 contained active nests, and 60 of those nests fledged young successfully, for an overall occupancy rate of 35 percent and a success rate of 48 percent. Figure 9 and Table B-11 compare the nest success rates for each treatment site and from the combined treatment and control nest boxes from 2014 through 2024.

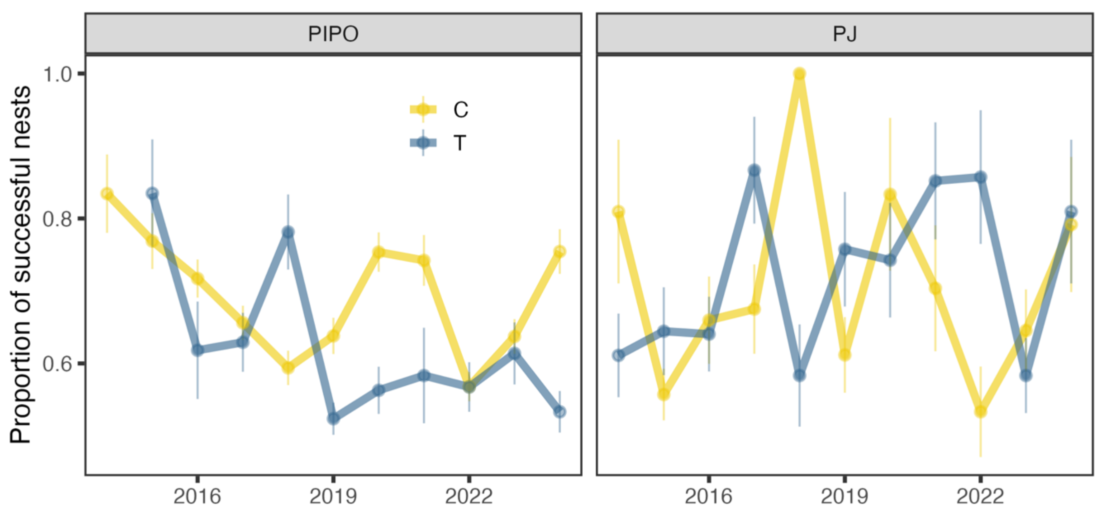

Figure 9. Mean proportion nest success across study period for treatment sites (blue) and control sites (yellow) in ponderosa pine habitat (left panel) and piñon-juniper habitat (right panel). Lines connecting sequential year's values to illustrate trends. Vertical lines represent standard error around mean values.

In 2024, three nests fledged young at TA-36 Minie, four at TA-16, and one at TA-39. Occupancy at TA-39 continues to be low compared with the other treatment sites and the overall network. The nest success rate at TA-39 has been highly variable since monitoring began in 2015, ranging between 0 percent and 100 percent. The high variability of nest success at TA-39 is due to the scarcity of occupied nest boxes. TA-39 is the lowest elevation treatment site. Wysner et al. (2019) found that western bluebirds, one of the target species of the network, have increased their nesting elevation over time in the study area. This shift in elevation is likely not due to individual nesting site preferences and more likely due to immigration of birds into the population (Abeyta et al. 2021). Upslope emigration out of TA-39 is a possible contributor to the low occupancy and variable nest success rates at this site. Success rates at both lower elevation PJ-dominated treatment sites (TA-36 Minie and TA-39) have fluctuated annually and have not displayed a decreasing trend over time. Nest success at PIPO-dominated firing sites (DARHT and TA-16) has been less variable over the last 5 years than PJ-dominated sites, showing slight decreasing trends since monitoring began in 2015 and 2017 (Figure 10).

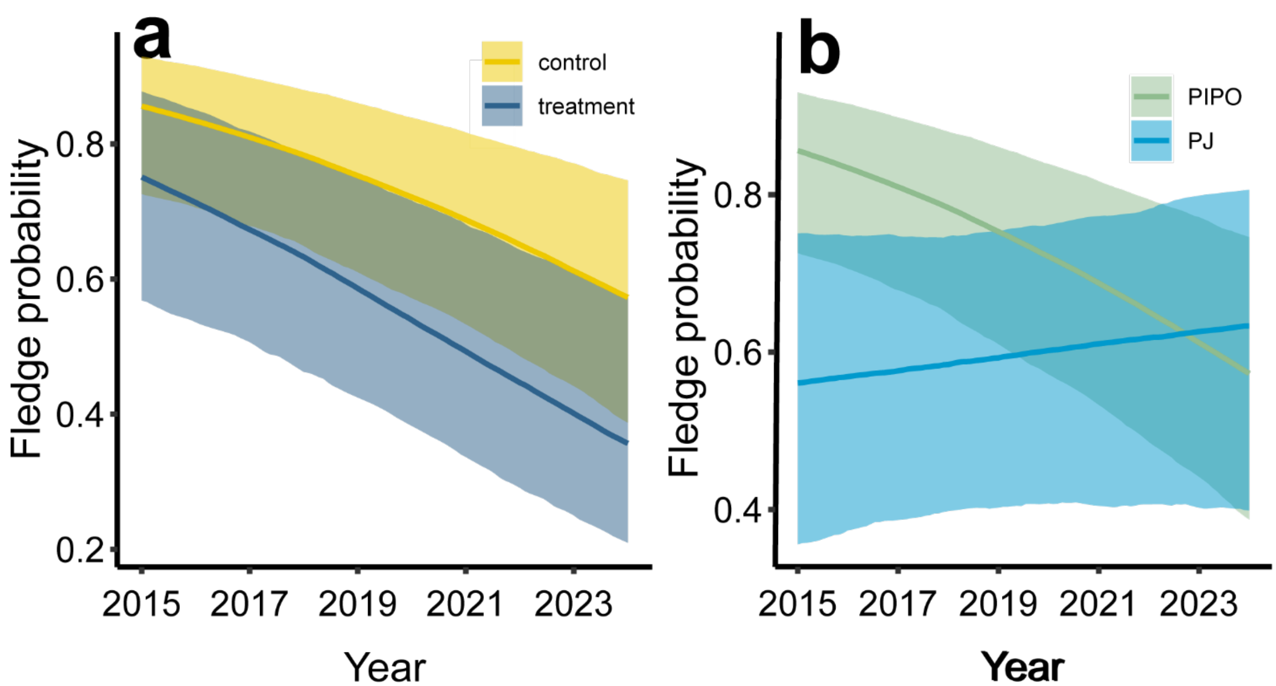

Figure 10. Probability of nest success over time. Bayesian model estimates from logistic models of nest success. Lines show median posterior estimates from models. Bands indicate 95 percent credible intervals. **(a)** Probability of nest success over time between control and treatment sites. **(b)** Probability of nest success over time between ponderosa pine (PIPO) and piñon-juniper (PJ) habitat types.

Nest success also varied between habitat types but contradicted the within-habitat-type nest success patterns (Figure 10a). In PIPO habitat, the proportion of nest success combined across all years was significantly lower at treatment sites relative to control sites (TA-16 and DARHT; $t = -5.292$, $df = 517.39$, $p < 0.01$). There was no discernable difference combined across all years between treatment and control sites in PJ habitat (Minie and TA-39; $t = 1.11$, $df = 248.77$, $p = 0.268$). Logistic modeling of nest success showed a general decline over time in the probability of successfully fledging young among both control and treatment sites (Figure 10a). The model estimated an interaction between habitat type and the probability of successfully fledging young with probability of success declining in PIPO habitat over time and marginally increasing in PJ habitat (Figure 10b). These results both suggest that long-term climatic trends are responsible for general declines in nest success among cavity-nesting birds at LANL rather than impacts from firing sites.

3.3 Chemical Analyses

In 2024, we submitted a total of six nonviable egg samples and one nestling sample for PFAS analyses. All samples were analyzed for 39 PFAS compounds, and detectable PFAS concentrations were compared with RSRLs. Perfluorooctanesulfonic acid (PFOS) was the most commonly detected PFAS compound and was observed in all samples from all locations, with a range of 7.6 to 16.0 ng/g in eggs and 24.0 ng/g in the nestling sample.

The one western bluebird nestling sample (n = 1) from a nest box near TA-16 Burn Ground contained two PFAS compounds—PFOS and perfluoroundecanoic acid—at 24.0 ng/g and 0.26 ng/g respectively. Only PFOS was above the RSRL of 2.15 ng/g.

Six PFAS compounds were detected in the one western bluebird egg sample collected from a nest box near TA-16 Burn Ground. All of the PFAS compounds detected were below the RSRLs except for one compound—perfluorohexanesulfonic acid—which was detected at a very low level of 1.40 ng/g (Table 2). The level detected for perfluorohexanesulfonic acid was slightly above the RSRL in passerine eggs at 0.932 ng/g.

The one western bluebird egg sample from a nest box near TA-36 Minie contained detectable PFAS but all were below the RSRLs (Table 2).

The one western bluebird egg sample collected from a nest box near TA-39 Point 6 contained two detectable compounds: perfluorohexanesulfonic acid at 1.30 ng/g and PFOS at 16 ng/g. Both perfluorohexanesulfonic acid and PFOS were above the RSRLs in passerine eggs, at 0.932 ng/g and 11.8 ng/g, respectively.

The one nonviable western bluebird egg sample collected from a nest box near DARHT contained PFOS at 11.0 ng/g, which was below the RSRL (Table 2).

Table 2. PFAS Concentrations (ng/g wet weight) Detected in Western Bluebird Egg Samples Collected from the Treatment Areas*

Element (ng/g)	TA-16 (n = 1) SFB-24-335583	TA-36 (n = 3) SFB-24-335578	TA-39 (n = 1) SFB-24-335479	DARHT (n = 1) SFB-24-335307	RSRL
Perfluorodecanoic acid	Not Detected	0.48	Not Detected	Not Detected	5.55
Perfluorododecanoic acid	Not Detected	0.27	Not Detected	Not Detected	3.89
Perfluorohexanesulfonic acid	**1.40**	0.53	**1.30**	Not Detected	0.932
Perfluorononanoic acid	2.70	1.10	Not Detected	Not Detected	4.11
Perfluorooctanesulfonic acid	7.60	8.10	**16.0**	11.0	11.8
Perfluorooctanoic acid	Not Detected	0.37	Not Detected	Not Detected	1.96
Perfluorotetradecanoic acid	1.30	Not Detected	Not Detected	Not Detected	4.00
Perfluorotridecanoic acid	1.90	Not Detected	Not Detected	Not Detected	5.98
Perfluoroundecanoic acid	1.20	0.55	Not Detected	Not Detected	4.45

*The RSRL is the upper limit background concentrations (mean + three standard deviations) for passerine eggs; bolded values are above the RSRL.

Overall, most PFAS were not detected, and most of those that were detected in avian samples were below the RSRLs; only perfluorohexanesulfonic acid and PFOS were above the RSRLs. Although perfluorohexanesulfonic acid is not as well-studied as other PFAS compounds (such as PFOS), an adverse effect from PFOS in avian eggs was determined at 92.4 ng/g (Dennis et al. 2021). The concentrations observed here are well below the levels associated with adverse effects. Additionally, the PFAS concentrations observed here are within the ranges observed in avian tissues from published studies, including studies that occurred away from point-source pollution and in the Arctic, where global deposition (or fallout) is the primary source of PFAS in the environment (Kannan et al. 2002; Martin et al. 2004). We are exploring other potential sources for some of the PFAS chemicals detected at LANL. Anticipated sources are atmospheric deposition and historical use of PFAS-containing materials.

4 DISCUSSION

In addition to supporting federally protected bird species such as the Mexican spotted owl (*Strix occidentalis lucida*) and the southwestern willow flycatcher (*Empidonax traillii extimus*), habitat on LANL property is important for migratory bird conservation. During the 11-year study period, LANL biologists have documented sensitive species from the “Sensitive Species Best Management Practices Source Document” (Berryhill et al. 2020) and the “Birds of Conservation Concern 2021” (USFWS 2021) at the treatment sites. Those species are Cassin’s finch (*Haemorhous cassinii*), juniper titmouse (*Baeolophus ridgwayi*), Grace’s warbler (*Setophaga graciae*), Virginia’s warbler (*Leiothlypis virginiae*), black-throated gray warbler (*Setophaga nigrescens*), evening grosbeak (*Coccothraustes vespertinus*), peregrine falcon (*Falco peregrinus*), pinyon jay (*Gymnorhinus cyanocephalus*), and mourning dove (*Zenaida macroura*). The gray vireo (*Vireo vicinior*) is the only sensitive species documented at control sites only. Of the 91 species detected at the four treatment sites, the Migratory Bird Treaty Act protects all but one species: the Eurasian collared-dove (*Streptopelia decaocto*), which is not native and is therefore not protected under the Migratory Bird Treaty Act.

Overall comparisons provide little evidence for firing sites’ potential negative impact on birds. Through further data collection and refining analyses to appropriately control for uneven sampling and site-specific variation, we gain to improve our understanding of differences between bird communities and productivity at treatment and control sites. It is likely that features of the local habitat, climate trends, and disturbance levels interact in complex ways that might obscure signals in the absence of large, long-term datasets. Continuing to document migratory bird occurrences and nest success among treatment and control sites will only increase our ability to detect such signals should they exist, allowing LANL biologists to assess the ecological health of bird communities at the three firing sites and one open burn site at LANL.

Anthropogenic noise variation has been documented to affect bird behavior (Derryberry et al. 2020; Bernat-Ponce, Gil-Delgado, and López-Iborra 2021). Because a primary disturbance of concern at the open firing sites is intermittent noise, we suggest measuring sound levels within the local bird communities using passive acoustic recording devices between and during firing operations and comparing those levels against appropriate controls.

The overall chemical analysis results indicate that the levels of constituents detected in eggs are not likely to cause adverse effects in breeding bird populations from these study sites. The majority of PFAS results were either not detected or were below RSRLs. These results suggest that the detectable concentrations observed here are not of ecological concern. More data from nonviable eggs and nestlings are needed to make a robust assessment and to examine trends over time. Evaluating avian nestling samples for high explosives is also of interest for future work as those samples become available.

This research meets requirements set forth by the Resource Conservation and Recovery Act permit while also meeting the Department of Energy's commitments under the Migratory Bird Treaty Act and the associated memorandum of understanding with the U.S. Fish and Wildlife Service. It also allows LANL to contribute to national goals in avian conservation monitoring and research.

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7 ACRONYMS AND ABBREVIATIONS

Acronym	Definition
DARHT	Dual-Axis Radiographic Hydrodynamic Test Facility
LANL	Los Alamos National Laboratory

Acronym	Definition
ng/g	nanograms per gram
PFAS	per- and polyfluoroalkyl substances
PFOS	perfluorooctanesulfonic acid
PIPO	ponderosa pine forest
PJ	piñon-juniper woodland
RSRL	regional statistical reference level
TA	technical area

Appendix A Tables of 2013–2024 Species Abundances among Firing Sites

Table A-1. Detected Species Abundances at TA-36 Minie Site (Piñon-Juniper Woodland Habitat)

Species	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Acorn woodpecker												
American crow												
American kestrel				1				1	1			1
American robin	1	1	2		2					5	1	4
Ash-throated flycatcher	11	5	14	13	13	10	17	12	12	7	5	3
Audubon’s warbler		2				5				1	2	4
Bewick’s wren	4	8	9	9	14	14	5	10	4	5	6	6
Black-chinned hummingbird		1	1				1	2	1	2	1	1
Black-headed grosbeak	1	3				1	1	2	1			
Black-throated gray warbler			1		2			2			1	
Blue-gray gnatcatcher	3	14	16	8	10	9	8	11	8	14	9	13
Blue grosbeak												
Broad-tailed hummingbird	2	1	3		1		3	2		5		6
Brown creeper												
Brown-headed cowbird	1								1			
Bullock’s oriole												
Bushtit		2		2		11				12	1	
Canada goose												
Canyon towhee	2		5	3	6	2	3	5	3			
Canyon wren					1							
Cassin’s finch						4						
Cassin’s kingbird	6	13	13	5	2	5	6	5	4		6	13
Chipping sparrow	3	16	17	29	6	22	10	10	10		18	23
Clark’s nutcracker												
Common nighthawk	6		5	2	4	4	1	5				1
Common raven	2	5	1		1	2	3			12	2	1

Species	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Cooper’s hawk					1							
Cordilleran flycatcher												
Dark-eyed junco												
Downy woodpecker				1								
Dusky flycatcher				1								
Eurasian collared-dove	3											
Evening grosbeak	3		4						1			2
Grace’s warbler							1				1	
Gray flycatcher	12	6	5	7	3	6	3	2	4	8	3	2
Great horned owl		3										
Green-tailed towhee	3	1								1		
Hairy woodpecker			2	1		1		1	1	1		1
Hammond’s flycatcher												
Hepatic tanager									2		1	
Hermit thrush						1						
House finch	16	17	26	17	12	18	17	11	11	17	7	21
House wren												
Juniper titmouse	12		7	6	9	3	26	8	20	3	5	5
Lark sparrow										2	2	2
Lesser goldfinch	2	6	7	4	9	12	8	4	4	8	1	6
MacGillivray’s warbler												
Merlin											1	
Mountain bluebird		2	20	10	11	1	9	3	2	5	5	2
Mountain chickadee	5	2	1	2						5		
Mourning dove	17	17	13	5	8	8	11	9	7	9	9	10
Northern mockingbird					2		1	4		8		1
Northern rough-winged swallow						3						
Olive-sided flycatcher												
Orange-crowned warbler												
Painted redstart												
Peregrine falcon									1			

Species	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Pine siskin	10	2		5	1			1				3
Pinyon Jay												30
Plumbeous vireo	10	10	7	3	9	9	15	3	3	7	6	5
Pygmy nuthatch				2		2	3		1			
Red crossbill					1							5
Red-shafted flicker	3	1	3	2	5	2	1		1	1	2	3
Red-tailed hawk							1	2	1			
Rock wren	3	3	4		2	10	11	10	4	5	5	13
Ruby-crowned kinglet												
Savannah sparrow												
Say's phoebe	2	1	2		2	5	1	1	2	2	1	3
Scaled quail			1									
Spotted towhee	17	8	19	27	32	24	19	20	17	18	12	30
Steller's jay							1					
Townsend's solitaire	1									1		1
Turkey vulture					1			2		2		
Vesper sparrow												
Violet-green swallow		5	7	1	3	2	1	6		3	3	1
Virginia's warbler					1	3	1					
Warbling vireo						2						
Western bluebird	15	11	18	17	16	19	21	23	8	11	5	14
Western tanager		2	3		1							
Western wood-pewee	10	8	18	11	10	7	18	14	10	13	3	3
White-breasted nuthatch	1	4	9	10	13	5	2	1	2	1		7
White-crowned sparrow											1	
White-throated swift												4
White-winged dove	1	5	9	2		3	2	1	1		1	1
Willow flycatcher												
Wilson's warbler												
Woodhouse's scrub-jay	5	1	3	4	8	7	14	10	10	7	6	11

Table A-2. Detected Species Abundances at TA-39 Point 6 (Piñon-Juniper Woodland Habitat)

Species	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Acorn woodpecker											4	1
American crow												
American kestrel	1			2					2			
American robin	1	1		2		4	2				1	
Ash-throated flycatcher	19	11	30	12	8	8	6	11	4	7	10	4
Audubon’s warbler				2				5		3	7	3
Bewick’s wren	3	10	15	9	2	8	1	2		1		
Black-chinned hummingbird	3	2				1	2	3			2	
Black-headed grosbeak		2	4	1		3	2	1	1	1		1
Black-throated gray warbler	5	6	4								3	1
Blue-gray gnatcatcher	2		7	5	4	2	13	5	2	13	11	10
Blue grosbeak									1			
Broad-tailed hummingbird	3	1	2		3	1	2	9	3	2		4
Brown creeper												
Brown-headed cowbird			2			3	2	10	3	12	5	5
Bullock’s oriole										1	2	
Bushtit	2	14			1	12		2				
Canada goose			16				2					
Canyon towhee	1	1	2	10	13	19	6	3	9	5	2	5
Canyon wren			2	3	8	6	2	4			3	1
Cassin’s finch												
Cassin’s kingbird	7	6	2	21	21	32	37	49	14	41	35	40
Chipping sparrow	6	6	5	8	15	25	27	24	16	20	19	22
Clark’s nutcracker												
Common nighthawk	5	1	3	2	7	5	7	3	1	6		
Common raven	1		2	1		1	2	5		2	4	1
Cooper’s hawk												
Cordilleran flycatcher												
Dark-eyed junco						1	1					
Downy woodpecker				1	2		1	2	1			

Species	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Dusky flycatcher			1		1					1		1
Eurasian collared-dove					4			2				
Evening grosbeak			8									
Grace’s warbler						2	4	1	6	3	6	2
Gray flycatcher	10	10	11	10	5	8	3	14	5	6	13	7
Great horned owl	1											
Green-tailed towhee	1											
Hairy woodpecker			5	3			1	1	4			3
Hammond’s flycatcher												
Hepatic tanager			1	2	1	2			1			2
Hermit thrush												
House finch	21	4	23	9	30	44	50	53	22	41	31	48
House wren							1					
Juniper titmouse	11	13	18	6	1			3	2	3		1
Lark sparrow												
Lesser goldfinch	4	12	9	10	14	19	15	27	8	31	13	8
MacGillivray’s warbler												
Mountain bluebird		4						2	1			
Mountain chickadee				1	1		1					
Mourning dove	13	22	10	3	15	11	8	10	9	16	7	15
Northern mockingbird		1							2	19	1	
Northern rough-winged swallow												
Olive-sided flycatcher												
Orange-crowned warbler											2	
Painted redstart												
Peregrine falcon			1						1			
Pine siskin	6		3	3						1	2	2
Plumbeous vireo	1		1	6	6	5	5	12	4	9	6	4
Pygmy nuthatch			2	4	12	9	11	10	1	8		6
Red crossbill		2						1				

Appendix A: Tables of 2013–2024 Species Abundances among Firing Sites

Species	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Red-shafted flicker	3	2	4	8		3	2	2		4	3	2
Red-tailed hawk			1	1	1	1					1	1
Rock wren	7	10	4	12	14	14	12	20	15	14	12	19
Ruby-crowned kinglet												
Savannah sparrow												
Say’s phoebe	2	1		5	2	4		6	5		2	
Scaled quail												
Spotted towhee	12	6	33	16	12	16	15	20	14	20	18	21
Steller’s jay												
Townsend’s solitaire												
Turkey vulture								1				4
Vesper sparrow												
Violet-green swallow	6	4	1	9	6	6	9	47	5		8	11
Virginia’s warbler			1	2	4		5		2	3		1
Warbling vireo												
Western bluebird	5	19	12	21	13	6	7	17	3	4	10	12
Western tanager		2	1	1	2	2	6	1	2	4		1
Western wood-pewee		4	2	10	8	11	12	18	12	16	3	8
White-breasted nuthatch			2	4	4	2	6	3	2	3	3	5
White-crowned sparrow									1			
White-throated swift		1						2				1
White-winged dove	7	5	6	16	15	15	5	2	5	7	1	11
Willow flycatcher									1			
Wilson’s warbler												
Woodhouse’s scrub-jay	8	10	4	8	6	4	5		2	3		1
Yellow-breasted chat											1	

Table A-3. Detected Species Abundances at TA-16 Burn Ground (Ponderosa Pine Forest Habitat)

Species	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Acorn woodpecker	5		3	2	3	5	3	5	1		2	2
American crow					1	1		1	1	5	2	2
American kestrel												
American robin	7		9	4	4	6	12	6	14		4	9
Ash-throated flycatcher	3	5	6	2	3	8	4	6	6	11	4	1
Audubon’s warbler	6	5	1	6		1	11	14	9	5	10	5
Bewick’s wren												
Black-chinned hummingbird	1		1		1		1	12	1			
Black-headed grosbeak			1	2		2		1	1	1	2	
Black-throated gray warbler												1
Blue-gray gnatcatcher		6	2	1	3	6	4	9	3	9	4	4
Blue grosbeak												
Broad-tailed hummingbird	5	11	11	5	7	10	8			11	6	10
Brown creeper	1											
Brown-headed cowbird	4	1			4	2	8	4	4	3	3	2
Bullock’s oriole												
Bushtit												
Canada goose												
Canyon towhee	1			1		1						
Canyon wren			2									
Cassin’s finch									1			2
Cassin’s kingbird				1				2		1		
Cedar waxwing												2
Chipping sparrow	1	5	3	10	5	21	8	32	6	19	12	19
Clark’s nutcracker		4		1								
Common nighthawk			1	2	2			1				
Common raven	5	6	2	2	5	5	7	4	2	9	5	12
Cooper’s hawk	1			1			1					
Cordilleran flycatcher	5	10	6	3	3	1	2	4		2	2	
Dark-eyed junco	6	2	4		5	2		2	3	3	1	2

Species	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Downy woodpecker		1		1	1	1						
Dusky flycatcher								2	1	1	2	7
Eurasian collared-dove						1						
Evening grosbeak	5		29			1						
Grace’s warbler	6	4	4	8	5	8	22	12	17	11	12	8
Gray flycatcher											1	1
Great horned owl												
Green-tailed towhee								1				
Hairy woodpecker	1	1		1	1	2	1	1				3
Hammond’s flycatcher	8	9	12	5	7	5	10	5	7	1		1
Hepatic tanager				1								
Hermit thrush		4	6	1	2	2	5	5	2	2	2	1
House finch	16	2	5	5	12	7	12	18	11	20	15	9
House wren	1	1		2	2	6	8	2	1	2		
Juniper titmouse												
Lark sparrow												
Lesser goldfinch	3		8	9	4	8	5	6	2	9	1	7
MacGillivray’s warbler				1	3			1		1		1
Merlin												
Mountain bluebird			4	4	4	7	4	5				1
Mountain chickadee	5	8	9	6	8	9	1	4	6	6		
Mourning dove	4		1	3	17	3	5	17	5	2	1	4
Northern mockingbird												
Northern rough-winged swallow												
Olive-sided flycatcher												
Orange-crowned warbler								1		1	1	
Painted redstart										1		
Peregrine falcon												
Pine siskin	12	4	5		4	2		6		1	5	1
Plumbeous vireo	11	16	15	14	11	18	16	24	17	19	7	11

Appendix A: Tables of 2013–2024 Species Abundances among Firing Sites

Species	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Pygmy nuthatch	11	13	26	29	41	20	16	23	5	21	6	20
Red crossbill		2	9	13	9		6	26	1			11
Red-shafted flicker	3	4	11	11	5	5	2	7	5	7	5	5
Red-tailed hawk										1		1
Rock wren	1	2	2	6			4	1			4	1
Ruby-crowned kinglet						2			1			3
Savannah sparrow								1				
Say’s phoebe	1		1	3	3	4	1	1	4		1	
Scaled quail												
Spotted towhee	11	18	16	14	21	22	34	24	16	23	16	25
Steller’s jay	3	2	5	6	3	4	4	2	1			3
Townsend’s solitaire					1							
Turkey vulture	1					1					1	2
Vesper sparrow							1					
Violet-green swallow		2	19	2	2	4	2	7	6	7	97	3
Virginia’s warbler	17	11	21	13	7	5	5	8	3	4	9	9
Warbling vireo	2	9	7	6	5	4	6	3	7	7	4	4
Western bluebird	20	20	49	37	32	27	20	27	8	32	16	31
Western tanager	2	3	7	2	4	6	16	10	7		8	4
Western wood-pewee	15	10	16	14	22	20	24	28	25	47	16	14
White-breasted nuthatch	9	8	7	9	20	10	10	8	10	9	4	11
White-crowned sparrow												
White-throated swift												
White-winged dove			1	2			1					
Willow flycatcher												
Wilson’s warbler												
Woodhouse’s scrub-jay	1										1	

Table A-4. Detected Species Abundances at Dual-Axis Radiographic Hydrodynamic Test Facility (Ponderosa Pine Forest Habitat)

Species	2017	2018	2019	2020	2021	2022	2023	2024
Acorn woodpecker		1	1	1		2		
American crow								2
American kestrel						1	1	
American robin	1		9	2	6	3		2
Ash-throated flycatcher	7	2	2	5	4	2		1
Audubon’s warbler		4	12	2	3	2	5	6
Bewick’s wren								1
Black-chinned hummingbird		1				1	1	2
Black-headed grosbeak		3	1			3	1	2
Black-throated gray warbler								
Blue-gray gnatcatcher	5	8	16	17	4	9	4	9
Blue grosbeak								
Brewer’s blackbird							1	
Broad-tailed hummingbird	3	4	5	10	1	7	5	4
Brown creeper								
Brown-headed cowbird		5	2	7	6	8	1	3
Bullock’s oriole								
Bushtit							1	
Canada goose								
Canyon towhee								
Canyon wren								
Cassin’s finch								
Cassin’s kingbird	9	14	13	1	15	10	9	8
Chipping sparrow	16	31	21	17	30	18	34	17
Clark’s nutcracker		1						
Common nighthawk								
Common raven	10	1	5	5	6	4		7
Cooper’s hawk								
Cordilleran flycatcher		1	1			3		1
Dark-eyed junco								2

Species	2017	2018	2019	2020	2021	2022	2023	2024
Downy woodpecker								
Dusky flycatcher						2		2
Eurasian collared-dove								
Evening grosbeak							2	1
Grace's warbler	6	8	12	4	7	6	1	6
Gray flycatcher			1		3		1	1
Great horned owl			2		2			
Green-tailed towhee								
Hairy woodpecker		1						
Hammond's flycatcher	1					1		
Hepatic tanager	1		1			2	1	2
Hermit thrush	1	1				1		
House finch	30	20	25	27	23	17	10	17
House wren								1
Juniper titmouse						2		
Lark sparrow	1	2			1		2	
Lesser goldfinch	19	12	20	25	5	9		10
Macgillivray's warbler								
Mountain bluebird	7	8	7	7	4	1	2	1
Mountain chickadee	3		7	7	4	1		
Mourning dove	1	1	5	5	7	6	5	5
Northern mockingbird		1		1	2	5	2	1
Northern rough-winged swallow			1					
Olive-sided flycatcher		1	1		3			
Orange-crowned warbler							1	
Painted redstart								
Peregrine falcon								
Pine siskin	1				3		2	2
Plumbeous vireo	11	14	19	14	9	12	2	9
Pygmy nuthatch	9	13	13	3	4	6	6	8
Red crossbill	4					4		8

Species	2017	2018	2019	2020	2021	2022	2023	2024
Red-shafted flicker	8	10	3	1	3	2		3
Red-tailed hawk	1		1			1	1	
Rock wren	2	1		1	2		3	3
Ruby-crowned kinglet								1
Savannah sparrow								
Say's phoebe	8	1	5	2	2	1		1
Scaled quail								
Spotted towhee	28	22	22	27	31	27	17	24
Steller's jay	1							
Townsend's solitaire		1				1		1
Turkey vulture	2	1		1			1	3
Vesper sparrow							1	2
Violet-green swallow	9	12	32	20	28	15	19	19
Virginia's warbler	12	8	4	1	8	2		4
Warbling vireo								1
Western bluebird	15	24	25	32	12	26	12	23
Western tanager	2	1	4	6	6	3	2	3
Western wood-pewee	14	19	22	14	17	25	4	10
White-breasted nuthatch	5	7	7	4	6	3	2	
White-crowned sparrow								
White-throated swift	8					3	1	3
White-winged dove		4	1	2		1	2	1
Willow flycatcher								
Wilson's warbler		2					2	
Woodhouse's scrub-jay	3					7	1	4

Appendix B Supplemental Statistics Tables

Table B-1. Yearly Species Abundance over Time for All Treatment and Control Sites

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Minie	193	186	275	210	222	242	245	203	209	229	134	263
TA-39	177	193	260	249	261	315	298	413	286	339	251	301
PJ Control 1	187	157	269	312	240	235	226	292	225	209	364	337
PJ Control 2	181	177	301	228	300	168	187	269	159	142	311	291
TA-16	220	209	347	271	302	285	310	389	283	340	406	273
DARHT	—	—	—	—	266	283	326	301	286	274	251	251
PIPO Control 1	258	223	432	323	447	374	364	373	349	337	382	359
PIPO Control 2	256	254	371	396	449	366	394	429	448	334	341	502

Table B-2. Yearly Species Richness over Time for All Treatment and Control Sites

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Minie	33	33	34	30	35	35	34	33	33	37	34	39
TA-39	31	31	39	38	34	36	38	40	38	36	40	39
PJ Control 1	29	30	33	36	37	30	30	37	33	43	42	39
PJ Control 2	30	29	37	33	39	23	33	32	25	22	37	35
TA-16	39	33	40	44	41	43	39	46	37	41	44	41
DARHT	—	—	—	—	36	44	37	41	42	45	44	48
PIPO Control 1	34	34	30	40	46	40	41	33	36	37	42	39
PIPO Control 2	33	36	43	43	44	39	40	40	44	36	41	44

Table B-3. T-tests Comparing Yearly Shannon Diversity between Minie Site with PJ Control 1

		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Minie		3.14	3.14	3.19	2.97	3.13	3.21	3.06	3.13	3.00	3.31	2.74	3.16
PJ Control 1		2.76	2.83	3.05	2.91	2.98	2.88	2.75	2.87	2.82	2.98	3.15	2.83
Hutcheson's t-test	t	−3.93	−3.06	−2.10	−0.68	−1.73	−4.38	−3.31	−2.99	−1.87	−3.59	−3.73	-3.49
	df	327	272	534	511	450	458	392	493	419	331	388	587
	p-value	<0.01	<0.01	0.04	0.50	0.08	<0.01	<0.01	<0.01	0.06	<0.01	2.21	<0.01

Table B-4. T-tests Comparing Yearly Shannon Diversity between Minie Site with PJ Control 2

		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Minie		2.81	2.87	3.05	3.03	3.20	2.59	2.90	2.86	2.54	2.69	2.81	3.17
PJ Control 2		2.76	2.83	3.05	2.91	2.98	2.88	2.75	2.87	2.82	2.98	3.15	3.04
Hutcheson's t-test	t	−3.64	−2.94	−2.06	0.81	0.88	−7.20	−1.81	−3.42	−4.46	−7.49	−3.22	-1.49
	df	337	328	563	436	490	312	346	471	299	252	345	547
	p-value	<0.01	<0.01	<0.01	0.42	0.38	<0.01	0.07	<0.01	<0.01	<0.01	<0.01	0.14

Appendix B: Supplemental Statistics Tables

Table B-5. T-tests Comparing Yearly Shannon Diversity between TA-39 with PJ Control 1

		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
TA-39		3.09	3.07	3.14	3.32	3.18	3.13	3.08	3.09	3.03	3.11	2.74	3.07
PJ Control 1		2.76	2.83	3.05	2.91	2.98	2.88	2.75	2.87	2.82	2.98	3.07	2.83
Hutcheson's t-test	t	−3.36	−2.42	−1.12	−5.34	−2.40	−3.27	−3.37	−2.52	−2.15	−1.31	−3.17	-2.50
	df	330	268	509	540	425	497	444	561	462	361	447	618
	p-value	<0.01	0.02	0.26	0.00	0.02	<0.01	<0.01	0.01	0.03	0.19	<0.01	0.01

Table B-6. T-tests Comparing Yearly Shannon Diversity between TA-39 with PJ Control 2

		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
TA-39		3.09	3.07	3.14	3.32	3.18	3.13	3.08	3.09	3.03	3.11	2.80	3.04
PJ Control 2		2.81	2.87	3.05	3.03	3.20	2.59	2.90	2.86	2.54	2.69	3.07	3.07
Hutcheson's t-test	t	−3.04	−2.22	−1.13	−3.89	0.31	−6.21	−1.94	−2.92	−4.70	−4.90	−2.60	-0.33
	df	337	325	542	440	561	325	396	578	319	279	385	588
	p-value	<0.01	0.03	0.26	<0.01	0.76	<0.01	0.05	<0.01	<0.01	<0.01	<0.01	0.74

Table B-7. T-tests Comparing Yearly Shannon Diversity between TA-16 with PIPO Control 1

		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
TA-16		3.30	3.21	3.24	3.29	3.24	3.36	3.29	3.37	3.20	3.18	3.19	3.28
PIPO Control 1		3.14	3.12	2.91	3.14	3.13	3.04	3.13	2.90	3.01	2.96	2.84	3.18
Hutcheson's t-test	t	−2.42	−1.21	−5.22	−2.01	−1.41	−4.55	−2.38	−6.95	−2.85	−3.12	3.60	-1.51
	df	470	424	742	574	706	644	668	725	632	668	511	593
	p-value	0.02	0.23	<0.01	0.04	0.16	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	0.13

Table B-8. T-tests Comparing Yearly Shannon Diversity between TA-16 with PIPO Control 2

		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
TA-16		3.30	3.21	3.24	3.29	3.24	3.36	3.29	3.37	3.20	3.18	3.20	3.28
PIPO Control 2		3.20	3.16	3.26	3.11	3.23	3.10	3.29	3.18	3.22	3.05	2.84	3.04
Hutcheson's t-test	t	−1.58	−0.67	0.43	−2.40	−0.11	−3.85	−0.08	−3.15	0.18	−1.98	3.77	-3.38
	df	445	463	714	621	630	634	661	817	664	667	409	702
	p-value	0.11	0.50	0.67	0.02	0.91	<0.01	0.94	<0.01	0.86	0.05	<0.01	<0.01

Table B-9. T-tests Comparing Yearly Shannon Diversity between DARHT with PIPO Control 1

		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
DARHT		—	—	—	—	3.18	3.24	3.14	3.17	3.26	3.33	3.01	3.37
PIPO Control 1		—	—	—	—	3.13	3.04	3.13	2.90	3.01	2.96	3.19	3.18
Hutcheson's t-test	—	—	—	—	—	−0.72	−2.73	−0.24	−3.59	−3.40	−4.85	1.77	-2.56
	—	—	—	—	—	687	621	679	665	613	599	308	506
	—	—	—	—	—	0.47	0.01	0.81	0.00	0.00	0.00	0.07	0.01

Table B-10. T-tests Comparing Yearly Shannon Diversity between DARHT with PIPO Control 1

		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
DARHT		—	—	—	—	3.18	3.24	3.14	3.17	3.26	3.33	3.01	3.37
PIPO Control 2		—	—	—	—	3.23	3.10	3.29	3.18	3.22	3.05	3.20	3.04
Hutcheson's t-test	—	—	—	—	—	−2.05	2.43	0.16	−0.70	−3.86	−2.05	1.90	-4.27
	—	—	—	—	—	609	686	640	593	572	609	293	588
	—	—	—	—	—	0.04	0.02	0.87	0.49	<0.01	0.04	0.06	<0.01

Table B-11. Comparison of Yearly Percent Nest Success for Treatment Sites and Combined Treatment and Control Sites in Nest Box Network

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Firing and control sites	73%	67%	55%	49%	53%	61%	44%	44%	49%	42%
Minie	46%	64%	29%	33%	44%	86%	38%	40%	38%	50%
TA-39	100%	57%	0%	40%	0%	75%	0%	0%	67%	100%
TA-16	91%	64%	77%	63%	54%	50%	33%	36%	55%	33%
DARHT	—	—	62%	6.3%	46%	31%	56%	58%	23%	50%