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Author(s):	Mason, Noelle Maryann Gadek, Chauncey Ryland Abeyta, Elisa Janelle Stanek, Jenna Elizabeth Gaukler, Shannon Marie
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Los Alamos NATIONAL LABORATORY

2023 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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Prepared for: U.S. Department of Energy/National Nuclear Security Administration, LosAlamos Field Office

Prepared by: Noelle Mason, Chauncey Gadek, Elisa Abeyta, Jenna Stanek, and Shannon Gaukler
Environmental Protection and Compliance Division
Environmental Stewardship Group (EPC-ES)
Los Alamos National Laboratory

Editing and Layout by: Tamara Hawman, Communications Specialist
Communications and External Affairs Division
Technical Editing and Communications (CEA-TEC)
Los Alamos National Laboratory

*Cover photo: Western bluebird (*Sialia mexicana*) nestlings observed during nest box monitoring at Bandelier National Monument in 2023. Photo taken by Noelle Mason.*

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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 Facility (DARHT). 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 (e.g., 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 2023, LANL biologists completed multiple avian point count surveys at each of the following treatment sites except TA-36 Minie site, where only two surveys were completed due to heightened activity there. Additionally, avian nest boxes were monitored at control sites (at Bandelier National Monument) as well as the treatment sites:

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

LANL biologists completed the tenth year of this effort in 2023. We recorded a total of 849 birds representing 62 species at the four treatment sites and compared these results with data from their associated control sites. We also compared 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.

In 2023, abundance and species richness at treatment and control sites continued to trend similarly from year to year, with minor random deviations indicative of a stable avian community. Though richness remained stable across all sites, three new bird species were observed at the treatment sites—Brewer's blackbird (*Euphagus cyanocephalus*), merlin (*Falco columbarius*), and yellow-breasted chat (*Icteria virens)*. The species diversity at the TA-36 Minie site, TA-39, and DARHT was statistically higher than their associated controls. The species diversity at all three treatment sites has been consistently lower at the control sites relative to treatment sites, likely due to subtle habitat differences. Annual diversity at treatment sites in 2023 remains stable relative to past years, and overall diversity remains high across all sites relative to similar habitats.

Nest box occupancy and success continue to fluctuate annually; however, a long-term discrepancy between occupancy and nest success at treatment sites in ponderosa pine habitat warrants further data collection and analyses.

In 2023, nonviable avian eggs were opportunistically collected at TA-16 Burn Ground, TA-36 Minie, and DARHT. All egg samples were evaluated for per- and polyfluoroalkyl substances, which were detected in eggs from TA-16 Burn Ground and from DARHT.

Overall results from 2023 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 (hereafter 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 Facility (DARHT), 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 (e.g., 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).

Standard point count methodology to record avian abundance, richness, and diversity were used along transects at the three treatment sites and their associated control sites during the summer of 2023. 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 may 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 (e.g. 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. 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, including repelling oil, stains, grease, and water, which 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 is nondestructive to populations. Inorganic elements (i.e., 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, whereas 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 located 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 for breeding bird surveys 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 hours after sunrise.

The following steps apply to breeding bird surveys:

- Each survey consists of nine points along a transect spaced approximately 250 m apart.
- 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 as 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 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.

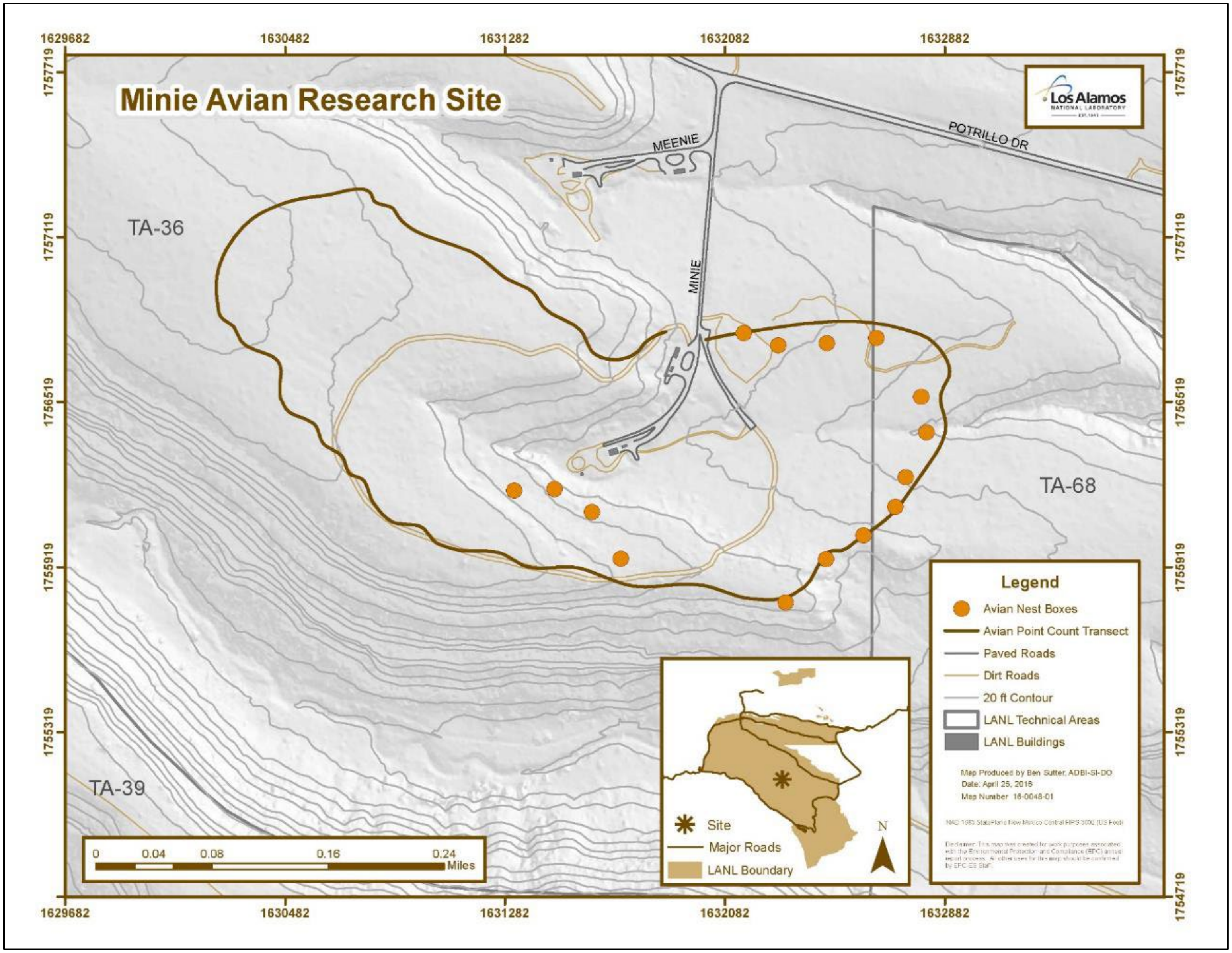

Figure 1. Breeding bird survey transect and nest box locations around TA-36 Minie Site.

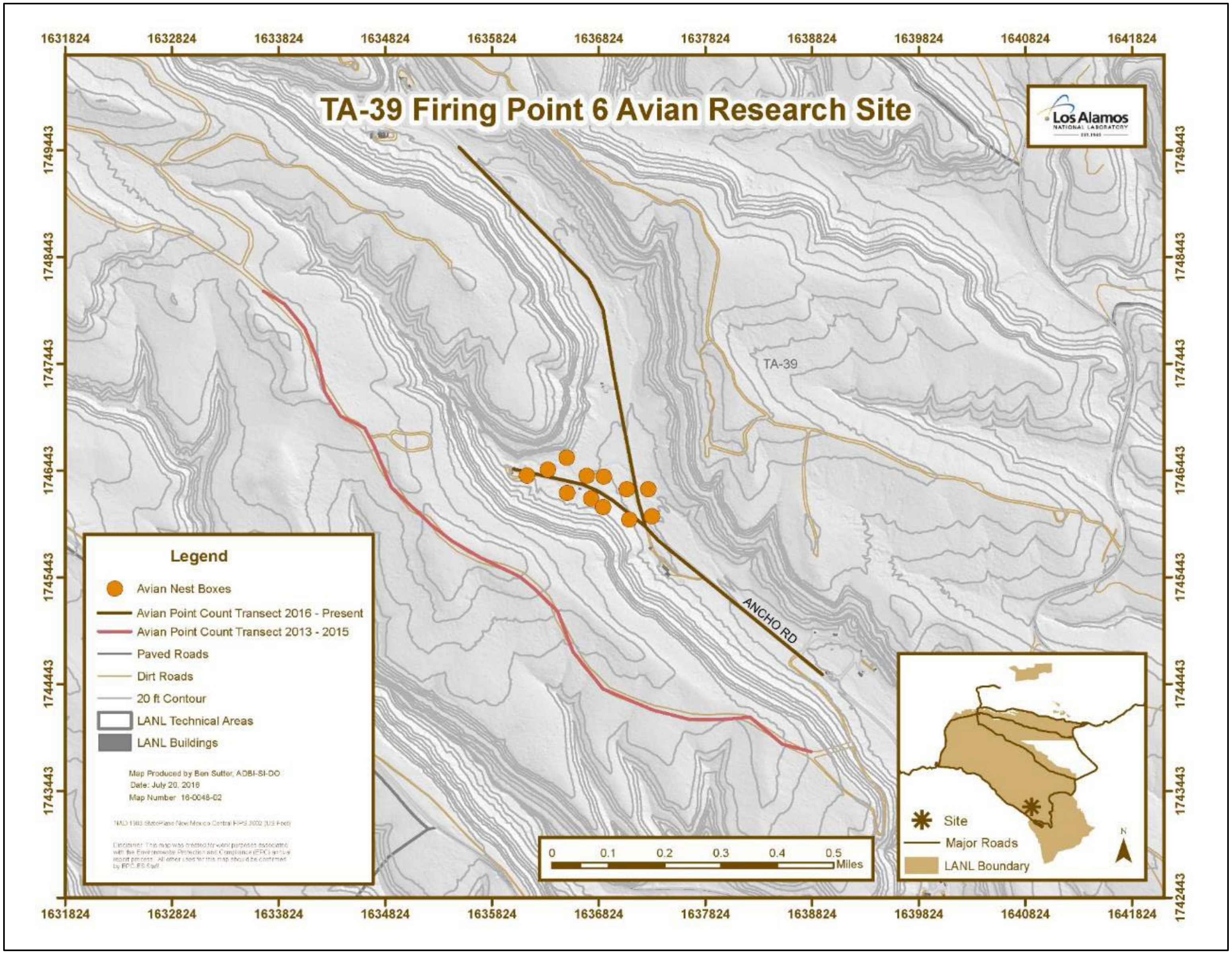

Figure 2. Breeding bird survey transect and nest box locations around TA-39 Point 6.

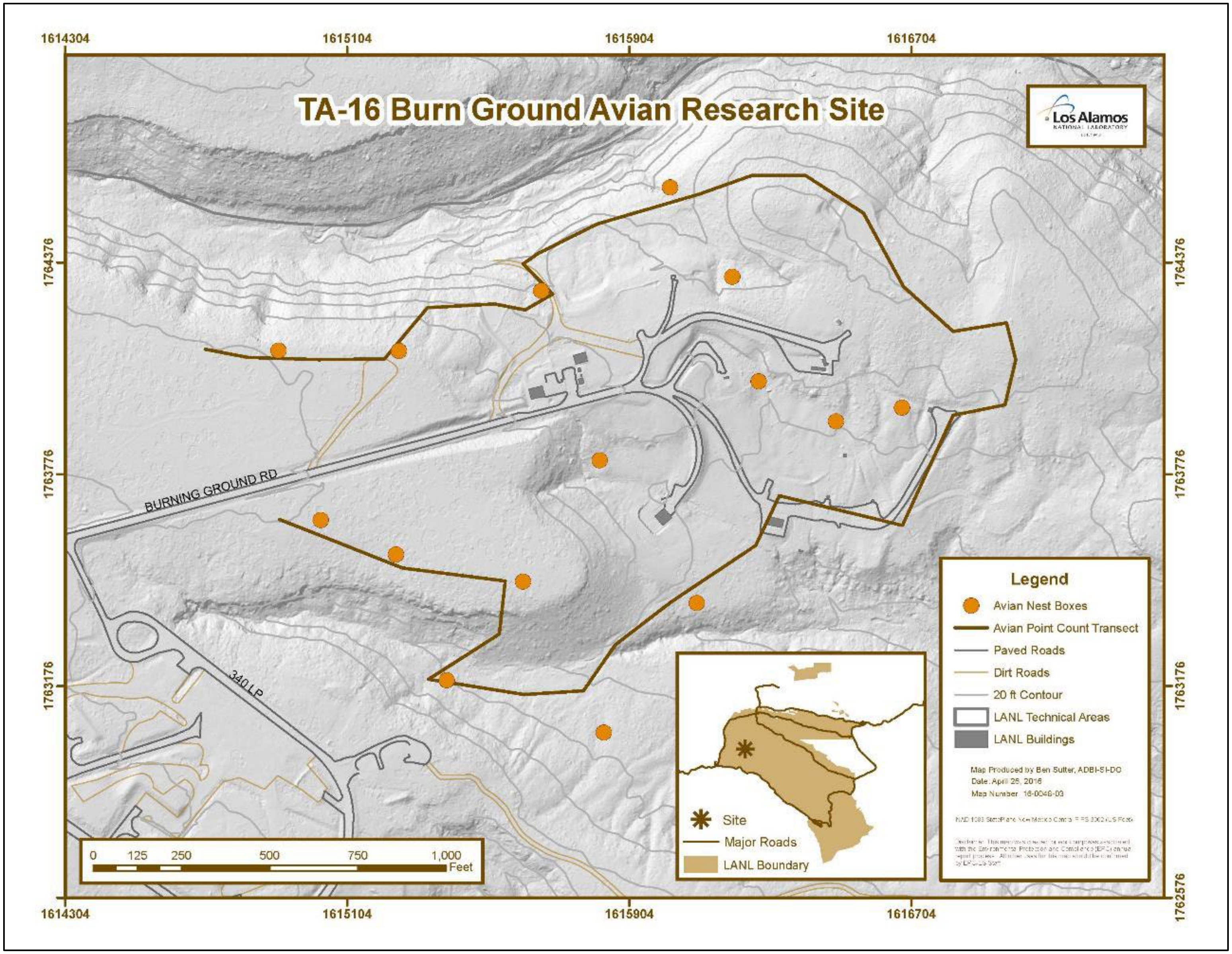

Figure 3. Breeding bird survey transect and nest box locations around TA-16 Burn Ground.

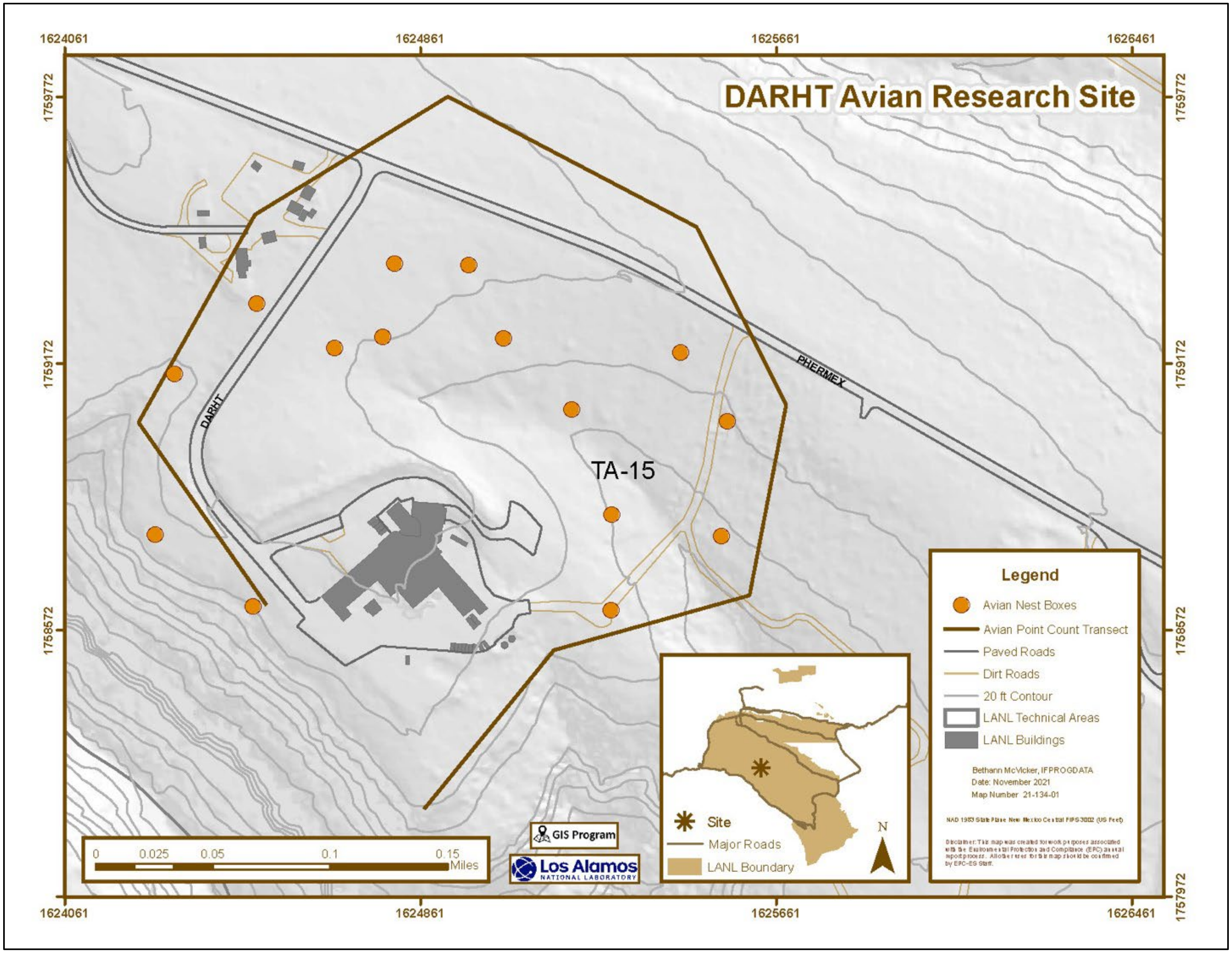

Figure 4. Breeding bird survey transect and nest box locations around the Dual-Axis Radiographic Hydrodynamic Test Facility.

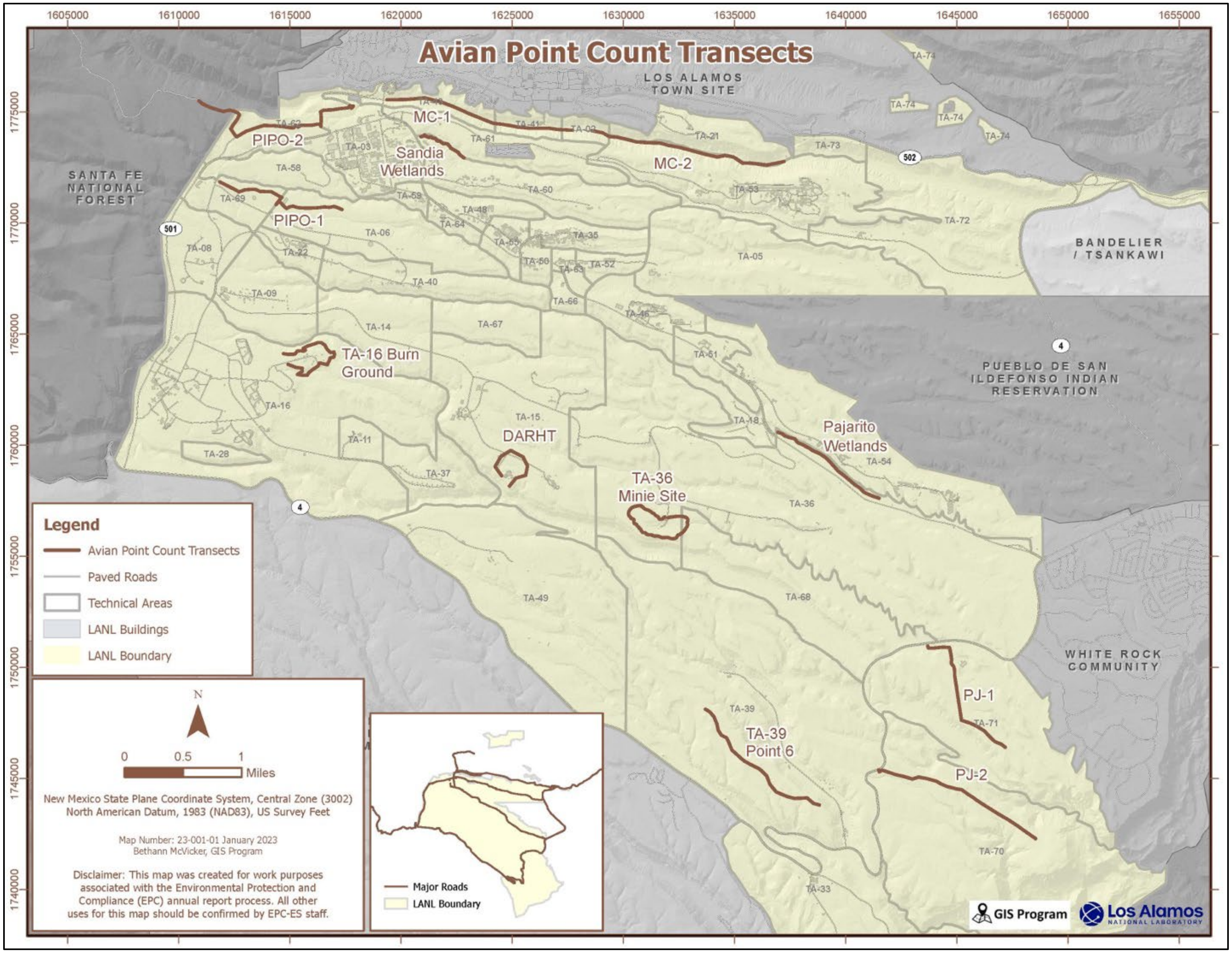

Figure 5. All avian point count transects around LANL ponderosa pine forest (PIPO) and piñon-juniper woodland (PJ). MC = mixed conifer.

2.2 Statistical Methods for Point Counts

We summarized breeding bird survey data to compare abundance, species richness, and 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 high values indicate high diversity.

We calculated all community metrics using the statistical software R (version 4.2.2; R Core Team 2023) 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

We calculated occupancy and nest success rates of the nest boxes at the four treatment sites and in the overall network. For any single site or overall, the occupancy rate was the number of active nest boxes divided by the total number of nest boxes. 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 2023 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.

2.5 Field Methods for Egg and Nestling Sample Collection

Eggs and nestlings are collected from nest boxes when they were determined to be nonviable based on documented timing of known incubation periods for the species. In 2023, we collected a total of five nonviable egg samples at LANL near the TA-16 Burn Ground (Figure 3), near open detonation site TA-36 Minie (Figure 1), and DARHT (Figure 4). At TA-16 Burn Ground, two nonviable western bluebird eggs were collected from one nest and were submitted as one composite sample. At TA-36 Minie, one western bluebird egg sample was collected and submitted as an individual sample. At DARHT, two nonviable western bluebird egg samples collected from two separate nests were submitted as individual samples. Additionally, we collected three samples from Bandelier National Monument; one western bluebird egg sample was collected and submitted as an individual sample, and two composite samples of nonviable western bluebird eggs were collected from two separate nests. All samples were collected during May through August 2023. Concentrations of PFAS chemicals in eggs have been monitored at these locations since 2022.

2.6 Chemical Analyses for Egg and Nestling Samples

Due to limited sample mass, nonviable eggs were analyzed for PFAS only and were analyzed at GEL Laboratories in Charleston, South Carolina. PFAS compounds were analyzed by liquid chromatograph triple quadrupole mass spectrometry (EPA:537M) and were reported on a ng/g (nanogram per gram) wet weight basis.

2.7 Statistical Methods for Egg and Nestling Samples

The 2023 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 were calculated from nonviable eggs of western bluebirds and ash-throated flycatchers collected from Bandelier National Monument in 2022 and 2023 (n = 4 samples). Nonviable egg 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 2023 except for TA-36 Minie site, where only two surveys were completed due to shot activity. Table 1 summarizes the species richness, diversity, and abundance for 2023 for each treatment and control site. A total of 849 birds representing 62 species were recorded at the treatment sites. A full account of the 2013–2023 data is detailed in Appendix A.

Table 1. Species Richness, Diversity, and Abundance Recorded during 2023 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	34	34	38	34	38	39	37	36
Diversity	3.15	3.06	2.74	2.81	2.82	3.01	3.18	3.18
Abundance	134	251	260	212	294	170	250	232

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 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.

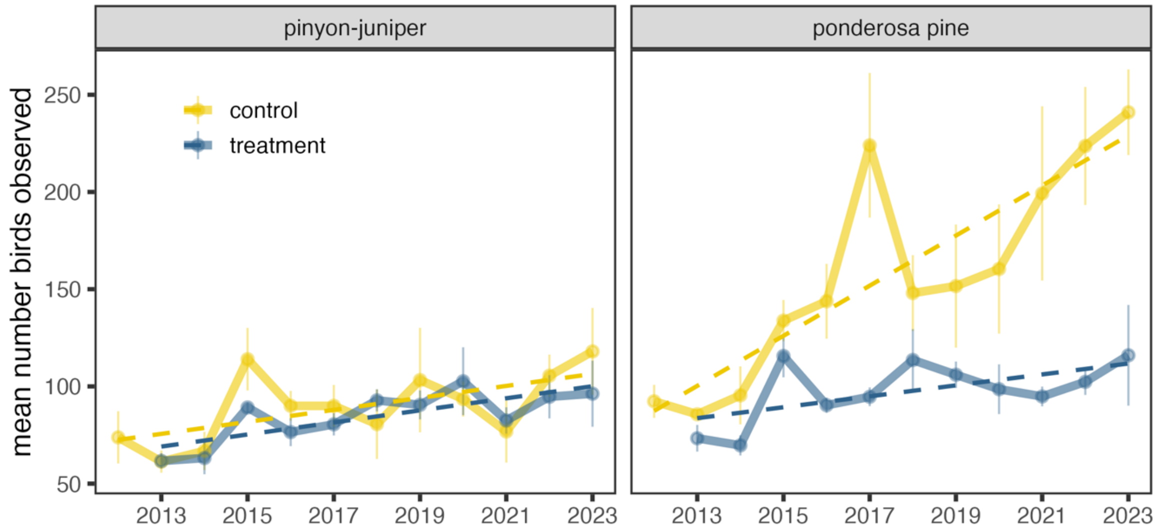

Figure 6. Mean bird abundances across all years of data collection for control (gold) and treatment (blue) compared by habitat type. Points indicate mean abundance from all annual surveys per treatment and control site. Vertical lines show standard error among surveys and sites. Thick solid lines connect 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). The only significant increase across all years occurred at PJ treatment sites ($t = 3.72$, $p < 0.01$). Species richness at both treatment and control sites has partially trended together, with average richness slightly higher at treatment sites than at control sites for most years. Though slight increasing trends seem promising, it cannot be ruled out that survey effort and detectability has changed across the study period, leading to increased identification ability. Future data collection should include surveyors' names to control surveyor variability in ongoing analyses.

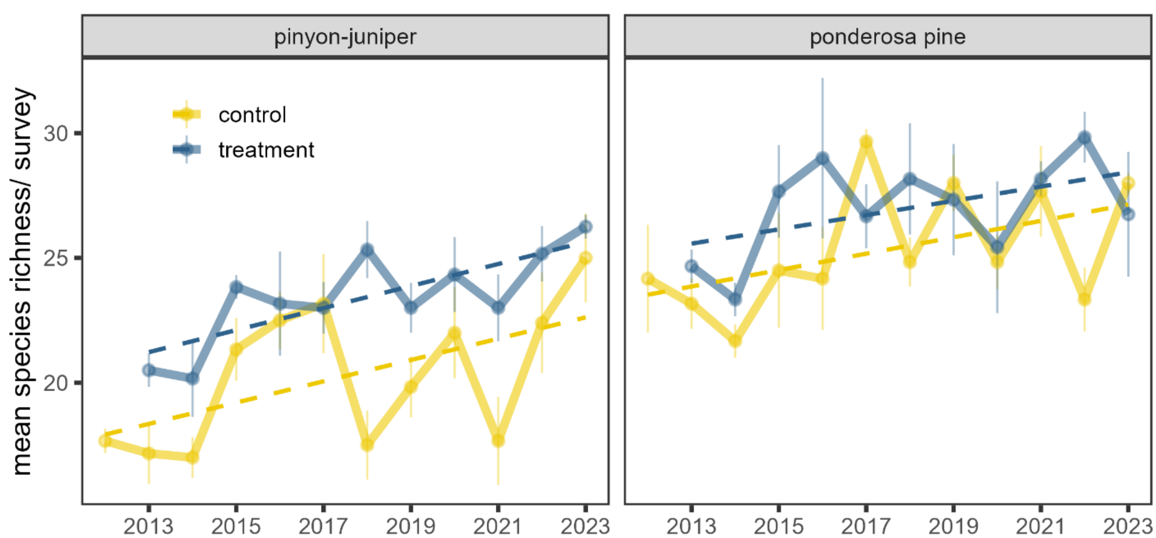

Figure 7. Mean bird species richness across all years of data collection for control (gold) and treatment (blue) compared by habitat type. Points indicate mean richness from three annual surveys per site. Vertical lines show standard error among surveys and sites. Thick solid lines connect annual means 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 substantially higher total diversity than the comparable control sites; however, TA-36 Minie's diversity dropped relatively substantially 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 similar between treatment and controls, including in 2023. Per-survey diversity indices between treatment and control sites in PIPO habitat marginally diverge in 2017, likely driven by the addition of DARHT surveys (Figure 8). The generally lower disturbance conditions at Weapons Facilities Operations relative to control sites could be driving the higher diversity we observed at treatment sites.

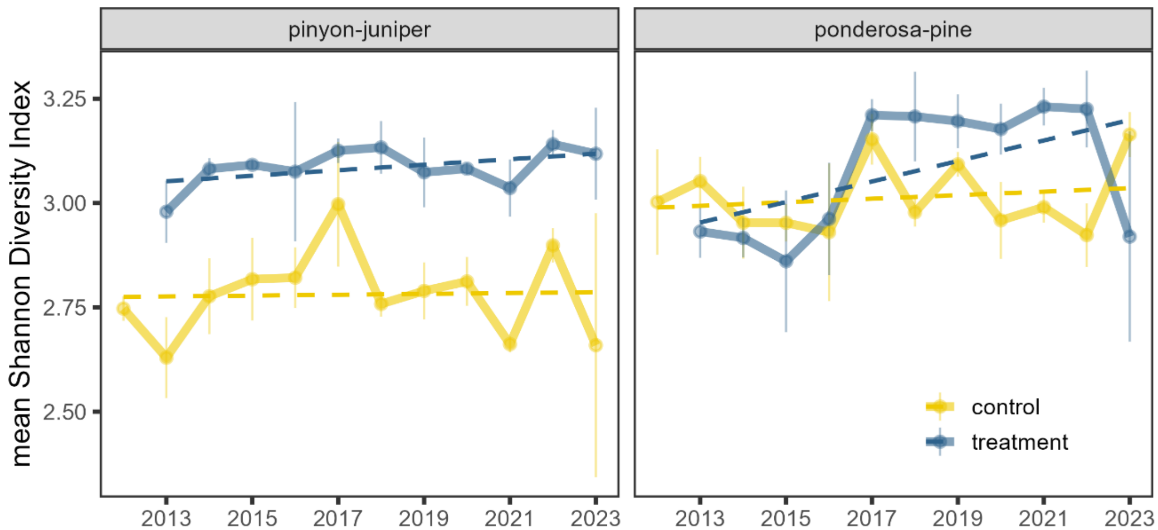

Figure 8. Mean Shannon Diversity Index across all years of data collection for control (gold) and treatment (blue) compared by habitat type. Points indicate mean diversity from three annual surveys per site. Vertical lines show standard error among surveys and sites. Thick solid lines connect annual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

3.2 Nest Box Occupancy and Success

During the 2023 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, 144 contained active nests, and 71 of those nests fledged young successfully, for an overall occupancy rate of 43 percent and a success rate of 49 percent. Occupancy rate continued to increase from a historic low in 2021, and nesting success rate increased from another record low in 2022. Figure 9, Figure 10, Table B-11, and Table B-12 compare the occupancy and nest success rates for each treatment site and the overall nest box network from 2014 through 2023.

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

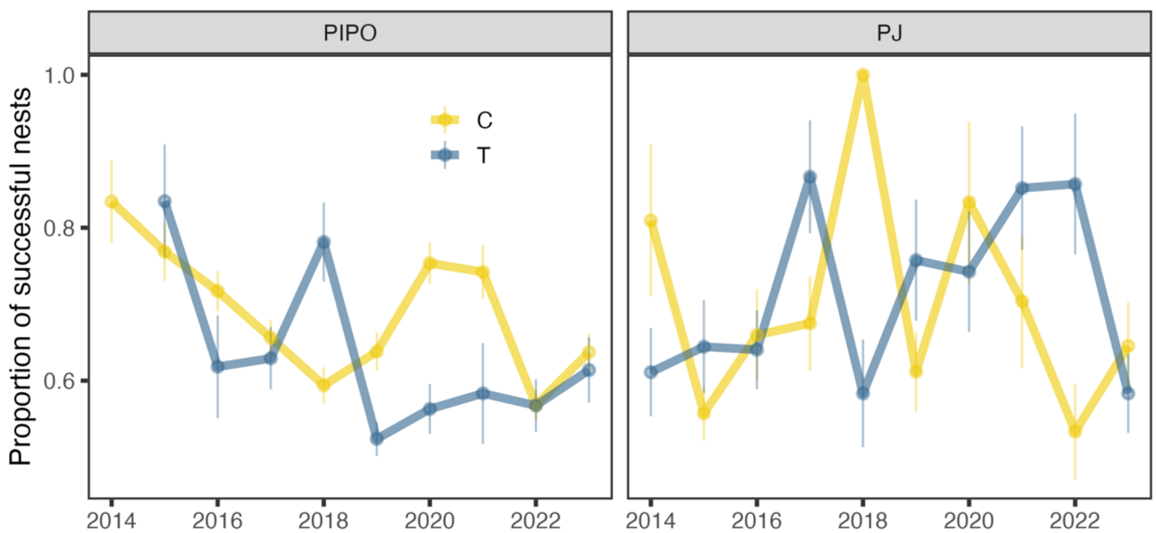

Figure 10. Mean proportion occupancy and success across study period for treatment sites (blue) and control sites (yellow) in ponderosa pine habitat (left panels) and piñon-juniper habitat (right panels). Lines connecting sequential year's values to illustrate trends. Vertical lines represent standard error around mean values.

In 2023, three nests fledged young at TA-36 Minie, six at TA-16, and four at TA-39. Occupancy at TA-39 continues to be low relative to 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. TA-39 is the lowest elevation treatment site, and occupancy has been decreasing over time at this site and surrounding areas of the avian nest box network (Table B-11). 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 to the population (Abeyta et al. 2021). Western bluebirds have the highest occupancy rates throughout the nest box network, and shifts in nesting elevation could be driving the lower occupancy rates at TA-39. Occupancy and success rates at the TA-36 Minie treatment site have fluctuated annually and have not displayed a decreasing trend over time. The success rate at TA-16 has climbed from a large decrease in 2021 (Table B-12), likely driven by extremely low precipitation levels in winter 2020 (NOAA 2023). Decreases in precipitation have been linked to declines in body mass, which could indirectly impact reproductive success (Smith, Reitsma, and Marra 2010). Drought has been shown to shift avian community dynamics, including decreases in abundance and richness of neotropical migrants in dry regions (Albright et al. 2010).

Overall occupancy patterns varied between habitat types (Figure 9). Proportion of site occupancy across all years was substantially higher in PIPO treatment sites than controls ($t = 3.1$, $df = 45.5$, $p < 0.001$) Conversely, PJ habitat showed no difference in occupancy combined across all years $t = 1.31$, $df = 29.8$, $p = 0.20$ (Figure 9).

Overall nest success also varied between habitat types but contradicted the within-habitat-type nest success patterns (Figure 9). In PIPO habitat, the proportion of nest success across all years was significantly lower at treatment sites relative to control sites (TA-16 and DARHT; $t = -2.76 df = 317.1$, $p < 0.01$). There was no discernable difference across all years between treatment and control sites in PJ habitat ($t = 1.16$, $df = 233.8$, $p = 0.249$).

3.3 Chemical Analyses

In 2023, we submitted nonviable eggs collected from nest boxes at the treatment and control sites for chemical analyses. A total of 10 nonviable egg samples and no nestlings were collected from treatment ($n = 5$) and control ($n = 5$) sites in 2023.

Detectable concentrations of PFAS were compared with RSRLs, which—for PFAS in eggs—were calculated from nonviable eggs of western bluebirds ($n = 3$) and ash-throated flycatchers ($n = 1$) at background locations from Bandelier National Monument collected in 2022 and 2023 ($n = 4$).

The one western bluebird composite egg sample ($n = 2$) collected from a nest box at TA-16 Burn Ground was tested for 37 PFAS compounds; one compound—perfluorotridecanoic acid—was detected at a very low level of 0.439 ng/g. The level detected for perfluorotridecanoic acid is below the RSRL in passerine eggs at 0.568 ng/g. No PFAS compounds were observed in the western bluebird egg sample collected from a nest box at TA-36 Minie.

The two separate nonviable western bluebird egg samples collected from nest boxes at DARHT were tested for 37 PFAS compounds. One egg sample did not contain any detectable PFAS compounds. In the other western bluebird egg sample, most of the PFAS compounds that were detected were below the RSRLs (Table 2). Perfluoroundecanoic acid, perfluorotridecanoic acid, perfluorododecanoic acid, 3-Perfluoroheptyl propanoic acid, 1H, 1H, 2H, 2H-Perfluorododecanesulphonic acid, and 1H, 1H, 2H, 2H-Perfluorodecane sulfonic acid were all detected and slightly above the RSRLs (Table 2).

Table 2. Detectable PFAS concentrations (ng/g wet weight) detected in one single egg sample collected near DARHT compared with RSRL. The RSRL is the upper limit background concentrations (mean + three standard deviations) for passerine eggs.

Element	Western Bluebird (n = 1) SFB-23-297569	RSRL
Perfluoroundecanoic acid	0.929	0.568
Perfluorotridecanoic acid	0.996	0.568
Perfluorotetradecanoic acid	0.657	0.689
Perfluorononanoic acid	0.369	0.568
Perfluorododecanoic acid	0.821	0.568
Perfluorodecanoic acid	0.898	1.27
3-Perfluoroheptyl propanoic acid	1.42	1.14
1H, 1H, 2H, 2H-Perfluorododecanesulphonic acid	2.76	1.14
1H, 1H, 2H, 2H-perfluorodecane sulfonic acid	6.51	1.32

Although these PFAS compounds are not as well-studied as other PFAS compounds such as perfluorooctanesulfonic acid (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 at least one order of magnitude 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*), LANL lands are important for migratory bird conservation. During the 10-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*), and mourning dove (*Zenaida macroura*). The gray vireo (*Vireo vicinior*) and pinyon jay (*Gymnorhinus cyanocephalus*) are the only sensitive species documented in only control sites. Of the 81 species detected at the three treatment sites, the Migratory Bird Treaty Act protects all but one species; the Eurasian collared-dove (*Streptopelia decaocto*) is not native and is therefore not protected under the Migratory Bird Treaty Act.

Overall comparisons provide mixed evidence for and against 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 sharpen our understanding of differences between bird communities and productivity at treatment and control sites. It is likely that a complex interaction of local habitat, climate trends, and disturbance levels interact in 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 contributes to 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
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 2013–2023 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
Acorn woodpecker											
American crow											
American kestrel				1				1	1		
American robin	1	1	2		2					5	1
Ash-throated flycatcher	11	5	14	13	13	10	17	12	12	7	5
Audubon’s warbler		2				5				1	2
Bewick’s wren	4	8	9	9	14	14	5	10	4	5	6
Black-chinned hummingbird		1	1				1	2	1	2	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
Blue grosbeak											
Broad-tailed hummingbird	2	1	3		1		3	2		5	
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
Chipping sparrow	3	16	17	29	6	22	10	10	10		18
Clark’s nutcracker											
Common nighthawk	6		5	2	4	4	1	5			
Common raven	2	5	1		1	2	3			12	2

Species	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Cooper’s hawk					1						
Cordilleran flycatcher											
Dark-eyed junco											
Downy woodpecker				1							
Dusky flycatcher				1							
Eurasian collared-dove	3										
Evening grosbeak	3		4						1		
Grace’s warbler							1				1
Gray flycatcher	12	6	5	7	3	6	3	2	4	8	3
Great horned owl		3									
Green-tailed towhee	3	1								1	
Hairy woodpecker			2	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
House wren											
Juniper titmouse	12		7	6	9	3	26	8	20	3	5
Lark sparrow										2	2
Lesser goldfinch	2	6	7	4	9	12	8	4	4	8	1
MacGillivray’s warbler										0	
Merlin											1
Mountain bluebird		2	20	10	11	1	9	3	2	5	5
Mountain chickadee	5	2	1	2						5	
Mourning dove	17	17	13	5	8	8	11	9	7	9	9
Northern mockingbird					2		1	4		8	
Northern rough-winged swallow						3					
Olive-sided flycatcher											
Orange-crowned warbler											
Painted redstart											

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

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
Acorn woodpecker											4
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
Audubon’s warbler				2				5		3	7
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	
Black-throated gray warbler	5	6	4								3
Blue-gray gnatcatcher	2		7	5	4	2	13	5	2	13	11
Blue grosbeak									1		
Broad-tailed hummingbird	3	1	2		3	1	2	9	3	2	
Brown creeper											
Brown-headed cowbird			2			3	2	10	3	12	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
Canyon wren			2	3	8	6	2	4			3
Cassin’s finch											
Cassin’s kingbird	7	6	2	21	21	32	37	49	14	41	35
Chipping sparrow	6	6	5	8	15	25	27	24	16	20	19
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
Cooper’s hawk											
Cordilleran flycatcher											
Dark-eyed junco						1	1				

Species	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Downy woodpecker				1	2		1	2	1		
Dusky flycatcher			1		1					1	
Eurasian collared-dove					4			2			
Evening grosbeak			8								
Grace's warbler						2	4	1	6	3	6
Gray flycatcher	10	10	11	10	5	8	3	14	5	6	13
Great horned owl	1										
Green-tailed towhee	1										
Hairy woodpecker			5	3			1	1	4		
Hammond's flycatcher											
Hepatic tanager			1	2	1	2			1		
Hermit thrush											
House finch	21	4	23	9	30	44	50	53	22	41	31
House wren							1				
Juniper titmouse	11	13	18	6	1			3	2	3	
Lark sparrow											
Lesser goldfinch	4	12	9	10	14	19	15	27	8	31	13
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
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
Plumbeous vireo	1		1	6	6	5	5	12	4	9	6
Pygmy nuthatch			2	4	12	9	11	10	1	8	

Species	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Red crossbill		2						1			
Red-shafted flicker	3	2	4	8		3	2	2		4	3
Red-tailed hawk			1	1	1	1					1
Rock wren	7	10	4	12	14	14	12	20	15	14	12
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
Steller’s jay											
Townsend’s solitaire											
Turkey vulture								1			
Vesper sparrow											
Violet-green swallow	6	4	1	9	6	6	9	47	5		8
Virginia’s warbler			1	2	4		5		2	3	
Warbling vireo											
Western bluebird	5	19	12	21	13	6	7	17	3	4	10
Western tanager		2	1	1	2	2	6	1	2	4	
Western wood-pewee		4	2	10	8	11	12	18	12	16	3
White-breasted nuthatch			2	4	4	2	6	3	2	3	3
White-crowned sparrow									1		
White-throated swift		1						2			
White-winged dove	7	5	6	16	15	15	5	2	5	7	1
Willow flycatcher									1		
Wilson’s warbler											
Woodhouse’s scrub-jay	8	10	4	8	6	4	5		2	3	
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
Acorn woodpecker	5		3	2	3	5	3	5	1		2
American crow					1	1		1	1	5	2
American kestrel											
American robin	7		9	4	4	6	12	6	14		4
Ash-throated flycatcher	3	5	6	2	3	8	4	6	6	11	4
Audubon’s warbler	6	5	1	6		1	11	14	9	5	10
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											
Blue-gray gnatcatcher		6	2	1	3	6	4	9	3	9	4
Blue grosbeak											
Broad-tailed hummingbird	5	11	11	5	7	10	8			11	6
Brown creeper	1										
Brown-headed cowbird	4	1			4	2	8	4	4	3	3
Bullock’s oriole											
Bushtit											
Canada goose											
Canyon towhee	1			1		1					
Canyon wren			2								
Cassin’s finch									1		
Cassin’s kingbird				1				2		1	
Chipping sparrow	1	5	3	10	5	21	8	32	6	19	12
Clark’s nutcracker		4		1							
Common nighthawk			1	2	2			1			
Common raven	5	6	2	2	5	5	7	4	2	9	5
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

Species	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Downy woodpecker		1		1	1	1					
Dusky flycatcher								2	1	1	2
Eurasian collared-dove						1					
Evening grosbeak	5		29			1					
Grace’s warbler	6	4	4	8	5	8	22	12	17	11	12
Gray flycatcher											1
Great horned owl											
Green-tailed towhee								1			
Hairy woodpecker	1	1		1	1	2	1	1			
Hammond’s flycatcher	8	9	12	5	7	5	10	5	7	1	
Hepatic tanager				1							
Hermit thrush		4	6	1	2	2	5	5	2	2	2
House finch	16	2	5	5	12	7	12	18	11	20	15
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
MacGillivray’s warbler				1	3			1		1	
Merlin											
Mountain bluebird			4	4	4	7	4	5			
Mountain chickadee	5	8	9	6	8	9	1	4	6	6	
Mourning dove	4		1	3	17	3	5	17	5	2	1
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
Plumbeous vireo	11	16	15	14	11	18	16	24	17	19	7

Species	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Pygmy nuthatch	11	13	26	29	41	20	16	23	5	21	6
Red crossbill		2	9	13	9		6	26	1		
Red-shafted flicker	3	4	11	11	5	5	2	7	5	7	5
Red-tailed hawk										1	
Rock wren	1	2	2	6			4	1			4
Ruby-crowned kinglet						2			1		
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
Steller’s jay	3	2	5	6	3	4	4	2	1		
Townsend’s solitaire					1						
Turkey vulture	1					1					1
Vesper sparrow							1				
Violet-green swallow		2	19	2	2	4	2	7	6	7	97
Virginia’s warbler	17	11	21	13	7	5	5	8	3	4	9
Warbling vireo	2	9	7	6	5	4	6	3	7	7	4
Western bluebird	20	20	49	37	32	27	20	27	8	32	16
Western tanager	2	3	7	2	4	6	16	10	7		8
Western wood-pewee	15	10	16	14	22	20	24	28	25	47	16
White-breasted nuthatch	9	8	7	9	20	10	10	8	10	9	4
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
Acorn woodpecker		1	1	1		2	
American crow							
American kestrel						1	1
American robin	1		9	2	6	3	
Ash-throated flycatcher	7	2	2	5	4	2	
Audubon's warbler		4	12	2	3	2	5
Bewick's wren							
Black-chinned hummingbird		1				1	1
Black-headed grosbeak		3	1			3	1
Black-throated gray warbler							
Blue-gray gnatcatcher	5	8	16	17	4	9	4
Blue grosbeak							
Brewer's blackbird							1
Broad-tailed hummingbird	3	4	5	10	1	7	5
Brown creeper							
Brown-headed cowbird		5	2	7	6	8	1
Bullock's oriole							
Bushtit							1
Canada goose							
Canyon towhee							
Canyon wren							
Cassin's finch							
Cassin's kingbird	9	14	13	1	15	10	9
Chipping sparrow	16	31	21	17	30	18	34
Clark's nutcracker		1					
Common nighthawk							
Common raven	10	1	5	5	6	4	
Cooper's hawk							
Cordilleran flycatcher		1	1			3	

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

Species	2017	2018	2019	2020	2021	2022	2023
Pygmy nuthatch	9	13	13	3	4	6	6
Red crossbill	4					4	
Red-shafted flicker	8	10	3	1	3	2	
Red-tailed hawk	1		1			1	1
Rock wren	2	1		1	2		3
Ruby-crowned kinglet							
Savannah sparrow							
Say’s phoebe	8	1	5	2	2	1	
Scaled quail							
Spotted towhee	28	22	22	27	31	27	17
Steller’s jay	1						
Townsend’s solitaire		1				1	
Turkey vulture	2	1		1			1
Vesper sparrow							1
Violet-green swallow	9	12	32	20	28	15	19
Virginia’s warbler	12	8	4	1	8	2	
Warbling vireo							
Western bluebird	15	24	25	32	12	26	12
Western tanager	2	1	4	6	6	3	2
Western wood-pewee	14	19	22	14	17	25	4
White-breasted nuthatch	5	7	7	4	6	3	2
White-crowned sparrow							
White-throated swift	8					3	1
White-winged dove		4	1	2		1	2
Willow flycatcher							
Wilson’s warbler		2					2
Woodhouse’s scrub-jay	3					7	1

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
Minie	193	186	275	210	222	242	245	203	209	229	134
TA-39	177	193	260	249	261	315	298	413	286	339	251
PJ Control 1	187	157	269	312	240	235	226	292	225	209	260
PJ Control 2	181	177	301	228	300	168	187	269	159	142	212
TA-16	220	209	347	271	302	285	310	389	283	340	294
PIPO Control 1	258	223	432	323	447	374	364	373	349	337	250
PIPO Control 2	256	254	371	396	449	366	394	429	448	334	232

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
Minie	33	33	34	30	35	35	34	33	33	37	34
TA-39	31	31	39	38	34	36	38	40	38	36	34
PJ Control 1	29	30	33	36	37	30	30	37	33	40	38
PJ Control 2	30	29	37	33	39	23	33	32	25	30	34
TA-16	39	33	40	44	41	43	39	46	37	40	39
PIPO Control 1	34	34	30	40	46	40	41	33	36	37	38
PIPO Control 2	33	36	43	43	44	39	40	40	44	39	37

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
Minie		3.14	3.14	3.19	2.97	3.13	3.21	3.06	3.13	3.00	3.31	2.74
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
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
	df	327	272	534	511	450	458	392	493	419	331	388
	p-value	<0.01	<0.01	0.04	0.50	0.08	<0.01	<0.01	<0.01	0.06	<0.01	2.21

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
Minie		2.81	2.87	3.05	3.03	3.20	2.59	2.90	2.86	2.54	2.69	2.81
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
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
	df	337	328	563	436	490	312	346	471	299	252	345
	p-value	<0.01	<0.01	<0.01	0.42	0.38	<0.01	0.07	<0.01	<0.01	<0.01	<0.01

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
TA-39		3.09	3.07	3.14	3.32	3.18	3.13	3.08	3.09	3.03	3.11	2.74
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
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
	df	330	268	509	540	425	497	444	561	462	361	447
	p-value	<0.01	0.02	0.26	0.00	0.02	<0.01	<0.01	0.01	0.03	0.19	<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
TA-39		3.09	3.07	3.14	3.32	3.18	3.13	3.08	3.09	3.03	3.11	2.80
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
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
	df	337	325	542	440	561	325	396	578	319	279	385
	p-value	<0.01	0.03	0.26	<0.01	0.76	<0.01	0.05	<0.01	<0.01	<0.01	<0.01

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
TA-16		3.30	3.21	3.24	3.29	3.24	3.36	3.29	3.37	3.20	3.18	3.19
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
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
	df	470	424	742	574	706	644	668	725	632	668	511
	p-value	0.02	0.23	<0.01	0.04	0.16	<0.01	0.02	<0.01	<0.01	<0.01	<0.01

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
TA-16		3.30	3.21	3.24	3.29	3.24	3.36	3.29	3.37	3.20	3.18	3.20
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
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
	df	445	463	714	621	630	634	661	817	664	667	409
	p-value	0.11	0.50	0.67	0.02	0.91	<0.01	0.94	<0.01	0.86	0.05	<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
DARHT		-	-	-	-	3.18	3.24	3.14	3.17	3.26	3.33	3.01
PIPO Control 1		-	-	-	-	3.13	3.04	3.13	2.90	3.01	2.96	3.19
Hutcheson's t-test	t	-	-	-	-	−0.72	−2.73	−0.24	−3.59	−3.40	−4.85	1.77
	df	-	-	-	-	687	621	679	665	613	599	308
	p-value	-	-	-	-	0.47	0.01	0.81	0.00	0.00	0.00	0.07

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
DARHT		-	-	-	-	3.18	3.24	3.14	3.17	3.26	3.33	3.01
PIPO Control 2		-	-	-	-	3.23	3.10	3.29	3.18	3.22	3.05	3.20
Hutcheson's t-test	t	-	-	-	-	−2.05	2.43	0.16	−0.70	−3.86	−2.05	1.90
	df	-	-	-	-	609	686	640	593	572	609	293
	p-value	-	-	-	-	0.04	0.02	0.87	0.49	<0.01	0.04	0.06

Table B-11. Comparison of Yearly Percent Occupancy for Treatment Sites and Overall Nest Box Network

	2015	2016	2017	2018	2019	2020	2021	2022	2023
Overall Network	40%	45%	48%	53%	44%	58%	30%	41%	65%
Minie	66%	73%	46%	20%	60%	47%	53%	33%	53%
TA-39	8%	58%	20%	33%	13%	27%	7%	13%	40%
TA-16	-	73%	100%	53%	87%	87%	80%	93%	80%
DARHT	-	-	87%	99%	73%	93%	64%	80%	86%

Table B-12. Comparison of Yearly Percent Nest Success for Treatment Sites and Overall Nest Box Network

	2015	2016	2017	2018	2019	2020	2021	2022	2023
Overall Network	66%	69%	57%	49%	51%	59%	45%	42%	60%
Minie	64%	23%	29%	33%	44%	86%	38%	40%	56%
TA-39	100%	57%	0%	40%	0%	75%	0%	0%	61%
TA-16	-	63%	76%	63%	54%	54%	33%	36%	55%
DARHT	-	-	62%	6.3%	45%	31%	56%	58%	68%