Assessing the Effects of Forest Management and Wildfire on Populations of New Mexico's Endemic Salamanders

NMDGF Share with Wildlife Grant, Final Project Report
30 September 2024

Dr. Nancy Karraker, Department of Natural Resources, University of Rhode Island, Kingston, RI
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Sacramento Mountain salamander (*Aneides hardii*) observed on the Lincoln National Forest in 2023. Photo by Kaitlyn White (University of Rhode Island).

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Introduction
Two endemic salamanders occur in the mountains of New Mexico: the Jemez Mountains salamander (*Plethodon neomexicanus*) and the Sacramento Mountain salamander (*Aneides hardii*). *P. neomexicanus* is federally-listed as Endangered and *A. hardii* is state-listed as Threatened. Relicts of past glacial events, populations of these species remain perched on cooler, moister mountaintops in mixed conifer forests, one in the north-central and the other in the south-central part of New Mexico, surrounded by lower elevation landscapes of pinyon-juniper and other arid-land plant communities. Both species are at risk of population declines or extirpation because of their relatively small geographic distributions and impacts to their populations from historic timber harvesting and more recent changes in forest structure; increased occurrence of moderate- and high-severity fires within their ranges; and warmer, drier weather patterns associated with climate change. Narrow thermal tolerances limit both species' abilities to cope with alterations in microclimate associated with changes in forest structure, and their elevational position on the upper slopes of mountains restricts their ability to shift their distributions upward in response to a warming climate. Furthermore, atypical wildfire activity may influence species' survival and habitat suitability. Comprehensive studies of the population demography, magnitude of historic disturbances, and microclimatic factors that influence salamander surface activity in addition to more accurate estimates of detection probabilities are needed to understand apparent differences in the population trajectories between the two species and inform guidelines for species surveys and forest management activities. Although both species are discussed in this report, the focus for this project is on *A. hardii*.

Despite the existence of historic unpublished accounts documenting population declines over the past two decades for both species (with *P. neomexicanus* apparently exhibiting more severe declines, formal and comprehensive assessments of population size and structure have not been undertaken for either species in recent years. In the 1960s through the 1990s, hundreds of *P. neomexicanus* could be captured in a year. Although extensive logging in the region from the late 1800s to the mid-1900s likely impacted populations, stand-replacing fires between the late 1990s and 2013 have apparently eliminated entire populations and significantly reduced the size of other populations.

It has been suggested that populations of *A. hardii* may be more resilient than *P. neomexicanus* populations to landscape-altering disturbances such as broad-scale logging and wildfires. To our knowledge, the last attempt to study populations of *A. hardii* using mark-recapture techniques, which was unsuccessful, occurred nearly two decades ago (Haan and Desmond 2005). Apparent contrasts in population sizes and trajectories between these two endemic plethodontid salamanders present an opportunity to identify the factors responsible for the differences, which ultimately may be useful for developing a recovery plan for *P. neomexicanus* that includes habitat restoration guidelines and identifying populations of *A. hardii* that would benefit from habitat restoration.

The unique life histories of these completely terrestrial salamander species have presented challenges to reliably detecting them during surveys, leading biologists to call for assessments of detection probability for both *P. neomexicanus* and *A. hardii* (Cummer and Painter 2007). Both species spend most of the year below ground and return to the surface during the warm, wet monsoon season, generally from July to September. However, they likely move above and below ground during the monsoon season in response to changes in microclimate suitability at the surface, thereby limiting the times and conditions under which they can be found during above-ground surveys. To our knowledge, aside from our research begun in 2019, no previous studies have attempted to quantify detection probabilities for *P. neomexicanus*. One previous attempt (Haan et al. 2007) to assess detection probabilities for *A. hardii* was unsuccessful because plots were surveyed only one time each, yielding a high number of false absences and low predictive power. Surveys designed to quantify detection probability must include multiple visits to multiple plots known to be occupied by salamanders with the goal of capturing: (1) within-season variation in detection probability related to within-season above- and below-ground movements influenced by changes in microclimate, (2) among-season variation in detection probability associated with annual variation in broader weather patterns, and (3) site-level variation in detection probability associated with variation among sites in salamander abundances, habitat and microhabitat structure, and microhabitat availability. Lower apparent abundances of salamanders within populations necessitate increased numbers of plots (when possible) and numbers of plot surveys and, in some cases, surveys over multiple years. Generating detection probability estimates for *P. neomexicanus* and *A. hardii* will be useful for developing species-specific guidelines for surveys to be implemented prior to ground disturbing activities. This will be particularly important for activities that fall within the range and suitable habitats of *P. neomexicanus*, for which survey requirements are currently negotiated with the U.S. Fish and Wildlife Service on a project-by-project basis.

Forest management tools such as thinning and prescribed burning are employed to reduce the presence of fuels that can lead to stand-replacing fires that impact wildlife habitats, yet protections for migratory or threatened species, including salamanders, constrain flexibility in implementing forest management activities. Forest thinning and prescribed burning must be conducted outside of the breeding periods for species like Mexican spotted owls (March-August) and the activity periods of both species of salamanders (July-September). Wildlife protections coupled with the fact that higher elevation forests where these species occur are inaccessible from approximately December-March, yields a window for forest management activities of October-November each year. Ironically, fire exclusion and restrictions on timing of thinning and prescribed burning activities have led to an increase in the occurrence of high severity fires in higher-elevation forests of the southwest, where ecological impacts of such fires are more severe than in the past (O'Connor et al. 2014), thus increasing the vulnerability of salamander populations and their habitats. Optimal temperatures for surface activity are 11.4°C for *A. hardii* and 12.5°C for *P. neomexicanus* (Williams 1976), but to date, the temperature and moisture levels and durations of those conditions that bring salamanders to the surface or drive them below ground within the monsoon season have not been quantified. Developing an understanding of these temperature and moisture thresholds may allow land managers to make empirically-based decisions to initiate forest management activities such as hand thinning during periods in which microclimatic conditions indicate that salamanders should be below ground and unlikely to be impacted. Such information could allow for greater flexibility in implementing forest management tools within the ranges of both species while still ensuring minimal species impacts from such activities and could also contribute needed information to a recovery plan for *P. neomexicanus.*

The primary objectives of this project are to: (1) Quantify the population demography of *A. hardii* (population size, density, sex ratio, and age class structure) as related to forest structure, composition, and disturbance history; (2) Evaluate the impacts of wildfire along a burn severity gradient on *A. hardii* occupancy; (3) Calculate detection probabilities for populations of *A. hardii*; (4) Identify the temperature and precipitation thresholds, and durations of those thresholds, that initiate or cause the cessation of surface activity in *A. hardii*; and (5) Summarize results in a way that informs land managers about the status of *A. hardii* in relation to conservation and habitat restoration needs.

Methods

Standard biosecurity and disease protocols for amphibians were followed for all surveys. A new bag was used to handle each salamander and all measurements were made from outside of the bag with the salamander enclosed in the bag. All persons who handled a salamander from its capture, to measurements, to release disinfected their hands with a 95% ethanol-based disinfecting solution immediately afterward and then rinsed them in clean water. Equipment used to measure, weigh, and anesthetize salamanders were decontaminated with Virkon Aquatic after each use and then rinsed in clean water. New anesthetic liquid (MS-222) and recovery liquid (spring water) were used for each salamander. Boots and any other equipment that contacted soil at a site were decontaminated with Virkon Aquatic after each visit to a site. This decontamination was done at the vehicles on a dirt road at least 200 m from a surveyed site.

Population Demography

To evaluate the demography of *A. hardii* populations, we established plots for mark-recapture surveys in the White and Sacramento Mountains. In each mountain range, we selected two sites and at each site delineated three 25 x 25 m plots located at least 100 m from one another. In the White Mountains (Smoky Bear District, Lincoln National Forest), plots were established at Big Bear Canyon and Ski Apache (Deep Freeze); in the Sacramento Mountains (Sacramento District, Lincoln National Forest), plots were established at Lightning Lake and Russia Canyon (Figure 1). Sites were located at least 5 km from one another. We were unable to establish plots in the Capitan Mountains because of their remoteness, challenging driving terrain, lengthy time required to reach suitable habitat, and concerns about our ability to resurvey these sites regularly within the optimal survey timeframe for *A. hardii*.

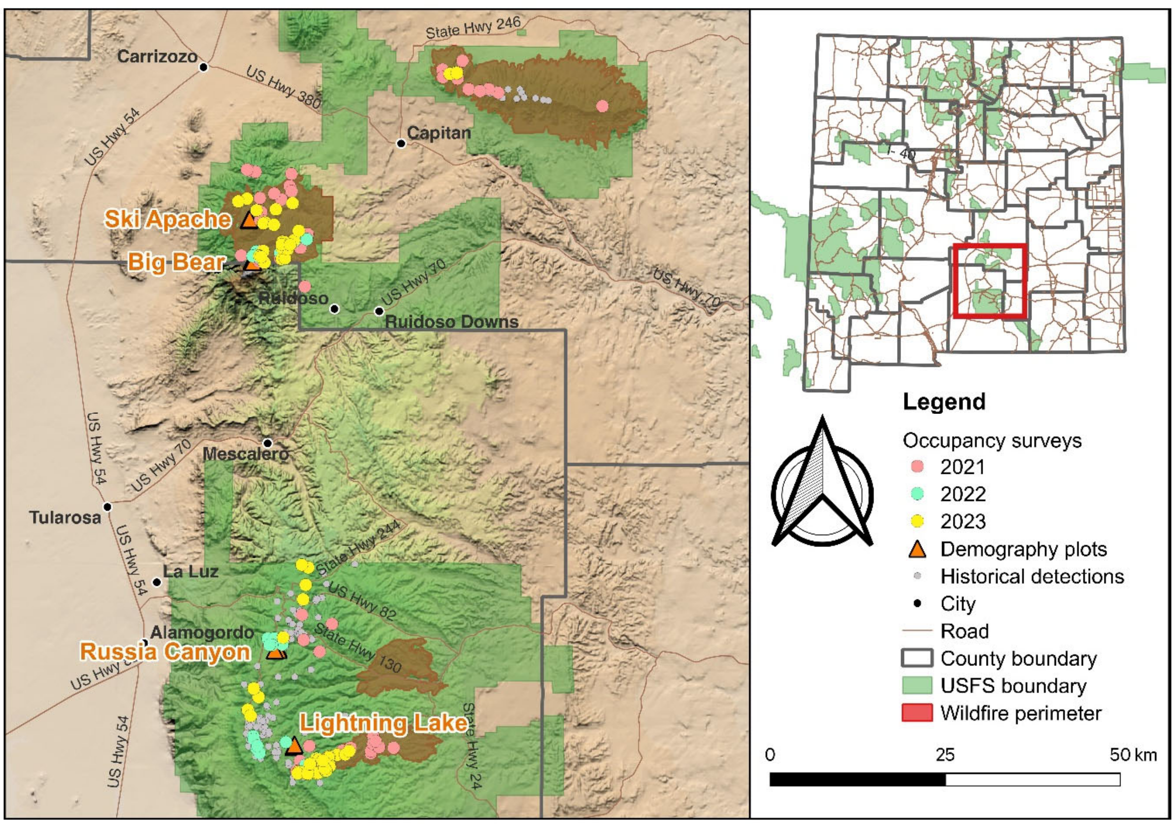

Figure 1. Locations of demography plots and occupancy survey locations for the Sacramento Mountain salamander (*A. hardii*) on the Lincoln National Forest in 2021–2023.

We surveyed plots for salamanders approximately every two weeks during the monsoon season (late June through early September) by turning over all rock and wood cover objects and searching other suitable microhabitats, including bark, leaf litter, and moss. We weighed, measured, and attempted to determine the sex of all captured salamanders. A subset of captured salamanders were swabbed for pathogens. To do this, we swabbed the ventral surfaces of the abdomen, feet, and chin with a cotton swab and stored the swab in a 1.5 mL cryovial with three drops of 70% ethanol. Cryovials were stored in a cooler in the field and later transferred to a refrigerator for longer-term storage prior to being sent to a commercial lab for processing. Salamanders with a trunk length >30 mm (adults) were anesthetized using tricaine methanesulfonate (MS-222). Adult salamanders were then injected (subcutaneously on the right lateral side of the body) with a 9 mm passive integrated transponder (PIT) tag containing a unique numeric code (Figure 2). After PIT tag implantation, salamanders were allowed to recover in fresh water. Smaller salamanders were injected subcutaneously on the ventral surface with visual implant elastomer, a fluorescent polymer applied in unique locations and color combinations to identify individuals. After processing, salamanders were released beneath the cover object where they were originally detected.

Figure 2. Graduate student Marissa Ardovino (University of Rhode Island) marks a salamander with a PIT tag in 2022. Photo by Virginia Seamster (NM Department of Game and Fish).

We collected microhabitat data for most salamanders captured during population demography surveys. We recorded geographic coordinates and characteristics of the rock or woody cover object under which a salamander was found (rock: dimensions, percent embedded in soil, and whether it was layered with other rocks; log: species, dimensions, decay class, percent char on log surface, and whether the log had fallen or been cut). We also recorded percent ground cover by rock, wood, or vegetation (herbaceous and woody) and canopy cover in a 1 x 1 m plot centered on the point of capture.

Demography plots were surveyed every two weeks from July to late-August or early-September including six surveys in 2021, four surveys in 2022, and four surveys in 2023, totaling 14 surveys of each plot over the course of the study. These data will be used to determine the probability of detecting *A. hardii* given the number of surveys completed, using multiple-visit, multiple-season detection probability modeling, specifically at sites known to be occupied by salamanders. This analysis will provide an empirical basis for determining how many surveys are needed to detect salamanders (with 95% confidence) at sites occupied by salamanders and incorporating particular survey-level covariates. This information will be useful for developing guidelines for surveys to be conducted prior to commencement of ground-disturbing activities.

Impacts of Wildfire on Occupancy

To evaluate the impacts of wildfire severity on salamander occupancy, we conducted one person-hour, time-constrained surveys for *A. hardii* in areas that were unburned, burned at low/moderate severity, or burned at high severity within the White and Sacramento Mountains of the Lincoln National Forest. We did not conduct surveys in the Capitan Mountains in 2023. To select survey sites, we used spatial data available on the Monitoring Trends in Burn Severity website (https://burnseverity.cr.usgs.gov/products/mtbs). Each site was surveyed once and measurement and release of salamanders followed the methods described above. No salamanders were marked during occupancy surveys. However, up to five salamanders captured at a given site were swabbed for fungal pathogens as described above. For most salamanders captured during occupancy surveys, we collected microhabitat data following the methods described above for the population demography plots.

Microclimate and Surface Activity

To understand the environmental conditions that influence vertical (from below ground to surface) and horizontal (across the ground surface) salamander movements, we combined bi-weekly surveys of PIT-tagged salamanders on population demography plots, using enhanced detection technology (see further details below), with environmental monitoring by weather stations. Prior to initiating surveys, we installed HOBO weather stations (Figure 3) in each plot to record the ambient temperature, precipitation, and relative humidity just above ground level; soil temperature and moisture beneath one log and temperature within the center of the log; and soil temperature and moisture beneath one rock. Instrumented logs and rocks are of dimensions and types that are commonly used by salamanders. Weather stations were surrounded in hardware cloth and wiring was buried below ground to protect sensitive instruments from damage by rodents or other small animals. Weather stations were set to record measurements continuously every 30 minutes for the duration of the study.

Figure 3. HOBO weather station monitoring environmental variables in a Sacramento Mountain salamander (*A. hardii*) demography plot. Orange flagging crosses above the location of an instrumented rock.

In 2021 and 2022 during bi-weekly visits to demography plots, the entire area of each plot was scanned for PIT-tagged salamanders using a PIT tag reader (Biomark HPR Plus) and antenna (Biomark BP Plus). The antenna permits detection of tagged salamanders beneath rocks, logs, and other cover objects and up to about 25 cm below ground (Figure 4). Upon detection of a PIT-tagged salamander, the reader emits a beep and the unique PIT tag code of the salamander is displayed on the screen. For salamander detections using the antenna, we recorded geographic coordinates at the point of detection and the cover object type associated with the detection. Salamander locations and movements were not monitored in 2023, due to time and personnel constraints.

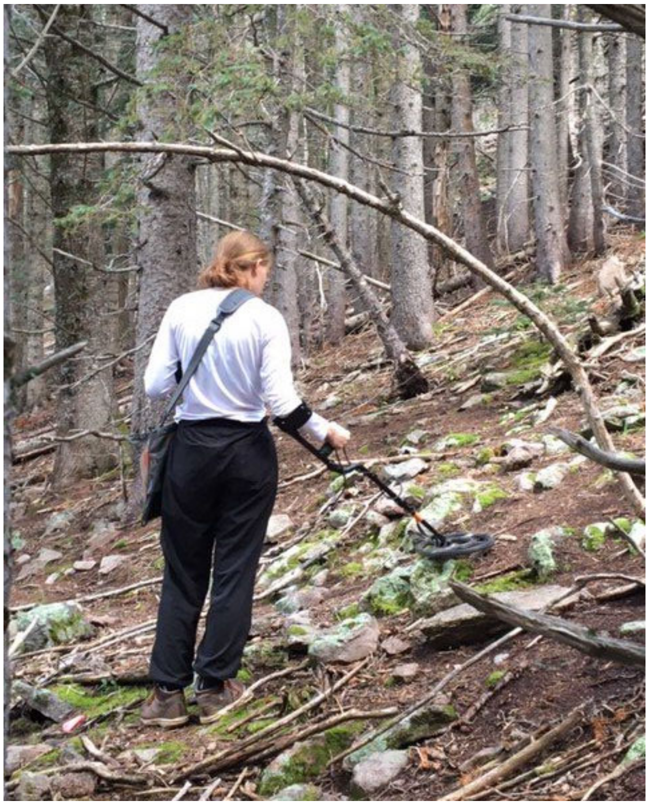

Figure 4. Research assistant Lily Collyer (University of Rhode Island) searching for PIT-tagged salamanders in and around cover objects at Deep Freeze site in 2022. Photo by Virginia Seamster (NM Department of Game and Fish).

We will develop models relating the location of salamanders to aboveground microenvironmental characteristics and to soil moisture and thermal conditions. These models could then be used to provide important information that can guide the timing of forest management treatments relative to seasonal conditions, within-season weather events, and likely salamander activity patterns. Independent variables for this analysis may include precipitation amount, air temperature, relative humidity, and soil moisture and temperature at the surface and at varying depths below cover objects; all variables to be assessed at varying intervals preceding salamander detections and movements (e.g., in the preceding 24-, 48-, or 72-hrs). Model covariates will include variables that may influence aboveground microenvironments and soil moisture and thermal regimes, including topography (e.g., elevation, slope, and aspect), soil type, and forest structure and composition. Our data will also allow us to evaluate whether and how salamander cover objects (logs and rocks) respond to seasonal and event-scale weather, including whether cover objects of different types, conditions, and dimensions differentially retain moisture. This information is important for understanding how natural disturbances (e.g., wildfires and beetle outbreaks) and management treatments (e.g., thinning and prescribed fire) that affect the presence and characteristics of cover objects may influence salamander habitat and is also critical for developing guidelines for restoration treatments that can include intentional provisioning of cover objects.

Results and Discussion

We conducted surveys for *A. hardii* in population demography plots and occupancy survey sites, collected microhabitat data for most salamander detections, and tracked PIT-tagged salamanders in demography plots from early-June to early-September in 2021–2023. We maintained weather stations in demography plots nearly continuously from June 2021–present, with some data losses due to damage by wildlife and sensor failure.

Population Demography

We surveyed demography plots six times in 2021, and four times each in 2022 and 2023. In these plots during the study period (2021-2023), we captured a total of 1024 individual salamanders and recaptured 213 individuals (Table 1). These numbers include only individuals that were marked and potentially available for recapture; individuals that were too small to mark or escaped prior to marking or a mark being documented are not included in these numbers. Given that our sampling approach included three plots per site, plots of the same size (25 x 25 m), and equal numbers of surveys (n=14) of plots at each site, we can compare relative abundance of individuals among sites, with the understanding that these numbers contain variation based on plot immigration, emigration, and deaths. Based on captured of new individuals during surveys, the highest abundances of salamanders were documented at Lightning Lake, followed by Deep Freeze and then Russia Canyon (Table 1). We observed few salamanders at Big Bear. We documented the highest number of recaptures of marked salamanders at Deep Freeze (23%), followed by Lightning Lake (14%) and Russia Canyon (14%; Table 1). We did not recapture any salamanders at Big Bear. Note that recaptures include individuals recaptured only once and salamanders recaptured multiple times.

Table 1. Details on *Aneides hardii* marked with visual implant elastomer or a passive integrated transponder (PIT) tag in population demography plots at four sites (three 25 x 25 m plots at each site) on the Lincoln National Forest from 2021 to 2023. Note that individuals with a total length of <30 mm were considered too small to mark and were not included in mark-recapture summary or analyses. Numbers do not include individuals that escaped before being marked or before a mark was documented.

Mountain range Site	**Salamander captures**	**Salamander recaptures**	**Snout-vent length range (mm)**	**Percentage of adults**
White				
Big Bear	9	0	20–53	44
Deep Freeze	329	99	12–64	59

Sacramento				
Lightning Lake	385	63	21–65	58
Russia Canyon	301	51	17–63	56

Clear scientific guidance for determining sex in *Aneides hardii* by external morphological characteristics of live individuals is not available. We found sex determination to be extremely difficult for this species, and, with the exception of gravid females, we were unable to confidently assign sex to most adults. For individuals captured, we assessed age class (adult, subadult) following Williams (1978), in which females are known to reach sexual maturity at ≥36 mm snout-vent length and males at ≥39 mm snout-vent length. Because we could not confidently determine the sex of most individuals and to conservatively follow Williams (1978), we assigned the adult age class to salamanders ≥39 mm snout-vent length. All salamanders <39 mm in snout-vent length were classified as subadults (Table 1). We found that the proportion of each population made up of adults ranged from 56–59%, with the exception of Big Bear, a site for which we had few salamander captures.

We are currently evaluating population models, based on 2021–2023 data, that will yield estimates of annual apparent survival at each site and estimated population sizes at each site from mark-recapture data. For annual apparent survival, we are evaluating models in which survival parameters and recapture probabilities are fully time-dependent, fully constant, and with time-dependent survival parameters and constant recapture probabilities, and constant survival parameters and time-dependent recapture probabilities. Competing models will be compared using Akaike's Information Criterion, AICc weights, and parameter and variance estimates. Fit of final models will be evaluated with a bootstrapping goodness-of-fit test.

We are estimating population sizes for each site following a similar approach as described above that includes fully time-dependent, fully constant, and every combination of time-dependent and constant states for survival parameters, recapture probabilities, and probability of entrance into a population. Models will be compared and evaluated as described above.

We measured microhabitat characteristics in the areas where salamanders were captured or recaptured. For 1296 total cover objects in demography plots across all sites and years, 45% of salamanders (captures and recaptures) were located under or inside of logs (Table 2), 49% were under rocks (Table 3), and 6% were under other cover object types including bark, leaves, and cow feces. We did not measure the availability of cover object types surrounding detection locations. We found that 87% of logs providing cover for salamanders had a small end diameter of ≤7 inches (≤18 cm), 92% of logs had a small end diameter of ≤9 inches (≤23 cm), and 96% of logs had a small end diameter of ≤12 inches (≤31 cm). We detected salamanders within or under logs ranging from decay class 1-5, with 1% of salamanders associated with decay class 1 logs, 4% associated with decay class 2 logs, 16% associated with decay class 3 logs, 34% associated with decay class 4 logs, and 45% associated with decay class 5 logs.

Table 2. Characteristics of log cover objects under which or within which *Aneides hardii* were located in population demography plots, Lincoln National Forest, 2021-2023. Length includes only the portion of the log making contact with the ground.

Measure	**Small end diameter (cm)**	**Large end diameter (cm)**	**Length (m)**
Mean	10.2	16.3	2.1
SD	9.9	14.8	6.5
Minimum	0.5	1.0	0.1
Maximum	64.0	140.0	91.0

Table 3. Characteristics of rock cover objects under which *Aneides hardii* were located in population demography plots, Lincoln National Forest, 2021-2023.

Measure	**Length (cm)**	**Width (cm)**	**Thickness 1 (cm)**	**Thickness 2 (cm)**
Mean	25.3	17.9	7.3	6.9
SD	10	7	5	5
Minimum	0.5	5	0.9	0.5
Maximum	69	52	42	40

Overstory canopy cover above occupied cover objects averaged 82% (SD±18) and ranged from 10–96%. Canopy cover was ≥75% above the cover objects of 80% of salamander observations.

Impacts of Wildfire on Occupancy

We surveyed a total of 119 sites known to be historically occupied by *A. hardii*, including 36 unburned sites, 38 sites that burned at low severity, and 45 sites that burned at moderate/high severity (Table 4).

Table 4. Number of historically-occupied unburned sites, sites burned at low severity, and sites burned at moderate/high severity surveyed for *A. hardii* and percent of those sites occupied by salamanders.

	Total sites surveyed			**Percent of sites occupied by *A. hardii***		
Year	Unburned	Low	Mod/high	Unburned	Low	Mod/high
2021	7	3	12	57	100	33
2022	15	3	3	80	67	33
2023	14	32	30	36	6	6

Total	**36**	**38**	**45**	**58**	**7**	**7**

We have developed occupancy models that include site-level and survey-level covariates (Tables 5 and 6) that evaluate the relationships between occupancy and detection and those covariates for *A. hardii* at surveyed sites. Covariates considered in these analyses were associated with plethodontid salamander occupancy and detection probability as reported in the published literature.

Table 5. Detection covariates considered in occupancy models for Sacramento Mountain salamanders (*Aneides hardii*), Lincoln National Forest, New Mexico, 2021–2023.

Detection (*p*) covariate	**Description**
Date	Ordinal date (1-365) of each survey
Time	Time of day (0000-2400) of each survey start
Temperature[1]	Air temperature (°C) at the beginning of each survey
Relative humidity[1]	% relative humidity et the beginning of each survey
Precipitation[2]	Sum of precipitation (mm) from two days prior to survey date

1. In-field measure via Kestrel 3000 pocket weather meter (Nielsen-Kellerman, Boothwyn, PA, USA)
2. Remote measure via DAYMET Single Pixel (1 km x 1 km) Extraction Tool (Thornton et al. 2022)

Table 6. Occupancy covariates considered for occupancy models for Sacramento Mountain salamanders (*Aneides hardii*), Lincoln National Forest, New Mexico, 2021–2023.

Occupancy (ψ) covariate	**Description**
Elevation[3]	Elevation (m) of each site center point
Aspect[3]	Orientation of slope face (0-360°) of each site center point
Slope[3]	% incline of each site center point
Enhanced Vegetation Index (EVI) 2 years post-fire[4]	Scaled measure (0-1) of vegetation greenness, accounting for vegetation density

1. Remote measure via USGS ⅓ Arc Second DEM (U.S. Geological Survey 2022)
2. Remote measure via MODIS/Terra Vegetation Indices 16 Day L3 250m spatial resolution (Didan 2021)

We are using an information-theoretical approach to build, compare, and evaluate occupancy models that. First, we developed models containing only detection covariates (Table 3), including single- and multi-covariate models. All detection probability models contained the covariate year (2021, 2022, 2023), because of significant differences in the timing, strength, and pattern of the monsoon season among years. In particular, the monsoon was late, weak, and patchy in 2023 and this may have influenced our ability to detect salamanders due to reduced moisture in forest soils. Next, we developed models containing only occupancy covariates (Table 4), including single-and multi-covariate models. All occupancy models contained the covariate burn severity (unburned, low severity, moderate/high severity), which was the factor by which we stratified our sampling.

We evaluated detection probability and occupancy model sets separately by Akaike's Information Criterion corrected for small sample sizes (AICc), delta AICc (change in AICc between models), and AICc cumulative weight. Competing models in each model set were those that made up 90% of the AICc cumulative weight. Competing models for each set were retained and then a new set of combined occupancy/detection probability models were developed that included competing models from each set as described above. This new set of combined models were evaluated using the same approach as for the separate model sets.

Although evaluation of the final model set is ongoing, the top detection probability models include the covariates Julian date, precipitation, and start time, along with the covariate year, which appeared in all detection probability models. The top occupancy models include the covariates elevation and slope, along with the covariate burn severity, which appeared in all occupancy models. Evaluation of occupancy models that incorporate detection probability (combined models) is currently underway.

Microclimate and Surface Activity
In 2021 and 2022, we scanned demography plots with a Biomark scanner and antenna on a bi-weekly basis to detect PIT-tagged salamanders and document their movements.

Table 7. Movement distances between detections for salamanders that moved on demography plots in the Lincoln National Forest, south-central New Mexico in 2021.

Site	**Mean distance moved (m)**	**SD (m)**	**Range (m)**
Big Bear	18.0	14.1	8.0–28.0
Deep Freeze	2.6	3.3	0.2-17.0
Lightning Lake	2.6	2.4	0.1–11.0
Russia Canyon	1.5	1.5	0.2–7.1
All sites	*6.2*	*7.9*	*0.1–28.0*

We are still summarizing and analyzing surface activity and movement data from 2021 and 2022.

We collected microclimate data from weather stations installed in demography plots continuously from July 2021 to present, with the exception of some losses of data due to weather station theft, damage by animals, and sensor/battery failure. Microclimate data indicate daily and seasonal trends and variability in above- and belowground environments and differences in microenvironments associated with log vs. rock cover objects (Figure 5). These data will be used to relate microclimatic conditions to habitat characteristics and salamander surface activity as described above (for years 2021 and 2022).

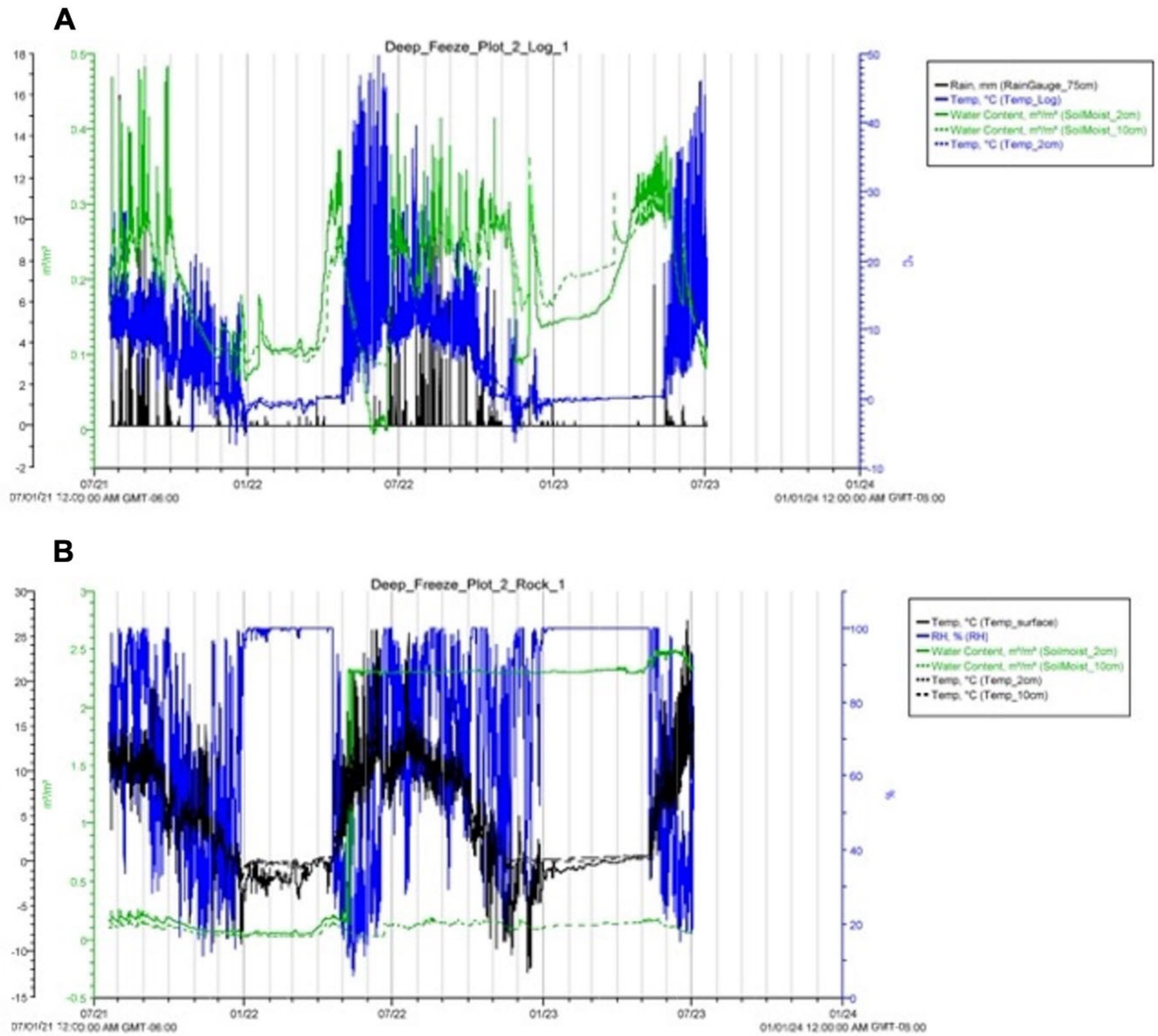

Figure 5. Microclimate data from weather stations associated with *Aneides hardii* demography plots (data for the Deep Freeze site shown here, for one log and one rock cover object per site). Instrumentation in panel A (log cover object) includes a surface rain gauge, temperature sensor within a log cover object, temperature sensor at 2 cm depth below soil surface, and soil moisture sensors at 2 cm and 10 cm below soil surface. Instrumentation in panel B (rock cover object) includes a surface temperature and relative humidity sensor, temperature sensors at 2 cm and 10

cm below soil surface, and soil moisture sensors at 2 cm and 10 cm below soil surface. These data will be used in models relating salamander surface activity to varying above and belowground microhabitat and weather conditions (for example, thresholds of soil moisture, soil temperature, or rainfall).

Management Recommendations

We plan to summarize the results from all three tasks above to develop conservation guidelines and actions to inform the protection of remaining *A. hardii* populations and the restoration of habitats within their geographic range. Management recommendations will include safe operational periods for management activities (forest thinning, salvage logging, prescribed burning), and downed wood and canopy cover retention guidance within habitats that may be occupied by *A. hardii*.

Important Note Regarding This Report:

Because of personnel changes partway through the project, progress on completing all objectives for this final report were delayed. Please be advised that all results reported here are preliminary and any uses of these preliminary results must first be approved by the authors of the report. Manuscripts for all elements of this project will be submitted to peer-reviewed journals following completion of analyses, and results in those manuscripts may differ from what is presented above.

Acknowledgments

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